Technische Universität München

Fakultät für Maschinenwesen

Lehrstuhl für Ergonomie

Design of Active Vehicle Pitch and Roll Motions as Feedback for the Driver During Automated Driving

Stephanie Cramer

Vollständiger Abdruck der von der Fakultät für Maschinenwesen der Technischen Universität München zur Erlangung des akademischen Grades eines Doktor-Ingenieurs (Dr.-Ing.) genehmigten Dissertation.

Vorsitzender:		Prof. Dr.-Ing. Gunther Reinhart
Prüfer der Dissertation:	1.	Prof. Dr. phil. Klaus Bengler
	2.	Prof. Dr. phil. Berthold Färber

Die Dissertation wurde am 15.11.2018 bei der Technischen Universität München eingereicht und durch die Fakultät für Maschinenwesen am 24.05.2019 angenommen.

Acknowledgements

This thesis would not have been possible without the support and contributions of many people. I would like to thank all of these people and in particular the following. First, special thanks go to my supervisor Prof. Bengler. You opened up the field of human factors for me close to the end of my studies and made it possible to conduct my doctoral thesis. Especially, I would like to thank you for your trust, as well as the challenging discussions and remarks. Moreover, special thanks go to Prof. Färber for your interest in this thesis and for joining the committee as an examiner, and Prof. Reinhart for serving as chair of the examination committee.

I would like to cordially thank my colleagues of the chair of ergonomics at TU Munich. I really enjoyed the time at the institute, especially the scientific and social discussions. In particular, I would like to thank Martin Albert, Anna Feldhütter, Patrick Gontar, and Sonja Schneider for various reasons.

Huge thanks go to my colleagues from the AI-Lab and my supervisor Dr. Karl-Heinz Siedersberger at Audi. It was always a pleasure to work or spend time outside work with you guys in such a friendly and respectful manner. The mutual support was excellent. Keep going AI-Lab! It was a great time!

It would not have been possible to get my “OI, Kleiner, Kübel, or Shrek” (or however we might have called “that” vehicle) running for my driving studies without you two guys: Stephan Bültjes and Stefan Sandig. Although, it was a tough time, I love to remind myself of the time in the workshop when we disaggregated the actuators and repaired them. Your positive and funny attitude always brought OI and me back on track. Moreover, Bülti, I do not know how many hours we spent in that vehicle on the test track or the motorway - laughing, being desperate, or just talking social stuff - but I know that I could not have imagined a better companion for that!

Furthermore, I would like to thank all of my students who supported me in technical issues or in my driving studies. Without them, this research would have never been possible. Especially, I would like to thank Benjamin Miller, Ina Kaup, Jana Klohr, and Mareike Schüle. Spending weeks on the test track or even in the test vehicle was tough but really worth it. Thanks for being such a great company and for your extraordinary passion you put into the work!

This thesis would not have been possible without the support, understanding, and motivation of my family and friends. Thanks mum and dad for the freedom and support you gave me to achieve my goals. Thanks Oana for supporting me throughout my doctoral studies with proofreading all my papers and my final thesis!

Finally, I would like to thank Alex. You supported me from the very first day until the end of this project through all the ups and downs. You always had an open ear and motivated me. Thanks Alex for being so amazing!

Abstract

During partially automated driving, the automation system takes over the lateral and longitudinal vehicle guidance; the driver has to supervise the automation system permanently and must be able to take over the vehicle guidance at once at system limits. Therefore, having awareness of the automation system's functionality is essential for drivers to fulfill their supervising task sufficiently. Feedback on state transitions and intentions of the automation system, e. g. lane changes, is crucial to obtain, as well as increase the driver's awareness of the automation system. So far, this feedback is usually presented visually to the driver. Conversely, in this thesis, the feedback for state transitions and intentions of the automation is communicated to the driver via active pitch and roll motions of the chassis; this is realized with an electromechanical active body control vehicle.

First of all, the theoretical foundations on the relation between the driver and the automation system, as well as on human perception of motions are presented. Following, a feedback concept via active pitch and roll motions for partially automated motorway driving is described. Subsequently, relevant research questions regarding this feedback concept are addressed in four driving studies either on a test track or on the motorway. Several pitch and roll motion designs were implemented in an automated test vehicle. The studies focused on the detailed designs of active pitch and roll motions for certain test scenarios, the perceptibility, timing, intensity, and comprehensibility of the feedback, and further on the questions of acceptance, induced discomfort, and support of the driver's supervising task by the feedback. The results indicate that pitch motions should inform the driver about driving actions in the longitudinal direction, e. g. the detection of a cutting-in vehicle, and roll motions about driving actions in the lateral direction, e. g. announcing lane changes. The course of the rotational motions should have a degressive profile and be clearly perceptible. Participants perceived active pitch motions and did not regard them as passive pitch motions induced by the vehicle's acceleration or deceleration. Following, most of these non-expert participants understood the meaning of these motions. Moreover, feedback via pitch and roll motions is considered useful, supporting the drivers regarding their mode/system awareness, and not misleading. Thus, active rotational motions can complement visual feedback, resulting in multi-modal feedback. Comparing this multi-modal to visual-only feedback, the reaction behavior of the participants at a system failure was independent of the type of feedback. However, the system awareness was significantly higher for multi-modal feedback.

Kurzfassung

Beim teilautomatisierten Fahren führt das Automationssystem die Fahrzeuglängs- und -querführung aus. Dabei muss der Fahrer die Automation dauerhaft überwachen und jederzeit in der Lage sein die Fahrzeugführung an Systemgrenzen sofort zu übernehmen. Deswegen ist es für den Fahrer unbedingt notwendig ein Bewusstsein über die Funktionalitäten des Automationssystems zu haben, um die Überwachungsaufgabe angemessen auszuführen. Rückmeldung über Zustandsänderungen und Intentionen der Automation, beispielweise Fahrstreifenwechsel, sind wichtig, um das Bewusstsein des Fahrers über die Automation zu erhalten bzw. zu erhöhen. Bisher wurden diese Informationen üblicherweise visuell an den Fahrer übertragen. Im Gegensatz dazu werden in dieser Dissertation die Rückmeldungen über Zustandsänderungen und Intentionen der Automation mit Hilfe von aktiven Nick- und Wankbewegungen des Fahrzeugs gestaltet. Zunächst werden dafür die theoretischen Grundlagen über das Zusammenspiel von Fahrer und Automation sowie über die menschliche Bewegungswahrnehmung geschaffen. Anschließend wird das Rückmeldekonzept mit aktiven Nick- und Wankbewegungen für teilautomatisiertes Fahren beschrieben. Darauf aufbauend werden die für dieses Rückmeldekonzept relevanten Forschungsfragen in vier Realfahrzeugstudien, entweder auf der Teststrecke oder der Autobahn, adressiert.

Verschiedene Variationen der Nick- und Wankbewegungen wurden in einem automatisiert fahrenden Testfahrzeug implementiert. Die Studien haben sich auf die detaillierte Gestaltung dieser aktiven Bewegungen für bestimmte Testszenarien, die Wahrnehmbarkeit, den Zeitpunkt, die Intensität, die Verständlichkeit, die Akzeptanz und den Diskomfort der Rückmeldung sowie den Beitrag zum Systembewusstsein des Fahrers für die Automation fokussiert. Die Ergebnisse zeigen, dass Nickbewegungen den Fahrer über Fahraktionen in Längsrichtung, z. B. die Detektion eines einscherenden Fahrzeugs, und Wankbewegungen über Fahraktionen in Querrichtung, z. B. die Ankündigung eines Fahrstreifenwechsels informieren sollten. Der Verlauf der Rotationsbewegungen sollte degressiv und deutlich wahrnehmbar gestaltet sein. Probanden nahmen die aktiven Nickbewegungen wahr und haben diese nicht als passive Nickbewegungen empfunden, wie sie z. B. durch Beschleunigungen oder Verzögerungen hervorgerufen werden. Fast alle dieser Probanden, welche keine Experten waren, haben die Bedeutung der Bewegungen verstanden. Des Weiteren wurde die Rückmeldung durch Nick- und Wankbewegungen als sinnvoll, nicht irreführend und das Systembewusstsein des Fahrers unterstützend betrachtet. Folglich können aktive Rotationsbewegungen eine visuelle Rückmeldung ergänzen, was zu einer multi-modalen Rückmeldung führt. Beim Vergleich dieser multi-modalen zu einer rein visuellen Rückmeldung konnte kein Unterschied im Reaktionsverhalten der Probanden beobachtet werden. Allerdings verbesserte sich das Systembewusstsein signifikant mit der multi-modalen Rückmeldung.

Publications

The author of this thesis published as first author the following thesis related papers:

- Cramer, S., Kaup, I., & Siedersberger, K.-H. (2018). Comprehensibility and Perceptibility of Vehicle Pitch Motions as Feedback for the Driver During Partially Automated Driving. *IEEE Transactions on Intelligent Vehicles*, 4(1), 3–13. doi: 10.1109/TIV.2018.2886691 © 2018 IEEE

- Cramer, S. & Klohr, J. (2019). Announcing Automated Lane Changes: Active Vehicle Roll Motions as Feedback for the Driver. *International Journal of Human-Computer Interaction*, 35(11), 980–995. doi: 10.1080/10447318.2018.1561790

- Cramer, S., Lange, A., Bültjes, S. & Klohr, J. (2017). Design Possibilities for Vehicle Roll Motions as Feedback for the Driver during Automated Driving. In A. Löcken et al. (Eds.), *9th International ACM Conference on Automotive User Interfaces and Interactive Vehicular Applications* (pp. 152-157). doi: 10.1145/3131726.3131746

- Cramer, S., Miller, B., Siedersberger, K.-H. & Bengler, K. (2017). Perceive the Difference: Vehicle Pitch Motions as Feedback for the Driver. In *IEEE International Conference on Systems, Man, and Cybernetics* (pp. 1699-1704). doi:10.1109/SMC.2017.8122860 © 2017 IEEE

- Cramer, S., Siedersberger, K.-H. & Bengler, K. (2017). Active Vehicle Pitch Motions as Feedback-Channel for the Driver during Partially Automated Driving. In Uni-DAS e. V. (Ed.), *11. Workshop Fahrerassistenz und automatisiertes Fahren* (pp. 74-83).

Supervised Theses

Within the scope of this thesis, following topic related student theses occurred with a significant scientific, content-related, and specialist knowledge of this thesis' author. Thanks to all students for their support for this research.

- Bentz, J. (2017). *Menschliche Wahrnehmung von Fahrdynamikgrößen.* (Semester thesis). Technische Universität München.
- Kaup, I. (2017). *Teilautomatisiertes Fahren: Unterstützung des Fahrers durch ein vestibuläres Feedback.* (Master's thesis). Technische Universität München.
- Klohr, J. (2017). *Evaluation aktiver Fahrzeugwankbewegungen als Rückmeldung beim teilautomatisierten Fahren.* (Master's thesis). Technische Universität Darmstadt.
- Miller, B. (2016). *Wirkweise und Akzeptanz von Nick- und Wankbewegungen als Feedback-Kanal für den Fahrer beim automatisierten Fahren.* (Master's thesis). Technische Universität Darmstadt.
- Titze, S. (2017). *Informationsgestaltung für den Fahrer eines Kraftfahrzeugs in Abhängigkeit des Automatisierungslevels.* (Semester thesis). Technische Universität München.

Contents

1 Introduction

Advanced driver assistance systems (ADAS) play a significant role in research and development in the automotive industry as well as university research. The term ADAS covers all technical systems that support drivers during their driving task, and in doing so relieve the drivers specifically (Maurer, 2009). This concerns the primary and parts of the secondary driving task (Bubb, 2015b; Bubb & Bengler, 2015). Existing ADAS in series production vehicles are, for example: adaptive cruise control (ACC), lane keeping assistance (LKA), automated parking systems, or traffic jam assistance (Bartels, Rohlfs, Hammel, Saust, & Klauske, 2016; Gotzig, 2016; Lüke, Fochler, Schaller, & Regensburger, 2016; Winner & Schopper, 2016). Currently, the development and research of ADAS tend towards higher levels of automation. As a first step, motorway driving represents a suitable entry scenario for higher automation level systems due to its manageable complexity (Bengler et al., 2014). Motorway traffic represents a structured environment that facilitates the technical implementation of automated driving. In addition, it offers the possibility to support the driver in a repetitive and monotonous driving scenario. Moreover, studies show that drivers preferably consider automated driving as most useful on motorways (Sommer, 2013). From a technical perspective, conditionally or even highly automated driving (SAE-Level 3 and 4 (SAE, 2016)) come within reach. However, the driver has to take over the vehicle guidance within a certain amount of time for level 3 (Gasser, Arzt, Ayoubi, Bartels, Bürkle, et al., 2012). Nevertheless, there are still some remaining technical challenges concerning, for instance, functional safety, sensors, and situation interpretation. Therefore, partially automated driving (SAE-Level 2) is an intermediate step on the way to higher levels of automation and will prospectively be available parallel to higher automated driving systems. From level 2 upwards, the system can take over the longitudinal and lateral vehicle guidance, at least temporarily and depending on the situation (SAE, 2016; VDA, 2015). The main difference between SAE-Levels 2 and 3 is that during partially automated driving, the driver must continuously supervise the system and serves as a fallback level at system limits, while at level 3 the driver must be able to do so after a sufficient time budget (Gasser, Arzt, Ayoubi, Bartels, Bürkle, et al., 2012; SAE, 2016). (Cramer, Kaup, & Siedersberger, 2018)

1.1 Motivation

For all the before mentioned levels, the consideration of the human-computer interaction, in this specific case the human-vehicle interaction, is essential for developing such systems. So far, studies focused, for instance, on the design of visual displays (e. g. Harvey, Stanton, Pickering, McDonald, & Zheng, 2011; Lee, Hwangbo, & Ji, 2016; Normark, 2015; Pfannmüller, Kramer, Senner, & Bengler, 2015), haptic interfaces (e. g. Petermeijer, Cieler, & de Winter, 2017; Wan & Wu, 2017), auditory or rather speech-based interfaces (e. g. Koo et al., 2015; Sirkin, Fischer, Jensen, & Ju, 2016), trust in automation (e. g. Choi & Ji, 2015; Körber, Baseler, & Bengler, 2018), take-over requests (e. g. Gold, Damböck, Lorenz, & Bengler, 2013; Gold, Happee, & Bengler, 2017), and shared control (e. g. Flemisch, Bengler, Bubb, Winner, & Bruder, 2014; Hoc, Young, & Blosseville, 2009; Petermeijer, Abbink, & de Winter, 2015).

Automation of vehicle guidance does not only include positive effects (Bainbridge, 1983). One risk is that the driver mentally withdraws from the vehicle guidance. This is especially challenging at system limits of the automation system, as the driver possibly has an increased reaction time and, hence, needs some seconds to take over the vehicle guidance completely (Gold, Damböck, Bengler, & Lorenz, 2013). From assisted, over partially, to conditionally automated driving, this has to be considered because drivers have to take over the vehicle guidance immediately or after a relatively short amount of time (Gasser, Arzt, Ayoubi, Bartels, Bürkle, et al., 2012). “Out-of-the-loop” effects occur because of a lack of monitoring of the system, omission of feedback, insufficient transparency of the automation system, distractions, excessively high trust and misuse (Merat, Jamson, Lai, & Carsten, 2012; Parasuraman & Riley, 1997; Saffarian, de Winter, & Happee, 2012; Sarter & Woods, 1995). Moreover, a lack of understanding of the system, as well referred to as driver’s inaccurate mental models of the automation system (Beggiato et al., 2015; König, 2016; I. Wolf, 2016), accompanied by a lacking situation and mode awareness (Endsley & Kiris, 1995; Parasuraman & Wickens, 2008; Sarter & Woods, 1995) cause “out-of-the-loop” effects as well. To avoid this negative impact and keep the driver “in-the-loop”, feedback on system behavior and system state (e. g. current and prospective maneuver) is indispensable. This feedback plays an important role for the driver as supervisor during partially automated driving in conveying a coherent understanding of the system state (Beggiato et al., 2015; Bubb, Bengler, Breuninger, Gold, & Helmbrecht, 2015; Itoh & Inagaki, 2004; Norman, 1990; Sarter & Woods, 1995; Wickens, Hollands, & Parasuraman, 2013). Consequently, state transitions and intentions of the automation should be fed back to drivers in order to obtain as well as increase their mode awareness and, thus, fulfill their supervising task sufficiently (Beggiato et al., 2015; Sarter & Woods, 1995). Mode awareness of the current system state exists if the driver has a suitable mental model of the vehicle's automation system, therefore knows in which state the automation system is, and anticipates prospective state transitions (Boer & Hoedemaeker, 1998; Norman, 1990; Lange, Albert, Siedersberger, & Bengler, 2015).

So far, feedback on the system state, state transitions, or the intentions of the automation have mainly been carried out via the visual, auditory, or haptic sensory channels (Bubb, Bengler, et al., 2015; Knoll, 2016). Visual feedback is presented via the instrument cluster, other displays in the center console (e. g. Albert, Lange, Schmidt, Wimmer, & Bengler, 2015; Othersen, 2016), via the contact analogue head-up display (e. g. Damböck, Weißgerber, Kienle, & Bengler, 2012), or ambient light displays (e. g. Löcken, Heuten, & Boll, 2016). Visual feedback has the disadvantage that drivers have to focus on a display, which is usually not in their primary field of view. Regarding current displays showing visual information, these are already overloaded and present a lot of information unrelated to the supervising task (Fisher, Lohrenz, Moore, Nadler, & Pollard, 2016; van den Beukel, van der Voort, & Eger, 2016). Moreover, each sensory channel is limited in its performance (Wickens et al., 2013). Hence, feeding back information to the driver via multiple sensory channels is more effective (Bubb, Bengler, et al., 2015). Consequently, to support the driver's mode awareness or rather system awareness, the system state or state transitions should be communicated in advance in a multi-modal manner via several sensory channels (Bubb, Bengler, et al., 2015; Othersen, 2016). Multi-modal feedback is mentioned by Rhiu, Kwon, Bahn, Yun, and Yu (2015) as one of the areas where not enough research has been conducted by the human-computer interaction society and should be addressed in future research in particular in real vehicles.

Vehicle movements (sensed by the vestibular, visual, as well as haptic system) represent one possibility to complement visual feedback in order to generate a multi-modal feedback that is even perceptible without focusing on a display. Furthermore, Sivak and Schoettle (2015) mention that vehicle motion for anticipating the direction of motion should be improved in self-driving vehicles. An approach for using vehicle movements in the vehicle's lateral and longitudinal direction as feedback for the driver to announce, for example, an upcoming lane change is shown in Lange, Maas, Albert, Siedersberger, and Bengler (2014), and Lange, Albert, et al. (2015). C. Müller, Siedersberger, Färber, and Popp (2017) describe a vestibular feedback concept that supports the driver in the lateral vehicle guidance via active vehicle roll motions realized by an active body control vehicle. Moreover, Lange, Müller, Reichel, and Albert (2015) mentioned the idea of announcing maneuvers during automated driving via rotational body movements of the vehicle. This theoretical idea is picked up for this thesis and is specified as feeding back state transitions or intentions of the automation system at an early stage via rotational motions of the chassis during partially automated motorway driving. The rotational motions include active pitch (rotation around the vehicle's lateral axis) and roll motions (rotation around the vehicle's longitudinal axis) of the chassis, which are realized with an active body control vehicle that can lift and lower each wheel separately.

1.2 Research Objectives

To create a useful feedback concept, different design possibilities of pitch and roll motions are implemented in a test vehicle. The feedback concept is evaluated in certain motorway scenarios in four driving studies on the test track or the motorway. Therefore, essential research objectives are:

- Are active pitch and roll motions a suitable, useful, comprehensible, and accepted feedback for drivers to inform them about state transitions or upcoming maneuvers? Does this feedback concept positively contribute to drivers' system awareness?
- What are important design criteria for the pitch and roll motions to support drivers in their monitoring task while driving partially automated? In particular, how should the course or the direction of these rotational motions be? Are the rotational motions perceptible and not inducing discomfort at the same time?
- What impression of the automation system as well as the feedback concept do the participants receive regarding safety, trust, and acceptance of the automation system?
- Which motorway driving scenarios are and which are not suitable for feeding back state transitions or intentions of the automation system via pitch and roll motions?
- How is a visual-only feedback rated compared to a multi-modal feedback including visual and vestibular information? Thereby, trust, acceptance, reaction time at system failures, and system awareness should be evaluated for instance.

In the following chapters, answers to these research objectives are established. First, the outline of the thesis is described in detail in the next section.

1.3 Outline of this Thesis

First, the theoretical foundation for this thesis and the aforementioned research objectives are pointed out in **Chapter 2**. This includes the relation between the driver and the automation system, such as, automation levels and mode awareness. Moreover, the human perception of motions, in particular rotational motions, is outlined including the perception process as well as existing thresholds. The research demands form the transition to the subsequent chapters.

In **Chapter 3**, the vestibular feedback concept for partially automated motorway driving is explained. Therefore, requirements for the feedback are presented and included in the recommended design possibilities.

Chapter 4 includes the description of the functional architecture of the automation system, test vehicle, test equipment, active chassis, and implementation of the realized automation system. These components form the basis for the conducted driving studies.

In **Chapters 5**, **6**, **7**, and **8**, the four driving studies as well as their results are described. The first study focuses on the design of the pitch motions for certain driving scenarios. Following, the second driving study investigates the perceptibility and comprehensibility of pitch motion feedback as well as its occurrence, intensity, and timing depending on the driving scenario. The third driving study is similar to the first, but focuses on the design of roll motions for announcing lane changes or intensifying lane change aborts. Finally, the generated multi-modal feedback concept, including pitch and roll motions, as well as visual information, is compared to a purely visual feedback concept.

Concluding, **Chapter 9** discusses the findings and results, and finishes this thesis with an outlook on further research topics.

Parts of this thesis were prepublished in Cramer et al. (2018), Cramer and Klohr (2019), Cramer, Lange, Bültjes, and Klohr (2017), Cramer, Miller, Siedersberger, and Bengler (2017), and Cramer, Siedersberger, and Bengler (2017).

2 Theoretical Foundation: Human and Automation

The aim of this chapter is to provide the theoretical foundation for the research needs of this thesis, which are addressed in the previous chapter. The interaction between the driver and the automation system is essential for this thesis. The levels of automation are described in the first place. Following, fundamentals of the functional structure of automated systems, as well as of the driver's awareness of such a system are illustrated. Moreover, basics of the human perception of vehicle guidance and driving dynamics are presented. Subsequently, a closer look is taken at state of the art feedback and requirements for feedback during partially automated driving. Finally, thresholds for perceiving rotational motions, as well as comfort thresholds are outlined to design the active pitch and roll motions accordingly.

2.1 Levels of Vehicle Automation

Several assisted or automated systems have been developed in the past and will be in the future. These can be categorized according to their operation mode. Informing and warning systems (operation mode A, Gasser, Seeck, & Smith, 2016) only indirectly influence vehicle guidance via the driver (e. g. lane departure warning systems, cf. Bartels, Rohlfs, et al., 2016). Intervening emergency functions (operation mode C, Gasser et al., 2016) temporarily take over the vehicle guidance in near-accident situations, which can not be handled by the driver (e. g. forward vehicle collision avoidance systems, cf. Rieken, Reschka, & Maurer, 2016). Operation mode B includes continuously automated functions, whereby the driving task is distributed between the driver and the automation. To structure the numerous functionalities and characteristics of continuously automated systems (operation mode B, Gasser et al., 2016), different taxonomies have been introduced by consortia or institutions. The German "Bundesanstalt für Straßenwesen" (BASt) defines five levels of automation: "driver only", "assisted", "partially automated", "highly automated", and "fully automated" (Gasser, Arzt, Ayoubi, Bartels, Eier, et al., 2012; Gasser & Westhoff, 2012). The levels mainly differ in their task distribution between driver and automation as well as in the performance of the automation. Vehicle guidance is separated in longitudinal and lateral guidance. Further definitions are presented by the “National Highway Traffic Safety Administration” (NHTSA, 2013), the German “Verband der Automobilindustrie e.V.” (VDA, 2015), and the “Society of Automotive Engineers” (SAE, 2014). The last mentioned was updated in 2016 (SAE, 2016) and is used for this thesis. The six levels are “no driving automation” (level 0), “driver assistance” (level 1), “partial driving automation” (level 2), “conditional driving automation” (level 3), “high driving automation” (level 4), and “full driving automation” (level 5) (SAE, 2016). For this thesis, the relevant levels of automation are the ones where the driver is still responsible for a significant part of the driving task. In these levels, the driver must have sufficient knowledge on the state or intentions of the automation system in order to operate as a fallback for the automation. This holds for the SAE-levels 1, 2, and 3, where the automation system conducts at least a part of the vehicle guidance and the driver is at least responsible to serve as a fallback for the automation (SAE, 2016). The essential points of SAE-levels 1, 2, and 3 are described in the following:

- In level 1 (“driver assistance”), either the lateral (steering) or longitudinal (acceleration, deceleration) vehicle guidance is performed by the automation in specific situations. The other component is conducted by the driver who also has to monitor the system continuously and be able to take over the complete vehicle guidance immediately.
- Level 2 (“partial driving automation”) differs from level 1 in the sense that the automation system takes over both the lateral and longitudinal vehicle guidance. The driver has to supervise the system and be able to take over the vehicle guidance at once.
- For level 3 (“conditional driving automation”), the vehicle guidance is completely performed by the automation system for a certain time and/or in specific driving situations. The driver does not have to supervise the system permanently, but becomes the fallback-ready user, and has to take over the vehicle guidance after a request and a certain amount of time.

It is necessary for all three levels to support the driver’s awareness of the automation system. Nevertheless, the focus of this thesis is on the challenging “partial driving automation”, SAE-level 2, whereby the role of the driver changes from actively performing at least parts of the vehicle guidance to monitoring it. For being able to take over the vehicle guidance at once at system limits, a good situation and mode awareness is essential for drivers; this is discussed in Section 2.3 (Endsley, 1995; Sarter & Woods, 1995). Prior hereto, the basic functional structure for automated driving systems is explained in the following to establish the fundamentals for these systems, which are necessary for subsequent chapters and sections.

2.2 Basic Functional Structure for Automated Driving Systems

An automated driving system can be described as a driver-vehicle control loop (Figure 2.1). This control loop consists of the command variable *driving task*, the subsystems *driver* and *vehicle*, as well as the disturbance variable *environment* (Bubb, 2015a). In the case of ADAS or automated driving, the driver can partially or completely be replaced by the automation system. The automation system architecture typically consists of the subsystems *sensors*, *perception*, *behavior generation*, *actuators*, and *human machine interface (HMI)* (e. g. Bartels, Berger, Krahn, & Rumpe, 2009; Dietmayer, 2016; Hohm, Lotz, Fochler, Lueke, & Winner, 2014; Matthaei, 2015; Matthaei et al., 2016).

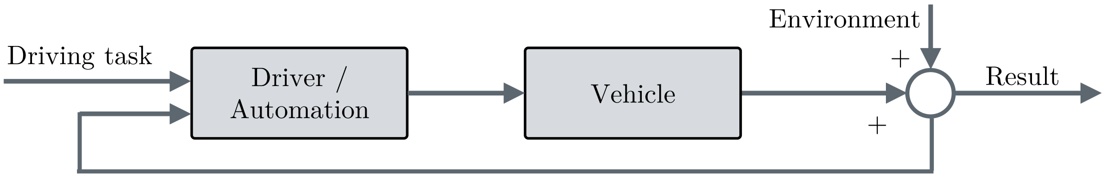


Figure 2.1: Driver-vehicle control loop according to Bubb (2015a)

Various resources are necessary to generate an environment model. A-priori knowledge is received from a digital map or vehicle2X communication (cf. Fuchs, Hofmann, Löhr, & Schaaf, 2016; Klanner & Ruhhammer, 2016; Kleine-Besten, Behrens, Pöchmüller, & Engelsberger, 2016). Moreover, sensors for the perception of the environment around the vehicle are radar, lidar, camera, and ultrasonic sensors (cf. Gotzig & Geduld, 2016; Noll & Rapps, 2016; Punke, Menzel, Werthessen, Stache, & Höpfl, 2016; Winner, 2016). Ego vehicle motion is measured via yaw rate, wheel speed, and acceleration sensors (Mörbe, 2016). Localization can be performed globally via Global Positioning System (GPS) or relative to landmarks (cf. Lategahn, 2013; Steinhardt & Leinen, 2016). All sensor technologies have advantages and disadvantages. To compensate the disadvantages, data fusion is used to summarize the positive features of all sensors and fulfill safety requirements for driving functions (cf. Darms, 2016). Afterwards, data association, filtering, tracking, and classification as well as situation assessment and prediction take place (cf. Darms, 2016; Dietmayer, 2016). It is, for example, possible to assign vehicles to lanes and predict their driving behavior. Consequently, the environment representation includes the situation awareness of the automation system and is, thus, input for the behavior generation.

Mainly, the subsystem behavior generation is responsible for the driving task. Donges (1982) divides the driving task in the hierarchical layers *navigation*, *guidance*, and *stabilization*. The *navigation* task selects a suitable route and adapts it if necessary due to, for instance, road works. The *guidance* layer derives a safe and reasonable driving behavior. The result can be represented as a target track and a desired velocity profile. The *stabilization* layer operates steering, braking, and engine in order to follow these targets and compensates disturbances (Donges, 1982, 2016). Donges (1999) connected his three-level model of the vehicle driving task with the three-level model for target-oriented human activities of Rasmussen (1983). The three levels are *knowledge-based*, *rule-based*, and *skill-based behavior*. The last mentioned includes reflex-like stimulus-response mechanisms. In contrast, *knowledge-based behavior* describes a mental process with problem-solving action alternatives (Rasmussen, 1983). In the third level, the *rule-based behavior*, humans select a stored behavioral pattern out of a repertoire. According to Donges (1999), the *stabilization* layer can be assigned to the *skill-based behavior*, and the *navigation* to the *knowledge-based behavior*. Regarding the *guidance* layer, the allocation is not clear. All three levels for target-oriented human activities of Rasmussen (1983) can be associated with the *guidance* layer of Donges (1982). Consequently, technical approaches for handling this layer for an automated system vary (c. f. Lange, 2018). Moreover, an interaction of the HMI can take place on every level of the driving task (Flemisch et al., 2014). Guidelines for designing the HMI can be looked up in Bengler, Pfromm, and Bruder (2016); Bruder and Didier (2016); Flemisch, Winner, Bruder, and Bengler (2016); Knoll (2016), and König (2016).

