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Multimodal Feedback for Passengers of Automated Driving Vehicles

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Abstract

Automated driving ranges from a partial delegation to a complete transfer of the driving task to the automated vehicle. The tasks of drivers vary from taking over specific driving tasks, monitoring the system, or completely handing over responsibility to the automated system. When using automated vehicles, drivers need a well-founded awareness of which level of automation they are in and which responsibilities they have. To maintain this awareness, feedback on both automation intentions and level changes is important. To date, information was typically presented visually, auditory, or haptically. This thesis additionally investigates the application of vestibular feedback using active pitch and roll motions of the vehicle chassis. Specifically, several research questions are addressed regarding the use of these motions in combination with visual and auditory feedback. The research questions include the effect and information content of combining different modalities at different levels of automation and their influence on non-driving related tasks.

To answer the research questions, three real-vehicle studies were conducted on the motorway with a total of 143 participants. For this purpose, different feedback combinations were implemented in an automated driving vehicle. The vehicle simulated assisted, partially, and highly automated driving. Depending on the level of automation, the driver relinquished control partially or completely to the automation. Initially, the combinations were considered separately in individual levels of automation and then studied in multi-level automation. The studies focused on the design of multimodal feedback to improve mode awareness, gaze behaviour, and acceptance, as well as to generate appropriate trust in automation.

The results indicate that additional pitch and roll motions support and relieve the driver in the monitoring task during partially automated driving. However, it is also revealed that the active rotational motions during highly automated driving are perceived as distracting when performing non-driving related tasks. Further results suggest that the combination of explanation and experience with active vehicle motions has an influence on the evaluation of these. After being educated about pitch and roll motions and then experiencing them, participants rated the motions as less meaningful. However, even with a combination of explanation and conscious experience, the system behaviour is perceived as more predictable due to the additional feedback. In conclusion, an overall concept was developed that represents a different feedback design of the levels of automation in a multi-level system. In partially automated driving, intentions should be additionally communicated by active vehicle motions. In highly automated driving, feedback should generally be kept to a minimum.

Kurzfassung

Automatisiertes Fahren gliedert sich in verschiedene Stufen, die vom manuellen Fahren bis hin zur vollständigen Abgabe der Fahraufgabe an das automatisiert fahrende Fahrzeug reichen. Die Aufgaben der Fahrenden variieren dabei von der Übernahme einzelner Fahraufgaben bis hin zur Ausführung fahrfremder Tätigkeiten. Bei der Nutzung automatisierter Fahrzeuge benötigen die Fahrenden ein fundiertes Bewusstsein, in welcher Automationsstufe sie sich befinden und welche Verantwortlichkeiten sie inne haben. Zur Aufrechterhaltung dieses Bewusstseins sind Rückmeldungen sowohl über Intentionen der Automation als auch über Zustandsänderungen wichtig. Bisher wurden dabei üblicherweise Informationen visuell, auditiv oder haptisch dargestellt. In dieser Arbeit wird zusätzlich der Einsatz von vestibulärem Feedback untersucht. Konkret werden verschiedene Fragestellungen hinsichtlich der Nutzung aktiver Nick- und Wankbewegungen in Kombination mit visuellen und auditiven Rückmeldungen adressiert. Die Forschungsfragen umfassen dabei die Auswirkung und den Informationsgehalt der Kombination verschiedener Modalitäten in unterschiedlichen Automationsstufen und deren Einfluss auf fahrfremde Tätigkeiten.
Zur Beantwortung der Forschungsfragen wurden drei Realfahrzeugstudien mit insgesamt 143 Probanden auf der Autobahn durchgeführt. Dafür wurden verschiedene Rückmeldekombinationen in einem automatisiert fahrenden Fahrzeug implementiert. Das Fahrzeug simulierte assistiertes, teil- und vollautomatisiertes Fahren. Je nach Automationsstufe gaben die Fahrenden die Kontrolle teilweise oder vollständig an die Automation ab. Die Studien fokussierten sich auf die Gestaltung multimodaler Rückmeldungen zur Verbesserung des Systembewusstseins, des Blickverhaltens und der Akzeptanz sowie zur Generierung eines angemessenen Vertrauens in die Automation.
Die Ergebnisse zeigen, dass zusätzliche Nick- und Wankbewegungen die Fahrenden während der teilautomatisierten Fahrt in der Überwachungsaufgabe unterstützen und entlasten. Während der Ausführung fahrfremder Tätigkeiten werden die Fahrzeugaufbaubewegungen jedoch als ablenkend empfunden. Weitere Ergebnisse deuten darauf hin, dass die Kombination von Aufklärung und Erleben der Fahrzeugaufbaubewegungen einen Einfluss auf deren Bewertung hat. Nach Aufklärung über die vestibuläre Rückmeldung und deren bewusstem Erleben wurden die Bewegungen als weniger nützlich bewertet. Dennoch wurde das Systemverhalten auch nach einer Kombination aus Aufklärung und bewusstem Erleben durch das zusätzliche Feedback als vorhersagbarer wahrgenommen. Abschließend wurde ein Gesamtkonzept hergeleitet, das eine unterschiedliche Modalitätengestaltung der Automationsstufen in einem mehrstufigen System aufweist. Hierbei sollten Intentionen in der teilautomatisierten Fahrt zusätzlich durch aktive Fahrzeugaufbaubewegungen mitgeteilt werden. In der vollautomatisierten Fahrt hingegen sollte Feedback generell auf ein notwendiges Minimum beschränkt werden.

Contents

1 Introduction **1**

1.1 Motivation . . . 2

1.2 Aims and Objectives . . . 4

1.3 Outline and Structure . . . 5

2 Theoretical Background **6**

2.1 Driving - From Human to Automation . . . 6

2.1.1 Fundamentals of Human Perception . . . 6

2.1.2 Information Processing . . . 15

2.1.3 The Driving Task . . . 17

2.1.4 Levels of Automation . . . 18

2.1.5 Transitions . . . 20

2.1.6 Changes in the Driver's Role . . . 21

2.2 Feedback in Automated Driving . . . 27

2.2.1 Visual Feedback . . . 30

2.2.2 Auditory Feedback . . . 32

2.2.3 Vestibular Feedback . . . 33

2.2.4 Enhancement through Multimodality . . . 36

3 General Method **38**

3.1 Overview of the Experiments . . . 38

3.2 Feedback Concept . . . 39

3.2.1 Visual Feedback Design . . . 41

3.2.2 Auditory Feedback Design . . . 43

3.2.3 Vestibular Feedback Design . . . 43

3.3 Test Vehicle . . . 44

3.3.1 Realization of the Automation System . . . 45

3.3.2 Experimental Setup . . . 46

3.4 Hygiene Concept . . . 47

3.5 Dependent Variables . . . 47

3.5.1 Subjective Data . . . 48

3.5.2 Objective Data . . . 49

3.6 Data Processing and Statistical Analysis . . . 49

4 Driving Experiment 1: Effect of Vestibular Feedback during Different Levels of Automation in a Multimodal Concept 51
4.1 Introduction 51
4.2 Method 52
4.2.1 Sample 53
4.2.2 Feedback Design 53
4.2.3 Study Design 54
4.2.4 Study Procedure 54
4.2.5 Dependent Variables 55
4.3 Results 56
4.3.1 Indisposition 56
4.3.2 Trust in Automation 57
4.3.3 Acceptance 58
4.3.4 Mode Awareness 59
4.3.5 Usability 60
4.3.6 Likability 61
4.3.7 Influence of Experience with Adaptive Cruise Control 62
4.4 Discussion and Conclusion 63

5 Driving Experiment 2: The Influence of Feedback on Transitions Between Different Levels of Automation 69
5.1 Introduction 69
5.2 Expert Interview 71
5.2.1 Procedure 71
5.2.2 Results 72
5.3 Method 73
5.3.1 Sample 74
5.3.2 Feedback Design 75
5.3.3 Study Design 76
5.3.4 Study Procedure 77
5.3.5 Dependent Variables 78
5.4 Results 80
5.4.1 Trust in Automation and Acceptance 80
5.4.2 Indisposition 81
5.4.3 Mode Awareness 81
5.4.4 Feedback Characteristics 84
5.4.5 Performance at Transitions 85
5.4.6 Required Information 88
5.4.7 Gaze Motions during Lane Changes 90
5.5 Discussion and Conclusion 91

6 Driving Experiment 3: The Influence of Feedback on Mode Awareness 98

6.1 Introduction 98
6.2 Method 99
6.2.1 Sample 100
6.2.2 Feedback Design 101
6.2.3 Study Design 101
6.2.4 Study Procedure 101
6.2.5 Dependent Variables 103
6.3 Results 104
6.3.1 Mode Awareness 104
6.3.2 Trust in Automation 106
6.3.3 Acceptance 107
6.3.4 Mental Model 108
6.3.5 Feedback Characteristics 109
6.3.6 Gaze Motions during Lane Changes 110
6.4 Discussion and Conclusion 112

7 Conclusion and Outlook 117

References 122

Acronyms 143

Appendix 145

1 Introduction

The importance of advanced driver assistance systems (ADAS) has increased significantly in recent years, especially in research and development at automobile manufacturers and university research institutes (Matthaei et al., 2015). Currently available ADAS support drivers in their driving task in both longitudinal and lateral guidance. The continuous development of sensor technology enables warning and informing systems (e.g., Lane Departure Warning), continuously acting automated driving functions (e.g., Adaptive Cruise Control (ACC)), or intervening systems (e.g., Electronic Stability Control) (Gasser, Seeck, & Smith, 2015). SAE international (2022) defined different levels of automation (LoA) to categorize continuously acting automated driving functions. The categories range from manual driving (SAE level 0) to fully automated driving (SAE level 5). Partially automated driving vehicles (PAD, SAE level 2) are already operating on motorways. In doing so, the driver is fully aware of the automated driving vehicle at all times and is able to take-over the driving task at any time (VDA, 2015). Recently, the use of conditionally automated driving vehicles (CAD, SAE level 3) is permitted on German motorways under certain conditions (Bundesministerium der Justiz und für Verbraucherschutz, 2022). The driver may legally perform non-driving related tasks (NDRT), for example using the smartphone. Sleeping, however, is prohibited, as a takeover must be possible at any time (Bundesministerium der Justiz und für Verbraucherschutz, 2022). In the future, higher automated vehicles (SAE level 4-5) promises to completely relieve the driver by eliminating the need for a constant readiness to take-over and allowing NDRT, including sleeping, to be performed (SAE international, 2022).

The development of automated vehicles poses a number of challenges (Matthaei et al., 2015). In addition to technical capabilities and legal issues, human interaction with automated systems is also important (Saffarian, de Winter, & Happee, 2012). According to Neale and Dingus (1998), human factors issues such as usability and acceptance are more important for users of automated vehicles rather than technological factors. Thus, an appropriate design of the interaction between the driver and the automated vehicle is required. Human-Machine Interfaces (HMI) are used to maintain communication between the driver and the vehicle. These HMI in (automated) vehicles often consist of output media to provide information to the driver and input media to read driver's input (Bengler, Rettenmaier, Fritz, & Feierle, 2020). In lower LoA (SAE level 0-2), driver communication is limited by the (partial) execution of vehicle control or monitoring. With increasing automation, new methods of interaction may arise as a result of the driver's new freedom to disengage from the driving task. Furthermore, increasing automation leads to a change in the need for information (Beggiato et al., 2015; Feierle, Danner, Steininger, & Bengler, 2020; Bengler et al., 2020). The information content depends on the LoA and thus on the driver's task (Beggiato et al., 2015; Bengler et al., 2020). While information about the driving task is important in manual driving, information about the vehicle's intentions is necessary to supervise the system in PAD (Beggiato et al., 2015).

1.1 Motivation

When automated vehicles combine several LoA, there will be certain risks. The driver is involved in different LoA to varying degrees. The latter could lead to confusion or incorrect behaviour. Inappropriate mental models (König, 2015), lack of situational (Parasuraman & Wickens, 2008), and system awareness (Othersen, 2016) as well as overconfidence or mistrust (Parasuraman & Riley, 1997) can potentially lead to critical situations: For example, if the driver mistakenly assumes that a higher LoA (e.g., CAD, SAE level 3) is active, even though PAD (SAE level 2) is active. Hence, the driver could completely withdraw from monitoring the system or not respond to takeover requests from the system (Gold, Damböck, Lorenz, & Bengler, 2013). However, the driver has to act as a fallback and therefore should not completely withdraw from the monitoring task. This confusion or incorrect behaviour occurs mainly when the functionalities, capabilities, and limitations of the automation systems are not sufficiently communicated (Flemisch, Winner, Bengler, & Bruder, 2017). To avoid the latter, the automation system should present information about the automated system state, its intentions, and behaviour to the driver (Beggiato et al., 2015; Diels & Thompson, 2018).

Accordingly, the driver should be supported in perceiving the system state, state changes and its intentions in order to show appropriate behaviour at the respective LoA. One possibility to support the driver in recognising the current system state is to train the driver before driving with the automated system, e.g. through interactive tutorials (Forster, Hergeth, Naujoks, Krems, & Keinath, 2019) or gamification (Feinauer, Schuller, Groh, Huestegge, & Petzoldt, 2022). Another method is the use of feedback during automated driving. In this case, feedback can be provided through different modalities. Feedback in automated driving vehicles is currently primarily conveyed via the visual, auditory, or haptic modality (Bubb, Bengler, Breuninger, Gold, & Helmbrecht, 2015; Knoll, 2015; Bengler et al., 2020). Visual feedback can be presented, for example, via the instrument cluster, centre console, or head-up display (e.g., Albert, Lange, Schmidt, Wimmer, & Bengler, 2015; Othersen, 2016; Schömig et al., 2018). Another way to provide visual information is through the peripheral field of view, for example by using LED strips (e.g., Utesch, 2014; Yang, Karakaya, Dominioni, Kawabe, & Bengler, 2018). The disadvantage of visual feedback is that the driver has to turn away from his current visual task field (e.g., monitoring the environment or performing an NDRT). In addition, current visual displays are cluttered by the amount of information (D. L. Fisher, Lohrenz, Moore, Nadler, & Pollard, 2016). According to Wickens (2002), each sensory channel is limited in its performance and can be relieved by dividing the task among additional sensory channels. Thus, feedback in automated systems should be multimodal (Wickens, 2002; Bengler et al., 2020; Bubb, Bengler, et al., 2015). Studies also showed that multimodal feedback improves the driver's takeover performance and can reduce reaction times (J.-H. Lee & Spence, 2008; Burke et al., 2006).

In addition to the commonly used modalities, another modality has been investigated to assist the driver in his tasks during automated driving. This feedback, which can additionally be used to convey automation intentions, is the vestibular modality (Lange, 2018; C. Müller, 2019; Cramer, 2019; Bengler et al., 2020). In doing so, information can be communicated, for example, through the driving style (e.g., Lange, 2018; Festner, 2019; Ossig, Hinkofer, Cramer, & Bengler, 2022; Ossig, Cramer, Eckl, & Bengler, 2022) or via rotational body movements of the vehicle's chassis (e.g., Sieber, Siedersberger, Siegel, & Färber, 2015; C. Müller, Siedersberger, Färber, & Popp, 2016; Cramer, Miller, Siedersberger, & Bengler, 2017). A lane change, for instance, can be announced by a lateral approach to the lane (Lange, 2018) or via active roll motions (Cramer, 2019). Cramer (2019) developed a concept in which system intentions and announcements are indicated by active pitch (rotation around the vehicle's lateral axis) and roll motions (rotation around the vehicle's longitudinal axis) realized by an active body control vehicle. These active movements have been considered useful to support the driver in terms of mode and system awareness during PAD (Cramer, Siedersberger, & Bengler, 2017; Cramer, 2019). This concept of Cramer (2019) is adopted for this thesis and will be extended to a multimodal feedback concept in multi-level automated driving systems.

1.2 Aims and Objectives

Although a variety of research on feedback has been carried out, Özkan, Mirnig, Meschtscherjakov, Demir, and Tscheligi (2021) highlight the need for further investigation of different feedback modalities for communicating automation modes. To date, little attention has been paid to the role of vestibular feedback in a multimodal concept for multi-level automated vehicles. Therefore, the aim of this thesis is to develop a multimodal feedback concept consisting of visual, auditory, and vestibular feedback for passengers of automated driving vehicles. Visual information serves as the foundation for the feedback concept because it can be perceived quickly and has a high coverage rate (Hoffmann, 2008). Auditory cues are used to direct attention due to their medium coverage rate and medium perception speed (Hoffmann, 2008). Vestibular feedback, on the other hand, provides low information rate but is perceived quickly (Hoffmann, 2008) and is used to communicate intentions (Cramer, 2019).

The research scope of this thesis is narrowed down to the following research question:

> *How should multimodal feedback in a multi-level automated driving vehicle be designed so that occupants accept, trust, and understand the automation system?*

Most of the recent studies regarding different feedback concepts took place in driving simulators (B. Zhang, de Winter, Varotto, Happee, & Martens, 2019). Those findings need to be confirmed in a real road environment (B. Zhang et al., 2019) and need to include more realistic scenarios (Eriksson & Stanton, 2017). Therefore, different concepts are implemented in a test vehicle and tested on the motorway. An automation system that enables assisted, partially, and highly automated driving on the motorway serves as the foundation. CAD was not considered in this work because time-limited takeovers on the motorway would introduce an excessive risk. In addition, several studies investigated the design of critical takeovers during CAD (Eriksson & Stanton, 2017). In this thesis, the driver is allowed to drive hands-free during PAD. However, the driver has to monitor the automated system and the environment. Highly automated driving (HAD) allows the driver to withdraw from supervision and perform an NDRT. Thus, the driver's tasks vary depending on the LoA. Hence, the feedback should support the driver in his respective tasks of the current LoA and should not be distracting. The multimodal feedback concept should facilitate the driver's mode awareness and knowledge about the required task (e.g., driving task, monitoring, or performing NDRT).

Further questions arise from the focal point, which are subdivided into the central research objectives:

1. Which modality combinations increase trust, acceptance, and mode awareness in different LoA?
2. What information should be provided to the driver in the different LoA to optimise the aforementioned constructs?
3. Which intensity of the modalities can be used without disturbing or distracting the driver in their respective tasks?
4. How do different feedback modalities influence the execution of NDRT regarding motion sickness and acceptance?

1.3 Outline and Structure

The theoretical foundation for explaining the basic motivation for the central research questions of this thesis is provided in **Chapter 2**. It deals with human perception and information processing. In addition, the human-vehicle interaction and the automation taxonomy are presented. Building on this information, the changing role of the driver is examined. Finally, feedback related to automated vehicles is presented on the basis of current research. Subsequent, **Chapter 3** describes the methodological approach and the developed concept. In addition, the architecture and test equipment of the test vehicle are explained and generally applicable aspects of the conducted studies are highlighted. **Chapters 4, 5**, and **6** present the individual studies and their results. The first study examines the influence of vestibular feedback in a multimodal concept on different LoA. Building upon these results, the second study investigates a multimodal concept for a multi-level system focusing on transitions. Finally, the generated multimodal feedback concept, including pitch and roll motions only in partially automated driving is compared to a purely visual feedback concept in a multi-level system. Concluding, **Chapter 7** discusses the results and derives implications for a multi-level automated driving system design. Moreover, limitations and recommendations for future research are provided.

Some parts of this thesis have been pre-published in Wald, Haentjes, Albert, Cramer, and Bengler (2021) as well as in Wald, Hiendl, Albert, and Bengler (2022) and in Wald, Henreich, Albert, Ossig, and Bengler (2022). Some passages of the written text have been literally adopted.

2 Theoretical Background

The aim of this chapter is to build the theoretical foundation for this thesis. The first section addresses the evolution of driving from human to automation. Subsequently, an insight into feedback for automated driving and the use of different modalities is provided. Finally, the advantage of multimodal feedback is outlined.

2.1 Driving - From Human to Automation

For a detailed analysis of the factors influencing feedback at different LoA, a general understanding of human information processing is required. The main components are information perception, information processing, and the transformation of information into an action. In this chapter, information processing is explained in the context of manual vehicle guidance. Before discussing the changing role of the driver in the context of increasing automation, a taxonomy of vehicle automation is presented.

2.1.1 Fundamentals of Human Perception

In order to understand how people process information and translate it into action, a general understanding of human perception is required. According to Handwerker and Schmelz (2010), general sensory physiology depicts the analysis of the relationship between the excitation of the sensory system and the sensation, as well as the description of the function of the sensory systems. In this context, sensory physiology has an objective and a subjective dimension (Handwerker & Schmelz, 2010). The interaction of both dimensions is shown in Figure 2.1. The process according to Handwerker and Schmelz (2010) starts with the stimuli existing in the environment. Stimuli that interact with the sense organs are converted into “Sensory stimuli”. If a stimulus crosses the perception threshold, the sensory nerves are excited. This leads to an excitation of the brain cells resulting in an “Integration in the sensory central nervous system”. These physiological processes of objective sensory physiology

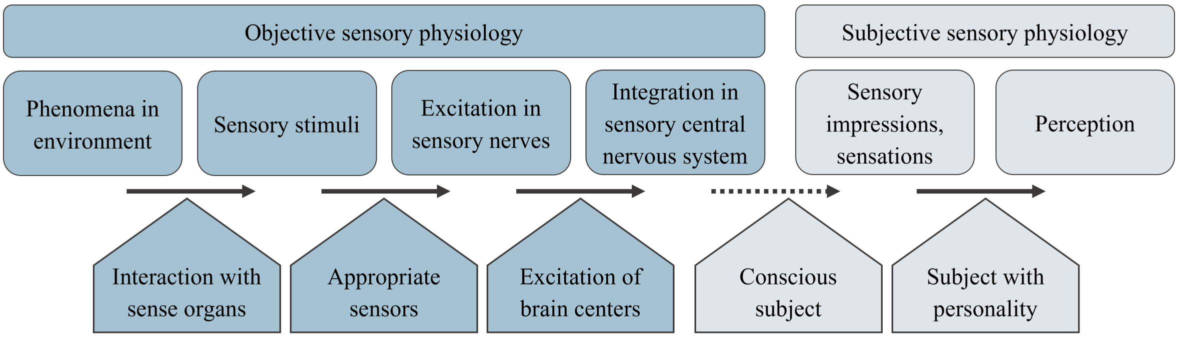


Figure 2.1: Schematic representation of the human perception process according to Handwerker and Schmelz (2010) with boxes as basic phenomena, arrows as "leads to" and dashed arrow as the transition from physiological to psychological process

induce subjective sensory impressions or sensations. The latter describes the activity of the respective sensory organ itself. Here, the physical stimulus of the environment is transformed into information. In the end, perception takes place, which is based on sensation and is shaped and modified by experience and knowledge.

The first preprocessing and associations of the stimuli already occur during the perception phase. In this context, bottom-up and top-down process are distinguished (Wickens & Horrey, 2009; Goldstein, 2010). Bottom-up refers to processing based on incoming data, which is always the starting point for perception. In contrast, top-down processing describes to processing that is based on knowledge (Goldstein, 2010). Thus, perception is influenced by the intensity of the stimuli and the direction of attention. The Salience-Effort-Expectancy-Value-Model (SEEV-Model) according to Wickens, Helleberg, Goh, Xu, and Horrey (2001) describes that the visual attentional focus depends on the following four factors:

- *Salience* defines the specific basic property of objects by which they attract attention. Example: A flashing warning light.
- *Effort* describes the energy required to view an object. Objects in the distance are looked at less than objects in the vicinity due to the higher effort. Example: The vehicle in front is viewed more than vehicles further away from the driver.
- *Expectancy* indicates the anticipation about the position of the relevant object. Example: Road signs at the edge of the roadway.
- *Value* represents the relevance of the information. Example: The traffic light phase is more important than the vehicle behind.

On the one hand, stimuli can attract attention involuntarily (bottom-up) through salience and effort. On the other hand, attention is consciously controlled by expectations of a stimulus as well as its relevance (top-down). Both intentional (top-down) and unintentional (bottom-up) processes are important for the reception of information (Wickens & Horrey, 2009).

2.1.1.1 Perception in the automotive context

According to Handwerker and Schmelz (2010), the sensory modality is referred to as the sensation conveyed by a sensory organ. Due to different information rates and speeds of perception, they differ in the amount and possible content of the transported information (Handwerker & Schmelz, 2010; Hoffmann, 2008). For the evaluation of perception in the automotive context, however, not all of the sensory channels listed are equally in focus. The visual channel is essential for the reception (Bubb, Vollrath, Reinprecht, Mayer, & Körber, 2015), because most of the information is perceived inside and outside the vehicle (Vollrath & Krems, 2011). However, acoustic, haptic, and vestibular perception are also important for the perception of information while driving (Bubb, Vollrath, et al., 2015). Table 2.1 presents the allocation of sensory channels to the required driver information according to Tomaske and Fortmüller (2001). Both longitudinal and lateral acceleration are perceived via the haptic and vestibular sensory channels. Longitudinal velocity is perceived through the visual and auditory sensory channels. On the other hand, lateral velocity is only noticed via the visual sensory channel.

Table 2.1: Sensory channel assignment of driver information referring to Tomaske and Fortmüller (2001)

Information	Visual	Acoustic	Haptic	Vestibular
Lane deviation	✓			
Driving velocity	✓	✓		
Lateral velocity	✓			
Acceleration (Lat and Lon)			✓	✓
Heading angle	✓			
Yaw rate	✓			
Yaw acceleration				✓
Pitch angle	✓			✓
Steering angle	✓		✓	
Actuation forces			✓	
Road noise		✓		

The visual, vestibular, auditory and haptic modalities play a role in the reception of driving information (cf. Table 2.1). As the haptic modality is not considered in this thesis, reference is made to Bubb, Vollrath, et al. (2015) for the fundamental functionalities of the haptic modality. In the following section, the sensory modalities that are essential for the present work will be discussed.

2.1.1.2 Visual Perception

For the driving task, the visual channel is the most dominant information channel (Bubb, Vollrath, et al., 2015), as shown in Table 2.1. Information about position, velocity, heading direction of the ego vehicle, and other road users can be perceived. Rockwell (1972) attributes up to 90 percent of all information perceived while driving to the visual channel. The aspects of visual perception that are central to the work are briefly described below, without going into the detailed structure of the eye. For a more detailed insight into the structure of the dioptric apparatus, as well as their functional principles, it is referred to Eysel (2010), Goldstein (2010) or Bubb, Vollrath, et al. (2015).

Visual perception occurs when stimuli (light rays) enter the eyeball. The light rays pass through the cornea and lens, which filter, refract, and focus the light onto the innermost layer. The light rays are refracted to produce an upside-down reduced real image at the back of the eye on the retina. The retina, as the innermost layer, contains two different types of photoreceptors: the rods and cones. The cones enable daylight vision and are responsible for colour vision. They are capable of high visual acuity. Rods, on the other hand, are responsible for light-dark perception and have the ability to generate usable nerve impulses for the brain at low light intensity. In the fovea centralis, the area of sharpest vision, only cones are present. This corresponds to a visual acuity range of approximately 2° to 3° (Bubb, Vollrath, et al., 2015). Beyond the fixation point, peripheral vision provides only blurred and optically distorted impressions. In order to perceive objects outside of this area, first the eyes, then the head, and finally the torso have to be moved. In most cases, the eye movements of drivers differ by less than 6° around the target point (Rockwell, 1972).

According to Goldstein (2010), although visual acuity decreases with growing distance from the fovea centralis, dynamic sensitivity and the perception of movement and orientation in space increase. With the help of depth perception and optic flow, internal (e.g., direction of motion) and external (e.g., traffic signs) information related to traffic events can be perceived. Binocular vision enables depth resolution, which is important for road traffic, and thus the perception of spatial distance. In this process, the information is recorded with both eyes from different angles, and spatial vision up to about 20 m is possible due to the central processing of the double image (Bubb, Vollrath, et al., 2015). Optic flow, first introduced by Gibson (1950), on the other hand, allows the driver to process his own direction of motion as well as the associated speed. Optic flow describes the characteristic distribution of local motion directions over the entire visual field. It represents a vector field generated by self-motion. In this case, the vectors close to the observer are longer and move faster. Towards the target point, they become smaller and slower. Thus, motion gradients in the three spatial directions can be detected, allowing conclusions about the direction and speed of the own motion (Goldstein, 2010). However, in addition to visual perception, the vestibular sensory system also plays an important role in the perception of movement (Goldstein, 2010; Bubb, Vollrath, et al., 2015), which will be described in the following section.

2.1.1.3 Vestibular Perception

The vestibular channel is the second most important sensory modality in the performance of the driving task, accounting for up to eleven percent (Sivak, 1996). The vestibular system is primarily responsible for the perception of motion and for the correct functioning of the spatial orientation and motion sense (Zenner, 2010a). However, additional information from the visual and proprioceptive sensory systems is required for a clear interpretation of motion and position sensations. The vestibular organ is located next to the auditory organ in the labyrinth of the inner ear (Zenner, 2010a). Figure 2.2 illustrates the structure of the labyrinth on the left side.

According to Zenner (2010a), the vestibular organ consists of two otolithic organs and three semicircular canals. The otolithic organs (saccule and utricle) are orthogonal to each other and record linear accelerations in horizontal and vertical directions. Accordingly, they measure changes in translational velocity. The three semicircular canals, on the other hand, are responsible for the rotational acceleration. The semicircular canals are filled with endolymph and are oriented in three spatial directions. These five sensory organs have sensory epithelium whose hair cells function as sensory cells. In the otolithic organ, the sensory cells with their extensions (stereocilia) project into a gelatinous membrane containing otoliths. Otoliths are fine calcium carbonate crystals that increase the density of the membrane and, in turn, provide an inertial effect. A change in speed causes the gelatinous mass to start moving. The fine hair of the sensory cells is thereby sheared off leading to an excitation of the sensory cells. For each head position, there is a specific constellation of shearing of the otolithic in both inner ears (Zenner, 2010a). On the other hand, the semicular canals are responsible

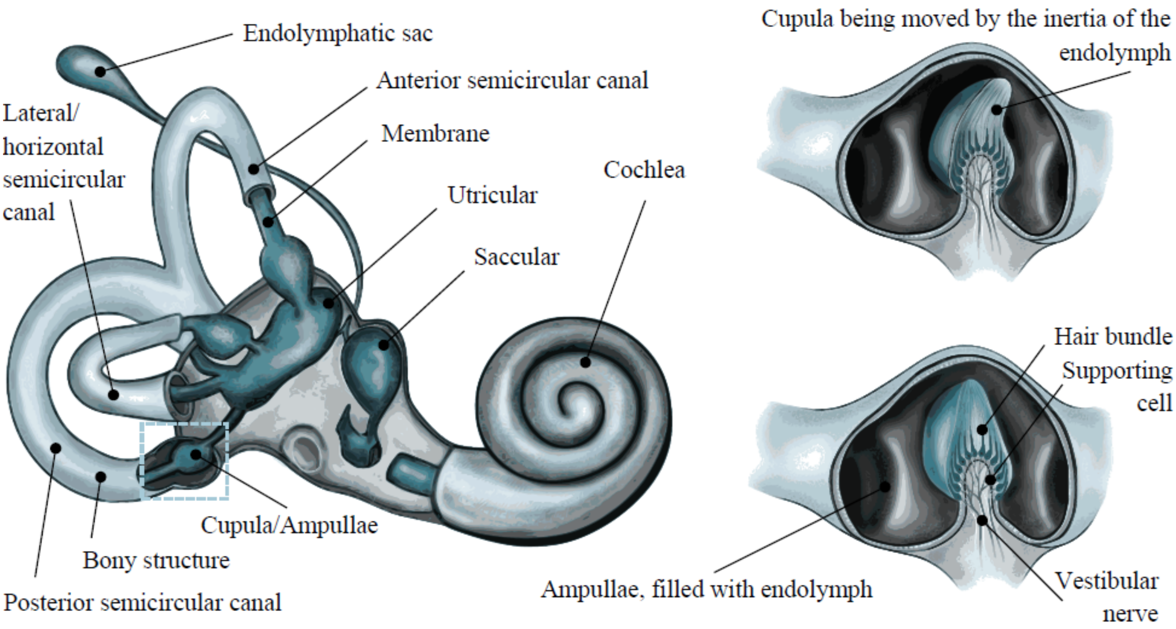


Figure 2.2: Anatomy of the vestibular organ with semicircular canals and otolithic organs (left); receptor of angular motion (right) taken from Bohrmann (2022)

for detecting angular motion. The fine hair of the sensory cells of the three canals protrudes into the gelatinous cupula, which interrupts the endolymph. Figure 2.2 depicts the deflection of the cupula on the right side. When a change in velocity occurs, the endolymph remains behind in the semicircular canal because of its inertia. As a result, the endolymph pushes the cupula to the side shearing off the stereocilia of the hair cells. This triggers a stimulus and stimulates the sensory cells. For each angular acceleration, a specific pattern of activity increase or inhibition exists in the arcades of the two inner ears, which is evaluated centrally (Zenner, 2010a). In addition to vestibular and visual perception, auditory also play a role in the reception of driving information (cf. Table 2.1), which will be described in the following section.

2.1.1.4 Auditory Perception

As seen in Table 2.1, longitudinal velocity and other environmental sounds (e.g., engine or wind noise) can be perceived through auditory perception. In this process, the ear converts sound waves and transmits them to the auditory organ via the inner ear. The exact structure of the ear and how it works can be found in Bubb, Vollrath, et al. (2015) or in Zenner (2010b). The perceived sounds during vehicle driving do not constitute entirely new information, but provide additional information for the assessment of driving dynamics variables. These help in the subjective estimation of driving speed and longitudinal acceleration (Tomaske & Fortmüller, 2001). The distance between the two ears makes it possible to detect differences in travel time and intensity, which enables directional orientation (Bubb, Vollrath, et al., 2015). Accordingly, auditory perception does not generate direct inferences about motion. Bengler, Bubb, Totzke, Schumann, and Flemisch (2012) present an overview of acoustic elements drivers receive during driving. This overview shows that auditory elements are provided by external sources (e.g., radio), other people (e.g., passengers), and the vehicle itself (e.g., warnings). In the present work, auditory perception is not considered by driving-related sounds, but by feedback from the automated vehicle (cf. Section 2.2). In the following section, the needed perception thresholds that are essential for exciting the sensory nerves will be discussed.

2.1.1.5 Perception Thresholds

The relationship between stimuli and subjective sensation can be analysed using the concept of perceptual thresholds (Handwerker & Schmelz, 2010; Goldstein, 2010). A distinction is made between absolute and difference thresholds. The absolute threshold is the minimum stimulus intensity that just evokes a sensation in a sensory system. The difference threshold, on the other hand, describes the stimulus increase that triggers a sensation that is just noticeably stronger (Handwerker & Schmelz, 2010; Goldstein, 2010). Weber's law states that this stimulus increment is a constant fraction of the initial stimulus, except for stimuli that are close to the stimulus threshold. There, the ratio is no longer constant but increases (Handwerker & Schmelz, 2010). Thresholds can be determined using different methods. The method of constant stimuli is the most accurate method (Goldstein, 2010). Here, a threshold is defined as a stimulus that is perceived 50% of the time it is presented. It is shown that thresholds are not absolute but yield a usually s-shaped psychometric function (Handwerker & Schmelz, 2010). This is because thresholds depend on the person, the stimulus property, the context, and the sensory channel (Bubb, Vollrath, et al., 2015).

In the literature, there are many reviews of visual and auditory thresholds (cf. Goldstein, 2010; Bubb, Vollrath, et al., 2015; Handwerker & Schmelz, 2010), so that only kinaesthetic and vestibular thresholds are presented below. According to Zenner (2010a), the vestibular system is unable to perceive velocitiy but only acceleration. However, humans are able to perceive the velocity of their own movement with the help of visual information (Zenner, 2010a). In the literature on perception thresholds for rotational and translational motions varying results occur. H. J. Wolf (2009) presented a wide-ranging overview of rotational thresholds for pitch and roll motions as well as translational thresholds for lateral, longitudinal, and vertical motions. Specifically for the automotive context, Heißing, Kudritzki, Schindlmaister, and Mauter (2000) provided an insight into the perception thresholds for rotational and translational acceleration. The authors illustrated that the perception threshold for the longitudinal accelerations varies in the range between $0.02\,m/s^2$ to $0.8\,m/s^2$ and for the lateral accelerations between $0.05\,m/s^2$ to $0.1\,m/s^2$. The reason for the range of these values is probably due to the very different experimental conditions under which these values were obtained (Lange, 2018).

A detailed literature review of perception thresholds for longitudinal translational acceleration is provided by T. Müller (2015). This review revealed similar perceptual thresholds as Heißing et al. (2000): $0.02\,m/s^2$ to $0.78\,m/s^2$. Furthermore, T. Müller (2015) identified difference thresholds for accelerations in the longitudinal direction based on real vehicle studies. The results pointed out that an acceleration reduction at $0.08\,m/s^2$ and an acceleration increase at $0.12\,m/s^2$ resulted a detection probability of 50% (T. Müller, 2015). The perception thresholds for both pitch and roll motion accelerations range from $0.1°/s^2$ to $0.2°/s^2$ (Heißing et al., 2000). For the perception thresholds of velocities, Nesti, Nooij, Losert, Bülthoff, and Pretto (2016) stated that the thresholds values vary between $0.5°/s$ and $2.0°/s$. According to Muragishi, Fukui, and Ono (2007), perception thresholds for acceleration depend on the presentation of additional visual feedback. Following the statements of the authors, visual feedback increases the perception threshold for lateral and vertical movements, while it lowers the perception threshold for yaw and pitch motions. Moreover, Gundry (1978) found that the perception threshold for roll motions depends on the duration of the stimulus: The greater the roll accelerations, the shorter the detection time (Gundry, 1978).

In addition to perception thresholds, comfort thresholds play an important role in the design of automated vehicles. However, comfort is a diffuse term that expresses convenience, and satisfaction (Bubb, Vollrath, et al., 2015). Based on L. Zhang, Helander, and Drury (1996), Bubb, Vollrath, et al. (2015) distinguish comfort and discomfort as influencing variables. Discomfort is associated with suffering or pain, but can be measured psychophysically. Comfort, on the other hand, is associated with pleasure, relaxation, and well-being, but cannot be easily measured. Well-being also limits the intensity of vehicle movements for human transport. Sauer, Kramer, and Ersoy (2017) stated that the pitch and roll motions are seen as side effects of driving behaviour and the aim is to keep them small. Lange (2018) presented an literature review on acceptable lateral ($0.75\,m/s^2$ to $1.3\,m/s^2$) and longitudinal ($1.0\,m/s^2$ to $3.5\,m/s^2$) accelerations. Moreover, several studies investigated comfortable tilting motions. Bär (2014) revealed with the help of an expert evaluation that roll velocities greater than $4°/s$ would reduce comfort. Bitterberg (1999) showed that thresholds of $5°/s$ or $15°/s^2$ are perceived as comfortable tilt motions. Cramer (2019) investigated acceptable pitch and roll motions during partially automated driving (PAD, SAE level 2) in several studies. It was revealed that pitch motions are comfortable at a $1°$ angle with an acceleration of $-5°/s^2$ or $2°$ angle with $-4°/s^2$. In contrast, roll motions are perceived as comfortable at a $3°$ angle with $-3.2°/s^2$ (Cramer, 2019).

Perceptual Phenomenon: Motion Sickness

As previously described, individuals can perceive things differently. This is because thresholds depend on the person, the stimulus property, the context, and the sensory channel (Bubb, Vollrath, et al., 2015). An important perceptual phenomenon for this work is motion sickness. Motion sickness is a diverse field and is also known as airsickness, seasickness, simulator sickness, carsickness, or VR-sickness (Golding, 2006; Diels, 2014; Somrak et al., 2019), among others. According to Reason and Brand (1975), motion sickness is a feeling of discomfort caused by a conflict between the different sensory systems visual and vestibular. The sense of balance is confused when the translational and/or rotational signals do not match the signals from the eyes, which perceive the relative movements between the human body and its environment. Furthermore, motion sickness occurs when there is a loss of control over one's own movements (Golding & Gresty, 2005) or when there is a decreased ability to anticipate the direction of movement (Rolnick & Lubow, 1991). A reduced field of view, a different direction of gaze, or a change in body posture can compound the conflict and make anticipation more difficult (Sivak & Schoettle, 2015). Common symptoms of motion sickness include nausea, cold-sweating, pallor, and vomiting (Reason & Brand, 1975). In addition to symptoms, motion sickness also varies intraindividual (Golding, 1998). Thus, it is not experienced in the same way by all individuals.

In the context of driving, motion sickness occurs more frequently in front-seat passengers than in drivers (Reason & Brand, 1975; Rolnick & Lubow, 1991), as they are usually less able to anticipate future movements. When the driver becomes a passive passenger at higher LoA, control over the own movements is lost and the ability to anticipate upcoming movements is degraded (Sivak & Schoettle, 2015). Performing NDRT also creates a conflict between visual (mostly static) and vestibular (dynamic due to vehicle movements) signals (Kato & Kitazaki, 2008). Rapid acceleration, braking, or cornering can cause carsickness (Griffin & Newman, 2004). Automated vehicles performing abrupt manoeuvres produce the same effect (Sivak & Schoettle, 2015). Accordingly, movements should be as slow, even, and "smooth" as possible, and accelerations should occur at a low and even level (Sivak & Schoettle, 2015; Diels, 2014). Based on human perception, the information processing is explained in the following.

2.1.2 Information Processing

In the subsequent information processing, the perceived environmental impressions are combined. This combination is used to anticipate future states and to design appropriate reactions (Bubb, Vollrath, et al., 2015). To investigate human information processing, various model concepts with different basic assumptions have been developed. A distinction is made between sequential and resource models. Sequential models describe the flow of information from stimulus reception to reaction (Schlick, Bruder, & Luczak, 2018). Different stages of processing are followed and a processing time is allocated to each stage (Schlick et al., 2018). The sequential process will be explained on the basis of situation awareness. There are numerous models for this in the literature, of which Rauch (2019) provides a wide-ranging overview. One of the most well-known models is provided by Endsley (1995) (cf. Figure 2.3) stating that situation awareness is the ability to perceive situations comprehensively and to interpret them appropriately.

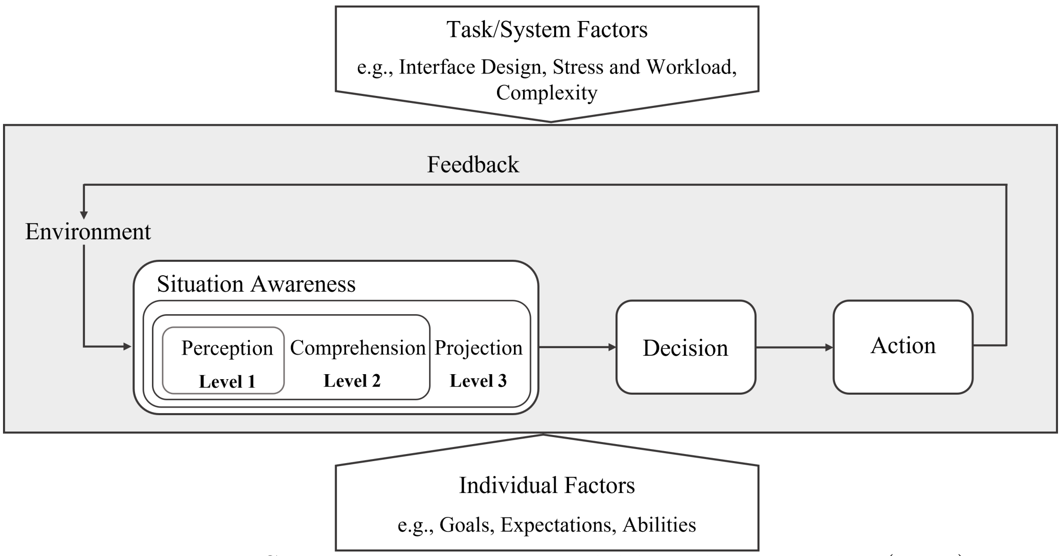


Figure 2.3: Situation awareness model based on Endsley (1995)

Following the model of Endsley (1995), situation awareness is divided into three hierarchical levels. The first level describes the perception of current stimuli in the environment. This process may be controlled willingly (top-down) or involuntarily (bottom-up) by conspicuous stimuli (Durso & Gronlund, 1999). The following level describes the comprehension of the stimuli meaning. The perceived information is compiled into a holistic picture of the situation and then meaning is attached to it. The third level describes the projection of this interpreted information into the immediate future. This involves anticipating upcoming actions or events. These three levels are affected by the current task, the automated system, and individual factors (Endsley, 1995). Accordingly, situation awareness forms the basis for decision making. Thus, the subsequent planning and execution of actions is no longer part of the situation awareness (Endsley, 1995, 2000).

While sequential models are determined by the factor time, resource models are limited by cognitive capacity. Accordingly, this cognitive capacity is assumed to be present only to a limited amount (Schlick et al., 2018). Wickens (2002) multiple resource model, for example, states that multiple capacities with resource-like properties are present. As seen in Figure 2.4, the model is divided into four dimensions: processing stages, perceptual modalities, visual channels, and processing codes.

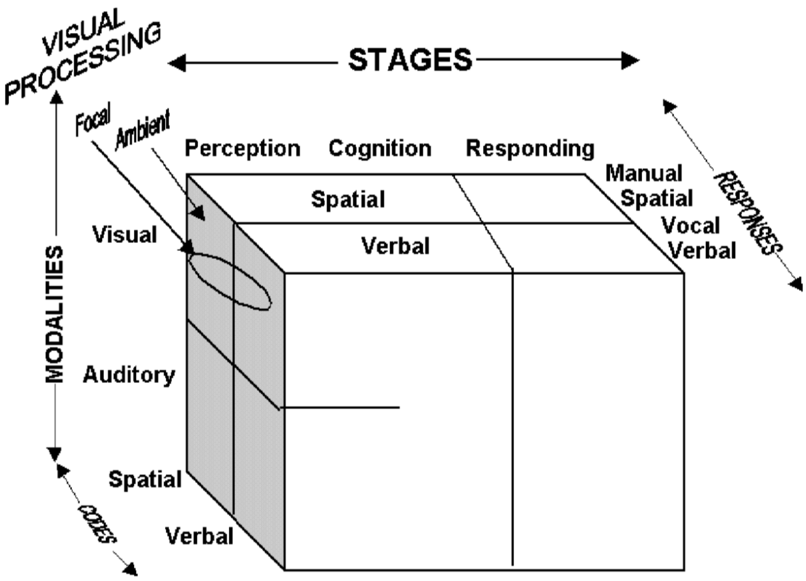


Figure 2.4: Multiple resource model taken from Wickens (2002)

The multiple resource model states that two tasks interfere if their execution requires access to the same resource characteristics (e.g., both require visual perception). Thus, if tasks access the same resources, performance is degraded. This interference can be minimised if two concurrent processes are less similar. Hence, the further apart the resources are (e.g., a visual and an auditory perceptual requirement), the better the performance. Interference therefore occurs when the total capacity of the resources is exceeded or when one resource is accessed too intensively (Wickens, 2002).

In addition to information reception and processing, the resulting execution is essential. In this process, the compiled action designs are translated into reality with the help of the musculature (Bubb, Vollrath, et al., 2015). These actions can be expressed through movement or verbal expression. In order to consider the actions of the driver in interaction with the vehicle, the driving tasks and the interaction between the driver and the vehicle are explained in the following section.

2.1.3 The Driving Task

The relationship between driver, vehicle, and environment can be illustrated by the control loop according to Bubb (2015a), which is determined by the (driving) task, its realisation, and the result. The driver variable is referred to as the controller. The feedback of the result, which closes the control loop, describes that the controller can compare the task and the result. The driver thus reacts to discrepancies between the task and the result by acting on the vehicle. External environmental influences that are not part of the task can affect this process (Bubb, 2015a).

The driving task consists several subtasks, which are divided into three categories according to Bubb (2015b), based on a proposal by Geiser (1985). A distinction is made between primary, secondary, and tertiary driving tasks. Here, the primary driving task is divided by Donges (1982) into three hierarchically structured layers: navigation, guidance, and stabilisation. Figure 2.5 presents the compounded driver-vehicle control loop including the model from Bubb (2015a) as well as the driving tasks according to Bubb (2015b) and Donges (1982).

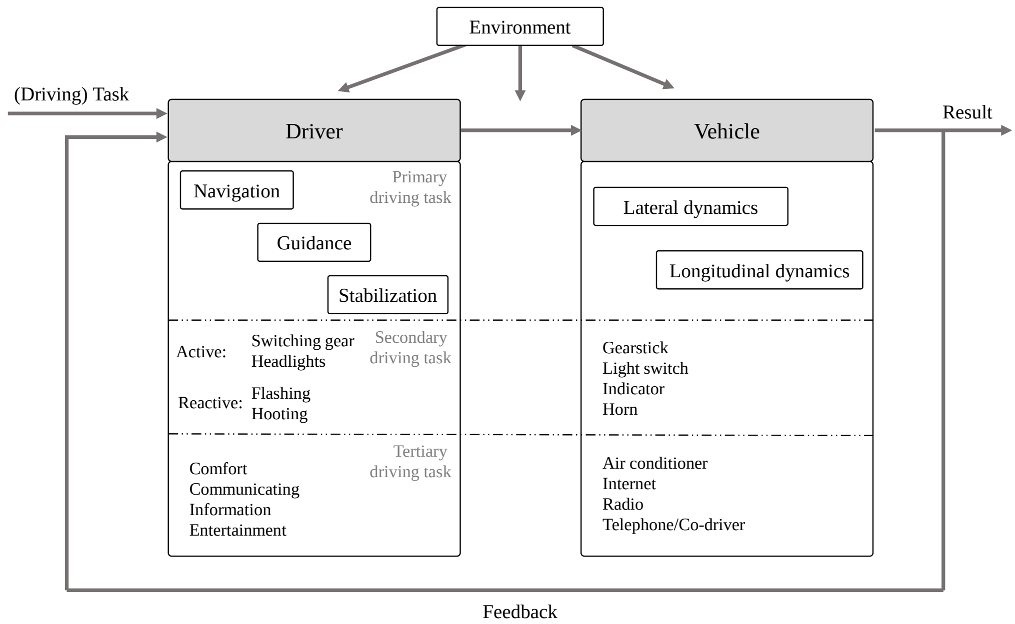


Figure 2.5: Driver-vehicle control loop based on Bubb (2015a), Bubb (2015b), and Donges (1982)

The primary driving task serves to move the vehicle through the environment (Bubb, 2015b). The task of the navigation layer is to select an appropriate route. During the guidance task, the driver determines the target course and target speed depending on external conditions, such as road conditions or traffic density. The stabilisation task is used to maintain the specified target values by operating the controls (Donges, 1982, 2009). The secondary driving tasks according to Bubb (2015b) are performed in direct dependence on the primary driving task due to traffic or the environment. Following Bubb (2015b), these are divided into active or reactive tasks. The driver either actively interacts with the environment by, for instance, blinking, or reactively responds to environmental stimuli by, for example, using the windshield wiper during rain. Other tasks, that are not part of the immediate driving task, such as adjusting the air conditioning or using the radio, are defined as tertiary tasks (Bubb, 2015b).

Rasmussen (1983) developed a three-level model for target oriented human activities. The levels are divided into knowledge-based, rule-based, and skill-based behaviours based on different levels of human cognitive input. Knowledge-based behaviour is used when complex situations require untrained actions (e.g., novice drivers in traffic). If actions are retrieved from a repertoire of previous occasions, the behaviour is referred to as rule-based. Skill-based behaviour is based on reflexive stimulus-response mechanisms. According to Donges (2009), the navigation task is assigned to knowledge-based behaviour and the stabilisation level to skill-based behaviour. All three levels by Rasmussen (1983) can be assigned to the guidance level (Donges, 2009).

2.1.4 Levels of Automation

According to Gasser et al. (2015), systems that support the driver or take over parts of the driving task can be classified into three categories based on the type of intervention. Category A describes informing and warning systems supporting the driver in receiving information such as warning systems. Category B defines continuously operating automated driving functions. These have an influence on vehicle control over a certain period of time. Emergency systems that intervene immediately in critical situations beyond the driver's control are classified in category C (Gasser et al., 2015).

A closer look at category B was taken by the German "Bundesanstalt für Straßenwesen" (BASt), which defines five LoA ranging from driver only to fully automation (Gasser, 2012). Furthermore, the SAE international (2022) clarifies six categories (cf. Figure 2.6). The definition of each LoA is composed of automation system performance and the role of the vehicle driver (Damböck, 2013). The latter indicates that the LoA differ in terms of the assignment of vehicle guidance, the role of the driver as a supervisor and fallback level, and the recognition of system limits by the automation. The taxonomy by SAE international (2022) starts from "No Driving Automation" (SAE level 0) representing manual driving (MAN), where the driver performs the entire dynamic driving task (DDT). In assisted driving (ASD, SAE level 1), the automation system takes over either lateral or longitudinal control. In higher LoA (SAE level 2 up to level 5), the automation system performs both lateral and longitudinal guidance. Partially automated driving (PAD, SAE level 2) requires the driver to constantly monitor the system and the environment. From "Conditional Driving Automation" (CAD, SAE level 3), the driver is allowed to release the monitoring responsibility and engage in an NDRT. The automated system can take over the DDT in specific use cases during conditional and highly automated driving (HAD, SAE level 4). However, during CAD the driver must respond to a take-over request (TOR) with sufficient time reserve. Thus, the driver is omitted as a fallback in HAD. The highest level of the taxonomy describes "Full Driving Automation" without the restriction to specific use cases (SAE level 5).

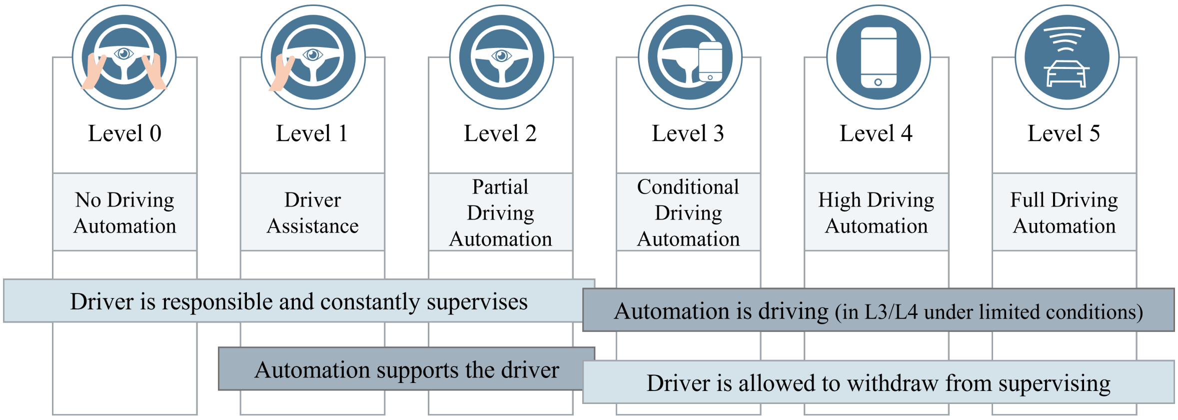


Figure 2.6: Taxonomy of automated driving vehicle based on SAE international (2022)

Due to the complex taxonomy, the BASt (2021) published a further classification (Geißler & Shi, 2022). This simplified model includes only three categories in order to define clear and distinct roles for better user communication (Bundesanstalt für Straßenwesen, 2021). This model distinguishes exclusively between assisted, automated, and autonomous driving. In assisted mode, the system supports the driver in the DDT. Regardless of whether the support is provided laterally, longitudinally, or both, the driver has to permanently monitor the system and the environment as well as take corrective action if necessary. During automated driving, the driver is allowed to perform an NDRT and has to resume the driving task with sufficient time after being prompted. In the third mode, the system completely takes over the DDT. Thus, the driver is only a passenger (Bundesanstalt für Straßenwesen, 2021). Automated driving vehicles can contain several LoA. A change from one LoA to another is called a transition. The following section describes and categorises transitions between LoA.

2.1.5 Transitions

According to Lu, Happee, Cabrall, Kyriakidis, and de Winter (2016), transitions can be divided into monitoring and control transitions. Figure 2.7 represents the classification of transitions according to Lu et al. (2016). A control transition occurs whenever lateral and/or longitudinal control changes between the driver and the vehicle. Transitions between CAD, HAD, and full driving automation change the monitoring behaviour. For control transitions, Lu et al. (2016) created a categorisation based on the classification of Martens et al. (2008), which consists of three dimensions. The first dimension describes the initiator of a transition. A distinction is made between human-initiated and automation-initiated transitions. The second dimension deals with the control holder after the transition: automation or driver. The third dimension is concerned with the reason for the transition. The reason can be either optional or mandatory. Optional transitions are voluntary and are only initiated by the driver. Mandatory transitions, on the other hand, can be initiated by both the driver and the automation and are always necessary when control must be relinquished.

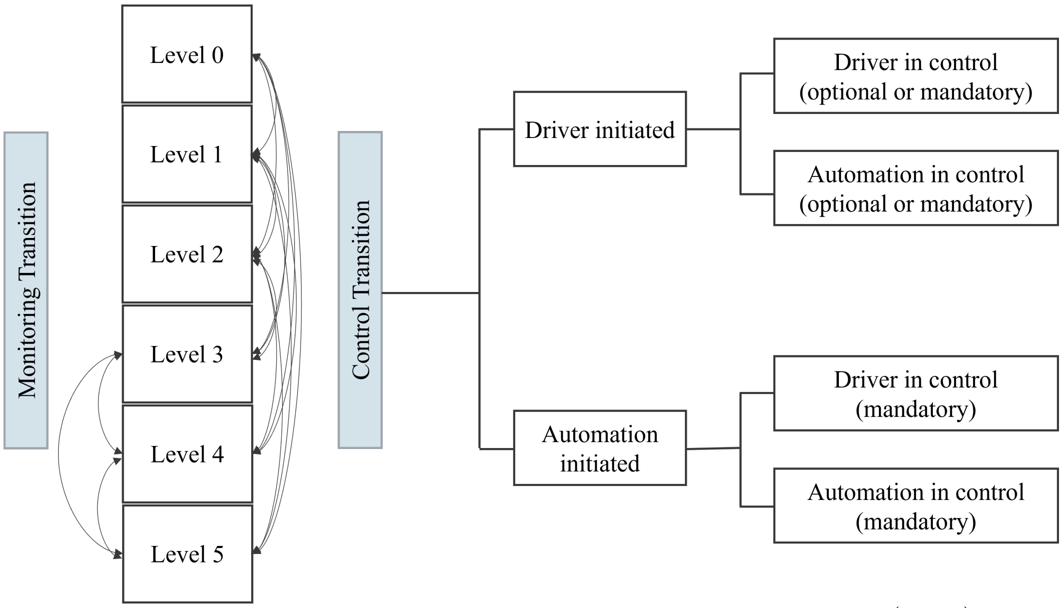


Figure 2.7: Classification of transitions based on Lu et al. (2016).