Different functional architectures for automated driving show a similar hierarchical structure as Donges (1982) (cf. Hohm et al., 2014; Matthaei, 2015; Ziegler et al., 2014). However, most functional architectures have four layers, and often divide the guidance layer into a behavior and a motion planning layer. Likewise, Löper, Kelsch, and Flemisch (2008) and Damböck (2013) present the same four layered hierarchical structure for the vehicle guidance. In the following thesis, a hierarchical architecture with four layers is used: *navigation*, *maneuver planning*, *trajectory planning*, and *stabilization*. *Navigation* defines a driving route (cf. Kleine-Besten et al., 2016) which is input for *maneuver planning*. The last mentioned level specifies an adequate maneuver for the actual situation. Ardelt, Coester, and Kaempchen (2012) and Ulbrich and Maurer (2015) present two possible approaches for handling *maneuver planning*. Following, *trajectory planning* generates a continuous vehicle motion either with a time-based path (trajectory, e. g. Werling, 2010) or no time-based path. The last mentioned is realized with a path planning in lateral vehicle direction (e. g. Kammel et al., 2009) and an ACC approach in the longitudinal direction (cf. Winner & Schopper, 2016). Finally, *stabilization* guides the vehicle along the planned trajectory or path by controlling the actuators (Brake, engine, and steering, cf. Reimann, Brenner, & Büring, 2016; Remfrey, Gruber, & Ocvirk, 2016; Winner & Schopper, 2016) via path following in combination with velocity controllers or a trajectory following controller (e. g. Gottmann, Böhm, & Sawodny, 2017; Katriniok, Maschuw, Christen, Eckstein, & Abel, 2013). The detailed functional and technical architecture for this thesis will be explained in Section 4.1.

2.3 Situation, Mode, and System Awareness

"*Situation awareness* is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1987, 1988, as cited in Endsley, 1995). Therefore, this definition includes three hierarchical phases for achieving situation awareness. The first level of situation awareness is the "perception of the elements in the environment" (Endsley, 1995). For automated driving, this is, for instance, the status of the automation, the own vehicle's dynamics, as well as the location and dynamics of surrounding vehicles. The second level outlines the "comprehension of the current situation" (Endsley, 1995). In this phase, the elements of the first level are combined, and a holistic picture of the environment is generated. Here, the goals of the system operator, which can either be the driver or the automation, are also considered. As an example for this combination, the ego vehicle is assigned to the right lane on a motorway with a certain velocity, another vehicle is on the middle lane with a higher velocity, and the right lane is free in front of the ego vehicle. This presents the understanding of the current situation. Finally, the highest or third level of situation awareness reflects the "projection of future status" and, thus, follows the second level (Endsley, 1995). For the situation described before, it is probable that the other vehicle will cut into the right lane and the ego vehicle might have to reduce its own velocity to ensure the safety distance. Overall, this pictures a scenario for assisted or automated driving (c. f. Ulbrich, Menzel, Reschka, Schuldt, & Maurer, 2015). Situation awareness is the base for decision making which will result in the performance of action (Endsley, 1995). Thus, mental models are an essential part of situation awareness. "Mental models are cognitive-emotional representations of objects, object relationships and processes - in short, internal representations of the external world" (I. Wolf, 2016). Expectation, prior experience, as well as current perception of system characteristics are the basis for mental models, and form the user's understanding of the system and decision-making (I. Wolf, 2016). Hence, mental models describe the driver's representation of the system behavior and can be influenced by experience or feedback on the system (Endsley, 1995; I. Wolf, 2016).

Considering automated driving, besides having awareness of the elements in the surrounding environment, it is crucial to gain a good awareness of the automation system. This includes the system state as well as limits, and capabilities of the automation. Moreover, intentions of the automation and, thus, feed-forward information (Koo et al., 2015) are crucial for the driver's awareness of the automation system. Sarter and Woods (1995) define this awareness as *mode awareness* which is part of situation awareness (Endsley, 1995). In current research, the term *mode* is mostly used synonymously for an automation level or the extent to which the driver is integrated in vehicle guidance. Mode awareness thus is necessary for the driver to handle the transition between different levels of automation, or how and to what extent the driver has to take over the driving task (e. g. Feldhütter, Segler, & Bengler, 2017; Kerschbaum, Lorenz, & Bengler, 2015; Kyriakidis et al., 2017; Langlois & Soualmi, 2016; Martens & van den Beukel, 2013; Weller & Schlag, 2016). However, the focus of this thesis is on having awareness within one automation level, partial driving automation, whereby the driver always has the same role. Consequently, awareness of the system state or intentions of the automation system should be differentiated and is subsequently called *system awareness*.

Transferring situation and system awareness to partially automated driving represents the following: The monitoring task is accompanied by a permanent assessment by the driver on whether the system's actions are appropriate according to the respective driving situation (Othersen, 2016; Warm, Dember, & Hancock, 1996). This includes the perception of information from different sources, e. g. environment or automation system, the interpretation of this information regarding the current system status, as well as the comparison of system status and driving situation (Endsley, 1995; Warm et al., 1996). In addition, the driver has to assess the future behavior of the system. Moreover, there must be a readiness to intervene or take over the vehicle guidance at system limits (Gasser et al., 2016). Hence, an adequate situation and system awareness is essential for the interaction between driver and automation system as well as for an appropriate action and decision-making process (Sarter & Woods, 1995). However, the transfer of the vehicle guidance to the automation system can potentially lead to a loss of situation and system awareness of the driver (Endsley, 1995; Parasuraman & Wickens, 2008; Sarter & Woods, 1995). This is also known as the "out-of-the-loop" effect (Endsley & Kiris, 1995). Reasons for this effect are a lack of monitoring of the system, omission of feedback, excessively high trust and misuse, insufficient transparency of the automation system, and a shortage of understanding about the system (Endsley & Kiris, 1995; Parasuraman & Riley, 1997; Saffarian et al., 2012;

I. Wolf, 2016). Furthermore, corresponding mental models for understanding the automation system might be inaccurate (Beggiato et al., 2015; König, 2016; I. Wolf, 2016). Other aspects that contribute to a lack of situation and system awareness are high trust, misuse, and distractions, for instance caused by secondary activities such as telephoning (Merat et al., 2012; Parasuraman & Riley, 1997; Saffarian et al., 2012; I. Wolf, 2016).

In order to have adequate awareness of the surroundings of the vehicle as well as the current state and intentions of the automation system, drivers should have a suitable mental model of their vehicle's automation system (Boer & Hoedemaeker, 1998; Endsley, 1995; I. Wolf, 2016). Therefore, drivers need appropriate feedback from the environment and especially from the automation system to keep their mental models up-to-date, to be aware of the current state and to anticipate prospective state transitions, in other words to fulfill their supervising task sufficiently (Beggiato et al., 2015; Boer & Hoedemaeker, 1998; Norman, 1990; Parasuraman & Wickens, 2008; Sarter & Woods, 1995; Wickens et al., 2013). Only if drivers are aware of the state and capabilities of the automation, they can decide if the automation correctly interprets and handles the situation. Moreover, an adequate situation and system awareness has a positive effect on the supervising task of the drivers and their reaction times (Othersen, 2016; Stanton & Young, 2005). To keep drivers "in-the-loop" during partially automated driving and to support their supervising task, an additional possibility besides adequate feedback would be to integrate the driver via an appropriate interaction design (e. g. Albert et al., 2015; Cramer, Lange, & Bengler, 2015; Flemisch et al., 2003; Wimmer, 2014; Winner, Hakuli, Bruder, Konigorski, & Schiele, 2006). However, for all concepts, transparency, controllability and predictability of the system should be ensured (Beggiato et al., 2015; König, 2016).

Beggiato et al. (2015), Bubb, Bengler, et al. (2015), Itoh and Inagaki (2004), Norman (1990) as well as Sarter and Woods (1995) postulate that feedback for supervisors, in this case drivers, is one of the most important factors in conveying a coherent understanding of the system state. The approach of this thesis is accordingly to provide feedback on the current and prospective system state during partially automated motorway driving to support drivers in their supervising task. Before the actual feedback concept for this thesis is presented in Chapter 3, the foundation of human perception of vehicle guidance and driving dynamics as well as existing feedback concepts are presented in the following.

2.4 Human Perception of Vehicle Guidance and Driving Dynamics

Drivers must receive information, process it, and react accordingly if necessary. Thus, the information flow consists of information reception, information processing, and information execution (Bubb, Vollrath, Reinprecht, Mayer, & Körber, 2015). The information reception is realized via several senses. The fundamentals of the perception process can be looked up in Handwerker and Schmelz (2010) and R. F. Schmidt, Lang, and Heckmann (2010). For vehicle guidance, the relevant sensory channels are visual, auditory, vestibular, and haptic (Bubb, Vollrath, et al., 2015; T. Müller, 2015). Visual information for vehicle guidance includes, for example, the detection of the position of lane markings as well as surrounding vehicles, or collecting information from vehicle displays. Auditory information for vehicle guidance consists, for instance, of warning tones, indicator signal, or wind noise. Haptic information is, for example, perceived via the steering wheel or an active gas pedal. Vehicle accelerations, for instance, are part of vestibular information for vehicle guidance. In addition, it should be pointed out that vehicle guidance consists to a large extent of visual sensing (Lachenmayer, Buser, Keller, & Berger, 1996; Rockwell, 1971, as cited in Bubb, Vollrath, et al., 2015).

Vehicle movements are mostly sensed by not just a single sensory channel but at least two. Before the perception of driving dynamics is described in more detail, the coordinate system as a basis for the definition of vehicle motions is explained in the following as well as visualized in Figure 2.2. Translational motions can either be in the longitudinal direction (x-axis), lateral direction (y-axis), vertical direction (z-axis) or a combination of the three. Rotational motions occur in the form of pitch (θ, rotation around y-axis), roll (φ, rotation around x-axis), or yaw (ψ, rotation around z-axis) motions.

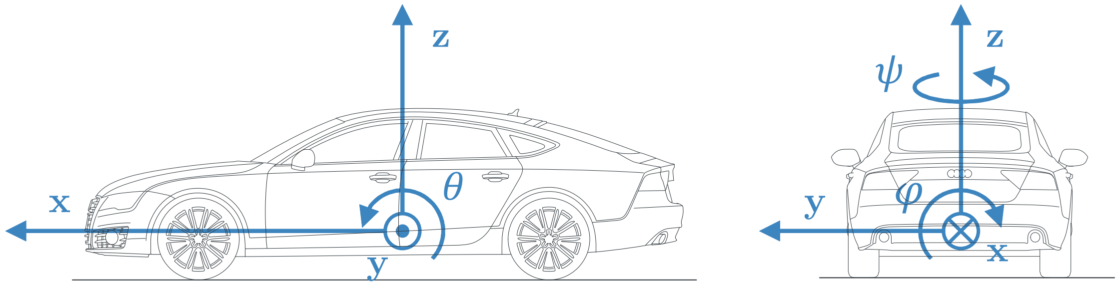


Figure 2.2: Coordinate system according to International Organization for Standardization (2011-12)

As aforementioned, vehicle motions are sensed by at least two sensory channels. Hence, a translational longitudinal acceleration is perceived via the haptic, acoustic, and vestibular sensory system, a translational longitudinal velocity via the visual and acoustic sensory channel, and a yaw acceleration via the haptic and vestibular sensory system (T. Müller, 2015; Tomaske, 2001, as cited in Bubb, Vollrath, et al., 2015). The acoustic sensory channel does not play an import role for perception of automated vehicle driving behavior. Moreover, the focus of this thesis is on rotational motions, which do not include acoustic information. Here, it is referred to Bubb, Vollrath, et al. (2015) and Zenner (2010b) for the fundamental functionalities of the auditory sensory channel.

Information for spatial orientation and sensation of movements is mainly gained from the vestibular system (equilibrium organ in the inner ear) which is displayed in Figure 2.3 (Baloh, Honrubia, & Kerber, 2011; Zenner, 2010a). However, for a definite interpretation of the spatial orientation and the sensation of movements, additional information is necessary from the visual and parts of the somatosensory sensory system (R. F. Schmidt, 2001; Zenner, 2010a). One task of the last mentioned is, for example, to determine the head posture with regard to the body via the neck muscles and joints (Zenner, 2010a). The visual information represents how the movement takes place compared to the environment. For a malfunction of the inner ear, the visual sensors can partly compensate but only if it is bright enough (Zenner, 2010a). Hence, a shared control signal is calculated out of the different sensory systems to regulate the equilibrium (Blümle, 2003).

The optical flow is essential for the assessment of where and how fast the own vehicle, and thus the driver and passengers are heading (Goldstein, 2010). This can be described as a field of velocity vectors. These are longer close to the observer, and hence indicate more rapid flow. In contrast, the arrows are smaller towards the destination point (focus of expansion) and are zero when they reach the focus of expansion. This is called the gradient of flow and informs the observers how fast they are moving (Goldstein, 2010). However, drivers use additional information, for instance distance to lane markings or distance to road boundaries, to determine the heading direction. Moreover, vestibular sensing is used to determine whether the movements are internal or external (Goldstein, 2010). For more detailed information and the fundamental functionalities of the visual sensory system, it is referred to Bubb, Vollrath, et al. (2015), Eysel (2010), and Goldstein (2010).

Haptic information is perceived via mechanoreceptors and proprioceptors of the somatosensory system (Handwerker & Schmelz, 2010; Treede, 2010). Mechanoreceptors (sense of touch) are responsible for the transmission of pressure, vibrations, and touch.

The sensing of the position and movements of the body, joints, and limbs, as well as muscle strength is achieved by the proprioceptors (depth perception, Treede, 2010). Further information can be looked up in R. F. Schmidt (2001) and Treede (2010). During automated driving, whereby the vehicle is performing the lateral und longitudinal vehicle guidance, haptic information is mainly perceived via pressure sensing of the seat and the position of the head as compared to the body. According to Handwerker (2006), information of the vestibular system is also used for proprioception. This can be explained on the basis of tilting motions of the head. Thus, humans can differentiate if they perform motions by themselves or due to external accelerations (Zenner, 2010a).

As mentioned before, spatial orientation and sensation of movements is mainly gained from the vestibular system (Baloh et al., 2011; Zenner, 2010a). The belonging organs are located in the labyrinth of the inner ear and consist of two macules (saccular and ultricular) as well as three semicircular canals (anterior, horizontal, and posterior) for each inner ear (Zenner, 2010a, see Figure 2.3). These five organs are specialized sensory channels for translational as well as rotational accelerations. Moreover, they have sensory epitheliums with hair cells as their sensory cells. These consist of small hairs (cilia). The smaller ones, the stereocilia, are responsible for the receptor properties of the hair cells. Furthermore, the hair cells are embedded in a gel, which is called cupula for the semicircular canals and, due to small calcium carbonate crystals (otoconia), otolithic membrane for the macula (Baloh et al., 2011; Zenner, 2010a).

The macula organs perceive translational accelerations, which also include gravitational acceleration. Because of the storage of otoconia, the otolithic membrane has a higher specific density than the surrounding endolymph. During translational accelerations of the body, the sliding otolithic membrane stays slightly behind. Consequently, the stereocilia shears off and the hair cells of the macula are adequately stimulated. For each head position, a certain constellation of shearing of the two macula of each ear is available. Hence, this results in a certain stimulus constellation for the associated afferent nerve fibers, which is assessed in the central nervous system for the head position in space. (Baloh et al., 2011; R. F. Schmidt, 2001; Zenner, 2010a)

The semicircular canals are responsible for perceiving rotational accelerations. Each semicircular canal is interrupted by the cupula, which is grown together with the bony canal wall. Hence, if the head receives a rotational acceleration, the cupula moves as fast as the head. The endolymph rotates as well but slower due to its inertia, and thus stays slightly behind in comparison to the canal walls. Consequently, the cupula bumps against the retained endolymph, and hence leads to a shearing of the stereocilia, whereby these are adequately stimulated. For each rotational acceleration, a specific pattern of increase or inhibition of activity can be created due to the three semicircular canals of both ears. Velocities of head rotations are perceived as well. Mostly, the rotational movements are only short. Thereby, the head is accelerated first, and

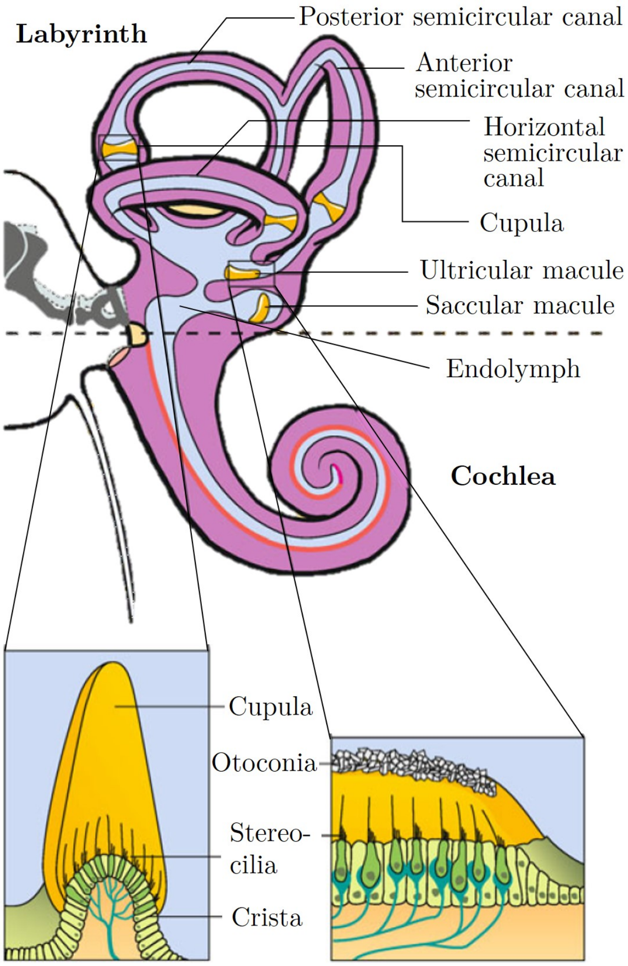


Figure 2.3: Vestibular system, referring to Zenner (2010a) for the figure and Baloh et al. (2011) for the English terms

decelerated afterwards. Therefore, the cupula organs approximately report the velocity of the head rotation for small rotations even though the rotational acceleration induces the stimuli. The course of the discharge rate in the nerves corresponds approximately to the rotational velocity. (Baloh et al., 2011; R. F. Schmidt, 2001; Zenner, 2010a)

This thesis focuses on active vehicle pitch and roll motions, which are achieved with an active body control vehicle that can lift and lower each wheel separately (cf. Section 4.3). The vehicle's roll and pitch motions are visualized in Figure 2.4 and 2.5. Concerning roll motions, a positive roll angle expresses a rotational motion of the vehicle to the right and a negative roll angle a rotational motion of the vehicle to the left (International Organization for Standardization, 2011-12). Pitch motions with a positive pitch angle correspond to a forward rotational motion of the vehicle and pitch motions with negative pitch angle to a backward rotational motion of the vehicle (International Organization for Standardization, 2011-12).

Figure 2.4: Roll motion of the test vehicle with a negative (left in the figure) and a positive (right in the figure) roll angle compared to the horizontal position of the vehicle chassis (middle in the figure), referring to Cramer et al. (2018); Cramer, Lange, et al. (2017)

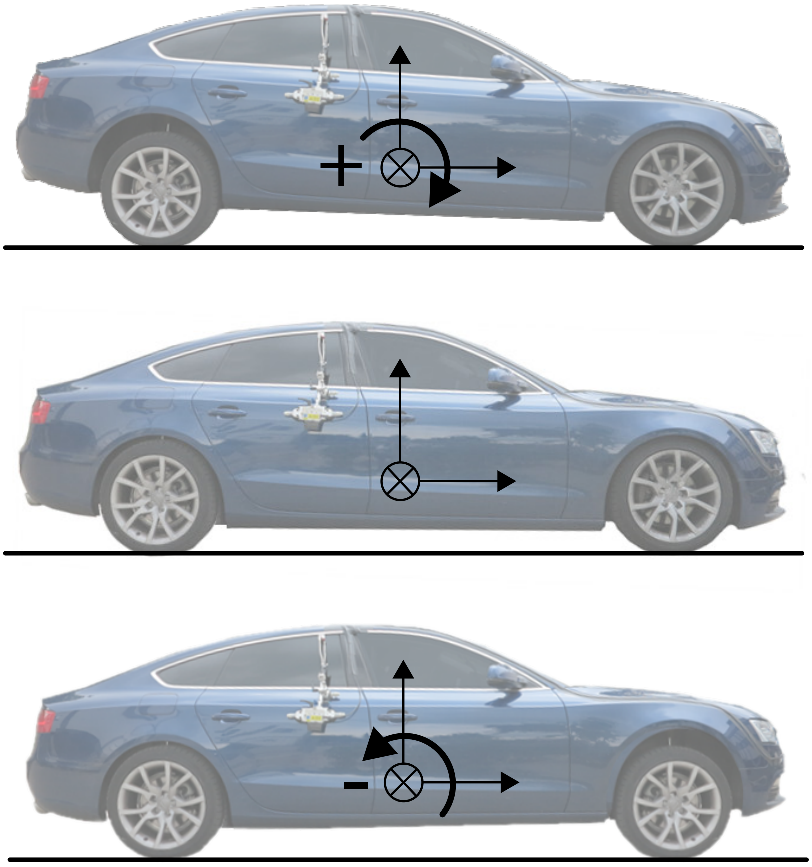


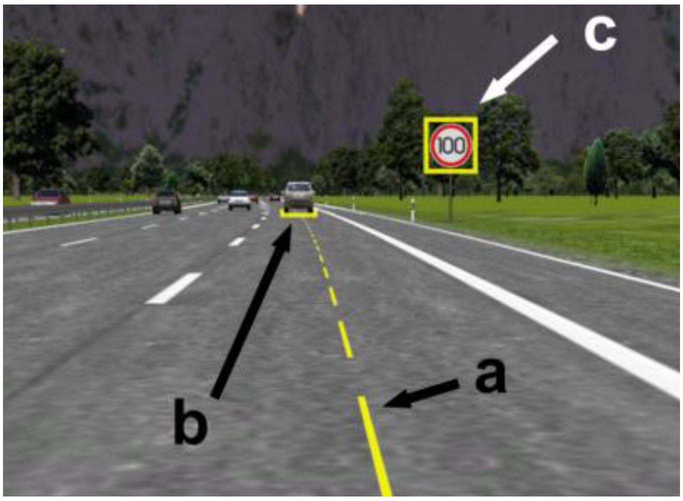
Figure 2.5: Pitch motion of the test vehicle with a positive (top in the figure) and a negative (bottom in the figure) pitch angle compared to the horizontal position of the vehicle chassis (middle in the figure), referring to Cramer et al. (2018)

2.5 State of the Art Feedback

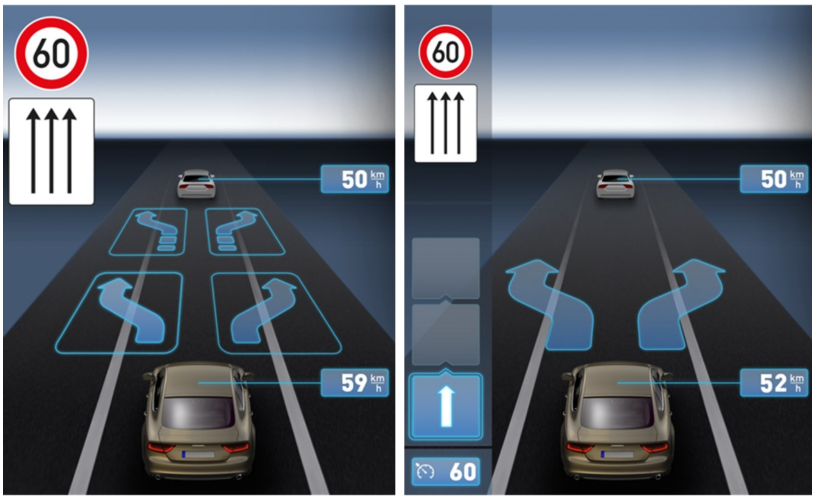
To use active vehicle pitch and roll motions as a feedback for the driver during partially automated driving, existing feedback concepts for partial driving automation as well as their requirements are presented in the following. Afterwards, the perception (minimum value) and comfort (maximum value) thresholds of rotational and translational motions for humans are examined to further design them appropriately. As described in previous sections, feedback on system state and intentions of the automation should be developed for supporting the driver's system awareness and, thus, the driver's supervising task. In this section, existing feedback types are presented with regard to their used sensory channel. Hoffmann (2008) defined information rate and speed of perception for each sensory channel. The auditory channel shows a medium value for both criteria. The haptic and vestibular sensory channels are perceived very fast but present a low information rate. In contrast, the visual information rate is very high, and thus complex information can be transmitted to the driver. Moreover, visual information is perceived fast (Hoffmann, 2008; Lange, 2018). Until now, human-vehicle interaction has mainly been realized via the visual, auditory, or parts of the somatosensory sensory channel (Bubb, Bengler, et al., 2015; Knoll, 2016). Additionally, two papers are presented which do not address the supervising task of the driver but evaluate a feedback approach via active roll motions of an active chassis.

Visual Feedback

The series production ACC system visually signals the activation state, set velocity, and existence of a target preceding vehicle (Winner & Schopper, 2016). The desired distance or time gap is often only displayed for a few seconds if the driver modifies these settings. LKA systems also show their activation and availability using a visual symbol in the instrument cluster or head-up display (Bartels, Rohlfs, et al., 2016). The location of the information should always be in the primary or peripheral field of view for the actual monitoring task. Therefore, lane change assistance systems present the existence of other vehicles in the critical areas of the neighboring lanes in the side mirrors (Bartels, Meinecke, & Steinmeyer, 2016). Damböck et al. (2012) presented visual information to the driver on the current status and future actions of the automation system via a contact analogue head-up display. Therefore, the trajectory as well as the detection of speed signs and the preceding vehicle was displayed to the driver (Figure 2.6a). This feedback helps the participants to better understand the system and to react faster at system failures (Damböck et al., 2012). Albert et al. (2015) implemented four interaction concepts for different automation levels on a tablet computer with touch functionality in a test vehicle. Lane changes were either presented visually after an input of the driver, as a suggestion to the driver, or just to notify the driver that a lane change will occur (Albert et al., 2015, Figure 2.6b). Othersen (2016) announced maneuvers like lane changes via the instrument cluster or the head-up display during partially automated driving. Another possibility is to announce maneuvers via ambient light displays (Löcken et al., 2016). The light patterns were perceived as intuitive but unobtrusive.



(a) Visual information via the contact analogue head-up display, a: trajectory, b: preceding vehicle, and c: speed sign, taken from Damböck et al. (2012)



(b) Visual information presented on the tablet computer at the top of the center console, taken from Albert et al. (2015)

Figure 2.6: Two examples for visual feedback during automated driving

Auditory Feedback

Considering auditory feedback, sound signals, noise, and speech output are possible (Bubb, Bengler, et al., 2015; König, 2016). As a result, this feedback reflects an emphasizing warning character or transmits linguistic content. Warning signals are designed with different frequencies according to their urgency (Bubb, Bengler, et al., 2015). These can, for instance, turn up at system limits, take-over requests for an ACC system or as a warning for an impending front vehicle collision (Rieken et al., 2016; Winner & Schopper, 2016). Koo et al. (2015) evaluated speech output for explaining auto-braking actions. Therefore, they included "why" and "how" the vehicle is acting. They point out that "how"- and "why"-information is needed for safety critical situations, but can result in a negative emotional response of the driver and overload the driver (Koo et al., 2015). Furthermore, Sirkin et al. (2016) investigated a speech-based robot vehicle interface during automated driving. Results indicate that many of the conversions are about driving and control of the vehicle. Interestingly, perceptual informing on what the vehicles sees was unwelcome at the beginning, but over time increased trust (Sirkin et al., 2016).

Haptic Feedback

Information of the mechanoreceptors and proprioceptors of the somatosensory system is used, especially for force-feedback-control systems, as communication to the driver via the control elements (König, 2016; Petermeijer, Abbink, Mulder, & de Winter, 2015). Moreover, feedback can include warnings or information about the vehicle guidance (Petermeijer, Abbink, Mulder, & de Winter, 2015). Front vehicle collision warning systems can, for example, use an active gas pedal to give feedback to the driver (Rieken et al., 2016). Cramer et al. (2015) designed a lateral cooperative vehicle guidance for lane changes with communication via the steering wheel. Therefore, the path of the automation system is adapted to the driver's input within non-critical driving limits. On the contrary, the haptic sensory channel can reflect a warning character as, for instance, via a reversive belt pretensioner (Rieken et al., 2016), or vibrating steering wheel or seat (Bartels, Rohlfs, et al., 2016; Petermeijer et al., 2017). Furthermore, Löcken, Buhl, Heuten, and Boll (2015) used a vibro-tactile belt to inform drivers about distances of upcoming vehicles from behind on the neighboring lane.

Vestibular Feedback

Vestibular feedback can be achieved, for example, by braking jerks (Rieken et al., 2016). Lange et al. (2014) investigated the lateral vehicle dynamics during an automated lane change. The research question was if the driving dynamics could transfer information to the driver without inducing discomfort. The participants experienced partially and highly automated lane changes and accepted higher accelerations in level 2 than level 3 driving. The participants showed a positive attitude towards vestibular feedback. Over 85 % of the participants stated that they would like to receive feedback via vehicle motions during partial driving automation (Lange et al., 2014). On this basis, Lange, Albert, et al. (2015) developed a concept using the vestibular perception of the drivers of level 2 systems to feed back different automation states. For instance, the preparation of a lane change can be signaled by a longitudinal acceleration and a lateral offset towards the target lane. Subsequently, this scenario was implemented in a test vehicle and evaluated in comparison to a non-feedback automated lane change (Lange, 2018). The feedback concept showed a considerable effect on the predictability of lane changes.