Transitions can be critical or non-critical (McDonald et al., 2019). Critical transitions are initiated by a triggering event (e.g., unexpectedly reaching system limits). When the automated system detects the need for intervention, it issues a TOR to the driver. This take-over process has been investigated in a multitude of studies (e.g., Damböck, Farid, Tönert, & Bengler K, 2012; Gold, Damböck, Lorenz, & Bengler, 2013). For reviews on the investigation of TOR see Eriksson and Stanton (2017), B. Zhang et al. (2019) or McDonald et al. (2019). Accordingly, non-critical transitions include all other transitions. These can be initiated by the driver as well as by the automated system. Transitions initiated by the system thereby cover preliminarily recognised system limits. For example, if HAD is only available on the motorway, the automated driving vehicle will inform the driver about the take-over in a timely manner before a departure. Non-critical transitions are usually without time pressure and can occur to both higher and lower LoA (McDonald et al., 2019). Multi-level automated driving systems change the driver's role through the varying tasks in the different LoA and the transitions between them. This is discussed in more detail below.

2.1.6 Changes in the Driver's Role

As shown in the previous chapter, the role of the driver changes as the vehicle becomes more automated. The driver switches from an active role to a passive passenger. Thus, motoric-manual parts of the driving task are replaced by cognitive-mental tasks (Vollrath & Krems, 2011). The reduction of certain subtasks of the driving task is actually intended to reduce workload. However, higher LoA also means higher complexity and demands on humans (Hollnagel, 1998). Now, the task of monitoring the system and making decisions about whether the vehicle's intentions are reasonable and safe is added (Vollrath & Krems, 2011). As illustrated in "Ironies of Automation" by Bainbridge (1983), automation is not necessarily relieving. The shift from an active to a passive role means that the driver is no longer part of the driver-vehicle control loop (Bubb, 2015a). This release of the driver may cause a loss of skills (Bainbridge, 1983; Endsley & Kiris, 1995), changes in driver workload (Young & Stanton, 2002; de Winter, Happee, Hartens, & Stanton, 2014), vigilance reductions (Bainbridge, 1983; Sarter, Woods, & Billings, 1997), and a loss of situational and system awareness (Endsley, 1995; Sarter & Woods, 1995), which promotes a decrease in the ability to detect and respond to system errors (Endsley & Kiris, 1995). Moreover, the low-requirement monitoring activity can lead to attentional shifts (Merat, Jamson, Lai, & Carsten, 2012), or misuse of the automation system (Parasuraman & Riley, 1997).

Another change exists from CAD (SAE Level 3 - Level 5) where the driver is not required to remain in the control loop for defined situations. The driver is allowed to withdraw from the driving or monitoring task and perform an NDRT. However, it is problematic within CAD, in which the driver has to fully take-over the vehicle guidance within a certain time after being requested to do so. Various studies show that humans need between three to eight seconds to be able to take-over again (Damböck et al., 2012; Gold, Damböck, Lorenz, & Bengler, 2013). However, this must be distinguished from the time needed to mentally stabilise after a transition. Strayer, Cooper, Turrill, Coleman, and Hopman (2015) demonstrated that humans need 27 s to regain full attention after an NDRT. Merat, Jamson, Lai, Daly, and Carsten (2014) revealed that it can even take up to 40 s. This suggests that the cognitive processing of a take-over situation takes more time than the (reflexive) motor response to a TOR (Zeeb, Buchner, & Schrauf, 2016). HAD is an extension of CAD, in which the driver serves no longer as a fallback level. The take-over time can be several minutes, so any distraction has little effect on the take-over of manual vehicle control (Othersen, 2016). As a result, the switch from an active role to a passive passenger leads to new tasks (e.g., supervising or performing an NDRT). Psychological constructs including, for example, mode awareness (Sarter & Woods, 1995) and trust (Körber, 2019) associated with automated driving also evolve.

2.1.6.1 Mode Awareness

With respect to automated systems, in addition to situation awareness (cf. Section 2.1.2), the driver also needs knowledge about the current and future states and behaviours of the automation system (Othersen, 2016). This mode awareness is a part of situation awareness and is defined according to Sarter and Woods (1995) as the knowledge about functions of the different modes, when to use which mode, how to change from one mode to another, and the recognition of which mode is currently active. Thus, the same processes are important as in situation awareness: perceiving system information, understanding it, and anticipating a future state. The only difference between mode awareness and situation awareness is the amount of information. While knowledge about the whole situation is available in situation awareness, mode awareness describes the knowledge representation of the system (Kolbig & Müller, 2013). A further distinction is made by Cramer (2019), in which system awareness ought to be distinguished. Here, system awareness is defined as "awareness of the system state or intentions of the automation system" (Cramer, 2019, p. 11). Incomplete mental models about the system can lead to mode error or mode confusion (Sarter & Woods, 1995; Bredereke & Lankenau, 2002; Kolbig & Müller, 2013). Mode errors are caused by incorrect information and can lead to inappropriate or absent actions (Sarter & Woods, 1995; Othersen, 2016). In mode confusion, on the other hand, the system behaves differently than expected, which results from incorrect knowledge or incorrect observation (Bredereke & Lankenau, 2002).

An appropriate mental model is a precondition to building adequate situation, system, and mode awareness (Sarter & Woods, 1995). In this context, a mental model describes the internal representation of the external world (I. Wolf, 2016). This representation is a portrayal of previously acquired knowledge about situations, system state, and behaviour (Sarter & Woods, 1995; Endsley, 1995). It serves to interpret the situation by drawing on previous experiences and to form anticipations about its possible development (Endsley, 2000). Previous experiences with automation systems, certain expectations of assisted or automated driving vehicles, and currently perceived system information form mental models (Norman, 1990; I. Wolf, 2016). Adequate feedback about the environment, the automation system, the system's actions, and intentions helps drivers to build accurate mental models and to anticipate whether the automation system is acting correctly in the environment (I. Wolf, 2016). Various studies show that similar LoA (for example PAD and CAD) can lead to mode confusion (Petermann & Schlag, 2010; Petermann & Kiss, 2010; Feldhütter, Härtwig, Kurpiers, Hernandez, & Bengler, 2019) as well as to decreasing mode awareness (Feldhütter, Segler, & Bengler, 2018; Feldhütter et al., 2019). Petermann and Schlag (2010) recommend integrating only three LoA in an automated vehicle, which should be clearly distinguishable from each other (Petermann-Stock, 2015). Mistakes can thus occur when information is communicated incorrectly or misunderstood. To prevent these mistakes, correct mental models and an adequate knowledge representation must first be created (Boer & Hoedemaeker, 1998; Beggiato et al., 2015; I. Wolf, 2016).

In the beginning, assistance is needed to build the basic model and to learn the system functions. This could be done, for example, through driving simulator training (Ebnali, Hulme, Ebnali-Heidari, & Mazloumi, 2019), gamification (Feinauer et al., 2022), interactive tutorials (Forster et al., 2019) or an in-car tutor (Feinauer, Voskort, Groh, & Petzoldt, 2023). If users have previous experience with MAN or ADAS, mental models can be formed more easily (Othersen, 2016). Involving the driver through certain system interactions can also engage the driver in the driving experience, even when the automation system performs the vehicle guidance. (e.g., Albert et al., 2015; Flemisch, Bengler, Bubb, Winner, & Bruder, 2014). Maintenance and updating of a correct mental model can be generated by system feedback (Sarter & Woods, 1995). Feedback prevents the occurrence of surprises, strengthens the formation of situation awareness as well as mode awareness, and is especially important when multiple LoA are used in a system (Kolbig & Müller, 2013). Information from the environment as well as information related to the automation system such as status, intentions, current, and future actions or upcoming transitions are essential components (Boer & Hoedemaeker, 1998; Norman, 1990; Sarter & Woods, 1995; Beggiato et al., 2015). The different LoA affect not only mode awareness and mental models. They also have an impact on trust and acceptance (Beggiato & Krems, 2013; Körber, Baseler, & Bengler, 2018), which is described below.

2.1.6.2 Trust

According to Wickens, Helton, Hollands, and Banbury (2022), trust is probably the most important construct in the use of automated systems. Trust is described as “the attitude that an agent will help achieve an individual’s goals in a situation characterised by uncertainty and vulnerability” (J. D. Lee & See, 2004, p. 51). Two entities are required to establish a trust relationship: the trustor and the trustee (Mirnig, Wintersberger, Sutter, & Ziegler, 2016). In the context of automated driving, the trustor is the person who uses the automated system and gives trust. The trustor must rely on rational and affective information to trust the system (J. D. Lee & See, 2004). In contrast, the trustee is an agent who is trusted. In this context, the automation system is the trustee.

There are several models that describe trust (for an overview see Manchon, Bueno, & Navarro, 2021). The trust model of Hoff and Bashir (2015), which is based on the model established by J. D. Lee and See (2004), describes three levels of variability in trust.

- *Dispositional* trust is based on age, gender, culture, and the personality of the trustor (e.g., Gold, Körber, Hohenberger, Lechner, & Bengler, 2015; Feldhütter, Gold, Hüger, & Bengler, 2016). It is relatively stable and independent from the context of the automated system.
- *Situational* trust is more flexible and depends on external and internal sources. External factors include, for example, usage complexity, operator’s workload or benefits during interaction (e.g., Clement et al., 2022). Internal factors encompass the trustor’s state of mind, mood or self-confidence.
- *Learned* trust is differentiated into initially learned and dynamically learned trust. Prior knowledge and expectations may influence the perception of the automated system and the understanding of its functions (e.g., Körber et al., 2018). Through the interaction with the automated system, this initial trust can evolve into dynamically learned trust. This evolution is influenced by certain design features such as appearance, communication style, feedback, and the performance of the system such as predictability, reliability, or usefulness of automation (e.g., Koo et al., 2015; Wintersberger, von Sawitzky, Frison, & Riener, 2017).

“People tend to rely on automation they trust and tend to reject automation they do not” (J. D. Lee & See, 2004, p. 51). Hence, trust often determines the use or non-use of automation. In a driving simulator study, Körber et al. (2018) showed that the amount of trust was related to the participant's behaviour during automated driving. The higher the level of trust in the automation system, the fewer control glances were made while performing an NDRT. Thus, trust in automation indicates whether an automated system is used and also how it is used (Parasuraman & Riley, 1997). According to Parasuraman and Riley (1997), there are four interaction styles in the use of automation. "Use" is described as the appropriate amount of trust that coincides with the functionalities of the automated system. "Disuse", on the other hand, is present when the level of trust is below the capabilities. Thus, the user will not accept and use the system (Parasuraman & Riley, 1997). "Misuse" means the opposite, in this case too much trust is applied. "Absuse" describes the improper implementation of automation by designers (Parasuraman & Riley, 1997).

To avoid disuse or misuse of the automated system, the user should establish appropriate trust. Trust is therefore an important consideration in the design of automated systems (Körber et al., 2018). Trust can be generated at different levels and feedback plays a major role in updating the learned trust. Therefore, Manchon et al. (2021) argue that further research on the influence of feedback on trust is needed. Furthermore, trust not only determines the use of automation but also influences the user's acceptance (Manchon et al., 2021) of the automated system (e.g., Wintersberger et al., 2017).

2.1.6.3 Acceptance

Davis (1989) Technology Acceptance Model (TAM) was originally used to model user acceptance of information technology (Davis, Bagozzi, & Warshaw, 1989). According to the model, acceptance is dependent on two constructs Perceived Usefulness and Perceived Ease of Use. Perceived Usefulness is defined as "the degree to which a person believes that using a particular system would enhance his or her job performance" (Davis, 1989, p. 320). In contrast, Perceived Ease of Use is described as "the degree to which a person believes that using a particular system would be free of effort" (Davis, 1989, p. 320). The two constructs are influenced by external variables that are not explained in this model. Both Perceived Usefulness and Perceived Ease of Use influence the "Attitude Toward Using", which in turn has a direct effect on the "behavioural Intention to Use". This intention finally affects the "Actual System Use" (Davis, 1989).

Another acceptance model based on eight models including TAM, is the Unified Theory of Acceptance and Use of Technology (UTAUT) by Venkatesh, Morris, Davis, and Davis (2003). In this context, UTAUT is built on four constructs as the determining factors:

- *Performance Expectancy* is characterised as the extent to which users perceive the system as personally enriching their performance.
- *Effort Expectancy* describes the ease of use.
- *Social Influence* determines the extent to which others perceive that users are using the system.
- *Facilitating Conditions* represents the user's perception of the support provided to them.

The first three constructs impact the "behavioural Intention", which describes the user's intended use. This intention in turn determines the "Use behaviour", which is influenced by the last construct (Facilitating Condition). In addition, the model is completed by age, gender, experience, and voluntariness of use, which moderate the effects of the four constructs (Venkatesh et al., 2003). On the basis of UTAUT, a follow-up model was developed by Venkatesh, Thong, and Xu (2012), which was extended by three factors: Hedonic Motivation, Price Value, and Habit (cf. Figure 2.8). Hedonic Motivation is defined as the pleasure derived from using technology. The cognitive trade-off between the benefits of the technology and the monetary costs is called Price Value. Habit denotes the individually perceived extent to which the use of technology is, in a sense, incidental. In terms of moderating variables, voluntariness has been removed from the UTAUT2 model because consumption in private settings is generally a voluntary behaviour (Venkatesh et al., 2012). The UTAUT model could explain 70 percent of the variance in usage behaviour (Venkatesh et al., 2003), while other acceptance models could only explain between 17 to 53 percent of the variance for usage intention. Thus, the UTAUT as well as UTAUT2 model is a successful further development and consolidation of the previously existing TAM (Kohl, 2021).

The central message of the acceptance models is that users will accept an information technology if it is useful and easy to use (Davis, 1989). Acceptance of a new technology can be viewed as the extent to which a person intends to use that technology (Venkatesh et al., 2003). "Acceptance of automated driving can be defined as drivers' willingness to adopt vehicle technologies" (Ayoub, Zhou, Bao, & Yang, 2019). An automated system should therefore be useful and satisfying. This can be achieved, for example, through correct feedback and good communication. Thus, feedback is one of the most important factors to maintain adequate system understanding, appropriate trust, and acceptance (Bubb, Bengler, et al., 2015; Sarter & Woods, 1995; Wintersberger et al., 2017). Therefore, a more detailed look at different feedback modalities and concepts of automated vehicle guidance is given in the following.

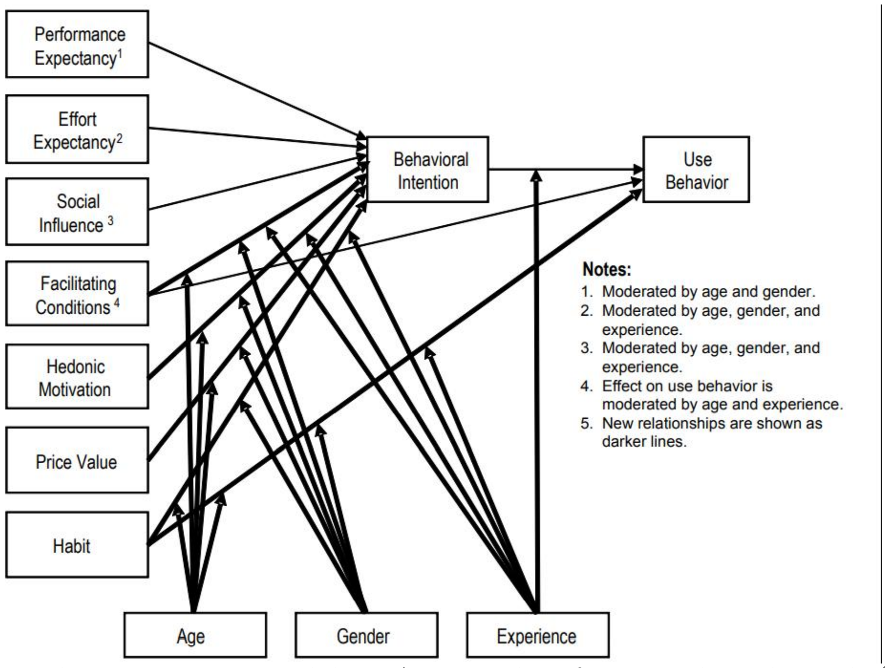


Figure 2.8: The acceptance model UTAUT2 taken from Venkatesh et al. (2012)

2.2 Feedback in Automated Driving

The switch of the drivers' role due to the increasing automation of driving means the need for information type and content of changes (Beggiato et al., 2015). It is essential that the driver is aware of the system status and the intention of the system at all times in order to maintain an adequate reaction (Boer & Hoedemaeker, 1998; Sarter & Woods, 1995; Beggiato et al., 2015). This corresponds to the three levels of situation awareness, where the driver perceives information, understands, and anticipates future actions (cf. Section 2.1.2). To avoid misuse of the automated driving system (Parasuraman & Riley, 1997) and to develop an adequate mental representation of the automation system (I. Wolf, 2016), it is important that the driver receives regular feedback from the automated system. Feedback is defined as the acknowledgment of an automated system outcome (Bubb, Bengler, et al., 2015). The outcome conveys information about the confirmation of a request to the system, the execution of an action, results achieved, and the presence of problems (Norman, 1988, 1990). Moreover, feedback informs the user about the state of the system (Pérez-Quiñones & Sibert, 1996).

System feedback can be represented using HMI. In the context of automated vehicle guidance, Bengler et al. (2020) designed a framework to distinguish between the different types of HMI, which is depicted in Figure 2.9. In addition to the information content, different sensory channels are assigned to each HMI type. Furthermore, the system is divided into internal and external communication.

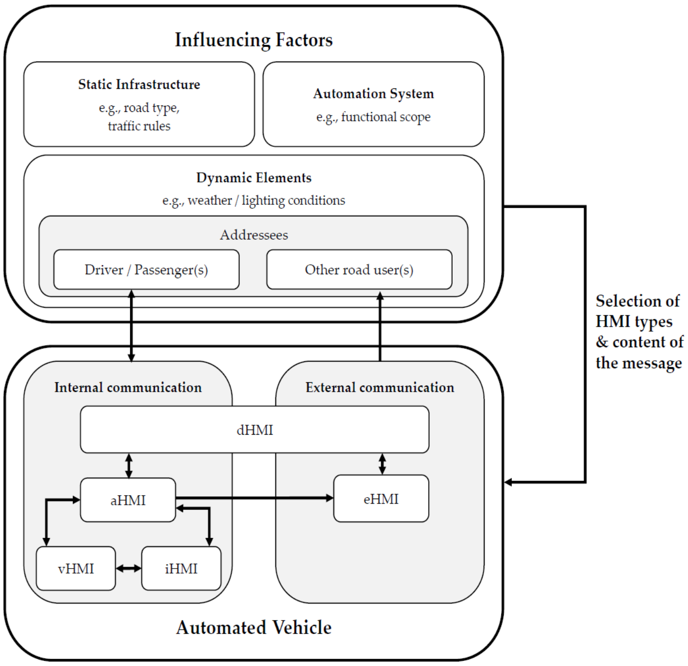


Figure 2.9: The HMI framework with influencing factors and the different HMI types taken from Bengler et al. (2020)

According to Bengler et al. (2020), information for vehicle operation is presented using the Vehicle HMI (vHMI). The Automation HMI (aHMI) provides information about the automation system state as well as current and planned activities of the automated driving vehicle. An additional interface for performing NDRT is provided by the Infotainment HMI (iHMI). These three types of HMI describe the vehicle's internal communication with the occupants and communicate via visual, auditory, or haptic stimuli (Bengler et al., 2020). Other ways of communicating information include the Dynamic HMI (dHMI) and the External HMI (eHMI). The dHMI communicates with both occupants and other road users through vehicle dynamics. It thus transmits information mainly via the vestibular channel to the passengers Bengler et al. (2020). The eHMI communicates visually and acoustically with other road users through the vehicle's surface of the vehicle or by means of projections (Bengler et al., 2020).

There are a large number of studies, recommendations, and guidelines for designing aHMI (e.g., Diels & Thompson, 2018; Ekman, Johansson, & Sochor, 2018; Carsten & Martens, 2019). Present in all sources is the importance of comprehensibility, transparency, and predictability of system states. System information should also be timely and clearly perceivable (Bengler et al., 2012; Saffarian et al., 2012) as well as being comfortable and associable (Lange, Albert, Siedersberger, & Bengler, 2015; Carsten & Martens, 2019). In addition, the European Commission (1998) states that system information should relieve the driver, be accurate, and not be distracting or induce safety-critical behaviour. In this context, Beggiato et al. (2015) used a focus group and a subsequent simulator study to investigate the requirements of feedback during MAN, PAD, and CAD. It is found that feedback in the context of automated driving varies depending on the driver's task. The driver's information requirements are higher for a PAD than for CAD due to the monitoring task. In both cases, it is important that the driver understands system actions at all times. Furthermore, it became apparent that information needs vary depending on the driver, and also on trust in the automated driving systems. In order to maintain a suitable mental model of the LoA, Beggiato et al. (2015) recommend displaying the system status, the certainty of being able to handle a situation, navigation instructions, as well as current and planned manoeuvres. Furthermore, the current speed, speed limits, and critical situations should be depicted.

In addition, Feierle et al. (2020) investigated the information needs for HAD in this context. The information need for drivers who performed an NDRT showed no difference compared to drivers who did not perform an NDRT. The authors conclude that drivers should remain informed about manoeuvres and future actions even during HAD. Diels and Thompson (2018) examined information expectations during CAD and HAD. For different scenarios, results revealed that participants want to receive information about the current situation ("What does the vehicle see") as well as about the (planned) behaviour of the vehicle. Information should be conveyed primarily visually (e.g., in the center display or head-up display) or auditorily. The relevant information that should be displayed in the different scenarios in both LoA coincides with the findings of Beggiato et al. (2015):

- Vehicle intentions in relation to critical situations
- Prospective manoeuvres
- Velocity limit during speed-restricted area
- Safe continuation of driving
- Detection of critical situations
- Ability to approve or overwrite vehicle actions in critical situations

Additionally, a number of studies assessed that further information like distance-based elements (Richardson, Flohr, & Michel, 2018), a reason to describe the vehicle behaviour (Koo et al., 2015) or uncertainty (Beller, Heesen, & Vollrath, 2013) are useful and improve driver behaviour. Danner, Pfromm, Limbacher, and Bengler (2020), e.g., revealed that predictive elements like a time budget is important for the activity planning process in automated driving. Koo et al. (2015) investigated feedforward information and depicted that drivers want to be informed about why, but not how the automated vehicle behaves. Interaction concepts build another possibility to provide and receive feedback from the automated driving vehicle. Albert (2018) presents an overview of various interaction concepts, e.g., H-Mode or Conduct-by-Wire (Flemisch et al., 2014; Bubb & Bengler, 2015), and created a manoeuvre interaction concept to integrate the driver.

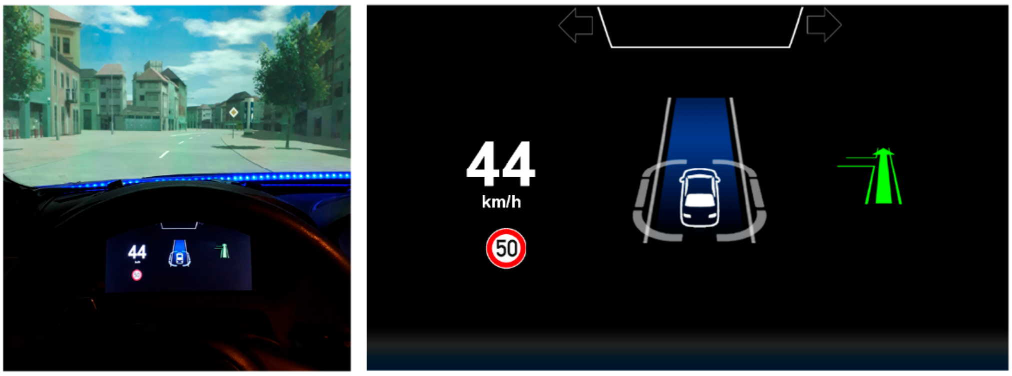
In summary, it can be concluded that comprehensibility, transparency, and predictability are very significant. Design recommendations usually only describe the importance of feedback, but not yet the appropriateness of its type and scope (Ekman et al., 2018). Feedback can occur in a variety of ways and through all sensory channels (Bubb, Bengler, et al., 2015). Research in this area (Bengler et al., 2020) has focused mainly on visual, auditory, or haptic feedback. Another modality for conveying system intentions is the vestibular one (Lange, 2018; C. Müller, 2019; Cramer, 2019). In the following, a detailed insight into feedback modalities that are important for this thesis is provided.

2.2.1 Visual Feedback

Bubb, Bengler, et al. (2015) distinguish visual feedback into digital, analog, pictorial, and contact analog displays. Real-world information and technical details of the system can be represented using range of values (for example, the current speed of the vehicle). Analog displays show the entire range of values using fixed scales and mark the current value with a moving pointer. This display option is particularly recommended when two or more values of an operating state are to be compared with each other (e.g., tachometer). A value range can be divided into several segments. Digital displays only show the value of the current segment. Digital visual feedback should be used when an accurate value needs to be read quickly because the error rate in reading is low compared to the other display options (Bubb, Bengler, et al., 2015). Pictorial displays represent the environment in an abstract simplified way. They facilitate the user's mental process and are primarily used for distance markings (for example, in ACC) or in navigation devices. In contact analog displays, artificial information is projected in the environment (Bubb, Bengler, et al., 2015).

Visual feedback can be used for communication with vehicle occupants (aHMI, iHMI, and vHMI) as well as with other road users (eHMI) (Bengler et al., 2020). Information for vehicle passengers can be presented in the central display, instrument cluster, head-up display (HUD), or using LED light indicators, among others (Bengler et al., 2020; Bubb, Bengler, et al., 2015). An example of an instrument cluster concept with

LED stripes is set out in Figure 2.10. The classic medium for visual feedback is the instrument cluster, as it is located below the primary viewing area and thus requires only a little gaze avert. It is therefore particularly suitable as a display location for additional information regarding the drive or as an early warning system (Werneke, Wäller, Gonter, Rhede, & Vollrath, 2011; Bengler et al., 2020).



(a) (b)

Figure 2.10: An HMI example for visual feedback during automated driving taken from Feierle et al. (2020) with a) LED-stripes and b) the instrument cluster

HUD form a promising opportunity to project information into the primary field of view and to induce little gaze averting (Knoll, 2015). Augmentation in HUD could be used, for example, to highlight other traffic participants, selected driving-related information, or navigation cues (Knoll, 2015; Bengler et al., 2020). Various studies for PAD and HAD depicted that augmented reality in HUD lead to higher trust (Feierle, Beller, & Bengler, 2019) and is perceived as more understandable and useful (Schömig et al., 2018). Feierle et al. (2019) presented two different visual concepts, with both including information from the HUD and the instrument cluster and one additional containing augmented reality in HUD. Participants perceived both concepts during PAD in an urban setting. Results revealed that the subjective workload was rated higher for the concept without augmented reality. Moreover, the augmented reality concept generated a higher gaze duration on the road, probably because more is projected onto the environment (Feierle et al., 2019). In another study by Schömig et al. (2018) participants experienced several scenarios in CAD with two different HMI concepts. One concept included additional augmented reality information in the HUD. 83 percent of the participants preferred augmented reality in the HUD concept. They stated that relevant information was easier to perceive and that visual attention can stay on driving relevant areas (Schömig et al., 2018).

Another method to present visual information is using LED strips. They do not lead to gaze averting due to peripheral perception (Utesch, 2014). Currently used LED ambient lighting in ADAS indicate, for example, other vehicles in the side mirror (Bartels, Meinecke, & Steinmeyer, 2015). With this type of feedback warning cues

(Utesch, 2014), changes in the system status (Bengler et al., 2020) or uncertainty (Kunze, Summerskill, Marshall, & Filtness, 2019) can be communicated. LED concepts have already proven to be intuitive (Dziennus, Kelsch, & Schieben, 2015; Hecht, Weng, Kick, & Bengler, 2022) and improve mode awareness (Othersen, 2016). Additionally, Yang et al. (2018) investigated LED ambient lighting with changeable illumination patterns installed on the windshield. The lighting presents information about traffic situations, intentions, limits of the system, and TOR. The LED ambient light was found to increase drivers' trust in automation and improves take-over from the automated system (Yang et al., 2018).

With the help of the visual sensory channel, humans can perceive information quickly and receive a very high rate of information (Hoffmann, 2008). Thus, visual feedback is suitable for the presentation of complex information (Hoffmann, 2008). The visual presentation of information is also beneficial because information can be presented over a longer period of time, thus continuously informing the driver (Seppelt & Lee, 2007). However, visual feedback requires the driver's attention. The driver needs to focus on the additional visual information provided by the feedback and thus, distract themselves from the primary driving task. The execution of multiple parallel visual tasks overloads the visual sensory channel. This negatively affects the performance of the primary as well as distracting task (Navon & Miller, 1987; Wickens, 1984, 2002). Visual displays are also often cluttered (D. L. Fisher et al., 2016), sidetracking drivers from the task they are performing (for example, monitoring in PAD) (D. L. Fisher et al., 2016). Furthermore, distracting visual stimuli increase the risk of accidents (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006).

In summary, it can be concluded that visual feedback should be used as the foundation of an automated driving feedback concept. The user can be informed permanently and receive complex information (Hoffmann, 2008). However, it is important to ensure that the visual feedback does not overload the visual channel and distract the driver from the currently executed tasks. The auditory modality, for example, can relieve the visual channel and is presented below.

2.2.2 Auditory Feedback

In addition to visual feedback, the field of acoustics plays an important role in vehicles, mostly for clarifying warnings (König, 2015). Auditory feedback is divided into two categories according to Bubb, Bengler, et al. (2015). On the one hand, acoustic feedback can be used as a hint or warning. On the other hand, auditory feedback conveys content-related information with the help of voice output. Hints and warnings are coded by pitch and temporal frequency. The more urgent action is requested, the higher the frequency. Bubb, Bengler, et al. (2015) recommend frequencies between 1000 and 5000 Hz for this purpose. However, these should only be used in urgent situations. Speech outputs provide semantic information and reduce the need to look away from the driving scene (Alvarez et al., 2011). In this context, a voice output is particularly suitable for specific instructions to the driver (Wickens et al., 2022). Voice-based signals should consist of short sentences and should not include subordinate clauses. This method is a popular tool in navigation systems (Bubb, Bengler, et al., 2015).

Humans perceive auditory information moderately quickly through the auditory sensory channel and have limited ability to draw information from auditory signals (Hoffmann, 2008). Auditory signals are fleeting. There is a possibility that the driver may not notice the signal due to distraction or masking of another acoustic signal. For this, Bubb, Bengler, et al. (2015) recommend a visual fallback. Auditory feedback should thus be used so that the driver's attention is directed to a specific action. Since high information content cannot be conveyed using auditory signals, they should only be used in urgent situations (e.g., emergency brake assistant). Speech output, on the other hand, can be used to relieve the driver visually (Alvarez et al., 2011). Another modality to exonerate the visual channel is, for example, the vestibular modality which will be depicted in the following.

2.2.3 Vestibular Feedback

Vestibular feedback can be provided, for example, by brake pressure (Rieken, Reschka, & Maurer, 2015), lateral and longitudinal vehicle dynamics (Lange, Maas, Albert, Siedersberger, & Bengler, 2014), as well as pitch (Cramer, Siedersberger, & Bengler, 2017; Cramer, Miller, et al., 2017; Cramer, Kaup, & Siedersberger, 2019) and roll (Sieber et al., 2015; C. Müller et al., 2016; Cramer & Klohr, 2019) motions. Lange et al. (2014) designed a layout for trajectory planning in lateral and longitudinal vehicle guidance. Results of the study indicate that the participants have a positive attitude towards vestibular feedback. Furthermore, Lange et al. (2015) developed concepts in which the different automation states were encoded by vehicle movements. Among others, the preparation for a lane change was represented by longitudinal acceleration and lateral displacement to the target lane. Lange (2018) implemented these approaches in a test vehicle and showed using an experimental study that vestibular movements have an influence on the predictability of lane changes.

Sieber et al. (2015) implemented an active roll movement as an avoidance recommendation for a sudden obstacle. It was shown that no increased braking and steering activities occurred during manual driving. 66 percent of the participants did not notice the movement. The authors conclude that rolling movements are not suitable as warning signals (Sieber et al., 2015). In contrast, C. Müller et al. (2016) and C. Müller, Sieber, Siedersberger, Popp, and Färber (2017) showed that vestibular movements are useful as information systems. In this context, a feedback concept for lateral vehicle guidance was designed. In addition to steering wheel actuation, the participants received an active roll movement as feedback when crossing the lane marking compared to a pure steering wheel actuation alone. It was found that the additional roll movement was understandable, noticeable, and less demanding (C. Müller et al., 2016).

Cramer (2019) developed another concept that incorporates vehicle motion as a feedback modality in PAD. Both pitch and roll motions of the vehicle were investigated and perceived as useful, not misleading, increased system awareness, and did not induce motion sickness (Cramer, Siedersberger, & Bengler, 2017; Cramer, Miller, et al., 2017; Cramer & Klohr, 2019). Figures 2.11 and 2.12 illustrates the active pitch and roll motions introduced by Cramer (2019). Pitch motions were expected to be motion-compliant, exhibit vehicle-like behaviour, and represent longitudinal manoeuvres (Cramer, Siedersberger, & Bengler, 2017; Cramer, Miller, et al., 2017; Cramer et al., 2019). Participants preferred an angle of 1° for pitch motions, but tended to 2° pitch angle in critical situations (Cramer, Siedersberger, & Bengler, 2017; Cramer, Miller, et al., 2017). As revealed by Cramer (2019), the pitch motion consisted of a degressive pitch profile and a linear course return of the pitch angle. Roll motions, on the other hand, were thought to represent lateral manoeuvres including a 3.0 ° angle and a degressive roll profile (Cramer & Klohr, 2019). It was found that lane changes to the left lanes should be indicated by roll motions to the left and lane changes to the right should be announced by roll motions to the right (Cramer & Klohr, 2019).

Vestibular feedback is classified as dHMI according to Bengler et al. (2020) and thus conveys information to vehicle passengers and to other road users. The vestibular sensory channel has a low information rate with a very high perceptual speed (Hoffmann, 2008). Hence, less complex information can be transmitted quickly. Accordingly, pitch and roll motions provide a possibility to communicate state transitions or system intentions to the driver during PAD (Cramer, 2019). In conclusion, active pitch motion should be used for detecting a slower preceding vehicle. In contrast, active roll motions should announce lane changes. Both pitch and roll motions relieve the driver during PAD, increase the system awareness, are perceived as intuitive and useful, and do not generate motion sickness (Cramer, 2019). The present thesis is based on the findings of Cramer (2019), but is extended to include a multimodal concept. The advantages of multimodal feedback in automated driving are outlined below.

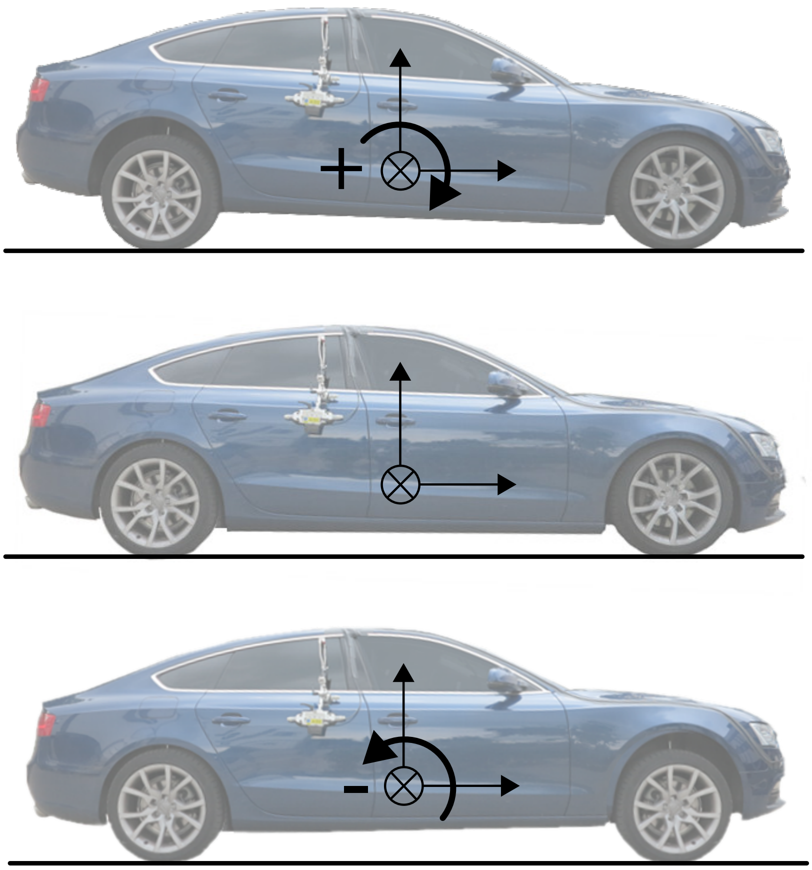


Figure 2.11: Positive (top) and negative (bottom) pitch motions of the automated driving vehicle compared to the horizontal position (middle in the figure) taken from Cramer (2019) referring to Cramer et al. (2019)

Figure 2.12: Positive (right) and negative (left) roll motions of the automated driving vehicle compared to the horizontal position (middle) taken from Cramer (2019) referring to Cramer and Klohr (2019)

2.2.4 Enhancement through Multimodality

In addition to a higher perceptibility of a single stimulus, multimodality may be utilized. Based on Wickens (2002) multiple resource model (cf. Section 2.1.2), the comprehension and holistic perception of information can be improved by combining different modalities. Purely visual feedback contains a high information rate and can be perceived quickly (Hoffmann, 2008), but it reduces the amount of visual attention drivers can focus on the roadway (Horrey, Wickens, & Consalus, 2006). A multimodal design of feedback may better distribute information among available resources to ensure rapid processing (Wickens, 2002).

Several studies showed that multimodal concepts are more effective than purely visual displays, are preferred by drivers in automated vehicles, and reduce driver reaction time (Burke et al., 2006; J.-H. Lee & Spence, 2008; Pitts, Williams, Wellings, & Attridge, 2009; Blanco et al., 2015). For this purpose, Burke et al. (2006) conducted a meta-analysis analyzing 43 studies that tested multimodal feedback compared to unimodal feedback. This analysis used studies from a variety of research areas with different tasks, types of interfaces, and different comparison values. Adding an additional modality to visual feedback was found to improve reaction time and performance (Burke et al., 2006). Significant main effects showed that both visual-auditory and visual-tactile feedback lead to more favorable performance outcomes than visual-only feedback. Burke et al. (2006) suggest that shifting information from the superimposed visual channel to additional sensory channels may reduce demands on cognitive resources. In addition, users' attention may be captured more quickly by a sound than by a visual cue, which may lead to faster acquisition times (Burke et al., 2006). One explanation of the better response performance to visual-tactile feedback is the natural tendency of the body to respond faster to tactile stimuli. It should be noted that, on the one hand, multimodal feedback did not reduce error rates in these studies (Burke et al., 2006). On the other hand, significant results depended on the workload and the number of tasks to be solved. Visual-auditory feedback is most effective under normal conditions in single tasks. In turn, it increases workload when the number of tasks is higher (Burke et al., 2006). Visual-tactile feedback, on the other hand, is more effective when the user completes multiple tasks with a higher workload. In addition, visual-auditory feedback was found to have an effect on goal-setting tasks but not on alerting, warning, and interrupting tasks. Burke et al. (2006) suggest that when noise levels are high, filtering another sound is less effective. In contrast, visual-tactile feedback also showed an effect on alerting, warning, and interruption signals.

J.-H. Lee and Spence (2008) demonstrated an improvement in subjective and objective measures of driving performance by presenting multimodal feedback compared to unimodal. Adding the auditory or tactile modality to the visual component improved both driver performance and reaction times. It can be concluded that multimodal feedback can reduce the workload on drivers and assist them in their tasks. Multimodal feedback is thus particularly suitable for task performance in complex environments (such as driving in traffic) and should be used preferentially (J.-H. Lee & Spence, 2008). In another study by Hackenberg, Bendewald, Othersen, and Bongartz (2013) results revealed that multimodal feedback could increase performance during PAD. In a driving simulator study, 40 participants perceived three modalities and one multimodality. A visual display, an LED bar or sound signal, and a combination of LED bar and sound were tested. The combination of the LED bar and sound signal resulted in better system awareness, where the sound signal attracted the driver's attention and the LED bar clarified the system status via colour coding. The authors conclude that multimodal interfaces should be used for PAD (Hackenberg et al., 2013).

Building on the theoretical foundations established in this chapter, the following chapter discusses the three conducted studies and presents their approach.

3 General Method

The following chapter gives an overview of the conducted studies. Subsequently, parts of the test vehicle including the equipment, an insight into the automation system, and experimental setup are described. Moreover, the used feedback is explained and the concept created on the basis of this feedback is outlined. Finally, the mostly utilized measurements are characterised and the data process is depicted.

3.1 Overview of the Experiments

Within this thesis, three main experiments were performed. All experiments were conducted in German and took place on the German motorway A9 with an Audi A5 prototype (cf. Section 3.3). An overview of the experiments is provided in Table 3.1.

Table 3.1: Overview of the experiments

Experiment	Independent variable	Participants	NDRT	RQ
Experiment 1	Feedback concept (within)			1, 4
	LoA (between)			
	ASD	$N = 20$	None	
	PAD	$N = 20$	None	
	HAD	$N = 20$	Video	
Experiment 2	LoA sections (within)		STDP	1, 2, 3, 4
	Feedback concept (within)			
	Experience in years with ACC (between)			
	zero	$N = 16$		
	little	$N = 16$		
	high	$N = 15$		
Experiment 3	LoA sections (within)		STDP	1, 3, 4
	Feedback concept (between)			
	Visual-auditory	$N = 18$		
	Visual-auditory-vestibular	$N = 18$		

Note. RQ = Research Question; STDP = Spot-The-Difference Puzzle.

In all experiments, different LoA were examined and a part of the participants was allowed to perform an NDRT in HAD. In the first experiment, participants had to watch videos on the tablet mounted in the centre console. During the other studies, participants should play a spot-the-difference puzzle on the same tablet. In this case, participants had to identify the differences between two similar photos. The studies were conducted to answer the research questions, which were elucidated in Section 1.2. All experiments address the first research question to optimize the use of different LoA. For this purpose, the first experiment provides an insight into different LoA, while the other studies compare a multi-level system. The second experiment investigates the needed information which is addressed in the second research question. The last two experiments were designed to answer the third research questions. In this context, the experiments addressed the properties of the feedback concepts with a closer look at disturbing, distracting, and relieving. Overall experiments, the influence of the feedback design on the execution of NDRT was evaluated.

3.2 Feedback Concept

Based on the literature recommendations (cf. Section 2.2), the concept described in this section forms the framework of this thesis. The concept is designed for automated motorway driving. In the literature there is a variety of manoeuvre catalogs that categorize the domain motorway into different manoeuvres (e.g., Tölle, 1996; Vollrath, Schießl, Altmüller, Dambier, & Kornblum, 2005; Dambier, 2010). Basic manoeuvres, for example, include lane following at a constant speed, following a vehicle in front, or changing lanes (Winner, Hakuli, Bruder, Konigorski, & Schiele, 2006). Moreover, Dambier (2010) defined merging, overtaking, and approaching as further important manoeuvres. Figure 3.1 illustrates the main manoeuvres and their transitions regarded in this thesis. According to Lange (2018) and Cramer (2019), the manoeuvres *follow lane* and *lane change* are considered. Following a lane includes the states *no preceding vehicle* and *follow preceding vehicle* (Dambier, 2010). The two states are distinguished by the presence of a relevant preceding vehicle. A vehicle is considered relevant if it drives or merges in at a slower target velocity than the ego vehicle. The change from *no preceding vehicle* to *follow preceding vehicle* will be described as approaching (Lange, 2018). The two states of *follow lane* can also be represented as transitions back to themselves. For example, adjustments to the target velocity due to speed limits depict a transition from the manoeuvre *no preceding vehicle* back to itself. If a vehicle merges into the free gap between the ego and the preceding vehicle, this is a transition from following one vehicle to following another (Cramer, 2019). The manoeuvre *lane change* is representative for both directions (left and right). Lane changes can also be aborted, in which case the ego vehicle returns to the starting lane. Manoeuvres should be announced in time to allow the driver to react promptly. Feedback should therefore be announced early enough to serve as a reliable predictor for upcoming manoeuvres (Bubb, Bengler, et al., 2015). Nevertheless, the announcement and the execution of the manoeuvre should occur within a short period of time so that they can be connected. Regarding lane changes, it is found that the driver should be informed at least $2\,s$ before the execution of the manoeuvre (Wakasugi, 2005; Gold, Damböck, Bengler, & Lorenz, 2013). Based on the path planning by Lange (2018), it requires approximately $2\,s$ for the vehicle to reach the lane markings after initializing a lane change manoeuvre (preparation phase) . Thus, timely announcement for potential takeover is possible (Cramer, 2019).

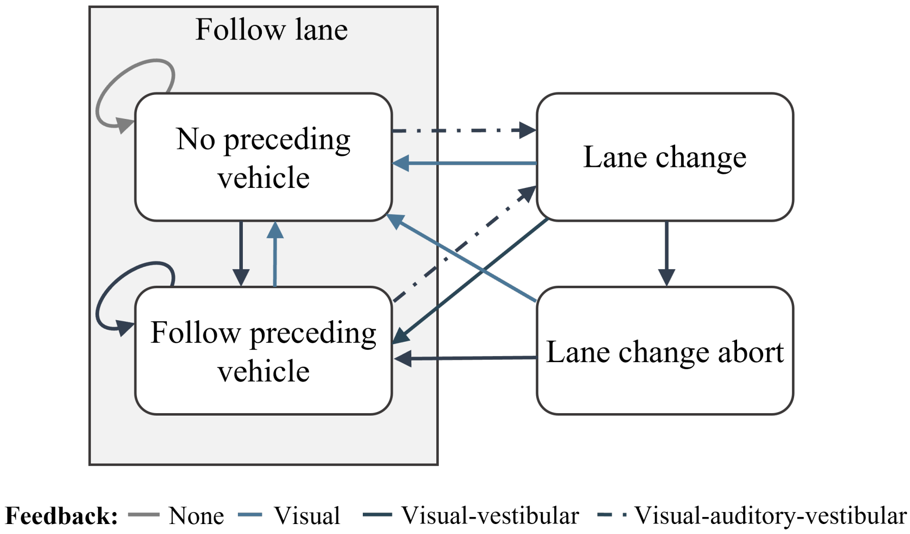


Figure 3.1: Selected manoeuvre transitions referring to Cramer (2019). The different lines indicate the applied feedback.

Cramer (2019) illustrated the used time sequence of detecting and reacting to a slower preceding vehicle for the conducted studies. Figure 3.2 depicts this time sequence. In the described example, the ego vehicle is driving with $v_x = 120\,km/h$ and the preceding vehicle with $v_x = 80\,km/h$. The sensors of the system detect the slower preceding vehicle (cf. Figure 3.2: s_5) at the earliest about $250\,m$ (Winner & Schopper, 2015). However, the driver may detect the preceding vehicle before depending on the visibility (s_6). At a velocity of $120\,km/h$, the used test vehicle classifies the detected preceding vehicle (s_4) as relevant at the distance of approximately $150\,m$ (Cramer, 2019). Thus, the transition to the state *follow preceding vehicle* occurs and the respective feedback is depicted. Subsequently, the vehicle reduces its own velocity (s_3). If the test vehicle does not recognise the slower preceding vehicle, the driver has to react at least at s_2 to avoid decreasing below the safety distance (s_1) (Cramer, 2019). Considering the timely feedback for detecting a preceding vehicle, Cramer (2019) calculated based on Gold, Damböck, Bengler, and Lorenz (2013) that feedback should occur at a relative distance of 130.1 m at 120 km/h, which is later than the used distance in this thesis (approximately 150 m at s_4).

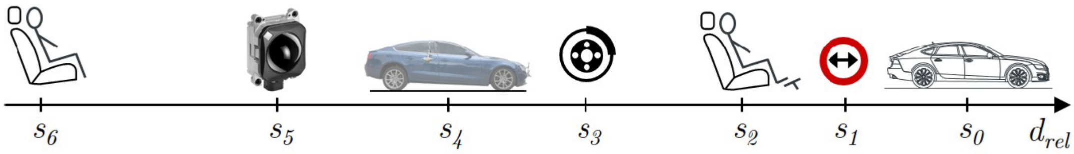


Figure 3.2: Time sequence of detecting and reacting to a slower preceding vehicle taken from Cramer (2019)

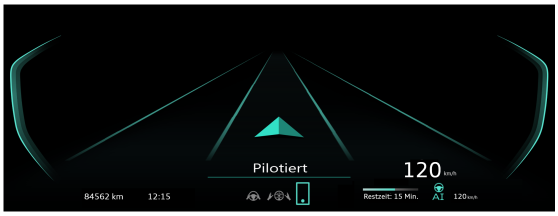
The applied feedback for the manoeuvre transitions is depicted in Figure 3.1 and consists of three feedback modalities: visual, auditory, and vestibular. All transitions are accompanied by visual information (cf. Section 3.2.1) because visual feedback provide a high rate of information (Hoffmann, 2008), can continuously inform the driver (Seppelt & Lee, 2007), and serves as a fallback level (Bubb, Bengler, et al., 2015). Transitions to the state *no preceding vehicle* are depicted only visual. Cramer (2019) revealed that vestibular feedback for static objects (e.g., speed limits) could lead to misunderstanding and should only be used for slower dynamic preceding vehicles. A slower preceding vehicle is announced with a visual information and a positive pitch motion (cf. Section 3.2.3). Transitions to regular *lane changes* (preparation phase) are composed of a visual hint and a roll motion (cf. Section 3.2.3). Moreover, during the lane change execution, the indicator is audible (cf. Section 3.2.2). A *lane change abort* is depicted visual and with a roll motion. In the next sections, an exact description of the used feedback will be presented.

3.2.1 Visual Feedback Design

Figure 3.3 presents the visual elements in the instrument cluster. The display consisted of four sections (Wald et al., 2021), which are marked in Figure 3.3a. The simulation section in the upper two-thirds of the instrument cluster always showed three lanes representing a three-lane motorway. The colours of the lane markings changed between the different LoA. If the driver had to take-over the lateral control, the lane markings were depicted in white. In contrast, the markings were blue during PAD and HAD (cf. Figure 3.3). The ego vehicle was displayed as a triangle and if a preceding vehicle existed, it was depicted as a square. Moreover, upcoming and current lane changes were graphically and textually depicted. Upcoming lane changes were represented with a grey and current lane changes with a blue arrow to the right or left lane. Furthermore, the current velocity was shown.

(a) Display in ASD including the four sections: (1) simulation, (2) description, (3) status, and (4) function

(b) Display in PAD



(c) Display in HAD

Figure 3.3: Visual HMI displays for different LoA

Directly below the simulation section was the description area, which presented the current LoA. Underneath this description, the status and the function section were located. The status section indicated the tasks, which the driver had to do or was allowed to do. In ASD the driver had to monitor the system and take over the lateral guidance. Thus, hands on a steering wheel were shown (cf. Figure 3.3a). During PAD the vehicle took over lateral and longitudinal guidance, whilst the driver had to supervise the vehicle and the environment. As a result, an eye on the steering wheel with hands off was displayed (cf. Figure 3.3b). The driver was allowed to accomplish an NDRT during HAD, hence a smartphone was depicted (cf. Figure 3.3c). The current task was highlighted, and the other were grayed out. Next to the status section on the right was the function section, which represents the tasks of the vehicle. Longitudinal guidance was displayed with two cars and a connection (cf. Figure 3.3a), whilst lateral guidance was depicted with two dashed lines (cf. Figure 3.3b). If the driver was allowed to engage in NDRT, the function was indicated with an “AI” symbol. Furthermore, the remaining time of the automated driving was displayed in minutes for HAD. During the TOR to manual driving, the screen showed a steering wheel with a hands-on symbol (cf. Appendix B.2) and the information that the driver has to take-over (Wald et al., 2021).

3.2.2 Auditory Feedback Design

The auditory feedback was for all driving study concepts the same. Auditory hints were only given during the execution of a lane change or to signalize a transition (Wald et al., 2021). Cramer (2019) demonstrated that using the indicator during the preparation phase can cause nervousness if the vehicle does not execute the lane change directly. Thus, the indicator was applied when the automated driving vehicle executes the lane change or the lane change abort. Transitions to manual driving were announced using an intrusive gong sound. For the announcement of transitions to other LoA, a more inconspicuous sound was selected to unobtrusively inform the driver. The auditory hints during this work were used to direct the driver's attention to the HMI and to the upcoming actions.

3.2.3 Vestibular Feedback Design

The vestibular feedback of this thesis is built on the results of Cramer (2019). Thus, the vestibular feedback was composed of pitch (cf. Figure 2.11) and roll (cf. Figure 2.12) motions. During the first study, a positive pitch motion was initiated whenever a slower preceding vehicle was detected in sensor range (c.f. Cramer et al., 2019). In the other studies, parameters like relative velocity, vehicle type, and distance to the preceding vehicle were taken into account (Cramer, 2019). In doing so, pitch motions were supposed to be at a greater distance if the vehicle in front was a truck, the relative velocity was smaller, or longitudinal acceleration was greater. Thus, pitch motions were not initialized when the relative velocity to the preceding vehicle was positive (e.g. cutting-in vehicle from the left lane which is faster than the ego vehicle). The pitch profile was set to 1.0 ° with an acceleration of $\ddot{\theta} = \text{-}5.0\,°/s^2$ in uncritical situations and to 2.0 ° with an acceleration of $\ddot{\theta} = \text{-}4.0\,°/s^2$ in critical situations, according to results of previous studies (Cramer, Siedersberger, & Bengler, 2017; Cramer, Miller, et al., 2017). As revealed by Cramer (2019), the pitch motion consisted of a degressive pitch profile and a linear course return of the pitch angle. On the other hand, lane changes were announced with motion compliant roll motions including a 3.0 ° angle and a degressive roll profile (Cramer & Klohr, 2019). Motion compliant means that lane changes to the right were announced with positive roll motions and vice versa. Cramer (2019) used an acceleration of $\ddot{\varphi} = \text{-}3.2\,°/s^2$. In contrast, this thesis implemented an acceleration of $\ddot{\varphi} = \text{-}4.5\,°/s^2$ because some participants reported in Cramer (2019) that the roll motions could be more intensive (Wald et al., 2021). Roll motions were only used when the automated vehicle took over the lateral guidance, hence in partially and highly automated driving.

3.3 Test Vehicle

The driving studies were conducted with an Audi A5 (year of construction: 2012). The used test vehicle builds upon the theses of C. Müller (2019) and Cramer (2019). This vehicle is enhanced with a prototypical automation system that is able to simulate PAD and HAD. The prototypical technical realization of the automated system is depicted in Figure 3.4. The test vehicle is equipped with the series production systems ACC and Lane Keeping Assistance (LKA). Thus, their interfaces to the vehicle actuators realize the automation and are able to control the vehicle. The inertial sensors of the ESC (Electronic Stability Control) control unit and the radar sensor (Freundt & Lucas, 2008; Robert Bosch GmbH, 2009) were used for the environment perception (cf. Cramer, 2019, p. 35). Additionally, the test vehicle is equipped with a vehicle computer for the manipulation, a dSPACE MicroAutoBox and a highly accurate Differential Global Positioning System (DGPS) with an inertial sensor platform (iMAR, 2012).

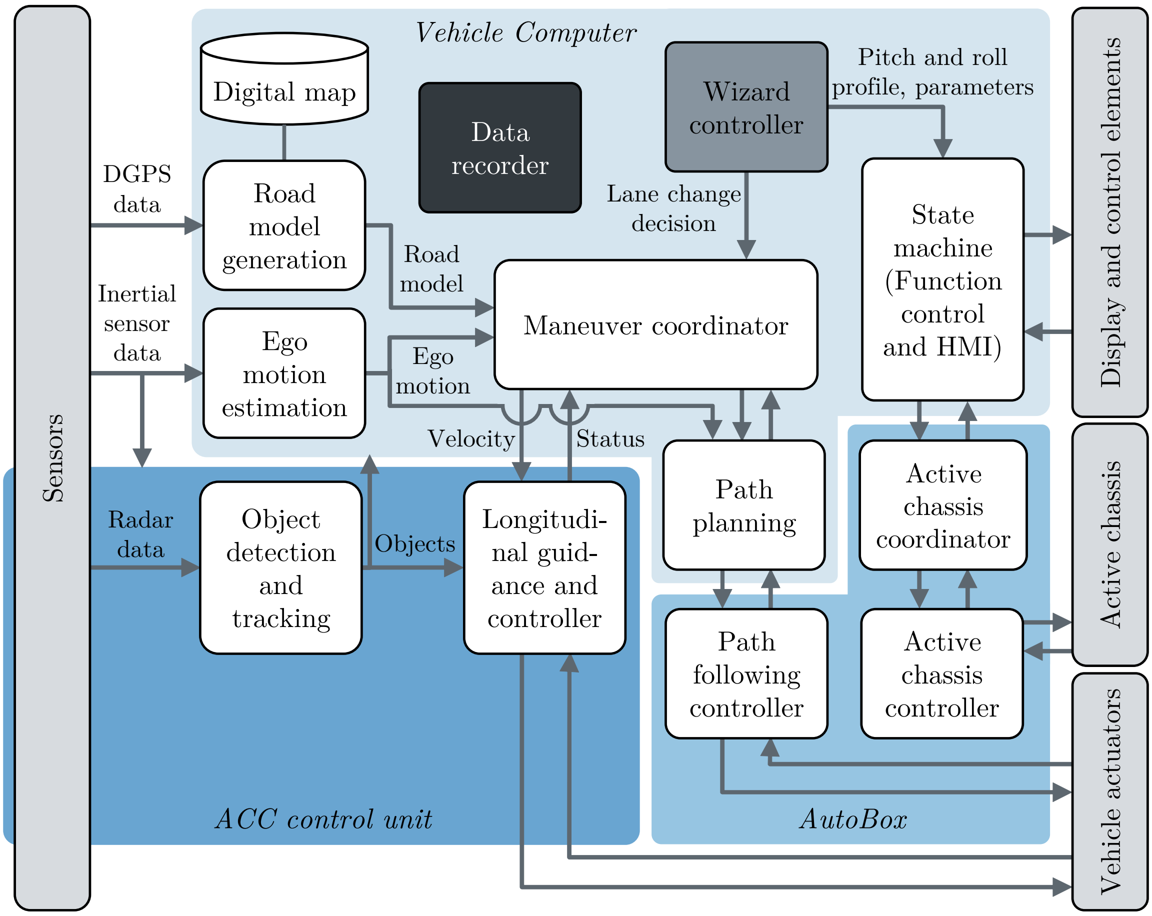


Figure 3.4: Prototypical technical realization taken from Cramer (2019) referring to Lange (2018)

The display and control elements for feedback to and from the vehicle are augmented by a prototypical active chassis, which was subsequently installed. Therefore, a prototypical electromechanical active body control (eABC) system is used and, thus, providing height adjustments on each wheel separately (Münster et al., 2009; Bär, 2014). In doing so, actuators of the front axle are based on an adjustment of the spring seat, whereby the rotational movements of the electric motor are converted into translational movements of the spring seat (Münster et al., 2009; Thomä et al., 2008). Contrary, the translational movements of the actuators of the rear axle are induced by a lever action (Bär, 2014).