Active Roll Motions

C. Müller, Siedersberger, et al. (2017) developed a feedback concept for assisted lateral vehicle guidance (LKA, hands-on). Herein, the ADAS controls the steering wheel actuator as well as roll steering induced by active roll motions of an active chassis. In doing so, there are no disturbing steering forces for the drivers and they still receive feedback via active roll motions if they drive eccentrically in the lane. This concept was compared to a prototypical system very similar to a standard LKA system, which only uses the steering actuator. The new concept is mainly comprehensible and perceptible, less demanding, supports the performance of the lateral vehicle guidance, and was rated positively considering steering and driving behavior. Furthermore, active roll motions were evaluated as feedback for informing and warning systems (operation mode A, Gasser et al., 2016) in C. Müller, Sieber, Siedersberger, Popp, and Färber (2017). For the warning system, the participants drove manually while carrying out a cover-story (Sieber, Siedersberger, Siegel, & Färber, 2015). Suddenly, an obstacle appeared from the right side. An evasion recommendation was implemented with a highly dynamic roll motion. No undesirable driver reactions occurred but 66 % did not notice the roll motion. Moreover, no differences in steering and braking behavior could be found compared to the control group without the recommendation. Consequently, this feedback is not recommended for warning systems. In contrast, it is considered useful for informing systems (C. Müller, Sieber, et al., 2017). For this use case, a roll motion was induced shortly before an exit in a roundabout. This was repeated in four roundabouts. The participants were instructed to take the exit for which they received a notification. After a period of learning, for the fourth roundabout, 87 % took the right exit and rated the feedback as useful. However, the highly dynamic design of the roll motion should be questioned because some participants perceived it rather as a road unevenness (C. Müller, Sieber, et al., 2017).

2.6 Feedback Requirements

The “Code of Practice for the Design and Evaluation of ADAS” describes a concept for ADAS development which includes requirements, best practices, and methods focusing on risk assessment and controllability evaluation (PReVENT, 2009). The Code of Practice includes human machine interaction and system dialog specifications, and thereby builds upon the “European Statement of Principles on Human Machine Interface for In-Vehicle Information and Communication Systems” (European Commission, 1998). However, until now there are no guidelines about designing and evaluating human machine interaction for automated driving. A “Code of Practice for Automated

Driving Functions" will be available in 2021 the earliest (Knapp, 2018). Consequently, this thesis refers to the following references for feedback requirements.

During partially automated driving, information for monitoring the automation plays an important role for the driver (Beggiato et al., 2015). In general, according to the European Commission (1998) and Bubb, Bengler, et al. (2015, p. 269), system responses should be designed to be timely and clearly perceptible (exceeding the perception threshold of the driver). Beggiato et al. (2015) associate feedback with the terms transparent and predictable. Additionally, it is essential for feedback to be comprehensible (PReVENT, 2009). Lange, Albert, et al. (2015) point out that feedback should further be comfortable and associable. Moreover, the European Commission (1998) states that the system information should support the driver, be accurate, not allocate a lot of the driver's attention, and not distract or instigate drivers to a safety critical behavior. Therefore, it is essential to inform the driver about the current status of the system (European Commission, 1998).

Beggiato et al. (2015) evaluated the information needs for seven motorway scenarios: *Enter motorway*, *follow lane without speed limit*, *speed limit*, *overtaking*, *construction zone*, and *exit motorway*. A focus group created a catalog for potential information needs depending on the automation level. Subsequently, information needs, which were classified with at least 50% importance, were investigated in a driving simulator study. The results indicate that the information needs varied according to the driver and were dependent on the trust in the automation (Beggiato et al., 2015). During manual driving, information for performing the vehicle guidance was crucial. In contrast, information for supervising the automation system (e. g. system state, subsequent maneuvers) played an important role in partial driving automation. In addition, information needs for nearly all information types were consistently rated higher for partially than for conditionally automated driving. The amount of information should be adjustable according to Beggiato et al. (2015). However, some information should always be available (sorted by relevance):

- Status of system: active or inactive
- Certainty if the automation system can handle the driving situation
- Navigation information for the route
- Current and prospective maneuver
- Current velocity and speed limits
- Prospective challenging or critical driving situations (e. g. construction sites)

In the previous paragraph and mainly in Section 2.5, it is pointed out that feedback for supporting the supervising task and, thus, maintaining or increasing the system awareness of the driver, is mainly based on driving actions on the maneuver layer (cf. Section 2.2) or relevant elements of the environment perception, for example a speed sign or a preceding vehicle. Driving actions on the aforementioned layer include maneuvers, for instance, lane changes as well as their belonging states. Beggiato et al. (2015), Josten, Schmidt, Philipsen, Eckstein, and Ziefle (2017), Lange, Albert, et al. (2015), and Othersen (2016) addressed feedback on the maneuver layer or determined that this is important for partially automated driving. Furthermore, it is essential to display the state of the automation system (active or inactive) to the driver at all times.

As pointed out in Section 1.1, so far feedback on current and prospective maneuvers, states, or state transition is mainly presented visually to the driver and implies negative effects as well. Moreover, each human sensory channel is limited according to its performance (Wickens et al., 2013). Consequently, it is more effective to transfer information to the driver using not only one sensory channel but designing a multi-modal feedback (Bubb, Bengler, et al., 2015; van den Beukel et al., 2016). Additionally, this is more fruitful due to the fact that natural human interaction with the world is often multi-modal, for instance speech and gesture (Bubb, Bengler, et al., 2015; Jain, Lund, & Wixon, 2011). In this thesis, vestibular feedback via vehicle motions, in detail active pitch and roll motions, is examined. Thereby, it is important to evaluate if these vehicle motions are useful and fulfill the aforementioned requirements for feeding back state transitions or announcing maneuvers, and thus possibly add up to a multi-modal feedback. In doing so, perception and comfort thresholds are necessary to design the active pitch and roll motions. These thresholds are focused in the following section.

2.7 Thresholds for Active Pitch and Roll Motions

As aforementioned in Section 2.4, rotational motions are perceived as a combination of visual, haptic, and vestibular sensations. However, the key role is within the vestibular sensing (Zenner, 2010a). Table 2.1 assigns the angle, velocity, and acceleration of active pitch and roll motions to their belonging primary sensory channels used for perception. The basis for this mapping is presented in Schimmel (2010) as well as Tomaske (2001), as cited in Bubb, Vollrath, et al. (2015). A tilt angle is perceived visually as well as via gravitational acceleration, which results in lateral and longitudinal accelerations due to the tilting of the vehicle chassis. As a consequence, a roll angle of 1 ° corresponds to approximately $0.17\,m/s^2$ lateral acceleration. The cross in Table 2.1 for perceiving

Table 2.1: Sensory channels for perceiving pitch and roll motions

	Sensory channel			
	Auditory	Haptic	Vestibular	Visual
Pitch (θ) and roll angle (φ)			x	x
Pitch ($\dot{\theta}$) and roll velocity ($\dot{\varphi}$)			(x)	x
Pitch ($\ddot{\theta}$) and roll acceleration ($\ddot{\varphi}$)		(x)	x	

rotational velocities via the vestibular system is in brackets due to the fact that, strictly speaking, the vestibular system can only perceive accelerations but not velocities. However, for small rotational motions, the vestibular organs can approximately report the velocity of the head rotation (Zenner, 2010a). Zaichik, Rodchenko, Rufov, Yashin, and White (1999), as well as Benson, Hutt, and Brown (1989), as cited in Heerspink et al. (2005), even state that the detection of rotational motion is mainly dependent on the rotational velocity. In addition, the perception of rotational accelerations via the haptic sensory channel is put in parentheses. This is based on the fact that if the rotational axis is within the body, no haptic information is transmitted to the person. However, if the rotational axis is outside the body, the person perceives a vertical movement as well. Therefore, the vertical acceleration contributes to the perceptibility of active pitch or roll motion accelerations. Additional contribution to perceiving rotational motions is provided by the position of the head in comparison to the body, and thus the muscle strength of the neck. Although rotational motions are perceived via several sensory channels, feedback via active pitch and roll motions is referred to as *vestibular feedback* in the following for this thesis.

Perception Thresholds

To estimate the perceptibility of these pitch and roll motions, perception thresholds are used. Thereby, it can be distinguished between the *absolute threshold* and the *difference threshold*. The first mentioned is the "smallest amount of stimulus energy necessary to detect a stimulus" (Goldstein, 2010, p. 13) or necessary to distinguish from no stimulus energy (Handwerker & Schmelz, 2010). The *absolute threshold* is defined as the probability of detection of 50 % (Schiffman, 2001, as cited in T. Müller, 2015). The *difference threshold* determines the "smallest difference between two stimuli that a person can detect" (Goldstein, 2010, p. 15) in 50 % of the cases (Kingdom & Prins, 2010, as cited in T. Müller, 2015). The *difference threshold* can also be called the *just noticeable difference* (Handwerker & Schmelz, 2010). Thresholds are different depending on the sensory channel(s), stimulus context, individual person, stimulus duration, stimulus frequency, and the intensity of the reference stimulus (Bubb, Vollrath, et al., 2015; Handwerker & Schmelz, 2010). *Weber's law* states that the

ratio of the stimulus increase to the reference stimulus is constant (Goldstein, 2010; Handwerker & Schmelz, 2010). However, if the stimulus converges to the perception threshold, the ratio, called *Weber fraction*, is no longer constant but increases instead (Handwerker & Schmelz, 2010).
The thresholds are not absolute values but represent a probability function (T. Müller, 2015). This psychometric function reflects the relation between stimulus' intensity and probability of detection, and its course is usually s-shaped (Handwerker & Schmelz, 2010). The perception threshold is usually defined as the stimulus intensity that is detected in 50 % of the trials (Goldstein, 2010).

Very varying perception thresholds exist in literature for rotational and translational motions. This is in part because these thresholds were surveyed with different basic conditions, for instance with or without visual information, or in real driving or in laboratory conditions (Lange, 2018). In the following, it is focused on rotational thresholds for pitch and roll motions as well as translational thresholds for lateral, longitudinal, and vertical motions, in accordance with the topic of this thesis. Thereby, a tilt angle is perceived due to gravitational acceleration, which results in lateral and longitudinal accelerations due to the tilting of the vehicle chassis. As a consequence, a roll angle of 1 ° corresponds to approximately $0.17\,m/s^2$ ($= sin(1\,°) \cdot 9.81\,m/s^2$) lateral acceleration. The subsequently presented perception thresholds are assumed *absolute thresholds*, if not stated otherwise.

Table 2.2 points out a range of perception thresholds for translational accelerations: lateral a_y, longitudinal a_x, and vertical a_z acceleration. T. Müller (2015) presented a literature review for a_x perception thresholds and conducted driving studies as well. The thresholds from literature show a wide range from 0.02 to $0.78\,m/s^2$, which are similar to the values of Heißing, Kudritzki, Schindlmaister, and Mauter (2000). T. Müller (2015) revealed difference thresholds for a_x reduction ($0.08\,m/s^2$) and increase ($0.12\,m/s^2$). The perception thresholds for a_y and a_z are within a similar range (cf. Table 2.2).

Perception thresholds for rotational motions are displayed in Table 2.3. Thereby, pitch $\ddot{\theta}$ and roll $\ddot{\varphi}$ accelerations, as well as pitch $\dot{\theta}$ and roll $\dot{\varphi}$ velocities are considered due to the aforementioned fact that small rotational velocities can also be perceived via the vestibular system. According to the literature review of Heißing et al. (2000), the perception thresholds are both for pitch and roll motions between $0.1\,°/s^2$ and $0.2\,°/s^2$. Benson et al. (1989), as cited in Heerspink et al. (2005), support these findings that thresholds for pitch and roll motions are similar. Muragishi et al. (2007) pointed out that the perception thresholds differ if the rotational motions are perceived via visual or body sensory information (cf. Table 2.3). Interestingly, the perception thresholds for

Table 2.2: Perception thresholds for translational motions: lateral a_y, longitudinal a_x, and vertical a_z acceleration

Reference	Vehicle motion variables		
	a_x (m/s^2)	a_y (m/s^2)	a_z (m/s^2)
Heißing et al. (2000)	0.02 - 0.8	0.05 - 0.1	0.02 - 0.05
Literature review of T. Müller (2015)	0.02 - 0.78	-	-
T. Müller (2015)	0.08*, 0.12**	-	-
Muragishi et al. (2007)	-	≈ 0.25 † ≈ 0.01 ‡	≈ 0.27 † ≈ 0.01 ‡
Nesti, Barnett-Cowan, Macneilage, and Bülthoff (2014)	-	-	0.065 - 0.067

* Acceleration reduction, difference threshold.
** Acceleration increase, difference threshold.
† Visual information.
‡ Body sensory information.

Table 2.3: Perception thresholds for rotational motions: pitch velocity $\dot{\theta}$ and acceleration $\ddot{\theta}$, as well as roll velocity $\dot{\varphi}$ and acceleration $\ddot{\varphi}$

Reference	Vehicle motion variables			
	$\dot{\theta}$ ($^\circ/s$)	$\ddot{\theta}$ ($^\circ/s^2$)	$\dot{\varphi}$ ($^\circ/s$)	$\ddot{\varphi}$ ($^\circ/s^2$)
Gundry (1978) as cited in Bubb, Vollrath, et al. (2015); H. J. Wolf (2009)	-	-	-	1.0 - 10.0*
Heißing et al. (2000)	-	0.1 - 0.2 *	-	0.1 - 0.2 §
Muragishi et al. (2007)	≈ 0.08 † ≈ 0.40 ‡	-	≈ 0.25 † ≈ 0.20 ‡	-
Nesti et al. (2012)	-	-	6.3 **	-
Nesti, Nooij, Losert, Bülthoff, and Pretto (2016)	0.5 - 2.0	-	0.5 - 2.0	-

* Dependent on detection time.
§ In the original reference Heißing et al. (2000), the unit next to the numbers is $^\circ/s$. However, the authors speak of accelerations before the numbers and units are mentioned. Bubb, Vollrath, et al. (2015) refer to Heißing et al. (2000) and present these thresholds as acceleration thresholds. Consequently, in this thesis, the values are also interpreted as rotational accelerations.
† Visual information.
‡ Body sensory information.
** With active vehicle guidance to complete a curve section in a driving simulator.

pitch and roll motions act contrarily depending on with which sensory system they are perceived. Another important aspect was revealed by Gundry (1978): the perception threshold is reliant on the stimulus duration for detecting the stimulus. Consequently, a stimulus duration of approximately 100 - 150 ms is necessary for detecting a roll acceleration of 10.0 $°/s^2$ and approximately 1.0 s for 1.0 $°/s^2$. According to Nesti et al. (2016), tilt thresholds are mainly measured in darkness and show values between 0.5 and 2.0 $°/s$. The thresholds can be even higher when performing another task, for instance, the driving task (Nesti et al., 2012).
The displayed thresholds are very different due to, as mentioned before, stimulus duration and sensory channel(s). Moreover, Guedry (1974), as cited in Nesti et al. (2016), pointed out that tilt thresholds are reliant on the frequency of the tilt motion. However, it is not enough to look at perception thresholds alone, but consideration of comfort thresholds is also necessary, to ensure that the pitch and roll motions do not induce discomfort.

Comfort Thresholds

Driving comfort can be described as the well-being of the vehicle occupants during driving (Sauer, Kramer, & Ersoy, 2017). This well-being limits the intensity of the rotational motions. Until now, pitch and roll motions have mainly been surveyed as undesirable side effects from the driving behavior, and the goal was to keep them small (Sauer et al., 2017). The maximum angle size of additional tilt motions, which are not influenced by the real driving behavior, was not surveyed so far. Acceptable lateral (for instance, 0.75 - 1.13 m/s^2 (Lange, 2018)) or longitudinal accelerations (for example, 1.08 - 1.47 m/s^2 (Hoberock, 1976)) would result in a tilting angle of at least 4.3 ° ($= arcsin(0.75\, m/s^2 \,/\, 9.81\, m/s^2)$) if it was directly converted from gravitational acceleration. If this threshold can be transferred from translational accelerations is questionable and should be examined. However, Bär (2014) and Bitterberg (1999) surveyed active roll motions, and thus present two relevant references for this thesis. Bär (2014) developed und evaluated a concept to reduce lateral forces on the vehicle occupants during driving. This was realized with an active body control vehicle. Experts rated that roll velocities higher than 4.0 $°/s$ reduce comfort. Moreover, Bitterberg (1999) defined thresholds of 5.0 $°/s$ as well as 15.0 $°/s^2$ for a comfortable tilting train.

Comfort is, however, a diffuse term and means to be at ease and satisfied with the overall situation, and includes *convenience*, but is not scientifically clearly defined (Bubb, Vollrath, et al., 2015). Bubb, Vollrath, et al. (2015) refer to Zhang, Helander, and Drury (1996) and distinguish between two orthogonal terms *comfort* and *discomfort*. The latter, also called *suffering*, can be measured with psychophysical methods in contrast to *comfort*. For this thesis, the term *discomfort* is used to rate the pitch and roll motion feedback. Thereby, the goal is to keep the *discomfort* at a small level.

2.8 Summary and Conclusion

This chapter presented the theoretical foundations for this thesis. The focus was on the relation between the human and the automation system. An overview was given on the different levels of automation with focus on the role of the driver. Following, the driver-vehicle control loop was described as well as the functional structure of automated systems. For partially automated driving, it is necessary to have sufficient awareness of the automation system. Therefore, the fundamentals of situation and mode awareness were explained, and the term *system awareness* was defined. The latter includes the awareness of system state or intentions of the automation system within one level of automation. For designing feedback via pitch or roll motions, it is essential to have knowledge on human perception of vehicle guidance and driving dynamics, perception and comfort thresholds, as well as state of the art feedback for informing the driver about state transitions or upcoming maneuvers. As is pointed out so far, feedback is mainly visually (van den Beukel et al., 2016; Fisher et al., 2016; Othersen, 2016). Contrarily, the vestibular sensory channel is barely used to feed back information directly, and can thus be used to complement visual feedback in order to achieve a multi-modal feedback (Bubb, Bengler, et al., 2015). Consequently, active pitch and roll motions, and hence the vestibular sensory system is used in this thesis to design feedback on state transitions and intentions of the automation during partially automated driving. Building up upon the theoretical foundation in this chapter, the concept for this feedback is explained in the following chapter.

3 Concept

In the previous Sections 2.5 and 2.6, it was pointed out that information on system state, state transitions, as well as current and prospective maneuver is important for monitoring a partial driving automation. This information is necessary to obtain, respectively increase drivers' system awareness (cf. Section 2.3). Moreover, as aforementioned (Section 2.6), it is more effective to transfer information to the driver using not only one sensory channel but designing a multi-modal feedback (Bubb, Bengler, et al., 2015; van den Beukel et al., 2016). So far, the vestibular sensory channel is barely used (cf. Sections 1.1 and 2.5), although it provides a further opportunity to add up to multi-modal feedback next to visual information. Lange, Müller, et al. (2015) presented the idea of announcing maneuvers during automated driving via rotational body movements of the vehicle's chassis. This theoretical idea is picked up for this thesis and is specified as feeding back state transitions or intentions of the automation system via active pitch and roll motions (Figure 2.4 and 2.5) for partial driving automation.

3.1 Maneuvers, State Transitions, and Feedback

In the first instance, the domain motorway is considered for this feedback concept. Hereby, only "normal" motorway driving is considered, while disregarding driving on and from the motorway, and emergency stop maneuvers. Winner et al. (2006) defined, for instance, "lane keeping with following a preset velocity or a preset time gap to the preceding vehicle" and "lane change" as basic motorway scenarios. Nagel, Enkelmann, and Struck (1995) considered 17 maneuvers for automated driving, whereby the maneuvers "follow a road, "follow a preceding vehicle, "approaching to obstacles ahead", "overtaking", and "merging to the left or right" are relevant for this thesis. Dambier (2010), for example, mentioned the maneuvers "merge", "lane change", "follow a preceding vehicle/road", "approach", and "overtake" as relevant motorway maneuvers. However, overtaking can be subdivided in lane changes to the left and right, and lane following in between (Dambier, 2010). The maneuvers "merge" and "lane change" are similar. However, for this thesis, merging is defined as performing a lane change within a certain period of time or space (e.g. merging from the motorway access). This maneuver is not included in this feedback concept in the first instance. Consequently, the two essential motorway maneuvers *follow lane* and *lane change* and their associated states *follow preceding vehicle* and *no preceding vehicle*, respectively *regular lane change* and *lane change abort* are considered for this thesis. Thereby, approaching reflects the state transition to *follow preceding vehicle.* Lane changes are possible to the left and right lane. A lane change abort represents an automated return to the start lane if, for instance, the target lane is suddenly occupied. The relevant maneuvers, their belonging states, as well as their possible transitions are displayed in Figure 3.1.

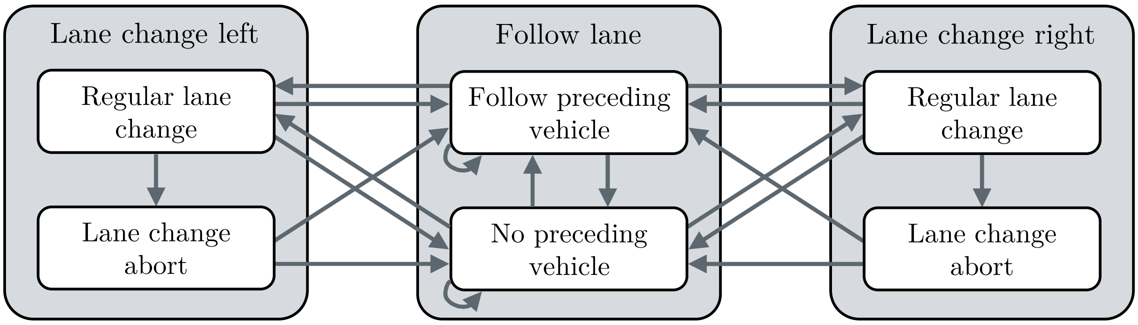


Figure 3.1: Relevant maneuvers and states of the domain motorway, referring to Cramer et al. (2018)

The arrow from *follow preceding vehicle* or *no preceding vehicle* to *regular lane change* represents the announcement of an upcoming lane change. The state transitions from the two states of the *lane change* maneuver to the two states of the *follow lane* maneuver are carried out when the lane change or lane change abort is completed, and thus the target lane is completely reached by the vehicle. There are two arrows from one state back to the same. One represents a vehicle that cuts into the gap between the ego and a preceding vehicle. This is described as transition from following one vehicle to following another. The other arrow represents a speed limit, which is characterized as a transition from following the lane with a certain velocity to following with another velocity.

Figure 3.2 presents a simplified version of Figure 3.1. In a first instance, out of all these state transitions, certain state transitions (blue arrows in Figure 3.2) were selected for the feedback concept of this thesis. These represent transitions that might lead to a collision avoiding or velocity reducing take-over by the driver if the automation system performs incorrectly. For example, announcing lane changes and subsequently executing them presents a higher risk and needs better supervising of the automation system by the driver than completing lane changes. The same applies for the detection of a preceding vehicle, which presents a higher risk than the omission of it.

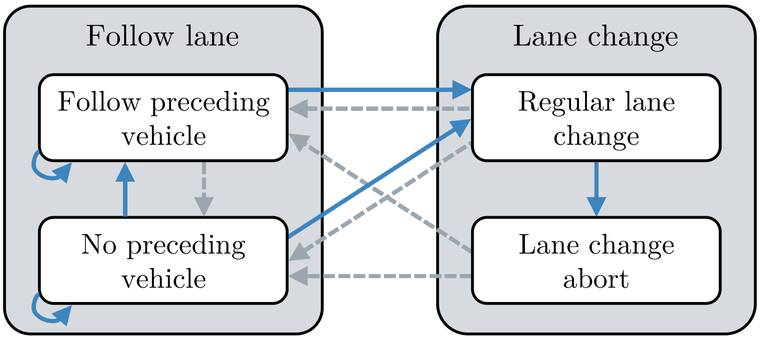


Figure 3.2: Selected state transitions for the feedback concept via rotational vehicle motions, referring to Cramer et al. (2018)

The proposed feedback concept should inform the driver at an early stage about the state transitions described before from one maneuver or state to another. At an early stage means that this information is communicated to the driver before the automation system reacts in its driving behavior according to the state transition. Thus, the feedback stimulus is perceived before the driving reaction stimulus. However, the time interval should not be too large. According to the principle of contiguity and contingency, feedback should be close to the subsequent driving reaction and be a reliable predictor for the upcoming driving reaction for the feedback to be effective (Becker-Carus & Wendt, 2017).
This feedback is realized via active pitch and roll motions (Figure 2.4 and 2.5) of the chassis. The rotational motions occur when the state transitions take place (blue arrows in Figure 3.2) and should feed back these transitions to the driver. The pitch and roll motions have to fulfill certain requirements as aforementioned in Section 2.6. Thus, feedback should be clearly perceptible, predictable, comprehensible, and comfortable. Moreover, it is essential for a feedback to be timely (cf. Section 2.6). In the following, it is focused on the latter requirement exemplary for the state transition from *no preceding vehicle* to *follow preceding vehicle*, and to *regular lane change*.

3.2 Timely Feedback

The time sequence of detecting and reacting to a slower preceding vehicle (PV) is presented in Figure 3.3. This is exemplarily explained in the following for detecting a PV with a relative velocity of $v_{rel} = \text{-}\,40\,km/h$, whereby the ego vehicle is driving $v_x = 120\,km/h$. This is a usual case for approaching to a slower truck on a motorway. First, the driver detects the PV at the relative distance s_6. This might be some hundred meters before reaching the PV, or even more when the course of the motorway is widely visible. The sensors detect the PV at the relative distance s_5, which is, depending on the sensor, about $250\,m$ at the earliest (Winner & Schopper, 2016).

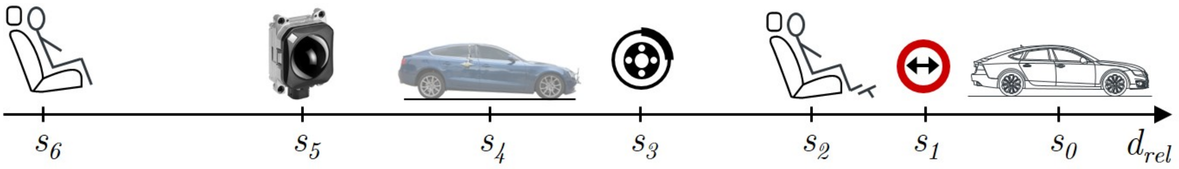


Figure 3.3: Time sequence of detecting and reacting to a slower preceding vehicle

Following, at a relative distance s_4 of about 150 m at $120\,km/h$ (in the case of the system used in this thesis, cf. Section 4.2), the automation system can classify this detected vehicle as the relevant object among several objects. The relevant object is, for instance, the preceding vehicle in the same lane. At this point in time, the feedback for the state transition to *follow preceding vehicle* takes place. The vehicle will start reducing the velocity at a relative distance s_3. At s_2, the driver would have to react and brake if the automation failed to detect the preceding vehicle in order to attain a velocity equal to that of the preceding vehicle without falling below the safety distance (s_1). It should be reviewed, if the feedback is early enough to allow the driver to react in time and avoid an accident. Presuming that the driver can decelerate with a just acceptable longitudinal deceleration of $a_x = 1.47\,m/s^2$ (Hoberock, 1976; Section 2.7), $42.0\,m$ $(= {v_{rel}}^2/(2 \cdot a_x))$ are needed for reducing $40\,km/h$. Additionally, $17.8\,m$ are added as safety distance which represents a time gap of $0.8\,v_x$ (International Organization for Standardization, 2010-04-15), and $41.7\,m$ for a reaction time of $1.25\,s$ (Green, 2000). This time is a human perception-brake reaction time for unexpected but common signals. Contrarily, Gold, Damböck, Bengler, and Lorenz (2013) presented an intervention time of $2.11\,s$ ($\hat{=}\,70.3\,m$). Here, the participants drove conditionally automated before they were requested to supervise the automation system and, subsequently, experienced a take-over request. Summing up, for a conservative calculation, the feedback should be at least at a relative distance of $130{,}1\,m$ which is considerably later than when the feedback actually takes place.

Considering a lane change, to comply with the intervention time of Gold, Damböck, Bengler, and Lorenz (2013), a lane change should be announced at least $2.11\,s$ before its execution starts. However, after initiating the execution of this maneuver, it takes additionally approximately $2\,s$ to reach the lane markings (Lange, 2018; used similar path planning as in this reference). Consequently, a lane change would be announced early enough to enable the driver to intervene in a critical driving scenario.

On the basis of this feedback concept, the feedback requirements (Section 2.6), and thresholds for active pitch and roll motions (Section 2.7), the general research objectives (cf. Section 1.2) were examined in detail in four driving studies which are described in the following.

4 Automation System and Test Vehicle

In the following chapter, parts of the automation system and the test vehicle are described. The presented system is the basis for the following Chapters 5, 6, 7, and 8, and the therein outlined driving studies. Moreover, essential components of the test vehicle for the driving studies are depicted as well.

4.1 Functional Architecture

The functional architecture is based on the basic structure of automated systems, which is described in Section 2.2. For this thesis, the focus is on the behavior generation of the automation system, which influences the perceived driving behavior as well as the system state of the automation, and is structured in four-levels as mentioned before. The functional architecture of the used automated system is presented in Figure 4.1 and includes the subsystem perception, the subsystem behavior generation and HMI, the vehicle actuators, the active chassis, and the display and control elements.

The functional architecture used by Lange (2018) is similar to the one presented in this thesis. This is due to the fact that both doctoral theses were located in the same department at AUDI AG and, hence, built upon the same existing technical architecture.

In the present case, the automation system takes over the longitudinal and lateral vehicle guidance, the driver has to monitor the partial driving automation and must be able to take over the vehicle guidance any time at system limits (SAE-level 2, SAE (2016)). The navigation is very simplified, and only displays if the vehicle is driving on a released route.