3.3.1 Realization of the Automation System

The implementation is related to Lange (2018) and Cramer (2019) due to the use of a similar test vehicle. The automated driving system is realized by software modules that are implemented on the vehicle computer in the Automotive Data and Time triggered Framework (ADTF). Additionally, this computer records relevant data and comprises the subsystems perception and behaviour generation. Thus, the computer receives inertial sensor data and localization data from a DGPS system, with which the automatic vehicle guidance parameter are calculated and transmitted across the dSPACE MicroAutoBox to the vehicle actuators (Lange, 2018; Cramer, 2019). The road model is based on a digital map and shares its situational information to the manoeuvre coordinator (cf. Figure 3.4). Depending on this information and driver inputs, manoeuvres (e.g., lane change), and target velocity are managed by the manoeuvre coordinator. Since the automated vehicle is equipped with sensors which had inadequate sight range, small parts of the automation system have to be realized with a Wizard of Oz (WoOz) technique (Schmidt, Kiss, Babbel, & Galla, 2008). Consequently, a Wizard gaming controller is used to manipulate lane change decisions. Moreover, the gaming controller provides information to the state machine. The latter is responsible for the activation and deactivation of the system due to system limits or user input and for the coordination of the feedback to the driver. Thus, the state machine offers states about the system and the manoeuvre to the display elements as well as pitch and roll parameters to the active chassis controller. The active chassis controller is located in the dSPACE MicroAutoBox, which contains important driving and vehicle parameters to build the interface for the communication of different components. The chassis controller calculates the required offset for each actuator and sends its position to the active chassis (cf. Göhrle, 2014).

In this thesis, the test vehicle takes over lateral and longitudinal guidance. Figure 3.4 shows that the sensors provide data to the ACC control unit and the vehicle computer. A combination of longitudinal control through ACC and DGPS-based lateral path planning (Heil, Lange, & Cramer, 2016) defines the vehicle trajectory. In doing so, the series production system ACC measures the distance to vehicles in front and adjusts the longitudinal guidance of the vehicle by accelerating and decelerating. The actors of the LKA keep the vehicle in the lane by means of steering interventions and are used for the implementation to follow the path planned by the prototypical automation system.

3.3.2 Experimental Setup

The test vehicle setup is presented in Figure 3.5. A camera for driver observation was mounted on the right top side of the windshield. The eye tracker Smart Eye AI-X (Smart Eye, 2021) was available for the first two experiments, whilst an extra observer camera existed for the third experiment. Both were fitted behind the steering wheel. Moreover, a microphone was mounted inside the vehicle for the third experiment to record participants' comments.

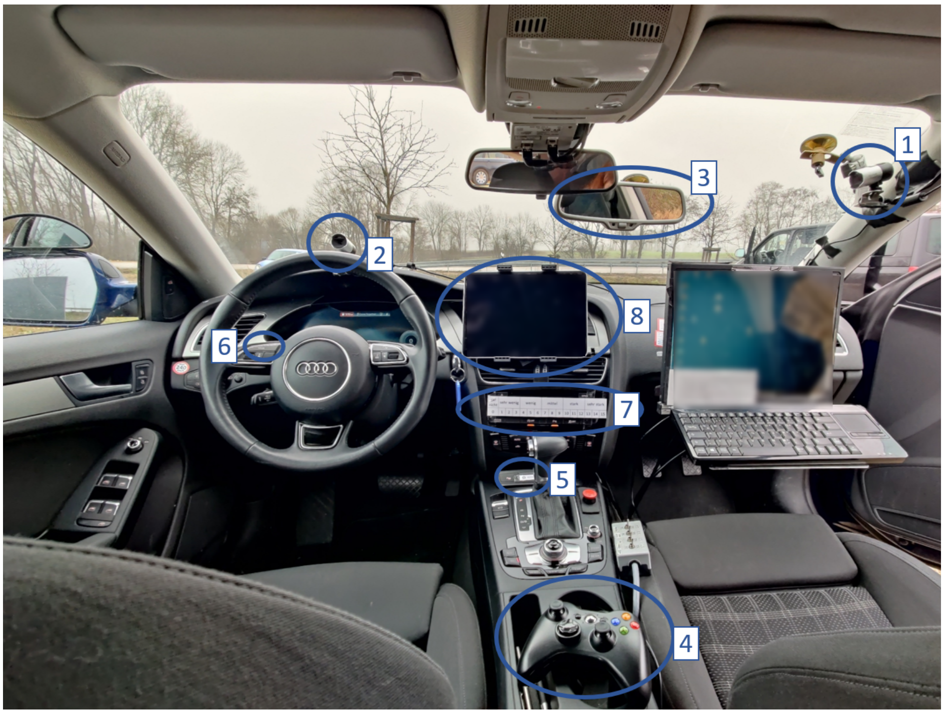


Figure 3.5: Interior of the test vehicle for the driving studies with driver camera [1], eye tracker [2], second interior mirror [3], gaming controller [4], relevant buttons (AUTOMATION-button [5] and MODE-button [6]), scale for oral assessment [7] and tablet for NDRT [8]

In the centre console, a tablet to perform an NDRT and a scale for oral examination were installed. Participants could activate the automated system by pressing the “AUTOMATION”-button in the centre console. Changing between different LoA could be done using the “MODE”-button on the steering wheel (cf. Figure 3.5). The participant sat in the driver’s seat in all experiments. The experimenter in the passenger seat acted as a safety co-driver. Additional equipment such as a second interior mirror, additional exterior mirrors, driving school pedals, and a monitor displaying essential information about the system, assisted the safety co-driver. In all studies, a gaming controller was used to adapt to speed limits and to provoke lane changes, to indicate HMI symbols, and to trigger transitions and pitch respectively roll motions. A second experimenter sat in the back seat coordinating the questionnaires and giving the participants instructions.

3.4 Hygiene Concept

The studies took place during the COVID-19 pandemic situation. Thus, a hygiene concept for the first driving experiment was developed with experts and adjusted for the other experiments (cf. Appendix B.1 as well as Sections 5.3.4 and 6.2.4). The following fundamental principles were agreed for all experiments. Participants who showed symptoms of illness or had contact with an ill person in the past two weeks were not allowed to participate. Experimenters and participants had to disinfect their hands and wore a protective mask for the entire duration of the experiment. All used surfaces (vehicle interfaces, tablet, and laptop) were disinfected after each utilization. The vehicle was aired before and after each drive as well as during the breaks. Sufficient time was allowed between successive participants to avoid contact.

3.5 Dependent Variables

Both subjective and objective data were compiled as dependent variables. With this combination, on the one hand, participants’ behaviour with the automated system can be analysed with driving and gaze data. On the other hand, the driver’s assessment can be determined via questionnaires. The dependent variables collected across the studies are presented below. The data used that are not shared between studies are described for each study in Sections 4.2.5, 5.3.5, and 6.2.5.

3.5.1 Subjective Data

The subjective database consisted of a combination of quantitative and qualitative measures. Questionnaires, which were commonly used in most of the studies, are listed below and explained in more detail.

- **Trust** was gathered with the subscales *Propensity to Trust*, *Reliability/Competence*, *Understanding/Predictability*, and *Trust in Automation* of the Trust in Automation questionnaire (TiA) by Körber (2019). Participants rated the subscales on a five-point Likert scale ranging from 1 ("strongly disagree") to 5 ("strongly agree") to obtain the respective trust of each feedback concept.
- **Acceptance** was evaluated with the German version (Kondzior, n.d.) of the Acceptance Scale (AS) designed by van der Laan, Heino, and de Waard (1997). This survey consists of two dimensions *usefulness* and *satisfaction*. Participants estimated nine pairs of adjectives on a five-point semantic differential.
- **Driving comfort** was measured with the subscales *discomfort* and *comfort* of the questionnaire to measure driving comfort and enjoyment developed by Engelbrecht (2013). Participants evaluated thirteen adjectives on a five-point rating scale from 1 ("strongly disagree") to 5 ("strongly agree").
- **Mode Awareness** was quantified with a questionnaire compiled by Othersen (2016). Seven statements had to be evaluated on a fifteen-point scale consisting of five categories from "very little" to "very strong". During the concept drive, participants were asked to verbally validate the two items from the questionnaire: *task awareness* ("I was always aware which tasks I had and which ones the system had.") and *monitoring behaviour* ("I have permanently monitored the system.") on the same scale with the additional opportunity "no answer".
- **Feedback characteristics** were constituted by different attributes. Three statements declared whether the feedback was perceived as *annoying*, *distracting*, and *relieving*. Participants were asked to rate these statements on a seven-point rating scale from 1 ("does absolutely not apply") to 7 ("does absolutely apply"). Moreover, the *predictability* of the automated vehicle ("How predictable was the system behaviour in the previous mode?" from Petermann-Stock (2015)) was evaluated on a fifteen-point rating scale consisting of five categories from "very little" to "very strong" with the additional opportunity "no answer". Additionally, participants were asked to rate the (assumed) *supportiveness* of both feedback concepts after clarification from 1 ("strongly disagree") to 7 ("strongly agree").
- **Motion Sickness** was assessed with the Fast Motion Sickness Scale (FMS) from Keshavarz and Hecht (2011). Driver's malaise was rated on a 0 ("no sickness at all") to 20 ("frank sickness") scale. If participants chose a value greater than zero, symptoms were queried.

3.5.2 Objective Data

The objective data consisted of a combination of vehicle and eye tracking data. The data included test vehicle data like the angle and acceleration of active vehicle motions, driver input data as well as video and audio recordings of participants. Due to the real driving setting, there are limitations in the detection quality of the pupil. The evaluation is therefore based on gazes on "Areas of Interest" (AOI). The International Organization for Standardization (2014) defined a gaze duration as a gaze movement from an entry to an exit to an AOI. Sequential fixations with a duration of at least 120 ms (International Organization for Standardization, 2014) were summarized as gazes. The AOI were categorized as lane change relevant respectively driving relevant (windscreen, instrument cluster, left side, right side, and driving mirror) and non-driving relevant.

Gaze behaviour was operationalised by calculating the attention ratio, the number of gazes, and the first gaze during lane changes. International Organization for Standardization (2014) defined attention ratio as the percentage of time participants spent looking at one or a set of AOI in a specified amount of time (e.g., looking at driving relevant areas during specific LoA). Attention ratio on the NDRT served as a behavioural measure for mode awareness (Kurpiers, Biebl, Mejia Hernandez, & Raisch, 2020). The first gaze during lane changes was assessed both in the *preparation* phase and in the *execution* phase of the lane change. According to Lange (2018), the preparation phase is defined as the announcement of a lane change $2s$ before the execution (cf. Section 3.2). In addition, lane changes at the beginning were compared with lane changes at the end. In this context, *begin* represents lane changes during the first PAD section and *end* denotes lane changes during the last PAD section. The aim was to examine which feedback concept focuses the driver's attention more quickly on driving relevant AOI, and whether there is a learning effect over time.

3.6 Data Processing and Statistical Analysis

Eye tracking data were recorded using the Smart Eye AI-X (Smart Eye, 2021) during the first two experiments. In the last experiment, a driver camera was used. Data from the driver camera and driving data were recorded using ADTF. The eye tracking data were combined with the driving data and processed using MATLAB R2020a (The MathWorks, Inc., 2020). Because of the inadequate quality, the eye tracking data had to be labeled with ADTF.

Statistical analysis was performed using the computer software R (R Core Team, 2021). The respective statistical analysis (t-test, correlation, analysis of variance, or analysing of categorical data) is declared in the results of each experiment. A significance level of $\alpha = 0.05$ was initially applied. Normal distribution was tested using the Shapiro-Wilk test. If the normal distribution was violated, the nonparametric Wilcoxon rank-sum test was used for the t-test. Additionally, analysis of variance (ANOVA) was performed, as the ANOVA is considered robust against a violation of the normal distribution (Blanca, Alarcón, Arnau, Bono, & Bendayan, 2017). Homogeneity of variance was assessed by Levene's test for equality of error variances. If Levene's test is significant and thus the homogeneity of variance is violated, the ANOVA cannot be analysed. However, the post-hoc comparisons are allowed to be interpreted because they are independent of the assumptions of the ANOVA (Hsu, 1996, p.177). Unless otherwise stated, data were homogenous in variance. Greenhouse-Geisser corrected degrees of freedom are reported when Mauchly's test for sphericity showed significance. Appendix A presents the results of Levene's and Mauchly's tests for all three experiments. Analysing the relationship between two categorical variables was performed using the Fisher's exact test (R. A. Fisher, 1922) because in every examination the chi-square distribution was inaccurate (expected frequencies in each cell was lower than five). Effect size is given by the rank correlation r for the Mann-Whitney U-test, by partial eta-squared for mixed ANOVA, and for the other tests by Cohen's d. The false discovery rate for post-hoc comparisons was controlled with Benjamini-Hochberg corrected p-values (Benjamini & Hochberg, 1995).

4 Driving Experiment 1: Effect of Vestibular Feedback during Different Levels of Automation in a Multimodal Concept

This study and its results [1] have been prepublished in Wald et al. (2021). Some parts of the written text were adopted literally from the paper. Figures, tables, and statistical analyses were adapted for a consistent representation throughout this thesis. The Ethics Board of the Technical University Munich provided ethical approval for this study and the hygiene concept, the corresponding ethical approval code is 389/20 S.

4.1 Introduction

An automated driving vehicle including different LoA requires different driver interactions during the driving task. Appropriate situation, system, and mode awareness are required to behave according to the LoA (Sarter & Woods, 1995). In other words, during PAD, the driver must act as a fallback and should not completely withdraw from the driving task, while executing NDRT in HAD is allowed (SAE international, 2022). A problem arises when the driver is not aware of the responsibilities. Incorrect mental models (König, 2015), lack of situation and system awareness (Othersen, 2016), as well as overconfidence (Parasuraman & Riley, 1997) can lead to the driver distracting from the driving or monitoring task. Thus, a correct mental model must be generated and maintained.

Mode awareness can be established through adequate instruction and constantly updated by providing feedback (cf. Section 2.1.6.1). Thereby, presented feedback in automated driving vehicles has to be perceptible, comprehensible, and clear (Beggiato

[1] The driving study was conducted with the assistance of Jan Haentjes as part of his Master's thesis (Haentjes, 2020).

et al., 2015). Currently, information about the system state and its intention is primarily conveyed via the visual, auditory, or haptic modality (Bubb, Bengler, et al., 2015; Knoll, 2015). Since the perception of environmental information is mainly visual and thus stresses the driver's visual channel, feedback should be designed multimodally (Wickens, 2002). Vestibular feedback is discussed as a further modality to improve human-vehicle interaction in PAD (Cramer, 2019). However, the influence of vestibular feedback in a multimodal concept in different LoA has remained unclear. Moreover, very little is currently known about the influence of additional vehicle movements in ASD (only longitudinal support like ACC) or on performing NDRT.

This experiment examines the relationship between multimodal feedback and different LoA. It is expected that the additional movement will not cause motion sickness or discomfort (cf. Cramer, 2019). Moreover, it is hypothesized that the additional vestibular feedback will increase trust and acceptance and support the driver in the corresponding tasks. The aim of this experiment, therefore, is to investigate in an exploratory way whether additional vestibular feedback can support drivers during different LoA. Hence, two different feedback concepts, one having active vehicle motions and one without motions, were assessed in a real-world driving study. The main research questions are:

- RQ1: Does vestibular feedback cause indisposition?
- RQ2: Depending on the feedback concepts, what impression does the driver receive regarding trust, acceptance, mode awareness, and usability?
- RQ3: In which LoA is additional feedback via active body motions preferred?

4.2 Method

To answer the main research question (cf. Section 4.1), two different feedback concepts were evaluated in a real-world driving study with a test vehicle. Accordingly, three groups divided by LoA (ASD, PAD, and HAD) experienced the two different feedback concepts: visual-auditory (VA) feedback as well as visual-auditory-vestibular (VAV) feedback. In the following, the method of the first experiment will be described in more detail.

4.2.1 Sample

Sixty-two participants took part in this study, two of whom had to be excluded due to congestion on the motorway. Thus, sixty drivers participated in the experiment who were evenly and randomly distributed over different LoA. The age of the drivers ranged from 19 to 59 years, with a mean age of $M = 33.45$ years ($SD = 10.38$). 13 participants (22%; ASD: 5, PAD: 4, HAD: 4) worked in the field of research and development of automated driving. The sample was composed of 16 male technicians (26.7%), 13 male non-technicians (21.6%), 16 female technicians (26.7%), and 15 female non-technicians (25.0%). Participants drove an average of $M = 19{,}250$ km per year ($SD = 8{,}773.31$). The sample had an average driving experience of $M = 15.55$ years ($SD = 10.04$, $min = 2$, $max = 40$). All participants were required to have experience using ACC. This requirement was imposed for safety reasons and to avoid participants focusing only on driving behaviour. 53 participants (88%; ASD: 17, PAD: 19, HAD: 17) had previous experience with LKA and 43 with partially automated driving vehicles (72%; ASD: 16, PAD: 14, HAD: 13). The sample showed on a 5-level scale a medium propensity to trust in automated driving ($M = 3.04$, $SD = 0.64$). Table 4.1 presents a detailed overview of the sample.

Table 4.1: Sample of the first study

Variable	ASD (L1)	PAD (L2)	HAD (L4)
Age $M(SD)$ in years	35.55 (11.26)	31.7 (10.53)	33.1 (9.43)
Gender N			
Female (T, NT)	11 (6, 5)	10 (4, 6)	10 (6, 4)
Male (T, NT)	9 (5, 4)	10 (5, 5)	10 (6, 4)
Experience with ADAS in years			
ACC $M(SD)$	3.04 (2.73)	3.97 (2.58)	2.15 (1.90)
LKA $M(SD)$	2.78 (2.50)	3.19 (2.40)	1.63 (1.32)
Driver's license $M(SD)$ in years	14.70 (9.42)	18.80 (10.62)	13.20 (9.68)
Propensity to trust $M(SD)$ [1-5]	3.12 (0.74)	2.88 (0.57)	3.12 (0.61)

Note. T = technicians; NT = non-technicians.

4.2.2 Feedback Design

The feedback design of this experiment is described in Section 3.2. Participants experienced both visual-auditory (VA) and visual-auditory-vestibular (VAV) feedback. The visual and auditory information (cf. Section 3.2) is equal in both concepts. Due to the fact that the vehicle in ASD took-over the longitudinal control but not lateral control, only feedback for longitudinal guidance was presented. Thus, no visual or vestibular feedback for lane changes were displayed.

4.2.3 Study Design

A real-driving study with the between-subject three-level factor LoA (ASD, PAD, and HAD) and the within-subject two-level factor feedback concept (VA and VAV) was performed. Participants were randomly assigned to one LoA and subjected to both feedback concepts in a randomised order. The LoA determined the tasks of the driver during the drive. Participants in ASD took over lateral guidance and had to monitor the system, while the vehicle performed the longitudinal control. In the other LoA, the system was responsible for both lateral and longitudinal guidance. Participants in PAD had to monitor the system and the environment. In the HAD group, participants watched videos on a tablet mounted in the centre console.

4.2.4 Study Procedure

Figure 4.1 presents the sequence of the driving study. The study was conducted on the three-lane A9 motorway between the Denkendorf and Manching exits, covering approximately 100 km driving distance per driver. For safety reasons, only the right and middle lanes were used and the maximum speed was set to 120 km/h.

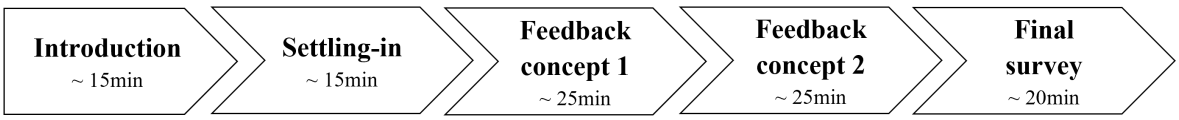


Figure 4.1: Sequence of the first driving study referring to Wald et al. (2021)

Participants were recruited via several mailing lists as well as contacts, whereupon interested persons could volunteer and complete a preliminary questionnaire (pre-questionnaire, cf. Appendix C.1) online. Filter questions were used to exclude participants who belonged to a COVID-19 risk group, hold their driver's license for less than two years or had already participated in studies with active vehicle motions. Based on the age, gender, and technical background persons the required profiles were contacted and an appointment for the real vehicle study was arranged. During the appointment, participants received information about the study procedure, the data collection, the hygiene concept (cf. Section 3.4) the functionalities, and the handling of the vehicle (cf. Appendix B.2).

The instructions were provided in the German language. After a verbal introduction of the procedure and the difference between the concepts, the experimenter in the passenger seat instructed the participants on the vehicle operation. Thereupon, participants had to rate their motion sickness. They then drove manually onto the motorway and started the settling-in drive in the right lane. The vehicle conducted no lane changes in the first three minutes since the participants got familiar with the system. Drivers then received both visual and vestibular feedback during this settling-in phase. Subsequently, participants rated their motion sickness again and experienced the two feedback concepts in a randomised order. After each concept drive, participants completed questionnaires (cf. Appendix C.2) about their perceived trust, acceptance, mode awareness, indisposition, and usability. Drivers in HAD also had to answer questions about the videos they watched. Finally, participants had to rate their likability of each feedback concept.

4.2.5 Dependent Variables

The recorded eye tracking data were of low quality, so this could not be evaluated. Here, approximately two-thirds of the data had less than 50% informative quality. Thus, only subjective data were used to answer the research questions. Table 4.2 presents the used metrics in dependence of the time of measurement.

Table 4.2: Overview of the dependent variables of the first study

Dependent variable	Operationalisation	Time of measurement
Trust	TiA questionnaire (Körber, 2019)	PQ, AC
Acceptance	AS from van der Laan et al. (1997)	AC
Mode Awareness	Questionnaire by Othersen (2016)	AC
Motion Sickness	FMS by Keshavarz and Hecht (2011)	AI, BC, AC
Comfort/Discomfort	Questionnaire by Engelbrecht (2013)	AC
Usability	SUS by Brooke (1996)	AC
Likability	Single-item	AE

Note. PQ = pre-questionnaire; AI = after instruction; BC = before concept drive; AC = after concept drive; AE = at the end.

In Section 3.5, the commonly applied questionnaires are described. Other metrics used in this study are explained in the following. Indisposition was assessed by *comfort/discomfort* and *motion sickness*. If participants rated their *motion sickness* above zero, they had to estimate the motion sickness symptoms of headache, dizziness, nausea, and feeling cold/warm on a seven-point scale from 1 (“strongly disagree”) to 7 (“strongly agree"). *Usability* was measured using the System Usability Scale (SUS) by Brooke (1996). The SUS is a questionnaire of 10 items on a five-point scale from 1 ("strongly disagree") to 5 ("strongly agree"). In the final survey, participants were asked to rate the *Likability* by verbally confirming their agreement with the statement "I liked the visual-auditory[-vestibular] feedback" to rate the two feedback concepts in randomised order on a seven-point scale ranging from 1 ("strongly disagree") to 7 ("strongly agree").

4.3 Results

The statistical analysis is described in Section 3.6 and the findings will be stated in accordance with Field, Miles, and Field (2012). The results of the questionnaires (cf. Appendix C.2) are presented according to the sequence of the research questions.

4.3.1 Indisposition

Mostly, participants reported feeling well, but at least 30 times mild symptoms were stated (FMS score < 5). A 3 (LoA) $\times$ 5 (time of measurement) ANOVA was calculated. The statistical analysis did neither find a significant main nor an interaction effect. Although it was explicitly stated that the FMS inquires about physical discomfort, many participants mentioned psychological symptoms such as agitation or nervousness. A descriptive analysis of the queried symptoms depicted that no single symptom occurred more than five times before or after a test drive.

The inspection of Table 4.3 suggests that the experienced *comfort* for both concepts was high and the *discomfort* low. For each subscale, a mixed 2 (feedback concept) $\times$ 3 (LoA) ANOVA was conducted. Results for *comfort* revealed a significant main effect for feedback with a medium effect size ($F(1, 57) = 6.17$, $p = .016$, $\eta_p^2 = 0.10$) stating that VA is more comfortable than VAV (cf. Table 4.3). Moreover, a significant difference for the groups was found with a medium effect size ($F(2, 57) = 3.76$, $p = .029$, $\eta_p^2 = 0.12$). Subsequent post-hoc tests indicated that participants in the PAD group experienced less *comfort* than the HAD group ($\eta_p^2 = 0.011$). The applied ANOVA did not yield a significant interaction effect. For the subscale *discomfort*, statistical analysis of variance revealed significant differences between the feedback concepts with a medium effect size ($F(1, 57) = 7.03$, $p = .010$, $\eta_p^2 = 0.11$) indicating that VA generated less *discomfort* than VAV. Further results neither find a main effect for LoA nor an interaction effect.

Table 4.3: Participants' mean ratings of their perceived comfort and discomfort for the different feedback concepts depending on the LoA

LoA	Comfort [1-5]		Discomfort [1-5]	
	VA ($M(SD)$)	VAV ($M(SD)$)	VA ($M(SD)$)	VAV ($M(SD)$)
ASD	4.34 (0.46)	3.94 (0.76)	1.36 (0.50)	1.67 (0.76)
PAD	4.01 (0.72)	3.70 (0.68)	1.42 (0.59)	1.71 (0.74)
HAD	4.26 (0.47)	4.26 (0.44)	1.29 (0.38)	1.39 (0.47)

4.3.2 Trust in Automation

Figure 4.2 displays the mean ratings for the trust questionnaire. The graphical analysis suggests that both feedback concepts were assessed as reliable ($M \approx 3.9$), predictable ($M \approx 4.3$), and generated high trust in automation ($M \approx 4.2$). In addition, it is recognisable that participants from the ASD or HAD groups rated VAV higher than VA for subscales reliability, predictability, and trust in automation on average. In contrast, the PAD group estimated VA higher on average. Moreover, the propensity to trust seemed to increase from the baseline to both feedback concepts.

For the subscales *Reliability/Competence*, *Understanding/Predictability*, and *Trust in Automation*, a mixed 2 (feedback concept: VA and VAV) × 3 (LoA) ANOVA was calculated. The analysis of variance did not indicate a significant difference between the concepts for the subscales *Reliability/Competence* and *Trust in Automation*. However, the ANOVA for *Understanding/Predictability* demonstrated a tendency towards significance between the concepts with a medium effect size ($F(1, 57) = 3.51$, $p = .066$, $\eta_p^2 = 0.06$) stating that VAV ($M = 4.40$, $SD = 0.47$) was perceived as more predictable than VA ($M = 4.23$, $SD = 0.77$). For the subscale *Propensity to Trust*, a 3 (time of measurement: pre-questionnaire, VA, and VAV) × 3 (LoA) ANOVA found a significant main effect for the feedback concept with a large effect size ($F(1.64, 93.45) = 10.59$, $p < .001$, $\eta_p^2 = 0.16$). Following post-hoc analysis using Benjamini-Holm correction revealed that the participants showed less propensity to trust before the experiment ($M = 3.04$, $SD = 0.64$) compared to after VA ($M = 3.33$, $SD = 0.66$, $p = .018$) and after VAV ($M = 3.36$, $SD = 0.58$, $p = .015$). Further results did not yield significant differences between the LoA groups for all subscales. In addition, no significant interactions were found except for the subscale *Trust in Automation* with a medium effect size ($F(2, 57) = 3.19$, $p = .049$, $\eta_p^2 = 0.10$), but post-hoc tests represented no significant differences ($p > .05$).

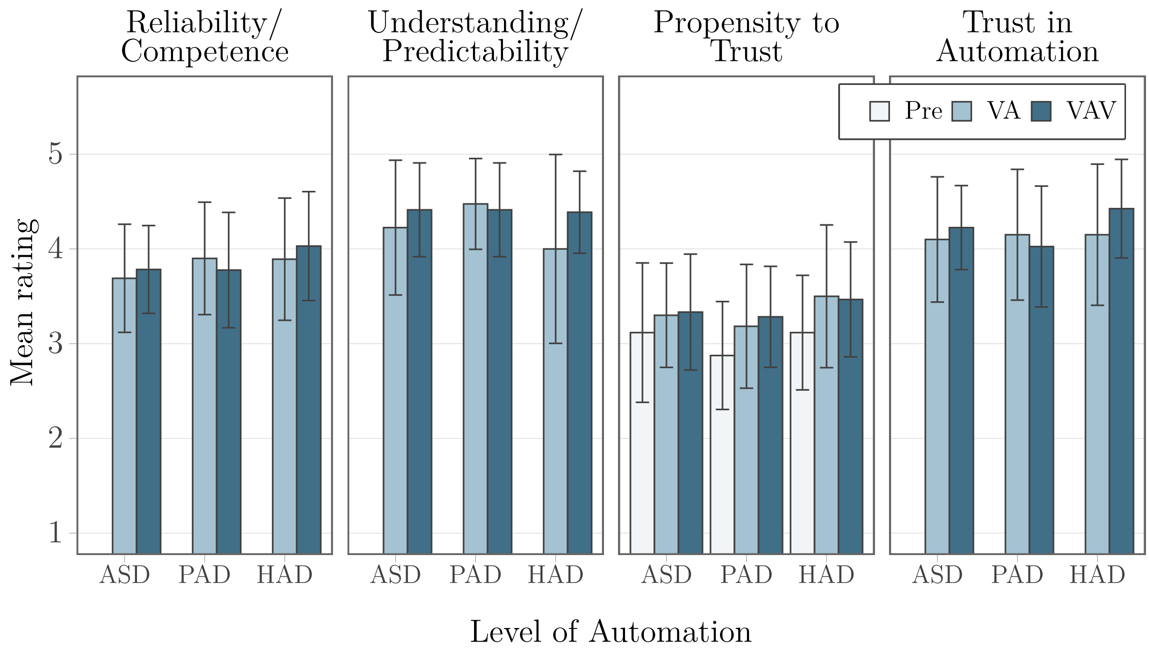


Figure 4.2: Subjective evaluation of the the trust questionnaire for ASD, PAD, and HAD groups according to time of measurement referring to Wald et al. (2021). Error bars indicate ± 1 SD

4.3.3 Acceptance

The ratings for acceptance are provided in Fig 4.3. A closer inspection of the figure shows that VA was rated as more *useful* and *satisfying* compared to VAV, especially by the PAD group. For each subscale, a mixed 2 (feedback concept) × 3 (LoA) statistical analysis of variance was conducted. Results indicated that there is no significant difference between the LoA groups for both *usefulness* and *satisfying*. However, the main effects for the feedback concept were found stating that VA was assessed as more *useful* with a medium effect size ($F(1, 57) = 6.51$, $p = .013$, $\eta_p^2 = 0.10$) and more *satisfying* with a large effect size ($F(1, 57) = 14.88$, $p < .001$, $\eta_p^2 = 0.21$) compared to VAV. The ANOVA for *usefulness* also revealed a significant interaction between feedback concept and LoA with a medium effect size ($F(2, 57) = 3.25$, $p = .046$, $\eta_p^2 = 0.10$). Subsequent post-hoc tests depicted that the VA concept ($M = 1.04$, $SD = 0.50$) was rated as significantly more *useful* than VAV ($M = 0.42$, $SD = 0.75$) during PAD ($p = .012$). Further post-hoc analyses using Benjamini-Holm correction pointed out that the VAV concept was rated less *useful* in PAD compared to VAV in ASD ($M = 1.01$, $SD = 0.83$, $p = .023$) and in HAD ($M = 1.04$, $SD = 0.68$, $p = .023$). Besides, the statistical analysis for *satisfying* yielded also a significant interaction effect with medium effect size ($F(2, 57) = 3.28$, $p = .045$, $\eta_p^2 = 0.10$). The following post-hoc analysis indicated for the PAD group that VA ($M = 1.25$, $SD = 0.60$) was significantly more *satisfying* than VAV ($M = 0.45$, $SD = 0.75$, $p < .001$).

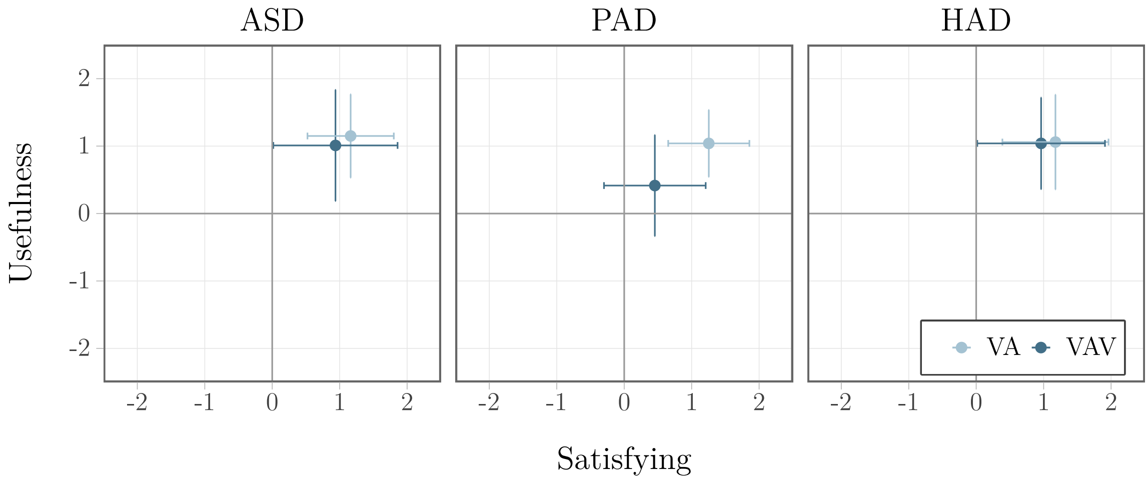


Figure 4.3: Evaluation of the subscales usefulness and satisfying for ASD, PAD, and HAD groups based on feedback concept. Error bars indicate ± 1 SD

4.3.4 Mode Awareness

Figure 4.4 presents the mean ratings as well as main and interaction effects. The graphical inspection suggests that there are only small differences between the feedback concepts for all items. However, the graphic depicts that there are differences between the different LoA for *permanent monitoring* and *control relinquishment*. It is shown that participants in HAD monitored the system less, but had a higher control relinquishment than the other two groups.

Subscale	LoA		Feedback		LoA*Feedback	
	$F(2,57)$	p	$F(1,57)$	p	$F(2,57)$	p
LoA awareness	**3.25**	**.046**	0.53	.471	1.84	.168
Permanent monitoring	**29.80**	**.000**	0.08	.775	0.54	.583
Task awareness	1.50	.233	0.46	.500	0.187	.830
Awareness to intervene	1.90	.159	0.05	.826	0.53	.593
System comprehension	1.14	.327	0.20	.660	1.23	.300
Control relinquishment	**21.57**	**.000**	0.40	.530	0.27	.764
Monitoring over time	0.47	.627	1.45	.234	**3.58**	**.034**

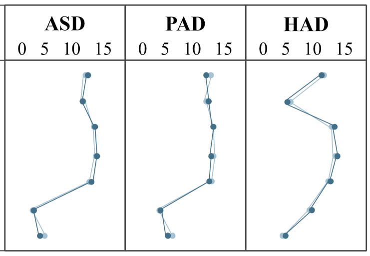


Figure 4.4: Effects and subjective evaluation of mode awareness [0-15] for the two concepts (light blue: VA, dark blue: VAV) depending on the LoA. Significant effects are highlighted. The mean value is indicated in each case

For each subscale of the mode awareness questionnaire, a 2 (feedback) × 3 (LoA) ANOVA was performed. The results of each subscale did not yield a main effect for feedback. However, significant group differences were found for *LoA awareness* ($F(2,57) = 3.25$, $p = .046$, $\eta_p^2 = 0.10$), *permanent monitoring* ($F(2,57) = 29.80$,

$p < .001$, $\eta_p^2 = 0.51$), and *control relinquishment* ($F(2, 57) = 21.57$, $p < .001$, $\eta_p^2 = 0.43$). Subsequently conducted post-hoc tests revealed that the HAD group ($M = 10.80$, $SD = 3.65$) had significant less *LoA awareness* compared to the ASD ($M = 12.38$, $SD = 3.18$, $p = .037$) and PAD ($M = 12.90$, $SD = 2.29$, $p = .009$) group. Moreover, participants in HAD ($M = 5.13$, $SD = 3.11$) did not monitor the system as the participants in ASD ($M = 10.78$, $SD = 3.42$, $p < .001$) and PAD ($M = 11.35$, $SD = 2.69$, $p < .001$). Besides, the ASD group ($M = 4.18$, $SD = 3.21$) as well as the PAD group ($M = 4.73$, $SD = 3.40$) gave the control significantly less than participants in HAD ($M = 10.13$, $SD = 4.05$, $p < .001$). Except for monitoring over time, no significant interaction effects across all subscales were found. Following Benjamini-Holm corrected post-hoc tests did not find any significant differences.

4.3.5 Usability

Participants' mean ratings for the perceived *usability* is depicted in Figure 4.5 on the scale of Bangor, Kortum, and Miller (2008). It can be seen that both concepts were assessed as acceptable (Bangor et al., 2008). In all three groups, participants evaluated VA as excellent ($M > 85$). However, values for the VAV concept varied among the groups. The concept was rated good in ASD ($M = 81.38$) as well as in PAD ($M = 72.63$) and also excellent in HAD ($M = 85.88$).

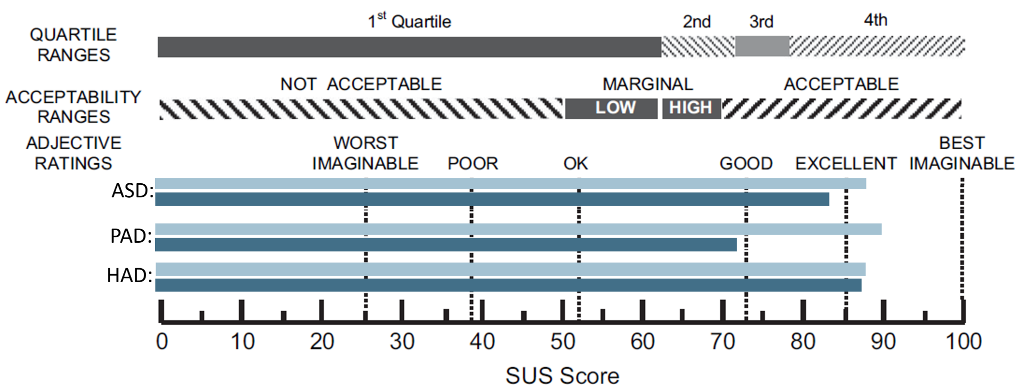


Figure 4.5: Mean ratings of the SUS for the two concepts (light blue: VA, dark blue: VAV) depending on the LoA

The mixed 2 (feedback concept) × 3 (LoA) ANOVA pointed out that the LoA groups do not significantly differ in their ratings. In contrast, the results revealed a main effect for feedback concept with a large effect size ($F(1, 57) = 16.23$, $p < .001$, $\eta_p^2 = 0.22$) suggesting that VA was perceived more user-friendly than VAV. Additionally, the statistical analysis yielded a significant interaction with a large effect size ($F(2, 57) = 6.56$, $p = .003$, $\eta_p^2 = 0.19$). Benjamini-Holm-corrected pairwise comparison showed that the *usability* of the VAV concept was rated higher in the HAD group compared to the PAD group ($p = .020$). Moreover, post-hoc tests revealed in the PAD group a significantly higher *usability* for VA compared to VAV ($p = .003$).

4.3.6 Likability

Figure 4.6 illustrates the mean ratings for *likability* in relation to feedback concept and LoA. The graphical inspection indicates that the PAD group preferred the VA concept, while the ASD and HAD groups demonstrated no preference for either concept.

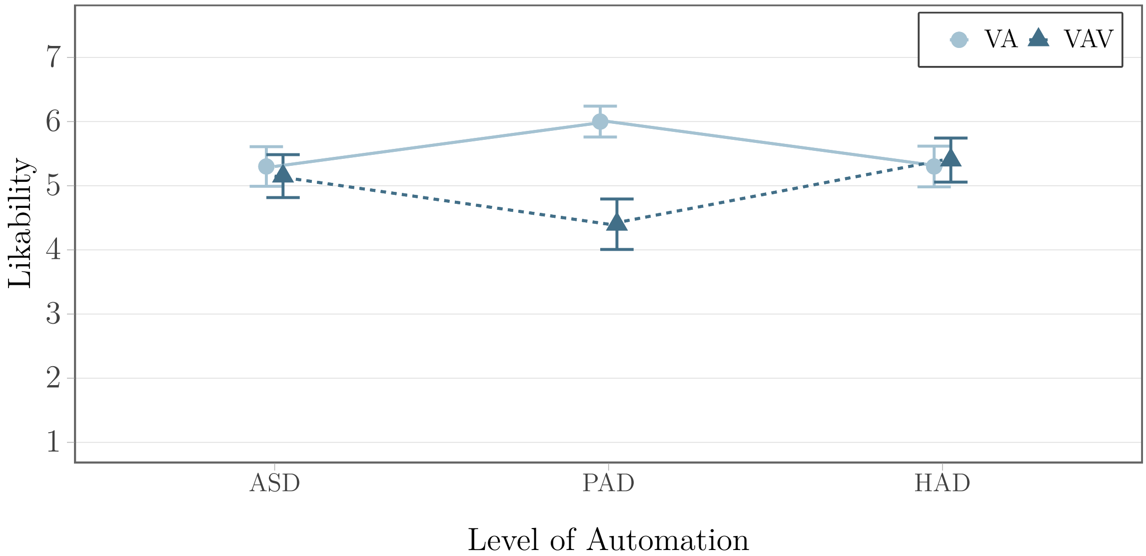


Figure 4.6: Evaluation of the likability for ASD, PAD, and HAD groups based on feedback concept. Error bars indicate ± 1 SE

A mixed 2 (feedback concept) × 3 (LoA) ANOVA for the *likability* of the concepts was conducted. The statistical analysis did not yield a main effect for LoA but indicated a tendency for feedback concept with a medium effect size ($F(1, 57) = 3.51$, $p = .066$, $\eta_p^2 = 0.06$) stating that VA ($M = 5.53$, $SD = 1.32$) was rated more likable than VAV ($M = 4.98$, $SD = 1.63$). Moreover, results revealed a significant interaction effect with a medium effect size ($F(2, 57) = 3.25$, $p = .046$, $\eta_p^2 = 0.10$). Following post-hoc analysis pointed out that VA ($M = 6.00$, $SD = 1.08$) was assessed significantly higher than VAV ($M = 4.40$, $SD = 1.76$) in the PAD group ($p = .003$).

4.3.7 Influence of Experience with Adaptive Cruise Control

Further inspection reveals that experience in years with ACC varied across the LoA groups (cf. Table 4.1). Thereby, the PAD group ($M = 3.97$, $SD = 2.58$) had the most ACC experience in years compared with ASD ($M = 3.04$, $SD = 2.73$) and HAD ($M = 2.15$, $SD = 1.90$). Hence, a correlation was performed between experience and different ratings. Consequently, a Spearman's rank order correlation was conducted to estimate the relationship between the experience with ACC and the ratings of the feedback concept. Table 4.4 shows the results of these correlations. For VAV, a negative correlation was found between experience and ratings for *usefulness*, *satisfaction*, *usability*, and *likability* ($p < .05$).

Table 4.4: Correlation matrix showing Spearman's r for experience with ACC and measurement scales in dependence of the feedback concept, referring to Wald et al. (2021). Significant effects are highlighted

Scale	visual-auditory (VA)		visual-auditory-vestibular (VAV)	
	r_s	p	r_s	p
Usefulness	-.08	.600	**-.45**	**.002**
Satisfying	-.11	.449	**-.51**	$<$ **.001**
Comfort	.05	.713	-.29	.059
Discomfort	-.06	.689	.29	.051
Usability	.11	.475	**-.58**	$<$ **.001**
Likability	.21	.156	**-.51**	$<$ **.001**

On the basis of the correlation results, a 2 (feedback concept) x 3 (LoA) x 2 (ACC experience) ANOVA was conducted for the different subscales. Thus, the sample was divided into little and high experiences according to the median ($Mdn = 2.75$ years). Due to the fact that only 46 participants provided their experience in years, only these were considered. Figure 4.7 presents the results with significant differences between the subscales depending on feedback concept and ACC experience.

Statistical analysis of variance revealed no significant interaction between ratings of *usefulness* and experience ($F(1, 35) = 1.80$, $p = .190$, $\eta_p^2 = 0.05$). However, ACC experience had a significant effect on satisfaction ratings with a medium to large effect size ($F(1, 35) = 5.68$, $p = .023$, $\eta_p^2 = 0.14$). Subsequent post-hoc analysis revealed that participants with high ACC experience rated VA ($M = 1.19$, $SD = 0.57$) significantly more *satisfying* than VAV ($M = 0.38$, $SD = 0.84$, $p < .001$). In addition, post-hoc tests showed that participants with low ACC experience ($M = 1.10$, $SD = 0.97$) evaluated VAV as significantly higher *satisfying* than those with high experience ($p = .032$).

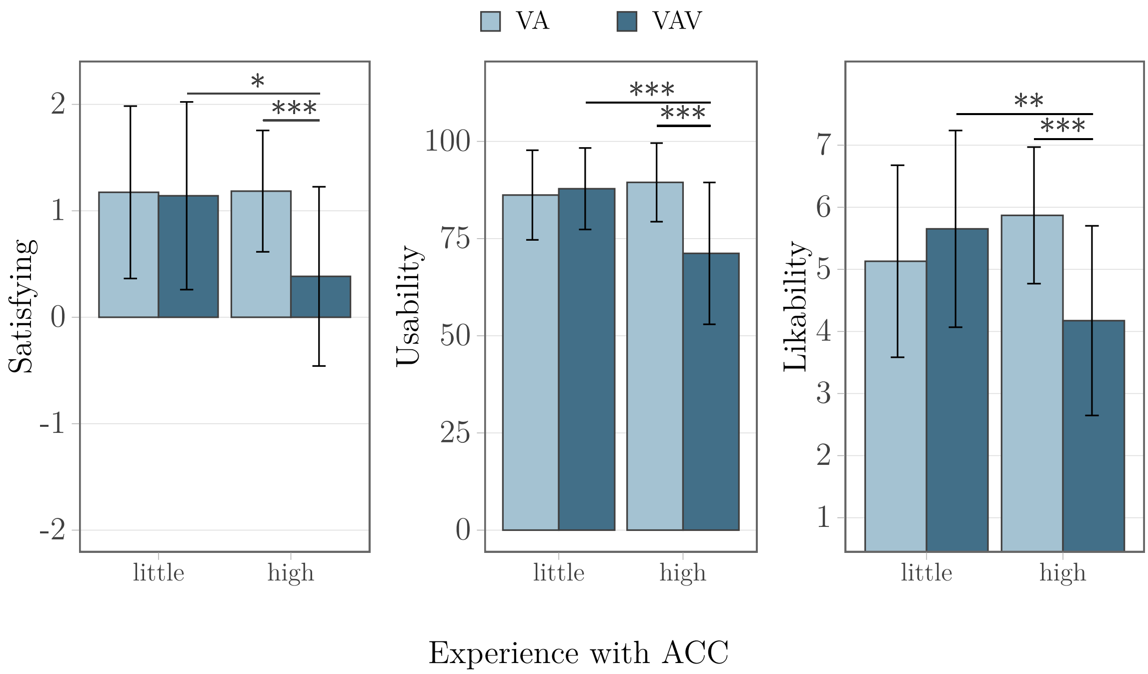


Figure 4.7: Evaluation of the items satisfying, usability, and likability depending on the feedback concept and experience with ACC referring to Wald et al. (2021). Error bars indicate ± 1 SD

Statistical analysis of variance for *usability* ($F(1,40) = 11.77$, $p = .001$, $\eta_p^2 = 0.23$) and *likability* ($F(1,40) = 8.59$, $p = .006$, $\eta_p^2 = 0.18$) revealed significant interactions between experience and rating. As illustrated in Figure 4.7, a subsequent post-hoc analysis indicated that participants with little ACC experience rated VAV significantly higher than participants with high ACC experience (Usability: $M_{little-high} = 16.63$, $p < .001$; Likability: $M_{little-high} = 1.48$, $p = .004$). Furthermore, a Benjamini-Holm post-hoc test demonstrated that participants with high ACC experience rated VA significantly higher than VAV (Usability: $M_{little-high} = 18.26$, $p < .001$; Likability: $M_{little-high} = 1.70$, $p < .001$).

4.4 Discussion and Conclusion

In a real-vehicle study on the German A9 motorway ($N = 60$), two feedback concepts were evaluated in terms of improving mode awareness and reducing negative effects such as motion sickness and discomfort. The central questions investigated the effects of the developed feedback concepts on trust, acceptance, mode awareness, indisposition, and on usability. Thus, the influence of different concepts in varying levels of automation was examined in detail. For this purpose, two different feedback concepts were developed and implemented. The essential requirements are based on theoretical principles, which are described in Section 2.2. The feedback concepts were derived according to these design guidelines. The basic concept consisted of visual and auditory feedback. In contrast, a concept was tested that additionally included vestibular feedback such as active pitch and roll motions. The additional active vehicle movements were intended to strengthen the system awareness and thus the mode awareness. Furthermore, they are supposed to help anticipate future manoeuvres in order to reduce motion sickness and to communicate the behaviour of the system. Both concepts were investigated in three different levels of automation: assisted driving, partially automated driving, and highly automated driving. During assisted driving, the driver performed lateral control. In partially and highly automated driving, the automated vehicle took over the dynamic driving task. Participants in partially automated driving had to monitor the system while participants in highly automated driving were allowed to perform a non-driving related task by watching a video. Here, participants were randomly assigned to one of three level of automation groups and experienced both concepts in a randomised order. The participants were informed about the difference between the concepts beforehand.

With regard to the first research question concerning indisposition, similar results could be generated for motion sickness as in Cramer, Miller, et al. (2017), Cramer et al. (2019), and Cramer (2019). The data provided no evidence that additional movements induce motion sickness. Regarding comfort, the results showed that both concepts were perceived as comfortable and generated little discomfort. However, additional vestibular feedback was found to decrease comfort and increase discomfort compared to the visual-auditory feedback concept. A possible explanation for this might be the knowledge of the differences between the concepts. Vestibular feedback could have been perceived as redundant information. One participant in partially automated driving stated that the visual feedback provided sufficient information. Moreover, participants could have perceived the feedback differently due to personal dispositions and made fewer associations. In the study by Cramer et al. (2019) on perceptibility, it was depicted that approximately 11% of participants did not perceive the pitching motions. In the present study, some participants mentioned that they were less able to perceive pitching motions during braking manoeuvres or rolling motions during lane changes. It may be that the participants focused on appearance excessively, as some also confirmed. Another influence could be the occurrence frequency of the pitching motions. In contrast to the fourth study by Cramer (2019), the test vehicle pitched whenever a preceding vehicle occurred in this experiment. When several vehicles in a short distance consecutively moved in front of the test vehicle, this resulted in a high number of pitching motions. Some participants remarked in this context that the movements occurred too frequently for them.

An initial objective of the project was to identify the influence of feedback on trust, acceptance, mode awareness, and usability. Both concepts were found to be predictable and reliable as well as generate a high level of trust in automation. These results reflect those of Cramer (2019) who also found that vestibular feedback in partially automated driving generates high trust. The current study found that visual-auditory-vestibular feedback tended to be rated as more predictable. Since in the visual-auditory concept the announcement of a manoeuvre is perceived only by looking into the instrument cluster, this information can possibly be overlooked. Thus, the participant would not notice the upcoming manoeuvre until it is executed. However, in the visual-auditory-vestibular concept the driver is not required to avert his gaze from his current task (monitoring the environment vs. non-driving related task), but can still anticipate the upcoming manoeuvre by vehicle movements. Besides predictability, the propensity to trust could be increased by both concepts. The baseline measurement took place before the participants became familiar with the vehicle and the automated driving system. Hoff and Bashir (2015) describe the influence of experience on trust in automated systems in their trust model. Thus, building up experience through learning and testing the automated vehicle could have increased trust. Another positive influence on the propensity to trust could have been the presence of the safety co-driver. The fact that the co-driver permanently monitors the system and can carry out any interventions could have conveyed a sense of security to the participants.

Regarding mode awareness, both feedback concepts had no influence on the different component items. However, level of automation was found to have an influence on mode awareness. Participants in the highly automated driving group showed less mode awareness. A possible explanation for this might be that participants were instructed to perform non-driving related task while driving. The mental model about currently deployed vehicles (mostly partially automated driving vehicles) and performing a non-driving related task in the driver's seat on the motorway compete with each other. Mental models require prior experience in addition to instruction and adequate feedback (Endsley, 2000). By the fact that the participants have never tested such a system before, the mode awareness could be less than in the other groups, who already had experience with similar systems. In addition, participants in the highly automated driving group monitored the system less and relinquished more control to the system compared to the other two groups. These results were anticipated, as the different tasks induced this behaviour. By performing a non-driving related task in highly automated driving, participants relinquished control to the automated driving system and were unable to monitor this system permanently.

Looking at acceptance, it was found that both concepts were considered as useful and satisfying. However, the results revealed that the visual-auditory concept was rated higher than the visual-auditory-vestibular in both subscales. A closer examination revealed that the differences between the concepts were mainly caused by the partially automated driving group. Here, both usefulness and satisfaction were rated significantly lower for visual-auditory-vestibular concept. This effect is not evident in the other two groups. Moreover, for usefulness, it was demonstrated that the partially automated driving group rated the additional vestibular feedback lower than the other two groups. Similar results were found for usability and likability. While for usability the visual-auditory feedback was rated as excellent in all three groups, visual-auditory-vestibular concept showed a larger difference in ratings. Participants in assisted and highly automated driving rated the additional vestibular feedback as good to excellent. Participants in partially automated driving, on the other hand, rated visual-auditory-vestibular concept as ok. In likability, which is investigated in the third research question, the descriptive scores for the concepts in the assisted and highly automated driving groups revealed no major differences. Consequently, the visual-auditory concept was rated better in both metrics, but this was mainly caused by the ratings of the partially automated driving group. For usability, the effects indicated that the partially automated driving group rated vestibular feedback significantly lower than the highly automated driving group. Moreover, the differences for both concepts became significant only in the partially automated driving group. For likability, the same behaviour is shown. The interaction presented again that only the difference between the feedback concepts was induced by the partially automated driving group. These results contradict previous studies (Cramer, 2019), which revealed that additional vestibular feedback is a good method to inform the driver about state transition and intentions in partially automated driving.

An explanation for these different results could be the differing conditions between the studies. Cramer (2019) started the settling-in drive with one modality (visual or vestibular) and added the other modality after a few minutes. In the current study, each participant experienced first the visual-auditory concept and then the visual-auditory-vestibular concept during the settling-in drive, which could lead to a sequence effect. In contrast to Cramer (2019), a roll acceleration of $\ddot{\varphi} = \text{-}4.5\,^{\circ}/s^2$ was used instead of $\ddot{\varphi} = \text{-}3.2\,^{\circ}/s^2$ to announce lane changes. Another difference between the two studies is the pitching behaviour of the automated driving system. Cramer (2019) considered parameters like relative velocity, vehicle type, and distance to the preceding vehicle. In doing so, pitch motions were supposed to be at a greater distance if the vehicle in front was a truck, the relative velocity was smaller, or longitudinal acceleration was higher. Thus, pitch motions were not initialized when the relative velocity to the preceding vehicle was positive (e.g., cutting-in vehicle from the left lane which is faster than the ego vehicle). The vehicle in the current study pitched whenever a new vehicle ahead was detected in the sensor area. Some participants mentioned that certain situations do not require pitch motion, such as a cutting vehicle with a high positive speed. The same results are evident in Cramer (2019), in which participants were skeptical of permanent pitch motions. Furthermore, the experience with Adaptive Cruise Control in years differed in the two samples. Participants in the current study who experienced partially automated driving had more experience with Adaptive Cruise Control than the other two groups (see Table 4.1) and than the sample of Cramer (2019).

Based on the inconsistent results to previous research (Cramer, 2019), the relationship between Adaptive Cruise Control experience and ratings was examined for this study. The results depicted that the higher the experience with Adaptive Cruise Control, the lower the ratings for additional vestibular feedback. Consequently, the sample was divided into two groups depending on their experience in years. It was found that high Adaptive Cruise Control experience in years negatively affected satisfaction, usability, and likability for the visual-auditory-vestibular concept. The results revealed that participants with high Adaptive Cruise Control experience in years rated the visual-auditory-vestibular concept as significantly less satisfying, usable, and likable than participants with little experience in these three metrics. Thus, the higher experience with Adaptive Cruise Control of the participants from the current study might have caused a low need for additional feedback. In this context, Beggiato et al. (2015) mentioned that the need for feedback decreases after a certain period of use and experience. Hence, individuals who already had a lot of experience with visual and auditory feedback from systems with automated longitudinal and lateral guidance might have perceived this feedback as more familiar and evaluated it more positively. Conversely, the additional vestibular feedback might have led to a more negative evaluation. One respondent noted here that he found it unfamiliar when the car moved additionally due to vestibular feedback.

The generalizability of these results is subject to certain limitations. Participants were selected based on their gender and technical background. The characteristics of the sample could lead to biases regarding attitudes towards automated driving, trust, and evaluation of the systems. In addition to the number of participants ($N = 20$ per group), the selection excluded participants without Adaptive Cruise Control experience, which could reduce the representativeness of the population. Furthermore, participants were contacted mainly by AUDI AG. Thus, the present sample could be a self-selection sample, as potential participants voluntarily responded to the request for participation. This suggests that primarily individuals with a high interest regarding automated driving participated in the experiment (Döring & Bortz, 2016). In addition, mainly employees of AUDI AG were recruited for participation. This could have led to employees perceiving the company's own products as particularly positive due to a high level of commitment on the one hand. On the other hand, this could have led them to be particularly critical in their assessment, as they wanted to promote the competitiveness of their own employer.

Due to the real scenario, standardization of the requirements is difficult. The associated high number of potential confounding variables that cannot be controlled for (e.g. weather or traffic conditions) can lead to a low level of internal validity. To ensure similar conditions, the study was conducted at the same times during the day. Other influencing factors may exist due to the technical limitations of the prototype and the resulting safety-related measures. The required presence of the safety co-driver may have had an impact on driver perception, sense of responsibility, and decisions. The manual release of lane changes by the safety co-driver could also limit the transferability of the results to other studies whose vehicles perform automated lane changes. Therefore, a defensive driving style was already considered in the decision to change lanes. Moreover, the visual feedback was criticized. The information provided by the instrument cluster was sufficient for most participants, yet some of them mentioned that they missed both the surrounding traffic and the changing ego position.

From the results, it can be concluded that the visual-auditory-vestibular concept is probably well suited for beginners to present the intentions of an automated vehicle. Individuals who have higher experience with similar systems did not seem to need additional feedback (cf. Beggiato et al., 2015). Furthermore, the results of this study indicated that the preference for the type of feedback depends on the experience with Adaptive Cruise Control. Pitch and roll motions in a multimodal feedback concept provide a way to announce the intentions of the automation system, especially for inexperienced users. However, pitching motion should be used more sparingly and consider parameters like relative velocity, vehicle type, and distance to the preceding vehicle (Cramer, 2019). Moreover, additional vestibular feedback was also shown to increase the predictability of the system, making the intentions of the vehicle well anticipated. The results further indicated that intention communication in a level of automation that have not yet been experienced can be supported by vestibular feedback. Users in highly automated driving rated the visual-auditory-vestibular concept more useful and user-friendly than users in partially automated driving. Thus, multimodal feedback with active vehicle movements opens up a new way to assist drivers with new tasks in automated driving (e.g., performing a non-driving related task). In general, visual-auditory-vestibular seems to be a good feedback concept to present the intentions of a yet unknown automation system. Further studies focused on vestibular feedback in a multi-level automated driving vehicle. Since vestibular feedback tends to be more predictable, the second driving experiment investigated whether vestibular feedback can positively influence transitions from one level of automation to another and focused on the differences between Adaptive Cruise Control experiences (Chapter 5).

5 Driving Experiment 2: The Influence of Feedback on Transitions Between Different Levels of Automation

This study and its results [2] have been prepublished in Wald, Hiendl, et al. (2022). Some parts of the written text were adopted literally from the paper. Figures, tables, and statistical analyses were adapted for a consistent representation throughout this thesis. The Ethics Board of the Technical University Munich provided ethical approval for this study and the hygiene concept, the corresponding ethical approval code is 295/21 S.

5.1 Introduction

The first driving experiment (cf. Chapter 4) on the motorway investigated the use of active vehicle motions in a multimodal concept as feedback during different individual LoA. Results revealed that additional vestibular feedback offers a new possibility to support inexperienced drivers or at little known LoA (e.g., SAE level 4). Moreover, the previous study revealed that experience with ACC in years has an influence on the evaluation of vestibular feedback. Thus, participants with high experience found the additional movements less acceptable and usable than participants with little experience with ACC. The present study extends these findings and applies them to a multi-level system.

As described in Section 2.1.6, the role of the driver is changing as driving functions become increasingly automated. While existing vehicles already include several LoA (e.g., MAN and ASD with ACC), future vehicles may include further LoA where the driver is legally distracted from the driving task (e.g., by performing an NDRT). Consequently, drivers have to be fully aware of the current LoA in order to legally

[2] The driving study was conducted with the assistance of Laura Hiendl as part of her Master's thesis (Hiendl, 2022).

perform their responsibilities. To keep the driver informed despite the rather passive role regular feedback from the vehicle is important. As shown in Section 2.2, the design and information content of the feedback depend on the LoA and thus on the driver's task (Beggiato et al., 2015; Bengler et al., 2020). As depicted in Chapter 2.2, feedback should be designed multimodally (Wickens, 2002). Cramer (2019) and the previous study revealed that multimodal feedback can be complemented by active vehicle movements. This vestibular feedback provides a new way to communicate automation intentions before a driving manoeuvre is initiated. The pitch and roll motions were found to be useful (Cramer, 2019) in PAD and predictable (cf. Section 4.3) during individual LoA. However, there has been no detailed investigation of active vehicle movements in a multi-level automated vehicle. Therefore, this study investigates whether additional vestibular feedback is also useful in a multi-level system and can assist in anticipating intentions.

The main challenges facing these multi-level systems are not only the different responsibilities for the driving task, but also the transitions between different LoA, which lead to new challenges in the design of HMI (Othersen, 2016). Transitions between different LoA (especially to SAE level 4) have been insufficiently studied, as most studies only examined transitions between an automated level and manual driving (McDonald et al., 2019). In addition, research has mainly focused on critical transitions (Eriksson & Stanton, 2017). The work of de Winter, Stanton, and Eisma (2021) criticised previous research on transition. In particular, the design of HMI in non-critical transitions is described as insufficient (de Winter et al., 2021). The aim of this study was therefore to investigate the important display content of transitions using an expert interview and a subsequent real vehicle study. Another point of discussion in transition research is realistic implementation, including cognitive readiness (de Winter et al., 2021). Previous literature mainly addresses issues concerning the time to regain manual control and the corresponding influencing factors (B. Zhang et al., 2019). The available time budget and the driver's response to a TOR are mostly between five and ten seconds (e.g., Gold, Damböck, Lorenz, & Bengler, 2013), while studies on the mental stabilisation time after a transition show that the driver needs up to 40 seconds to regain full attention (Merat et al., 2012). This indicates that the cognitive processing of a take-over situation requires more time than the (reflexive) motor response to a TOR (Zeeb et al., 2016) and should be further investigated (Merat et al., 2012). Thus, this study provides an overview of the activation times for different non-critical transitions depending on the feedback.

The aim of this study is to investigate in an exploratory way whether additional vestibular feedback can support drivers in their tasks during different LoA and the transitions between them. During PAD, it is hypothesised that additional vestibular feedback will increase gazes into lane change relevant AOI (cf. Section 3.5) and decrease gazes into the instrument cluster. Additionally, the influence of feedback on the performance during non-critical transitions will be investigated. Since most of the previous transition studies were conducted in driving simulators, these results need to be confirmed in a real road environment (B. Zhang et al., 2019). Therefore, two different feedback concepts were evaluated in a real-world driving study. One concept includes additional active vehicle movements (VAV), while the other serves as a baseline concept (VA). According to Petermann-Stock (2015) and Bundesanstalt für Straßenwesen (2021), only three LoA (MAN, PAD, and HAD) for a clearer differentiation were considered. Based on the negative correlation between ACC experience in years and feedback evaluation of the first experiment (cf. Section 4.3.7), the influence of ACC experience on feedback concept evaluation is also examined. Thus, three groups depending on ACC experience in years (zero, little, high) experienced the concepts and non-critical transitions. The main research questions are:

- RQ1: What is the driver's impression of trust, acceptance, indisposition, and mode awareness depending on the feedback concepts?
- RQ2: Does the feedback concept have an impact on performance during a transition?
- RQ3: What are the information needs in the case of non-critical transitions?
- RQ4: Does the experience with ACC affect the assessment of vestibular feedback?

5.2 Expert Interview

An expert interview was conducted to identify the information needs for non-critical transitions and for different LoA. Due to the fact that Petermann and Schlag (2010) recommend using only three LoA in a multi-level system to improve system understanding, the following three were considered: MAN, PAD, and HAD.

5.2.1 Procedure

Seven (2 female and 5 male) experts in designing HMI concepts for automated driving participated in the interview. Their expertise covered technical and user-centred HMI-development and ranged from three to five years. The experts worked in research or industry for an average of $M = 3.86$ ($SD = 1.03$) years and their age ranged between 26 and 30 years ($M = 27.57$, $SD = 1.81$). Each interview was conducted using a video conferencing tool and lasted approximately one hour. One moderator guided the expert through the interview using an interview guideline. Two independent observers recorded in written form. Subsequently, the answers were analysed. Similar statements were combined and clustered. Appendix C.3 depicts the interview. After instruction and collection of demographic data, the experts were asked to describe the design of various transitions using different scenarios. At first, experts described the process of a transition to higher and then to lower LoA. They were asked to be as precise as possible and to include any feedback. The participants followed up by designing the following four transitions using the given scenarios:

- Transition T1: from MAN to PAD
- Transition T2: from PAD to HAD
- Transition T3: from HAD to PAD
- Transition T4: from PAD to MAN

All transitions were discussed consecutively with regard to the expected information needs. After each description, they rated the mentioned information based on the perceived relevance from 0 to 100. At the end, the experts were asked to indicate which characteristics are important to distinguish between different LoA.

5.2.2 Results

The experts considered some general aspects as important for the non-critical transitions, regardless of the direction of change (up or down). It became apparent that non-critical transitions can be divided into three phases: announcement, activation, and confirmation.

- *Announcement*: For all transitions, an availability announcement should be displayed. Another additional modality, e.g., an acoustic indication, is not always beneficial. The experts suggested that additional signals are only useful when the driver has to take on more responsibility after the transition (T3 and T4). If an additional modality is used for transition to a higher LoA it should be unobtrusive and not frequent. In addition, a time budget and a reason could be displayed, but these are not considered essential for transitions to a higher LoA.

- *Activation*: The driver should always perform the activation of the new LoA for an upward transition Thus, the drivers are not patronised and can decide for themself. It is interesting to note, however, that the experts were uncertain about the transition T3. Several respondents indicated that the deactivation could be done by the automated driving system. In this case, the automation should ensure that the driver can regain control, for example, through video monitoring.

- *Confirmation*: A common view amongst interviewees was that confirmation about the new LoA is important. For transition T4, two experts reported uncertainty about whether confirmation should be made by the driver or by the system. They explained that this depends on how the vehicle behaves when it is not taken over. In addition, a task description immediately after the acceptance seems especially useful when the driver resumes more control after the transition (in this context: after T3 and T4).

In summary, an non-critical transition can be classified into announcement, activation, and confirmation. Upward transitions should be announced unobtrusively and the driver should not be stressed to accept them. The confirmation can be combined with a task description. Transitions to lower LoA need to be designed to be more urgent and accompanied by an acoustic indication, for example. Deactivation of the higher LoA should only occur when the driver is ready to resume control. Either the system monitors the driver or the driver should take control independently. Confirmation with a task description is essential.

Results for the differentiation of the LoA revealed that displays in the instrument cluster depend on the LoA. This finding further supports the results of Beggiato et al. (2015), where automated driving modes should display the vehicle's perception (e.g., surrounding traffic and lane detection). Furthermore, the current LoA should be portrayed by colour, textual, and pictorial descriptions. However, PAD and HAD should be distinguishable by different descriptions. Nevertheless, the experts stated that these automated driving descriptions and the vehicle's perception are not useful in manual vehicle guidance, which is also reported by Beggiato et al. (2015).

5.3 Method

To answer the main research question (cf. Section 5.1), two different feedback concepts were evaluated in a real-world driving study with a test vehicle. Accordingly, three groups divided by experience with ACC in years (zero, little, high) experienced the two different feedback concepts: visual-auditory (VA) feedback and visual-auditory-vestibular (VAV) feedback. In the following, the method of the second experiment will be described in more detail.

5.3.1 Sample

A total of 47 drivers attended the experiment and were divided equally into three groups based on their experience with ACC in years. Table 5.1 presents a detailed overview of the sample. The age of the participants ranged from 22 to 59 years, with a mean age of M = 32.91 (SD = 9.93) years. The sample was representative of a diversity of gender and technical background (23.4% technical female, 25.6% non-technical female, 31.9% technical male, and 19.1% non-technical male). 25.5% of the participants (zero: 3, little: 4, high: 5) worked in the field of research and development of automated driving.

Table 5.1: Sample of the second study

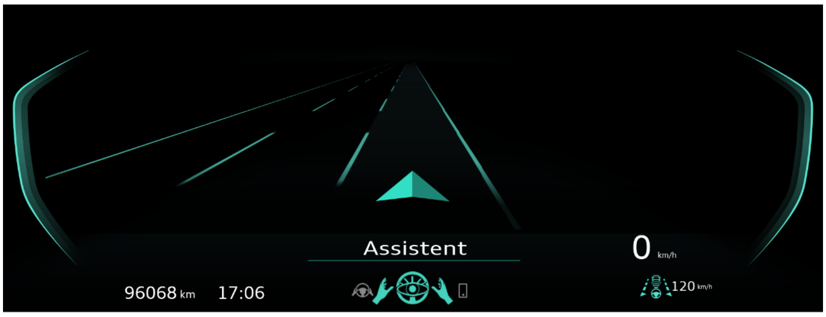
Variable	Zero	Little	High
Age $M(SD)$ in years	29.63 (10.42)	30.44 (7.39)	39.07 (9.45)
Gender N			
Female (T, NT)	8 (2, 6)	8 (5, 3)	7 (4, 3)
Male (T, NT)	8 (3, 5)	8 (6, 2)	8 (6, 2)
Experience with ADAS in years			
ACC $M(SD)$	-	1.29 (0.77)	8.73 (4.53)
LKA $M(SD)$	0.96 (0.38)	1.29 (1.23)	4.85 (2.61)
PAD $M(SD)$	-	0.93 (0.90)	3.11 (1.83)
Driver's license $M(SD)$ in years	12.00 (10.34)	12.19 (5.48)	22.20 (10.61)
Propensity to trust $M(SD)$ [1-5]	3.15 (0.57)	3.17 (0.40)	3.24 (0.71)

Note. T = technicians; NT = non-technicians.

The sample had an average driving experience of M = 15.32 (SD = 10.08, min = 5, max = 49) years. Participants drove an average of M = 14,468 (SD = 8,888) km per year before and M = 9,000 (SD = 5,782) km per year during the period affected by the COVID-19 pandemic situation with an average of 41.5% motorway driving. Two-thirds of the participants had previous experience with ACC: 16 participants with little experience (M = 1.29, SD = 0.77, min = 0.1, max = 2), and 15 with high experience (M = 8.73, SD = 4.53, min = 3, max = 18) with ACC in years. Additionally, 72% (zero: 8, little: 12, high: 14) of the sample had used LKA and 36% (zero: 0, little: 6, high: 11) partially automated driving systems before. On a 5-point scale (1 "strongly disagree" to 5 "strongly agree"), the sample showed a medium propensity to trust in automated driving ($M = 3.18$, $SD = 0.56$).

5.3.2 Feedback Design

For this experiment, the feedback presented in Section 3.2 was adapted. However, there were only changes in the visual design, as shown in Figure 5.1. To provide a better differentiation between the LoA, they were displayed in different colours: PAD in turquoise, HAD in green. Furthermore, the labels of the LoA were adjusted. PAD was named Assistant (cf. Figure 5.1a) and HAD was labelled Pilot (cf. Figure 5.1b). Additionally, the ego vehicle could now change lanes and was always displayed in the currently driven lane. The lines were depicted according to reality (solid for marginal lanes vs. dashed for centre lanes). Participants experienced both visual-auditory (VA) and visual-auditory-vestibular (VAV) feedback.



(a) Display in PAD

(b) Display in HAD

Figure 5.1: Visual HMI displays for different LoA during the second study

Due to the fact that the participants drove in a multi-level system, transitions between the LoA were added. The results of the expert interview (cf. Section 5.2) were used as a basis. Figure 5.2 presents the transition process with the different phases as an example for T3 (HAD to PAD). Transition T1 (MAN to PAD) was designed to be unobtrusive, giving only a visual indication that PAD was now available. After activation by the driver, the PAD display (cf. Figure 5.1a) was presented without a task description. The transitions T2 (PAD to HAD) and T3 were announced by a visual hint above the current view (cf. Figure 5.2) and an acoustic hint. The driver also had to accept these transitions independently. The HMI displayed the confirmations and added an additional task description for the new LoA. This description either stated that the participant was now allowed to perform an NDRT or that the driver must resume the monitoring task. The task description disappeared after approximately two seconds and the normal view was displayed without further information. The last transition (PAD to MAN) was designed conspicuous. The take-over screen described in Section 3.2 was used with an additional illustration. In the first study, participants often only assumed lateral control after taking over, but not longitudinal control directly. For this reason, a foot over a pedal was additionally displayed to signal a longitudinal takeover (cf. Appendix B.3).

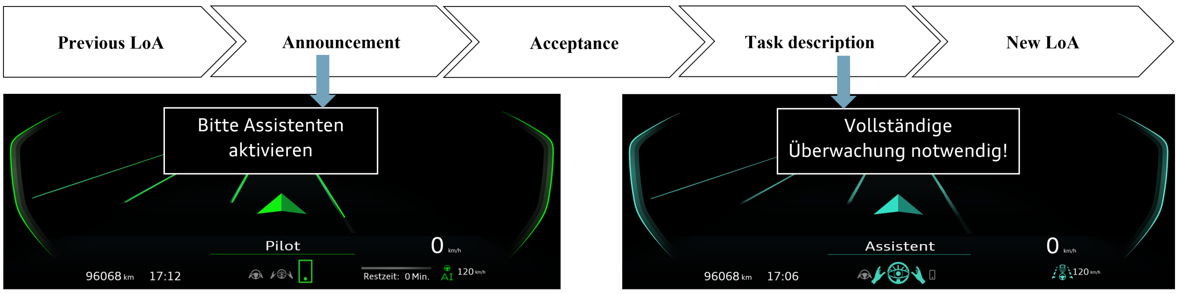


Figure 5.2: Sequence of the transition process using the example of transition T3

5.3.3 Study Design

For this study, a mixed design was conducted combining the between-subject three-level factor experience with ACC in years (zero, little: $0.1 - 2.9$, and high: > 2.9) and the within-subject factors feedback concept (two-level: VA and VAV), LoA (three-level: MAN, PAD, and HAD), and the four corresponding transitions (cf. Section 5.2). Participants were assigned to a group based on their ACC experience and experienced both feedback concepts in a randomised order. During PAD, participants had to monitor the system and the environment. In HAD, participants played a game on a tablet in the centre console.

5.3.4 Study Procedure

The study took place on the three-lane A9 motorway between the Denkendorf and Manching exits. For safety reasons, only the right and middle lanes were used and the maximum speed was 120 km/h. The recruitment of participants (cf. Appendix C.4) and the hygiene concept for the COVID-19 pandemic situation (cf. Appendix B.1) were similar to those of the first study presented in Section 3.4. Due to the higher requirements, a few adjustments were made. The participants had to test themselves on-site and wore an FFP2 mask during the experiment.

The experiment was conducted in German. The participants first received a verbal briefing on the procedure (cf. Appendix B.3). Subsequently, the different LoA (cf. Section 5.3.3) implemented in the vehicle and the possible transitions were explained, as well as the buttons to be pressed in each case. In addition, it was emphasised several times that this experiment consisted only of non-critical transitions. The buttons for transitions should not be pressed until the participants had a complete overview of the environment and the vehicle, so that they would feel ready to take-over at any time, and not as quickly as possible. They then practised activating the various LoA in the stationary test vehicle, which was followed by the test drives. Figure 5.3 presents the sequence of the study including LoA and transitions.

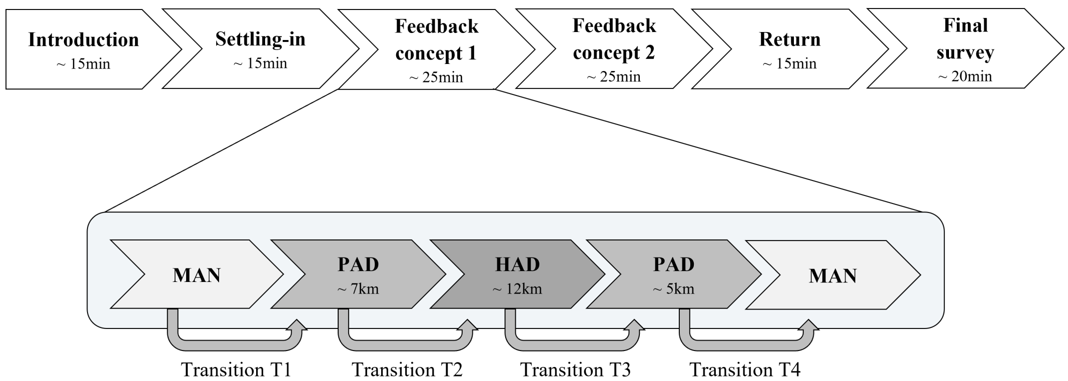


Figure 5.3: Sequence of the second driving study referring to Wald, Henreich, et al. (2022)

During all driving sessions, participants drove manually on the motorway and activated the automation system in the right lane. Drivers received no vestibular feedback during the settling-in phase, with only basic visual information such as current speed and position displayed in the instrument cluster. During the first three minutes of the settling-in drive, the test vehicle did not perform any lane changes as participants became familiar with the system. They then experienced two feedback concepts in a randomised order. There were a total of four transitions during a concept drive, which were initiated by the WoOz driver. The first transition (from MAN to PAD) could be performed as soon as the vehicle arrived in the right lane of the motorway. After about 7 km in PAD, the second transition to HAD occurred. The third transition back to PAD took place after about another 12 km. The cue for the final transition occurred approximately 1 km in front of the motorway exit. Participants were required to monitor the system and environment during PAD and were allowed to play a spot-the-difference puzzle on a tablet in HAD. The return drive was conducted as PAD and included an evaluation of the visual HMI. Thereupon, the return drive to the parking lot followed including an evaluation of the visual elements.

The participants completed questionnaires (cf. Appendix C.5) about their perceived trust, acceptance, mode awareness, comfort, and motion sickness after each concept drive. During the drives, the experimenter asked questions about all four transitions. These questions were related to the transition the participants had just experienced and to the previous LoA. For the transitions to a lower LoA, additional questions were asked about the deactivation. Moreover, the characteristics of the feedback concepts were requested. During the return drive, participants rated the visual information in terms of perceived relevance. Finally, the differences in the feedback concepts were inquired.

5.3.5 Dependent Variables

Both objective and subjective data were used as dependent variables to answer the research questions (cf. Section 5.1). Table 5.2 presents the metrics depending of the time of measurement. In Section 3.5, the commonly applied questionnaires are described. Mode awareness was measured with two questions from Othersen (2016) after each transition. Participants were asked to verbally validate their *task awareness* and their *monitoring behaviour* (cf. Section 3.5). Furthermore, participants had to assess their *certainty* about the LoA they had just activated (Petermann-Stock, 2015) on a fifteen-point scale consisting of five categories from “very little” to “very strong” with the additional opportunity “no answer”. For the performance at transitions, *mental stress*, *comprehensibility* of the transition proposal, *attention allocation* at a transition to lower LoA, and the *activation times* for different transitions were collected. Participants rated their *mental stress* (“How demanding is your current mental stress?”) as well as the *comprehensibility* of the transition proposal (“How comprehensible was the system proposal?”) on the fifteen-point scale. *Attention allocation* at a transition was assessed using two questions regarding environment (“How much did you consider the surrounding traffic when you took over?”) and visual HMI (“How much did you consider to the visual feedback when you took over?”) on the same scale.

To identify the required information during a specific LoA and the corresponding transition, the *perceived relevance* from 0 to 100 of different HMI information based on the results of the expert interview were evaluated. For the transitions T2 - T4, participants had to rate the relevance for an illustration showing the availability of the next LoA (cf. Figure 5.2) and a sound during the announcement. Moreover, they were asked to rate the task description after the confirmation. According to Beggiato et al. (2015), the *perceived relevance* (from 0 to 100) of the following visual information was measured to identify the information needs during different LoA: environment (lane detection and surrounding traffic), upcoming manoeuvre, designation (e.g., Assistant or Pilot), the colour and the pictorial description of the LoA, and maximum and current speed. With regard to the objective monitoring behaviour, the number of participants had to be reduced due to the lower quality of the data. To assess the latter, 14 participants remained in the zero group, 13 participants in the little group, and 11 in the high group. For mode awareness, the attention ratio and the number of gazes (cf. Section 3.5) at PAD were assessed. In HAD, participants performed an NDRT and were therefore facing away from the eye tracker. For this reason, no data could be recorded in HAD. Furthermore, gaze data were analysed into lane change relevant AOI based on a closer look at the first gaze.

Table 5.2: Overview of the dependent variables of the second study

Dependent variable	Operationalisation	Time of measurement
Subjective data		
Trust	TiA questionnaire (Körber, 2019)	PQ, AC
Acceptance	AS from van der Laan et al. (1997)	AC
Motion Sickness	FMS by Keshavarz and Hecht (2011)	AI, BC, AC
Comfort/Discomfort	Questionnaire by Engelbrecht (2013)	AC
Mode Awareness	Items by Othersen (2016) and Petermann-Stock (2015)	AT
Characteristics	Single-items (Section 3.5)	AC, AE
Performance	Item by Petermann-Stock (2015) and single-items	AT
Required information	Relevance	RD
Objective data		
Gaze behaviour	Attention ratio at defined AOI	
	Number of gazes at defined AOI	
	First gaze during lane changes	
Driver behaviour	Activation times	

Note. PQ = pre-questionnaire; AI = after instruction; BC = before concept drive; AC = after concept drive; AT = after transition; RD = return drive; AE = at the end.

5.4 Results

The statistical analysis is described in Section 3.6 and the findings will be denoted in accordance with Field et al. (2012). The results of the questionnaires (cf. Appendix C.5) are presented below according to the sequence of the research questions.

5.4.1 Trust in Automation and Acceptance

Figure 5.4 provides an overview of the mean ratings for the trust questionnaire according to group and feedback concept. The graphical inspection of this figure indicates that the ratings for *Reliability/Competence* and *Understanding/Predictability* did not vary widely among the concepts and the groups. For *Trust in Automation*, VAV ratings were slightly higher for participants with little and high experience descriptively. For each of the three subscales, a mixed ANOVA was performed with the two-level within-subject factor feedback concept and the three-level between-subject factor experience with ACC. In general, both concepts were perceived as reliable (VA: $M = 3.77$, $SD = 0.61$, VAV:$M = 3.70$, $SD = 0.57$), predictable (VA: $M = 4.20$, $SD = 0.58$, VAV:$M = 4.21$, $SD = 0.56$), and generated high trust in automation (VA: $M = 3.98$, $SD = 0.82$, VAV: $M = 4.09$, $SD = 0.69$). Results indicated no significant differences between the feedback concepts for *Reliability/Competence* ($F(1, 44) = 1.79$, $p = .188$, $\eta_p^2 = 0.04$), *Understanding/Predictability* ($F(1, 44) = 0.04$, $p = .850$ $\eta_p^2 < 0.001$), and *Trust in Automation* ($F(1, 44) = 1.27$, $p = .267$, $\eta_p^2 = 0.03$). Moreover, there was neither a main effect of experience with ACC nor an interaction for all three subscales ($p > .05$).

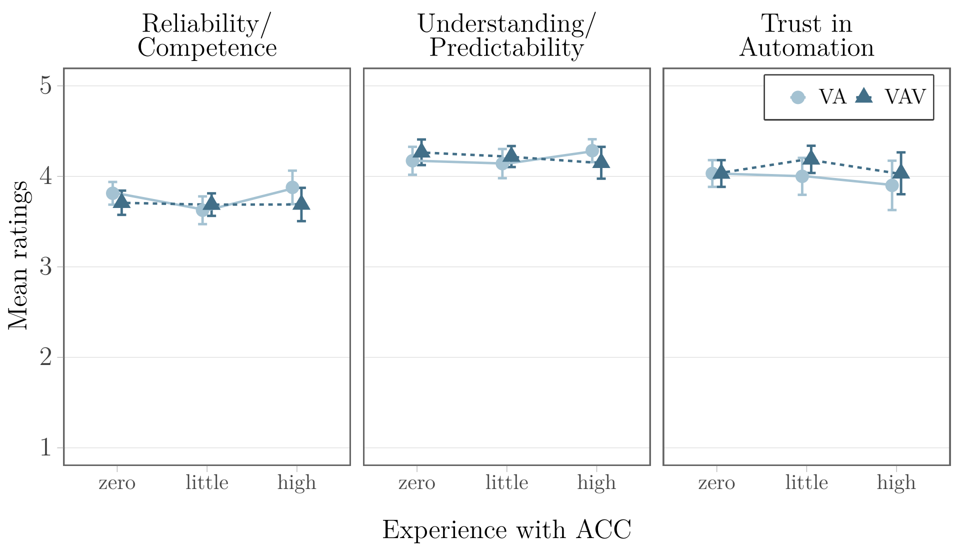


Figure 5.4: Subjective evaluation of the trust questionnaire according to the experience groups depending on the feedback concepts referring to Wald, Hiendl, et al. (2022). Error bars indicate ± 1 SE

In terms of acceptance (cf. Appendix C.5), both concepts were rated as *useful* (VA: $M = 0.74$, $SD = 0.32$, VAV: $M = 0.74$, $SD = 0.37$) and *satisfying* (VA: $M = 1.38$, $SD = 0.48$, VAV: $M = 1.34$, $SD = 0.64$). A mixed 2 (feedback concept) × 3 (experience) analysis of variance was performed for the subscales *satisfying* and *usefulness*. However, the results showed neither significant main effects nor an interaction effect for both subscales ($p < .05$).

5.4.2 Indisposition

Motion sickness was measured before and after the settling-in drive as well as after each concept drive. It was pointed out that the participants should only evaluate their physical complaints. Only eleven gave at least one score higher value than zero, ranging from one to six. Five participants in the VA condition and six participants in the VAV condition rated their *motion sickness* higher than zero. The most commonly reported symptoms were mild headache, mild indisposition in the stomach area, and excitement.

Participants rated their perceived *comfort* and *discomfort* after each concept drive. As can be seen in Table 5.3, the mean ratings did not vary widely between the concepts or the groups. In both concepts, the perceived *comfort* was medium to high and the *discomfort* was low (cf. Table 5.3). For both subscale, a mixed 2 (feedback concept) × 3 (experience) ANOVA was conducted. Results did neither yield a main nor an interaction effect on *comfort* or *discomfort* ($p > .05$).

Table 5.3: Participants' mean ratings of their perceived comfort and discomfort during the different feedback concepts depending on the experience with ACC

Experience	Comfort [1-5]		Discomfort [1-5]	
	VA ($M(SD)$)	VAV ($M(SD)$)	VA ($M(SD)$)	VAV ($M(SD)$)
Zero	3.88 (0.82)	3.84 (0.73)	1.77 (0.71)	1.83 (0.47)
Little	3.74 (0.65)	3.88 (0.64)	1.70 (0.57)	1.71 (0.51)
High	3.98 (0.66)	3.83 (0.44)	1.60 (0.77)	1.42 (0.44)

5.4.3 Mode Awareness

Mode awareness was estimated with the single-items task awareness, certainty about the LoA to be activated, self rated monitoring behaviour after each transition, and objective monitoring behaviour during PAD. A mixed 2 (feedback concept) $\times$ 4 (LoA) $\times$ 3 (experience) ANOVA was conducted for task awareness and certainty. For the subjective observing behaviour, three LoA and for the objective monitoring behaviour the two PAD segments are compared.

The mean ratings for *task awareness* are depicted in Figure 5.5. The graphical analysis indicates that there was a difference between the concepts only during HAD, in contrast to the other LoA. It can further be recognised that the PAD sections generated less *task awareness* than MAN or HAD. The mixed 2 (feedback concept) $\times$ 4 (LoA) $\times$ 3 (experience) statistical analysis for *task awareness* indicated that neither experience with ACC ($F(2, 44) = 1.89$, $p = .163$, $\eta_p^2 = 0.08$) nor the feedback concept ($F(1, 44) = 0.91$, $p = .345$, $\eta_p^2 = 0.02$) revealed a significant effect. However, a significant effect with a large effect size for LoA ($F(1.77, 77.68) = 17.34$, $p < .001$, $\eta_p^2 = 0.28$) was found. Homogeneity of variance was violated (cf. Appendix A.3). Thus, only the post-hoc comparisons are interpreted. Benjamini-Holm corrected post-hoc tests showed that the *task awareness* for MAN ($M = 14.37$, $SD = 1.28$) was highest compared to HAD ($M = 13.85$, $SD = 1.85$, $p = .014$) as well as to the first ($M = 12.67$, $SD = 2.67$, $p < .001$) and the second ($M = 12.90$, $SD = 2.09$, $p < .001$) PAD sections. Moreover, HAD generated a higher *task awareness* than the two PAD sections ($p < .001$). The applied ANOVA did not reveal any further significant interaction effects.

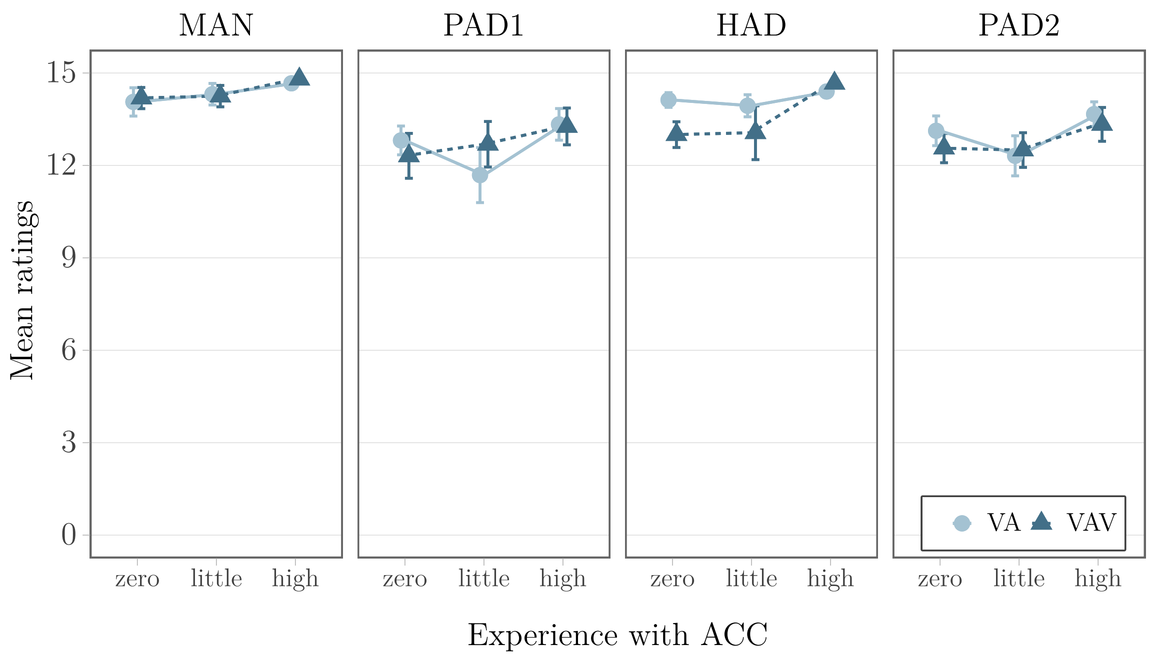


Figure 5.5: Subjective evaluation of the task awareness for the three groups depending on the feedback concept referring to Wald, Hiendl, et al. (2022). Error bars indicate $\pm$ 1 SE

The actual 2 (feedback concept) × 4 (LoA) × 3 (experience) ANOVA for the *certainty* about the LoA to be activated could not be evaluated because the homogeneity of variance is violated (cf. Appendix A.3). The post-hoc tests indicated that a transition to PAD (PAD1: $M = 12.53$, $SD = 2.90$; PAD2: $M = 13.26$, $SD = 1.96$) produced less *certainty* compared to transitions to MAN ($M = 13.94$, $SD = 1.43$, $p < .001$) and HAD ($M = 13.85$, $SD = 1.47$, $p < .01$). However, the statistical analysis indicated no further significant differences.

Figure 5.6 compares the *monitoring behaviour* for the subjective and objective monitoring. The box-plots on the left hand side in Figure 5.6 suggest that participants monitored the system more during PAD than during HAD. It also appears that the values decreased from the first PAD section to the second. Compared with the box-plots for objective monitoring on the right side of Figure 5.6, a similar decreasing monitoring behaviour is apparent.

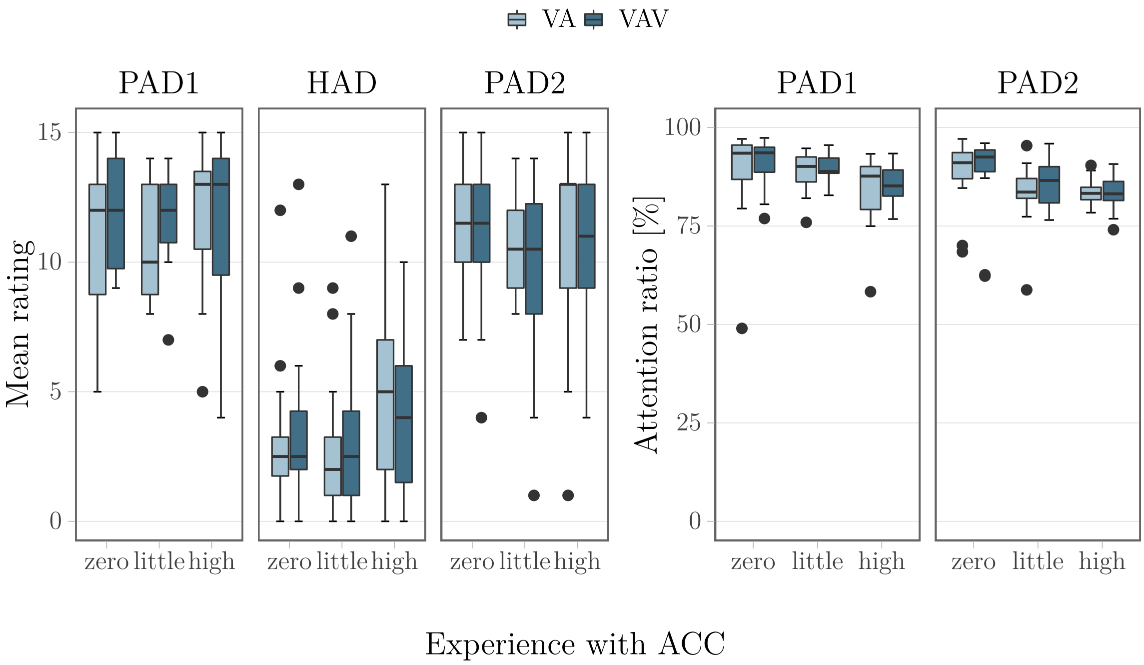


Figure 5.6: Subjective (left) and objective (right) monitoring behaviour for the three groups depending on the feedback concept. Error bars indicate ± 1 SD

The 2 (feedback concept) × 3 (LoA) × 3 (experience) statistical analysis of variances for self rated monitoring behaviour revealed neither a main effect for experience with ACC ($F(2,44) = 0.74$, $p = .485$, $\eta_p^2 = 0.03$) nor for feedback ($F(1,44) = 0.08$, $p = .774$, $\eta_p^2 = 0.002$) or any further interaction effects ($p > .05$). However, results yielded a significant difference between the LoA sections with a large effect size ($F(1.45, 63.63) = 184.63$, $p < .001$, $\eta_p^2 = 0.81$). Subsequent analysis showed that participants monitored the system significantly more during PAD compared to HAD ($M = 3.61$, $SD = 3.18$, $p < .001$). Moreover, post-hoc tests yielded a decreasing monitoring behaviour from the first ($M = 11.40$, $SD = 2.57$) to the second ($M = 10.69$, $SD = 2.87$, $p = .010$) PAD section. The 2 (feedback concept) × 2 (LoA) × 3 (experience) ANOVA applied to the objective monitoring behaviour confirmed the latter with a large effect size ($F(1, 35) = 6.08$, $p = .019$, $\eta_p^2 = 0.15$) indicating a decreasing monitoring behaviour (first PAD: $M = 0.88$, $SD = 0.08$, second PAD: $M = 0.86$, $SD = 0.08$). However, no other main or interaction effects were found.

5.4.4 Feedback Characteristics

Feedback characteristics were composed of the four statements *annoying*, *distracting*, *relieving*, and *predictability*. Table 5.4 displays the mean values for each statement depending on the feedback concept. The inspection of the means indicates that the feedback concepts were rated as less annoying and distracting ($M < 3$) and as medium to high relieving ($M > 4$). Descriptively, VAV was rated as more relieving in PAD compared to VA. Moreover, VAV appears to be more annoying and distracting in HAD.

Table 5.4: Descriptives of participants' mean ratings of the feedback characteristics for different LoA depending on feedback concept

Characteristic	PAD		HAD	
	VA ($M(SD)$)	VAV ($M(SD)$)	VA ($M(SD)$)	VAV ($M(SD)$)
Distracting [1-7]	1.70 (0.81)	1.70 (0.91)	1.81 (1.48)	2.26 (1.67)
Annoying [1-7]	1.40 (0.68)	1.40 (0.68)	1.49 (1.04)	1.81 (1.42)
Relieving [1-7]	4.43 (1.64)	5.04 (1.35)	4.53 (2.14)	4.40 (2.13)
Predictability [1-15]	11.49 (2.32)	11.90 (2.12)	10.65 (3.39)	10.89 (3.05)

The mixed 2 (feedback concept) × 3 (experience) × 2 (LoA) ANOVA found neither a significant main effect nor any significant interactions ($p > .05$) for *distracting* and *annoying*. The statistical analysis of *relieving* could not be evaluated because Levene's test was significant (cf. Appendix A.3). Post-hoc tests depicted that VAV was perceived as more *relieving* in PAD than VA ($p = .006$). Additionally, participants rated the perceived *predictability* of the feedback concept for the LoA they had experienced after each transition. From the data in Table 5.4, it is apparent that there were only small differences for the feedback concepts, descriptively indicating that VAV was perceived as more predictable than VA. A mixed 2 (feedback concept) × 3 (experience) × 2 (LoA) ANOVA was conducted approving that VAV ($M = 11.57$, $SD = 2.49$) was perceived as more predictable than VA ($M = 11.21$, $SD = 2.73$, $F(1, 41) = 5.77$, $p = .021$, $\eta_p^2 = 0.12$). The analysis of variance did neither yield further main effects nor an interaction effect ($p > .05$).

Prior to clarifying the feedback concepts, participants were asked to describe the perceived differences between these two concepts. Thirty participants (63.83%) stated that they had perceived a difference between the two concept drives. Based on the descriptions of the difference, it became clear that only seven (14.89%) participants had perceived the additional vestibular feedback. After clarifying the difference on the return drive, the mixed 2 (feedback concept) × 3 (experience) ANOVA revealed that VAV ($M = 5.13$, $SD = 2.08$) was rated as less supportive compared to VA ($M = 6.26$, $SD = 0.90$, $F(1, 44) = 9.80$, $p = .003$, $\eta_p^2 = 0.18$).

5.4.5 Performance at Transitions

Participants' performance at transitions consisted of multiple variables. The results will provide insight into *mental stress*, *comprehensibility* of the transition proposal, *attention allocation* at a transition to lower LoA, and the *activation times* for different transitions. In each case, mixed ANOVA with the within-subjects two-level factor feedback concept and the within-factor transition or the between-subjects three-level factor experience with ACC in years were computed to statistically examine all variables. Figure 5.7 presents the perceived *mental stress* at all four transitions depending on the feedback concept. In general, the mean values reflected low to moderate stress ($4 < M < 9$).

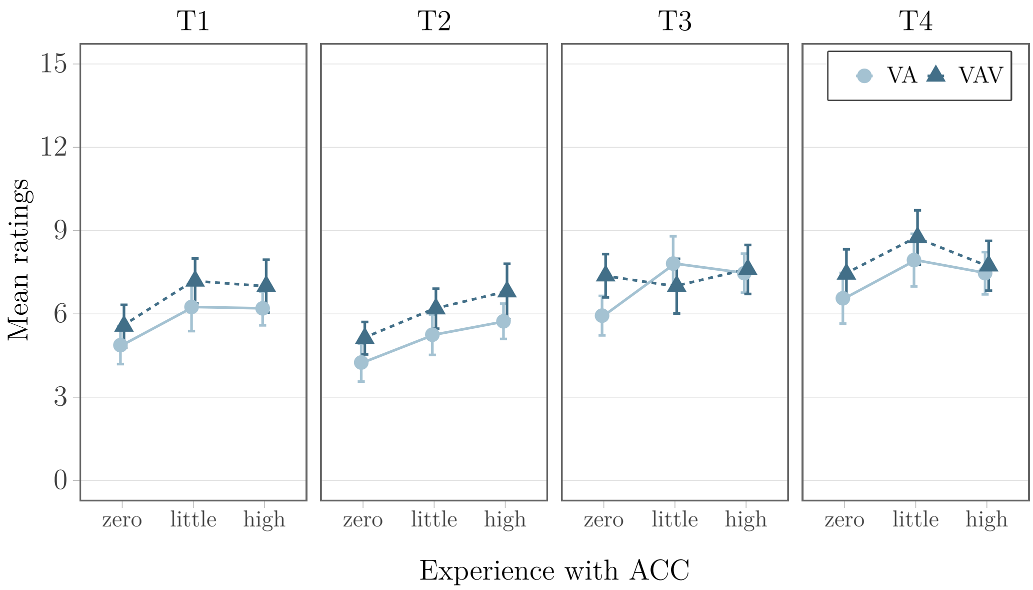


Figure 5.7: Subjective evaluation of mental stress during the transitions (T1: MAN to PAD, T2: PAD to HAD, T3: HAD to PAD, T4: PAD to MAN) for the three groups depending on the feedback concept. Error bars indicate ± 1 SE

The statistical analysis for *mental stress* revealed that additional vestibular feedback (VAV, $M = 6.97$, $SD = 3.43$) was perceived as more stressful with a large effect size than VA ($M = 6.30$, $SD = 3.22$, $F(1, 44) = 7.64$, $p = .008$ $\eta_p^2 = 0.15$). Additionally, a significant main effect for transition was found with a large effect size ($F(2.36, 103.94) = 13.90$, $p < .001$ $\eta_p^2 = 0.24$). Benjamini-Hochberg corrected post-hoc tests depicted that the second transition T2 ($M = 5.54$, $SD = 2.94$) generated the least *mental stress* compared to T1 ($M = 6.17$, $SD = 3.14$, $p = .005$), T3 ($M = 7.19$, $SD = 3.34$, $p < .001$), and T4 ($M = 7.65$, $SD = 3.54$, $p < .001$). Moreover, the first transition was perceived as less stressful than T3 ($p = .002$) and T4 ($p < .001$). The ANOVA for *mental stress* found no further significant main or interaction effects.

The perceived *comprehensibility* of the transition proposal is depicted in Figure 5.8. The graphical inspection indicates that the *comprehensibility* was rated as strong to very strong for both concepts. The statistical analysis could not be evaluated because the homogeneity of variance is violated (cf. Appendix A.3). Post-hoc tests depicted that transition T3 ($M = 13.26$, $SD = 1.96$) was significantly less understandable than transitions T2 ($M = 13.85$, $SD = 1.47$, $p = .004$) and T4 ($M = 13.94$, $SD = 1.43$, $p = .001$).

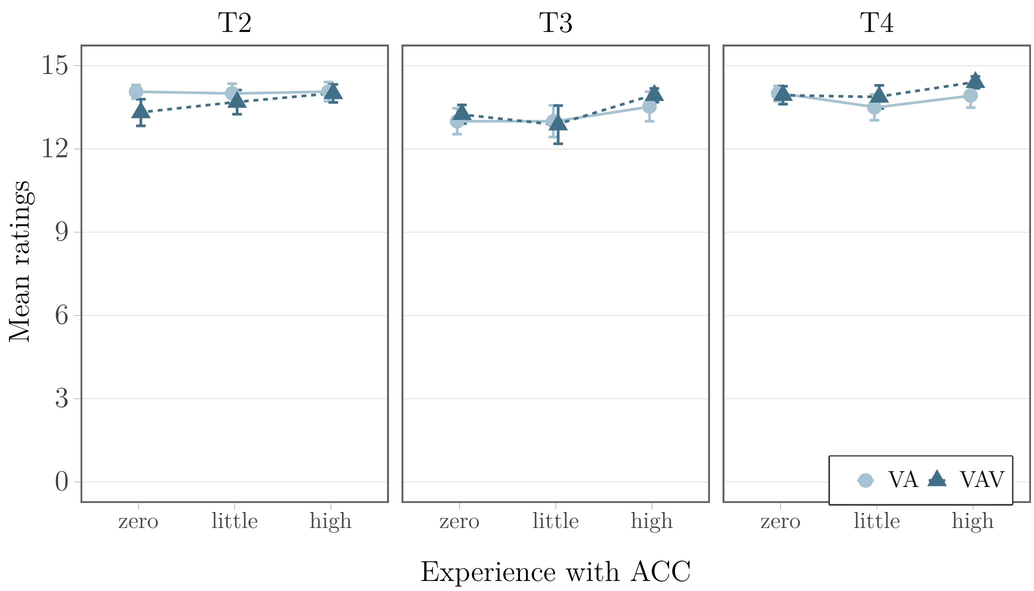


Figure 5.8: Subjective comprehensibility rating of the transition proposal (T2: PAD to HAD, T3: HAD to PAD, T4: PAD to MAN) for the three groups depending on the feedback concept referring to Wald, Hiendl, et al. (2022). Error bars indicate ± 1 SE

Participants were asked to rate their *attention* to the environment and the visual HMI during a transition to lower LoA (T3 and T4). Table 5.5 presents the mean values for the different transitions according to the information. It seems that participants with zero and little experience with ACC in years paid descriptively more *attention* to the traffic than to the visual HMI during both transitions. Contrary, participants with high experience seem to focus more attentively on the visual HMI. Furthermore, on a descriptive basis, it can be seen that participants with little experience observed more traffic in T3 than the other two groups. In the other conditions, however, it is evident that participants with zero or high experience paid more *attention* to the traffic and the visual HMI than participants with little experience.

Table 5.5: Participants' mean ratings of their attention allocation to the environment and to the visual HMI during transitions T3 (HAD to PAD) and T4 (PAD to MAN) depending on the experience with ACC and feedback concept

Experience	Transition T3 [0-15]		Transition T4 [0-15]	
	VA ($M(SD)$)	VAV ($M(SD)$)	VA ($M(SD)$)	VAV ($M(SD)$)
Traffic				
Zero	10.44 (3.86)	10.06 (3.38)	11.00 (3.23)	11.69 (2.02)
Little	11.25 (3.34)	11.44 (2.68)	10.88 (2.87)	11.00 (3.35)
High	8.53 (5.45)	9.47 (4.50)	11.20 (2.96)	11.53 (2.77)
visual HMI				
Zero	10.34 (2.83)	9.94 (3.45)	10.81 (2.74)	10.88 (3.30)
Little	8.50 (4.49)	7.69 (4.87)	9.31 (4.27)	7.69 (4.35)
High	10.80 (2.46)	10.53 (2.88)	12.00 (2.27)	11.80 (2.01)

The 2 (feedback) × 3 (experience) × 2 (transition) × 2 (information: traffic vs. visual HMI) ANOVA violated against the homogeneity of variance (cf. Appendix A.3) and thus, could not be calculated. Post-hoc analysis using Bejamini-Holm correction found a significant difference for transition T4 ($p = .006$). Here, participants with little experience paid less *attention* than participants with zero ($p = .022$) and high ($p = .003$) experience. Moreover, post-hoc tests indicated that participants with high experience focus more attentively on the information during T4 compared to T3 ($p = .012$). Furthermore, the post-hoc analysis revealed a significant difference between the groups for visual HMI ($p < .001$). Thus, participants with little experience paid less *attention* to the visual HMI than the other two groups ($p < .001$). The results also found that participants with little experience paid more *attention* to the traffic than to the visual HMI ($p < .001$).

The *activation times* are reported in Table 5.6 with mean (M), standard deviation (SD) as well as minimum and maximum for each transition depending on the feedback concept. This table illustrates that the third transition from PAD to HAD required the most time. A 2 (feedback concept) × 3 (experience) × 3 (transition) mixed ANOVA confirmed the latter with a significant difference in the transitions ($F(1.62, 63.18) = 18.48$, $p < .001$, $\eta_p^2 = 0.32$). Benjamini-Holm corrected post-hoc tests showed that participants spent more time accepting transition T3 ($M = 8.77s$, $SD = 4.83$) than accepting T2 ($M_{T3-T2} = 3.44$, $p < .001$) or T4 ($M_{T3-T4} = 3.13$, $p < .001$). One participant had to be excluded due to a safety abort of a transition. Results yielded neither further significant main nor interaction effects.

Table 5.6: Descriptives of participants' activation times in seconds for different transitions depending on feedback concept

Transition	Visual-auditory [s]			Visual-auditory-vestibular [s]		
	$M(SD)$	Min	Max	$M(SD)$	Min	Max
T2	5.41 (2.66)	2.36	15.77	5.24 (1.81)	2.82	12.68
T3	8.48 (3.70)	3.54	24.99	9.07 (5.77)	2.86	31.48
T4	5.34 (3.47)	1.71	23.78	5.95 (3.13)	2.26	15.96

5.4.6 Required Information

The required information was composed of the information need during transitions and during different LoA. The mean values of the information ratings during different transitions is depicted in Table 5.7. A mixed 3 (transition) × 3 (information: availability illustration, sound, and task description) ANOVA was conducted to identify relevant information for different transitions. The results revealed two significant main effects with large effect sizes for information ($F(1.54, 71.03) = 29.61$, $p < .001$ $\eta_p^2 = 0.39$) and transition ($F(1.56, 71.78) = 37.53$, $p < .001$ $\eta_p^2 = 0.45$) as well as a significant interaction between these variables ($F(2.1, 96.68) = 21.40$, $p < .001$ $\eta_p^2 = 0.32$). This interaction is semidisordinal, thus the main effect for information will not be considered. Post-hoc tests for LoA depicted that information during transition T2 ($M = 81.27$, $SD = 26.61$) was less relevant than information during transitions T3 ($M = 92.50$, $SD = 11.76$) and T4 ($M = 94.36$, $SD = 11.48$, $p < .001$).

Table 5.7: Descriptive mean ratings of the information relevance [0-100] during different transitions (T2: PAD to HAD, T3: HAD to PAD, T4: PAD to MAN)

Information	T2 ($M(SD)$)	T3 ($M(SD)$)	T4 ($M(SD)$)
Availability illustration	94.53 (9.58)	93.87 (7.87)	92.77 (13.18)
Sound	88.15 (21.81)	95.81 (7.27)	97.55 (6.19)
Task description	61.13 (30.74)	87.83 (16.46)	92.77 (13.18)

The interaction effect showed that the information was differently relevant for different transitions (cf. Table 5.7). The task description was assessed more relevant for transitions T3 and T4 compared to T2 ($p < .001$). Moreover, the sound was perceived as less relevant for transition T2 compared to transitions T3 ($p = .012$) and T4 ($p = .004$). For transitions T2 and T3, the post-hoc tests revealed that the task description was rated as less relevant than the sound ($p < .01$) and the availability illustration ($p < .05$).

Figure 5.9 presents the perceived relevance of the information depending on the LoA. The graphical analysis suggests that in both LoA the velocities (current and maximum) were perceived as highly relevant. Additionally, in both PAD and HAD the designation and the colour were rated as relevant. In contrast, information about the environment and manoeuvres appeared to be more important at PAD than at HAD. For the perceived relevance during the LoA a mixed 3 (experience with ACC) $\times$ 2 (LoA) $\times$ 7 (information) ANOVA was conducted. The results did not found a significant effect for experience with ACC ($F(2, 44) = 0.07$, $p = .937$, $\eta_p^2 = 0.003$). However, the statistical analyses yielded a main effect for LoA ($F(1, 44) = 28.03$, $p < .001$, $\eta_p^2 = 0.39$), indicating that information in PAD ($M = 75.69$, $SD = 36.92$) was perceived as more relevant than in HAD ($M = 64.49$, $SD = 31.33$).

Item	Post-hoc test		
	$F(1, 92)$	p	η_p^2
Environment	**13.93**	**.001**	**0.13**
Maneuver	**50.66**	**< .001**	**0.36**
Designation	1.14	.403	0.01
Color	0.14	.723	< 0.01
Icon	1.15	.403	0.01
Maximum velocity	0.13	.723	< 0.01
Current velocity	2.77	.231	0.03

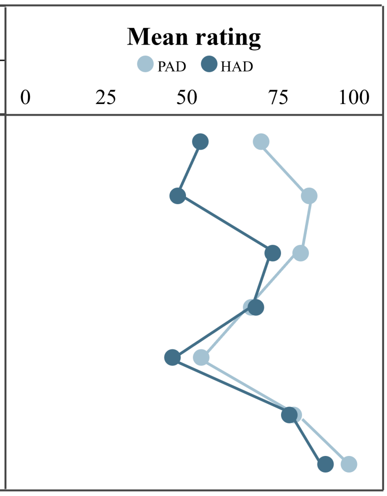


Figure 5.9: Mean ratings of the perceived relevance [0-100] for the different information depending on the LoA (right side) and post-hoc tests for the queried items (left side)

The information was perceived as significantly different in relevance ($F(4.16, 183.12) = 15.99$, $p < .001$, $\eta_p^2 = 0.27$). The results also revealed a significant semiordinal interaction between these two variables ($F(4.12, 181.36) = 15.21$, $p < .001$, $\eta_p^2 = 0.26$), thus the main effect for information cannot be interpreted. Figure 5.9 presents the post-hoc tests for all queried information in dependence of LoA. For environment and manoeuvre, there were significant differences between the LoA, indicating that this information was more relevant at PAD than at HAD. In addition, Benjamini-Holm corrected post-hoc tests showed for the interaction effect that in both PAD and HAD the information was perceived to be of different relevance. In PAD, the icon was significantly less needed compared to all other information ($p < .05$). In contrast, the current velocity was rated as more relevant than the colour ($p = .006$) and the environment ($p = .025$). During HAD, the icon was also rated lowest and the current velocity was rated highest. In this context, the icon was perceived as significantly less relevant than colour ($p < .001$), current and maximum velocity ($p < .001$), and designation ($p < .001$). The results also showed that environment and manoeuvre were perceived as significantly less relevant compared to colour ($p < .01$), maximum speed ($p < .001$), and description ($p < .01$).

5.4.7 Gaze Motions during Lane Changes

Figure 5.10 presents the percentage of the first gazes into lane change relevant AOI (cf. Section 3.5) and into the instrument cluster. For lane changes to the left, the VAV concept seemed to generate a slightly higher proportion of first gazes into lane change relevant AOI (cf. Figure 5.10a and 5.10b). The proportion of first gazes during the preparation phase of lane changes to the right differed between the first and the last lane changes (cf. Figure 5.10c). Thereby, participants had a higher proportion of first gazes into lane change relevant AOI at the beginning during VAV. In contrast, the first glances at the end went more often into the instrument cluster during VAV compared to VA. During the execution phase for lane changes to the right, the AOIs were similarly observed in both concepts.