The maneuver coordinator manages the maneuvers and their belonging states depending on the situational inputs of the environment model or user inputs. This could be, for example, the motivation to perform a lane change or the detection of a preceding vehicle. The possible maneuvers for automated motorway driving are *follow lane* and

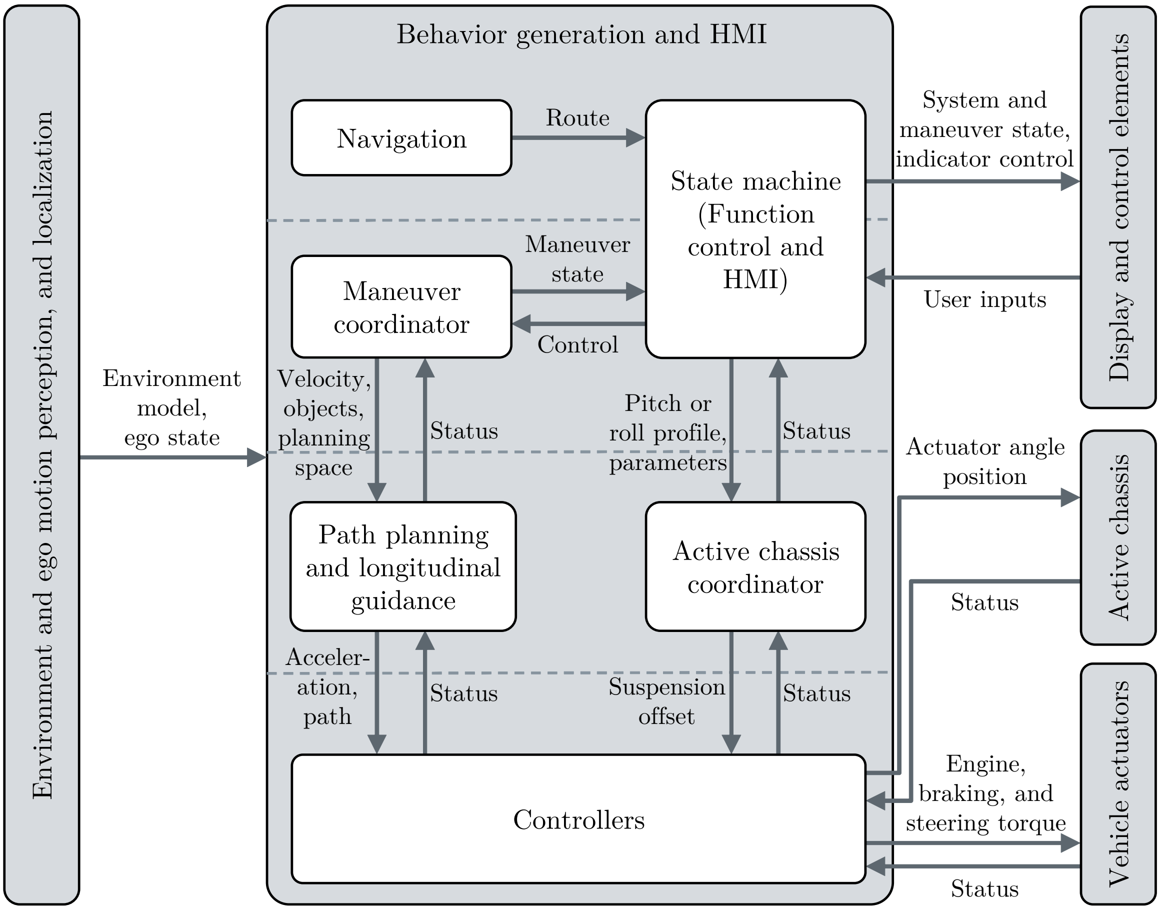


Figure 4.1: Functional system architecture

lane change, and their related states *follow preceding vehicle* and *no preceding vehicle*, or *regular lane change* and *lane change abort* (Figure 3.1). The additional maneuver *manual driving* is activated if the participants are performing the vehicle guidance on their own.

The state machine for function control as well as HMI is situated on the navigation level, or strategic layer, as well as on the maneuver planning layer, or tactical layer according to Matthaei (2015). Reasons therefore are the following: on the one hand, the state machine controls the activation and deactivation of the automation system using system limits and user inputs, and reports the status to the driver. On the other hand, feedback to the driver on state transitions of the automation system is also managed by the state machine. Consequently, the state machine transmits the system and maneuver state to the display elements, as well as the pitch or roll profile and belonging parameters (e. g. pitch/roll axis or holding time, cf. Section 5.2.2 or 7.2.3) to the active chassis controller. The latter is located on the trajectory planning or operational layer according to Matthaei (2015) and calculates a suspension offset for each actuator. Following, a chassis controller sends an actuator angle position to each actuator of the active chassis (cf. Göhrle, 2014; Unger, 2012). The hardware of the active chassis is described in Section 4.3.

In this thesis, the vehicle trajectory is calculated by a combination of a path planning module for lateral guidance and an ACC controller which generates the desired longitudinal acceleration. Therefore, the interface between maneuver coordinator and path planning and longitudinal guidance includes the dynamic and static objects, the target velocity, and the planning space. The last-named usually consists of the reference path, which is normally the middle of the lane as it is in this thesis, and the left and right boundaries. The target path is cyclically planned along the reference path with a fifth-order polynomial according to Werling (2010) and Heil, Lange, and Cramer (2016). The longitudinal control reacts to relevant objects in the longitudinal direction and adapts the velocity accordingly; this control also reacts to velocity limits. In this thesis, the longitudinal control is realized with a standard ACC system (cf. Winner & Schopper, 2016). Following, path and acceleration are controlled and engine, braking, and steering torque is sent to the vehicle actuators for performing the motions.

4.2 Test Vehicle and Equipment

The driving studies for this doctoral thesis were all conducted with an Audi A5, year of construction 2012. Relevant series production systems are ACC and LKA, whereby their interfaces to the actuators are used to control the vehicle and realize the automated system. The series production environment perception that was used for this thesis only included the inertial sensors of the ESC (Electronic Stability Control) control unit as well as the radar sensor (Freundt & Lucas, 2008; Robert Bosch GmbH, 2009). This long range radar sensor is a 76 - 77 GHz frequency modulated continuous wave radar with a distance range of 0.5 to 250 m (accuracy 0.1 m), a relative velocity range of -80 to + 30 m/s (accuracy 0.12 m/s), and a horizontal field of view of 12 °. The maximum number of simultaneously detectable objects is 32 (Freundt & Lucas, 2008; Robert Bosch GmbH, 2009). Out of these objects, the relevant object is selected in a distance range between 100 and 180 m depending on the ego velocity. For 60 km/h, the distance is approximately 118 m, for 100 km/h approximately 138 m, and for 120 km/h approximately 147 m. However, if the vehicle is driving many tight curves, as in the first (Section 5) and third driving study (Section 7), the distance for selecting the relevant object is reduced automatically by the series ACC system to 80 m to avoid false braking. Additionally, a highly accurate DGPS (Differential Global Positioning System) with an inertial sensor platform (iMAR, 2012) was integrated in the test vehicle. Two computers, a dSPACE MicroAutoBox, and hardware for the manipulation of the CAN communication were added in the trunk. The software framework ADTF (Automotive Data and Time triggered Framework) ran on the computers with software based on C++. Code models developed with MATLAB/Simulink operated on the MicroAutoBox. The detailed assignment of software to available hardware is described in Section 4.4. Furthermore, a prototypical active chassis was subsequently installed to carry out rotational vehicle motions. This is explained in detail in the following section.

The participants were seated on the driver seat for all four driving studies. One experimenter, author of this thesis, always sat on the passenger seat. Her main task was acting as a safety driver. Therefore, a monitor, a second interior mirror, and driving school mirrors for supervising the automated system were added. Moreover, driving school pedals were installed before the first motorway driving with participants (before the second study) to intervene in vehicle guidance in risky driving situations. Additionally, a video game “Wizard” controller was available during the driving studies which was used by the safety driver. Its exact functionality is explained in Section 4.4. A camera and a microphone were mounted inside the vehicle for audio and video recording of the participants’ comments, but also to check if the driver was paying attention in the important parts of the study (Figure 4.2). Furthermore, the location of the center display was used to present the statements and/or the scales for the oral examinations.

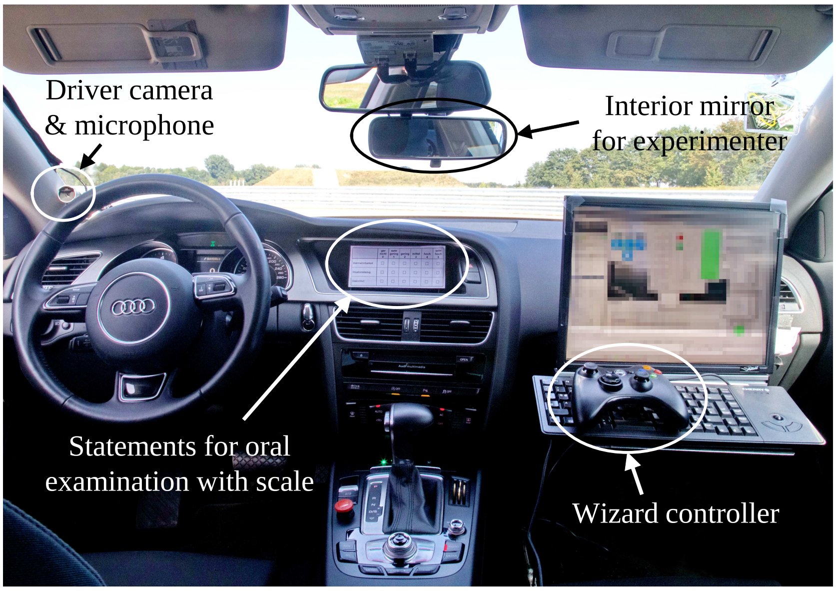
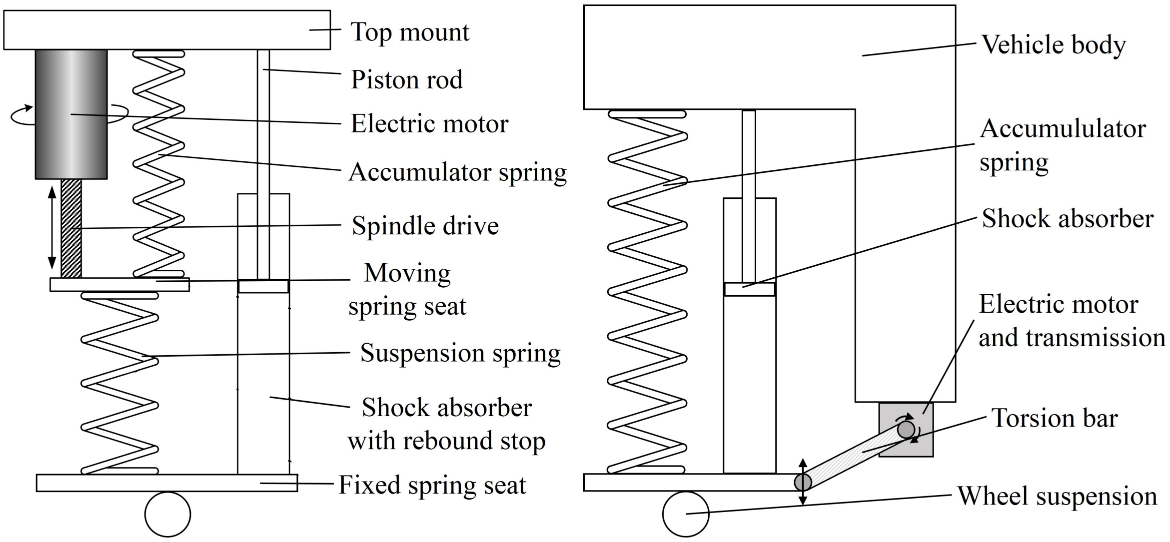


Figure 4.2: Interior of the test vehicle for the driving study, referring to Cramer, Miller, et al. (2017)

4.3 Active Chassis

Different potential active chassis systems for the required functionality are described in Ersoy, Elbers, Vortmeyer, and Wegener (2017), Göhrle (2014), and Bär (2014). For this thesis, a prototypical electromechanical active body control (eABC) system was available which was used and described in detail by Bär (2014) and Göhrle (2014). The actuators of the front axle (Figure 4.3a) are based on an adjustment of the spring seat. Therefore, the rotatory movements of the electric motor are transformed into translatory movements of the spring seat (Münster, Mair, Gilsdorf, & Thomä, 2009; Thomä et al., 2008). In contrast to the front axle actuators, the rear axle actuators are similar to an active anti-roll bar (Bär, 2014, Figure 4.3b). The electric motor initiates torque, and translatory movement is induced by the leverage effect.



(a) Front axle actuator *(b)* Rear axle actuator

Figure 4.3: Actuators active chassis, referring to Bär (2014)

As aforementioned, a chassis controller calculates the actuator position for each actuator (Göhrle, 2014; Unger, 2012). These are sent to each actuator with a frequency of 100 Hz and, thus, to provide individual height adjustment on each wheel (Bär, 2014). For a loaded test vehicle with test equipment and three vehicle occupants, a travel range of $\pm 60\,mm$ was available for each actuator. This results in nearly 4.5° roll or 2.5° pitch angle motions, provided the roll or pitch axis is in the middle of the track width or wheelbase, and the actuators thus move symmetrically up or down with the same velocity and range. Thereby, the maximum roll velocity is $16\,°/s$ (C. Müller, Sieber, et al., 2017) which corresponds to a maximum pitch velocity of $9\,°/s$.

4.4 Implementation of the Automation System

The technical realization of the automation system is based on the functional architecture described in the earlier Section 4.1 (Figure 4.1). Due to the use of similar test vehicles, the implementation presented herein resembles that of Lange (2018). Compared to prospective series production automation systems, some parts of this automation system are realized differently to ensure higher robustness and safety for the participants. The technical realization is visually presented in Figure 4.4 and the differences are explained in the following.

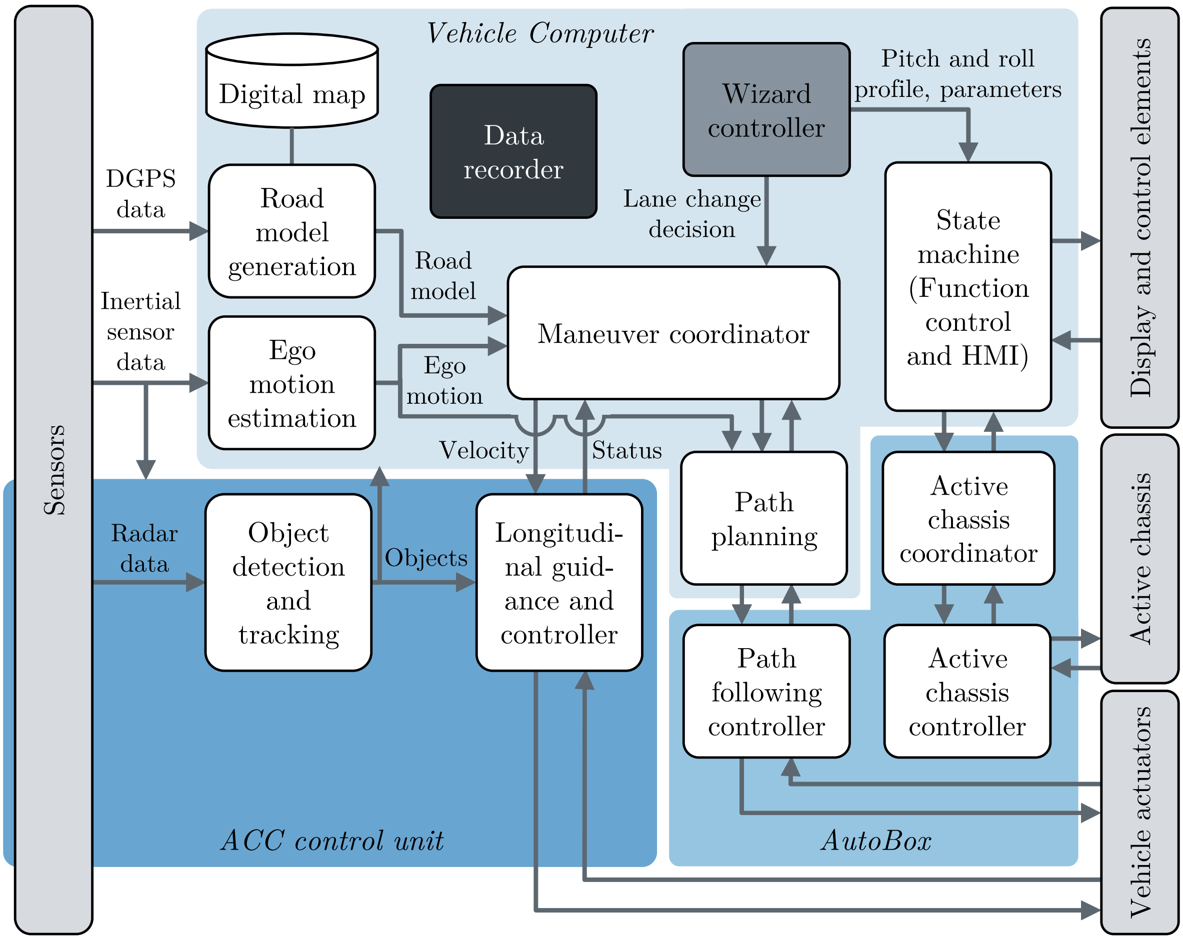


Figure 4.4: Prototypical technical realization

The software modules of the whole system were either implemented on the vehicle computer in ADTF, the dSPACE MicroAutoBox, or the control unit of the ACC system. Relevant data was recorded centrally on the vehicle computer. The road model was generated on the basis of a digital map. Localization occurred with a DGPS system (iMAR, 2012). Longitudinal control was realized with the series production ACC system. Therefore, object detection, tracking, and selection of the target object were carried out by the series ACC as well. The maneuver coordinator specified target velocity alone. The lateral guidance was taken over by a DGPS-based path planning (Heil et al., 2016).

For the navigation and maneuver layer, the software modules were not as robust and were still in development during the practical part of this thesis. In addition, the sensors placed on the side and back of the test vehicle had insufficient range of sight. For these reasons, small parts the automation system were realized with a Wizard of Oz technique. In this technique, a human takes over the role of technical system components and, thus, simulates complex processes (G. Schmidt, Kiss, Babbel, & Galla, 2008). Therefore, it is possible for human factors research to test future technologies even though the soft- or hardware is not (completely) available yet. In 1990, this method was widespread to test speech input with users when computing power was limited (G. Schmidt et al., 2008). The extent on how much technology is replaced by a human can vary. In the driving studies described in this thesis, the Wizard (experimenter on the passenger seat) operated only on parts of the navigation and maneuver layer of the vehicle guidance. Therefore, clearly defined rules were established. Accordingly, only lane change maneuvers or the detection of a preceding vehicle as part of the maneuver layer were triggered by the experimenter by pressing a button on a video game controller (Wizard controller in Figure 4.2). Moreover, the end of the automated drive was initiated by the experimenter as well. For the two studies on the test track, first and third study (Chapter 5 and 7), the experimenter additionally had to configure the different parameters of the pitch or roll motions via the Wizard controller.

Following, the relevant display and control elements are described for the first three studies. For driving study 4, these are explained in Section 8.1.1 and 8.1.4. The participants activated the automation system on their own. This was realized via the activation button of the LKA system on the left control lever. During the entire course of studies 1, 2, and 3, no visual feedback in the instrument cluster for detecting a preceding vehicle or announcing a lane change maneuver was presented to the participants. These state transitions were only communicated via active roll or pitch motions. Visual feedback was limited to the set and current velocity, and the activation status of the automation system (Figure 4.5). Therefore, the standard ACC (only the ego vehicle and the radar waves, not the preceding vehicle) and the standard LKA symbol for an Audi A5 were illuminated in green when the automation system was active. During the driving studies, the participants always drove hands-off and only had to grab the steering wheel approximately every 60 s to show their availability to the automation system. However, this time could be extended to not interrupt the participants while they answered questions, explained their thoughts, or experienced a roll or pitch motion. The hands-on reminder was implemented via the LKA symbol blinking orange. If the

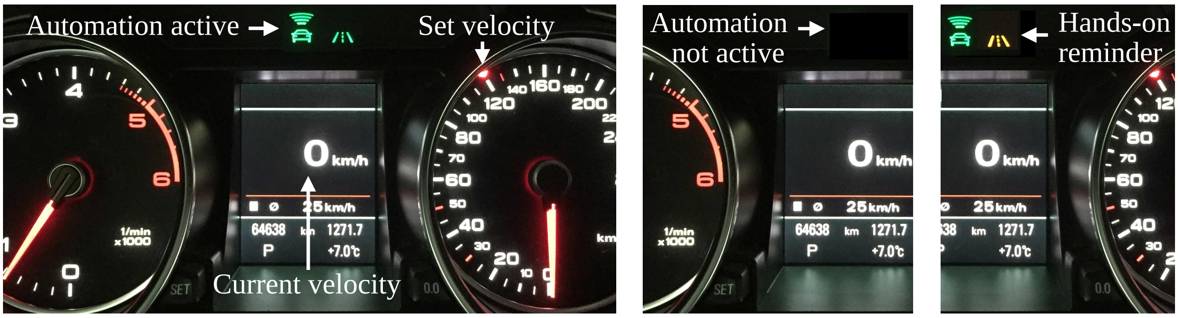


Figure 4.5: Visual feedback in the instrument cluster, referring to Cramer et al. (2018)

participant had not noticed this and, hence, not touched the steering wheel, a gong sounded.

5 Driving Study 1

The driving study and its results[1] are prepublished in Cramer, Siedersberger, and Bengler (2017), and Cramer, Miller, et al. (2017). Some parts of the written text are taken from these papers. Figures, tables, and statistics are adapted for an overall consistent representation throughout this thesis.

5.1 Introduction

As a first step, parts of the presented feedback concept via active pitch and roll motions (cf. Chapter 3) were realized in the test vehicle and were evaluated on a test track. Thereby, the focus was on pitch motions only. Roll motions were not considered. The goal was to gain a first impression on this type of feedback and adjust the concept if necessary. Moreover, the design of the pitch motions was evaluated in general as well as in detail according to the driving scenario. Four selected test scenarios were chosen to evaluate these pitch motions as feedback for state transitions and intentions of the automation. First, the method and design of the pitch motions are described. Subsequently, the results of the driving study are presented.

5.2 Method

The goal of this driving study was to identify the desired design of pitch motions as feedback on state transitions for the driver in selected driving scenarios. In the first instance, roll motions were not considered in this driving study. The design possibilities of active pitch motions were pitch angle, direction, return, as well as the exact course. Considering the direction of the pitch motions, it is possible that the pitch motion

---

[1] The driving study was designed and conducted with the assistance of Benjamin Miller as part of his Master's thesis (Miller, 2016). Furthermore, Miller (2016) analyzed parts of the data as well in his Master's thesis. For this Doctoral thesis, the data was evaluated separately.

represents the vehicle's natural pitch motion for each particular driving scenario, or the opposite which would represent a helicopter behavior. Using the example of the transition from *no preceding vehicle* to *follow preceding vehicle*, the natural vehicle pitch motion would be with a positive pitch angle due to the required deceleration. The amplitude of the pitch angle determines the discrepancy between being clearly perceptible or inducing discomfort for the driver. The preferred amplitude might also be dependent on the situation (e. g. its criticality). The return of the pitch motions can be designed so that the participants perceive the return in the horizontal position equally to the increase of the pitch motions, or in a way that makes the return hardly perceptible. For the latter, the focus for perceptibility of the feedback is only on the increase of the pitch motion. Several pitch profiles were implemented (cf. Section 5.2.2) and evaluated in different typical motorway driving scenarios (Figure 5.2). Next to the desired design, it is necessary for feedback to be perceptible, comprehensible, useful, as well as not inducing discomfort (cf. Section 2.6). System awareness is essential for the driver during partially automated driving to be able to take over the vehicle guidance immediately at system limits (Sarter & Woods, 1995). Feedback on state transitions and intentions of the automation system is necessary to maintain or increase system awareness of drivers. Thereby, essential research questions (RQ) were:

- *RQ1*: Which course of the pitch motion do the participants prefer in terms of pitch direction, amplitude, and return in the horizontal position for each driving scenario?
- *RQ2*: How *useful*, *misleading*, and *comprehensible* do the participants rate the feedback via pitch motions depending on the driving scenario?
- *RQ3*: Does the driver *perceive the state transition* and is the *system awareness increased* via pitch motions?
- *RQ4*: Is it possible for the participants to distinguish between several pitch profiles for one test scenario when the direction, angle, and return of the pitch motion are constant? Here, the evaluation is based on the items *perceptibility*, *situational context*, and *discomfort*.

Additionally, feedback should not have a negative influence on the driver's well-being. However, active pitch or roll motions represent no natural driving behavior and can, as a consequence, be hardly anticipated by the driver. A predictable driving behavior is an essential aspect for not inducing motion sickness (Sivak & Schoettle, 2015). Hence, motion sickness should be evaluated exploratory during the driving study. Moreover, the participants' general impression of the automation system regarding safety, trust, and logic of the automation system should be surveyed.

The evaluation of these items is described in detail in Section 5.3. Throughout the experiment, participants received no visual feedback on the state transitions, this feedback was achieved solely via pitch motions. However, the activation status of the automation system, as well as the set and current velocity were presented to the participants (Figure 4.5). The automation system, active body control vehicle, as well as the tasks of the experimenter on the passenger seat, and the test equipment are described in Chapter 4. The participants had to show their availability by grabbing the steering wheel once every round.

5.2.1 Test Scenarios

Section 3 describes for which state and maneuver transitions feedback can be accomplished using the vestibular sensory channel by means of pitch and roll motions. Four specific state transitions were chosen for the underlying driving study and were implemented in the test vehicle (blue arrows in Figure 5.1).

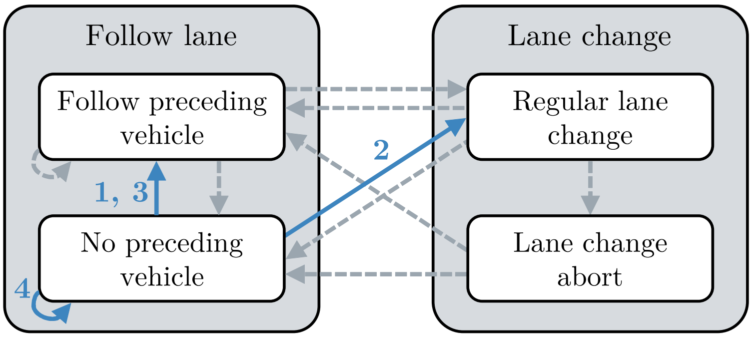
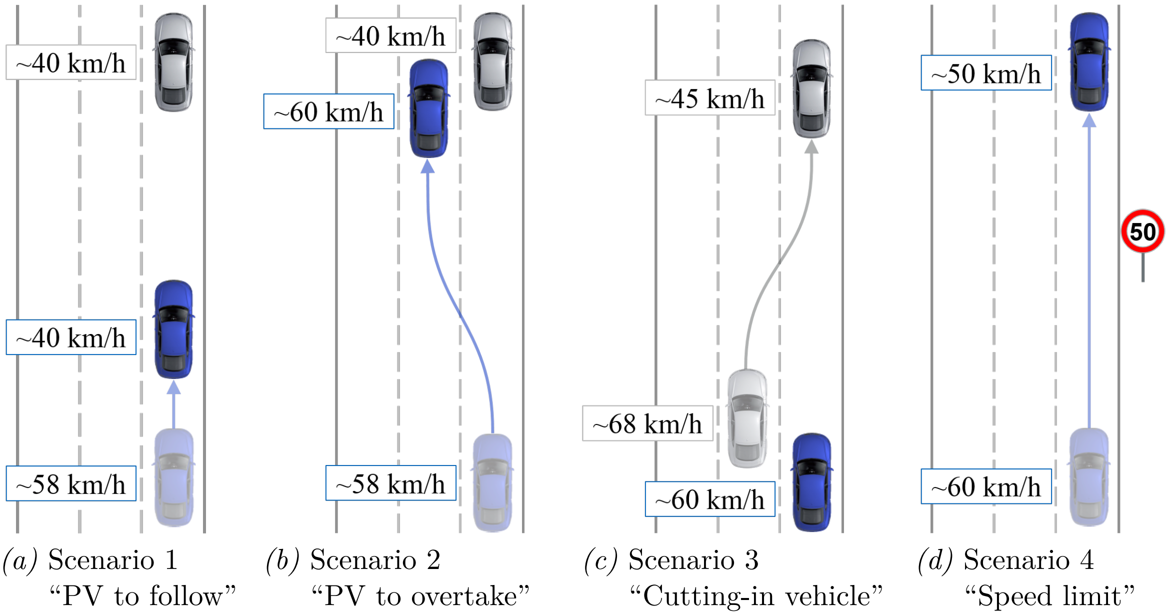


Figure 5.1: Realized feedback of state transitions in the driving study, referring to Cramer, Siedersberger, and Bengler (2017)

The driving study was carried out on an approximately 1.4 km three-lane oval test track. During each test scenario, the test track was driven around multiple times without stopping the automation system. The maximum velocity was 60 km/h on the straight part of the track and the minimum velocity approximately 22 km/h in the curves. To accomplish the test scenarios, a second vehicle was driven manually. One test scenario was conducted on each straight. The four test scenarios are shown in Figure 5.2 and based on the state transitions marked in blue in Figure 5.1.

The state transition from *no preceding vehicle* to *follow preceding vehicle*, for instance the detection of a preceding vehicle (PV) was experienced twice by the participants: in the scenario “cutting-in vehicle” (scenario 3, Figure 5.2c) as well as in the scenario “PV to follow” (scenario 1, Figure 5.2a). However, these differed in their criticality.



(a) Scenario 1 "PV to follow"
(b) Scenario 2 "PV to overtake"
(c) Scenario 3 "Cutting-in vehicle"
(d) Scenario 4 "Speed limit"

Figure 5.2: Test scenarios of the driving study, referring to Cramer, Siedersberger, and Bengler (2017)

By the time the PV crossed the lane marking in the scenario "cutting-in vehicle", its velocity was approximately 63 - 69 km/h and the distance approximately 10 - 15 m. The scenarios 1 and 2 (Figure 5.2b) were identical until the PV was detected. On the one hand, it was a "PV to follow" and on the other a "PV to overtake" and, consequently, the subsequent driving action differed. In both scenarios, the velocity of the PV was approximately 40 km/h. For these two scenarios, the set velocity (60 km/h) of the ACC system was not entirely reached, as the acceleration of the ACC during the last km/h was so low, that the maneuver had to be started prior to reaching the set velocity in order to finish within the length of the straight. In scenario 4 (Figure 5.2d), the automation system received a new external condition (a "speed limit"), and thus the velocity was reduced accordingly.

The trigger time for the feedback varied between the test scenarios. For scenarios 1 and 2, the detection of the PV as the relevant object with the ACC radar (mean distance 79,7 m) automatically initiated a pitch motion. The same occurred for scenario 4 at a distance of approximately 70 m (approximate distance for traffic sign detection at the time this study took place (Stadtler, 2015)) to the speed limit sign. On the contrary, the pitch motion for scenario 3 was triggered manually by the experimenter via the video game controller when the front right wheel of the second vehicle had completely passed the lane marking. This was necessary because the ACC system performed badly for recognizing the cutting-in vehicle due to the use of a relatively old not up-to-date technology radar sensor.

5.2.2 Design of Pitch Motions

The pitch motion contained the following variations: positive or negative angle, 1 ° or 2 °, and symmetric or slow linear return to the vehicle's horizontal position. An exemplary course of the pitch motion is displayed in Figure 5.3. It comprises three parts: the increase (τ_1), the holding period (τ_2), and the return of the pitch angle ($\tau_{3,1}$ or $\tau_{3,2}$).