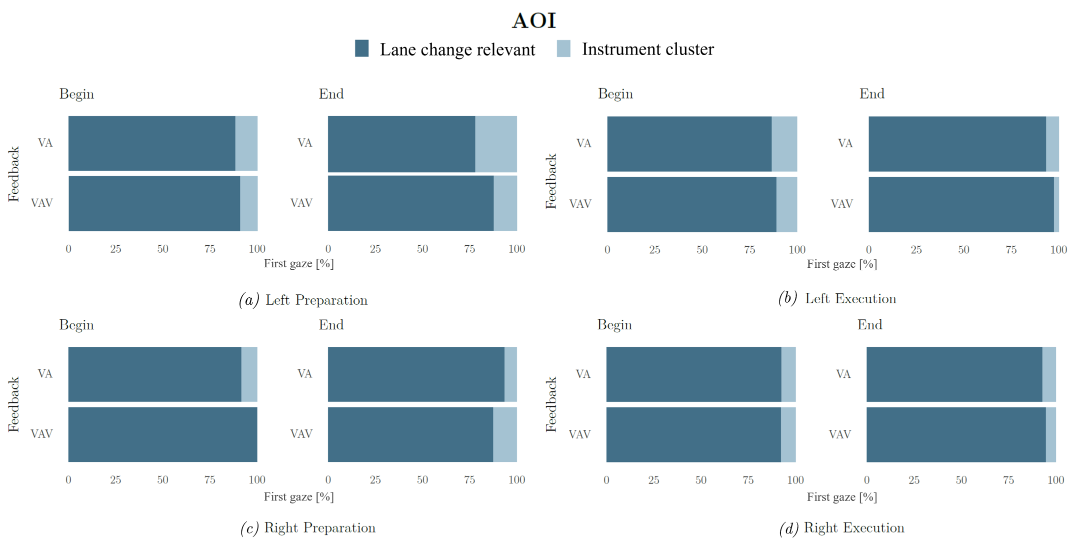


Figure 5.10: Percentage of first gazes in defined AOI depending on feedback concept, time of measurement, direction, and lane change phase.

Fisher's exact test was used to determine if there was a significant association between the feedback concept and the first gaze. Results revealed only a significant difference between the concepts for lane changes to the right during the preparation phase, indicating that VAV (M = 100%) generated a higher percentage of first gazes into lane change relevant AOI than VA (M = 92%, p = .006). Fisher's exact tests did neither find any further significant differences.

5.5 Discussion and Conclusion

In this study, two feedback concepts were examined to improve the understanding of different levels of automation and their transitions in a multi-level automated driving vehicle. Therefore, a real-driving study was conducted on the German motorway A9. This study investigated the effect of the feedback concepts on mode awareness, transition performance, and the information need during different levels of automation and transitions. The concepts were based on literature recommendations (cf. Section 2.2) and on the results of the previous study (cf. Section 4). One feedback concept was composed of visual and auditory feedback. The second concept included additional vestibular feedback consisting of active vehicle pitch and roll motions. These motions were intended to improve mode awareness. Moreover, these pitch and roll motions should relieve drivers in their tasks and support anticipating future manoeuvres. The feedback concepts were implemented in a multi-level automated driving vehicle to investigate the concepts in a complex system. Therefore, three different groups depending on the experience with Adaptive Cruise Control in years experienced both feedback concepts in partially and highly automated driving as well as different transitions. Based on the recommendations of Petermann and Schlag (2010), only three levels of automation (manual driving, partially, and highly automated driving) were combined. During manual driving, participants had to perform the entire dynamic driving task. During partially and highly automated driving, the vehicle took over lateral and longitudinal guidance. In partially automated driving, participants had to monitor the automated driving system and the environment, while in highly automated driving they were allowed to play a spot-the-difference puzzle.

The first research question examined the effect of both feedback concepts on different aspects such as trust, indisposition, and mode awareness. Regarding trust, both concepts were rated as reliable, predictable, and generated high trust in automation reflecting the findings of Cramer (2019). Results did not reveal a difference between the concepts, contradicting the previous study where the visual-auditory-vestibular feedback tended to be more predictable. Comparing the ratings of this study with the ratings of the partially and highly automated driving groups from the first study, it is apparent that trust achieved similar ratings in both studies. However, the multi-level system was evaluated as slightly less reliable and predictable compared to the first study. Considering acceptance, both subscales were rated with higher values in this study than in the first study. Thus, both concepts were rated as useful and satisfying. This also accords with previous observations by Cramer (2019). However, no differences were found between the concepts, which contradicts the results of the previous study (cf. Section 4.3.3) stating that the visual-auditory feedback concept was perceived as more acceptable. One possible explanation for these different results could be that participants in the previous experiment got an explanation for the differences in the feedback concept. The participants in this experiment were not informed about the differences. This implies that prior explanation influences the ratings of the feedback concepts. Thus, the visual-auditory-vestibular feedback is as well accepted as purely auditory-visual feedback without prior explanation and needs to be investigated further. Overall, both concepts were rated as trustworthy and acceptable.

In terms of indisposition, the results for motion sickness are consistent with data obtained in previous studies (Bär, 2014; Cramer, Miller, et al., 2017; Wald et al., 2021). The data showed that additional vehicle motions did not cause motion sickness. Only a few people reported mild motion sickness regardless of the feedback concept. This indicates that the symptoms were not caused by the vehicle movements, but rather as a result of the automated driving. Rather than a feedback-specific cause of the discomfort, this supports a person-dependent sensitivity to motion sickness in general. Descriptively, the construct discomfort was estimated slightly higher and comfort marginally lower in the present study than in the previous study. The first study found significant differences between the feedback concepts, but this was not confirmed in this study. A possible explanation for this might be that the pitch motions were used more sparingly compared to the first driving experiment. Another possible explanation for this is that participants in this study were not previously informed of the feedback differences. In the first study, participants received the differences between the concepts during the instruction. It is possible that the participants focused on appearance excessively, as some of them confirmed (cf. Section 4.4).

Mode awareness was gathered with different single-item questions during the automated drive. Regarding the items task awareness and certainty about the level of automation to be activated, no significant differences between the concepts were found. Descriptively, participants with zero and little experience with Adaptive Cruise Control had a higher task awareness in highly automated driving during the visual-auditory concept drive. These findings could be an indication that additional vehicle movements may affect the performance of the non-driving related task. This is reflected in the fact that participants with less experience with Adaptive Cruise Control had problems inferring their role in highly automated driving from the additional vehicle movements. Results revealed also that partially automated driving exhibited a lower task awareness than manual and highly automated driving. These results support the idea of recent studies indicating that the driving task should either be completely taken over by the driver or completely handed over to the automated driving system (Petermann-Stock, 2015). The latter is confirmed for the certainty showing that a transition to partially automated driving generates lower certainty than the other transitions. Compared to the results of Petermann-Stock (2015), who also investigated non-critical transitions on the motorway with a Wizard of Oz vehicle, the present work yielded descriptively higher values, as higher minimum values were recorded on the response scale.

For monitoring behaviour, feedback concept had no significant effect on either objective or subjective monitoring. Descriptively, a tendency for feedback concept during the subjective ratings is apparent stating that the visual-auditory-vestibular feedback concept increase the monitoring behaviour in both levels of automation. This result may be explained by the fact that the additional movements motivate drivers to monitor the system more carefully. Further results found that participants monitored the system and the environment less during highly automated driving than during partially automated driving. These results were expected, as the various tasks elicited this behaviour. Moreover, this study confirms that the monitoring behaviour decreased from the first partially automated driving section to the second partially automated driving section (Feldhütter et al., 2019; Petermann-Stock, 2015) for both subjective and monitoring behaviour. Some participants mentioned that they had increased confidence in the system due to longer use, performing a non-driving related task in between, and the safety co-driver.

The visual-auditory-vestibular feedback concept was perceived as more predictable than the visual-auditory concept, although the Understanding/Predictability subscale of the trust questionnaire showed no differences between the feedback concepts. This inconsistency may be due to the fact that the subscale considered understanding in addition to predictability, thus allowing a more precise measurement. The predictability of the visual-auditory-vestibular feedback supports the findings of Cramer (2019) as well as of the first study, which stated that the visual-auditory-vestibular concept relieves the driver in receiving vehicle intentions. The latter is confirmed by the significant result that the visual-auditory-vestibular concept was perceived as more relieving in partially automated driving compared to the visual-auditory concept. The gaze motions during lane changes showed similar effects. Descriptively, the visual-auditory-vestibular feedback concept generated more first gazes into lane change relevant areas of interest during partially automated driving than the the visual-auditory concept.

Regarding highly automated driving, additional vestibular feedback appeared to be distracting and annoying. It may be that when playing a game on the tablet mounted in the centre console, the active vehicle motions were perceived as more distracting.

30 out of 47 participants stated that they had perceived a difference between the two feedback concepts. Only 7 (14.89%) recognised that the vehicle additionally pitched and rolled. Participants' comments indicated that some had perceived the active pitching and rolling motions in their own words. However, they did not consider these motions as feedback, but rather as bumps or unsteady driving behaviour. A related effect was also reported by (C. Müller et al., 2017), who used a highly dynamic design of roll motions. In this case, some participants perceived roll motions as road unevenness. Further results revealed that the visual-auditory-vestibular feedback was rated as less likable than the visual-auditory feedback after explanation which is in line with the results of the first study. In the first study, experience with Adaptive Cruise Control in years was found to have an influence on the negative evaluation of vestibular feedback. This is not the case in the present study. This indicates that the visual-auditory-vestibular feedback concept is rated as less supportive after explanation, regardless of previous experience. It can be concluded that evaluation without prior knowledge (intuitive acquisition before explanation) and conscious preference (subjective evaluation after explanation) do not necessarily coincide and that the final judgment may depend not only on an expectation but also on available knowledge.

The second research question investigated the influence of the feedback concept on the transitions between different levels of automation. Results revealed that participants felt higher mental stress during the visual-auditory-vestibular concept than during the visual-auditory concept. This result is consistent with the fourth study by Cramer (2019). In this case, participants felt higher mental demanding when they experienced the visual-auditory-vestibular concept as first feedback concept compared to participants who experienced the visual-auditory concept first. Results of this study revealed also that the second transition (from partially to highly automated driving) was at least mental demanding compared to the other transitions. Moreover, the first transition was perceived as less mentally demanding than the third and fourth transitions. Thus, the relinquishment of control to the vehicle could decrease the feeling of stress because the drivers can release motoric tasks. On the contrary, resuming control after the transition leads to more mental stress as the drivers have to assume responsibility again. Moreover, the drivers have to orientate themself in the environment before taking over. The latter can also be seen in the activation times: Participants needed the longest activation times during transition T3. The mental processing of a transition after the interruption of the game takes consequently more time than a purely motor response in the form of a button press, such as at T2 or T4, supporting previous literature (c.f. Zeeb et al., 2016). This finding is consistent with that of B. Zhang et al. (2019), who found that the available time influenced the takeover time. With respect to the measured activation times, relatively low mean values ($5.24s < M < 9.07s$) with large ranges ($Min = 1.71s$, $Max = 31.48s$) can be seen for noncritical transitions. However, the maximum values should not be ignored. Maximum values for all three transitions amount to at least 12 seconds, which exceeds the current recommendations of take-over times (e.g., Walch, Mühl, Baumann, & Weber, 2017). When averting from the non-driving related task it can even take up to 32 seconds, which is within the range suggested by Merat et al. (2014) and Strayer et al. (2015). The takeover time thus seems to depend on cognitive processes (e.g., non-driving related task) and mental status (c.f. Zeeb et al., 2016).

The feedback concept had no significant effect on the attention paid to the different types of information during the transitions. Descriptively, participants experiencing the visual-auditory-vestibular concept paid more attention to the surrounding traffic compared to the visual-auditory concept drive. On the contrary, the visual-auditory-vestibular concept appeared to reduce the attention to the visual human-machine interface during a transition. These findings seem to show that the visual-auditory-vestibular feedback concept directs attention on monitoring the environment and reduces the visual effort spent on the visual human-machine interface. No differences were found between the feedback concepts in terms of the comprehensibility of the transition proposal. A possible explanation could be that the same proposal was presented in both concepts. Thus, the experienced feedback before a transition has no effect on comprehensibility. However, results revealed that the third transition was at least comprehensible compared to the second and the fourth transition. The proposal during T3 indicated that the driver had to switch to partially automated driving again and displayed a task description ("Full monitoring required!") after the confirmation. This result is in line with previous findings indicating that the third transition required the longest activation time. Moreover, the reduced task awareness in partially automated driving could have a negative effect on the comprehensibility.

The third research question addressed the required information during non-critical transitions. At first, an expert interview was conducted. The results of this expert interview revealed that an non-critical transition should be composed of an announcement, activation by the driver, and confirmation by the automated system. During the study, participants had to rate their perceived relevance for the availability illustration, sound, and task description. Results revealed that the information presented in transition T2 was at least relevant compared to transitions T3 and T4. The task description and the sound were perceived as more relevant in T3 and T4 than in T2. Thus, resuming control after the transition led to a higher information need as the driver has to assume responsibility again.

Regarding the information needs of different levels of automation, the results of Beggiato et al. (2015) were used as a reference. In an expert interview, seven important elements were crystallised, which were also mentioned in previous studies (Beggiato et al., 2015; Diels & Thompson, 2018). The most important information in these studies included, among others, the display of system status, current and planned manoeuvres, as well as current speed. A similar result was found in the current study. However, lower overall ratings were observed for highly automated driving than for partially automated driving. This finding is contrary to Feierle et al. (2020), who suggested that the information need is the same for driver performing a non-driving related task and drivers who did not perform a non-driving related task. This inconsistency may be due to the fact that the study by Feierle et al. (2020) was conducted for urban automated driving. On the contrary, this study was designed for motorway automated driving. The present results support, however, the previous literature regarding the higher need for information in partially automated driving and the varying human-machine interface requirements (Beggiato et al., 2015), which can consequently also be applied to non-critical transitions and automated modes in real traffic. Furthermore, as in Beggiato et al. (2015), the information needs showed strong differences between participants in terms of content and its relevance. This illustrates that not all information presented is equally important to each participants, which should be taken into account when designing human-machine interface concepts, e.g. through adaptable information content.

The final research question addresses the influence of experience with Adaptive Cruise Control in years. Contrary to expectations, this study did not find a significant effect of experience on the rating of the feedback concept. For this study, it can be assumed that experience had no influence on the evaluation, but rather the prior knowledge about the feedback modality. The difference between the first and this study, besides the different individuals, is the instruction of the feedback types as well as the number of levels of automation experienced by the participants. Whether prior knowledge of the feedback or the presence of multiple levels of automation has an influence cannot be clearly extracted. Presumably, prior knowledge plays a greater role, as participants in this study rated the visual-auditory-vestibular concept lower after explanation of the vestibular feedback. This should be investigated in further studies.

The study limitations of the first driving study (cf. Section 4.4) considering the recruiting of the sample, the real scenario standardisation, and the presence of the safety co-driver also applied. With regard to the methodology, there were certain disadvantages.

During the test drive, the same questions were often asked, which could be tiring and possibly demotivating for the participants. In addition, the relatively short drive (25 km) was filled with comparatively many transitions. This resulted in a short driving time in one level of automation to become accustomed to the level of automation and to generate typical phenomena. To avoid sequence effects, both feedback concepts were presented in a randomised order. However, carry-over effects could have occurred due to the immediate presentation of both concepts. Thus, the concepts could have merged and become difficult to separate. This effect could be counteracted by longer periods between the concepts. In addition, the present work aimed to measure how much time is required to perform and process a transition not only motorically but also mentally. Therefore, the participants received the instruction “do not press the button until you really feel mentally ready to do so”. Thus, the data on activation times is tied to the conscientious execution of this instruction by the participants in the experiment. Moreover, the times could not be more accurately recorded and validated by any objective data source, such as a recording of electrodermal activity as, for example, in Petermann-Stock (2015).

In general, the positive effect of vestibular feedback in automated driving is clearly supported by the current findings. The results of this investigation show that additional vehicle motions were perceived as more predictable and more relieving during partially automated driving. Thus, additional vestibular feedback seems to support the driver’s monitoring task and provides a new possibility of communicating the automated driving system’s intentions to the driver (c.f. Cramer, 2019). However, additional vestibular feedback appeared to be distracting from the non-driving related task during highly automated driving. Until now, the design of the automated system feedback in this work has been based on the consistent feedback design of varying levels of automation. Whether examined individually or in a multi-level system, partially and highly automated driving were always considered either with or without active vehicle motions. The third study investigated a feedback concept based on the results of the first two studies, but with a different modality design for different levels of automation in a multi-level system. Therefore, additional vestibular feedback was only applied during partially automated driving to support drivers in their supervising tasks, but not in highly automated driving.

6 Driving Experiment 3: The Influence of Feedback on Mode Awareness

This study and its results [3] have been prepublished in Wald, Henreich, et al. (2022) Some parts of the written text were adopted literally from the paper. Figures, tables, and statistical analyses were adapted for a consistent representation throughout this thesis. The Ethics Board of the Technical University Munich provided ethical approval for this study and the hygiene concept, the corresponding ethical approval code is 650/21 S.

6.1 Introduction

The first two driving experiments (cf. Chapter 4 and 5) on the motorway investigated the use of active vehicle motions in a multimodal concept as feedback during different LoA. First, individual LoA were evaluated and then a multi-level system was assessed. The results revealed that additional vestibular feedback opens up a new possibility to assist inexperienced drivers or at little known LoA (e.g., SAE level 4). The second experiment found that additional vestibular feedback was rated as more predictable and more relieving during PAD. However, during HAD, vestibular feedback appeared to distract from the NDRT. The current study follows up on these results and examines whether a different design of the LoA in a multi-level system can improve mode awareness. Moreover, the route length was increased to avoid too short driving times in one LoA.

The co-existence of multiple assisted and automated modes might lead to a lack of awareness of the currently active mode (Sarter & Woods, 1995; Lassmann et al., 2020; Feldhütter et al., 2018). A potential risk may be that the driver behaves inappropriately, i.e. the driver distracts from the supervising task during PAD or fails to respond to a TOR. The lack of mode awareness can be strengthened by incomplete

[3] The driving study was conducted with the assistance of Niklas Henreich as part of his Bachelor's thesis (Henreich, 2022).

communication about the functionalities, limitations, and capabilities of the automated system (Sarter & Woods, 1995). Consequently, automated driving feedback should be comprehensible and support the driver in perceiving the automated system state, intentions, and abilities (Beggiato et al., 2015). The respective LoA and thus the driver's task influence the design and information content of the feedback (Beggiato et al., 2015; Bengler et al., 2020). As described in Section 2.2.4, multimodal feedback and interfaces are advantageous and lead to better system awareness (Wickens, 2002; Bubb, Bengler, et al., 2015).

Although there is existing research on feedback, Özkan et al. (2021) emphasize the need for further research on different feedback modalities for communicating automation modes. On this basis, there is still uncertainty about the use of various modalities in different LoA. Furthermore, little attention has been paid to the role of vestibular feedback in a multimodal concept for multi-level automated vehicles. Thus, this study analyses the effect of different LoA designs in a multi-level automated driving system. One design concept includes additional active vehicle movements in PAD only, while the other concept consists of purely visual and auditory information. It is assumed that the different design of PAD and HAD increases the mode awareness and that the gaze behaviour during a lane change in PAD is more adequate in the VAV group. Hence, the aim of this experiment, therefore, is to investigate the following research questions:

- RQ1: Can the additional vestibular feedback improve the driver's mode awareness in a multi-level system?
- RQ2: Does the feedback concept has an influence on trust, acceptance, and mental model?
- RQ3: Does the concept have an impact on the perception of different feedback characteristics?
- RQ4: Can vestibular feedback enhance the driver's gaze behaviour during PAD compared to the purely visual and auditory concept?

6.2 Method

Two different feedback concepts were evaluated to answer the research question (cf. Section 6.1). Participants experienced one concept in a multi-level automated driving system on the motorway within different LoA: MAN, PAD, and HAD. The baseline concept consisted of visual-auditory (VA) feedback. The other feedback concept applied additional vestibular feedback during the PAD driving sections. In the following, the method of the second experiment will be described in more detail.

6.2.1 Sample

A total of 38 drivers participated in the study. Two participants had to be excluded from the data analysis due to traffic jams and bad weather conditions. Thus, $N = 36$ drivers with a mean age of $M = 27.92$ years ($SD = 8.24$, $min = 20$, $max = 55$) were available for this study. The participants were divided into four groups according to gender and field of work (19% technical female, 19% non-technical female, 50% technical male, 12% non-technical male). 3 participants (VA: 2, VAV: 1) worked in the field of research and development of automated driving. Before the COVID-19 pandemic situation, the median mileage per year was 14,243 km ($SD = 8{,}139$) and 10,343 km ($SD = 5{,}083$) during the pandemic with an average of 45 % motorway driving. The sample had an average driving experience of $M = 10.58$ years ($SD = 7.74$, $min = 3$, $max = 37$). All participants were required to have previous experience with ACC to exclude effects on the evaluation of higher automated systems due to first impressions with ADAS. Furthermore, 86% (VA: 16, VA: 15) of the participants had previous experience with LKA and 69% (VA: 12, VAV: 13) with partially automated driving systems (e.g., traffic jam assistance). The sample showed on a 5-point scale (1 "strongly disagree" to 5 "strongly agree") a medium propensity to trust in automated driving ($M = 2.94$, $SD = 0.79$). Table 6.1 presents the sample according to the feedback concept.

Table 6.1: Sample of the third study

Variable	VA	VAV
Age $M(SD)$ in years	28.67 (8.58)	27.17 (8.07)
Gender N		
Female (T, NT)	7 (4, 3)	7 (3, 4)
Male (T, NT)	11 (9, 2)	11 (9, 2)
Experience with ADAS in years		
ACC $M(SD)$	3.11 (2.46)	2.56 (2.50)
LKA $M(SD)$	2.47 (1.96)	2.86 (2.52)
Driver's license $M(SD)$ in years	11.17 (7.88)	10.00 (7.78)
Propensity to trust $M(SD)$ [1-5]	2.78 (0.69)	3.10 (0.88)

Note. T = technicians; NT = non-technicians.

6.2.2 Feedback Design

For this study, the feedback presented in Section 5.3.2 (based on the concept described in Section 3.2) was used as a basis. In this experiment, the baseline concept (VA) was composed of visual information and auditory cues. Based on the results of the second driving experiment, the VAV feedback concept was adapted to include additional vehicle motions only during PAD. Thus, the VAV group experienced visual-auditory-vestibular feedback during PAD and visual-auditory feedback during HAD. Participants experienced either the baseline concept or the concept with additional vestibular feedback (cf. Section 3.2).

After a transition confirmation between automated LoA (T2 and T3), only basic visual elements, such as the current velocity and the position of the ego vehicle, were displayed. Neither visual nor vestibular (if present) announcement of lane change information was presented. This screen was displayed while participants answered questions, as it was supposed to have no influence on the responses.

6.2.3 Study Design

For this study, a mixed design was conducted combining the between-subject factor feedback concept (two-level: VA and VAV) and the within-subject factor LoA section (six-level: PAD1, PAD2, PAD3, PAD4, HAD1, and HAD2, cf. Figure 6.1). To test the between factor, participants were randomly assigned to one of the two concepts differing in the availability of vestibular feedback. Thus, one concept consisted of visual and auditory feedback only, while the other one included additional active vehicle motions in PAD. During PAD, participants had to monitor the system and the environment. In HAD, participants played a game on a tablet in the centre console.

6.2.4 Study Procedure

The study was conducted on the three-lane German motorway A9 between the Greding and Manching exits, covering approximately 130 km per driver. For safety reasons, only the right and middle lanes were used and the maximum speed was 120 km/h. The recruitment of participants, the pre-questionnaire procedure (cf. Appendix C.6), and the hygiene concept for the COVID-19 pandemic situation (cf. Appendix B.1) were similar to the first studies (cf. Section 3.4). A few adjustments were made due to the increased requirements. Participants had to provide evidence of being recovered, vaccinated or tested and wear an FFP2 mask. The legal requirements were tightened during the experiment, with the result that the last eight participants only drove with the safety co-driver. In this case, the second experimenter was added by telephone.

The experiment was conducted in German. Participants first presented their verification and received verbal instructions on data collection (cf. Appendix B.4), the hygiene concept as well as on the functionalities of the automated driving vehicle. The experimenter clearly communicated the responsibilities of the driver for the different LoA (cf. Section 6.2.3). Thereupon, participants completed a questionnaire (cf. Appendix C.7) about their mental model and acceptance of the described automation system as a baseline measurement. This was followed by instructions on how to operate the vehicle. Participants then drove manually in the right lane of the motorway and started with the settling-in drive. Here, the vehicle did not make any lane changes for the first three minutes to familiarise participants with the system. Drivers received no vestibular feedback during the settling-in phase, with only basic visual information such as current speed, position, and transition suggestions displayed in the instrument cluster. The fixed sequence of the LoA shown is depicted in Figure 6.1.

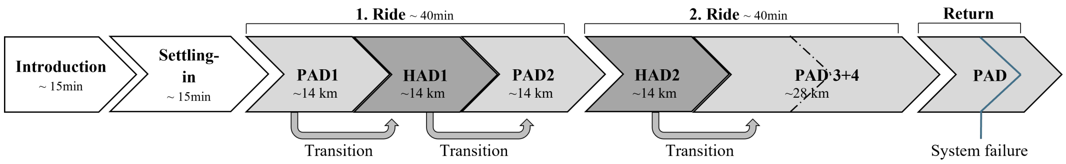


Figure 6.1: Sequence of the third driving study referring to Wald, Henreich, et al. (2022)

Depending on the LoA section, the vehicle simulated PAD or HAD, which the participants had to identify. The first six LoA sections were segmented into two consecutive drives. During the first drive, the sequence was composed of PAD followed by HAD and again PAD. The second drive started with HAD and ended with two consecutive PAD sections. Each section was 14 km long and lasted about 8 minutes. Participants had to monitor the system and the environment during PAD and were allowed to play a spot-the-difference puzzle on a tablet in HAD. The return drive was performed as PAD and included a system failure. The system failure consisted of a slow deceleration on the right lane when it was free. Due to varying traffic conditions, only 25 participants experienced the failure.

After each transition, participants orally answered questions about their mode awareness. Prior to the return drive, participants answered questionnaires about their perceived trust, acceptance, mode awareness, and mental model. Moreover, the characteristics of the feedback concepts were requested. Thereupon, the return drive including the system failure ensued. Participants then rated their perceived trust and acceptance again. Subsequently, the differences in the feedback between PAD and HAD were inquired. Finally, participants experienced both feedback concepts in the stationary vehicle and then rated the (assumed) supportiveness of the concepts.

6.2.5 Dependent Variables

Both objective and subjective data were used as dependent variables to answer the research questions (cf. Section 6.1). Table 6.2 presents the metrics depending of the time of measurement. In Section 3.5, the commonly applied questionnaires are described. Mode awareness was measured with the question about the subjective *monitoring behaviour* after each transition. Moreover, attention ratio and number of gazes during the LoA sections were assessed. After the concept drive, participants rated their mode awareness using the questionnaire by Othersen (2016) as well as their *task awareness* (Othersen, 2016) for the three LoA.

Table 6.2: Overview of the dependent variables of the third study

Dependent variable	Operationalisation	Time of measurement
Subjective data		
Trust	TiA questionnaire (Körber, 2019)	PQ, AC, AS
Acceptance	AS from van der Laan et al. (1997)	AI, AC, AS
Mode Awareness	Questionnaire by Othersen (2016)	AT, AC
Mental Model	Self developed questionnaire	AI, AC
Characteristics	Single-items (Section 3.5)	AC, AE
Objective data		
Gaze behaviour	Attention ratio at defined AOI	
	Number of gazes at defined AOI	
	First gaze during lane changes	

Note. PQ = pre-questionnaire; AI = after instruction; AC = after concept drive; AT = after each transition; AS = after system failure; AE = at the end.

The mental model was measured with self-developed questions (cf. Appendix C.7), which were based on previous mental model questionnaires (Feinauer et al., 2022; Forster et al., 2019; Beggiato & Krems, 2013). The questionnaire consisted of a total of 12 items for both PAD and HAD. Two items covered participants' knowledge about the number of modes, while the other ten items included the understanding of mode activation and function, system limits, and responsibilities. Additionally, gaze data (cf. Section 3.5) during lane changes were analysed into lane change relevant AOI based on a closer look at the first gaze, attention ratio, and number of gazes.

6.3 Results

The statistical analysis is described in Section 3.6 and the results are presented according to Field et al. (2012). The results of the questionnaires (cf. Appendix C.7) are presented below according to the sequence of the research questions.

6.3.1 Mode Awareness

Mode awareness after the concept drive was assessed using the questionnaire by Othersen (2016). Wilcoxon rank-sum tests for independent samples were performed for all subscales of the questionnaire due to violation of the normality assumption (cf. Appendix A). The statistical analysis of the statements after the test drive revealed that there is only a significant effect of the subscale *system comprehension* with a medium effect size (cf. Table 6.3). This indicates that the feedback concept with additional vestibular feedback in PAD (VAV) generated higher system comprehension than the VA concept.

Table 6.3: Results of the Wilcoxon tests considering the mode awareness ratings [1-15] for the feedback concepts

Subscale	Mdn (VA)	Mdn (VAV)	W	p	r
LoA awareness	15.00	15.00	173.00	.700	0.09
Permanent monitoring	13.00	13.00	153.50	.785	0.13
Task awareness	15.00	14.50	168.00	.837	0.16
Awareness to intervene	12.50	14.00	127.50	.265	0.10
System comprehension	10.00	13.00	81.00	**.009**	0.39
Control relinquishment	14.00	15.00	139.00	.444	0.02
Monitoring over time	10.50	10.00	155.50	.836	0.16

Task awareness was additionally measured for each LoA. The mixed 2 (feedback concept) $\times$ 3 (LoA) ANOVA for *task awareness* at the end did neither discover a significant main effect for feedback nor an interaction effect ($p > .05$). However, the results indicated a significant difference of LoA with a large effect size ($F(1.4, 47.71) = 12.68$, $p < .001$, $\eta_p^2 = 0.27$). The post-hoc test using Benjamini-Hochberg correction revealed that MAN ($M = 14.81$, $SD = 0.71$) generated significantly more *task awareness* than PAD ($M = 12.64$, $SD = 3.08$, $p < .001$) and HAD ($M = 14.19$, $SD = 1.60$, $p = .027$). Furthermore, the post-hoc tests showed a significantly higher *task awareness* during HAD than in PAD ($p = .009$).

Figure 6.2 compares the *monitoring behaviour* for the subjective and objective monitoring. The graphical analysis shows slightly higher monitoring behaviour values from the VA group for both subjective and objective measurements. Moreover, Figure 6.2 suggests higher monitoring behaviour values in the PAD sections.

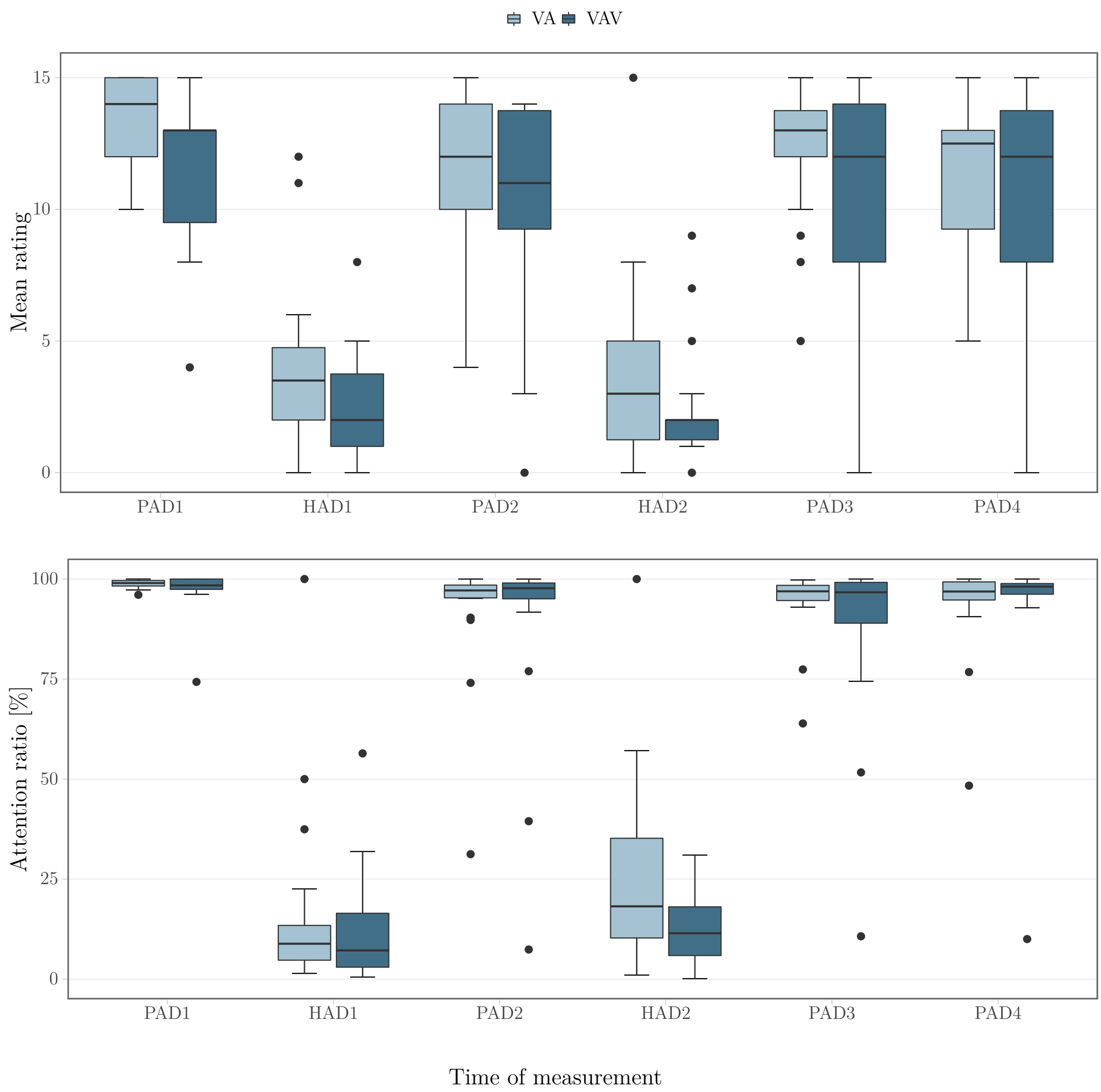


Figure 6.2: Subjective (top) and objective (down) monitoring behaviour during the different LoA depending on the feedback concept. Error bars indicate ± 1 SD

Two mixed 2 (feedback concept) × 6 (LoA section) ANOVA for both subjective and objective monitoring behaviour were performed. The statistical analysis for subjective monitoring behaviour did neither yield a significant main effect for feedback concept nor an interaction effect ($p > .05$). However, the results revealed a significant difference between the LoA sections with a large effect size ($F(2.76, 93.83) = 99.97$, $p < .001$, $\eta_p^2 = 0.75$). Post-hoc Benjamini-Hochberg comparisons showed that the self-rated monitoring decreased from the first PAD section ($M = 12.42$, $SD = 2.43$) to the second

PAD section ($M = 11.00$, $SD = 3.54$, $p = .003$), to the third PAD section ($M = 11.22$, $SD = 3.71$, $p = .019$), and to the last PAD section ($M = 11.06$, $SD = 3.82$, $p = .023$). Moreover, participants monitored the system significantly less in both HAD sections (HAD1: $M = 3.11$, $SD = 2.82$, HAD2: $M = 3.11$, $SD = 3.06$) than in all PAD sections ($p < .001$). The results for the objective monitoring behaviour indicated a significant main effect for the LoA section with a large effect size ($F(2.98, 101.19) = 235.35$, $p < .001$, $\eta_p^2 = 0.87$), but not for the feedback concept. Furthermore, the ANOVA found no significant interaction effect. Post-hoc tests showed that the attention ratio decreased from the first PAD section ($M = 98.00$, $SD = 4.20$) to the second PAD section ($M = 90.00$, $SD = 20.70$, $p = .043$) and to the third PAD section ($M = 91.00$, $SD = 17.30$, $p = .041$). Contrary to the self-assessment ratings, the attention ratio did not decrease significantly from the first PAD section to the last PAD section ($M = 93.00$, $SD = 16.90$, $p = .121$). Participants monitored the system significantly less in both HAD sections than in the PAD sections ($p < .001$), which is consistent with the self-rated monitoring.

6.3.2 Trust in Automation

Generally speaking, both feedback concepts were perceived as reliable, predictable, and generated high trust in automation. Student's t-tests for independent samples were conducted to compare means of *Reliability/Competence* and *Understanding/Predictability* between the two feedback concepts. For *Trust in Automation* the Mann-Whitney U-test was performed, due to a violation of the normality assumption. The results revealed that the feedback concept with vestibular feedback in partially automated driving ($M = 3.95$, $SD = 0.57$) was perceived as significantly more reliable than without active vehicle motions ($M = 3.56$, $SD = 0.50$), with a medium to large effect size ($t(34) = -2.23$, $p = .033$, $d = -0.74$). Moreover, the VAV concept generated more trust in automation ($M = 4.50$, $SD = 0.73$) than VA ($M = 3.92$, $SD = 0.83$) with a medium effect size ($U = 86$, $p = .013$, $r = 0.37$). Student's t-test showed a tendency for VAV ($M = 4.28$, $SD = 0.48$) to be perceived as more predictable than VA ($M = 4.21$, $SD = 0.59$, $t(34) = -0.39$, $p = .070$, $d = -0.13$).

Concerning the system failure ($N = 25$), Figure 6.3 presents the ratings for the three subscales of the trust questionnaire before and after the system failure. The graphical inspection suggests that *Reliability/Competence* of the automated driving system decreased after the failure, while *Understanding/Predictability* remained unchanged. Participants in the VA group seem to have a higher *Trust in Automation* after the system failure compared to before the failure. A mixed ANOVA with the between-subjects two-level factor feedback concept (VA and VAV) and the two-level within-subjects factor time of measurement (before and the system failure) was conducted for each of the three subscales. The ANOVA indicated neither significant differences between the feedback concepts nor significant interaction effects for either subscale ($p > .05$). Furthermore, no significant main effect of time of measurement was found for *Understanding/Predictability* and *Trust in Automation*. However, the perceived *Reliability/Competence* of the system decreased significantly from after the test drive ($M = 3.85$, $SD = 0.56$) to after the system failure ($M = 3.64$, $SD = 0.68$), with a large effect size ($F(1, 23) = 9.41$, $p = .005$, $\eta_p^2 = 0.30$).

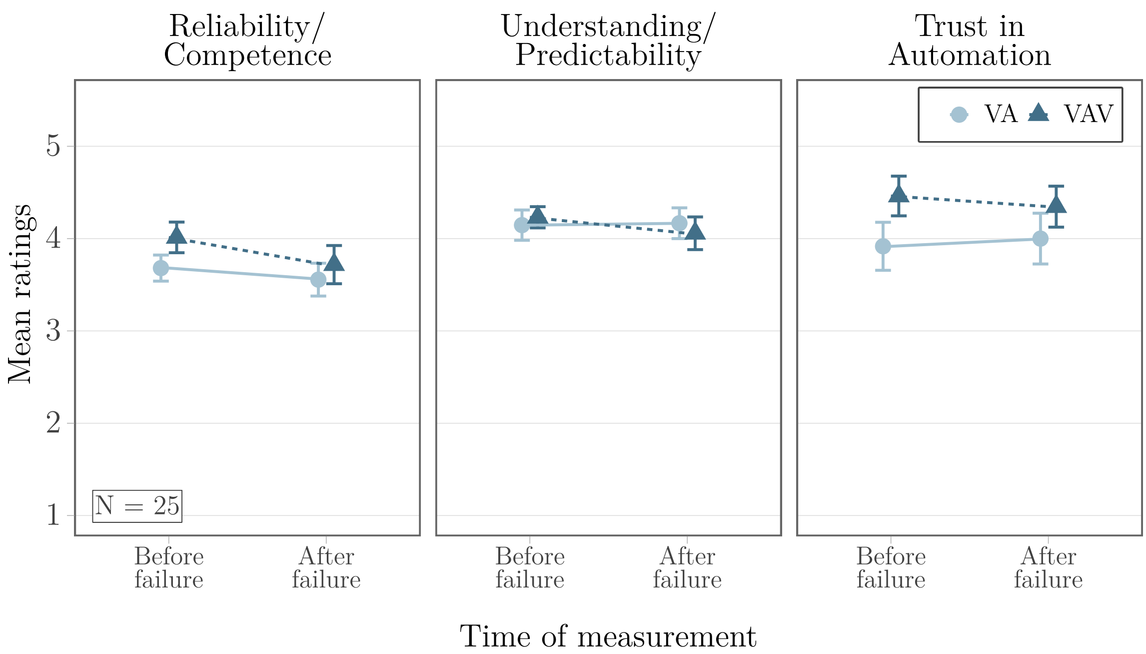


Figure 6.3: Subjective evaluation of the subscales of the trust questionnaire according to the feedback groups in relation to the time of measurement, referring to Wald, Henreich, et al. (2022). Error bars indicate ± 1 SE

6.3.3 Acceptance

Figure 6.4 displays the ratings for *usefulness* and *satisfying* depending on the feedback concept for the different times of measurement. The graphical inspection suggests that participants with the VAV concept rated their acceptance of automated driving in general as slightly less *useful* than the other group. However, both groups rated the experienced feedback concept as *satisfying* and *useful*. A mixed 2 (feedback concept) $\times$ 3 (time of measurement: after instruction, after concept drive, and after system failure) ANOVA was conducted for each of the two subscales *satisfying* and *usefulness*. The results did neither reveal a significant main effect for feedback nor an interaction

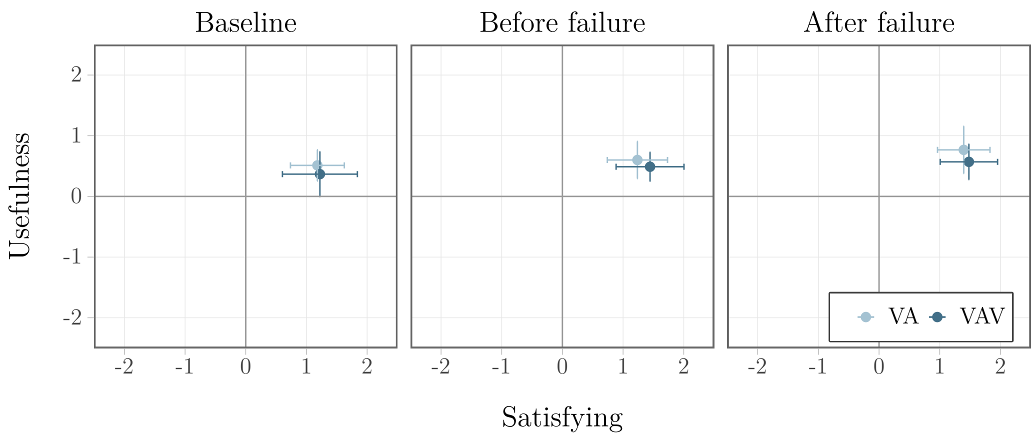


Figure 6.4: Evaluation of the subscales usefulness and satisfying for the three times of measurement depending on the two feedback groups. Error bars indicate ± 1 SD

effect ($p > .05$). However, a significant main effect for time of measurement with a large effect size for *usefulness* ($F(2,46) = 8.09$, $p < .001$, $\eta_p^2 = 0.26$) and for *satisfying* ($F(2,46) = 4.00$, $p = .025$, $\eta_p^2 = 0.15$) was found. Figure 6.4 and following post-hoc analysis using the Benjamini-Hochberg correction indicated that the *usefulness* increased from baseline ($M = 0.42$, $SD = 0.31$) to after the test drive ($M = 0.57$, $SD = 0.28$, $p = .028$), and after the system failure ($M = 0.66$, $SD = 0.35$, $p = .008$), but post-hoc Benjamini-Hochberg tests represented no significant differences for *satisfying* ($p > .05$).

6.3.4 Mental Model

A mixed 2 (feedback concept) × 2 (time of measurement: after instruction and after concept drive) ANOVA for the self-developed mental model questionnaire was conducted. The statistical analysis did neither yield an effect for feedback nor for the interaction ($p > .05$). However, a significant main effect with a large effect size ($F(1,34) = 7.83$, $p = .008$, $\eta_p^2 = 0.19$) for the time of measurement was found, indicating that participants had a better mental model after the concept drive ($M = 8.53$, $SD = 0.85$) compared to after the instruction ($M = 8.08$, $SD = 1.13$).

6.3.5 Feedback Characteristics

Feedback characteristics consisted of the items *annoying*, *distracting*, and *relieving* as well as *predictability* and *supportiveness*. A mixed 2 (feedback concept) × 2 (LoA) ANOVA for each item was conducted. The mean values for distracting, annoying, and relieving are shown in Figure 6.5. The graphical inspection of the means indicates that the feedback concepts were rated as low annoying and distracting ($M < 3$) and as medium to high relieving ($M > 4$). Moreover, it seems that the concept with vestibular feedback was perceived as more annoying and distracting.

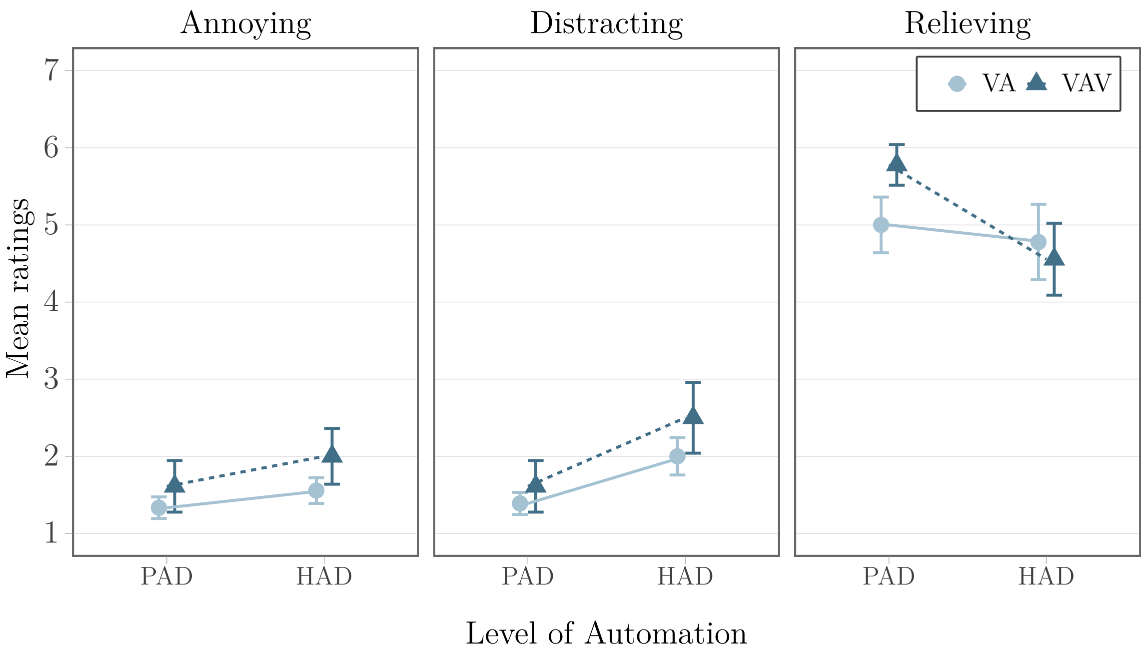


Figure 6.5: Assessment of annoying, distracting, and relieving for PAD and HAD depending on the feedback concept. Error bars indicate ± 1 SE

The analysis of variance for *annoying* and *distracting* found neither a significant main effect for feedback nor a significant interaction effect ($p > .05$). For both statements, the ANOVA yielded a significant main effect for LoA with a large effect size. Participants evaluated feedback (regardless of the used modalities) as more *annoying* ($F(1, 34) = 7.43$, $p = .010$, $\eta_p^2 = 0.14$) and more *distracting* ($F(1, 34) = 12.28$, $p = .005$, $\eta_p^2 = 0.30$) in HAD than in PAD. The graphical analysis of Figure 6.5 suggests that VAV is perceived as more *relieving* in PAD compared to VA. The statistical analysis showed no significant main effect for feedback or interaction effect, though. The results revealed that feedback generally was assessed as more *relieving* in PAD compared to HAD with a large effect size ($F(1, 34) = 6.64$, $p = .015$, $\eta_p^2 = 0.16$).

Predictability of the feedback concept was gathered with a single-item question after each transition. Table 6.4 presents the means for each LoA in dependence of the feedback groups. The table indicates that PAD was perceived as more predictable than HAD. There are also small differences between the groups, indicating that the VA group rated the predictability of both LoA slightly higher than the VA group. A robust mixed 2 (feedback concept) $\times$ 2 (LoA) ANOVA was used since the assumption of homogeneity of variance was violated (cf. Appendix A). The analysis of variance did neither yield a main effect nor an interaction effect ($p > .05$).

Table 6.4: Mean ratings for the predictability and supportiveness depending on the feedback concepts groups

Group	Predictability [1-15]		Supportiveness [1-7]	
	PAD ($M(SD)$)	HAD ($M(SD)$)	VA ($M(SD)$)	VAV ($M(SD)$)
VA	12.10 (1.63)	10.75 (3.31)	5.44 (1.46)	5.50 (1.25)
VAV	11.69 (2.25)	10.06 (4.80)	4.56 (1.72)	4.83 (1.54)

Table 6.4 demonstrates the means of each group for the perceived *supportiveness* of both feedback concepts. In both groups, participants assessed the feedback concept with additional vestibular feedback as more supportive than without active vehicle motions. However, the statistical analysis did not support this finding ($F(1,34) = 0.19$, $p = .667$, $\eta_p^2 = 0.01$). No significant interaction effect was found. The results yielded a significant main effect for the feedback groups stating that the VA group rated the *supportiveness* with higher values than the VAV group with a large effect ($F(1,34) = 5.82$, $p = .021$, $\eta_p^2 = 0.15$).

6.3.6 Gaze Motions during Lane Changes

The gaze data into lane change relevant AOI were analysed using the attention ratio, the number of gazes, and a closer examination of the first gaze (cf. Section 3.5). Figure 6.6 presents the attention ratio into lane change relevant AOI for both feedback concepts depending on the direction, time of measurement, and phase. It becomes apparent that the VAV concept generated a higher attention ratio during the execution of lane changes to the left. For the other conditions, similar attention ratios appear. A mixed 2 (feedback concept) $\times$ 2 (lane change phase: preparation or execution) $\times$ 2 (time of measurement: begin or end) $\times$ 2 (direction: left or right) ANOVA was performed on attention ratio. Statistical analysis revealed no main effect of the feedback concept ($F(1,16) = 0.02$, $p = .890$, $\eta_p^2 < 0.01$). The results yielded two significant main effects: On the one hand, the lane change phase differed stating that the participants looked longer into lane change relevant AOI during the execution phase ($M = 89.70\%$, $SD = 10.40\%$) than during the preparation phase ($M = 75.00\%$, $SD = 17.70\%$) with a large effect size ($F(1,16) = 64.06$, $p < .001$, $\eta_p^2 = 0.80$). On the other hand, the significant differences for the time of measurement declared that the attention ratio into lane change relevant AOI was significantly higher at the end ($M = 86.60\%$, $SD = 13.40\%$) compared to the beginning ($M = 77.90\%$, $SD = 17.80\%$) of the test drive with a large effect ($F(1,16) = 10.08$, $p = .006$, $\eta_p^2 = 0.39$). The results depicted no further main or interaction effects.

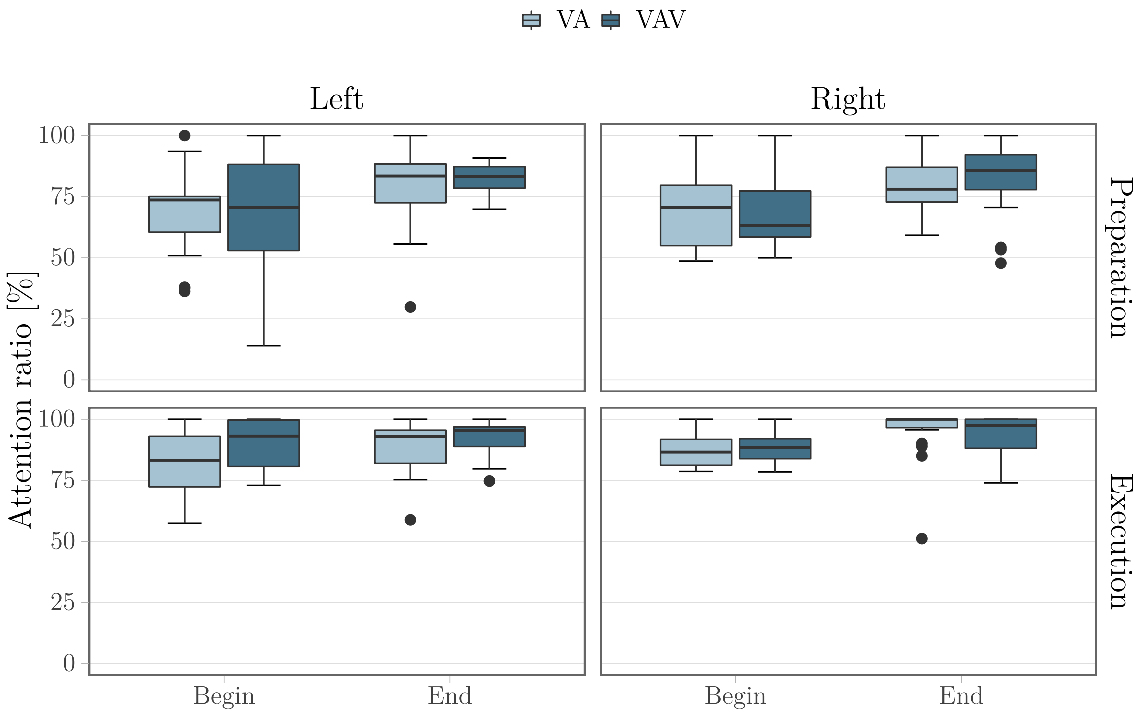


Figure 6.6: Attention ratio for lane change relevant AOI depending on the feedback group, direction, time of measurement, and phase. Error bars indicate ± 1 SD

The mixed 2 (feedback concept) × 2 (lane change phase: preparation or execution) × 2 (time of measurement: begin or end) × 2 (direction: left or right) ANOVA for the number of gazes did not yield a significant difference between the two feedback concepts ($F(1,16) = 0.75$, $p = .400$, $\eta_p^2 = 0.05$). The results revealed only a main effect for phase with a large effect ($F(1,16) = 51.88$, $p < .001$, $\eta_p^2 = 0.76$), indicating that participants made more gaze changes during the execution ($M = 85.50\%$, $SD = 11.20\%$) than during the preparation ($M = 71.50\%$, $SD = 13.80\%$), but no other main or interaction effects ($p > .05$).

Table 6.5 presents the percentage of first gazes into lane change relevant AOI depending on feedback concept, time of measurement, direction, and lane change phase. As can be seen from the table, the VAV concept generated slightly more first gazes into lane change relevant AOI during the preparation phase. In the execution phase, however, VA induced higher percentages compared to VAV. Fisher's exact test was used to determine if there was a significant association between feedback concept and the first gaze. The results did not find any significant differences in the execution phase for both directions. The results indicated, though, a tendency that VA generated a higher percentage during lane changes to the left in the execution phase at the end (cf. Table 6.5). Fisher's exact test revealed also a significant difference for lane changes to the right during the preparation phase at the beginning. Following post-hoc analysis using the Benjamini-Hochberg correction depicted a tendency for the VAV concept to produce more first gazes into the lane change relevant AOI (p = .055). As shown in Table 6.5, no other significant differences were found.

Table 6.5: Percentage of first gazes in lane change relevant AOI depending on feedback concept, time of measurement, direction, and lane change phase

	Begin			End		
	VA [%]	VAV [%]	p	VA [%]	VAV [%]	p
Left						
Preparation	43	50	.395	22	26	.743
Execution	91	85	.276	89	78	.056
Right						
Preparation	27	43	**.037**	34	44	.192
Execution	94	86	.097	92	86	.258

6.4 Discussion and Conclusion

This study investigated two feedback concepts to improve the mode awareness in a multi-level automated driving car. Therefore, a real-driving study was performed on the German motorway A9. This study investigated the effect of the concepts regarding trust, acceptance, mode awareness, and gaze behaviour. The feedback concepts were based on literature recommendations (cf. Section 2.2) and on the results of the previous studies (cf. Sections 4 and 5). One group experienced the baseline concept, which was composed of visual and auditory feedback. On the other hand, the second concept included an additional vestibular modality during partially automated driving. This vestibular modality consisted of active vehicle movements such as pitch and roll motions, which were intended to improve the monitoring behaviour in partially automated driving. Moreover, these pitch and roll motions should relieve the drivers in their tasks and support anticipating future manoeuvres. The feedback concepts were implemented in a multi-level automated driving vehicle to investigate the concepts in a complex system. Therefore, the two groups based on the feedback concept experienced partially and highly automated driving as well as the transitions.

The first question in this study aimed to determine the effect of different feedback concepts on the driver's mode awareness in a multi-level system with partially and highly automated motorway driving. Mode awareness, as measured by the Othersen (2016) questionnaire, was rated slightly higher in this study compared to the first study (cf. Section 4.3.4). While no difference was found between the feedback concepts in the first experiment, there was a significant difference between the concepts for system comprehension in this study. This result indicated that the concept with vestibular feedback resulted in better system comprehension than the visual-auditory concept. The different feedback design of the levels of automation in a multi-level system in this experiment might have improved the understanding of the system. Regarding task awareness for each level of automation, no significant differences were found. Indeed, results revealed that during partially automated driving participants had less task awareness than in manual and highly automated driving. These results reflect those of recent studies (Feldhütter et al., 2018; Petermann-Stock, 2015; Wald, Hiendl, et al., 2022), which suggest that either the driver or the vehicle should be fully responsible for driving, as shared vehicle control makes task comprehension more difficult. Similar results were also found in the subjective and objective assessment of monitoring behaviour. In this case, no differences were found between the groups. However, for both metrics it was shown that monitoring performance decreased for partially automated driving with increasing time. These results support previous work (e.g., Feldhütter et al., 2018; Petermann-Stock, 2015; Wald, Hiendl, et al., 2022). Some participants mentioned that the monitoring task became too monotonous over time and that they wanted to cheer themselves up by looking at the tablet, for example. Others stated that they had more trust in the automated driving system because of the highly automated driving sections where performing a non-driving related task was allowed and due to the safety co-driver. In addition, the monitoring performance was found to be significantly lower in highly than in partially automated driving. This was expected, as the various tasks elicited this behaviour.