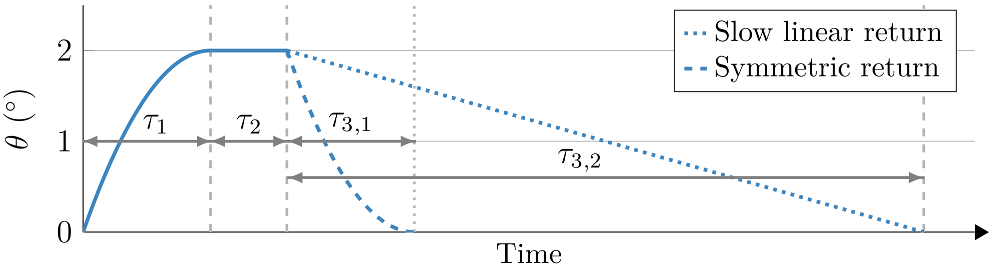
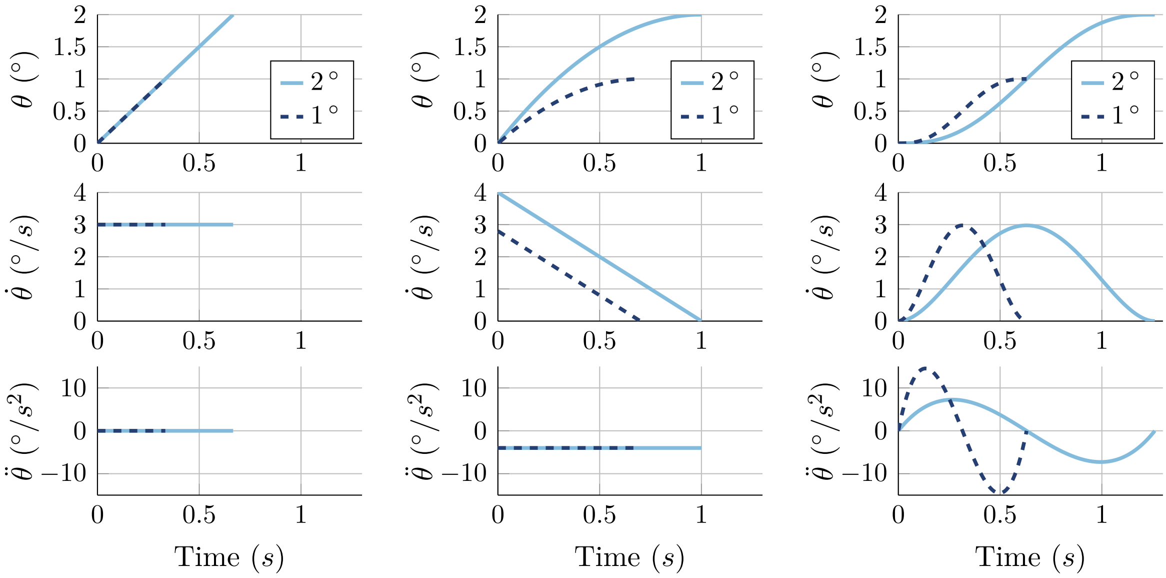


Figure 5.3: Composition and profile of pitch motions, referring to Cramer, Miller, et al. (2017)

A 1 ° pitch angle results in a longitudinal acceleration of $0.17\,m/s^2$ which is exceeding the translational perception thresholds (cf. Section 2.7). Varying the holding period (τ_2 in Figure 5.3) was tested in a pre-study with experts. Noticeably different holding periods were rather not suitable for the experts and they mainly favored a holding period of up to $1\,s$. Consequently, the holding period was set to $0.6\,s$ in the main study to reduce the variations of the pitch motions. Moreover, modifying the pitch axis was also tested during the pre-study. However, the participants could not perceive any difference, therefore the pitch axis was set to the middle of the wheelbase for the main study.

The slow linear return ($\tau_{3,2}$ in Figure 5.3) had a constant pitch velocity of $0.4\,°/s$. This value was based on the perception threshold of pitch motions via body sensory information according to Muragishi et al. (2007), which is the smallest value for perception thresholds depending on the rotational velocity (cf. Section 2.7). Thus, it was just or rather not noticed due to vibrations of the chassis while driving. The increase (τ_1 in Figure 5.3) and the symmetric return ($\tau_{3,1}$ in Figure 5.3) of the pitch motion were realized in three variations: linear, degressive, and polynomial (fifth order). During the pre-study, experts chose these among a variety of profiles addressing the conflict between a comfortable and perceptible pitch motion. The three chosen pitch profiles are presented with their pitch angle, velocity, and acceleration in Figure 5.4. The goal of the selection of the pitch profiles was to select profiles with an equal maximum velocity. The latter was chosen as the design criteria as it is not quite clear in literature if the intensity of rotational motions is mainly perceived according



(a) Linear pitch motion *(b)* Degressive pitch motion *(c)* Polynomial pitch motion

Figure 5.4: Angular position θ, velocity $\dot{\theta}$ and acceleration $\ddot{\theta}$ of the six pitch profiles with a positive pitch angle, referring to Cramer, Miller, et al. (2017)

to their acceleration or velocity (cf. Section 2.7). The most suitable reference bears on roll velocities of the active chassis (cf. Bär, 2014). According to the ratings of experts during the pre-study, a maximum velocity of $3\,°/s$ was selected which is above the perception thresholds for rotational velocities without performing the driving task (cf. Section 2.7). However, experts evaluated the degressive profiles, especially the 2 ° profile, rather too slow during the pre-study. Consequently, it was decided to increase the velocity of the degressive 2 ° profile but keep the roll acceleration equal to the degressive 1 ° profile. Thus, the 1 ° pitch profiles had the same maximum velocity and were thus comparable. According to Bär (2014) and Bitterberg (1999), roll velocities or accelerations should not be designed to exceed $4\,°/s$ or $15\,°/s^2$. None of the profiles (Figure 5.4) exceeded the described thresholds. The pitch profiles are further displayed in Figure 5.5. Herein, the time spans until reaching the maximum angle can be directly compared.

To be sure that the participants were able to distinguish between the pitch profiles, the designed ideal and the actually performed pitch motions were compared. This is shown in Figure 5.6. The pitch angles were measured with a highly accurate inertial platform (iMAR, 2012). The difference between the ideal and measured pitch motions was caused by the inertia of the chassis.

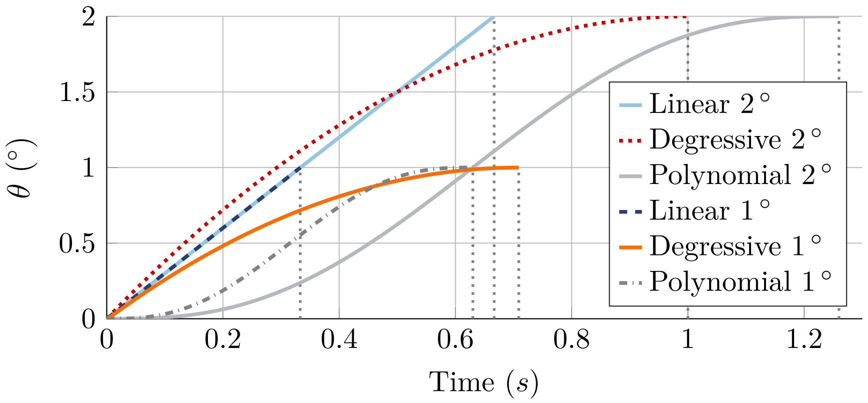


Figure 5.5: Angular position θ of the six pitch profiles with a positive pitch angle, referring to Cramer, Miller, et al. (2017)

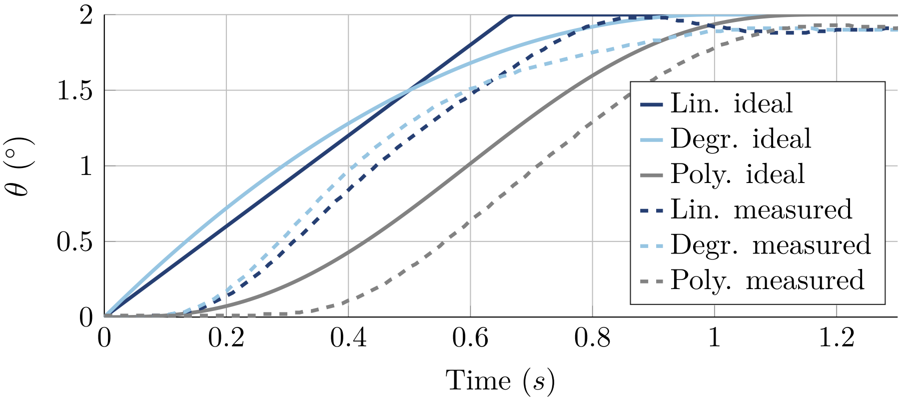


Figure 5.6: Angular position θ of the three ideal and the three measured 2° pitch profiles, referring to Cramer, Miller, et al. (2017)

5.2.3 Study Design

The participants received some first notes about the study at the time the appointment was arranged (Appendix D.1). By doing this, the participants were able to read these notes in advance without being in a hurry. These notes included information about the data collection, the functionalities as well as handling of the test vehicle, and the test procedure. The sequence of the driving study is presented in Figure 5.7. Following a verbal briefing (included important parts of first notes as well) and a settling-in phase, the participants ran through the four driving scenarios in a randomized order. At the end of each driving scenario and at the end of the driving study, an investigation of the gained impressions took place via a questionnaire. The study was conducted in German.

In each test scenario, the participants experienced feedback with the following randomized variations: pitch motion with positive and negative pitch angles as well as

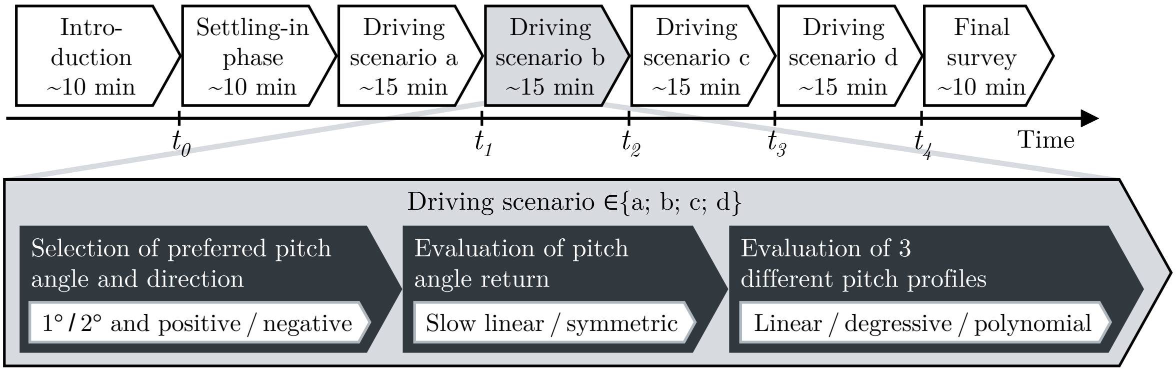


Figure 5.7: Sequence of the first driving study, referring to Cramer, Siedersberger, and Bengler (2017)

1 ° and 2 ° maximum pitch angles. Therefore, the degressive pitch profiles (Figure 5.3 and 5.4b) were selected. During these four alternatives, the return of the test vehicle into the horizontal position was constant, either using the symmetric or the slow linear return (Figure 5.3). After the participants observed the four alternatives and chose their favorite pitch motion, they experienced their preferred pitch motion with the two possible returns and selected an overall favorite pitch motion for each test scenario and evaluated it afterwards. Subsequently, the participants experienced the scenario three more times with the different pitch profiles (degressive, linear, and polynomial, Figure 5.4) in randomized order. Following each pitch motion, the participants had to rate the items *perceptibility*, *situational context*, and *discomfort* orally. The items and the scale were presented in a printed version on the display in the center of the dashboard (cf. Figure 4.2). Generally speaking, the approach is similar to the design of a “User-Derived Interface,” whereby the users (here drivers or participants) design and evaluate the interface and, thus, create a “natural” interface (Wigdor & Wixon, 2011).

5.2.4 Processing and Evaluation of Data

The data from the questionnaires were processed with the software MATLAB (The MathWorks, Inc., 2015), and the statistical and analysis software SPSS (IBM Corp., 2016). The coding of the different response scales of the questionnaires was chosen with increasing intensity from 1 (e. g. “does absolutely not apply” and “not at all”) to mostly 6 (e. g. “does absolutely apply” and “very high”). For the following statistical tests, it should be pointed out that items that were surveyed via frequency, intensity, or agreement rating scales were assumed as interval scaled variables (Döring & Bortz, 2016, p. 244, 245) because the answer scales were equidistant. Moreover, normal distribution of the data was assumed for sample sizes $N > 30$ (Bortz & Schuster, 2010, p. 87; Field,

2012, p. 134). For $N \leq 30$, Kolmogorov–Smirnov tests were performed to test normal distribution. These results are outlined in Appendix A. For parametric tests with independent variables homogeneity of variance is assumed. If the latter needs to be tested, the results are presented in Appendix B. For this thesis, the significance level was set to $p < .05$.
To evaluate the data of this driving study, one-way analyses of variance (ANOVA) and Friedman's tests were conducted with their belonging post-hoc tests.

5.2.5 Sample

A sample of $N = 35$ participants was available for this driving study which consisted of 34.3 % female and 65.7 % male participants. At the time of the driving study, the mean age of the participants was 29.74 years ($SD = 4.49$, $MIN = 19$, $MAX = 41$) and the mean mileage per year was 21,286 km ($SD = 10{,}158\,km$, $MIN = 5{,}000\,km$, $MAX = 50{,}000\,km$). Moreover, all participants had experienced cruise control, 94.3 % ACC, 91.4 % LKA, and 57.1 % partially automated driving systems (PAD, e. g. traffic jam assistance) before. The distributions of the frequency of use of ACC, LKA, and PAD systems of the participants who had used these assistance systems before are shown in Figure 5.8. Supplementary information about the sample is presented in Appendix C.

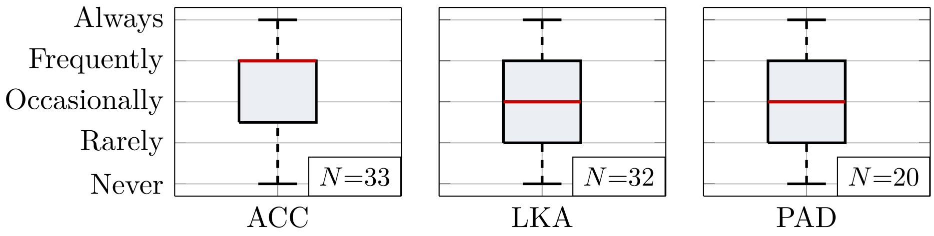


Figure 5.8: Frequency of use of ADAS of the first study's sample

5.3 Results

The results of the research questions are presented in the same order as they are introduced at the beginning of Section 5.2. The findings are reported according to the recommendations in Field (2012). The pre-questionnaire and the questionnaire during the driving study are listed in the Appendix E.1 and E.2.

5.3.1 Direction of Pitch Motion

After each driving scenario, the favorite pitch motion was evaluated. Figure 5.9 displays the distribution for the preferred direction of pitch motions. Further analysis of the data showed that 25 of the participants (71.4 %) chose a motion compliant feedback. That means that “acceleration” (scenario 2) was assigned to one and “deceleration” (scenario 1, 3, and 4) to the other pitch direction. Out of these 71.4 %, four participants favored pitch motions equivalent to a helicopter behavior. These participants assigned a forward pitch motion to an acceleration and a backward pitch motion to a deceleration. Whereas, 21 of the participants (60.0 %) selected a pitch motion direction in accordance with the estimated vehicle behavior.

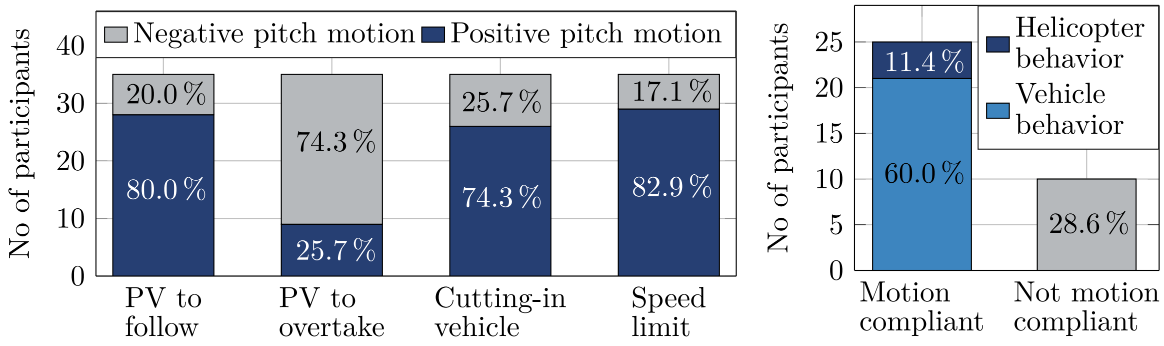


Figure 5.9: Distribution of the favored direction of the pitch motion ($N = 35$), referring to Cramer, Siedersberger, and Bengler (2017)

5.3.2 Angle of Pitch Motion

The distribution of favored amplitudes is presented in Figure 5.10. It becomes apparent that a 1 ° (either positive or negative angle) pitch motion was preferred. However,

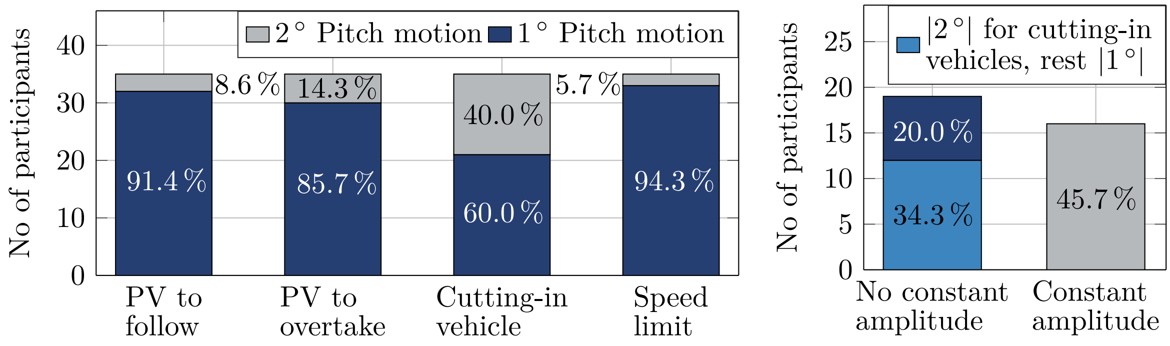


Figure 5.10: Distribution of the favored amplitude of the pitch angle ($N = 35$), referring to Cramer, Siedersberger, and Bengler (2017)

40.0 % of the participants chose a feedback with 2 ° for the test scenario "cutting-in vehicle". Allover, 16 participants (45.7 %) kept a constant amplitude of the pitch motion for all four test scenarios which was always 1 °. 12 participants (34.3 %) decided on a 2 ° feedback for the scenario "cutting-in vehicle" and a 1 ° feedback for the remaining test scenarios. Seven participants (20.0 %) had no explicit scheme of their favored amplitude depending on the test scenario.

5.3.3 Return of Pitch Motion

As seen in Figure 5.11, there was a minor tendency towards the slow linear return. Moreover, 26 participants (74.3 %) had no constant behavior for a preferred return of the vehicle to the horizontal position according to the test scenarios. Whereas, five participants (14.3 %) constantly preferred a slow linear return and four participants (11.4 %) a symmetric return. Further analysis of the data showed that for 1 ° pitch motions, the slow linear return is favored and for 2 ° pitch motions, there is a minor tendency towards the symmetric return, with exception of the scenario "PV to overtake".

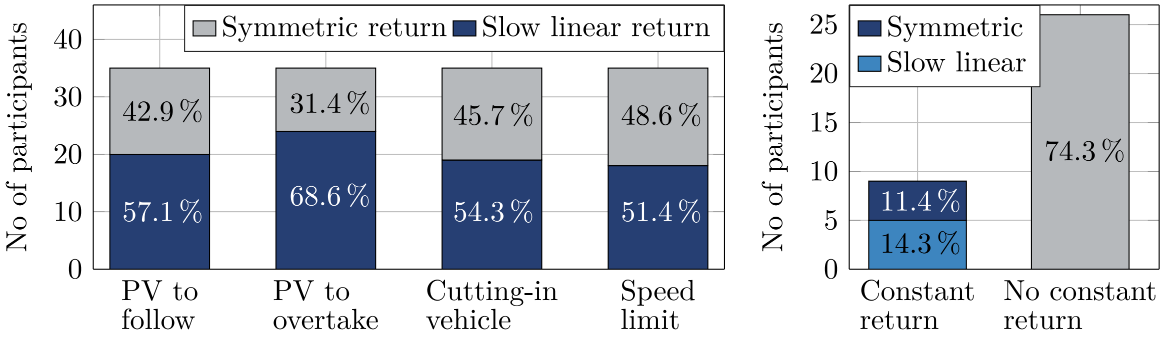


Figure 5.11: Distribution of the favored return of the pitch angle ($N = 35$), referring to Cramer, Siedersberger, and Bengler (2017)

5.3.4 System Awareness

After designing the favored pitch motion for each scenario, the participant's agreement to the following statements was surveyed on a six-point rating scale (1 ≙ does absolutely not apply - 6 ≙ does absolutely apply) via a questionnaire after each test scenario (items written in italics):

- I find the pitch motions *useful.*
- I find the pitch motions *misleading.*

- I perceived the *state transition* via the pitch motions.
- The pitch motions increased the system transparency as well as my *system awareness* for the automation.
- The pitch motions were *comprehensible* and clearly assigned to the driving situation.

A graphic representation of the evaluated items can be seen in Figure 5.12. Generally, all items received positive mean ratings for each scenario. The scenario “cutting in vehicle” attained the best evaluation out of the four test scenarios. An ANOVA with following post-hoc analysis using Bonferroni correction was conducted. If Mauchly’s test for sphericity showed significance, the data was corrected (Greenhouse-Geisser). The results indicated significant main effects for the items *useful*, *state transition perceived*, *system awareness increased*, and *comprehensible*. Contrarily, the item *misleading* showed no significant main effect. The related data is presented in Table 5.1.

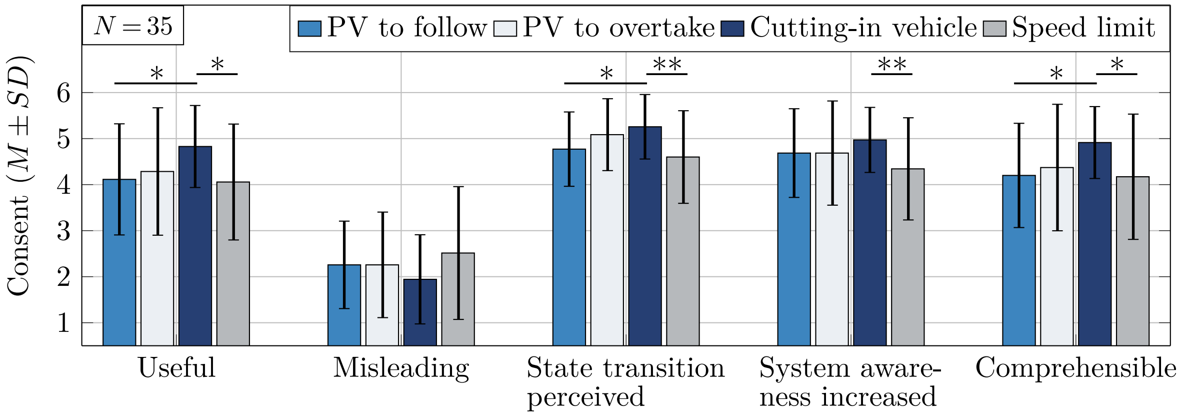


Figure 5.12: Evaluation of the items *useful*, *misleading*, *state transition perceived*, *system awareness increased*, and *comprehensible* (scale: 1 ≙ “does absolutely not apply” - 6 ≙ “does absolutely apply”; $^*p < .05$, $^{**}p < .01$), referring to Cramer, Siedersberger, and Bengler (2017)

Table 5.1: Results of the ANOVAs considering the items within the driving scenarios of the study, referring to Cramer, Siedersberger, and Bengler (2017)

Main effect	F	p	η_p^2
Useful	$F(3, 102) = 4.08$	.009	.11
Misleading	$F(2.17, 73.62) = 1.91$	.144	.05
State transition perceived	$F(3, 102) = 6.62$	<.001	.16
System awareness increased	$F(3, 102) = 3.49$	.018	.09
Comprehensible	$F(3, 102) = 3.99$	.010	.10

Considering the item *useful*, post-hoc analysis revealed significant differences between scenario 1 and 3 ($M_{1-3} = -.69$, $p = .012$), and scenario 3 and 4 ($M_{3-4} = .77$, $p = .013$).

State transition perceived indicated a significant difference between scenario 1 and 3 ($M_{1-3} = -.49$, $p = .036$) as well as scenario 3 and 4 ($M_{3-4} = .66$, $p = .006$). Moreover, the analysis between scenario 2 and 4 demonstrated a tendency towards significance ($M_{2-4} = .49$, $p = .090$). The post-hoc analysis for the topic *system awareness increased* indicated significant results between scenario 3 and 4 ($M_{3-4} = .63$, $p = .006$). Concluding, the item *comprehensible* revealed significant differences between scenario 1 and 3 ($M_{1-3} = -.71$, $p = .011$), as well as 3 and 4 ($M_{3-4} = .74$, $p = .010$).

5.3.5 Pitch Profiles

The absolute numbers of the preferred pitch motion for each driving scenario are presented in Table 5.2. A further differentiation regarding the return of the vehicle to the horizontal position was neglected. This was based on the fact that the results showed no clear preference for one type of return (Section 5.3.3). Moreover, the participants mentioned that the return is the least important design element (direction, maximum angle, and return of the pitch motion). For further analysis, the five largest groups of Table 5.2 (highlighted in blue) were analyzed in detail. The requirements for parametric tests were violated. Therefore, non-parametric Friedman's tests were conducted. The participants had to rate the three different pitch profiles considering the items *perceptibility*, *situational context*, and *discomfort* on a six-point rating scale ($1 \mathrel{\hat{=}}$ "not at all", $2 \mathrel{\hat{=}}$ "very low", $3 \mathrel{\hat{=}}$ "low", $4 \mathrel{\hat{=}}$ "intermediate", $5 \mathrel{\hat{=}}$ "high", $6 \mathrel{\hat{=}}$ "very high").

Table 5.2: Favored pitch motion for the feedback, referring to Cramer, Miller, et al. (2017)

Pitch angle	1 °	−1 °	2 °	−2 °
Test scenario				
PV to follow	26	6	2	1
PV to overtake	9	21	0	5
Cutting-in vehicle	14	7	12	2
Speed limit	27	6	2	0

Scenario "PV to Follow"

26 participants chose a positive small pitch motion for the feedback of scenario 1. The mean values and standard deviations of the ratings for the items *perceptibility*, *situational context*, and *discomfort* are shown in Figure 5.13. The items *discomfort*

($\chi^2(2) = 0.35$, $p = .839$) and *situational context* ($\chi^2(2) = 0.56$, $p = .756$) were not significantly influenced by the pitch profile. On the contrary, the *perceptibility* showed significant results ($\chi^2(2) = 10.03$, $p = .007$). However, post-hoc Dunn-Bonferroni tests represented no significant differences between the three pitch profiles (*perceptibility*: degr.-poly. $z = -2.01$, $p = .133$, degr.-lin. $z = 2.15$, $p = .095$, and poly.-lin. $z = 0.14$, $p = 1.00$).

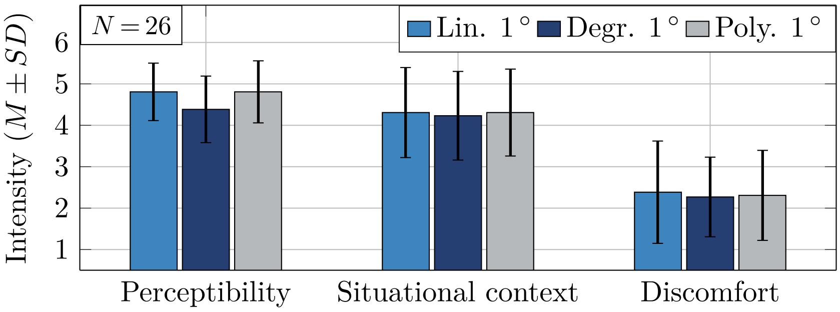


Figure 5.13: Evaluation of the items *perceptibility*, *situational context*, and *discomfort* for 1° pitch motions for the scenario “PV to follow” (scale: 1 ≙ “not at all” - 6 ≙ “very high”), referring to Cramer, Miller, et al. (2017)

Scenario “PV to Overtake”

For scenario 2, 21 participants selected a 1° pitch motion with a negative angle, the surveyed results are displayed in Figure 5.14. The three different pitch profiles did not affect the item *situational context* significantly ($\chi^2(2) = 1.33$, $p = .513$). Whereas, the *discomfort* ($\chi^2(2) = 8.22$, $p = .016$) as well as the *perceptibility* ($\chi^2(2) = 7.19$, $p = .027$) were significantly affected. Post-hoc Dunn-Bonferroni tests showed no significant differences between any of the profiles (*discomfort*: degr.-poly. $z = -1.54$, $p = .368$, degr.-lin. $z = 1.70$, $p = .269$, and poly.-lin. $z = 0.15$, $p = 1.00$; *perceptibility*: degr.-poly. $z = -1.31$, $p = .569$, degr.-lin. $z = 1.70$, $p = .269$, and poly.-lin. $z = 0.39$, $p = 1.00$).