The second research question examined the effect of both feedback concepts on different aspects such as trust, acceptance, and mental model. Regarding trust, both concepts were rated as reliable, predictable, and generated high trust in automation reflecting the results of Cramer (2019) and of the previous study (cf. Section 5.4.1). This study pointed out that additional vestibular feedback during partially automated driving was perceived as more reliable than visual-auditory feedback and generated higher trust in automation. The results also revealed a tendency for the visual-auditory-vestibular concept to be perceived as more predictable, which is in line with the previous studies (cf. Sections 4.3.2 and 5.4.4). Comparing the ratings of this study with the ratings of the partially and highly automated driving groups from the first study and the ratings of the second study, it is apparent that trust achieved similar ratings in all three studies. Regarding the system failure, the reliability ratings decreased significantly after the failure. The failure was caused by an erroneous detection of a preceding vehicle. As a result, the automated system braked. Due to the fact that some participants did not recognise the reason for the braking and thought that a speed limit caused the braking although a preceding vehicle was indicated by visual or visual-vestibular feedback, participants were informed of the failure reason before being interviewed again to provide a consistent understanding of the failure. The automated driving vehicle may lose reliability due to false detection of a preceding vehicle.

In terms of acceptance, usefulness was rated slightly lower in this study compared to the other studies. Satisfaction, though, was estimated similarly to the other studies. Both concepts were considered as useful and satisfying. This also accords with earlier observations of Cramer (2019) and the second study (cf. Section 5.4.1). However, no differences were found between the concepts which contradicts the results of the first study (cf. Section 4.3.3) stating that visual-auditory feedback was perceived as more acceptable. This discrepancy could be attributed to the fact that the prior explanation of the feedback concept differences influences the ratings of the feedback concepts. This explanation changes the perception of the additional vestibular feedback from stimulus-driven (bottom-up) to concept-driven perceptual processes (top-down). The informed participants from the first experiment expected an additional movement to occur and focused on it. In contrast, the participants in the current study did not expect any additional vehicle behaviour, thus the information was stimulus-driven and not expected. Regarding the system failure, usefulness increased significantly from the baseline measurement to after the test drive and after the failure. Although an incorrect message was displayed, the system did not appear to have lost its usefulness. Similar findings were found in the fourth study by Cramer (2019).

The final aspect of the second research question considered the mental model. The results revealed that the feedback concept had no influence on the mental model, but the experience with the automated system did. In this experiment, participants had a better understanding of the functionalities and system limitations after experiencing the automated driving system. Thus, participants had a better mental model after the test drive. The latter was also reported by Feinauer et al. (2022). Beggiato and Krems (2013) stated that the experience of the system's functionality in specific settings (bottom-up information) refreshes the mental model (top-down information) appropriately.

Regarding the third research question, feedback characteristics were assessed. Descriptively, the visual-auditory-vestibular concept was experienced as more relieving, but appeared to be more distracting and annoying. However, these differences were not significant. Comparison of the findings with those of the second study (cf. Section 5.4.4) confirms that visual-auditory-vestibular feedback in partially automated driving can relieve and support drivers in their tasks. The results also revealed that feedback in highly automated driving was perceived as more annoying and distracting than in partially automated driving. A possible explanation for this might be that the visual feedback in highly automated driving distracted from the non-driving related task. Some participants mentioned that the visual announcement of a lane change attracted their attention. Contrary to the result of the trust questionnaire regarding predictability, the single-item question did not yield a difference between the feedback concepts. However, both concepts were rated as highly predictable. On a descriptive level, participants rated partially automated driving as more predictable than highly automated driving. These relationships may partly be explained by the drivers' task. During partially automated driving, the participants had to monitor the system and the environment. This allowed them to concentrate on the feedback. In highly automated driving, on the other hand, the participants were able to concentrate on a non-driving related task and therefore did not have to pay attention to the feedback from the automated system. Descriptively, the visual-auditory-vestibular concept was rated as more supportive than the visual-auditory concept after education. This finding should be considered with caution because participants did not experience the additional vestibular feedback after explanation while driving, but only while standing in the parking lot. It may be that the experience of driving on the motorway was different to that of standing still. For a proper evaluation, it is therefore necessary to experience the concepts in action.

The final question examined gaze behaviour during lane changes. Contrary to the second experiment (cf. Section 5.4.7), visual-auditory-vestibular feedback had only a small positive effect on gaze behaviour during the lane change preparation phase. The additional vestibular feedback significantly improved the first gazes into lane change relevant area of interest only during the first lane changes to the right in the preparation phase. In contrast, the visual-auditory feedback concept induced a slightly higher percentage of first gazes during the execution phase. It is possible that participants experiencing the visual-auditory-vestibular concept benefited from the additional movements as a bottom-up stimuli during the preparation phase and thus directed their first gaze directly to lane change relevant area of interest. In this case, participants were able to monitor the environment and then compare the system status through the visual human-machine interface during the execution phase. Although a visual announcement announces an upcoming lane change during the preparation phase, some participants in visual-auditory feedback group may not have noticed the lane change until the execution phase because of the movement of the lane change. The visual human-machine interface presents the current state of automated driving. The participants can permanently receive information from this interface (top-down). The announcement of a lane change is not continuously present, meaning that this information can be regarded as bottom-up stimuli. It seems that a purely visual announcement is not as effective as additional vestibular feedback in directing attention to lane change relevant areas of interest. However, this interpretation should be considered with caution, as the percentage values in the execution phase are considerably larger than in the preparation phase. The visual-auditory-vestibular feedback did not improve the attention ratio or the number of gazes. However, the effect was that participants exhibited a higher attention ratio and more gaze changes during the execution phase than during the preparation phase. The results are in line with the results from the first gazes into lane change relevant areas of interest. A possible explanation for this could be that participants did not perceive the lane change announcement in the preparation phase correctly until the execution phase and therefore increased their control gazes during the execution phase. There was also a learning effect over time. The attention ratio into the lane change relevant areas of interest was higher at the end than at the beginning.

The study limitations of the first and second driving studies (cf. Sections 4.4 and 5.5) considering the recruitment of the participants and presence of the experimenters also applied. The difference between this study and the previous ones was that this time the feedback concepts were experienced by two different groups rather than by the same participants. This could imply that one group might have a tendency to evaluate with higher values than the other group. To prevent this, the participants were randomly assigned to the feedback concepts. In addition, the results regarding the system failure should be interpreted with caution, as the sample size was reduced in this context ($N = 25$). Further research should take this into account and choose scenarios that allow all participants to experience the system failure. In addition, the safety co-driver may have had an influence on the behaviour during the failure. Therefore, it is suggested to place the safety co-driver in the back seat for testing system failures. Moreover, the influence of vestibular feedback on the behaviour at critical system failure could be examined.

Overall, it can be stated that additional vestibular feedback in partially automated driving improves trust, predictability, and supportiveness. The results of this driving study, in conjunction with the results of Cramer (2019) and the previously conducted driving studies (cf. Sections 4.3 and 5.4), present that vestibular feedback opens up new possibilities for providing additional feedback to the driver to support his supervising task in partially automated driving.

7 Conclusion and Outlook

In a multi-level automated driving system, feedback on intentions and transitions is essential for the driver to increase mode awareness and thus to adequately perform the respective tasks (Sarter & Woods, 1995; Beggiato et al., 2015; Bubb, Bengler, et al., 2015). It is important that feedback is provided through multiple modalities, as this is more effective and increases the system understanding (Burke et al., 2006; J.-H. Lee & Spence, 2008). In this thesis, feedback was presented through active vehicle motions in addition to visual and auditory information, which is usually the case (Bubb, Bengler, et al., 2015; Bengler et al., 2020). The vestibular feedback was composed of active vehicle pitch and roll motions to inform the driver about the intentions of the automated driving vehicle.

Based on a literature review on feedback in automated driving (cf. Section 2.2), it was expected that additional vehicle motions would be advantageous for the design of multi-level automated driving systems. Four research questions were developed that investigated the influence of feedback on mode awareness and transitions as well as the use of intensity and information content. The design of the use of feedback modalities during different levels of automation was developed in three driving experiments. The first study (cf. Chapter 4) examined whether additional vestibular feedback could independently support the driver during different levels of automation. Based on the results of the first study, the second driving experiment (cf. Chapter 5) investigated transitions and additional vestibular feedback in a multi-level system taking into account the experience with Adaptive Cruise Control in years. Subsequently, the third driving experiment (cf. Chapter 6) analysed two feedback concepts in a multi-level system. The results are mainly discussed in each driving study (cf. Sections 4.4, 5.5, and 6.4).

Across all three studies, multimodal feedback with and without vestibular feedback was found to generate medium to high trust and acceptance, which is similar to Cramer (2019) and Lange (2018). An outstanding result is that visual-auditory-vestibular feedback tended to or even significantly increased the predictability of the system across all studies. The feedback concept had only a small effect on participants' mode awareness in all three studies. Only within the third study, visual-auditory-vestibular produced a higher system understanding in complex situations than visual-auditory.

The feedback prior to a transition did not seem to have an effect on the transition itself. Neither activation times nor attentional allocation during the transition were influenced by the feedback concept. Indisposition was assessed to be low for both feedback concepts. It was found that neither visual-auditory nor visual-auditory-vestibular induced motion sickness across all driving experiments, which is consistent with the data reported by Cramer (2019). In the first experiment, visual-auditory-vestibular feedback appeared to produce less acceptance, less comfort, and more discomfort compared to visual-auditory feedback. These contradicts the results of Cramer (2019) and the other two experiments. A possible explanation for this could be that the participants, in the first driving experiment, on the one hand, did not experience multi-level systems and, on the other hand, were informed about the differences between the feedback concepts beforehand. The prior explanation of the feedback differences influences the mental model. Thus, informed participants focus more on the additional vestibular feedback, as some also mentioned. The increased attention to additional movements of the vehicle might cause participants to feel more uncomfortable.

It became apparent that the instruction and experience of the feedback had an impact on the perception and assessment of the concepts. Once participants learned about and subsequently experienced the use and meaning of vestibular feedback, active vehicle motions were rated as less user-friendly and likable compared to the ratings before clarification. This was the case even if they perceived the feedback concept as positive prior to this knowledge. Another result of the studies indicated that visual-auditory-vestibular, especially in partially automated driving, relieved the driver during the monitoring task and increased the predictability of the system. A tendency towards this was also found in the objective data. Here, visual-auditory-vestibular tended to have a higher proportion of first gazes in lane change relevant areas of interest, especially in the preparation phase. Thus, active vehicle motions during partially automated driving may help to monitor the situation prior to a lane change in a timely manner. In highly automated driving, on the other hand, the additional movements were perceived as annoying and distracting. However, during the last study, feedback was generally perceived as more annoying and distracting in highly than in partially automated driving.

As in previous literature (e.g., Burke et al., 2006; J.-H. Lee & Spence, 2008; Bengler et al., 2020), the results of this thesis support that feedback should be communicated multimodally to the driver. Throughout the three studies, it became apparent that a different modality design of levels of automation could be beneficial in a multi-level automated driving system. The results of this thesis indicated that both the information content and the modality design of partially and highly automated driving should be different from each other in a multi-level automated driving system. The following implications for design recommendations arise from the results:

- Participants perceived the visualisation of the environment and upcoming or current manoeuvres as less relevant in highly than in partially automated driving. This confirms the findings of Beggiato et al. (2015) that the desire for information content decreases as driver control of the vehicle decreases. Besides the different need for information, it also became apparent that feedback was generally perceived as annoying and distracting in highly automated driving. Thus, consideration should be given to a less prominent representation of the automated driving vehicle intentions. Participants indicated that they were distracted by both peripheral visual information and active vehicle motions when performing a non-driving related task. Thus, a more unobtrusive presentation of information in highly automated driving (Beggiato et al., 2015; Diels & Thompson, 2018) is recommended. In partially automated driving, on the other hand, an accurate representation of the environment and the intentions of the automated vehicle should be presented. The results demonstrated that the different feedback design for each level of automation using varying modalities led to improved predictability. Additional vestibular feedback in partially automated driving supports the driver in the supervising task and relieves the driver.

- It also appears that partially automated driving should be used with caution. In addition to a reduced task awareness in partially automated driving compared to manual and highly automated driving, the results showed that the monitoring task performance decreased over time. This supports the findings of Petermann-Stock (2015) and Feldhütter et al. (2019), where participants also showed decreasing monitoring behaviour. When designing multi-level driving systems, care should be taken to ensure that the driver is continuously monitoring and ready to take-over the vehicle during partially automated driving. On the one hand, countermeasures could include monitoring mechanisms (Feldhütter, 2021). On the other hand, human-machine interface design should be utilized in a manner that prevents the driver from being distracted by other inputs. In addition to an obtrusive design, the driver could briefly take-over the system after a certain period of time to prevent fatigue effects or boredom.

- Non-critical transitions should also be designed differently from each other in terms of their display information. In general, a non-critical transition should always consist of an announcement, an activation by the driver, and a confirmation by the automated system. Depending on the type and nature of the transition, different information is required. Transitions leading to control release can be provided with less information than transitions where the driver takes more control. Transition with more control should be designed with a higher information content, e.g. a task description and a conveyed urgency.

- As in Beggiato et al. (2015) stated, the need for human-machine interface feedback showed strong differences between participants in terms of content and relevance. This illustrates that not all information presented is equally important to each person. The latter should be taken into account when designing feedback concepts, especially considering of the fact that the display and the visual feedback in general should not be too cluttered (D. L. Fisher et al., 2016). Individual information was rated very differently; for example, some found a notification too unobtrusive and would have preferred a more prominent design such as a louder signal. This highlights the challenge of finding a suitable approach in designing feedback concepts.

Multi-level automated vehicles should therefore present a different feedback design for the existing level of automation. Feedback in partially automated driving should consist of visual, auditory and vestibular modalities. Visual information provides the foundation for information from the vHMI and aHMI, including vehicle intentions and actions. Auditory cues should be used to direct attention (e.g. triggering take-over requests or signalling lane changes). The additional active vehicle movements should be used as described by Cramer (2019) to indicate the approach of a slower vehicle in front, to announce a lane change, and to indicate cutting-in vehicles (except vehicles with a large relative distance or a high positive relative velocity). In contrast, a less intrusive feedback concept should be adopted in the design of highly automated driving. Since the vehicle's own movements interfered with the execution of a tablet game in the centre console, no additional vestibular feedback should be used in this case. In addition, the visual announcement of lane changes seemed to distract from a visual non-driving related task. In this case, a less distracting (e.g., less salient) presentation of information should be used. Auditory cues are recommended to be used only for attentional allocation.

The limitations of each study are described in the respective discussion sections (cf. Sections 4.4, 5.5, and 6.4). Across all studies, there was a self-selecting sample, as presumably, people with a high interest in automated vehicles participated. In addition, real-world traffic was another limitation, as validity across all participants could not be provided due to varying traffic and weather conditions. This was attempted to be minimized by using the same times of day consistently. However, the first two studies took place in summer during frequent sunlight and warm temperatures, while the last study was conducted in winter with snow and little sunlight. In addition, the safety co-driver as a Wizard of Oz actor is another limitation. A. I. Müller, Weinbeer, and Bengler (2019) presented methodological challenges. Particularly challenging is the ability to produce similar driving styles at different times of measurement. In all three studies, lane changes and transitions were manually initiated by the safety co-driver. Due to the real traffic conditions, the triggers for lane changes and transitions could not be implemented in a standardised way across all participants.

There is also technical limitation of the prototype. The visual representation could only be simplified (cf. Section 3.2). The ego vehicle was only displayed as a triangle. In addition, the front vehicle was displayed as a square, but no further environment was depicted. The simplified and incomplete presentation of the visual feedback was criticised across all studies. In addition, the vehicle was not equipped with a HUD, so indications could not be projected directly into the driver's field of view. Due to the absence of a proper eye tracker, most of the data measured and analysed were subjective. This should be taken into account when interpreting the results. Further studies could address and improve these limitations. The visual feedback could be expanded to include the missing content and additionally be presented on a HUD. The finding that visual-auditory-vestibular in partially automated driving is beneficial, supportive, and relieving should be revisited with this increased visual information content. In the present work, it can be observed that many participants did not recognise the active vehicle motions as such but rather as road unevenness. At this point, further research should be carried out, e.g. using an active chassis that compensates for the natural unevenness of the road and only transmits the vestibular feedback. As mentioned by Cramer (2019), another investigation could be the assessment of the vestibular feedback from different seating positions in the vehicle. This was originally planned for this thesis as well, but could not be implemented due to the COVID-19 pandemic situation.

In summary, the results of the studies revealed that additional vestibular feedback provided an advantage during partially automated driving in a multi-level automated driving system. Similar to Cramer (2019), active vehicle movements in partially automated driving were shown to increase both predictability and trust in the automated driving vehicle. Announcing intentions and manoeuvres using pitch and roll motions supported and relieved the driver in the supervising task. Lange (2018), C. Müller (2019) and Cramer (2019) support this statement with their results. Overall, the present work thus contributes to the research in the field of designing the interaction between humans and automated vehicles. It could be demonstrated that additional vestibular feedback should be used to communicate intentions to the driver in partially automated driving in a multi-level automated driving system.

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List of Figures

2.1 Schematic representation of the human perception process according to Handwerker and Schmelz (2010) 7
2.2 Anatomy of the vestibular organ taken from Bohrmann (2022) 11
2.3 Situation awareness model based on Endsley (1995) 15
2.4 Multiple resource model taken from Wickens (2002) 16
2.5 Driver-vehicle control loop based on Bubb (2015a), Bubb (2015b), and Donges (1982) 17
2.6 Taxonomy of automated driving vehicle based on SAE international (2022) 19
2.7 Classification of transitions based on Lu et al. (2016). 20
2.8 The acceptance model UTAUT2 taken from Venkatesh et al. (2012) . 27
2.9 The HMI framework by Bengler et al. (2020) 28
2.10 An HMI example for visual feedback during automated driving taken from Feierle et al. (2020) 31
2.11 Pitch motions of the automated driving vehicle taken from Cramer (2019) 35
2.12 Roll motions of the automated driving vehicle taken from Cramer (2019) 35

3.1 Selected manoeuvre transitions referring to Cramer (2019) 40
3.2 Time sequence of detecting and reacting to a slower preceding vehicle taken from Cramer (2019) 41
3.3 Visual HMI displays for different LoA 42
3.4 Prototypical technical realization taken from Cramer (2019) 44
3.5 Interior of the test vehicle for the driving studes 46

4.1 Sequence of the first driving study 54
4.2 Subjective evaluation of the trust questionnaire for the three groups in relation to feedback concept. 58
4.3 Evaluation of the acceptance for the feedback concepts depending on the three groups. 59
4.4 Effects and subjective evaluation of system awareness for the two concepts depending on the LoA. 59
4.5 Mean ratings of usability for the two concepts depending on the LoA 60

4.6 Evaluation of the likability for the feedback concepts depending on the three groups . . . 61
4.7 Evaluation of the items satisfying, usability and likability depending on the feedback concept and experience with ACC . . . 63

5.1 Visual HMI displays for different LoA during the second study . . . 75
5.2 Sequence of the transition process using the example of transition T3 76
5.3 Sequence of the second driving study . . . 77
5.4 Subjective evaluation of the trust questionnaire for the three groups in relation to feedback concept . . . 80
5.5 Subjective evaluation of the task awareness for the three groups depending on the feedback concept . . . 82
5.6 Subjective and objective monitoring behaviour for the three groups depending on the feedback concept. . . . 83
5.7 Subjective evaluation of mental stress during the transitions for the three groups depending on the feedback concept . . . 85
5.8 Subjective comprehensibility rating of the transition proposal for the three groups as a function of the feedback concept . . . 86
5.9 Mean ratings for the different information depending on the LoA and post-hoc tests for the queried items . . . 89
5.10 Percentage of first gazes in defined AOI depending on feedback concept, time of measurement, direction, and lane change phase . . . 90

6.1 Sequence of the third driving study . . . 102
6.2 Subjective and objective monitoring behaviour during the different LoA depending on the feedback concept. . . . 105
6.3 Subjective evaluation of the trust questionnaire for the feedback groups in relation to the time of measurement . . . 107
6.4 Evaluation of the acceptance for the three times of measurement depending on the two groups . . . 108
6.5 Assessment of feedback characteristics for different LoA depending on the feedback concept . . . 109
6.6 Attention ratio for lane change relevant AOI depending on the feedback group, direction, time of measurement, and phase . . . 111

List of Tables

2.1 Sensory channel assignment of driver information referring to Tomaske and Fortmüller (2001) . . . 8

3.1 Overview of the experiments . . . 38

4.1 Sample of the first study . . . 53
4.2 Overview of the dependent variables of the first study . . . 55
4.3 Participants' mean ratings of their perceived comfort and discomfort for the different feedback concepts depending on the LoA . . . 57
4.4 Correlation matrix showing Spearman's r for ACC experience and measurement scales . . . 62

5.1 Sample of the second study . . . 74
5.2 Overview of the dependent variables of the second study . . . 79
5.3 Participants' mean ratings of their perceived comfort and discomfort during the different feedback concepts depending on the experience with ACC . . . 81
5.4 Descriptives of participants' mean ratings of the feedback characteristics for different LoA depending on feedback concept . . . 84
5.5 Participants' mean ratings of their attention allocation to the environment and to the visual HMI during transitions T3 (HAD to PAD) and T4 (PAD to MAN) depending on the experience with ACC and feedback concept . . . 87
5.6 Descriptives of participants' activation times in seconds for different transitions depending on feedback concept . . . 88
5.7 Descriptive mean ratings of the information relevance during different transitions . . . 88

6.1 Sample of the third study . . . 100
6.2 Overview of the dependent variables of the third study . . . 103
6.3 Results of the Wilcoxon rank-sum tests considering the mode awareness ratings for the feedback concepts . . . 104
6.4 Mean ratings for the predictability and supportiveness depending on the feedback concepts groups . . . 110

6.5 Percentage of first gazes in lane change relevant AOI depending on feedback concept, time of measurement, direction, and lane change phase 112

A.1 Test results of Levene's tests for homogeneity of variance for the first driving experiment 145
A.2 Test results of Levene's and Mauchly's tests for Propensity to Trust and the FMS scale of the first driving experiment 146
A.3 Test results of Levene's tests for homogeneity of variance and Mauchly's sphericity test for the second driving experiment 146
A.4 Test results of Levene's and Mauchly's tests for information need during different LoA for the second driving experiment 148
A.5 Test results of Levene's and Mauchly's tests for information need during different transitions for the second driving experiment 148
A.6 Test results of Levene's and Mauchly's tests of monitoring behaviour for the third driving experiment 148
A.7 Test results of Levene's tests for homogeneity of variance of attention ratio and number of glances for the third driving experiment 148
A.8 Test results of Levene's tests for homogeneity of variance and Mauchly's sphericity test for the third driving experiment 149
A.9 Test results of Levene's tests for homogeneity of variance and Mauchly's sphericity test for the third driving experiment depending on LoA . . 149

Acronyms

ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance Systems
ADTF	Automotive Data and Time-Triggered Framework
aHMI	Automation HMI
dHMI	Dynamic HMI
eHMI	External HMI
iHMI	Infotainment HMI
vHMI	Vehicle HMI
ANOVA	Analysis Of variance
AOI	Area of interest
AS	Acceptance Scale
ASD	Assisted Driving
BASt	Bundesanstalt für Straßenwesen
CAD	Conditional Automated Driving
DDT	Dynamic Driving Task
DGPS	Differential Global Positioning System
eABC	Electromechanical Active Body Control
FMS	Fast Motion Sickness Scale
HAD	Highly Automated Driving
HUD	Head-up Display
MAN	Manual Driving
HMI	Human-Machine Interface
LoA	Level of Automation
LKA	Lane Keeping Assistance

NDRT	Non-Driving Related Task
PAD	Partially Automated Driving
SUS	System Usability Scale
TAM	Technology Acceptance Model
TiA	Trust in Automation
TOR	Take-over Request
UTAUT	Unified Theory of Acceptance and Use of Technology
VA	Visual-Auditory
VAV	Visual-Auditory-Vestibular
WoOz	Wizard of Oz

Appendix

A Additional Statistics

A.1 Driving Experiment 1

Table A.1: Test results of Levene's tests for homogeneity of variance for the first driving experiment

	Visual-auditory	Visual-auditory-vestibular
Reliability	$F(2,57) = 0.04, p = 0.957$	$F(2,57) = 1.60, p = 0.210$
Predictability	$F(2,57) = 1.43, p = 0.249$	$F(2,57) = 0.16, p = 0.851$
Trust in Automation	$F(2,57) = 0.06, p = 0.938$	$F(2,57) = 1.43, p = 0.247$
Usefulness	$F(2,57) = 0.57, p = 0.569$	$F(2,57) = 0.47, p = 0.626$
Satisfying	$F(2,57) = 0.16, p = 0.852$	$F(2,57) = 0.24, p = 0.789$
Satisfying (ACC)	$F(1,39) = 1.64, p = 0.208$	$F(1,39) = 0.01, p = 0.914$
Comfort	$F(2,57) = 2.04, p = 0.139$	$F(2,57) = 0.93, p = 0.402$
Discomfort	$F(2,57) = 0.34, p = 0.711$	$F(2,57) = 0.93, p = 0.401$
LoA awareness	$F(2,57) = 2.59, p = 0.084$	$F(2,57) = 0.57, p = 0.567$
Permanent monitoring	$F(2,57) = 0.37, p = 0.690$	$F(2,57) = 1.50, p = 0.232$
Task awareness	$F(2,57) = 0.86, p = 0.427$	$F(2,57) = 0.23, p = 0.797$
Awareness to intervene	$F(2,57) = 2.10, p = 0.132$	$F(2,57) = 1.47, p = 0.238$
System comprehension	$F(2,57) = 0.16, p = 0.849$	$F(2,57) = 0.87, p = 0.424$
Control relinquishment	$F(2,57) = 2.18, p = 0.122$	$F(2,57) = 0.75, p = 0.477$
Monitoring over time	$F(2,57) = 1.42, p = 0.249$	$F(2,57) = 0.32, p = 0.726$
Usability	$F(2,57) = 0.72, p = 0.493$	$F(2,57) = 1.39, p = 0.256$
Usability (ACC)	$F(1,44) = 0.36, p = 0.552$	$F(1,44) = 3.80, p = 0.058$
Likability	$F(2,57) = 0.63, p = 0.535$	$F(2,57) = 0.65, p = 0.525$
Likability (ACC)	$F(1,44) = 3.45, p = 0.070$	$F(1,44) = 0.37, p = 0.547$

Table A.2: Test results of Levene's and Mauchly's tests for Propensity to Trust and the FMS scale of the first driving experiment

	Initial	Pre VA	After VA	Pre VAV	After VAV
Propensity to Trust					
$F(2,57)$	0.60	-	1.83	-	0.30
p	0.551	-	0.170	-	0.740
Mauchly's test			$W = 0.78$, $p < 0.001$		
FMS					
$F(2,57)$	1.02	0.42	2.84	0.77	1.02
p	0.366	0.658	0.067	0.468	0.369
Mauchly's test			$W = 0.39$, $p < 0.001$		

A.2 Driving Experiment 2

Table A.3: Test results of Levene's tests for homogeneity of variance and Mauchly's sphericity test for the second driving experiment

	Visual-auditory	Visual-auditory-vestibular
Reliability	$F(2,44) = 1.16, p = 0.323$	$F(2,44) = 0.78, p = 0.467$
Predictability	$F(2,44) = 0.34, p = 0.715$	$F(2,44) = 0.86, p = 0.432$
Trust in Automation	$F(2,44) = 1.63, p = 0.207$	$F(2,44) = 0.95, p = 0.395$
Usefulness	$F(2,44) = 0.30, p = 0.746$	$F(2,44) = 0.18, p = 0.835$
Satisfying	$F(2,44) = 0.14, p = 0.868$	$F(2,44) = 0.26, p = 0.770$
Comfort	$F(2,44) = 0.58, p = 0.567$	$F(2,44) = 0.19, p = 0.829$
Discomfort	$F(2,44) = 0.47, p = 0.628$	$F(2,44) = 0.66, p = 0.524$
Supportiveness	$F(2,44) = 0.49, p = 0.618$	$F(2,44) = 0.33, p = 0.719$
Task awareness		
MAN	$F(2,44) = 0.73, p = 0.488$	$F(2,44) = 1.28, p = 0.288$
PAD1	$F(2,44) = 3.53, p = 0.038$	$F(2,44) = 0.45, p = 0.639$
HAD	$F(2,44) = 1.25, p = 0.296$	$F(2,44) = 1.99, p = 0.149$
PAD2	$F(2,44) = 1.09, p = 0.344$	$F(2,44) = 0.17, p = 0.848$
Certainty about next LoA		
MAN	$F(2,44) = 0.21, p = 0.814$	$F(2,44) = 3.26, p = 0.048$
PAD1	$F(2,44) = 0.43, p = 0.652$	$F(2,44) = 2.92, p = 0.064$
HAD	$F(2,44) = 0.37, p = 0.692$	$F(2,44) = 1.43, p = 0.250$
PAD2	$F(2,44) = 1.41, p = 0.256$	$F(2,44) = 1.10, p = 0.343$
Subjective monitoring		
PAD1	$F(2,44) = 0.42, p = 0.661$	$F(2,44) = 2.38, p = 0.104$
HAD	$F(2,44) = 0.19, p = 0.158$	$F(2,44) = 0.13, p = 0.875$
PAD2	$F(2,44) = 1.27, p = 0.291$	$F(2,44) = 0.34, p = 0.713$
Mauchly's test	$W = 0.50$, $p < 0.001$	

	Visual-auditory	Visual-auditory-vestibular
Objective monitoring		
PAD1	$F(2,35) = 0.41, p = 0.669$	$F(2,35) = 0.56, p = 0.576$
PAD2	$F(2,35) = 1.13, p = 0.334$	$F(2,35) = 0.47, p = 0.629$
Mental Stress		
T1	$F(2,44) = 0.56, p = 0.574$	$F(2,44) = 0.13, p = 0.882$
T2	$F(2,44) = 0.03, p = 0.974$	$F(2,44) = 1.43, p = 0.250$
T3	$F(2,44) = 2.56, p = 0.089$	$F(2,44) = 0.75, p = 0.477$
T4	$F(2,44) = 0.77, p = 0.486$	$F(2,44) = 0.24, p = 0.784$
Mauchly's test	$W = 0.72,\ p = 0.016$	
Attention at deactivation		
T3	$F(2,44) = 0.35, p = 0.702$	$F(2,44) = 1.55, p = 0.219$
T4	$F(2,44) = 0.60, p = 0.550$	$F(2,44) = 7.41, p = 0.001$
Activation times		
T2	$F(2,44) = 0.67, p = 0.519$	$F(2,44) = 0.74, p = 0.482$
T3	$F(2,44) = 1.80, p = 0.178$	$F(2,44) = 2.01, p = 0.147$
T4	$F(2,44) = 1.31, p = 0.282$	$F(2,44) = 0.61, p = 0.547$
Mauchly's test	$W = 0.77,\ p = 0.006$	
Distracting		
PAD	$F(2,44) = 0.39, p = 0.682$	$F(2,44) = 1.79, p = 0.178$
HAD	$F(2,44) = 2.08, p = 0.137$	$F(2,44) = 1.20, p = 0.311$
Annoying		
PAD	$F(2,44) = 1.11, p = 0.340$	$F(2,44) = 0.03, p = 0.968$
HAD	$F(2,44) = 0.76, p = 0.474$	$F(2,44) = 0.43, p = 0.652$
Relieving		
PAD	$F(2,44) = 0.29, p = 0.746$	$F(2,44) = 1.64, p = 0.968$
HAD	$F(2,44) = 2.54, p = 0.091$	$F(2,44) = 4.70, p = 0.014$
Predictability LoA		
PAD1	$F(2,44) = 0.01, p = 0.992$	$F(2,44) = 0.53, p = 0.594$
HAD	$F(2,44) = 0.42, p = 0.658$	$F(2,44) = 0.25, p = 0.777$
PAD2	$F(2,44) = 0.02, p = 0.976$	$F(2,44) = 0.53, p = 0.595$
Comprehensibility		
T2	$F(2,44) = 0.30, p = 0.739$	$F(2,44) = 0.55, p = 0.579$
T3	$F(2,44) = 0.24, p = 0.790$	$F(2,44) = 3.50, p = 0.039$
T4	$F(2,44) = 0.96, p = 0.390$	$F(2,44) = 0.67, p = 0.516$
Mauchly's test	$W = 0.78,\ p = 0.006$	

Table A.4: Test results of Levene's and Mauchly's tests for information need during different LoA for the second driving experiment

	Environment	Maneuver	Designation	Colour	Icon	Current velocity	Max. velocity
Levene's test							
PAD (p)	0.222	0.586	0.998	0.547	0.204	0.230	0.618
HAD (p)	0.985	0.944	0.743	0.674	0.535	0.345	0.905
Mauchly's test	$W = 0.20$, $p < 0.001$						

Table A.5: Test results of Levene's and Mauchly's tests for information need during different transitions for the second driving experiment

	Availability	Sound	Task description
Levene's test			
T2	$F(2,44) = 0.09$, $p = 0.915$	$F(2,44) = 1.87$, $p = 0.165$	$F(2,44) = 0.36$, $p = 0.700$
T3	$F(2,44) = 3.07$, $p = 0.057$	$F(2,44) = 2.63$, $p = 0.083$	$F(2,44) = 0.70$, $p = 0.500$
T4	$F(2,44) = 0.17$, $p = 0.846$	$F(2,44) = 0.55$, $p = 0.583$	$F(2,44) = 0.17$, $p = 0.847$
Mauchly's test	$W = 0.13$, $p < 0.001$		

A.3 Driving Experiment 3

Table A.6: Test results of Levene's and Mauchly's tests of monitoring behaviour for the third driving experiment

	PAD1	PAD2	PAD3	PAD4	HAD1	HAD2
subjective (p)	0.445	0.593	0.065	0.270	0.232	0.136
Mauchly's test	$W = 0.17$, $p < 0.001$					
objective (p)	0.207	0.561	0.241	0.896	0.569	0.448
Mauchly's test	$W = 0.20$, $p < 0.001$					

Table A.7: Test results of Levene's tests for homogeneity of variance of attention ratio (AR) and number of glances (NG) for the third driving experiment

	Status	Direction	Begin	End
AR	Preperation	Left	$F(1,34) = 2.20, p = 0.148$	$F(1,24) = 3.36, p = 0.079$
		Right	$F(1,19) = 0.06, p = 0.814$	$F(1,34) = 0.13, p = 0.716$
	Execution	Left	$F(1,34) = 0.48, p = 0.493$	$F(1,34) = 0.95, p = 0.335$
		Right	$F(1,19) = 0.65, p = 0.430$	$F(1,34) = 0.17, p = 0.679$
NG	Preperation	Left	$F(1,34) = 2.14, p = 0.153$	$F(1,24) = 4.07, p = 0.055$
		Right	$F(1,19) = 0.01, p = 0.913$	$F(1,34) = 0.14, p = 0.714$
	Execution	Left	$F(1,34) = 3.16, p = 0.084$	$F(1,34) = 0.10, p = 0.758$
		Right	$F(1,19) = 0.13, p = 0.718$	$F(1,34) = 0.64, p = 0.428$

Table A.8: Test results of Levene's tests for homogeneity of variance and Mauchly's sphericity test for the third driving experiment

	Initial	After drive	After failure
Reliability		$F(1,34) = 0.17, p = 0.680$	
Predictability		$F(1,34) = 0.99, p = 0.328$	
Trust in Automation		$F(1,34) = 0.02, p = 0.903$	
Usefulness $F(1,34)$	$2.35, p = 0.134$	$0.45, p = 0.507$	-
Satisfying $F(1,34)$	$2.77, p = 0.105$	$0.82, p = 0.373$	-
Failure			
Reliability $F(1,23)$	-	$0.81, p = 0.376$	$0.48, p = 0.496$
Predictability $F(1,22)$	-	$0.96, p = 0.339$	$0.63, p = 0.437$
Trust in Automation $F(1,22)$	-	$0.02, p = 0.900$	$0.61, p = 0.443$
Usefulness $F(1,23)$	$2.35, p = 0.139$	$0.29, p = 0.595$	$1.54, p = 0.226$
Satisfying $F(1,23)$	$1.81, p = 0.191$	$0.46, p = 0.503$	$0.05, p = 0.820$
Mental Model $F(1,34)$	$1.68, p = 0.204$	$3.06, p = 0.089$	-
LoA awareness		$F(1,34) = 2.16, p = 0.151$	
Permanent monitoring		$F(1,34) = 0.07, p = 0.797$	
Task awareness		$F(1,34) = 0.39, p = 0.539$	
Awareness to intervene		$F(1,34) = 0.00, p = 1.000$	
System comprehension		$F(1,34) = 2.26, p = 0.142$	
Control relinquishment		$F(1,34) = 0.84, p = 0.367$	
Monitoring over time		$F(1,34) = 0.97, p = 0.331$	
Supportiveness			
VA		$F(1,34) = 0.74, p = 0.396$	
VAV		$F(1,34) = 0.48, p = 0.493$	

Table A.9: Test results of Levene's tests for homogeneity of variance and Mauchly's sphericity test for the third driving experiment depending on LoA

	MAN	PAD	HAD
Task awareness $F(1,34)$	$0.05, p = 0.818$	$0.96, p = 0.335$	$1.61, p = 0.212$
Mauchly's test		$W = 0.58,\ p < 0.001$	
Annoying $F(1,34)$	-	$0.59, p = 0.449$	$1.73, p = 0.197$
Distracting $F(1,34)$	-	$0.37, p = 0.546$	$3.60, p = 0.066$
Relieving $F(1,34)$	-	$1.18, p = 0.286$	$0.00, p = 1.000$
Predictability LoA $F(1,34)$	-	$4.25, p = 0.047$	$0.99, p = 0.327$

B Information for the Driving Experiments

B.1 Hygiene concept

Infektionsschutzmaßnahmen

Zum Schutz vor einer Infektion mit CoVid-19 wurden Maßnahmen getroffen, die von Ihnen und den Versuchsleitern einzuhalten sind. Es ist erforderlich, dass Sie

- sich vor Versuchsbeginn mit dem bereitgestellten Desinfektionsmittel die Hände desinfizieren.
- Sachen, welche Sie während des Versuchs nicht benötigen, in Ihrem Fahrzeug lassen.
- während den Versuchsfahrten eine medizinische oder FFP2-Maske tragen, die Sie von der AUDI AG zur Verfügung gestellt bekommen.
- keine Kontaktperson eines bestätigten Covid-19 Erkrankten sind.
- in den letzten zwei Wochen keine Krankheitssymptome wie Atemwegsbeschwerden, Geruchs- und Geschmackverlust oder Fieber gezeigt haben.
- keiner CoVid-19 Risikogruppe angehören.

- *Zusatz 2. Studie:* sich vor Versuchsbeginn mit dem bereitgestellten COVID-19 Selbsttest testen.
- *Zusatz 3. Studie*: Entweder geimpft, genesen oder getestet sind.

Die Versuchsleiter unterliegen den gleichen Anforderungen. Es ist gewährleistet, dass das Fahrzeug vor Ihrem Eintreffen gereinigt und desinfiziert ist. Des Weiteren wird das Fahrzeug regelmäßig in den Pausen gelüftet.

Nochmals vielen Dank für Ihre Teilnahme!

B.2 Notes Driving Experiment 1

Realfahrzeugstudie: Gruppe assistiertes Fahren

Bewertung multimodaler Rückmeldungen während des automatisierten Fahrens auf der Autobahn

Herzlich Willkommen zur Probandenstudie zum Thema „Bewertung multimodaler Rückmeldungen während des automatisierten Fahrens auf der Autobahn“. Vorab vielen Dank, dass Sie an dieser Studie teilnehmen. Bitte nehmen Sie sich Zeit die folgenden Hinweise zu lesen, um etwas über den Versuch und dessen Ablauf zu erfahren.

Funktionen des Fahrzeugs und Ihre Aufgaben als Fahrer

Bitte vergewissern Sie sich, dass es sich bei dem in diesem Versuch eingesetzten Fahrzeug um einen Prototyp handelt. Das Fahrzeug ist ein Audi A5 Prototyp und Eigentum der AUDI AG. Das integrierte Automationssystem wurde in Testfahrten erprobt und arbeitet nach unserem Kenntnisstand zuverlässig. Trotzdem ist es dringend erforderlich, dass Sie mit hoher Aufmerksamkeit und Vorsicht an diesem Versuch teilnehmen und Ihnen klar ist, dass ein Fahrfehler des Automationssystems oder Ihrerseits auftreten kann.

Funktionen des Automationssystems

- Längsführung (eigenständiges Bremsen und Beschleunigen)
  - Die maximale Geschwindigkeit beträgt 120 km/h
  - Die Geschwindigkeit wird an das vorausfahrende Fahrzeug angepasst

Aktivierung des Automationssystems

Nachdem Sie auf die Autobahn aufgefahren sind, ändert sich nach kurzer Zeit die Farbe der Pilottaste in der Mittelkonsole in Weiß (siehe Abbildung 1).

Abbildung 1: Farbe der Pilotttaste wechselt in Weiß (System kann aktiviert werden)

Nun können Sie das Automationssystem durch Drücken der Pilottaste aktivieren. Während der Aktivierung sollten Sie beachten:

- Fahren Sie auf dem rechten Fahrstreifen.
- Beschleunigen, Bremsen oder Lenken Sie während der Aktivierung nicht.

Sobald die Pilottaste Türkis leuchtet und die Anzeige im Kombi-Instrument „Assistiert“ anzeigt (siehe Abbildung 2), ist das System aktiv und übernimmt die Längsführung.

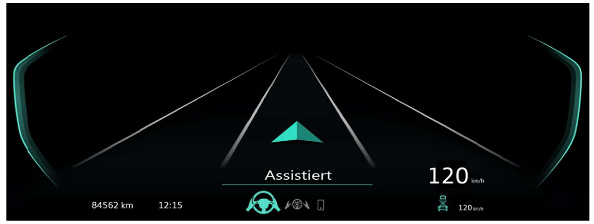

Abbildung 2: Aktiviertes Automationssystem, Kombi-Instrument

Es handelt sich um ein assistiertes System, das heißt im Normalfall müssen Sie lediglich die Querführung übernehmen und gegebenenfalls Fahrstreifenwechsel veranlassen und ausführen. Sie müssen das Fahrgeschehen dauerhaft überwachen und jederzeit zu einer vollständigen Übernahme der Fahrzeugführung bereit sein.

Potentiell unkritische Situationen

- Unregelmäßigkeiten im Fahrverhalten (z. B. leicht schwankende Lenkradbewegungen)
  Grund: Unterschiedliche Fahrbahnbeschaffenheit und Ungenauigkeiten in der Umfeldwahrnehmung

Potentiell kritische Situationen
Hier sollten Sie besonders aufmerksam sein:

- Nahe vor dem Fahrzeug einscherende Fahrzeuge (z. B. nach Autobahnauffahrten) oder seitlich sehr nahekommende Fahrzeuge
  Grund: Diese Fahrzeuge werden möglicherweise nicht oder zu spät erkannt
- Fahrzeuge, die sich während einem Fahrstreifenwechsel mit einer deutlich höheren Geschwindigkeit von hinten annähern und Fahrzeuge, die sich während einem Fahrstreifenwechsel im Zielfahrstreifen befinden oder sich dort hinbewegen
  Grund: Diese Fahrzeuge werden möglicherweise nicht oder zu spät erkannt
- Sehr stark bremsende Vorderfahrzeuge
  Grund: Ihr Fahrzeug wird keine Notbremsung durchführen

Falls Sie das Gefühl haben, dass das Automationssystem einen Fehler macht oder die Situation Ihnen zu gefährlich wird, können Sie das Automationssystem übersteuern, d.h. selbst die Fahrzeugführung übernehmen.

Übernahme der Fahrzeugführung / Deaktivierung des Automationssystems

- Drücken des Pilotknopfes in der Mittelkonsole (diesen wird Ihnen die Sicherheitsbeifahrerin zeigen)
- Betätigung des Bremspedals
- Betätigung des Gaspedals

Ein deaktiviertes System ist zu erkennen, wenn der Pilotknopf in der Mittelkonsole wieder Weiß, Rot oder gar nicht leuchtet.

Sollte es vorkommen, dass sich das Automationssystem durch die oben genannten Bedienhandlungen nicht deaktivieren lässt, kann durch Betätigung des Notschalters (siehe Abbildung 3) in der Mittelkonsole eine Abschaltung des Automationssystems ausgelöst werden. Dies ist allerdings nur im Notfall zu tun, da es einen Neustart des gesamten Fahrzeugs sowie der zugehörigen Technikkomponenten notwendig macht.

Abbildung 3: Notschalter in der Mittelkonsole des Fahrzeuges

Die Person auf dem Beifahrersitz verfügt zusätzlich über eine Fahrschulpedalerie, mithilfe derer sie in kritischen Situationen eingreifen kann. Sollte Ihnen das Verhalten jedoch zu irgendeinem Zeitpunkt zu unsicher werden, dürfen Sie jederzeit die Fahrzeugführung übernehmen (Deaktivierung des Automationssystems).

Übernahmeaufforderung

Es kann vorkommen, dass Sie die komplette Systemsteuerung während der Fahrt wieder übernehmen müssen. Dies wird Ihnen durch einen Gong, der Anzeige im Kombi-Instrument (siehe Abbildung 4) und das Blinken der Pilottaste in Rot mitgeteilt. Übernehmen Sie in diesem Fall die Steuerung des Fahrzeuges erneut und fahren Sie manuell weiter.

Abbildung 4: Übernahmeaufforderung im Kombi-Instrument

Inhalt und Ablauf des Versuchs

Die Versuchsleiter werden Sie am Pendlerparkplatz (Ingolstädter Str., 85101 Lenting) an der Autobahnauffahrt Lenting empfangen.

Die Strecke des Versuches reicht von der Autobahnausfahrt *85095 Denkendorf* bis zur Autobahnausfahrt *85077 Manching* mit *Lenting* als Start- und Endpunkt.

Der erste Teil des Versuchs von Lenting nach Denkendorf dient zur Eingewöhnung. Zunächst fahren Sie manuell, um sich mit dem Fahrzeug vertraut zu machen. Wenn Sie sich an die Fahrzeugführung gewöhnt haben, können Sie das assistierte System auf der rechten Spur aktivieren. Dabei wird der Abstand zum Vorderfahrzeug geregelt.

In Denkendorf werden Sie von der Autobahn abfahren. Dort werden Ihnen die weiteren Schritte des Versuchs erklärt.
Im zweiten Abschnitt beginnen die Hauptversuche (erster Teil von *Denkendorf* nach *Manching* und zweiter Teil von *Manching* nach *Denkendorf*). In diesem Zeitraum erleben Sie zwei Rückmeldekonzepte, welche Sie im Anschluss an die Fahrt bewerten. Die Auffahrt auf die Autobahn sowie die Abfahrt erfolgen dabei manuell. Wenn Sie auf die Autobahn aufgefahren sind, aktivieren Sie das assistierte System. Am Ende der Fahrt, kurz vor den Autobahnabfahrten, erhalten Sie eine Übernahmeaufforderung. Bitte übernehmen Sie daraufhin das Fahrzeug und fahren manuell von der Autobahn ab.
Nach dem Hauptteil des Versuchs erfolgt im dritten und letzten Abschnitt die gemeinsame Rückfahrt zum Ausgangspunkt in Lenting. Vor Beginn des Versuchs erfolgt eine erneute mündliche Einweisung zu den Funktionen des Fahrzeugs und Ihren Aufgaben als Fahrer. Falls Sie noch offene Fragen haben, zögern Sie nicht diese Ihren Versuchsleitern zu stellen.

Realfahrzeugstudie: Gruppe teilautomatisiertes Fahren

Bewertung multimodaler Rückmeldungen während des automatisierten Fahrens auf der Autobahn

Herzlich Willkommen zur Probandenstudie zum Thema „Bewertung multimodaler Rückmeldungen während des automatisierten Fahrens auf der Autobahn“. Vorab vielen Dank, dass Sie an dieser Studie teilnehmen. Bitte nehmen Sie sich Zeit die folgenden Hinweise zu lesen, um etwas über den Versuch und dessen Ablauf zu erfahren.

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Funktionen des Automationssystems

- Längsführung (eigenständiges Bremsen und Beschleunigen)
  - Die maximale Geschwindigkeit beträgt 120 km/h, gegebenenfalls erfolgt eine Anpassung an Geschwindigkeitsbegrenzungen
  - Die Geschwindigkeit wird an das vorausfahrende Fahrzeug angepasst
- Querführung
  - Eigenständiges Lenken, um dem Verlauf des Fahrstreifens mittig zu folgen
  - Das Fahrzeug kann eigenständig einen Fahrstreifenwechsel durchführen
  - Sie werden nur in der rechten und mittleren Spur der Autobahn fahren

Aktivierung des Automationssystems

Nachdem Sie auf die Autobahn aufgefahren sind, ändert sich nach kurzer Zeit die Farbe der Pilottaste in der Mittelkonsole in Weiß (siehe Abbildung 1).

Abbildung 1: Farbe der Pilotttaste wechselt in Weiß (System kann aktiviert werden)

Nun können Sie das Automationssystem durch Drücken der Pilottaste aktivieren. Während der Aktivierung sollten Sie beachten:

- Fahren Sie auf dem rechten Fahrstreifen.
- Beschleunigen, Bremsen oder Lenken Sie während der Aktivierung nicht.

Gerne können Sie auch während des Versuchs alle versuchsbezogenen Fragen stellen. Damit Sie sich bestmöglich auf Ihre jeweilige Aufgabe während des Versuchs konzentrieren können und somit eine Interpretation der gewonnenen Ergebnisse möglich ist, bitten wir Sie jedoch sich Ihre weiteren Fragen für das Ende des Versuchs aufzuheben. Wir nehmen uns im Anschluss gerne Zeit, Ihre Fragen zu beantworten.

Während der Fahrt

Sie werden bei den assistierten Fahrten zwei Rückmeldekonzepte erleben und diese im Anschluss an die Fahrt bewerten. Lassen Sie während der Fahrt Ihren Eindruck und Ihre Empfindungen über die Rückmeldungen auf sich wirken. Vergessen Sie dabei nicht, den Verkehr zu beobachten und bei aktiver Längsführung die Füße von den Pedalen zu nehmen.

Im Anschluss an die Fahrt werden Sie gebeten, Ihre erlebten Eindrücke und Empfindungen zu der Fahrt und den Rückmeldekonzepten in Fragebögen mitzuteilen.

Wenn Sie während der Fahrt Gedanken zu dem System haben, können Sie diese gerne den Versuchsleitern mitteilen.

Zur Teilnahme an diesem Versuch sind noch drei Erklärungen notwendig, die Sie im Anhang der E-Mail finden. Bringen Sie diese bitte unterschrieben zum Versuch mit.
Es steht Ihnen natürlich frei den Versuch ohne Angaben von Gründen jederzeit abzubrechen.

Nochmals vielen Dank für Ihre Teilnahme!

- Sie können während der Aktivierung ihre Hände noch wenige Zentimeter unter dem Lenkrad halten. Sobald das System aktiv ist, entfernen Sie Ihre Hände bitte komplett vom Lenkrad.

Sobald die Pilottaste Türkis leuchtet und die Anzeige im Kombi-Instrument „Teilautomatisiert“ anzeigt (siehe Abbildung 2), ist das System aktiv und übernimmt die Steuerung.

Abbildung 2: Aktiviertes Automationssystem, Kombi-Instrument

Es handelt sich um ein teilautomatisiertes System, das heißt im Normalfall müssen Sie das Fahrgeschehen nicht aktiv beeinflussen. Sie müssen das Fahrgeschehen dauerhaft überwachen und jederzeit zu einer vollständigen Übernahme der Fahrzeugführung bereit sein.

Potentiell unkritische Situationen

- Unregelmäßigkeiten im Fahrverhalten (z. B. leicht schwankende Lenkradbewegungen)
  Grund: Unterschiedliche Fahrbahnbeschaffenheit und Ungenauigkeiten in der Umfeldwahrnehmung

- Zeitweise nicht ganz mittige Positionierung des Fahrzeugs im Fahrstreifen
  Grund: Ungenauigkeiten in der Lokalisierung des Fahrzeugs

Potentiell kritische Situationen
Hier sollten Sie besonders aufmerksam sein:

- Nahe vor dem Fahrzeug einscherende Fahrzeuge (z. B. nach Autobahnauffahrten) oder seitlich sehr nahekommende Fahrzeuge
  Grund: Diese Fahrzeuge werden möglicherweise nicht oder zu spät erkannt

- Fahrzeuge, die sich während eines Fahrstreifenwechsels mit einer deutlich höheren Geschwindigkeit von hinten annähern und Fahrzeuge, die sich während eines Fahrstreifenwechsels im Zielfahrstreifen befinden oder sich dort hinbewegen
  Grund: Diese Fahrzeuge werden möglicherweise nicht oder zu spät erkannt

- Sehr stark bremsende Vorderfahrzeuge
  Grund: Ihr Fahrzeug wird keine Notbremsung durchführen

- Baustellen
  Grund: Das Fahrzeug erkennt keine Baustellen bzw. Verschiebung der Fahrspuren

Falls Sie das Gefühl haben, dass das Automationssystem einen Fehler macht oder die Situation Ihnen zu gefährlich wird, können Sie das Automationssystem übersteuern, d.h. selbst die Fahrzeugführung übernehmen.

Übernahme der Fahrzeugführung / Deaktivierung des Automationssystems

- Drücken des Pilotknopfes in der Mittelkonsole (diesen wird Ihnen die Sicherheitsbeifahrerin zeigen)
- Betätigung des Bremspedals
- Betätigung des Gaspedals
- Aufbringung einer starken Lenkbewegung

Ein deaktiviertes System ist zu erkennen, wenn der Pilotknopf in der Mittelkonsole wieder Weiß, Rot oder gar nicht leuchtet.

Sollte es vorkommen, dass sich das Automationssystem durch die oben genannten Bedienhandlungen nicht deaktivieren lässt, kann durch Betätigung des Notschalters (siehe Abbildung 3) in der Mittelkonsole eine Abschaltung des Automationssystems ausgelöst werden. Dies ist allerdings nur im Notfall zu tun, da es einen Neustart des gesamten Fahrzeugs sowie der zugehörigen Technikkomponenten notwendig macht.

Abbildung 3: Notschalter in der Mittelkonsole des Fahrzeuges

Die Person auf dem Beifahrersitz verfügt zusätzlich über eine Fahrschulpedalerie, mithilfe derer sie in kritischen Situationen eingreifen kann. Sollte Ihnen das Verhalten jedoch zu irgendeinem Zeitpunkt zu unsicher werden, dürfen Sie jederzeit die Fahrzeugführung übernehmen (Deaktivierung des Automationssystems).

Übernahmeaufforderung

Es kann vorkommen, dass Sie das System während der Fahrt wieder übernehmen müssen. Dies wird Ihnen durch einen Gong, der Anzeige im Kombi-Instrument (siehe Abbildung 5) und das Blinken der Pilottaste in Rot mitgeteilt. Übernehmen Sie in diesem Fall die Steuerung des Fahrzeuges erneut und fahren Sie manuell weiter.

Abbildung 4: Übernahmeaufforderung im Kombi-Instrument

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Der erste Teil des Versuchs von Lenting nach Denkendorf dient zur Eingewöhnung. Zunächst fahren Sie manuell, um sich mit dem Fahrzeug vertraut zu machen. Wenn Sie sich an die Fahrzeugführung gewöhnt haben, können Sie das automatisierte System auf der rechten Spur aktivieren. Dabei hält das Fahrzeug selbstständig die Spur und regelt den Abstand zum Vorderfahrzeug. Er wird aber zunächst keinen Fahrstreifenwechsel durchführen.

Wenn Sie sich allmählich an das Automationssystem gewöhnt haben, werden Fahrstreifenwechsel aktiviert. Das Fahrzeug wird nun selbstständig Entscheidungen für einen Fahrstreifenwechsel treffen und diesen automatisiert durchführen.
In Denkendorf werden Sie von der Autobahn abfahren. Dort werden Ihnen die weiteren Schritte des Versuchs erklärt.
Im zweiten Abschnitt beginnen die Hauptversuche (erster Teil von *Denkendorf* nach *Manching* und zweiter Teil von *Manching* nach *Denkendorf*). In diesem Zeitraum erleben Sie zwei Rückmeldekonzepte, welche Sie im Anschluss an die Fahrt bewerten. Die Auffahrt auf die Autobahn sowie die Abfahrt erfolgen dabei manuell. Wenn Sie auf die Autobahn aufgefahren sind, aktivieren Sie das automatisierte System. Am Ende der Fahrt, kurz vor den Autobahnabfahrten, erhalten Sie eine Übernahmeaufforderung. Bitte übernehmen Sie daraufhin das Fahrzeug und fahren manuell von der Autobahn ab.

Nach dem Hauptteil des Versuchs erfolgt im dritten und letzten Abschnitt die gemeinsame Rückfahrt zum Ausgangspunkt in Lenting. Vor Beginn des Versuchs erfolgt eine erneute mündliche Einweisung zu den Funktionen des Fahrzeugs und Ihren Aufgaben als Fahrer. Falls Sie noch offene Fragen haben, zögern Sie nicht diese Ihren Versuchsleitern zu stellen.

Gerne können Sie auch während des Versuchs alle versuchsbezogenen Fragen stellen. Damit Sie sich bestmöglich auf Ihre jeweilige Aufgabe während des Versuchs konzentrieren können und somit eine Interpretation der gewonnenen Ergebnisse möglich ist, bitten wir Sie jedoch sich Ihre weiteren Fragen für das Ende des Versuchs aufzuheben. Wir nehmen uns im Anschluss gerne Zeit, Ihre Fragen zu beantworten.

Während der Fahrt

Sie werden bei den automatisierten Fahrten zwei Rückmeldekonzepte erleben und diese im Anschluss an die Fahrt bewerten. Lassen Sie während der Fahrt Ihren Eindruck und Ihre Empfindungen über die Rückmeldungen auf sich wirken. Vergessen Sie dabei nicht, den Verkehr zu beobachten und bei aktiver Automatisierung die Füße von den Pedalen zu nehmen.