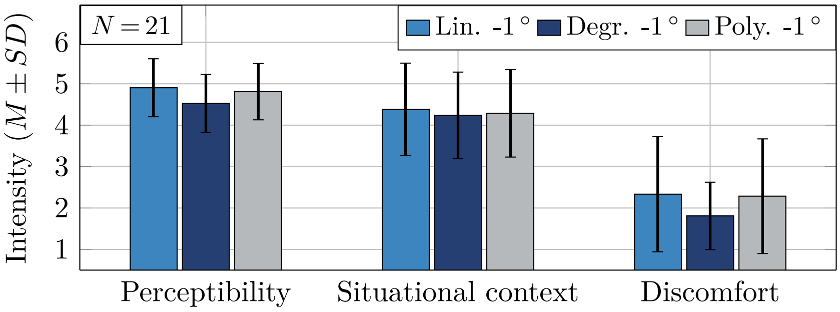


Figure 5.14: Evaluation of the items *perceptibility*, *situational context*, and *discomfort* for −1° pitch motions for the scenario “PV to overtake” (scale: 1 ≙ “not at all” - 6 ≙ “very high”), referring to Cramer, Miller, et al. (2017)

Scenario “Cutting-in Vehicle”

14 participants chose a 1 ° pitch motion and 12 a 2 ° pitch motion for scenario 3 (evaluation in Figure 5.15). Therefore, none of the items were found to be significantly influenced by the pitch profile (1 °: *perceptibility* $\chi^2(2)=2.33$, $p=.311$, *situational context* $\chi^2(2)=3.85$, $p=.146$, and *discomfort* $\chi^2(2)=1.81$, $p=.405$; 2 °: *perceptibility* $\chi^2(2)=3.60$, $p=.165$, *situational context* $\chi^2(2)=0.00$, $p=1.00$, and *discomfort* $\chi^2(2)=0.29$, $p=.867$).

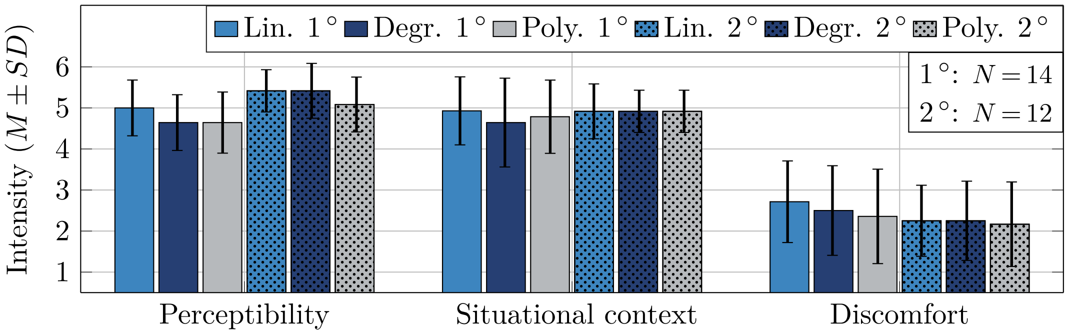


Figure 5.15: Evaluation of the items *perceptibility*, *situational context*, and *discomfort* for 1 ° and 2 ° pitch motions for the scenario “cutting-in vehicle” (scale: 1 ≙ “not at all” - 6 ≙ “very high”), referring to Cramer, Miller, et al. (2017)

Scenario “Speed Limit”

27 participants selected a positive small pitch motion for scenario 4. The ratings for the three items are presented in Figure 5.16. All items were not significantly influenced by the pitch profile (*discomfort*: ($\chi^2(2)=2.86$, $p=.239$, *situational context*: $\chi^2(2)=0.18$, $p=.913$, and *perceptibility*: $\chi^2(2)=0.48$, $p=.786$).

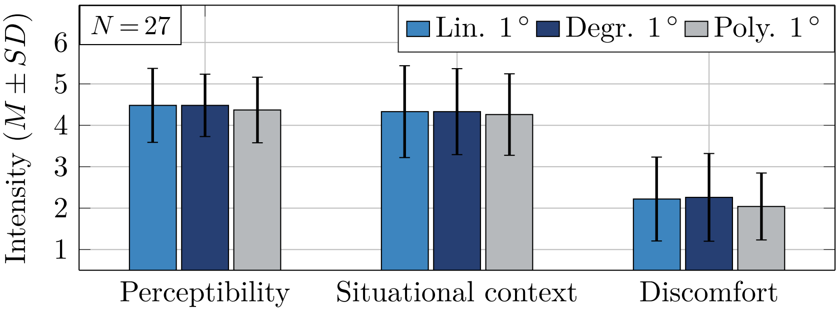


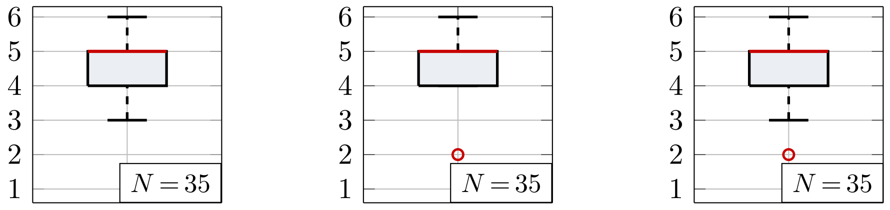
Figure 5.16: Evaluation of the items *perceptibility*, *situational context*, and *discomfort* for 1 ° pitch motions for the scenario “speed limit” (scale: 1 ≙ “not at all” - 6 ≙ “very high”)

5.3.6 Motion Sickness

The participants answered the following question several times (t_0, t_1, t_2, t_3, and t_4 in Figure 5.7) on a scale from 1 - 7 (1 $\widehat{=}$ not at all - 7 $\widehat{=}$ very strong): “Do you experience nausea, headache, or dizziness? If yes, how much?” Only three participants answered this question at least once with yes. One already had a slight headache before even starting with the driving study and the extent kept constant. Two participants just mentioned in one test scenario that they experience a slight headache which was gone after the next scenario.

5.3.7 Automation System

At the end of the driving study, three statements (Figure 5.17) related to the overall automation system were evaluated on a six-point rating scale (1 $\widehat{=}$ does absolutely not apply - 6 $\widehat{=}$ does absolutely apply). The distributions indicated that the participants had a positive experience with the automation. Consequently, further results were not negatively influenced by the prototypical implementation of the automation system.



(a) “The automation system gave me a feeling of safety.”

(b) “I can trust the automation system.”

(c) “I could understand the logic of the automation system better because of the pitch motions.”

Figure 5.17: Evaluation of these statements in the final questionnaire (scale: 1 $\widehat{=}$ “does absolutely not apply” - 6 $\widehat{=}$ “does absolutely apply”), referring to Cramer, Miller, et al. (2017)

5.4 Discussion and Conclusion

The results of the design of pitch motions showed that these should be motion compliant and represent a vehicle-like behavior. The return of the vehicle from 1 ° in a horizontal position revealed a tendency towards the slow linear return and from 2 ° a tendency towards the symmetric return. Though, for the scenario “PV to overtake” overall a slow linear return was preferred. The comments of the participants point out that a slow linear return from 2 ° takes too long and they could not identify the tilt position of the vehicle. Because of this, the gradient of the slow linear return for 2 ° pitch motions should be increased. Moreover, 1 ° pitch motions were preferred. Nevertheless, the increased number of favored 2 ° motions for the scenario "cutting-in vehicle" showed evidence that the feedback depends on the criticality of the situation. The comments of the participants supported this assumption.

The evaluation of pitch motions indicated a generally positive attitude towards the new feedback concept. The scenario "PV to overtake" showed a wider range of rating scores. This was due to the fact that the study revealed two different rating tendencies: the participants who liked the feedback as it was and the ones who found the feedback important but did not like the pitch motion itself for this feedback. 10 of the participants mentioned that a roll motion would be preferred for the announcement of the upcoming lane change. These statements enhance the assumption that feedback on state transitions resulting in a longitudinal driving action should be realized with a pitch motion and state transitions resulting in a lateral driving action should be performed with a roll motion. Accordingly, the design of feedback for an upcoming lane change or an abort of a lane change should be investigated in detail.
The study contained three scenarios with feedback in combination with a dynamic object and one with a static object (scenario 4). The last mentioned scenario had a tendency to a positive rating and showed feasibility for such feedback. However, the ratings varied a lot and the test vehicle was alone on the test track during the study. Therefore, a chance of misunderstanding might exist if other vehicles and speed signs are simultaneously to be fed back. Consequently, the scenario "speed limit" and generally static objects are not further considered for the feedback via pitch motions to avoid misunderstanding.

The lower ratings for the scenario "PV to follow" should be critically questioned. The main point was that the PV was always driving in front of the test vehicle throughout the entire scenario. So, the participant saw the PV nonstop, just the radar sensor lost the PV when it drove away. Because of this and the fact that the scenario was very uncritical, the ratings might have been negatively influenced. This was also reflected by the comments of the participants. Additionally, further comments showed that the intensity and trigger time of the feedback for a "PV to follow" or a "cutting-in" vehicle should be reliant on relative velocity and distance to the PV. Therefore, a driving study on the motorway will be conducted to investigate the last mentioned fact.

In summary, it can be stated that it is hard for a driver to differentiate between several pitch profiles. On the basis of the results regarding *perceptibility*, *situational*

context, and *discomfort*, and the fact that the degressive 1 ° profile takes the longest to reach its maximum angle, it was comprehensible that for this particular profile, the items *perceptibility* and *discomfort* receive some of the lowest scores. By contrast, for 2 ° pitch motions the polynomial profile was found to receive lowest scores for the aforementioned items. This profile takes the longest to reach the maximum angle of the 2 ° pitch motions. Therefore, it is probable that not the exact profile or the maximum velocity is relevant for the differentiation of pitch profiles but rather the time needed to reach the maximum angle. The participants were instructed to supervise the system and no secondary tasks were allowed. Nevertheless, drivers tend to do secondary tasks with higher automation levels (Carsten, Lai, Barnard, Jamson, & Merat, 2012). Hence, the perceptibility could be lower while doing a secondary task.
Considering the item *situational context*, no specific profile was preferred. Nevertheless, these well-founded results are important for subsequent studies. Instead of focusing on detailed profiles for rotational vehicle motions it is recommended to simply consider the time span needed to reach the maximum angle. However, the degressive pitch profile has the positive characteristic of raising awareness at the beginning of the profile due to its steep gradient, while still having a rather harmonic ending (lower gradient). In conclusion, the degressive profile is recommended for future implementations using pitch motion feedback. The acceleration of the 1 ° degressive profile can be increased from $4\,^{\circ}/s^2$ up to $5\,^{\circ}/s^2$ for better perceptibility. Accordingly, 1 ° will ideally be reached in $0.63\,s$ instead of $0.71\,s$.

The sample was recruited via several mailing lists, mainly of the AUDI AG. Interested persons could register for the driving study. Therefore, it was a self-selection sample (Lavrakas, 2008). This could have positively influenced the results because the participants are open to and interested in automated driving, and enthusiastic about the brand Audi. However, the Audi employees might be even more critical because they want to develop or sell really useful systems or products. Moreover, cultural and ethnographic background was not surveyed within the participants. This might have an influence on the results of this driving study and should be investigated for adaption of the results to the general driving population. Furthermore, the participants spent approximately 1.5 hours in the vehicle with the experimenter sitting on the passenger seat, the instructions were orally explained to the participants, and some data were orally collected. Consequently, some participants might have answered in a socially desirable manner (Döring & Bortz, 2016, p. 382). However, the communication was necessary to be sure that the participants understood everything and the data were available according to the driving scenarios.

The driving study was carried out on a test track with only two vehicles on it. Consequently, the boundary conditions were constant, and thus an equal setting for evaluating each pitch motion was guaranteed. However, the missing traffic could influence the ratings because the participants would probably allocate more attention to the traffic than to the actual pitch motion. Furthermore, the maximum speed was only $60\,km/h$ and the road surface was smooth. Motorway driving would include velocities reaching up to approximately $120\,km/h$. Additionally, motorway roads have road bumps and unevenness as well as road gradients which can influence the perceptibility (Bär, 2014). Consequently, the results should be tested in real traffic as well.

The data provided no evidence that the pitch motions induce motion sickness. With this, as well as the results mentioned before, it is derived that pitch motions are suitable for multi-modal feedback of state and maneuver transitions during automated driving to keep the driver “in-the-loop”. Further studies focused on timing of feedback for pitch motions (Chapter 6) and design of roll motions for announcing lane change maneuvers (Chapter 7).

6 Driving Study 2

The driving study and its results[2] are prepublished in Cramer et al. (2018), and Cramer, Lange, et al. (2017). Some parts of the written text are taken from these papers. Figures, tables, and statistics are adapted for an overall consistent representation throughout this thesis.

6.1 Introduction

A first driving study on a test track evaluated different pitch motion designs, for example, pitch direction, maximum angle, or course of the pitch motion, in different driving scenarios for signalizing other vehicles in the vehicle's longitudinal direction (cf. Chapter 5). The participants knew about the feedback concept via pitch motions. In Section 5.3 and 5.4 it is pointed out that vestibular feedback was rated positively and should exclusively feed back state transitions related to dynamic objects. The course of the pitch motions should have a degressive profile and a slow linear return (cf. Section 5.3 and 5.4).

This driving study was built upon the results of the first driving study (cf. Chapter 5). However, this study ($N = 36$) was conducted in real traffic on the motorway to examine other research questions for this new feedback approach, and to check the transferability of the results from the test track. Therefore, it was focused on pitch motions as well. For the evaluation, driving scenarios were selected which show the detection of a PV. These scenarios are associated with the state transitions to the state *follow preceding vehicle* (cf. Figure 3.2). The feedback's *comprehensibility* and *perceptibility* were evaluated in detail, as these are mentioned as important criteria for the design of feedback (Beggiato et al., 2015; Bubb, Bengler, et al., 2015; European Commission, 1998; Lange, Albert, et al., 2015). *Perceptibility* is defined as the ability to notice feedback using one's senses

---

[2] Ina Kaup assisted in designing and conducting the driving study, as well as processing and labeling the data as part of her Master's thesis (Kaup, 2017). Furthermore, Kaup (2017) analyzed parts of the data as well in her Master's thesis. For this Doctoral thesis, the data was evaluated separately.

(*Perceptible*, n.d.). *Comprehensibility* refers to the participants understanding of the meaning of the feedback (*Comprehensible*, n.d.). Another goal of this driving study was to survey which factors, for instance relative distance or velocity to the preceding vehicle, influence the desired timing as well as the need for feedback via pitch motions, considering the participants having mentioned this as an important design criteria in the first driving study (cf. Section 5.4).

6.2 Method

It is essential for feedback to be perceptible and noticed after a short time (Bubb, Bengler, et al., 2015; European Commission, 1998). Thereby, feedback should not be misunderstood or matched to other information or vehicle behavior. Effective feedback must be comprehensible for the driver (cf. Section 2.6). Thus, feedback must be clear as well as consistent. What is referred to as feedback logic in this driving study, is that the detection of a PV is communicated to the driver via pitch motions in several driving scenarios (Section 6.2.2). The design of the feedback as well as the engagement of the driver in the vehicle guidance might influence the perceptibility and comprehensibility of the feedback.

The driving study on the test track revealed that a positive pitch motion should feed back the detection of a PV that the ego vehicle will follow (cf. Section 5.3 and 5.4). This needs to be validated in real traffic.

Lange, Albert, et al. (2015) mentioned that feedback via the vestibular sensory channel should be comfortable. Considering that, one aspect to evaluate is if this kind of feedback is accepted by the driver, as it might induce discomfort. System awareness is crucial for the driver to be “in the loop” (Sarter & Woods, 1995) and be able to take over vehicle guidance at system limits. Furthermore, trust and feeling of safety are important for an automation system to be used (e. g. Ghazizadeh, Lee, & Boyle, 2012; Muir & Moray, 1996). Thereby, it should be questioned if these aforementioned items are rated differently according to design criteria for the timing and need for feedback. Moreover, the first study showed that the need, timing, and intensity of feedback might depend on certain variables, for instance relative velocity or distance. As a result, the research questions are the following:

- *RQ1*: Do the participants perceive the active pitch motions?
- *RQ2*: Do the participants understand the logic of the feedback?
- *RQ3*: Which direction of the pitch motion do the participants prefer for this feedback?

- *RQ4*: How do the participants rate the automation system and its feedback via pitch motions considering acceptance, system awareness, trust, and feeling of safety?
- *RQ5*: Which factors, for instance relative velocity to the preceding vehicle, influence the need, intensity, as well as the desired timing of feedback via pitch motions depending on the driving scenario?

Moreover, the feedback should not have a negative influence on the driver's well-being. Therefore, the participants were asked about typical symptoms (e. g. headache) of motion sickness as it was done for the first study. In addition, after experiencing the partial driving automation for nearly 2 hours, it was surveyed which sensory channel is suitable to feed back the detection of a PV, and which active rotational vehicle motions are suitable to announce an upcoming lane change to the driver.

The metrics for the evaluation of these research questions are presented in connection with the results in Section 6.3.

6.2.1 Test Setup and Equipment

The driving study was conducted on the three-lane motorway A9 in Germany between the exits Lenting and Holledau/Wolnzach. The A9 is used as a digital test bed for automated driving (Federal Ministry of Transport and Digital Infrastructure, 2015). In one direction, the track was $32\,km$ long and, in total, the driving study covered approximately $135\,km$ ($128\,km$ on the motorway). The automation system, active chassis, visual feedback for the participant, tasks of the experimenter on the passenger seat, and test equipment are described in Chapter 4. Apart from the first experimenter on the passenger seat, a second experimenter was seated in the back row. Her main task was to coordinate the questionnaires and functional variations as well as to provide the participants with instructions. Furthermore, the second experimenter triggered the pitch motions with a small noiseless push-button (Wizard controller on the left in Figure 6.1) during the interpretation part of the driving study (cf. Section 6.2.4). During the two design parts (cf. Section 6.2.4), the participants had to use a hands-on or hands-off push button (Figure 6.2) to fulfill their specific task. Comparing to the initially displayed test vehicle interior (cf. Figure 4.2), a front camera and a separate microphone with a higher quality were added (Figure 6.1).

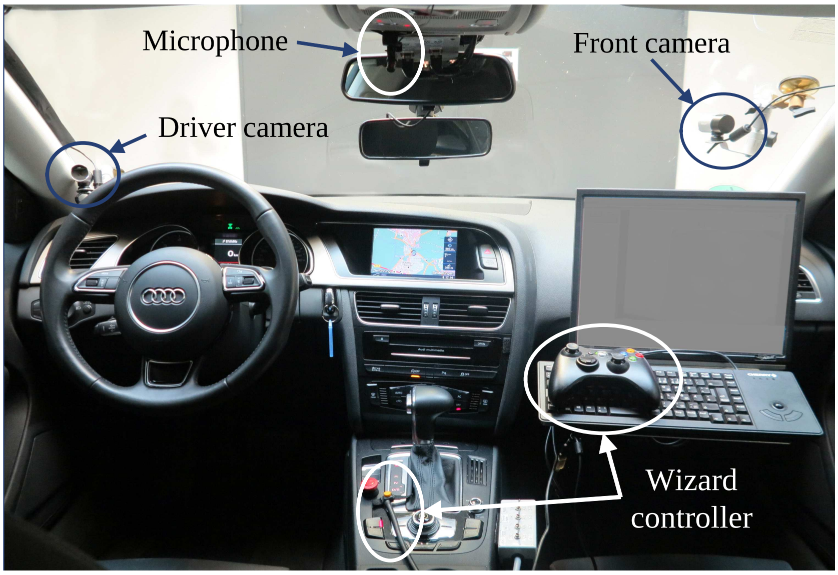


Figure 6.1: Test equipment in the test vehicle, referring to Cramer et al. (2018)

(a) Hands-on push button

(b) Hands-off push button

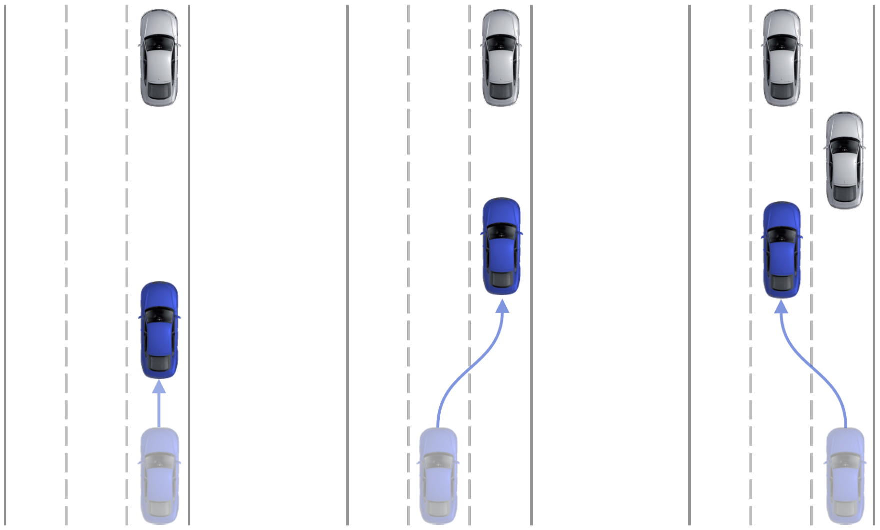
Figure 6.2: Hands-on and hands-off push button for the participants

Data evaluation was conducted using audio recording, the recording of the driving scenarios via the front camera, and the recording of vehicle data as well as internal data of the automation system.

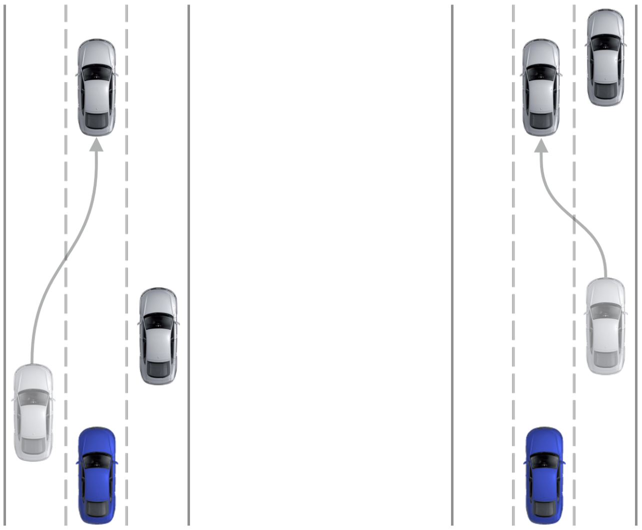
6.2.2 Test Scenarios

As aforementioned, the driving study was carried out on a three-lane part of the A9 motorway in Germany. For safety reasons, the automated vehicle was kept in the right or middle lane. The maximum velocity was 120 km/h and was adjusted to current speed limits.

For the interpretation part of the study (cf. Section 6.2.4), in which the second experimenter triggered the pitch motions, the initiation of the pitch motions occurred depending on the driving situation and, thus, the driving behavior of the surrounding vehicles or one's own test vehicle. This was based on clearly defined rules. Overall, five test scenarios resulted in feedback via pitch motions for the detection of a PV and can be seen in Figure 6.3. These scenarios were chosen according to the scenarios of a previous study (cf. Section 5.2.1) as well as discussion with experts.



(a) Scenario 1 "Approaching" *(b)* Scenario 2 "Ego cutting-in" *(c)* Scenario 3 "Ego cutting-out"



(d) Scenario 4 "PV cutting-in from left" *(e)* Scenario 5 "PV cutting-in from right"

Figure 6.3: Test scenarios of the driving study for feeding back the detection of the PV to the driver, referring to Cramer et al. (2018)

Scenario 1 (Figure 6.3a) displayed the approach towards a slower PV. The pitch motion was triggered by the second experimenter when the radar (Long Range Radar LRR3 from Bosch (Freundt & Lucas, 2008)) detected the PV (gray) as the relevant ACC object with a plausibility of 90 %. This was approximately $145\,m$ (measured value) in front of the ego vehicle (blue) at $120\,km/h$ (cf. Section 4.2). For scenarios 2 and 3, the automated vehicle was to change lanes either as a cutting-in or as a cutting-out vehicle (Figure 6.3b and 6.3c) with a PV approximately within the radar range for a relevant ACC object ($\approx 145\,m$). The second experimenter activated the pitch motion when the plausibility of that PV reached 90 %. Scenarios 4 and 5 (Figure 6.3d and 6.3e) represented the PV as a cutting-in vehicle either from the right (right lane) or left (left or middle lane), and also approximately within the radar range for a relevant ACC object. Hereby, the ego vehicle can follow the lane either following a PV or not. In these cutting-in cases of the PV, the ACC system performed badly for recognizing the cutting-in vehicle. Consequently, the pitch motions were initiated by the experimenter when the right (scenario 4) or left (scenario 5) front wheel of the PV had completely passed the lane marking.

For the two design parts (cf. Section 6.2.4), the participants decided on their own in which situation a feedback should occur.

6.2.3 Design of Pitch Motions

Pitch motions have either a positive or a negative pitch angle and consist of three parts (cf. Figure 2.5 and 5.3). The first is the increase, where the pitch angle is built up to a maximum angle. The second part is the holding period of the maximum angle, and the third is the return of the pitch angle back to zero (cf. Section 5.2.2). According to the results of a previous study (cf. Section 5.2.2, 5.3, and 5.4), the increase of the pitch motion is realized with a degressive pitch profile, the holding period is defined as 0.6 s, the pitch axis is set to the middle of the wheelbase, and the return of the pitch angle to the horizontal position of the vehicle's chassis is designed with a linear course. Moreover, a 1.0 ° (PP1) and a 2.0 ° (maximum angle, PP2) pitch profile (PP) was used in the previous study on the test track (cf. Section 5.2.2). However, experts rated a 1.0 ° pitch motion less perceptible on the motorway under real street and driving conditions for non-expert drivers. Consequently, a 1.5 ° pitch profile was added for the interpretation part (cf. Section 6.2.4) of the driving study. The course of the pitch angle θ is exemplarily displayed for the selected positive pitch motions in Figure 6.4.

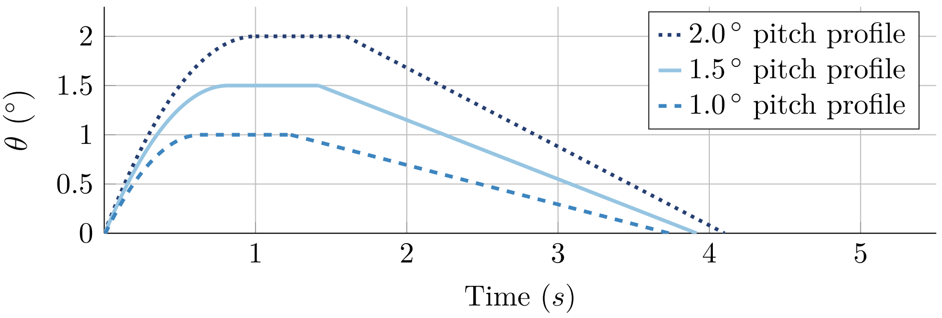


Figure 6.4: Composition and profile of pitch motions, referring to Cramer et al. (2018)

The increase of the pitch motion is characterized by the following equations for the pitch angle θ, velocity $\dot{\theta}$, and acceleration $\ddot{\theta}$, as well as the parameters in Table 6.1 whereby a and b are constants. Thus, the profiles have a constant pitch acceleration $\ddot{\theta}$.

$$\theta(t) = a\,t^2 + b\,t\,; \qquad \dot{\theta}(t) = 2\,a\,t + b\,; \qquad \ddot{\theta}(t) = 2\,a \tag{6.1}$$

According to the results of the first driving study (cf. Section 5.3 and 5.4), the time for reaching the maximum angle $t(\theta_{max})$ determines the perceptibility and discomfort of pitch motions and, thus, the pitch profile. Therefore, the increase of pitch profile PP3 (Table 6.1, Figure 6.4) is designed with regard to the time aspect and corresponding maximum angle of PP1 and PP2. Herein, $t(\theta_{max})$ of PP3 is the mean of $t(\theta_{max})$ of PP1 and PP2. Consequently, approximately $0.18\,s$ are added to the time $t(\theta_{max})$ for every additional $0.5\,°$ of θ_{max}. (Cramer, Lange, et al., 2017)

Table 6.1: Selected increase of the pitch profiles (exemplarily for a positive pitch angle) as feedback for the driver, referring to Cramer, Lange, et al. (2017)

Profile	θ_{max}	$\ddot{\theta} = 2\,a$	$t(\theta_{max})$	b
PP1	$1.0\,°$	$-5.0\,°/s^2$	$0.63\,s$	$3.16\,°/s$
PP2	$2.0\,°$	$-4.0\,°/s^2$	$1.00\,s$	$4.00\,°/s$
PP3	$1.5\,°$	$-4.5\,°/s^2$	$0.82\,s$	$3.68\,°/s$

The return of the pitch motion was evaluated in a previous study as well (cf. Section 5.3.3). Two options existed for this: a return course identical to the increase course of the pitch motion (symmetric return) or a slow linear return with a constant velocity of $0.4\,°/s$. The participants rated the return as the least important design element (direction, maximum angle, and return of the pitch motion), but showed a tendency towards the linear return for the 1.0 ° and a minor tendency towards the symmetric return for the 2.0 ° pitch profile. The comments for the decision of the latter case were mainly that the slow linear return takes too long and that the test participants did not know what the tilting position of their vehicle was (cf. Section 5.3.3 and 5.4). As a result, we chose a linear return for the design of the pitch profiles but increased the gradient of the linear return depending on the maximum angle of $0.4\,°/s$ (PP1), $0.6\,°/s$ (PP3), or $0.8\,°/s$ (PP2). Besides that, all profiles exceed the rotational perception thresholds from literature for yaw motions: $\approx 0.58\,°/s$ (without visual perception) and $\approx 0.08\,°/s$ (with visual perception) (Muragishi et al., 2007), $1.15\,°/s^2$ ($3\,s$ stimuli duration without visual perception) and $0.48\,°/s^2$ ($3\,s$ stimuli duration with visual perception) (Rodenburg, Stassen, & Maas, 1981), and for pitch motions $\approx 0.4\,°/s$ (without visual perception) and $\approx 0.08\,°/s$ (with visual perception) (Muragishi et al., 2007). Moreover, the pitch profiles do not exceed certain thresholds for comfortable roll motions: $4\,°/s$ (Bär, Siedersberger, & Meitinger, 2011), $5\,°/s$ and $15\,°/s^2$ (Bitterberg, 1999).