Im Anschluss an die Fahrt werden Sie gebeten, Ihre erlebten Eindrücke und Empfindungen zu der Fahrt und den Rückmeldekonzepten in Fragebögen mitzuteilen.

Wenn Sie während der Fahrt Gedanken zu dem System haben, können Sie diese gerne den Versuchsleitern mitteilen.

Zur Teilnahme an diesem Versuch sind noch drei Erklärungen notwendig, die Sie im Anhang der E-Mail finden. Bringen Sie diese bitte unterschrieben zum Versuch mit.
Es steht Ihnen natürlich frei den Versuch ohne Angaben von Gründen jederzeit abzubrechen.

Nochmals vielen Dank für Ihre Teilnahme!

Realfahrzeugstudie: Gruppe vollautomatisiertes Fahren

Bewertung multimodaler Rückmeldungen während des automatisierten Fahrens auf der Autobahn

Herzlich Willkommen zur Probandenstudie zum Thema „Bewertung multimodaler Rückmeldungen während des automatisierten Fahrens auf der Autobahn“. Vorab vielen Dank, dass Sie an dieser Studie teilnehmen. Bitte nehmen Sie sich Zeit die folgenden Hinweise zu lesen, um etwas über den Versuch und dessen Ablauf zu erfahren.

Funktionen des Fahrzeugs und Ihre Aufgaben als Fahrer

Bitte vergewissern Sie sich, dass es sich bei dem in diesem Versuch eingesetzten Fahrzeug um einen Prototyp handelt. Das Fahrzeug ist ein Audi A5 Prototyp und Eigentum der AUDI AG. Das integrierte Automationssystem wurde in Testfahrten erprobt und arbeitet nach unserem Kenntnisstand zuverlässig. Trotzdem ist es dringend erforderlich, dass Sie mit hoher Aufmerksamkeit und Vorsicht an diesem Versuch teilnehmen und Ihnen klar ist, dass ein Fahrfehler des Automationssystems oder Ihrerseits auftreten kann.

Funktionen des Automationssystems

- Längsführung (eigenständiges Bremsen und Beschleunigen)
  - Die maximale Geschwindigkeit beträgt 120 km/h, gegebenenfalls erfolgt eine Anpassung an Geschwindigkeitsbegrenzungen
  - Die Geschwindigkeit wird an das vorausfahrende Fahrzeug angepasst

- Querführung
  - Eigenständiges Lenken, um dem Verlauf des Fahrstreifens mittig zu folgen
  - Das Fahrzeug kann eigenständig einen Fahrstreifenwechsel durchführen
  - Sie werden nur in der rechten und mittleren Spur der Autobahn fahren

Aktivierung des Automationssystems

Nachdem Sie auf die Autobahn aufgefahren sind, ändert sich nach kurzer Zeit die Farbe der Pilottaste in der Mittelkonsole in Weiß (siehe Abbildung 1).

Abbildung 1: Farbe der Pilotttaste wechselt in Weiß (System kann aktiviert werden)

Nun können Sie das Automationssystem durch Drücken der Pilottaste aktivieren. Während der Aktivierung sollten Sie beachten:

- Fahren Sie auf dem rechten Fahrstreifen.
- Beschleunigen, Bremsen oder Lenken Sie während der Aktivierung nicht.
- Sie können während der Aktivierung ihre Hände noch wenige Zentimeter unter dem Lenkrad halten. Sobald das System aktiv ist, entfernen Sie Ihre Hände bitte komplett vom Lenkrad.

Sobald die Pilottaste Türkis leuchtet und die Anzeige im Kombi-Instrument „Pilotiert“ anzeigt (siehe Abbildung 2), ist das System aktiv und übernimmt die Steuerung.

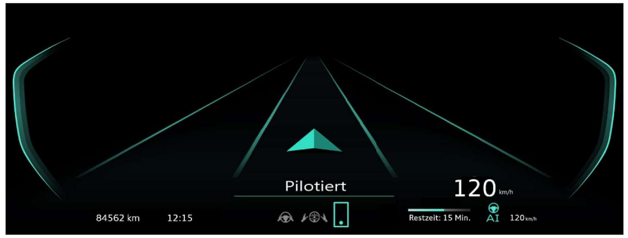

Abbildung 2: Aktiviertes Automationssystem, Kombi-Instrument

Es handelt sich um ein vollautomatisiertes System, das heißt im Normalfall müssen Sie das Fahrgeschehen nicht beobachten und aktiv beeinflussen. Eine mögliche Fahrzeugübernahme wird Ihnen mit ausreichend Vorlaufzeit angekündigt.

Potentiell unkritische Situationen

- Unregelmäßigkeiten im Fahrverhalten (z. B. leicht schwankende Lenkradbewegungen)
  Grund: Unterschiedliche Fahrbahnbeschaffenheit und Ungenauigkeiten in der Umfeldwahrnehmung

- Zeitweise nicht ganz mittige Positionierung des Fahrzeugs im Fahrstreifen
  Grund: Ungenauigkeiten in der Lokalisierung des Fahrzeugs

Potentiell kritische Situationen
Hier sollten Sie besonders aufmerksam sein:

- Nahe vor dem Fahrzeug einscherende Fahrzeuge (z. B. nach Autobahnauffahrten) oder seitlich sehr nahekommende Fahrzeuge
  Grund: Diese Fahrzeuge werden möglicherweise nicht oder zu spät erkannt

- Fahrzeuge, die sich während eines Fahrstreifenwechsels mit einer deutlich höheren Geschwindigkeit von hinten annähern und Fahrzeuge, die sich während eines Fahrstreifenwechsels im Zielfahrstreifen befinden oder sich dort hinbewegen
  Grund: Diese Fahrzeuge werden möglicherweise nicht oder zu spät erkannt

- Sehr stark bremsende Vorderfahrzeuge
  Grund: Ihr Fahrzeug wird keine Notbremsung durchführen

- Baustellen
  Grund: Das Fahrzeug erkennt keine Baustellen bzw. Verschiebung der Fahrspuren

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Falls Sie das Gefühl haben, dass das Automationssystem einen Fehler macht oder die Situation Ihnen zu gefährlich wird, können Sie das Automationssystem übersteuern, d.h. selbst die Fahrzeugführung übernehmen.

Übernahme der Fahrzeugführung / Deaktivierung des Automationssystems

- Drücken des Pilotknopfes in der Mittelkonsole (diesen wird Ihnen die Sicherheitsbeifahrerin zeigen)
- Betätigung des Bremspedals
- Betätigung des Gaspedals
- Aufbringung einer starken Lenkbewegung

Ein deaktiviertes System ist zu erkennen, wenn der Pilotknopf in der Mittelkonsole wieder Weiß, Rot oder gar nicht leuchtet.

Sollte es vorkommen, dass sich das Automationssystem durch die oben genannten Bedienhandlungen nicht deaktivieren lässt, kann durch Betätigung des Notschalters (siehe Abbildung 3) in der Mittelkonsole eine Abschaltung des Automationssystems ausgelöst werden. Dies ist allerdings nur im Notfall zu tun, da es einen Neustart des gesamten Fahrzeugs sowie der zugehörigen Technikkomponenten notwendig macht.

Abbildung 3: Notschalter in der Mittelkonsole des Fahrzeuges

Die Person auf dem Beifahrersitz verfügt zusätzlich über eine Fahrschulpedalerie, mithilfe derer sie in kritischen Situationen eingreifen kann. Sollte Ihnen das Verhalten jedoch zu irgendeinem Zeitpunkt zu unsicher werden, dürfen Sie jederzeit die Fahrzeugführung übernehmen (Deaktivierung des Automationssystems).

Übernahmeaufforderung

Es kann vorkommen, dass Sie das System während der Fahrt wieder übernehmen müssen. Dies wird Ihnen durch einen Gong, der Anzeige im Kombi-Instrument (siehe Abbildung 5) und das Blinken der Pilottaste in Rot mitgeteilt. Übernehmen Sie in diesem Fall die Steuerung des Fahrzeuges erneut und fahren Sie manuell weiter.

Abbildung 4: Übernahmeaufforderung im Kombi-Instrument

Inhalt und Ablauf des Versuchs

Die Versuchsleiter werden Sie am Pendlerparkplatz (Ingolstädter Str., 85101 Lenting) an der Autobahnauffahrt Lenting empfangen.

Die Strecke des Versuches reicht von der Autobahnausfahrt *85095 Denkendorf* bis zur Autobahnausfahrt *85077 Manching* mit *Lenting* als Start- und Endpunkt.

Der erste Teil des Versuchs von Lenting nach Denkendorf dient zur Eingewöhnung. Zunächst fahren Sie manuell, um sich mit dem Fahrzeug vertraut zu machen. Wenn Sie sich an die Fahrzeugführung gewöhnt haben, können Sie das automatisierte System auf der rechten Spur aktivieren. Dabei hält das Fahrzeug selbstständig die Spur und regelt den Abstand zum Vorderfahrzeug. Er wird aber zunächst keinen Fahrstreifenwechsel durchführen.

Wenn Sie sich allmählich an das Automationssystem gewöhnt haben, werden Fahrstreifenwechsel aktiviert. Das Fahrzeug wird nun selbstständig Entscheidungen für einen Fahrstreifenwechsel treffen und diesen automatisiert durchführen.
In Denkendorf werden Sie von der Autobahn abfahren. Dort werden Ihnen die weiteren Schritte des Versuchs erklärt.
Im zweiten Abschnitt beginnen die Hauptversuche (erster Teil von *Denkendorf* nach *Manching* und zweiter Teil von *Manching* nach *Denkendorf*). In diesem Zeitraum werden Sie Videos auf einem Tablet anschauen und zwei Rückmeldekonzepte erleben, welche Sie im Anschluss an die Fahrt bewerten. Die Auffahrt auf die Autobahn sowie die Abfahrt erfolgen dabei manuell. Wenn Sie auf die Autobahn aufgefahren sind, aktivieren Sie das automatisierte System. Am Ende der Fahrt, kurz vor den Autobahnabfahrten, erhalten Sie eine Übernahmeaufforderung. Bitte übernehmen Sie daraufhin das Fahrzeug und fahren manuell von der Autobahn ab.

Nach dem Hauptteil des Versuchs erfolgt im dritten und letzten Abschnitt die gemeinsame Rückfahrt zum Ausgangspunkt in Lenting. Vor Beginn des Versuchs erfolgt eine erneute mündliche Einweisung zu den Funktionen des Fahrzeugs und Ihren Aufgaben als Fahrer. Falls Sie noch offene Fragen haben, zögern Sie nicht diese Ihren Versuchsleitern zu stellen.

Gerne können Sie auch während des Versuchs alle versuchsbezogenen Fragen stellen. Damit Sie sich bestmöglich auf Ihre jeweilige Aufgabe während des Versuchs konzentrieren können und somit eine Interpretation der gewonnenen Ergebnisse möglich ist, bitten wir Sie jedoch sich Ihre weiteren Fragen für das Ende des Versuchs aufzuheben. Wir nehmen uns im Anschluss gerne Zeit, Ihre Fragen zu beantworten.

Während der Fahrt

Während der Fahrt ist es Ihre Aufgabe, das Video auf einem installierten Tablet anzuschauen. Im Nachhinein erfolgen Fragen zu dem gezeigten Video, die Sie bestmöglich beantworten sollen. Außerdem werden Sie bei den automatisierten Fahrten zwei Rückmeldekonzepte erleben und diese im Anschluss an die Fahrt bewerten. Vergessen Sie dabei nicht, das Video zu schauen und bei aktiver Automatisierung die Füße von den Pedalen zu nehmen.

Im Anschluss an die Fahrt werden Sie gebeten, Ihre erlebten Eindrücke und Empfindungen zu der Fahrt und den Rückmeldekonzepten in Fragebögen mitzuteilen.

Zur Teilnahme an diesem Versuch sind noch drei Erklärungen notwendig, die Sie im Anhang der E-Mail finden. Bringen Sie diese bitte unterschrieben zum Versuch mit.
Es steht Ihnen natürlich frei den Versuch ohne Angaben von Gründen jederzeit abzubrechen.

Nochmals vielen Dank für Ihre Teilnahme!

B.3 Notes Driving Experiment 2

Realfahrzeugstudie

Evaluation multimodaler Rückmeldungen während Transitionen auf der Autobahn

Herzlich Willkommen zur Probandenstudie zum Thema „Evaluation multimodaler Rückmeldungen während Transitionen auf der Autobahn". Vorab vielen Dank, dass Sie an dieser Studie teilnehmen. Bitte nehmen Sie sich Zeit, die folgenden Hinweise zu lesen, um etwas über den Versuch und dessen Ablauf zu erfahren.

Funktionen des Fahrzeugs und Ihre Aufgaben als Fahrer_in

Bitte vergewissern Sie sich, dass es sich bei dem in diesem Versuch eingesetzten Fahrzeug um einen Prototyp handelt. Das Fahrzeug ist ein Audi A5 Prototyp und Eigentum der AUDI AG. Das integrierte Automationssystem wurde in Testfahrten erprobt und arbeitet nach unserem Kenntnisstand zuverlässig. Trotzdem ist es dringend erforderlich, dass Sie mit hoher Aufmerksamkeit und Vorsicht an diesem Versuch teilnehmen und Ihnen klar ist, dass ein Fahrfehler des Automationssystems oder Ihrerseits auftreten kann.

Funktionen des Automationssystems

- Längsführung (eigenständiges Bremsen und Beschleunigen)
  - Die maximale Geschwindigkeit beträgt 120 km/h, gegebenenfalls erfolgt eine Anpassung an Geschwindigkeitsbegrenzungen
  - Die Geschwindigkeit wird an das vorausfahrende Fahrzeug angepasst
- Querführung
  - Eigenständiges Lenken, um dem Verlauf des Fahrstreifens mittig zu folgen
  - Das Fahrzeug kann eigenständig einen Fahrstreifenwechsel durchführen
  - Sie werden nur in der rechten und mittleren Spur der Autobahn fahren

Aktivierung des Automationssystems

Nachdem Sie auf die Autobahn aufgefahren sind, ändert sich nach kurzer Zeit die Farbe der Automationstaste in der Mittelkonsole in Weiß (siehe Abbildung 1).

Abbildung 1: Farbe der Automationstaste wechselt in Weiß (System kann aktiviert werden)

Nun können Sie das Automationssystem durch Drücken der Automationstaste aktivieren. Während der Aktivierung sollten Sie beachten:

- Fahren Sie auf dem rechten Fahrstreifen.
- Beschleunigen, bremsen oder lenken Sie während der Aktivierung nicht.
- Sie können während der Aktivierung ihre Hände noch wenige Zentimeter unter dem Lenkrad halten. Sobald das System aktiv ist, entfernen Sie Ihre Hände bitte komplett vom Lenkrad

Sobald die Automationstaste türkis leuchtet und die Anzeige im Kombi-Instrument „Assistent" anzeigt (siehe Abbildung 2), ist das System aktiv und übernimmt die Steuerung.

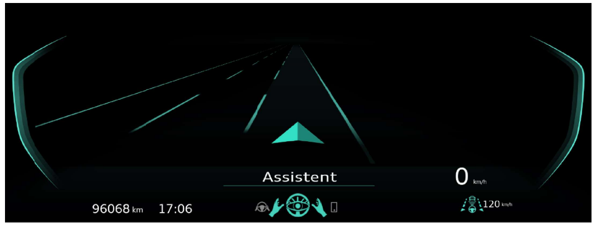

Abbildung 2: Aktiviertes Automationssystem, Assistierte Fahrt, Kombi-Instrument

Es handelt sich um ein assistiertes System, das heißt im Normalfall müssen Sie das Fahrgeschehen nicht aktiv beeinflussen. Sie müssen das Fahrgeschehen dauerhaft überwachen und jederzeit zu einer vollständigen Übernahme der Fahrzeugführung bereit sein.

Das automatisierte System ist in einem bestimmten Abschnitt der Autobahn in der Lage, pilotiert zu fahren. Das bedeutet, dass Sie im Normalfall das Fahrgeschehen weder beobachten noch aktiv beeinflussen müssen. Eine mögliche Fahrzeugübernahme wird Ihnen mit ausreichend Vorlaufzeit angekündigt. Sie erhalten zu Beginn dieses Abschnitts einen Systemvorschlag, die pilotierte Fahrt zu aktivieren. Die Aktivierung erfolgt über den „Mode" Taster am Lenkrad (siehe Abbildung 3).

Abbildung 3: Mode-Taste zur Aktivierung des Piloten

Nach erfolgreicher Aktivierung zeigt die Anzeige im Kombi-Instrument „Pilot“ an (siehe Abbildung 4). Solange der Modus aktiv ist, dürfen Sie eine fahrfremde Tätigkeit ausführen.

Abbildung 4: Aktiviertes Automationssystem, Pilot, Kombi-Instrument

Potentiell unkritische Situationen

- Unregelmäßigkeiten im Fahrverhalten (z. B. leicht schwankende Lenkrad-bewegungen)
  Grund: Unterschiedliche Fahrbahnbeschaffenheit und Ungenauigkeiten in der Umfeldwahrnehmung
- Zeitweise nicht ganz mittige Positionierung des Fahrzeugs im Fahrstreifen
  Grund: Ungenauigkeiten in der Lokalisierung des Fahrzeugs

Potentiell kritische Situationen
Hier sollten Sie besonders aufmerksam sein:

- Nahe vor dem Fahrzeug einscherende Fahrzeuge (z. B. nach Autobahnauffahrten) oder seitlich sehr nahekommende Fahrzeuge
  Grund: Diese Fahrzeuge werden möglicherweise nicht oder zu spät erkannt
- Fahrzeuge, die sich während einem Fahrstreifenwechsel mit einer deutlich höheren Geschwindigkeit von hinten annähern, und Fahrzeuge, die sich während einem Fahrstreifenwechsel im Zielfahrstreifen befinden oder sich dort hinbewegen
  Grund: Diese Fahrzeuge werden möglicherweise nicht oder zu spät erkannt
- Sehr stark bremsende Vorderfahrzeuge
  Grund: Ihr Fahrzeug wird keine Notbremsung durchführen
- Baustellen
  Grund: Das Fahrzeug erkennt keine Baustellen bzw. Verschiebung der Fahrspuren

Falls Sie das Gefühl haben, dass das Automationssystem einen Fehler macht oder die Situation Ihnen zu gefährlich wird, können Sie das Automationssystem übersteuern, d.h. selbst die Fahrzeugführung übernehmen.

Übernahme der Fahrzeugführung / Deaktivierung des Automationssystems

- Drücken des Automationsknopfes in der Mittelkonsole (diesen wird Ihnen die Versuchsleiterin zeigen)
- Betätigung des Bremspedals
- Betätigung des Gaspedals
- Aufbringung einer starken Lenkbewegung

Ein deaktiviertes System ist zu erkennen, wenn der Automationsknopf in der Mittelkonsole wieder Weiß, Rot oder gar nicht leuchtet.
Sollte es vorkommen, dass sich das Automationssystem durch die oben genannten Bedienhandlungen nicht deaktivieren lässt, kann durch Betätigung des Notschalters (siehe Abbildung 5) in der Mittelkonsole eine Abschaltung des Automationssystems ausgelöst werden. Dies ist allerdings nur im Notfall zu tun, da es einen Neustart des gesamten Fahrzeugs sowie der zugehörigen Technikkomponenten notwendig macht.

Abbildung 5: Notschalter in der Mittelkonsole des Fahrzeuges

Die Person auf dem Beifahrersitz verfügt zusätzlich über eine Fahrschulpedalerie, mithilfe derer sie in kritischen Situationen eingreifen kann. Sollte Ihnen das Verhalten jedoch zu irgendeinem Zeitpunkt zu unsicher werden, dürfen Sie jederzeit die Fahrzeugführung übernehmen (Deaktivierung des Automationssystems).

Übernahmeaufforderung
Es kann vorkommen, dass Sie das System während der Fahrt wieder übernehmen müssen. Dies wird Ihnen durch einen Gong, der Anzeige im Kombi-Instrument (siehe Abbildung 6) und das Blinken der Automationstaste in Rot mitgeteilt. Übernehmen Sie in diesem Fall die Steuerung des Fahrzeuges erneut und fahren Sie manuell weiter.

Abbildung 6: Übernahmeaufforderung im Kombi-Instrument

Inhalt und Ablauf des Versuchs

Die Versuchsleiter_innen werden Sie am Pendlerparkplatz (Ingolstädter Str., 85101 Lenting) an der Autobahnauffahrt Lenting empfangen. Die Strecke des Versuches reicht von der Autobahnausfahrt *Denkendorf* bis zur Autobahnausfahrt *Manching* mit *Lenting* als Start- und Endpunkt.

Der erste Teil des Versuchs von Lenting nach Denkendorf dient zur Eingewöhnung. Zunächst fahren Sie manuell, um sich mit dem Fahrzeug vertraut zu machen. Wenn Sie sich an die Fahrzeugführung gewöhnt haben, können Sie das automatisierte System auf der rechten Spur aktivieren. Dabei hält das Fahrzeug selbstständig die Spur und regelt den Abstand zum Vorderfahrzeug. Er wird aber zunächst keinen Fahrstreifenwechsel durchführen.
Wenn Sie sich allmählich an das Automationssystem gewöhnt haben, werden Fahrstreifenwechsel aktiviert. Das Fahrzeug wird nun selbstständig Entscheidungen für einen Fahrstreifenwechsel treffen und diesen automatisiert durchführen.
In Denkendorf werden Sie von der Autobahn abfahren. Dort werden Ihnen die weiteren Schritte des Versuchs erklärt.

Im zweiten Abschnitt beginnen die Hauptversuche (erster Teil von *Denkendorf* nach *Manching* und zweiter Teil von *Manching* nach *Denkendorf*). In diesem Zeitraum erleben Sie zwei Rückmeldekonzepte, welche Sie im Anschluss an die Fahrt bewerten. Die Auffahrt auf die Autobahn sowie die Abfahrt erfolgen dabei manuell. Wenn Sie auf die Autobahn aufgefahren sind, aktivieren Sie das Automationssystem. Das Fahrzeug ist in einem bestimmten Abschnitt der Autobahn in der Lage, pilotiert zu fahren. Das bedeutet, Sie können die Kontrolle vollständig an das System abgeben und sich fahrfremden Tätigkeiten zuwenden. Sie erhalten zu Beginn dieses Abschnitts einen Vorschlag vom System, in den nächsthöheren Modus zu schalten. Sobald Sie den höheren Modus aktiviert haben, ist es Ihnen erlaubt, eine fahrfremde Tätigkeit auszuführen. Sobald das Ende des Abschnitts erreicht ist, fordert Sie das System auf, wieder in die assistierte Fahrt zu wechseln. Nach Bestätigung dieser Aufforderung, müssen Sie das System wieder permanent überwachen. Am Ende der Fahrt, kurz vor den Autobahnabfahrten, erhalten Sie eine Übernahmeaufforderung. Bitte übernehmen Sie daraufhin das Fahrzeug und fahren manuell von der Autobahn ab.

Nach dem Hauptteil des Versuchs erfolgt im dritten und letzten Abschnitt die gemeinsame Rückfahrt zum Ausgangspunkt in Lenting.

Vor Beginn des Versuchs erfolgt eine erneute mündliche Einweisung zu den Funktionen des Fahrzeugs und Ihren Aufgaben als Fahrer_in. Falls Sie noch offene Fragen haben, zögern Sie nicht, diese Ihren Versuchsleiter_innen zu stellen.

Gerne können Sie auch während des Versuchs alle versuchsbezogenen Fragen stellen. Damit Sie sich bestmöglich auf Ihre jeweilige Aufgabe während des Versuchs konzentrieren können und somit eine Interpretation der gewonnenen Ergebnisse möglich ist, bitten wir Sie jedoch, sich Ihre weiteren Fragen für das Ende des Versuchs aufzuheben. Wir nehmen uns im Anschluss gerne Zeit, Ihre Fragen zu beantworten.

Während der Fahrt

Sie werden bei den automatisierten Fahrten zwei Rückmeldekonzepte erleben und diese im Anschluss an die Fahrt bewerten. Lassen Sie während der Fahrt Ihren Eindruck und Ihre Empfindungen über die Rückmeldungen auf sich wirken. Vergessen Sie dabei nicht, den Verkehr zu beobachten und bei aktiver Automatisierung die Füße von den Pedalen zu nehmen.
Im Anschluss an die Fahrt werden Sie gebeten, Ihre erlebten Eindrücke und Empfindungen zu der Fahrt und den Rückmeldekonzepten in Fragebögen mitzuteilen.
Wenn Sie während der Fahrt Gedanken zu dem System haben, können Sie diese gerne den Versuchsleiter_innen mitteilen.

Zur Teilnahme an diesem Versuch sind noch drei Erklärungen notwendig, die Sie im Anhang der E-Mail finden. Bringen Sie diese bitte unterschrieben zum Versuch mit. Es steht Ihnen natürlich frei, den Versuch ohne Angabe von Gründen jederzeit abzubrechen.

Nochmals vielen Dank für Ihre Teilnahme!

B.4 Notes Driving Experiment 3

Realfahrzeugstudie

Evaluation multimodaler Rückmeldungen auf der Autobahn

Herzlich Willkommen zur Probandenstudie zum Thema „Evaluation multimodaler Rückmeldungen auf der Autobahn“. Vorab vielen Dank, dass Sie an dieser Studie teilnehmen. Bitte nehmen Sie sich Zeit, die folgenden Hinweise zu lesen, um etwas über den Versuch und dessen Ablauf zu erfahren.

Funktionen des Fahrzeugs und Ihre Aufgaben als Fahrer_in

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Funktionen des Automationssystems

- Längsführung (eigenständiges Bremsen und Beschleunigen)
  - Die maximale Geschwindigkeit beträgt 120 km/h, gegebenenfalls erfolgt eine Anpassung an Geschwindigkeitsbegrenzungen
  - Die Geschwindigkeit wird an das vorausfahrende Fahrzeug angepasst
- Querführung
  - Eigenständiges Lenken, um dem Verlauf des Fahrstreifens mittig zu folgen
  - Das Fahrzeug kann eigenständig einen Fahrstreifenwechsel durchführen
  - Sie werden nur in der rechten und mittleren Spur der Autobahn fahren

Aktivierung des Automationssystems

Nachdem Sie auf die Autobahn aufgefahren sind, ändert sich nach kurzer Zeit die Farbe der Automationstaste in der Mittelkonsole in Weiß (siehe Abbildung 1).

Abbildung 1: Farbe der Automationstaste wechselt in Weiß (System kann aktiviert werden)

Nun können Sie das Automationssystem durch Drücken der Automationstaste aktivieren. Während der Aktivierung sollten Sie beachten:

- Fahren Sie auf dem rechten Fahrstreifen.
- Beschleunigen, bremsen oder lenken Sie während der Aktivierung nicht.
- Sie können während der Aktivierung ihre Hände noch wenige Zentimeter unter dem Lenkrad halten. Sobald das System aktiv ist, entfernen Sie Ihre Hände bitte komplett vom Lenkrad.

Sobald die Automationstaste türkis leuchtet und die Anzeige im Kombi-Instrument „Assistent“ anzeigt (siehe Abbildung 2), ist das System aktiv und übernimmt die Steuerung.

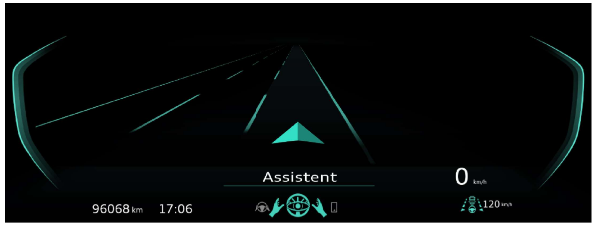

Abbildung 2: Aktiviertes Automationssystem, Assistierte Fahrt, Kombi-Instrument

Es handelt sich um ein assistiertes System, das heißt im Normalfall müssen Sie das Fahrgeschehen nicht aktiv beeinflussen. Sie müssen das Fahrgeschehen dauerhaft überwachen und jederzeit zu einer vollständigen Übernahme der Fahrzeugführung bereit sein.

Das automatisierte System ist in einem bestimmten Abschnitt der Autobahn in der Lage, pilotiert zu fahren. Das bedeutet, dass Sie im Normalfall das Fahrgeschehen weder beobachten noch aktiv beeinflussen müssen. Eine mögliche Fahrzeugübernahme wird Ihnen mit ausreichend Vorlaufzeit angekündigt. Sie erhalten zu Beginn dieses Abschnitts einen Systemvorschlag, die pilotierte Fahrt zu aktivieren. Die Aktivierung erfolgt über den „Mode“ Taster am Lenkrad (siehe Abbildung 3).

Abbildung 3: Mode-Taste zur Aktivierung des Piloten

Nach erfolgreicher Aktivierung zeigt die Anzeige im Kombi-Instrument „Pilot“ an (siehe Abbildung 4). Solange der Modus aktiv ist, dürfen Sie eine fahrfremde Tätigkeit ausführen.

Abbildung 4: Aktiviertes Automationssystem, Pilot, Kombi-Instrument

Potentiell unkritische Situationen

- Unregelmäßigkeiten im Fahrverhalten (z. B. leicht schwankende Lenkrad-bewegungen)
  Grund: Unterschiedliche Fahrbahnbeschaffenheit und Ungenauigkeiten in der Umfeldwahrnehmung
- Zeitweise nicht ganz mittige Positionierung des Fahrzeugs im Fahrstreifen
  Grund: Ungenauigkeiten in der Lokalisierung des Fahrzeugs

Potentiell kritische Situationen
Hier sollten Sie besonders aufmerksam sein:

- Nahe vor dem Fahrzeug einscherende Fahrzeuge (z. B. nach Autobahnauffahrten) oder seitlich sehr nahekommende Fahrzeuge
  Grund: Diese Fahrzeuge werden möglicherweise nicht oder zu spät erkannt
- Fahrzeuge, die sich während einem Fahrstreifenwechsel mit einer deutlich höheren Geschwindigkeit von hinten annähern, und Fahrzeuge, die sich während einem Fahrstreifenwechsel im Zielfahrstreifen befinden oder sich dort hinbewegen
  Grund: Diese Fahrzeuge werden möglicherweise nicht oder zu spät erkannt
- Sehr stark bremsende Vorderfahrzeuge
  Grund: Ihr Fahrzeug wird keine Notbremsung durchführen
- Baustellen
  Grund: Das Fahrzeug erkennt keine Baustellen bzw. Verschiebung der Fahrspuren

Falls Sie das Gefühl haben, dass das Automationssystem einen Fehler macht oder die Situation Ihnen zu gefährlich wird, können Sie das Automationssystem übersteuern, d.h. selbst die Fahrzeugführung übernehmen.

Übernahme der Fahrzeugführung / Deaktivierung des Automationssystems

- Drücken des Automationsknopfes in der Mittelkonsole (diesen wird Ihnen die Versuchsleiterin zeigen)
- Betätigung des Bremspedals
- Betätigung des Gaspedals
- Aufbringung einer starken Lenkbewegung

Ein deaktiviertes System ist zu erkennen, wenn der Automationsknopf in der Mittelkonsole wieder Weiß, Rot oder gar nicht leuchtet.
Sollte es vorkommen, dass sich das Automationssystem durch die oben genannten Bedienhandlungen nicht deaktivieren lässt, kann durch Betätigung des Notschalters (siehe Abbildung 5) in der Mittelkonsole eine Abschaltung des Automationssystems ausgelöst werden. Dies ist allerdings nur im Notfall zu tun, da es einen Neustart des gesamten Fahrzeugs sowie der zugehörigen Technikkomponenten notwendig macht.

Abbildung 5: Notschalter in der Mittelkonsole des Fahrzeuges

Die Person auf dem Beifahrersitz verfügt zusätzlich über eine Fahrschulpedalerie, mithilfe derer sie in kritischen Situationen eingreifen kann. Sollte Ihnen das Verhalten jedoch zu irgendeinem Zeitpunkt zu unsicher werden, dürfen Sie jederzeit die Fahrzeugführung übernehmen (Deaktivierung des Automationssystems).

Übernahmeaufforderung
Es kann vorkommen, dass Sie das System während der Fahrt wieder übernehmen müssen. Dies wird Ihnen durch einen Gong, der Anzeige im Kombi-Instrument (siehe Abbildung 6) und das Blinken der Automationstaste in Rot mitgeteilt. Übernehmen Sie in diesem Fall die Steuerung des Fahrzeuges erneut und fahren Sie manuell weiter.

Abbildung 6: Übernahmeaufforderung im Kombi-Instrument

Inhalt und Ablauf des Versuchs

Die Versuchsleiter_innen werden Sie am Pendlerparkplatz (Ingolstädter Str., 85101 Lenting) an der Autobahnauffahrt Lenting empfangen. Die Strecke des Versuches reicht von der Autobahnausfahrt *Greding* bis zur Autobahnausfahrt *Manching* mit *Lenting* als Start- und Endpunkt.

Der erste Teil des Versuchs von Lenting nach Manching dient zur Eingewöhnung. Zunächst fahren Sie manuell, um sich mit dem Fahrzeug vertraut zu machen. Wenn Sie sich an die Fahrzeugführung gewöhnt haben, können Sie das automatisierte System auf der rechten Spur aktivieren. Dabei hält das Fahrzeug selbstständig die Spur und regelt den Abstand zum Vorderfahrzeug. Er wird aber zunächst keinen Fahrstreifenwechsel durchführen.
Wenn Sie sich allmählich an das Automationssystem gewöhnt haben, werden Fahrstreifenwechsel aktiviert. Das Fahrzeug wird nun selbstständig Entscheidungen für einen Fahrstreifenwechsel treffen und diesen automatisiert durchführen.
In Manching werden Sie von der Autobahn abfahren. Dort werden Ihnen die weiteren Schritte des Versuchs erklärt.

Im zweiten Abschnitt beginnt der Hauptversuch (zwischen *Manching* und *Greding*). In diesem Zeitraum erleben Sie ein Rückmeldekonzept, welches Sie im Anschluss an die Fahrt bewerten. Die Auffahrt auf die Autobahn sowie die Abfahrt erfolgen dabei manuell. Wenn Sie auf die Autobahn aufgefahren sind, aktivieren Sie das Automationssystem. Das Fahrzeug ist in einem bestimmten Abschnitt der Autobahn in der Lage, pilotiert zu fahren. Das bedeutet, Sie können die Kontrolle vollständig an das System abgeben und sich fahrfremden Tätigkeiten zuwenden. Sie erhalten zu Beginn dieses Abschnitts einen Vorschlag vom System, in den nächsthöheren Modus zu schalten. Sobald Sie den höheren Modus aktiviert haben, ist es Ihnen erlaubt, eine fahrfremde Tätigkeit auszuführen. Sobald das Ende des Abschnitts erreicht ist, fordert Sie das System auf, wieder in die assistierte Fahrt zu wechseln. Nach Bestätigung dieser Aufforderung, müssen Sie das System wieder permanent überwachen. Am Ende der Fahrt, kurz vor den Autobahnabfahrten, erhalten Sie eine Übernahmeaufforderung. Bitte übernehmen Sie daraufhin das Fahrzeug und fahren manuell von der Autobahn ab.

Nach dem Hauptteil des Versuchs erfolgt im dritten und letzten Abschnitt die gemeinsame Rückfahrt zum Ausgangspunkt in Lenting.

Vor Beginn des Versuchs erfolgt eine erneute mündliche Einweisung zu den Funktionen des Fahrzeugs und Ihren Aufgaben als Fahrer_in. Falls Sie noch offene Fragen haben, zögern Sie nicht, diese Ihren Versuchsleiter_innen zu stellen.

Gerne können Sie auch während des Versuchs alle versuchsbezogenen Fragen stellen. Damit Sie sich bestmöglich auf Ihre jeweilige Aufgabe während des Versuchs konzentrieren können und somit eine Interpretation der gewonnenen Ergebnisse möglich ist, bitten wir Sie jedoch, sich Ihre weiteren Fragen für das Ende des Versuchs aufzuheben. Wir nehmen uns im Anschluss gerne Zeit, Ihre Fragen zu beantworten.

Während der Fahrt

Sie werden bei den automatisierten Fahrten ein Rückmeldekonzept erleben und dieses im Anschluss an die Fahrt bewerten. Lassen Sie während der Fahrt Ihren Eindruck und Ihre Empfindungen über die Rückmeldungen auf sich wirken. Vergessen Sie dabei nicht, den Verkehr zu beobachten und bei aktiver Automatisierung die Füße von den Pedalen zu nehmen.
Im Anschluss an die Fahrt werden Sie gebeten, Ihre erlebten Eindrücke und Empfindungen zu der Fahrt und dem Rückmeldekonzept in Fragebögen mitzuteilen.
Wenn Sie während der Fahrt Gedanken zu dem System haben, können Sie diese gerne den Versuchsleiter_innen mitteilen.

Zur Teilnahme an diesem Versuch sind noch drei Erklärungen notwendig, die Sie im Anhang der E-Mail finden. Bringen Sie diese bitte unterschrieben zum Versuch mit. Es steht Ihnen natürlich frei, den Versuch ohne Angabe von Gründen jederzeit abzubrechen.

Nochmals vielen Dank für Ihre Teilnahme!

C Questionnaires of the Driving Experiments

C.1 Pre-Questionnaire Driving Experiment 1

Ihre Erfahrungen in der Nutzung und Entwicklung von Fahrerassistenzsystemen

ACC (Adaptive Cruise Control / Abstandsregeltempomat)					
A1. Sind Sie bereits (privat oder dienstlich) mit einem Abstandsregeltempomat (ACC) gefahren?	☐ Ja		☐ Nein		
A2. Wenn Sie mit einem Fahrzeug fahren, welches mit ACC ausgestattet ist, wie häufig schalten Sie dieses auf der Autobahn ein?	nie	selten	gele-gent-lich	oft	immer
	☐	☐	☐	☐	☐
A3. Wie viele Jahre sind Sie insgesamt mit Fahrzeugen gefahren, die mit einem ACC ausgestattet waren?	ca. ____________ Jahre				

Spurhalteassistent					
A4. Sind Sie bereits (privat oder dienstlich) mit einem aktiven Spurhalteassistenten (z. B. Audi Active Lane Assist) gefahren?	☐ Ja		☐ Nein		
A5. Wenn Sie mit einem Fahrzeug fahren, welches mit einem aktiven Spurhalteassistenten ausgestattet ist, wie häufig schalten Sie dieses auf der Autobahn ein?	nie	selten	gele-gent-lich	oft	immer
	☐	☐	☐	☐	☐
A6. Wie viele Jahre sind Sie insgesamt mit Fahrzeugen gefahren, die mit einem aktiven Spurhalteassistenten ausgestattet waren?	ca. ____________ Jahre				

Nutzung teilautomatisierter Funktionen		
A7. Sind Sie bereits (privat oder dienstlich) mit einer Kombination aus aktivem Spurhalteassistent und ACC (teilautomatisiertes System, z. B. Stauassistent) gefahren?	☐ Ja	☐ Nein

Erfahrung mit hochautomatisierten Funktionen		
A8. Haben Sie bereits an Testfahrten mit einem teil- oder hochautomatisierten System teilgenommen?	☐ Ja	☐ Nein

Berufliche Tätigkeit in der Entwicklung automatisierter Fahrfunktionen		
A9. Sind Sie bereits in der Entwicklung und/oder Forschung automatisierter Fahrfunktionen tätig gewesen oder momentan tätig?	☐ Ja	☐ Nein

Ihre Fahrgewohnheiten

B1. Wie lange besitzen Sie bereits Ihren Führerschein der Klasse B?	ca. ____________ Jahre	
B2. Legen Sie Ihren Arbeitsweg oder sonstige Strecken (privat oder dienstlich) regelmäßig mit dem Auto zurück?	☐ Ja	☐ Nein
B3. Wie hoch ist Ihre durchschnittliche wöchentliche Kilometerleistung durch den Arbeitsweg und sonstige Fahrten?	ca. ____________ Kilometer	
B4. Wie hoch ist Ihre jährliche Kilometerleistung (inkl. Urlaubsfahrten, etc.) insgesamt? *Geben Sie bitte den Bereich an.*	bis 5.000 km	☐
	5.001 – 10.000 km	☐
	10.001 – 15.000 km	☐
	15.001 – 20.000 km	☐
	20.001 – 25.000 km	☐
	25.001 – 30.000 km	☐
	30.001 – 35.000 km	☐
	35.001 – 40.000 km	☐
	über 40.000 km	☐
B5. Wie verteilen sich Ihre Fahrten mit dem Auto (in km) auf folgende Straßentypen (gesamt 100%)? *Falls Sie einen Straßentypen nicht nutzen, tragen Sie bitte Null ein.*	Stadt (%)	
	Land-/Bundesstraße (%)	
	Autobahn (%)	

Ihre Einstellung zu Technik

C Wie sehr treffen die folgenden Aussagen auf Sie zu?

Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Machen Sie in jeder Zeile ein Kreuz.

		trifft absolut nicht zu	trifft eher nicht zu	weder noch	trifft eher zu	trifft absolut zu
		1	2	3	4	5
1	Ich kann ziemlich viele der technischen Probleme, mit denen ich konfrontiert bin, alleine lösen.	☐	☐	☐	☐	☐
2	Technische Geräte sind oft undurchschaubar und schwer zu beherrschen.	☐	☐	☐	☐	☐
3	Es macht mir richtig Spaß, ein technisches Problem zu knacken.	☐	☐	☐	☐	☐
4	Weil ich mit bisherigen technischen Problemen gut zurecht gekommen bin, blicke ich auch zukünftigen optimistisch entgegen.	☐	☐	☐	☐	☐
5	Ich fühle mich technischen Problemen gegenüber so hilflos, dass ich lieber die Finger von ihnen lasse.	☐	☐	☐	☐	☐
6	Auch wenn Widerstände auftreten, bearbeite ich ein technisches Problem weiter.	☐	☐	☐	☐	☐
7	Wenn ich ein technisches Problem löse, so geschieht das meist durch Glück.	☐	☐	☐	☐	☐
8	Die meisten technischen Probleme sind so kompliziert, dass es wenig Sinn hat, sich mit ihnen auseinanderzusetzen.	☐	☐	☐	☐	☐

Ihre Einstellung zum automatisierten Fahren

D Welche Einstellung haben Sie zum automatisierten Fahren?

Bitte sagen Sie uns, ob Sie der jeweiligen Aussage zustimmen oder nicht.

		Ich neige dazu, zu widersprechen	Ich stimme eher zu	Kann ich nicht beantworten
1	Automatisiertes Fahren kann mich in monotonen oder stressigen Fahrsituationen entlasten.	☐	☐	☐
2	Automatisiertes Fahren kann schwere Unfälle verhindern.	☐	☐	☐
3	Ich glaube nicht, dass es jemals zuverlässig funktionieren wird.	☐	☐	☐
4	Wenn das Auto selber fährt, kann ich andere Dinge tun.	☐	☐	☐
5	Automatisiertes Fahren macht mir Angst.	☐	☐	☐

Ihr Vertrauen in Automationssysteme

E Die folgenden Fragen erfassen Ihr Vertrauen in Automationssysteme.

Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Machen Sie in jeder Zeile ein Kreuz.

		Stimme gar nicht zu				Stimme voll zu
		1	2	3	4	5
1	Bei unbekannten automatisierten Systemen sollte man eher vorsichtig sein.	☐	☐	☐	☐	☐
2	Ich vertraue einem System eher, als dass ich ihm misstraue.	☐	☐	☐	☐	☐
3	Automatisierte Systeme funktionieren generell gut.	☐	☐	☐	☐	☐

Ihre Neigung zu Reiseübelkeit

F1 Wie oft haben Sie sich als Kind (jünger als 12 Jahre) krank gefühlt oder Übelkeit verspürt?

Bitte beurteilen Sie jedes nachfolgende Transportmittel oder Freizeitbeschäftigung. Machen Sie in jeder Zeile ein Kreuz.

		Nie krank gefühlt	Selten krank gefühlt	Manchmal krank gefühlt	Öfters krank gefühlt	Nicht zutreffend – nie benutzt
1	Autos	☐	☐	☐	☐	☐
2	Busse / Reisebusse	☐	☐	☐	☐	☐
3	Züge	☐	☐	☐	☐	☐
4	Flugzeuge	☐	☐	☐	☐	☐
5	Kleine Bote	☐	☐	☐	☐	☐
6	Schiffe / Fähren	☐	☐	☐	☐	☐
7	Schaukeln auf Spielplätzen	☐	☐	☐	☐	☐
8	Karussells auf Spielplätzen	☐	☐	☐	☐	☐
9	Achterbahnen / Kirmesbahnen	☐	☐	☐	☐	☐

F2 Wie oft haben Sie sich über die letzten 10 Jahre krank gefühlt oder Übelkeit verspürt?

Bitte beurteilen Sie jedes nachfolgende Transportmittel oder Freizeitbeschäftigung. Machen Sie in jeder Zeile ein Kreuz.

		Nie krank gefühlt	Selten krank gefühlt	Manchmal krank gefühlt	Öfters krank gefühlt	Nicht zutreffend – nie benutzt
1	Autos	☐	☐	☐	☐	☐
2	Busse / Reisebusse	☐	☐	☐	☐	☐
3	Züge	☐	☐	☐	☐	☐

4	Flugzeuge	☐	☐	☐	☐	☐
5	Kleine Bote	☐	☐	☐	☐	☐
6	Schiffe / Fähren	☐	☐	☐	☐	☐
7	Schaukeln auf Spielplätzen	☐	☐	☐	☐	☐
8	Karussells auf Spielplätzen	☐	☐	☐	☐	☐
9	Achterbahnen / Kirmesbahnen	☐	☐	☐	☐	☐

Demographie

G1	**Ihr Alter:** *Geben Sie bitte den Bereich an, in dem sich Ihr Alter befindet.*	<=24	25 -44	45-64	>=65
		☐	☐	☐	☐
G2	**Ihr Geschlecht:**	☐ weiblich ☐ männlich ☐ divers			
G3	**Ihr beruflicher Hintergrund:**	☐technisch ☐ nicht technisch			

C.2 Questionnaire Driving Experiment 1

Fragebogen direkt vor und nach den Versuchsfahrten

A1 Bitte beurteilen Sie Ihre Motion Sickness.

Geben Sie auf einer Skala von 0 – 20 an, wie Sie sich fühlen. Ein Wert von 0 (kein Unwohlsein) bedeutet dabei, dass es Ihnen sehr gut geht und Sie keine Beschwerden haben, während ein Wert von 20 (extrem starkes Unwohlsein) bedeutet, dass Sie sich extrem unwohl fühlen und sich eventuell übergeben müssen.

Bitte konzentrieren Sie sich bei Ihrer Angabe auf generelles Unwohlsein, Übelkeit, Magenbeschwerden, Temperaturempfinden und Kopfschmerzen. Es ist sehr wichtig, dass Sie ehrlich auf diese Frage antworten. Bitte ignorieren Sie bei Ihrer Bewertung weitere Gefühle wie Langeweile, Aufregung, Müdigkeit, Nervosität etc.

Bitte setzen Sie die Auswahl an die Stelle, die Ihrer Antwort entspricht. Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus.

Kein Unwohlsein	0	20	**Extrem starkes Unwohlsein**

Falls A1 > 0

A1.1 Bitte beurteilen Sie, welche Symptome bei Ihnen in welcher Intensität vorhanden sind.

Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Bitte machen Sie jeweils ein Kreuz pro Zeile.

	Keine Beschwerden	Sehr leichte Beschwerden						Sehr starke Beschwerden	
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Keine Angabe**
Kopfschmerzen	☐	☐	☐	☐	☐	☐	☐	☐	☐
Schwindel	☐	☐	☐	☐	☐	☐	☐	☐	☐
Übelkeit	☐	☐	☐	☐	☐	☐	☐	☐	☐
Schwankung der Körpertemperatur (warm/kalt)	☐	☐	☐	☐	☐	☐	☐	☐	☐

A2 Auf einer Skala von 1 bis 10 – wie schläfrig fühlen Sie sich im Moment?

Kreuzen Sie bitte zutreffendes an. Bitte setzen Sie nur ein Kreuz.

a	☐	Extrem wach
b	☐	Sehr wach
c	☐	Wach
d	☐	Ziemlich wach
e	☐	Weder wach noch müde
f	☐	Etwas müde
g	☐	Müde, aber noch keine Anstrengung nötig, um wach zu bleiben
h	☐	Müde und anstrengend, wach zu bleiben
i	☐	Sehr müde, Kampf gegen den Schlaf
j	☐	Extrem müde, kann nicht mehr wach bleiben
	☐	Keine Angabe

Fragebogen nach den Versuchsfahrten

Beurteilung des Feedbacks des Automationssystems

B1 Bitte geben Sie an, wie stark Sie den Aussagen über das Feedback des Automationssystems zustimmen.

Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Bitte machen Sie jeweils ein Kreuz pro Zeile.

		Trifft absolut nicht zu				Trifft absolut zu	
		1	2	3	4	5	Keine Angabe
a	Ich kann mir sehr gut vorstellen, das Feedback regelmäßig zu nutzen.	☐	☐	☐	☐	☐	☐
b	Ich empfinde das Feedback als unnötig komplex.	☐	☐	☐	☐	☐	☐
c	Ich empfinde das Feedback als einfach zu nutzen.	☐	☐	☐	☐	☐	☐
d	Ich denke, dass ich technischen Support brauchen würde, um das Feedback zu nutzen.	☐	☐	☐	☐	☐	☐
e	Ich finde, dass die verschiedenen Funktionen des Feedbacks gut integriert sind.	☐	☐	☐	☐	☐	☐
f	Ich finde, dass es im Feedback zu viele Inkonsistenzen gibt.	☐	☐	☐	☐	☐	☐
g	Ich kann mir vorstellen, dass die meisten Leute das Feedback schnell zu beherrschen lernen.	☐	☐	☐	☐	☐	☐
h	Ich empfinde die Bedienung als sehr umständlich.	☐	☐	☐	☐	☐	☐
i	Ich habe mich bei der Nutzung des Feedbacks sehr sicher gefühlt.	☐	☐	☐	☐	☐	☐
j	Ich musste eine Menge Dinge lernen, bevor ich mit dem Feedback arbeiten konnte.	☐	☐	☐	☐	☐	☐

Beurteilung des Automationssystems

C1 Bitte beurteilen Sie das Automationssystem. Lesen Sie hierfür aufmerksam jedes Wortpaar.

Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Bitte machen Sie jeweils ein Kreuz pro Zeile.

		1	2	3	4	5		Keine Angabe
a	nützlich	☐	☐	☐	☐	☐	nutzlos	☐
b	angenehm	☐	☐	☐	☐	☐	unangenehm	☐
c	schlecht	☐	☐	☐	☐	☐	gut	☐
d	nett	☐	☐	☐	☐	☐	nervig	☐
e	effizient	☐	☐	☐	☐	☐	unnötig	☐
f	ärgerlich	☐	☐	☐	☐	☐	erfreulich	☐
g	hilfreich	☐	☐	☐	☐	☐	wertlos	☐
h	nicht wünschenswert	☐	☐	☐	☐	☐	wünschenswert	☐
i	aktivierend	☐	☐	☐	☐	☐	einschläfernd	☐

C2 Bitte geben Sie an, wie stark Sie den Aussagen über das Automationssystem zustimmen.

Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Bitte machen Sie jeweils ein Kreuz pro Zeile.

		Trifft absolut nicht zu				Trifft absolut zu	
		1	**2**	**3**	**4**	**5**	**Keine Angabe**
a	Das System ist imstande Situationen richtig einzuschätzen.	☐	☐	☐	☐	☐	☐
b	Mir war durchgehend klar, in welchem Zustand sich das System befindet.	☐	☐	☐	☐	☐	☐
c	Bei unbekannten automatisierten Systemen sollte man eher vorsichtig sein.	☐	☐	☐	☐	☐	☐
d	Das System arbeitet zuverlässig.	☐	☐	☐	☐	☐	☐
e	Das System reagiert unvorhersehbar.	☐	☐	☐	☐	☐	☐
f	Ich vertraue dem System.	☐	☐	☐	☐	☐	☐
g	Ein Ausfall des Systems ist wahrscheinlich.	☐	☐	☐	☐	☐	☐
h	Ich konnte nachvollziehen, warum etwas passiert ist.	☐	☐	☐	☐	☐	☐
i	Ich vertraue einem System eher, als dass ich ihm misstraue.	☐	☐	☐	☐	☐	☐
j	Das System kann wirklich komplizierte Aufgaben übernehmen.	☐	☐	☐	☐	☐	☐
k	Ich kann mich auf das System verlassen.	☐	☐	☐	☐	☐	☐
l	Das System könnte stellenweise einen Fehler machen.	☐	☐	☐	☐	☐	☐
m	Zu erkennen, was das System als Nächstes macht, ist schwer.	☐	☐	☐	☐	☐	☐
n	Automatisierte Systeme funktionieren generell gut.	☐	☐	☐	☐	☐	☐
o	Ich bin überzeugt von den Fähigkeiten des Systems.	☐	☐	☐	☐	☐	☐

C3 Bitte geben Sie an, wie stark Sie den Aussagen über das Automationssystem zustimmen.

Bitte beantworten Sie diese Fragen anhand der Skala, welche aus 5 verbalen Kategorien von „Sehr gering" bis „Sehr hoch" besteht. Wählen Sie zunächst die Kategorie aus, die Ihrem Empfinden nach am besten passt. Dann nutzen Sie die Zahlen darunter, um eine Tendenz innerhalb der Kategorie anzugeben. Beispielsweise ist 9 „neutral mit der Tendenz zu hoch".

Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Bitte machen Sie jeweils ein Kreuz pro Zeile.

Keine Angabe

1. Ich war mir jederzeit darüber bewusst, in welcher Stufe sich das System befand.

sehr gering			gering			neutral			hoch			sehr hoch			Keine Angabe
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	☐

2. Ich habe das System permanent überwacht.

sehr gering			gering			neutral			hoch			sehr hoch			Keine Angabe
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	☐

3. Ich war mir jederzeit darüber bewusst, welche Aufgaben/Funktionen bei mir und welche beim System liegen.

sehr gering			gering			neutral			hoch			sehr hoch			Keine Angabe
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	☐

4. Ich war mir jederzeit darüber bewusst, dass ich in das Fahrgeschehen eingreifen muss, wenn die Situation dies erfordert.

sehr gering			gering			neutral			hoch			sehr hoch			Keine Angabe
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	☐

5. Ich war mir auch in komplexen Situationen darüber bewusst, was das System macht und konnte den Handlungen des Systems gut folgen.

sehr gering			gering			neutral			hoch			sehr hoch			Keine Angabe
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	☐

6. Ich habe dem System die Kontrolle in den Fahrsituationen komplett abgegeben und es nicht mehr überwacht.															☐
sehr gering			gering			neutral			hoch			sehr hoch			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
7. Über die Zeit fiel es mir schwerer das System zu überwachen.															☐
sehr gering			gering			neutral			hoch			sehr hoch			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	

Beurteilung Ihres Wohlbefindens und Ihrem Erleben der Fahrt

D1 Bitte versetzen Sie sich in die Lage, wie sich während der letzten Fahrt gefühlt haben.

Stellen Sie sich bitte die ganze Fahrt noch einmal vor und bewerten Sie diese mit Hilfe der folgende Adjektive. Beachten Sie, dass die Adjektive „gefühlsmäßig" zu verstehen sind. Markieren Sie also möglichst spontan eine Antwort.

Bitte machen Sie jeweils ein Kreuz pro Zeile.

	Ich habe die Fahrt erlebt als:	Trifft absolut nicht zu				Trifft absolut zu	
		1	**2**	**3**	**4**	**5**	**Keine Angabe**
a	umständlich	☐	☐	☐	☐	☐	☐
b	überfordernd	☐	☐	☐	☐	☐	☐
c	lästig	☐	☐	☐	☐	☐	☐
d	stressig	☐	☐	☐	☐	☐	☐
e	mühevoll	☐	☐	☐	☐	☐	☐
f	unterstützend	☐	☐	☐	☐	☐	☐
g	bequem	☐	☐	☐	☐	☐	☐
h	unkompliziert	☐	☐	☐	☐	☐	☐
i	stressfrei	☐	☐	☐	☐	☐	☐
j	anstrengend	☐	☐	☐	☐	☐	☐
k	beschwerlich	☐	☐	☐	☐	☐	☐
l	entspannend	☐	☐	☐	☐	☐	☐
m	entlastend	☐	☐	☐	☐	☐	☐
n	kompliziert	☐	☐	☐	☐	☐	☐
o	belastend	☐	☐	☐	☐	☐	☐
p	mühelos	☐	☐	☐	☐	☐	☐

Nur für Probanden der vollautomatisierten Fahrt mit vestibulärer Systemankündigung

D2 Bitte beurteilen Sie die Nick- und Wankbewegungen.

Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus.

		Trifft Absolut Nicht zu						Trifft absolut zu
		1	**2**	**3**	**4**	**5**	**6**	**7**
a	Die Nick- und Wankbewegungen des Systems haben mich beim Ausführen der fahrfremden Tätigkeiten abgelenkt.	☐	☐	☐	☐	☐	☐	☐

Anmerkungen

E1	**Haben Sie positive Anmerkungen zu der zuletzt erlebten Fahrt?**
E2	**Haben Sie negative Anmerkungen zu der zuletzt erlebten Fahrt?**
E3	**Haben Sie sonstige Anmerkungen zu der zuletzt erlebten Fahrt?**

Abschlussfragebogen

F1 Bitte geben Sie an, wie Ihnen das jeweilige Feedbackkonzept insgesamt gefallen hat.

Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Bitte machen Sie jeweils ein Kreuz pro Zeile.

		Sehr Schlecht						Sehr gut	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**Keine Angabe**
a	Visuelles und auditives Feedback	☐	☐	☐	☐	☐	☐	☐	☐
b	Visuelles, auditives und vestibuläres Feedback	☐	☐	☐	☐	☐	☐	☐	☐

F2 Sie haben nun zwei verschiedene Feedbackkonzepte kenngelernt. Bitte geben sie an, welches Konzept Sie bevorzugen.

Kreuzen Sie bitte zutreffendes an. Bitte setzen Sie nur ein Kreuz.

a	☐	Visuelles und auditives Feedback
b	☐	Visuelles, auditives und vestibuläres Feedback
c	☐	Keine Präferenz zwischen den beiden Konzepten

Vielen Dank für Ihre Teilnahme an der Studie.

Bitte geben Sie dem Versuchsleiter Bescheid. Es folgt noch ein kurzes Interview.