6.2.4 Study Design

The participants received some first notes about the study at the time the appointment was arranged (Appendix D.2). This was due to the same reasons as for the first study (Section 5.2.3). The driving study was conducted in German, and the sequence of it is shown in Figure 6.5. After receiving a verbal briefing on how to handle the test vehicle, participants drove manually on the motorway and began with the settling-in phase. First, they drove using only the standard ACC for five minutes. Hereby, the participants selected their preferred time gap ($\approx$1.0, 1.3, 1.8 (default value), or $2.3\,s$) and driving mode (comfort, auto (default value), and dynamic). After this standard ACC drive, the automation system with longitudinal and lateral vehicle guidance was activated which always set the default values for the ACC system. Only the visual feedback (Figure 4.5) was, thereby, displayed for the participants. Additionally, the indicators were illuminated during the automated lane change as they normally would be for a manually driven lane change. Following the first $32\,km$ settling-in phase, participants began with the interpretation part. First, the participants were informed

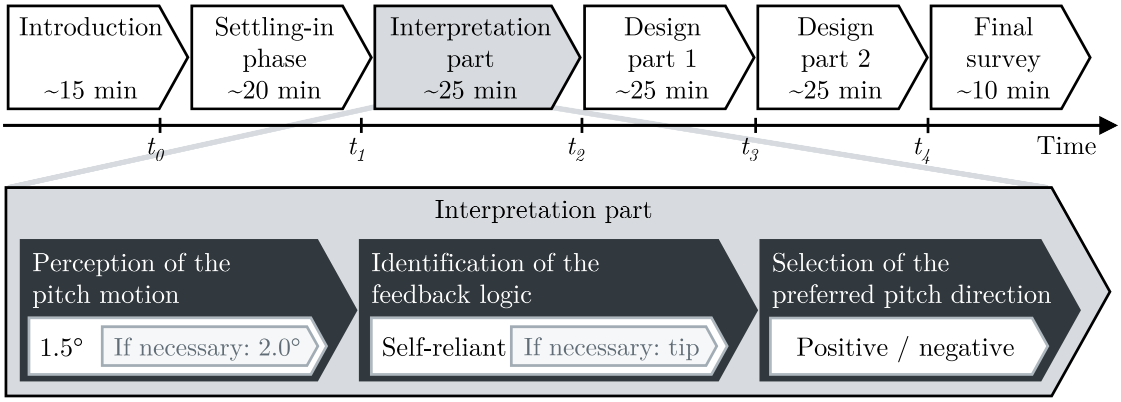


Figure 6.5: Sequence of the second driving study, referring to Cramer et al. (2018)

during a brief instruction that some form of feedback for supporting drivers during the supervising task of the automation system was to be expected. However, they were not given further information concerning the form of feedback, nor had they any knowledge of using pitch motions as feedback. The think-aloud method was chosen for the evaluation of the interpretation part and therefore the participants' task was to speak all of their thoughts out loud (Ericsson & Simon, 1980). Hereby, the two definitions of *perceptibility* and *comprehensibility* (Section 6.1) were transferred to the participants during their introduction. In the first instance, the participants focused on what kind of feedback they perceived and, thus, experienced. Afterwards, they were expected to try to understand the meaning or logic of this feedback.

The participants experienced feedback for the specific scenarios (Figure 6.3) with a 1.5 ° pitch profile, either with a positive or a negative pitch angle, as well as either hands-on or hands-off driving. These two factors were assigned equally in a randomized order. The participants who drove hands-off had to grab the steering wheel after a certain time as it is explained in Section 4.4. If the participants did not perceive the pitch motion with 1.5 ° after driving for about 12 km, the backup pitch profile with a maximum angle of 2.0 ° (Figure 6.4) was used. If the participants still did not perceive the bigger pitch angle after another 5 km, the pitch motions were indicated and explained to the participants. Thereafter, the task was modified to the identification of the feedback logic. If the participants failed to understand the logic by the time 19 km of the 32 km had been driven, the second experimenter gave a hint considering the logic of the feedback. Moreover, the logic was explained to the participant if it was not identified until 25 km of the 32 km had been driven. Finally, the two possible directions of the pitch motions (positive and negative pitch angle) were presented and the participants were asked to choose the preferred direction appropriate to the logic of the feedback for the driver. After the 32 km interpretation part, the participants answered a questionnaire and the design parts of the driving study followed.
Here, the timing and intensity of the feedback via pitch motions were designed by the participants themselves. The two design parts varied depending on whether the participants drove hands-on or -off. This was assigned in a randomized order. In both cases the participants used a push-button (Figure 6.2) to trigger when the pitch motion as feedback for a PV should occur, as well as its intensity. They were able to choose between PP1 and PP2. For PP1, the participants had to push the button for at least 100 ms. To trigger PP2, the participants had to push the button longer. If 500 ms were exceeded, PP2 was initiated. After each triggering, the second experimenter asked the participants if the timing and the intensity was suitable for them. If the participants did not trigger a pitch motion in a similar scenario as the selected test scenarios (Figure 6.3), the second experimenter asked them why. At first, the participants tested the push button independent of a desired feedback. Afterwards, approximately two triggering

scenarios with the belonging interview were conducted by the participants to get used to their task, and were, thus, not evaluated. Summing up, a final investigation of the gained impressions took place via a questionnaire.

6.2.5 Processing and Evaluation of Data

The recorded data had to be labeled for the evaluation subsequent to the driving study because this was organizationally and temporally not possible during the study. For this purpose, the video recording of the traffic in front of the vehicle, the audio recording, the data of the vehicle and radar sensor, as well as the internal data of the automation system were simultaneously looked at in the software framework ADTF. The recording stopped once a pitch motion was induced and the data were labeled. These items were, for example, the number of the relevant ACC object (32 available within a longitudinal range of 250 m, cf. Section 4.2), the perceptibility of the pitch motion, and the identified logic for the interpretation part of this driving study. For the design parts, these items were the number and type of ACC object (car or truck/transporter/bus/caravan), the lane of the PV for the desired feedback (before and after the feedback scenario), the lane of the ego vehicle (before and after the feedback scenario), and the existence of a PV as the relevant ACC object before the feedback scenario occurred. Moreover, the suitability of the timing and intensity of the feedback, as well as if the participants triggered a pitch motion or not were labeled. Data without suitable trigger times were removed, and data with incorrect intensity of the pitch motion were corrected while labeling. In contrast to driving study 1 (cf. Section 5.2.4), the data from the questionnaires were surveyed via online questionnaires and afterwards processed equally to the first driving study (Section 5.2.4).

6.2.6 Sample

For this study, $N = 38$ participants took part who have not participated in the first driving study. Two could not be considered for the evaluation. One did not fulfill the task properly even after several instructions, and one had to be excluded because of data recording problems. Consequently, $N = 36$ participants were available with a mean age of 33.9 years ($SD = 7.3$, $MIN = 24$, $MAX = 54$). The participants consisted of eight groups which were divided by answers of the pre-questionnaire (Appendix E.3). The eight groups were formed as a variation of gender (50 % female and 50 % male), field of work (50 % technical and 50 % nontechnical), and experience with ACC. Nevertheless, all participants must had used ACC before. Group A (50 %) were the participants with a lot of ACC experience, and an ACC system in their own vehicle, with experience of over one year. The participants who had no ACC system in their own vehicle and had less than or equal to one year experience with ACC built group B (50 %). Despite having nearly five times as many registered persons than needed, not all requirements were fulfilled for all participants to fill all eight groups. Out of group B, two participants violated this requirement and had two or three years experience. In group A, three participants had one year experience and not more than one year. The existing experience with ACC was set due to safety reasons, on the one hand, as the study took place in real traffic on the motorway, and, on the other hand, in order to guarantee that the participants were already used to some ADAS, and avoid them focusing only on the driving behavior of the self-driving vehicle. Accordingly, the participants could focus on their task and evaluate the roll motions. The median mileage per year was 20,000 - 30,000 km and the mean mileage per week was 472 km (SD =296 km) with an average of 45 % motorway driving. Furthermore, 34 participants had experience with LKA and 15 with PAD systems (e. g. traffic jam assistance). The frequencies of use of these ADAS of the participants who had already used these systems are presented in Figure 6.6. Moreover, the duration of having experience with each driving assistance system is shown in Figure 6.7. Supplementary information about the sample is presented in Appendix C.

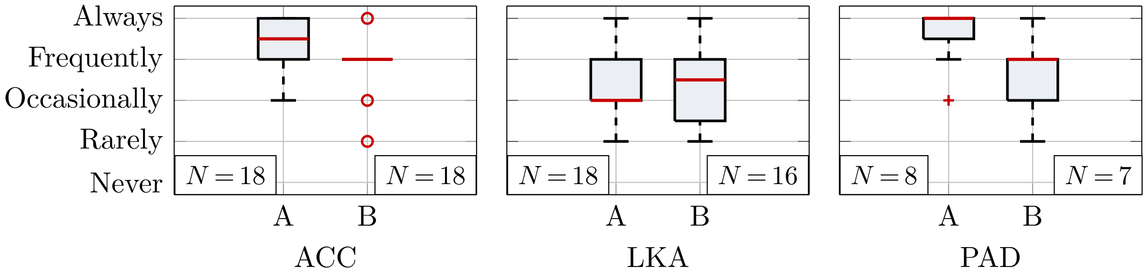


Figure 6.6: Frequency of use of ADAS of the second study's sample depending on the ACC experience (A: a lot, B: less)

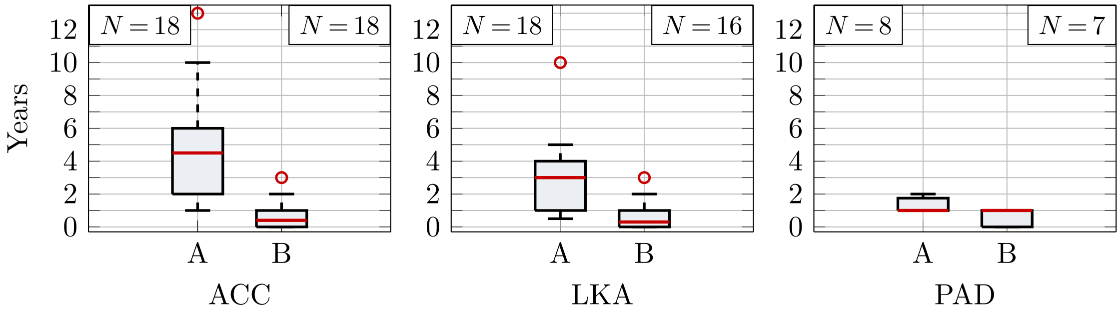


Figure 6.7: Experience with ADAS of the second study's sample depending on the ACC experience (A: a lot, B: less)

6.3 Results

The results of the research questions are presented in the same order as they are introduced at the beginning of Section 6.2. The findings are reported according to the recommendations in Field (2012).
For some research questions data were only available for 32 out of the 36 participants because further questions were added to the questionnaire about system awareness (Section 6.3.5), trust (Section 6.3.6), and feeling of safety (Section 6.3.7) after the fourth participant. These were initially only planned for the final survey. However, the pre-study and the comments of the first four participants showed that it would be interesting to also collect data for these aspects for t_2 to compare these items depending on the driving time. So, we only added the questions at t_2, the other questionnaire as well as the study design did not change. These questions were available in the questionnaire from participant five on. The pre-questionnaire and the questionnaire during the driving study are listed in the Appendix E.3 and E.4.

6.3.1 Perception of Pitch Motions

As described before and displayed in Figure 6.5, the interpretation part started with a 1.5 ° pitch motion either with a positive or negative pitch angle. If the participant failed to notice the 1.5 °, the experimenter changed the pitch motion to 2.0 °. The distribution of the perceived pitch motion is shown in Figure 6.8. 27 participants noticed the 1.5 °, five the 2.0 °, and four no pitch motion at all.

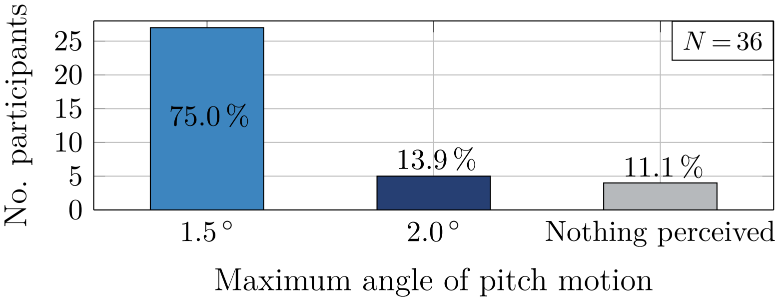


Figure 6.8: Distribution of the participants perceiving the pitch motion, referring to Cramer et al. (2018)

Figure 6.9 presents how many pitch motions were needed until they were perceived. For noticing the 1.5 ° pitch motion, the median value was 1 and the mean value 2.1 pitch motions.

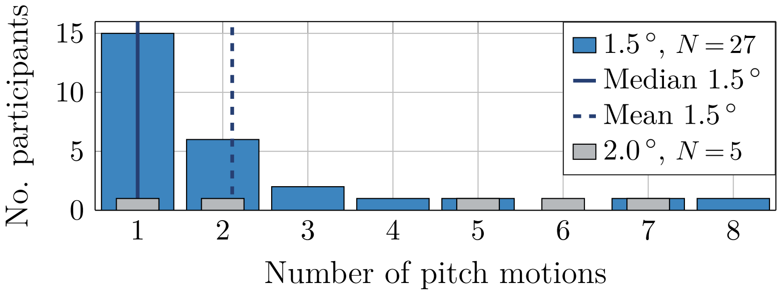


Figure 6.9: Required number of pitch motions in order to be perceived, referring to Cramer et al. (2018)

The first impression of the pitch motions was evaluated via the audio recording after the driving study. Three participants could not be analyzed because of a missing or indistinct statement. Three (9.1 %) of the four participants who did not perceive any pitch motion on their own (Figure 6.8) experienced a positive pitch angle and linked this to the normal braking behavior of the test vehicle or road bumps. Moreover, six (18.2 %) participants associated the first impression of the pitch motion with an acceleration or deceleration of the test vehicle. Interestingly, five out of these six had a negative pitch angle setup for the perceiving part, which is not the natural vehicle behavior during a deceleration. However, 24 participant (72.7 %) had an initial impression independent of the deceleration or acceleration of the test vehicle (passive pitch motions). Frequent statements were, for example: “The vehicle goes down at the front/back.”, “The vehicle is tilting.” or “The vehicle goes up at the front/back”.
Furthermore, the participants rated that the perceptibility of the pitch motions was rather not decreasing over the test duration.

6.3.2 Comprehensibility and Logic of the Feedback

Following the perception of the pitch motion, the participants were asked to identify the logic of the feedback. As described before, the participants received a hint after a certain amount of driving kilometers if they failed to understand the logic on their own. In total, 24 participants (66.7 %) identified the complete logic without a hint and two (5.5 %) with a hint. Two (5.5 %) only understood the approach to a slower vehicle with a hint and, in each case, one participant (2.8 %) either with or without a hint only for the cutting-in vehicles. Overall, the logic or at least parts of it were not identified by just one participant (2.8 %). Five participants (13.9 %) had no chance to understand the logic because they either had no time or too few pitch motions (less than ten: rounded integer number of the mean number of pitch motions for identifying the logic without a hint added with its standard deviation, see Figure 6.11) for identifying the logic. Consequently, 83.9 % of the participants who had a chance to identify the logic, managed to do so. These results are visually presented in Figure 6.10.

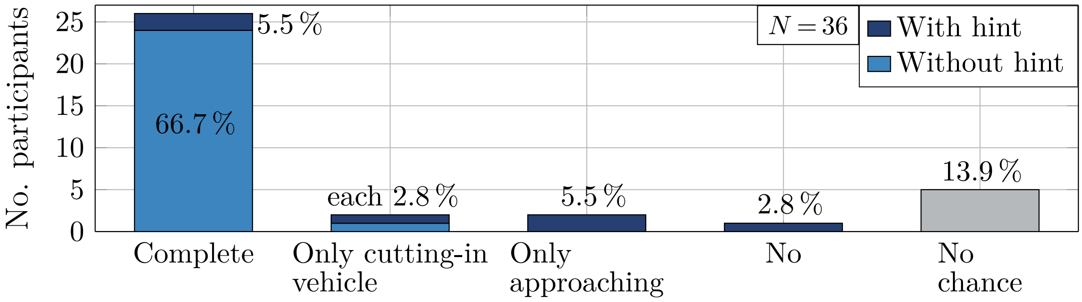


Figure 6.10: Distribution of the identified feedback logic, referring to Cramer et al. (2018)

Figure 6.11 displays how many pitch motions were necessary to identify the complete logic of the feedback. However, it has to be mentioned that the experienced driving scenarios differed in complexity, meaning that some participants had more unfavorable driving situations (e. g. very high traffic density) than others. So, the number of pitch motions only provides a guidance for how long it took the participants to understand the logic. Out of the participants who recognized the logic without a hint, the median amount of pitch motions was six. The mean value is considerably similar with a value of 6.13 pitch motions. However, it has to be mentioned that scenario 3 (Figure 6.3c) often caused confusions if the PV in the target lane had a positive relative velocity and was further away (still in the range of the radar relevant ACC object, approximately 145 m). This was based on the fact that most of the participants saw this scenario as an upcoming free driving without a PV.

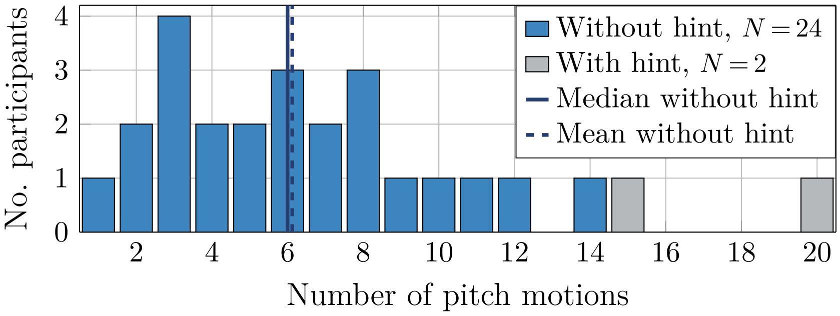


Figure 6.11: Required number of pitch motions for identifying the complete feedback logic, referring to Cramer et al. (2018)

A categorical analysis was further carried out on the results for understanding the feedback logic. The four categories were separated and sorted corresponding to how well the participant identified the feedback logic and were the following: Identified complete logic without hint, complete logic with hint, part of the logic, and no logic at all. Subsequently, these data were divided into groups according to the investigated factor(s).

The logic was neither understood in a significantly different manner considering the two pitch directions (Mann-Whitney test: $U = 109$, $z = -0.60$, $p = .552$, $r = .11$), nor considering the amount of ACC experience (Mann-Whitney test: $U = 115$, $z = -0.27$, $p = .787$, $r = .05$). Regarding both of these facts in combination, no significant differences in understanding the logic existed either (Kruskal-Wallis test: $H(3) = .47$, $p = .926$). However, the influence of hands-on/hands-off driving showed a tendency towards significance (Mann-Whitney test: $U = 86$, $z = -1.79$, $p = .073$, $r = .32$). Here, the participants who drove hands-off (grabbing the steering wheel approximately every 60 s) during the interpretation part had more problems in recognizing the feedback logic than those with their hands continuously on the steering wheel.

6.3.3 Direction of Pitch Motion

The last aspect of the interpretation part (Figure 6.5) was the selection of the preferred direction of pitch motions for this type of feedback. Half of the participants experienced negative, while the other half experienced positive pitch motions during the perception and feedback logic identification phases. Afterwards, the participants experienced the other pitch direction and were asked to decide which direction they favored. Only one participant (2.8 %) preferred a negative pitch angle out of those who had a positive pitch angle during the interpretation phase. On the contrary, out of the participants who experienced a negative pitch angle first, five (13.9 %) kept this direction. However, no significant correlation existed between the experienced and the preferred direction of the pitch motion (Fisher's exact test, two sided: $p = .177$). Overall, 30 participants (83.3 %) favored a positive pitch angle and six (16.7 %) a negative pitch angle. These results can be seen in Figure 6.12.

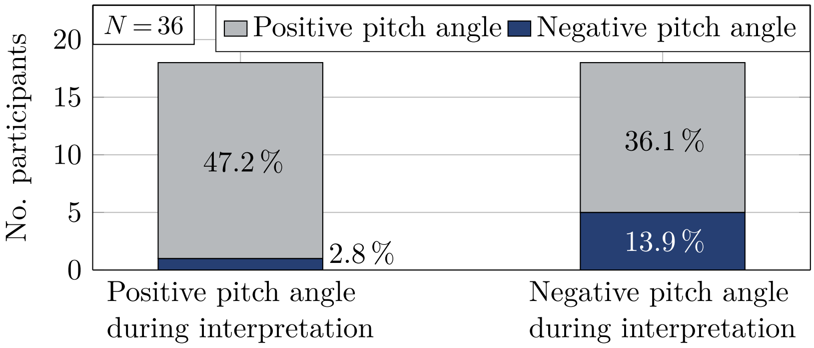


Figure 6.12: Distribution of the preferred pitch motion direction, referring to Cramer et al. (2018)

6.3.4 Acceptance

The acceptance of the experienced feedback via pitch motions was evaluated by the questionnaire of van der Laan, Heino, and de Waard (1997) in the German version (Kondzior, n.d.). This questionnaire has nine items on a five-point rating scale from -2 to 2 in which five items are included as their mean value in the *usefulness* scale (y-axes) and four in the *satisfying* scale (x-axes). Figure 6.13 presents the results of this questionnaire for the experienced feedback after the interpretation part (t_2, Figure 6.5). The ratings for the items *usefulness* and *satisfying* of all participants are displayed in gray with a solid line. The key message is that on average, feedback via pitch motions was evaluated as useful and satisfying and is represented by the positive mean values for both the *usefulness* ($M = 0.72$) and *satisfying* ($M = 0.38$) item. Moreover, it was interesting to know, if the acceptance of the feedback was rated differently, if the participants understood the complete logic on their own (CL, light blue, dashed) or if the participants required at least some explanation of the feedback logic (NCL, dark blue, dotted). Therefore, the ratings of the participants were split into two groups (CL and NCL). Overall, the feedback was evaluated as useful and satisfying in both groups. The CL group ($M = 0.45$, $SE = .14$) was not significantly more satisfied with the feedback than the NCL group ($M = 0.18$, $SE = .23$; requirements for a parametric test are fulfilled: t-test: $t(34) = 1.04$, $p = .305$, $r = .18$). Regarding the item *usefulness*, the absolute mean values are even close to 1 and did not differ significantly (CL: $Mdn = 0.9$, NCL: $Mdn = 0.8$; requirements for a parametric test are violated: Mann-Whitney test: $U = 119.5$, $z = -0.37$, $p = .709$, $r = .06$).

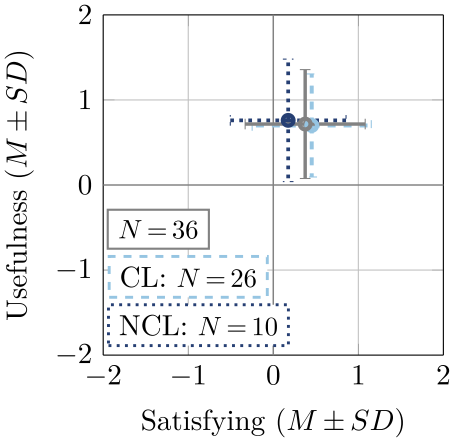


Figure 6.13: Evaluation of the feedback's acceptance at the time t_2 distinguished in three groups: all participants (solid), CL: participants identified the complete logic by themselves (dashed), and NCL: participants needed at least some explanation of the feedback logic (dotted; scale: five-point semantic differential), referring to Cramer et al. (2018)

The acceptance of the feedback via pitch motions was also evaluated at t_4 after the design part during the final survey. The feedback was rated significantly more satisfying at t_4 ($M = 0.87$, $SE = .11$) than t_2 ($M = 0.38$, $SE = .12$, t-test: $t(35) = -4.46$, $p < .001$, $r = .60$). Furthermore, the item *usefulness* was also evaluated significantly higher in the final survey ($M = 1.11$, $SE = .10$) than after the interpretation part ($M = 0.72$, $SE = .11$, t-test: $t(35) = -6.59$, $p < .001$, $r = .74$).

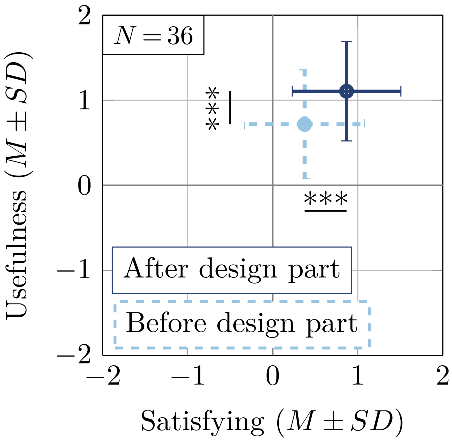


Figure 6.14: Evaluation of the acceptance of the feedback before (t_2) and after the design part (t_4; scale: five-point semantic differential; $^{***}p < .001$)

6.3.5 System Awareness

Only 32 participants were available for the evaluation of system awareness for the reasons mentioned at the beginning of Section 6.2.5. Figure 6.15 shows the distributions for the following statement: "Via the pitch motions, I had better awareness of the driving action that the vehicle (automation system) is currently performing/prospectively intends." on a scale from 1 ≙ "does absolutely not apply" to 5 ≙ "does absolutely apply" after the interpretation part. On average, it was rated that the use of pitch motions as feedback increased system awareness (mean values between 3 and 4). As had been previously carried out for the evaluation of acceptance, the two groups, CL and NCL, were distinguished to evaluate differences in ratings concerning system awareness. Besides the positive consent to the statement for supporting system awareness, assignment of the feedback to the current driving action (CL: $Mdn = 4.0$, NCL: $Mdn = 3.5$) did not occur significantly more often than to the prospective driving action (CL: $Mdn = 4.0$, NCL: $Mdn = 3.0$; Wilcoxon test: CL: $z = -1.33$, $p = .183$, $r = .27$, NCL: $z = -0.82$, $p = .414$, $r = .29$). System awareness was not rated significantly different if the participants understood the logic or not (Mann-Whitney test: Current driving action: $U = 87$, $z = -0.41$, $p = .682$, $r = .07$; prospective driving action: $U = 87.5$, $z = -0.39$, $p = .701$, $r = .07$).

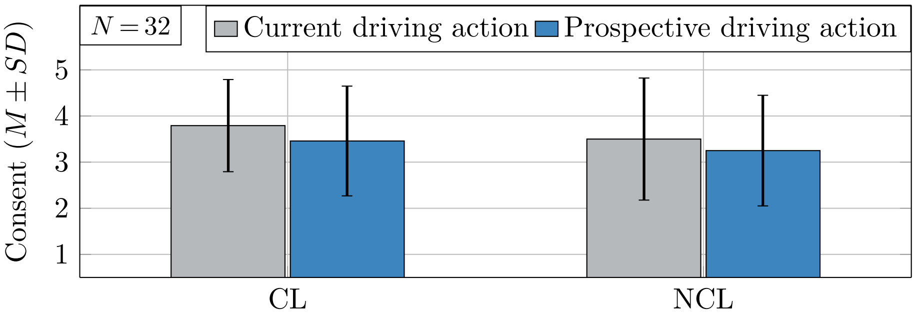


Figure 6.15: Ratings of the system awareness at t_2 by two groups: CL: participants understood the complete logic on their own, and NCL: participants needed at least some explanation about the feedback logic (scale: $1 \mathrel{\widehat{=}}$ "does absolutely not apply" - $5 \mathrel{\widehat{=}}$ "does absolutely apply")

The two statements ("Via the pitch motions, I had better awareness of the driving action that the vehicle (automation system) is currently performing/prospectively intends.") were also evaluated at t_4 after the design part. Figure 6.16 shows the distributions for these statements after the interpretation part and for the final survey.

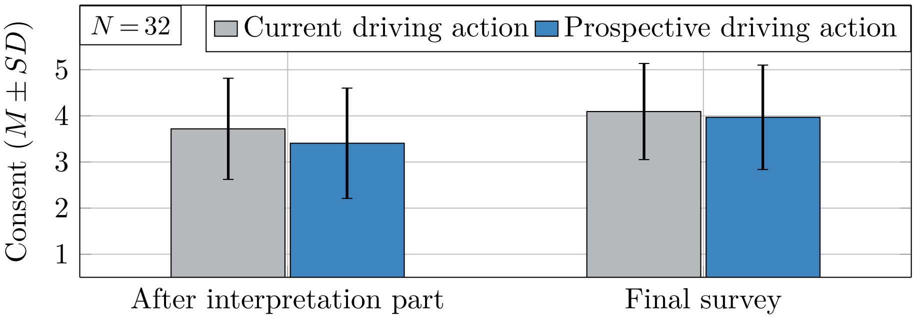


Figure 6.16: Ratings of the system awareness at t_2 and t_4 (scale: $1 \mathrel{\widehat{=}}$ "does absolutely not apply" - $5 \mathrel{\widehat{=}}$ "does absolutely apply")

A 2 (driving action) x 2 (time) ANOVA with repeated measures revealed that the main effect *driving action* ($F(1, 31) = 2.16$, $p = .152$, $r = .26$) as well as the interaction of *driving action * time* is not significant ($F(1, 31) = 0.85$, $p = .363$, $r = .16$). In contrast, the main effect *time* was significant ($F(1, 31) = 11.80$, $p = .002$, $r = .53$). Thus, the system awareness increased over time and with the self-designed feedback.

6.3.6 Trust

The participants had to answer two statements at the time t_2 and t_4 on a five-point rating scale ($1 \mathrel{\widehat{=}}$ "does absolutely not apply" - $5 \mathrel{\widehat{=}}$ "does absolutely apply") that consider the trust in the automation system: "I can trust the automation system without/with active pitch motions". As previously stated, data were only available for 32 participants. The participants experienced the automation system without pitch motions during the settling-in phase and with pitch motions during the interpretation and design parts (Figure 6.5). Overall, the trust in the automation system was high with a mean value around or over 4 (Figure 6.17).

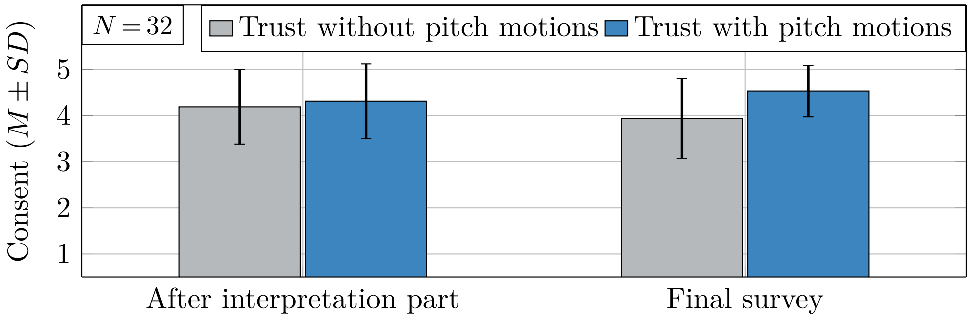


Figure 6.17: Ratings of trust in the automation system (scale: $1 \mathrel{\widehat{=}}$ "does absolutely not apply" - $5 \mathrel{\widehat{=}}$ "does absolutely apply")

A 2 (existence of pitch motions) x 2 (time) ANOVA with repeated measures indicated no significant influence of the *time* ($F(1,\ 31) = 0.24$, $p = .879$, $r = .03$) but the *existence of the active pitch motions* had a significant influence ($F(1,\ 31) = 6.07$, $p = .020$, $r = .40$). The results revealed a significant interaction effect of the *existence of the pitch motions* * *time* ($F(1,\ 31) = 8.39$, $p = .007$, $r = .46$). Here, the trust ratings for the automation system without pitch motions decreased over time, in contrast to the ratings for the automation system with active pitch motions which increased over time.