F3	**Welches Feedbackkonzept haben sie bevorzugt, wenn ja, warum haben Sie dieses im Vergleich zum anderen gewählt?**
F4	**Was würden Sie an dem von Ihnen bevorzugten Feedbackkonzept noch verbessern – was wären Ihre Wünsche?**
F5	**Wie müsste ein automatisiertes System generell gestaltet sein, damit Sie Ihm vollständig vertrauen?**
F6	**Haben Sie sonstige Anmerkungen?**

C.3 Expert Interview Driving Experiment 2

Interview

Hallo und vielen Dank, dass du dir die Zeit nimmst, Laura (meine Studentin) und mich zu unterstützen. Das Interview handelt von HMI Informationen während Transitionen und wird ca. eine Stunde dauern. Es gibt hierbei keine richtigen oder falschen Antworten, wir versuchen uns lediglich einen Gesamtüberblick zu verschaffen.

Demographie

- Geschlecht:
- Alter:
- Experten: wie lang im HMI Bereich tätig? →
  - HMI
  - Transitionen

Allgemein – Der Übergang von einem Level in ein anderes

Wie sollte der Vorgang einer Transition in ein **höheres** AL gestaltet sein? Bitte beschreibe diesen Vorgang so detailliert wie möglich und benenne jedes Feedback, welches vom System gegeben werden sollte. - Welche Informationen werden für eine Transition in ein **höheres** AL benötigt?
Wie sollte der Vorgang einer Transition in ein **niedrigeres** AL gestaltet sein? Bitte beschreibe diesen Vorgang so detailliert wie möglich und benenne jedes Feedback, welches vom System gegeben werden sollte. - Welche Informationen werden für eine Transition in ein **niedrigeres** AL benötigt?
(Welche Informationen im visuellen HMI sind wichtig für Transitionen?)
(Sollte zusätzlich zum visuellen Feedback eine weitere Modalität genutzt werden?)

Szenarien

Stell dir vor du sitzt in einem Auto, das mehrere Automationslevel vereint. Das System kann in vordefinierten Bereichen in bestimmte Automationslevel wechseln. In den nachfolgenden Szenarien geht es nicht um kritische Übernahmesituationen oder Systemfehler, es geht lediglich um einen normalen Übergang von einem Automationslevel in ein anderes.

Du möchtest nun mit eben diesem Auto auf der Autobahn in die Alpen fahren. Die Auffahrt auf die Autobahn erfolgt manuell. Sobald du dich auf dem rechten Fahrstreifen befindest, kannst du die teilautomatisierte Fahrt einschalten. Auf einigen Abschnitten der Strecke ist es sogar möglich vollautomatisiert zu fahren.

Szenario 1

Du fährst manuell auf die Autobahn auf und begibst dich auf den rechten Fahrstreifen. Sobald du dort angekommen bist, teilt das System dir mit, dass die Teilautomation verfügbar ist.

Wie sollte der Vorgang dieser Transition, also **manuell** zu **teilautomatisiert**, gestaltet sein? Bitte beschreibe diesen Vorgang so detailliert wie möglich und benenne jedes Feedback, welches vom System gegeben werden sollte. - Welche Informationen werden für eine Transition von **MAN** zu **TA** benötigt?
-
(Welche Informationen sind hierbei wichtig?)
(Welche Informationen im visuellen HMI sind wichtig?)
(Sollte zusätzlich zum visuellen Feedback eine weitere Modalität genutzt werden?)
Ich werde dir nun nochmal die Informationen nennen, die du genannt hast. Bitte bewerte jede einzelne Information hinsichtlich ihrer Relevanz bzw. Nützlichkeit auf einer Skala von 0 bis 100.
0 ——— 100 gar nicht ——— außerordentlich

Szenario 2

Du bist nun eine Weile teilautomatisiert gefahren. Das System teilt dir nun mit, dass die Vollautomation verfügbar ist.

Wie sollte der Vorgang dieser Transition, also **teilautomatisiert** zu **vollautomatisiert**, gestaltet sein? Bitte beschreibe diesen Vorgang so detailliert wie möglich und benenne jedes Feedback, welches vom System gegeben werden sollte.

- Welche Informationen werden für eine Transition von **TA** zu **VA** benötigt?

(Welche Informationen sind hierbei wichtig?)

(Welche Informationen im visuellen HMI sind wichtig?)

(Sollte zusätzlich zum visuellen Feedback eine weitere Modalität genutzt werden?)

Ich werde dir nun nochmal die Informationen nennen, die du genannt hast. Bitte bewerte jede einzelne Information hinsichtlich ihrer Relevanz bzw. Nützlichkeit auf einer Skala von 0 bis 100.

0 — 100

gar nicht — außerordentlich

Szenario 3

Der Abschnitt, in dem das System vollautomatisiert fahren kann, ist nun fast zu Ende. Das System teilt dir nun mit, dass es bald wieder in die Teilautomation wechselt.

Wie sollte der Vorgang dieser Transition, also **vollautomatisiert** zu **teilautomatisiert**, gestaltet sein? Bitte beschreibe diesen Vorgang so detailliert wie möglich und benenne jedes Feedback, welches vom System gegeben werden sollte.

- Welche Informationen werden für eine Transition von **VA** zu **TA** benötigt?

(Welche Informationen sind hierbei wichtig?)

(Welche Informationen im visuellen HMI sind wichtig?)

(Sollte zusätzlich zum visuellen Feedback eine weitere Modalität genutzt werden?)

Ich werde dir nun nochmal die Informationen nennen, die du genannt hast. Bitte bewerte jede einzelne Information hinsichtlich ihrer Relevanz bzw. Nützlichkeit auf einer Skala von 0 bis 100.

0 — 100

gar nicht — außerordentlich

Szenario 4

Die Ausfahrt der Alpen ist in Sicht und du musst demnächst von der Autobahn abfahren. Das System teilt dir mit, dass du die manuelle Kontrolle des Fahrzeugs übernehmen musst.

Wie sollte der Vorgang dieser Transition, also **teilautomatisiert** zu **manuell**, gestaltet sein? Bitte beschreibe diesen Vorgang so detailliert wie möglich und benenne jedes Feedback, welches vom System gegeben werden sollte.

- Welche Informationen werden für eine Transition von **TA** zu **MAN** benötigt?

Vor Transition:

- Keine Anzeige der Restzeitverfügbarkeit, da Fahrer die ganze Zeit involviert in Fahraufgabe
- Warnkaskade: visuelle Anzeige + Ton später, wenn dringender
- Übernahme durch Übersteuern (Bremsen, Lenken oder Taste an Lenkrad)

Nach Transition:

- Feedback: Icon und Hintergrund wechseln
- Aufgabenbeschreibung: visuell und beim ersten Mal auch Sprachausgabe, aber nicht so wichtig
- Grund für Transition („Autobahnausfahrt“)

(Welche Informationen sind hierbei wichtig?)

(Welche Informationen im visuellen HMI sind wichtig?)

(Sollte zusätzlich zum visuellen Feedback eine weitere Modalität genutzt werden?)

Ich werde dir nun nochmal die Informationen nennen, die du genannt hast. Bitte bewerte jede einzelne Information hinsichtlich ihrer Relevanz bzw. Nützlichkeit auf einer Skala von 0 bis 100.

0 — 100

gar nicht — außerordentlich

Abschluss

Was denkst du wie die Automationslevel am besten voneinander getrennt werden können?

- Sollten die Level eher durch Symbole oder Bezeichnungen dargestellt werden?

Welche Begriffe sollten für die drei gegebenen Automationslevel *manuell, TA* und *VA* genutzt werden?

- Sollten Sie eher umbenannt werden?
- Oder ist es abhängig wie das System instruiert wird?

Noch einmal vielen Dank, dass du dir die Zeit genommen hast! ☺

C.4 Pre-Questionnaire Driving Experiment 2

Ihre Erfahrungen in der Nutzung und Entwicklung von Fahrerassistenzsystemen

ACC (Adaptive Cruise Control / Abstandsregeltempomat)					
A1. Sind Sie bereits (privat oder dienstlich) mit einem Abstandsregeltempomat (ACC) gefahren?	☐ Ja		☐ Nein		
A2. Wenn Sie mit einem Fahrzeug fahren, welches mit ACC ausgestattet ist, wie häufig schalten Sie dieses auf der Autobahn ein?	nie	selten	gele-gent-lich	oft	immer
	☐	☐	☐	☐	☐
A3. Wie viele Jahre sind Sie insgesamt mit Fahrzeugen gefahren, die mit einem ACC ausgestattet waren?	ca. ____________ Jahre				

Spurhalteassistent					
A4. Sind Sie bereits (privat oder dienstlich) mit einem <u>aktiven Spurhalteassistenten</u> (z. B. Audi Active Lane Assist) gefahren?	☐ Ja		☐ Nein		
A5. Wenn Sie mit einem Fahrzeug fahren, welches mit einem <u>aktiven Spurhalteassistenten</u> ausgestattet ist, wie häufig schalten Sie dieses auf der Autobahn ein?	nie	selten	gele-gent-lich	oft	immer
	☐	☐	☐	☐	☐
A6. Wie viele Jahre sind Sie insgesamt mit Fahrzeugen gefahren, die mit einem aktiven Spurhalteassistenten ausgestattet waren?	ca. ____________ Jahre				

Nutzung teilautomatisierter Funktionen					
A7. Sind Sie bereits (privat oder dienstlich) mit einer Kombination aus aktivem Spurhalteassistent und ACC (<u>teilautomatisiertes System</u>, z. B. Stauassistent) gefahren?	☐ Ja		☐ Nein		
A8. Wenn Sie mit einem Fahrzeug fahren, welches mit einem <u>teilautomatisierten System</u> ausgestattet ist, wie häufig schalten Sie dieses auf der Autobahn ein?	nie	selten	gele-gent-lich	oft	immer
	☐	☐	☐	☐	☐
A9. Wie viele Jahre sind Sie insgesamt mit Fahrzeugen gefahren, die mit einem aktiven Spurhalteassistenten ausgestattet waren?	ca. ____________ Jahre				

Erfahrung mit hochautomatisierten Funktionen		
A10. Haben Sie bereits an Testfahrten mit einem <u>teil- oder hochautomatisierten System</u> teilgenommen?	☐ Ja	☐ Nein

Berufliche Tätigkeit in der Entwicklung automatisierter Fahrfunktionen		
A11. Sind Sie bereits in der <u>Entwicklung und/oder Forschung</u> automatisierter Fahrfunktionen tätig gewesen oder momentan tätig?	☐ Ja	☐ Nein

Ihre Fahrgewohnheiten

B1.	**Wie lange besitzen Sie bereits Ihren Führerschein der Klasse B?**	ca. ________________ Jahre	
B2.	**Legen Sie Ihren Arbeitsweg oder sonstige Strecken (privat oder dienstlich) regelmäßig mit dem Auto zurück?**	☐ Ja	☐ Nein
B3.	**Wie hoch ist Ihre durchschnittliche jährliche Kilometerleistung (inkl. Urlaubsfahrten, etc.) währen der aktuellen Corona Situation?**	ca. ________________ Kilometer	
B4.	**Wie hoch ist Ihre jährliche Kilometerleistung (inkl. Urlaubsfahrten, etc.) insgesamt (vor der aktuellen Corona Situation)?**	ca. ________________ Kilometer	
B5.	**Wie verteilen sich Ihre Fahrten mit dem Auto (in km) auf folgende Straßentypen (gesamt 100%)?** *Falls Sie einen Straßentypen nicht nutzen, tragen Sie bitte Null ein.*	Stadt (%)	
		Land-/Bundesstraße (%)	
		Autobahn (%)	

Ihre Einstellung zu Technik

C **Wie sehr treffen die folgenden Aussagen auf Sie zu?**

Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Machen Sie in jeder Zeile ein Kreuz.

		trifft absolut nicht zu	trifft eher nicht zu	weder noch	trifft eher zu	trifft absolut zu
		1	**2**	**3**	**4**	**5**
1	Ich kann ziemlich viele der technischen Probleme, mit denen ich konfrontiert bin, alleine lösen.	☐	☐	☐	☐	☐
2	Technische Geräte sind oft undurchschaubar und schwer zu beherrschen.	☐	☐	☐	☐	☐
3	Es macht mir richtig Spaß, ein technisches Problem zu knacken.	☐	☐	☐	☐	☐
4	Weil ich mit bisherigen technischen Problemen gut zurecht gekommen bin, blicke ich auch zukünftigen optimistisch entgegen.	☐	☐	☐	☐	☐
5	Ich fühle mich technischen Problemen gegenüber so hilflos, dass ich lieber die Finger von ihnen lasse.	☐	☐	☐	☐	☐
6	Auch wenn Widerstände auftreten, bearbeite ich ein technisches Problem weiter.	☐	☐	☐	☐	☐
7	Wenn ich ein technisches Problem löse, so geschieht das meist durch Glück.	☐	☐	☐	☐	☐
8	Die meisten technischen Probleme sind so kompliziert, dass es wenig Sinn hat, sich mit ihnen auseinanderzusetzen.	☐	☐	☐	☐	☐

Ihre Einstellung zum automatisierten Fahren

D Welche Einstellung haben Sie zum automatisierten Fahren?

Bitte sagen Sie uns, ob Sie der jeweiligen Aussage zustimmen oder nicht.

		Ich neige dazu, zu widersprechen	Ich stimme eher zu	Kann ich nicht beantworten
1	Automatisiertes Fahren kann mich in monotonen oder stressigen Fahrsituationen entlasten.	☐	☐	☐
2	Automatisiertes Fahren kann schwere Unfälle verhindern.	☐	☐	☐
3	Ich glaube nicht, dass es jemals zuverlässig funktionieren wird.	☐	☐	☐
4	Wenn das Auto selber fährt, kann ich andere Dinge tun.	☐	☐	☐
5	Automatisiertes Fahren macht mir Angst.	☐	☐	☐

Ihr Vertrauen in Automationssysteme

E Die folgenden Fragen erfassen Ihr Vertrauen in Automationssysteme.

Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Machen Sie in jeder Zeile ein Kreuz.

		Stimme gar nicht zu				Stimme voll zu
		1	2	3	4	5
1	Bei unbekannten automatisierten Systemen sollte man eher vorsichtig sein.	☐	☐	☐	☐	☐
2	Ich vertraue einem System eher, als dass ich ihm misstraue.	☐	☐	☐	☐	☐
3	Automatisierte Systeme funktionieren generell gut.	☐	☐	☐	☐	☐

Ihr allgemeines Befinden

Geben Sie bitte an, wie Ihr allgemeines Befinden ist.

Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Bitte machen Sie jeweils ein Kreuz pro Zeile.

		sehr			unentschieden			sehr		Keine Angabe
		3	2	1	0	1	2	3		
1	zufrieden	☐	☐	☐	☐	☐	☐	☐	unzufrieden	☐
2	energiegeladen	☐	☐	☐	☐	☐	☐	☐	energielos	☐
3	„gestresst“	☐	☐	☐	☐	☐	☐	☐	entspannt	☐
4	müde	☐	☐	☐	☐	☐	☐	☐	hellwach	☐
5	friedlich	☐	☐	☐	☐	☐	☐	☐	verärgert	☐
6	unglücklich	☐	☐	☐	☐	☐	☐	☐	glücklich	☐
7	lustlos	☐	☐	☐	☐	☐	☐	☐	hoch motiviert	☐
8	ruhig	☐	☐	☐	☐	☐	☐	☐	nervös	☐
9	begeistert	☐	☐	☐	☐	☐	☐	☐	gelangweilt	☐
10	besorgt	☐	☐	☐	☐	☐	☐	☐	sorgenfrei	☐

Demographie

G1	**Ihr Alter:** *Geben Sie bitte den Bereich an, in dem sich Ihr Alter befindet.*	<=24 ☐	25 -44 ☐	45-64 ☐	>=65 ☐
G2	**Ihr Geschlecht:**	☐ weiblich	☐ männlich	☐ divers	
G3	**Ihr beruflicher Hintergrund:**	☐technisch	☐ nicht technisch		

C.5 Questionnaire Driving Experiment 2

Fragebogen direkt vor und nach den Versuchsfahrten

A1 Bitte beurteilen Sie Ihre Motion Sickness.

Geben Sie auf einer Skala von 0 – 20 an, wie Sie sich fühlen. Ein Wert von 0 (kein Unwohlsein) bedeutet dabei, dass es Ihnen sehr gut geht und Sie keine Beschwerden haben, während ein Wert von 20 (extrem starkes Unwohlsein) bedeutet, dass Sie sich extrem unwohl fühlen und sich eventuell übergeben müssen.

Bitte konzentrieren Sie sich bei Ihrer Angabe auf generelles Unwohlsein, Übelkeit, Magenbeschwerden, Temperaturempfinden und Kopfschmerzen. Es ist sehr wichtig, dass Sie ehrlich auf diese Frage antworten. Bitte ignorieren Sie bei Ihrer Bewertung weitere Gefühle wie Langeweile, Aufregung, Müdigkeit, Nervosität etc.

Bitte setzen Sie die Auswahl an die Stelle, die Ihrer Antwort entspricht. Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus.

Kein Unwohlsein 0 ●———————— 20 **Extrem starkes Unwohlsein**

Falls A1 > 0

A1.1 Bitte nennen Sie uns den Grund für Ihr Unwohlsein.

Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus.

A2 Wie fühlen Sie sich im Moment?

Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Bitte machen Sie jeweils ein Kreuz pro Zeile.

		sehr			unentschieden			sehr		Keine Angabe
		3	**2**	**1**	**0**	**1**	**2**	**3**		
1	zufrieden	☐	☐	☐	☐	☐	☐	☐	unzufrieden	☐
2	energiegeladen	☐	☐	☐	☐	☐	☐	☐	energielos	☐
3	„gestresst“	☐	☐	☐	☐	☐	☐	☐	entspannt	☐
4	müde	☐	☐	☐	☐	☐	☐	☐	hellwach	☐
5	friedlich	☐	☐	☐	☐	☐	☐	☐	verärgert	☐
6	unglücklich	☐	☐	☐	☐	☐	☐	☐	glücklich	☐
7	lustlos	☐	☐	☐	☐	☐	☐	☐	hoch motiviert	☐
8	ruhig	☐	☐	☐	☐	☐	☐	☐	nervös	☐
9	begeistert	☐	☐	☐	☐	☐	☐	☐	gelangweilt	☐
10	besorgt	☐	☐	☐	☐	☐	☐	☐	sorgenfrei	☐

Fragebogen während den Versuchsfahrten

Wie kritisch würden Sie die eben erlebte Übergangssituation beurteilen?

unkontrollierbar	10	☐
gefährlich	9	☐
	8	☐
	7	☐
unangenehm	6	☐
	5	☐
	4	☐
unbedenklich	3	☐
	2	☐
	1	☐
unmerklich	0	☐

Transition in höhere Automationslevel

Die nachfolgenden Fragen beziehen sich auf den gerade erlebten Übergang.
Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus.

Keine Angabe

1. Wie verständlich (transparent) war der Systemvorschlag?

sehr wenig			wenig			mittel			stark			sehr stark			Keine Angabe
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	☐

Anhand welcher Informationen haben Sie den Vorschlag angenommen?

2. Wie sicher waren Sie sich darüber, was Sie gerade aktivieren?

sehr wenig			wenig			mittel			stark			sehr stark			Keine Angabe
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	☐

3. Wie hoch ist Ihr aktuelles Sicherheitsempfinden?

sehr wenig			wenig			mittel			stark			sehr stark			Keine Angabe
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	☐

4. Wie hoch ist Ihre aktuelle mentale Beanspruchung?

sehr wenig			wenig			mittel			stark			sehr stark			Keine Angabe
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	☐

Transition in niedrigere Automationslevel

Die nachfolgenden Fragen beziehen sich auf den vorherigen Systemmodus.
Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus.

Keine Angabe

1. Ich war mir jederzeit darüber bewusst, welche Aufgaben/Funktionen bei mir und welche beim System liegen.

sehr wenig			wenig			mittel			stark			sehr stark			Keine Angabe
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	☐

In welcher Stufe haben Sie sich zuvor befunden?

2. Wie vorhersagbar war das Systemverhalten?

sehr wenig			wenig			mittel			stark			sehr stark			Keine Angabe
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	☐

3. Ich habe das System permanent überwacht.

sehr wenig			wenig			mittel			stark			sehr stark			Keine Angabe
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	☐

Die nachfolgenden Fragen beziehen sich auf die eben von Ihnen getätigte Deaktivierung.
Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus.

Keine Angabe

1. Welche Informationen haben Sie sich eingeholt, bevor Sie wieder übernommen haben? ☐

2. Wie stark haben Sie bei der Übernahme den umliegenden Verkehr beachtet?

sehr wenig			wenig			mittel			stark			sehr stark			Keine Angabe
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	☐

3. Wie sehr haben Sie auf das visuelle Feedback geachtet?

sehr wenig			wenig			mittel			stark			sehr stark			Keine Angabe
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	☐

4. Wie schnell haben Sie auf die Übernahmeaufforderung reagiert? (Petermann-Stock, 2015)															
sehr wenig			wenig			mittel			stark			sehr stark			☐
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	

Fragebogen nach den Versuchsfahrten

Beurteilung des Automationssystems

B1 Bitte beurteilen Sie das Automationssystem. Lesen Sie hierfür aufmerksam jedes Wortpaar.

Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Bitte machen Sie jeweils ein Kreuz pro Zeile.

		1	2	3	4	5		Keine Angabe
a	nützlich	☐	☐	☐	☐	☐	nutzlos	☐
b	angenehm	☐	☐	☐	☐	☐	unangenehm	☐
c	schlecht	☐	☐	☐	☐	☐	gut	☐
d	nett	☐	☐	☐	☐	☐	nervig	☐
e	effizient	☐	☐	☐	☐	☐	unnötig	☐
f	ärgerlich	☐	☐	☐	☐	☐	erfreulich	☐
g	hilfreich	☐	☐	☐	☐	☐	wertlos	☐
h	nicht wünschenswert	☐	☐	☐	☐	☐	wünschenswert	☐
i	aktivierend	☐	☐	☐	☐	☐	einschläfernd	☐

B2 Bitte geben Sie an, wie stark Sie den Aussagen über das Automationssystem zustimmen.

Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Bitte machen Sie jeweils ein Kreuz pro Zeile.

		Trifft absolut nicht zu				Trifft absolut zu	
		1	2	3	4	5	Keine Angabe
a	Das System ist imstande, Situationen richtig einzuschätzen.	☐	☐	☐	☐	☐	☐
b	Mir war durchgehend klar, in welchem Zustand sich das System befindet.	☐	☐	☐	☐	☐	☐
c	Bei unbekannten automatisierten Systemen sollte man eher vorsichtig sein.	☐	☐	☐	☐	☐	☐
d	Das System arbeitet zuverlässig.	☐	☐	☐	☐	☐	☐
e	Das System reagiert unvorhersehbar.	☐	☐	☐	☐	☐	☐
f	Ich vertraue dem System.	☐	☐	☐	☐	☐	☐
g	Ein Ausfall des Systems ist wahrscheinlich.	☐	☐	☐	☐	☐	☐
h	Ich konnte nachvollziehen, warum etwas passiert ist.	☐	☐	☐	☐	☐	☐
i	Ich vertraue einem System eher, als dass ich ihm misstraue.	☐	☐	☐	☐	☐	☐
j	Das System kann wirklich komplizierte Aufgaben übernehmen.	☐	☐	☐	☐	☐	☐
k	Ich kann mich auf das System verlassen.	☐	☐	☐	☐	☐	☐
l	Das System könnte stellenweise einen Fehler machen.	☐	☐	☐	☐	☐	☐
m	Zu erkennen, was das System als Nächstes macht, ist schwer.	☐	☐	☐	☐	☐	☐

n	Automatisierte Systeme funktionieren generell gut.	☐	☐	☐	☐	☐	☐
o	Ich bin überzeugt von den Fähigkeiten des Systems.	☐	☐	☐	☐	☐	☐

Beurteilung Ihres Wohlbefindens und Ihres Erlebens während der fahrfremden Tätigkeit

D1 Bitte versetzen Sie sich in die Lage, wie sich während der letzten Fahrt gefühlt haben.

Stellen Sie sich bitte die ganze Fahrt noch einmal vor und bewerten Sie diese mit Hilfe der folgende Adjektive. Beachten Sie, dass die Adjektive „gefühlsmäßig" zu verstehen sind. Markieren Sie also möglichst spontan eine Antwort.

Bitte machen Sie jeweils ein Kreuz pro Zeile.

	Ich habe die Fahrt erlebt als:	Trifft absolut nicht zu				Trifft absolut zu	
		1	**2**	**3**	**4**	**5**	**Keine Angabe**
a	umständlich	☐	☐	☐	☐	☐	☐
b	überfordernd	☐	☐	☐	☐	☐	☐
c	lästig	☐	☐	☐	☐	☐	☐
d	stressig	☐	☐	☐	☐	☐	☐
e	mühevoll	☐	☐	☐	☐	☐	☐
f	unterstützend	☐	☐	☐	☐	☐	☐
g	bequem	☐	☐	☐	☐	☐	☐
h	unkompliziert	☐	☐	☐	☐	☐	☐
i	stressfrei	☐	☐	☐	☐	☐	☐
j	anstrengend	☐	☐	☐	☐	☐	☐
k	beschwerlich	☐	☐	☐	☐	☐	☐
l	entspannend	☐	☐	☐	☐	☐	☐
m	entlastend	☐	☐	☐	☐	☐	☐
n	kompliziert	☐	☐	☐	☐	☐	☐
o	belastend	☐	☐	☐	☐	☐	☐
p	mühelos	☐	☐	☐	☐	☐	☐

Bitte beurteilen Sie das Feedback des Fahrzeugs.

Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus.

		trifft absolut nicht zu						trifft absolut zu	
		1	**2**	**3**	**4**	**5**	**6**	**7**	Keine Angabe
a	Das Feedback des Systems hat mich bei der Ausführung der fahrfremden Tätigkeit abgelenkt.	☐	☐	☐	☐	☐	☐	☐	☐
b	Das Feedback des Systems hat mich bei der Ausführung der fahrfremden Tätigkeit gestört.	☐	☐	☐	☐	☐	☐	☐	☐
c	Das Feedback des Systems hat mich bei der Ausführung der fahrfremden Tätigkeit entlastet.	☐	☐	☐	☐	☐	☐	☐	☐

Anmerkungen

E1	**Haben Sie positive Anmerkungen zu der zuletzt erlebten Fahrt?**
E2	**Haben Sie negative Anmerkungen zu der zuletzt erlebten Fahrt?**
E3	**Haben Sie sonstige Anmerkungen zu der zuletzt erlebten Fahrt?**

Abschlussfragebogen

Inwieweit haben Sie einen Unterschied zwischen beiden erlebten Feedbackkonzepten wahrgenommen?

gar nicht	gering	mittel	hoch	völlig	Keine Angabe
☐	☐	☐	☐	☐	☐

Bitte beschreiben Sie den wahrgenommenen Unterschied.

Welches Feedbackkonzept würden Sie für eine automatisierte Fahrt auf der Autobahn präferieren, wenn Sie konzentriert eine fahrfremde Tätigkeit ausführen und den Blick vom Verkehrsgeschehen abwenden (z. B. Lesen)?

☐	von Fahrt 1
☐	von Fahrt 2
☐	kann ich nicht beantworten

Anmerkungen:

Welches Feedbackkonzept würden Sie für eine automatisierte Fahrt auf der Autobahn präferieren, wenn Sie konzentriert eine fahrfremde Tätigkeit ausführen und den Blick auf das Verkehrsgeschehen richten (z. B. Telefonieren)?

☐	von Fahrt 1
☐	von Fahrt 2
☐	kann ich nicht beantworten

Anmerkungen:

Welche Informationen im visuellen HMI waren für Sie bei der Transition wesentlich?
Haben Sie dabei bestimmte Informationen vermisst?
Hätten Sie sich weitere Informationen gewünscht?
Bitte bewerten Sie die im Display angezeigten Informationen hinsichtlich ihrer Relevanz bzw. Nützlichkeit auf einer Skala von 0 bis 100.
0 (gar nicht) — 100 (außerordentlich)
Welche Informationen würden Sie in den verschiedenen Automationsstufen benötigen?
Level 0 (manuelles Fahren):
Level 2 (teilautomatisiertes Fahren):
Level 4 (hochautomatisiertes Fahren, ohne Überwachung):

C.6 Pre-Questionnaire Driving Experiment 3

Ihre Erfahrungen in der Nutzung und Entwicklung von Fahrerassistenzsystemen

ACC (Adaptive Cruise Control / Abstandsregeltempomat)					
A1. Sind Sie bereits (privat oder dienstlich) mit einem Abstandsregeltempomat (ACC) gefahren?	☐ Ja		☐ Nein		
A2. Wenn Sie mit einem Fahrzeug fahren, welches mit ACC ausgestattet ist, wie häufig schalten Sie dieses auf der Autobahn ein?	nie	selten	gele-gent-lich	oft	immer
	☐	☐	☐	☐	☐
A3. Wie viele Jahre sind Sie insgesamt mit Fahrzeugen gefahren, die mit einem ACC ausgestattet waren?	ca. ____________ Jahre				

Spurhalteassistent					
A4. Sind Sie bereits (privat oder dienstlich) mit einem aktiven Spurhalteassistenten (z. B. Audi Active Lane Assist) gefahren?	☐ Ja		☐ Nein		
A5. Wenn Sie mit einem Fahrzeug fahren, welches mit einem aktiven Spurhalteassistenten ausgestattet ist, wie häufig schalten Sie dieses auf der Autobahn ein?	nie	selten	gele-gent-lich	oft	immer
	☐	☐	☐	☐	☐
A6. Wie viele Jahre sind Sie insgesamt mit Fahrzeugen gefahren, die mit einem aktiven Spurhalteassistenten ausgestattet waren?	ca. ____________ Jahre				

Nutzung teilautomatisierter Funktionen					
A7. Sind Sie bereits (privat oder dienstlich) mit einer Kombination aus aktivem Spurhalteassistent und ACC (teilautomatisiertes System, z. B. Stauassistent) gefahren?	☐ Ja		☐ Nein		
A8. Wenn Sie mit einem Fahrzeug fahren, welches mit einem teilautomatisierten System ausgestattet ist, wie häufig schalten Sie dieses auf der Autobahn ein?	nie	selten	gele-gent-lich	oft	immer
	☐	☐	☐	☐	☐
A9. Wie viele Jahre sind Sie insgesamt mit Fahrzeugen gefahren, die mit einem aktiven Spurhalteassistenten ausgestattet waren?	ca. ____________ Jahre				

Erfahrung mit hochautomatisierten Funktionen		
A10. Haben Sie bereits an Testfahrten mit einem teil- oder hochautomatisierten System teilgenommen?	☐ Ja	☐ Nein

Berufliche Tätigkeit in der Entwicklung automatisierter Fahrfunktionen		
A11. Sind Sie bereits in der Entwicklung und/oder Forschung automatisierter Fahrfunktionen tätig gewesen oder momentan tätig?	☐ Ja	☐ Nein

Ihre Fahrgewohnheiten

B1.	**Wie lange besitzen Sie bereits Ihren Führerschein der Klasse B?**	ca. ________________ Jahre	
B2.	**Legen Sie Ihren Arbeitsweg oder sonstige Strecken (privat oder dienstlich) regelmäßig mit dem Auto zurück?**	☐ Ja ☐ Nein	
B3.	**Wie hoch ist Ihre durchschnittliche jährliche Kilometerleistung (inkl. Urlaubsfahrten, etc.) währen der aktuellen Corona Situation?**	ca. ________________ Kilometer	
B4.	**Wie hoch ist Ihre jährliche Kilometerleistung (inkl. Urlaubsfahrten, etc.) insgesamt (vor der aktuellen Corona Situation)?**	ca. ________________ Kilometer	
B5.	**Wie verteilen sich Ihre Fahrten mit dem Auto (in km) auf folgende Straßentypen (gesamt 100%)?** *Falls Sie einen Straßentyp nicht nutzen, tragen Sie bitte Null ein.*	Stadt (%)	
		Land-/Bundesstraße (%)	
		Autobahn (%)	

Ihre Einstellung zu Technik

C **Wie sehr treffen die folgenden Aussagen auf Sie zu?**

Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Machen Sie in jeder Zeile ein Kreuz.

		trifft absolut nicht zu	trifft eher nicht zu	weder noch	trifft eher zu	trifft absolut zu
		1	**2**	**3**	**4**	**5**
1	Ich kann ziemlich viele der technischen Probleme, mit denen ich konfrontiert bin, alleine lösen.	☐	☐	☐	☐	☐
2	Technische Geräte sind oft undurchschaubar und schwer zu beherrschen.	☐	☐	☐	☐	☐
3	Es macht mir richtig Spaß, ein technisches Problem zu knacken.	☐	☐	☐	☐	☐
4	Weil ich mit bisherigen technischen Problemen gut zurecht gekommen bin, blicke ich auch zukünftigen optimistisch entgegen.	☐	☐	☐	☐	☐
5	Ich fühle mich technischen Problemen gegenüber so hilflos, dass ich lieber die Finger von ihnen lasse.	☐	☐	☐	☐	☐
6	Auch wenn Widerstände auftreten, bearbeite ich ein technisches Problem weiter.	☐	☐	☐	☐	☐
7	Wenn ich ein technisches Problem löse, so geschieht das meist durch Glück.	☐	☐	☐	☐	☐
8	Die meisten technischen Probleme sind so kompliziert, dass es wenig Sinn hat, sich mit ihnen auseinanderzusetzen.	☐	☐	☐	☐	☐

Ihre Einstellung zum automatisierten Fahren

D	**Welche Einstellung haben Sie zum automatisierten Fahren?** *Bitte sagen Sie uns, ob Sie der jeweiligen Aussage zustimmen oder nicht.*			
		Ich neige dazu, zu widersprechen	Ich stimme eher zu	Kann ich nicht beantworten
1	Automatisiertes Fahren kann mich in monotonen oder stressigen Fahrsituationen entlasten.	☐	☐	☐
2	Automatisiertes Fahren kann schwere Unfälle verhindern.	☐	☐	☐
3	Ich glaube nicht, dass es jemals zuverlässig funktionieren wird.	☐	☐	☐
4	Wenn das Auto selber fährt, kann ich andere Dinge tun.	☐	☐	☐
5	Automatisiertes Fahren macht mir Angst.	☐	☐	☐

Ihr Vertrauen in Automationssysteme

E	**Die folgenden Fragen erfassen Ihr Vertrauen in Automationssysteme.** *Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Machen Sie in jeder Zeile ein Kreuz.*					
		Stimme gar nicht zu				Stimme voll zu
		1	**2**	**3**	**4**	**5**
1	Bei unbekannten automatisierten Systemen sollte man eher vorsichtig sein.	☐	☐	☐	☐	☐
2	Ich vertraue einem System eher, als dass ich ihm misstraue.	☐	☐	☐	☐	☐
3	Automatisierte Systeme funktionieren generell gut.	☐	☐	☐	☐	☐

Demographie

G1	**Ihr Alter:** *Geben Sie bitte den Bereich an, in dem sich Ihr Alter befindet.*	<=24	25 -44	45-64	>=65
		☐	☐	☐	☐
G2	**Ihr Geschlecht:**	☐ weiblich ☐ männlich ☐ divers			
G3	**Ihr beruflicher Hintergrund:**	☐technisch ☐ nicht technisch			

C.7 Questionnaire Driving Experiment 3

Fragebogen nach der Instruktion

Wie viele Modi existieren?	____________________
Welche Modi existieren?	____________________
Bitte geben Sie den Modi an, welcher zu der jeweiligen Aussage passt *Überlegen Sie kurz und machen Sie entweder 1 oder 2 Kreuze.*	
1. Der … regelt den Abstand zum Vorderfahrzeug.	
☐ Assistent	☐ Pilot
2. Der … kann selbstständig die Spur halten.	
☐ Assistent	☐ Pilot
3. Der … führt selbstständig Fahrstreifenwechsel durch.	
☐ Assistent	☐ Pilot
4. Der … adaptiert an Geschwindigkeitsbegrenzungen.	
☐ Assistent	☐ Pilot
5. Der … deaktiviert sich, wenn ein Systemlimit auftaucht.	
☐ Assistent	☐ Pilot
6. Der … kann nur in bestimmten Geschwindigkeiten aktiviert werden.	
☐ Assistent	☐ Pilot
7. Im … muss der Fahrer dauerhaft das System überwachen.	
☐ Assistent	☐ Pilot
8. Der … ist nur auf bestimmten Abschnitten aktivierbar.	
☐ Assistent	☐ Pilot
9. Im … darf der Fahrer eine fahrfremde Tätigkeit ausführen.	
☐ Assistent	☐ Pilot
10. Im … wird eine Verfügbarkeitszeit angezeigt.	
☐ Assistent	☐ Pilot

Auf einer Skala von 1 bis 10 – wie schläfrig fühlen Sie sich im Moment?
Kreuzen Sie bitte zutreffendes an. Bitte setzen Sie nur ein Kreuz.

1	☐	Extrem wach
2	☐	Sehr wach
3	☐	Wach
4	☐	Ziemlich wach
5	☐	Weder wach noch müde
6	☐	Etwas müde
7	☐	Müde, aber noch keine Anstrengung nötig, um wach zu bleiben
8	☐	Müde und anstrengend, wach zu bleiben
9	☐	Sehr müde, Kampf gegen den Schlaf
10	☐	Extrem müde, kann nicht mehr wach bleiben
	☐	Keine Angabe

Bitte beurteilen Sie das Automationssystem. Lesen Sie hierfür aufmerksam jedes Wortpaar.
Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Bitte machen Sie jeweils ein Kreuz pro Zeile.

		1	2	3	4	5		Keine Angabe
a	nützlich	☐	☐	☐	☐	☐	nutzlos	☐
b	angenehm	☐	☐	☐	☐	☐	unangenehm	☐
c	schlecht	☐	☐	☐	☐	☐	gut	☐
d	nett	☐	☐	☐	☐	☐	nervig	☐
e	effizient	☐	☐	☐	☐	☐	unnötig	☐
f	ärgerlich	☐	☐	☐	☐	☐	erfreulich	☐
g	hilfreich	☐	☐	☐	☐	☐	wertlos	☐
h	nicht wünschenswert	☐	☐	☐	☐	☐	wünschenswert	☐
i	aktivierend	☐	☐	☐	☐	☐	einschläfernd	☐

Fragebogen nach der Eingewöhnungsfahrt

Wie stand es um Ihre mentale Beanspruchung
Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Bitte machen Sie jeweils ein Kreuz pro Zeile

		Gering 0	1	2	3	4	Hoch 5
1	Wie hoch waren die Anforderungen an die globale Aufmerksamkeit?	☐	☐	☐	☐	☐	☐
2	Wie hoch waren die visuellen Anforderungen?	☐	☐	☐	☐	☐	☐
3	Wie hoch waren die auditiven Anforderungen?	☐	☐	☐	☐	☐	☐
4	Wie hoch warn die manuellen Anforderungen?	☐	☐	☐	☐	☐	☐
5	Wie stark war das Stressniveau?	☐	☐	☐	☐	☐	☐
6	Wie hoch war die zeitliche Anforderung?	☐	☐	☐	☐	☐	☐
7	Wie stark war der Interferenzfaktor?	☐	☐	☐	☐	☐	☐

Auf einer Skala von 1 bis 10 – wie schläfrig fühlen Sie sich im Moment?
Kreuzen Sie bitte zutreffendes an. Bitte setzen Sie nur ein Kreuz.

1	☐	Extrem wach
2	☐	Sehr wach
3	☐	Wach
4	☐	Ziemlich wach
5	☐	Weder wach noch müde
6	☐	Etwas müde
7	☐	Müde, aber noch keine Anstrengung nötig, um wach zu bleiben
8	☐	Müde und anstrengend, wach zu bleiben
9	☐	Sehr müde, Kampf gegen den Schlaf
10	☐	Extrem müde, kann nicht mehr wach bleiben
	☐	Keine Angabe

Fragebogen während der Fahrt

Nach jeder Transition

Die nachfolgenden Fragen beziehen sich auf Ihren jetzigen Zustand, bzw. die vorgehende Fahrt.
Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus.

1. Wie stark ausgeprägt ist Ihre aktuelle mentale Beanspruchung?

gar nicht	sehr wenig			wenig			mittel			stark			sehr stark		
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

2. Wie stark wanderten Ihre Gedanken bei der Fahraufgabe?

gar nicht	sehr wenig			wenig			mittel			stark			sehr stark		
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

3. Wie schläfrig fühlen Sie sich momentan?

gar nicht	sehr wenig			wenig			mittel			stark			sehr stark		
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

4. In welchem Modus haben Sie sich zuvor befunden?	1 = MAN, 2 = ASSISTENT, 3 = PILOT
5. In welchem Modus befinden Sie sich nun?	1 = MAN, 2 = ASSISTENT, 3 = PILOT

6. Ich war mit jederzeit darüber bewusst, welche Aufgaben/Funktionen bei mir und welche beim System liegen

gar nicht	sehr wenig			wenig			mittel			stark			sehr stark		
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

7. Wie vorhersagbar war das Systemverhalten?

gar nicht	sehr wenig			wenig			mittel			stark			sehr stark		
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

8. Ich habe das System permanent überwacht.

gar nicht	sehr wenig			wenig			mittel			stark			sehr stark		
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Nach der unkritischen Geschwindigkeitsreduktion in der Abschlussfahrt

Wie kritisch würden Sie die eben erlebte Übergangssituation beurteilen?		
unkontrollierbar	10	☐
gefährlich	9	☐
	8	☐
	7	☐
unangenehm	6	☐
	5	☐
	4	☐
unbedenklich	3	☐
	2	☐
	1	☐
unmerklich	0	☐

Fragebogen nach der Fahrt

Wie stand es um Ihre mentale Beanspruchung
Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Bitte machen Sie jeweils ein Kreuz pro Zeile

		Gering 0	1	2	3	4	**Hoch** 5
1	Wie hoch waren die Anforderungen an die globale Aufmerksamkeit?	☐	☐	☐	☐	☐	☐
2	Wie hoch waren die visuellen Anforderungen?	☐	☐	☐	☐	☐	☐
3	Wie hoch waren die auditiven Anforderungen?	☐	☐	☐	☐	☐	☐
4	Wie hoch warn die manuellen Anforderungen?	☐	☐	☐	☐	☐	☐
5	Wie stark war das Stressniveau?	☐	☐	☐	☐	☐	☐
6	Wie hoch war die zeitliche Anforderung?	☐	☐	☐	☐	☐	☐
7	Wie stark war der Interferenzfaktor?	☐	☐	☐	☐	☐	☐

Auf einer Skala von 1 bis 10 – wie schläfrig fühlen Sie sich im Moment?
Kreuzen Sie bitte zutreffendes an. Bitte setzen Sie nur ein Kreuz.

1	☐	Extrem wach
2	☐	Sehr wach
3	☐	Wach
4	☐	Ziemlich wach
5	☐	Weder wach noch müde
6	☐	Etwas müde
7	☐	Müde, aber noch keine Anstrengung nötig, um wach zu bleiben
8	☐	Müde und anstrengend, wach zu bleiben
9	☐	Sehr müde, Kampf gegen den Schlaf
10	☐	Extrem müde, kann nicht mehr wach bleiben
	☐	Keine Angabe

Wie viele Modi existieren?	____________________
Welche Modi existieren?	____________________

Bitte geben Sie den Modi an, welcher zu der jeweiligen Aussage passt
Überlegen Sie kurz und machen Sie entweder 1 oder 2 Kreuze.

1. Der … regelt den Abstand zum Vorderfahrzeug.	
☐ Assistent	☐ Pilot
2. Der … kann selbstständig die Spur halten.	
☐ Assistent	☐ Pilot
3. Der … führt selbstständig Fahrstreifenwechsel durch.	
☐ Assistent	☐ Pilot
4. Der … adaptiert an Geschwindigkeitsbegrenzungen.	
☐ Assistent	☐ Pilot
5. Der … deaktiviert sich, wenn ein Systemlimit auftaucht.	
☐ Assistent	☐ Pilot
6. Der … kann nur in bestimmten Geschwindigkeiten aktiviert werden.	
☐ Assistent	☐ Pilot
7. Im … muss der Fahrer dauerhaft das System überwachen.	
☐ Assistent	☐ Pilot
8. Der … ist nur auf bestimmten Abschnitten aktivierbar.	
☐ Assistent	☐ Pilot
9. Im … darf der Fahrer eine fahrfremde Tätigkeit ausführen.	
☐ Assistent	☐ Pilot
10. Im … wird eine Verfügbarkeitszeit angezeigt.	
☐ Assistent	☐ Pilot

Bitte beurteilen Sie das Automationssystem. Lesen Sie hierfür aufmerksam jedes Wortpaar.

Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Bitte machen Sie jeweils ein Kreuz pro Zeile.

		1	2	3	4	5		Keine Angabe
a	nützlich	☐	☐	☐	☐	☐	nutzlos	☐
b	angenehm	☐	☐	☐	☐	☐	unangenehm	☐
c	schlecht	☐	☐	☐	☐	☐	gut	☐
d	nett	☐	☐	☐	☐	☐	nervig	☐
e	effizient	☐	☐	☐	☐	☐	unnötig	☐
f	ärgerlich	☐	☐	☐	☐	☐	erfreulich	☐
g	hilfreich	☐	☐	☐	☐	☐	wertlos	☐
h	nicht wünschenswert	☐	☐	☐	☐	☐	wünschenswert	☐
i	aktivierend	☐	☐	☐	☐	☐	einschläfernd	☐

Bitte geben Sie an, wie stark Sie den Aussagen über das Automationssystem zustimmen.

Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Bitte machen Sie jeweils ein Kreuz pro Zeile.

		Trifft absolut nicht zu				Trifft absolut zu	
		1	2	3	4	5	Keine Angabe
a	Das System ist imstande, Situationen richtig einzuschätzen.	☐	☐	☐	☐	☐	☐
b	Mir war durchgehend klar, in welchem Zustand sich das System befindet.	☐	☐	☐	☐	☐	☐
c	Bei unbekannten automatisierten Systemen sollte man eher vorsichtig sein.	☐	☐	☐	☐	☐	☐

d	Das System arbeitet zuverlässig.	☐	☐	☐	☐	☐	☐
e	Das System reagiert unvorhersehbar.	☐	☐	☐	☐	☐	☐
f	Ich vertraue dem System.	☐	☐	☐	☐	☐	☐
g	Ein Ausfall des Systems ist wahrscheinlich.	☐	☐	☐	☐	☐	☐
h	Ich konnte nachvollziehen, warum etwas passiert ist.	☐	☐	☐	☐	☐	☐
i	Ich vertraue einem System eher, als dass ich ihm misstraue.	☐	☐	☐	☐	☐	☐
j	Das System kann wirklich komplizierte Aufgaben übernehmen.	☐	☐	☐	☐	☐	☐
k	Ich kann mich auf das System verlassen.	☐	☐	☐	☐	☐	☐
l	Das System könnte stellenweise einen Fehler machen.	☐	☐	☐	☐	☐	☐
m	Zu erkennen, was das System als Nächstes macht, ist schwer.	☐	☐	☐	☐	☐	☐
n	Automatisierte Systeme funktionieren generell gut.	☐	☐	☐	☐	☐	☐
o	Ich bin überzeugt von den Fähigkeiten des Systems.	☐	☐	☐	☐	☐	☐

Bitte geben Sie an, wie stark Sie den Aussagen über das Automationssystem zustimmen.

Bitte beantworten Sie diese Fragen anhand der Skala, welche aus 5 verbalen Kategorien von „Sehr gering“ bis „Sehr hoch“ besteht. Wählen Sie zunächst die Kategorie aus, die Ihrem Empfinden nach am besten passt. Dann nutzen Sie die Zahlen darunter, um eine Tendenz innerhalb der Kategorie anzugeben. Beispielsweise ist 9 „neutral mit der Tendenz zu hoch“.

Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Bitte machen Sie jeweils ein Kreuz pro Zeile.

Frage	sehr gering			gering			neutral			hoch			sehr hoch			Keine Angabe
1. Ich war mir jederzeit darüber bewusst, in welcher Stufe sich das System befand.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	☐
2. Ich habe das System, wenn es erforderlich war, permanent überwacht.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	☐
3. Ich war mir jederzeit darüber bewusst, welche Aufgaben/Funktionen bei mir und welche beim System liegen.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	☐
4. Ich war mir jederzeit darüber bewusst, dass ich in das Fahrgeschehen eingreifen muss, wenn die Situation dies erfordert.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	☐
5. Ich war mir auch in komplexen Situationen darüber bewusst, was das System macht und konnte den Handlungen des Systems gut folgen.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	☐
6. Ich habe dem System die Kontrolle in den Fahrsituationen komplett abgegeben und es nicht mehr überwacht.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	☐
7. Über die Zeit fiel es mir schwerer das System zu überwachen.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	☐

Wie stand es um Ihre Gedanken während der Fahrt

Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Bitte machen Sie jeweils ein Kreuz pro Zeile.

		Trifft überhaupt nicht zu 1	Trifft eher nicht zu 2	Trifft weder noch zu 3	Trifft eher zu 4	Trifft voll und ganz zu 5
1	Ich dachte an angehörige meiner Familie	☐	☐	☐	☐	☐
2	Ich dachte an etwas, das mir ein Schuldgefühl gab	☐	☐	☐	☐	☐
3	Ich dachte über persönliche Sorgen nach	☐	☐	☐	☐	☐
4	Ich dachte über etwas nach, das mich wütend machte	☐	☐	☐	☐	☐
5	Ich dachte an etwas, das vorhin passiert ist	☐	☐	☐	☐	☐
6	Ich dachte an etwas, das in der jüngsten Vergangenheit passiert ist	☐	☐	☐	☐	☐
7	Ich dachte an etwas, das in der fernen Vergangenheit passiert ist	☐	☐	☐	☐	☐
8	Ich dachte an etwas, das vielleicht in der Zukunft passieren könnte	☐	☐	☐	☐	☐

Bitte beurteilen Sie das Feedback des Fahrzeugs.

Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus.

		1 (trifft absolut nicht zu)	2	3	4	5	6	7 (trifft absolut zu)	Keine Angabe
a	Das Feedback des Systems hat mich bei der Ausführung der fahrfremden Tätigkeit abgelenkt.	☐	☐	☐	☐	☐	☐	☐	☐
b	Das Feedback des Systems hat mich bei der Ausführung der fahrfremden Tätigkeit gestört.	☐	☐	☐	☐	☐	☐	☐	☐
c	Das Feedback des Systems hat mich bei der Ausführung der fahrfremden Tätigkeit entlastet.	☐	☐	☐	☐	☐	☐	☐	☐
d	Das Feedback des Systems hat mich bei der Überwachung des Systems abgelenkt.	☐	☐	☐	☐	☐	☐	☐	☐
e	Das Feedback des Systems hat mich bei der Überwachung des Systems gestört.	☐	☐	☐	☐	☐	☐	☐	☐
f	Das Feedback des Systems hat mich bei der Überwachung des Systems entlastet.	☐	☐	☐	☐	☐	☐	☐	☐

Bitte geben Sie an, wie stark Sie den Aussagen über das Automationssystem zustimmen.

Bitte beantworten Sie diese Fragen anhand der Skala, welche aus 5 verbalen Kategorien von „Sehr gering" bis „Sehr hoch" besteht. Wählen Sie zunächst die Kategorie aus, die Ihrem Empfinden nach am besten passt. Dann nutzen Sie die Zahlen darunter, um eine Tendenz innerhalb der Kategorie anzugeben. Beispielsweise ist 9 „neutral mit der Tendenz zu hoch".

Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Bitte machen Sie jeweils ein Kreuz pro Zeile.

Für den Modus: **Manuell**

Ich war mir jederzeit darüber bewusst, welche Aufgaben/Funktionen bei mir und welche beim System liegen.

sehr gering			gering			neutral			hoch			sehr hoch		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Für den Modus: **Assistent**

Ich war mir jederzeit darüber bewusst, welche Aufgaben/Funktionen bei mir und welche beim System liegen.

sehr gering			gering			neutral			hoch			sehr hoch		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Für den Modus: **Pilot**

Ich war mir jederzeit darüber bewusst, welche Aufgaben/Funktionen bei mir und welche beim System liegen.

sehr gering			gering			neutral			hoch			sehr hoch		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Anmerkungen

E1	**Haben Sie positive Anmerkungen zu der erlebten Fahrt?**
E2	**Haben Sie negative Anmerkungen zu der erlebten Fahrt?**
E3	**Haben Sie sonstige Anmerkungen zu der erlebten Fahrt?**

Fragebogen nach Fehler

Bitte beachten Sie bei der Beantwortung folgende Hinweise:

- Die Fragen beziehen sich ausschließlich auf die **zuletzt erlebte Fahrt**.
- Bitte antworten Sie *spontan* auf alle Fragen.
- Es gibt *keine* richtigen oder falschen Antworten, es geht ausschließlich um Ihre persönliche Einschätzung.

Wie stand es um Ihre mentale Beanspruchung

Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Bitte machen Sie jeweils ein Kreuz pro Zeile

		Gering **0**	**1**	**2**	**3**	**4**	**Hoch** **5**	**Keine Angabe**
1	Wie hoch waren die Anforderungen an die globale Aufmerksamkeit?	☐	☐	☐	☐	☐	☐	☐
Insgesamt alle mentalen (denken, entscheiden, …), visuellen und auditiven Faktoren, die insgesamt während des Versuchs erforderlich sind, um die Gesamtleistung zu erzielen								
2	Wie hoch waren die visuellen Anforderungen?	☐	☐	☐	☐	☐	☐	☐
Visuelle Faktoren, die währende des Versuchs erforderlich sind, um die Gesamtleistung zu erzielen (alles, was mit dem Sehen zu tun hat)								
3	Wie hoch waren die auditiven Anforderungen?	☐	☐	☐	☐	☐	☐	☐
Auditive Faktoren, die während des Versuchs erforderlich sind, um die Gesamtleistung zu erzielen (alles was mit dem Gehörten zu tun hat)								
4	Wie hoch warn die manuellen Anforderungen?	☐	☐	☐	☐	☐	☐	☐
Manuelle Faktoren, die während des Versuchs erforderlich sind, um die Gesamtleistung zu erzielen (alles was mit der Handhabung zu tun hat)								
5	Wie stark war das Stressniveau?	☐	☐	☐	☐	☐	☐	☐
Stressniveau während des Versuchsablaufs wie Irritation, Müdigkeit, Unsicherheit, Entmutigung, etc.								

6	Wie hoch war die zeitliche Anforderung?	☐	☐	☐	☐	☐	☐	☐
Gefühlte Belastung und spezifische Beeinträchtigung durch die schnelle Abfolge der Aufgaben								
7	Wie stark war der Interferenzfaktor?	☐	☐	☐	☐	☐	☐	☐
Beeinträchtigung des Fahrerzustandes auf die Fahrleistung durch die gleichzeitige Zweitaufgabe								

Auf einer Skala von 1 bis 10 – wie schläfrig fühlen Sie sich im Moment?

Kreuzen Sie bitte zutreffendes an. Bitte setzen Sie nur ein Kreuz.

1	☐	Extrem wach
2	☐	Sehr wach
3	☐	Wach
4	☐	Ziemlich wach
5	☐	Weder wach noch müde
6	☐	Etwas müde
7	☐	Müde, aber noch keine Anstrengung nötig, um wach zu bleiben
8	☐	Müde und anstrengend, wach zu bleiben
9	☐	Sehr müde, Kampf gegen den Schlaf
10	☐	Extrem müde, kann nicht mehr wach bleiben
	☐	Keine Angabe

Bitte geben Sie an, wie stark Sie den Aussagen über das Automationssystem zustimmen.
Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Bitte machen Sie jeweils ein Kreuz pro Zeile.

		stimme **gar nicht** zu **1**	stimme **eher nicht** zu **2**	stimme **weder zu noch nicht** zu **3**	stimme **eher** zu **4**	stimme **voll** zu **5**	Keine Angabe
a	Das System ist imstande, Situationen richtig einzuschätzen.	☐	☐	☐	☐	☐	☐
b	Mir war durchgehend klar, in welchem Zustand sich das System befindet.	☐	☐	☐	☐	☐	☐
c	Das System arbeitet zuverlässig.	☐	☐	☐	☐	☐	☐
d	Das System reagiert unvorhersehbar.	☐	☐	☐	☐	☐	☐
e	Ich vertraue dem System.	☐	☐	☐	☐	☐	☐
f	Ein Ausfall des Systems ist wahrscheinlich.	☐	☐	☐	☐	☐	☐
g	Ich konnte nachvollziehen, warum etwas passiert ist.	☐	☐	☐	☐	☐	☐
h	Das System kann wirklich komplizierte Aufgaben übernehmen.	☐	☐	☐	☐	☐	☐
i	Ich kann mich auf das System verlassen.	☐	☐	☐	☐	☐	☐
j	Das System könnte stellenweise einen Fehler machen.	☐	☐	☐	☐	☐	☐
k	Zu erkennen, was das System als Nächstes macht, ist schwer.	☐	☐	☐	☐	☐	☐
l	Ich bin überzeugt von den Fähigkeiten des Systems.	☐	☐	☐	☐	☐	☐

Bitte beurteilen das Automationssystem , wie Sie es Anhand der Instruktion präsentiert bekommen haben. Lesen Sie hierfür aufmerksam jedes Wortpaar.

Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Bitte machen Sie jeweils ein Kreuz pro Zeile.

		1	2	3	4	5		Keine Angabe
1	nützlich	☐	☐	☐	☐	☐	nutzlos	
2	angenehm	☐	☐	☐	☐	☐	unangeneh m	
3	schlecht	☐	☐	☐	☐	☐	gut	
4	nett	☐	☐	☐	☐	☐	nervig	
5	effizient	☐	☐	☐	☐	☐	unnötig	
6	ärgerlich	☐	☐	☐	☐	☐	erfreulich	
7	hilfreich	☐	☐	☐	☐	☐	wertlos	
8	nicht wünschens wert	☐	☐	☐	☐	☐	wünschens wert	
9	aktivierend	☐	☐	☐	☐	☐	einschläfern d	

Abschlussfragebogen

Inwieweit haben Sie einen Unterschied im Feedback zwischen beiden erlebten Systemmodi wahrgenommen?

gar nicht	gering	mittel	hoch	völlig	Keine Angabe
☐	☐	☐	☐	☐	☐

Bitte beschreiben Sie den wahrgenommenen Unterschied.

Haben Sie noch weitere Anmerkungen oder Hinweise?

Wie bewerten Sie das Konzept hinsichtlich der Unterstützung in Ihren Aufgaben?

Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus.

Trifft absolut nicht zu — Trifft absolut zu

		1	2	3	4	5	6	7	Keine Angabe
a	Mir hat das visuelle und auditive Feedbackkonzept gefallen	☐	☐	☐	☐	☐	☐	☐	☐
b	Mir hat das visuelle, auditive und vestibuläre Feedbackkonzept gefallen	☐	☐	☐	☐	☐	☐	☐	☐