6.3.7 Feeling of Safety

The consent to the following statement: "The pitch motions gave me a feeling of safety." was surveyed on a five-point rating scale from $1 \mathrel{\widehat{=}}$ "does absolutely not apply" to $5 \mathrel{\widehat{=}}$ "does absolutely apply" after the interpretation part and at the final survey. The feeling of safety via pitch motions was significantly higher at t_4 ($M = 4.16$, $SE = .17$) than at t_2 ($M = 3.59$, $SE = .23$, t-test: $t(31) = -3.04$, $p = .005$, $r = .48$) and is displayed in Figure 6.18.

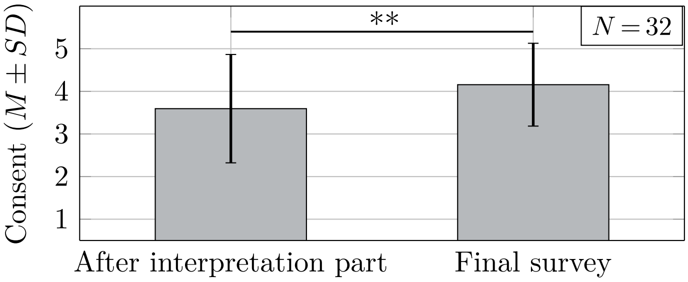


Figure 6.18: Ratings of feeling of safety in the automation system (scale: 1 ≙ “does absolutely not apply” - 5 ≙ “does absolutely apply”; $^{**}p < .01$)

6.3.8 Need for Feedback

During the labeling of the participants’ triggers and non-triggers for feedback, it was evaluated for all experienced test scenarios how often the participants wanted feedback via pitch motions for each test scenario (Figure 6.3). The distributions are presented in Table 6.2. It is distinguished between participants who always had the need for feedback, participants who wanted to receive feedback under certain situation-specific circumstances, and participants who never had the need for feedback.
Scenario 1 was divided in scenarios 1.1 and 1.2. depending on whether the ego vehicle was approaching from initially following the lane with (scenario 1.2) or without (scenario 1.1) a PV. In scenario 1.2, the ego vehicle approached a new PV, when the initial followed PV cut-out and the new PV was in the same lane in front of the initial PV in the radar range for the relevant ACC object. For scenario 1.1, most of the participants (61.1 %) always wanted feedback. 22.2 % of the participants needed feedback under certain circumstances. Mostly, they mentioned that it depended on the relative velocity to the PV. 16.7 % never desired a feedback via pitch motions, whereby some pointed out that it was useful in critical situations. Compared to the similar scenario 1.2, the participants’ opinion shifted towards less need for feedback. This was

Table 6.2: Distribution of the need for feedback depending on the driving scenario

Scenario	Feedback		
	Never	Always	Certain circumstances
Scenario 1.1 ($N = 36$)	16.7 %	61.1 %	22.2 %
Scenario 1.2 ($N = 36$)	44.5 %	33.3 %	22.2 %
Scenario 2 ($N = 32$)	21.9 %	53.1 %	25.0 %
Scenario 3 ($N = 36$)	44.4 %	16.7 %	38.9 %
Scenario 4 & 5 ($N = 36$)	0.0 %	8.3 %	91.7 %

mainly due to the fact that the situation stayed the same for the participants. If a further driving action would have been necessary, e. g. reducing the velocity, a feedback was stated to be necessary. The need for feedback for scenario 2 (4 participants did not experience this scenario) was similar to scenario 1.1. For scenario 3, 44.4 % of the participants never wanted a feedback, 16.7 % always, and 38.9 % under certain circumstances. The omission of the feedback was mostly due to the positive relative velocity of the PV on the target lane or the far distance of it. The relative velocity was also a main reason for the need or the omission of feedback in scenarios 4 and 5. Another reason was often the relative distance to the PV.

The further analysis focuses on the scenarios 1, 4, and 5. Table 6.3 presents the mean values of the percentage of how often the participants wanted feedback depending on their ACC experience. These values did not vary much. However, group A, which consisted of participants with a lot ACC experience, wanted feedback more often.

Table 6.3: Mean values for the need for feedback depending on ACC experience (A: a lot, B: less)

Scenario	Group A	Group B
Scenario 1	76.1 %	73.1 %
Scenario 4 & 5	66.6 %	55.4 %

Table 6.4 shows the influence of the PV being a car or a truck on whether feedback was requested or not in a certain scenario. For the "approaching" scenario, trucks were more often involved as a PV, but the type of vehicle was independent of needing feedback or not. This was contrary for "cutting-in vehicles from the left" (scenario 4). For scenario 5 ("cutting-in vehicle from the right"), the type of vehicle was nearly evenly distributed when feedback was needed, however, when feedback was not required, the percentage was much higher for cars than for trucks.

Table 6.4: Distribution of the need for feedback depending on the type of vehicle (NT ≙ no triggers, N ≙ triggers)

Scenario		Feedback	Car	Truck/transporter/bus/caravan
Scenario 1	($N_T = 306$)	yes	24.5 %	75.7 %
	($N_{NT} = 106$)	no	27.4 %	72.6 %
Scenario 4	($N_T = 248$)	yes	88.3 %	11.7 %
	($N_{NT} = 178$)	no	89.3 %	10.7 %
Scenario 5	($N_T = 135$)	yes	52.6 %	47.4 %
	($N_{NT} = 23$)	no	73.9 %	26.1 %

For scenarios 4 and 5, a logistic regression was conducted to survey the probability of a trigger for feedback and its influences. Overall, 426 analyzable scenarios 4 and 158 scenarios 5 existed during the two design parts of the driving study, whereby the need for feedback existed in 248 (58.2 %) scenarios 4 and 135 (85.4 %) scenarios 5. The values of the predictor variables, which are explained later, correspond to the moment the participants pressed the trigger button. In 8.09 % of the cases, the trigger was performed before the PV was detected by the radar. In these cases, the first time this object was detected by the radar sensor was taken for the evaluation. This was on average $0.88\,s$ ($SD = 0.43\,s$) after the trigger. If no trigger by the participants occurred, the data was labeled manually when the front and rear left wheel of the PV crossed the lane markings to the target lane when it was a “cutting-in vehicle from the right” (scenario 5) and appropriately inverse for “cutting-in vehicle from the left” (scenario 4).

On average, each participant experienced $M = 16.2$ ($SD = 6.6$) cutting-in scenarios. Five cases had to be excluded before the regression analysis due to implausible data. To survey the influences for the need for feedback, the only data relevant was that of participants which had triggered feedback in certain situations, but not triggered in others. For scenario 4, 33 participants varied whether they wanted feedback or not depending on the situation, and only nine participants did so for scenario 5.

As this was exploratory work due to no prior research, the backward method of regression was selected (Field, 2012, p. 272). Herefore, the predictors relative velocity (v_{rel}) and distance (d_{rel}) to the PV, type of PV (car or truck/transporter/bus/caravan), ego longitudinal acceleration (a_x), experience with ACC (group A and B, cf. Section 6.2.6), hands-on/-off driving, indicator usage of the PV, and whether the ego vehicle was following the lane with or without a PV before the new PV turned up were used. These predictors were selected in accordance with comments of pre-study participants and experts, as well as literature. According to Brackstone, Waterson, and McDonald (2009), during manual driving, the distance when following a PV is influenced by the type of vehicle. This relation might also affect the need for feedback. Moreover, in a simulator study, Josten, Zlocki, and Eckstein (2016) identified that take-over times in partially automated driving were shorter when the driver had his hands on the steering wheel. Thus, it is believed that the position of the hands influences the level of engagement the participants feel during the driving task, and hence their need for feedback on the system state. Knowledge of system limits of ACC systems (Weinberger, 2001) might be transferred to the usage of the presented partial driving automation, and should hence be surveyed.

Assumptions (linearity of the logit, no multicollinearity) for the logistic regression for scenario 5 were fulfilled. The regression model was significant ($\chi^2(2) = 29.77$, $p < .001$,

$R^2_N = .560$, $N = 57$ data sets of 9 participants) and included the predictors v_{rel} and d_{rel}. The results of this regression model are displayed in Table 6.5, and the following equation was developed:

$$P(Feedback_{Scenario5}) = \frac{1}{1 + e^{-(1.61 - 0.73\, v_{rel} - 0.05\, d_{rel})}} \tag{6.2}$$

Table 6.5: Results of the logistic regression model for the need for feedback for scenario 5 “PV cutting-in from right” (model 1)

	B (SE)	p	$Exp(B)$	95 % CI $Exp(B)$ Lower	Upper
Variables in the equation					
Constant	1.61 (0.75)				
$v_{rel}\,(m/s)$	-0.73 (0.23)	<.001	0.48	0.31	0.75
$d_{rel}\,(m)$	-0.05 (0.02)	.006	0.95	0.91	0.99
Variables not in the equation					
Vehicle [car=0, truck=1]	Removed in second step				
$a_x\,(m/s^2)$	Removed in third step				
ACC group [A=1, B=0]	Removed in fourth step				
Follow PV [yes=0, no=1]	Removed in fifth step				
Indicator [yes=1, no=0]	Removed in sixth step				
Hands [on=1, off=0]	Removed in seventh step				

For scenario 4, the data derived from 33 participants was divided in a first set from participants who triggered feedback in over 50 % of the scenarios (*many triggers*, model 2a, Table 6.6) and a second set from participants who triggered feedback in less than 50 % of the scenarios (*few triggers*, model 2b, Table 6.7) to achieve a best possible evaluation.

For model 2a, the multicollinearity assumptions were fulfilled. However, linearity of the logit was only obtained for v_{rel} (d_{rel}: $p < .05$). The resulting logistic regression model was significant ($\chi^2(4) = 84.56$, $p < .001$, $R^2_N = .417$, $N = 243$ data sets of 21 participants) and contained the predictors v_{rel}, d_{rel}, the type of vehicle, and whether the ego vehicle followed the lane with or without a PV (cf. Table 6.6). The model is defined by the following equation:

$$P(Feedback_{Scenario4-many}) = \frac{1}{1 + e^{-(5.80 - 0.19\, v_{rel} - 0.06\, d_{rel} - 2.15\, vehicle + 0.71\, followPV)}} \tag{6.3}$$

Table 6.6: Results of the logistic regression model for the need for feedback for scenario 4 “PV cutting-in from left” for participants with *many triggers* (model 2a)

	B (SE)	p	$Exp(B)$	95 % CI $Exp(B)$ Lower	95 % CI $Exp(B)$ Upper
Variables in the equation					
Constant	5.80 (1.08)				
$v_{rel}\,(m/s)$	-0.19 (0.04)	<.001	0.83	0.76	0.90
$d_{rel}\,(m)$	-0.06 (0.01)	<.001	0.94	0.92	0.96
Vehicle [car=0, truck=1]	-2.15 (0.89)	.016	0.12	0.02	0.67
Follow PV [yes=0, no=1]	0.71 (0.36)	.0496	2.03	1.00	4.12
Variables not in the equation					
$a_x\,(m/s^2)$	Removed in second step				
Indicator [yes=1, no=0]	Removed in third step				
Hands [on=1, off=0]	Removed in fourth step				
ACC group [A=1, B=0]	Removed in fifth step				

The multicollinearity assumptions were fulfilled for the logistic regression model of *few triggers* in scenario 4 (model 2b). However, linearity of the logit was only achieved for v_{rel} (d_{rel}: $p < .05$). The resulting regression model was significant ($\chi^2(2) = 32.68$, $p < .001$, $R_N^2 = .358$, $N = 129$ data sets of 12 participants) and included the same predictors as model 1: v_{rel} and d_{rel}. The results are outlined in Table 6.7, and the following equation was developed:

$$P(Feedback_{Scenario4-few}) = \frac{1}{1 + e^{-(2.35 - 0.59\,v_{rel} - 0.05\,d_{rel})}} \tag{6.4}$$

The qualities of all logistic regression models (models 1, 2a, and 2b) are presented in Appendix F.

Table 6.7: Results of the logistic regression model for the need for feedback for scenario 4 “PV cutting-in from left” for participants with *few triggers* (model 2b)

	B (SE)	p	$Exp(B)$	95 % CI $Exp(B)$	
				Lower	Upper
Variables in the equation					
Constant	2.35 (0.86)				
$v_{rel}\,(m/s)$	-0.59 (0.14)	<.001	0.56	0.42	0.74
$d_{rel}\,(m)$	-0.05 (0.02)	.059	0.96	0.91	1.00
Variables not in the equation					
ACC group [A=1, B=0]	Removed in second step				
Follow PV [yes=0, no=1]	Removed in third step				
Indicator [yes=1, no=0]	Removed in fourth step				
Vehicle [car=0, truck=1]	Removed in fifth step				
Hands [on=1, off=0]	Removed in sixth step				
$a_x\,(m/s^2)$	Removed in seventh step				

6.3.9 Intensity of Feedback

Overall, 25 (69.4 %) participants stated in the questionnaire that they varied the pitch angle and selected 1.0 ° as well as 2.0 ° pitch motions during the design parts. In contrast, 11 (30.6 %) participants only chose the 1.0 ° pitch motion and mostly mentioned that the intensity of the small angle was enough. However, 5 out of these 11 participants would have varied the pitch angle if they would have had more critical driving situations. In the labeled data it was surveyed that the amount of 1.0 ° pitch motions was noticeably higher than of the 2.0 ° pitch motions (Table 6.8). Scenario 5 reached the highest amount of big pitch motions as well as the highest percentage for varying the pitch angle. Overall, the participants rated as a median value that the variation of the pitch angle was rather important.

Table 6.8: Distribution of the intensity of feedback depending on the driving scenario of this study (N: Number of participants for variation of 1 °/ 2 °, N_T: Number of triggers for the amount of 1 ° and 2 °)

Scenario	Variation 1 °/ 2 °	Amount 1 °	Amount 2 °
Scenario 1.1 ($N=30$, $N_T=288$)	30.0 %	93.4 %	6.6 %
Scenario 4 ($N=36$, $N_T=248$)	36.1 %	92.3 %	7.7 %
Scenario 5 ($N=33$, $N_T=135$)	45.5 %	80.0 %	20.0 %

6.3.10 Timing of Feedback

It is necessary to know when feedback should occur depending on the scenario. The criteria for the timing of feedback were the lateral distance $d_{y,PV}$ of the PV for scenarios 4 and 5, and the longitudinal distance $d_{x,PV}$ of the PV for scenario 1. Thereby, data of all triggers of all participants were included in the linear multiple regression models. The same predictors were used as for the logistic regression models (Section 6.3.8). However, the time gap selected by the participants during the first 5 min of the settling-in phase using only the standard ACC system was added. Thereby, most participants (72.2 %) did not modify the default time gap of 1.8 s, 27.8 % selected a smaller time gap.

All assumptions for a linear multiple regression for scenario 5 (model 3) were fulfilled: linearity, homoscedasticity, normally distributed residuals, independent errors (Durbin-Watson statistic = 1.88), and no perfect multicollinearity within data. The regression model revealed that $d_{y,PV}$ was influenced by the selected time gap in the settling-in phase, v_{rel}, d_{rel}, and whether the ego vehicle was following a PV or not before the new PV cut in ($F(4,\ 128) = 9.62$, $p < .001$, $R^2 = .237$, $N = 129$). The results are displayed in Table 6.9 as well as in the following equation:

$$d_{y,PV} = -2.47 + 0.40\,timegap + 0.12\,v_{rel} + 0.01\,d_{rel} - 0.58\,followPV \qquad (6.5)$$

Table 6.9: Results of the multiple regression model for the timing of feedback for scenario 5 "PV cutting-in from right" (model 3)

	B (SE)	β	p
Variables in the equation			
Constant	−2.47 (0.17)		
Time gap [default=0, smaller=1]	0.40 (0.17)	.19	.019
v_{rel} (m/s)	0.12 (0.02)	.46	<.001
d_{rel} (m)	0.01 (0.00)	.37	<.001
Follow PV [yes=0, no=1]	−0.58 (0.20)	−.27	.004
Variables not in the equation			
Hands [on=1, off=0]	Removed in second step		
Indicator [yes=1, no=0]	Removed in third step		
ACC group [A=1, B=0]	Removed in fourth step		
Vehicle [car=0, truck=1]	Removed in fifth step		
a_x (m/s^2)	Removed in sixth step		

For scenario 4, all assumptions for a linear regression were fulfilled: linearity, homoscedasticity, normally distributed residuals, independent errors (Durbin-Watson statistic $= 1.84$), and no perfect multicollinearity within data (model 4). The regression model indicated that $d_{y,PV}$ was influenced by d_{rel} and whether the ego vehicle was following a PV or not before the new PV cut-in ($F(2,\ 246) = 29.90$, $p < .001$, $R^2 = .197$, $N = 247$). The results are presented in Table 6.10, and the following equation was developed:

$$d_{y,PV} = 3.08 - 0.02\,d_{rel} + 0.23\,followPV \tag{6.6}$$

Table 6.10: Results of the multiple regression model for the timing of feedback for scenario 4 “PV cutting-in from left” (model 4)

	B (SE)	β	p
Variables in the equation			
Constant	3.08 (0.09)		
d_{rel} (m)	−0.02 (0.00)	−.41	<.001
Follow PV [yes=0, no=1]	0.23 (0.09)	.15	.009
Variables not in the equation			
Hands [on=1, off=0]	Removed in second step		
Time gap [default=0, smaller=1]	Removed in third step		
a_x (m/s^2)	Removed in fourth step		
ACC group [A=1, B=0]	Removed in fifth step		
v_{rel} (m/s)	Removed in sixth step		
Vehicle [car=0, truck=1]	Removed in seventh step		
Indicator [yes=1, no=0]	Removed in eighth step		

Overall, 372 scenarios 1.1 (approaching from the maneuver *follow lane without a PV*) were experienced by the participants. In 288 (77.4 %) cases, the participants wanted a feedback for detecting a PV via pitch motions. On average, each participant experienced scenario 1.1 $M = 10.9$ ($SD = 3.6$) times. Most assumptions for a linear regression were fulfilled: linearity, homoscedasticity, independent errors (Durbin-Watson statistic $= 1.81$), and no perfect multicollinearity within data. The assumption for normally distributed residuals was slightly violated. One data set had to be excluded due to a high cooks distance. The regression model revealed that $d_{x,PV}$ was influenced by v_{rel}, the vehicle type, and a_x ($F(3,\ 286) = 104.83$, $p < .001$, $R^2 = .526$, $N = 287$). The results are shown in Table 6.11, and revealed the following equation:

$$d_{x,PV} = 85.71 - 4.87\,v_{rel} + 7.20\,vehicle + 73.63\,a_x \tag{6.7}$$

Table 6.11: Results of the multiple regression model for the timing of feedback for scenario 1 “Approaching” with a previous lane following without a PV (model 5)

	B (SE)	β	p
Variables in the equation			
Constant	85.71 (3.89)		
$v_{rel}\,(m/s)$	−4.87 (0.56)	−.40	<.001
Vehicle [car=0, truck=1]	7.20 (3.26)	.10	.028
$a_x\,(m/s^2)$	73.63 (5.21)	.58	<.001
Variables not in the equation			
Time gap [default=0, smaller=1]	Removed in second step		
Hands [on=1, off=0]	Removed in third step		
ACC group [A=1, B=0]	Removed in fourth step		

The qualities of all of the multiple regression models (models 3, 4, and 5) are presented in Appendix F.

6.3.11 Motion Sickness

It is important to consider motion sickness if additional vehicle motions are added to the normal driving behavior. Due to this, the question “Do you have nausea, a headache, or dizziness?” was surveyed after each part (t_0, t_1, t_2, t_3, and t_4) of the driving study (Figure 6.5). Only two of the 36 participants answered this question with yes. On many occasions, the participants directly mentioned that they were feeling very well. One participant felt very slightly dizzy (1 on a five-point rating scale from 1 $\widehat{=}$ very slight to 5 $\widehat{=}$ very strong) at time t_1 only. Another participant had a very slight headache (same rating scale) from time t_2 on until the end of the driving study and rarely gets a headache as a driver as well as sometimes as a passenger during driving.

6.3.12 Sensory Channels

In the final survey, the participants were asked how suitable they find the vestibular, haptic, visual, and auditory sensory channel on a five-point rating scale from 1 $\widehat{=}$ “does absolutely not apply” to 5 $\widehat{=}$ “does absolutely apply” for feeding back the detection of a PV (Figure 6.19). Thereby, two extreme variations of the criticality of the situation were also considered:

- uncritical situation, e. g. approaching to a PV with only a slightly lower velocity
- critical situation, e. g. near cutting-in vehicle after a motorway entry

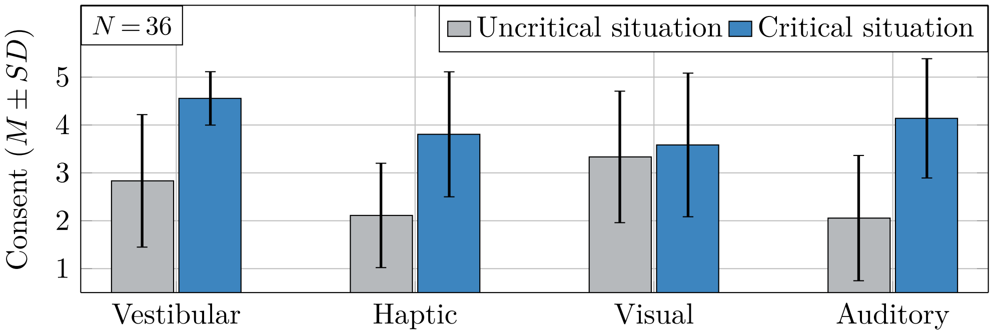


Figure 6.19: Ratings of the suitability of feedback for the detection of a preceding vehicle (scale: 1 ≙ "does absolutely not apply" - 5 ≙ "does absolutely apply")

A 4 (sensory channel) x 2 (criticality) ANOVA with repeated measures indicated significant main effects for the sensory channel ($F(1,\ 105) = 8.30$, $p < .001$, $\eta_p^2 = .19$) and the criticality ($F(1,\ 35) = 88.12$, $p < .001$, $\eta_p^2 = .72$). Consequently, feedback in critical situations is rated significantly more suitable than in uncritical situations. Contrasts were performed for the sensory channels to the baseline of the vestibular sensory channel. These revealed that the vestibular sensory channel is significantly more suitable than the haptic ($F(1,\ 35) = 26.02$, $p < .001$, $r = .65$) and auditory ($F(1,\ 35) = 20.05$, $p < .001$, $r = .60$), and less but not significantly suitable than the visual ($F(1,\ 35) = 2.02$, $p = .164$, $r = .23$) sensory channel. Moreover, significant interaction effects existed for sensory channel * criticality ($F(1,\ 105) = 9.21$, $p < .001$, $\eta_p^2 = .21$). Contrasts to the baseline vestibular sensory channel only indicated significant differences compared to the visual sensory channel ($F(1,\ 35) = 18.84$, $p < .001$, $r = .59$). Hereby, the visual sensory channel was evaluated similarly for uncritical and critical situations in contrast to the vestibular sensory channel, for which a feedback in a critical situation was rated noticeably more suitable than in an uncritical situation.

6.3.13 Announcing Lane Changes

In the final survey, the participants were asked if they could think of another situation where vestibular feedback would be useful. Hereby, the participants could come up with own ideas or choose from four given possible responses considering the announcement of an upcoming lane change to the left. The variations were forward and backward pitch motions as well as roll motions to the left or to the right (Figure 2.4). Multiple responses were allowed and 11 participants did not tick an option for announcing lane changes. Some participants mentioned that they could not imagine such a situation and did not want to guess. The results are presented in Figure 6.20. Consequently, roll motions should be used for signalizing upcoming lane change maneuvers.

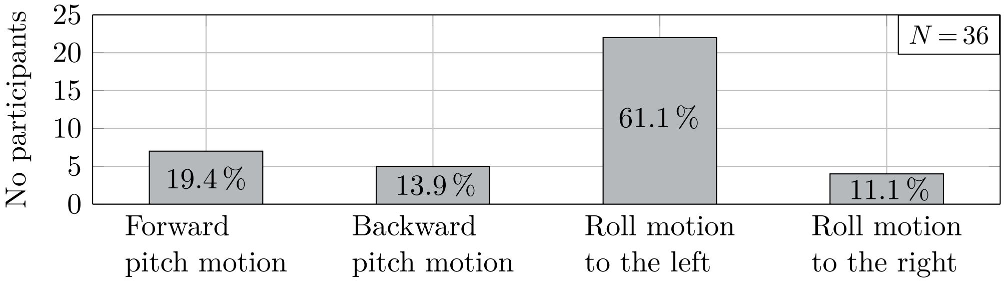


Figure 6.20: Distribution for possible announcements of a lane change to the left via active pitch or roll motions, referring to Cramer, Lange, et al. (2017)

6.4 Discussion and Conclusion

Regarding the perceptibility of pitch motions as a requirement for feedback (cf. Section 2.6), the results show that pitch motions are generally perceptible with 75.0 % noticing the 1.5 ° and 13.9 % noticing the 2.0 ° pitch motions. It has to be mentioned that some participants intensively looked at the available displays because they expected a visual feedback. Therefore, the visual perception of the pitch motions was missing what might have negatively influenced the number of perceived pitch motions. Besides, even after motivating the participants to speak out all of their thoughts, some were too shy and responded later than they had, in fact, perceived the pitch motions. During the study, the experimenters saw the participant's facial expressions. If a wondering expression was noticed, it was asked if they have any questions. Consequently, some mentioned the pitch motions but thought that this could not really be possible. Nevertheless, the four participants who did not notice the pitch motions at all have a negative effect on this result. For this, the travel range of the actuators should be discussed. In this test vehicle, a pitch angle of 2.0 °, provided that the pitch axis was in the middle of the wheelbase, represented nearly the maximum travel range of the actuators. The effect of decreasing perceptibility was measured after the interpretation phase and at the end of the driving study; ratings revealed that the perceptibility rather did not decrease during this period of time. However, this could be perceived differently after a long period of driving with pitch motions. 72.7 % of the participants assigned their first perception of the feedback to additional vehicle motions and not to the usual driving behavior. 8 out of the 10 participants who associated the feedback with normal driving behavior experienced a negative pitch angle during the interpretation part. Therefore, it might be possible that more participants perceive the pitch motions as additional motions if the favored positive pitch direction (83.3 %) for this feedback is realized. The results for the preferred direction of pitch motions as feedback for the detection of a preceding vehicle were similar to the results of the previous study (cf. Section 5.3.1). Moreover, the pitch motions caused no motion sickness which is supported by previous findings (cf. Section 5.3.6).

The results for identifying the logic of the feedback showed that it is comprehensible, associable, and transparent, with 26 out of 31 (83.9 %) analyzable participants understanding the logic of the feedback. These are essential requirements for the design of feedback as pointed out in Section 2.6. Admittedly, it has to be mentioned that due to real traffic, the participants did not have identical driving scenarios and, with this, the evaluation was restricted in some ways. Some might have had several clear scenarios in a row, while others experienced more complex driving scenarios or higher traffic density. Moreover, the feedback in scenario 3 often confused the participants because they falsely assigned it to driving with no preceding vehicle when said preceding vehicle was further away (still in the radar range) or driving with a positive relative velocity. Conducting this study on a test track with a fixed set of specific driving scenarios for each participant might have resulted in more comparable results, but it would not have been possible to draw conclusions for real traffic. Excluding scenario 3 could raise the percentage of identifying the feedback logic. The ACC experience of the participants as well as the experienced direction of the pitch motion had no effect on identifying the logic. However, hands-on/off driving showed a fairly substantial effect in that the participants conducting hands-on driving might have had a better understanding of the feedback logic. This could be due to the fact that they felt more responsible for the driving task and did not mentally withdraw from it.

The acceptance of feedback via pitch motions was assessed positively on both the usefulness and satisfying scale. Whether the participants understood the feedback logic before or not had no or only a small effect on these ratings. Furthermore, after experiencing the pitch motion feedback for approximately another 50 min, both scales for acceptance were rated higher with a large effect. The feedback was evaluated as supporting for the driver's system awareness, which is crucial for the driver's role as the supervisor of the automation system (Endsley, 1995; Sarter & Woods, 1995). Whether the logic was understood before or not also had no effect on these ratings. Moreover, a fairly moderate effect was assessed of participants assigning the feedback via pitch motions to previous or current driving actions. The assessment over time revealed that the system awareness increased with a large effect. It should be noted, however, that the present feedback focuses on only one aspect and does not support the driver in all driving scenarios. Some participants stated this as well. Especially, feedback for automated lane changes was missing to gain an overall system awareness.

The participants showed high trust in the automation system after experiencing the system for only two hours, whereby the existence of active pitch motions raised the trust rating with a medium effect after the participants had experienced the pitch motions for a longer time. Many participants commented that they had expected the automation system to perform worse with at least some errors. The high trust was important for the participants to concentrate on their study tasks. However, extensively high trust could lead to a neglect of the supervising task.

The need and intensity of feedback depends on the scenario as well as its criticality. Feedback was more often desired, for instance, for “cutting-in vehicles from the right” than “the left”, as these are usually driving with a negative relative velocity and are often trucks. A 1 ° pitch angle was preferred in most cases. However, for more critical situations, the participants chose a 2 ° pitch motion.

The regression models for the need and timing of feedback were a good representation because they provided a mathematical relationship between several input variables (predictors) and the output variable. Thus, it is possible to interpret the influence of each predictor on the model. Moreover, regression models are well-established in human factors research (Gold, 2016). Even though each model had outliers, the belonging cook distance stated that these cases had no big influence on the overall model. Multiple data sets were derived from the same participants, which would violate the assumption of independence of errors. However, the Durbin-Watson statistic stated no violation of this assumption for all models. Models 2a and 2b violate the assumption of linearity, and model 5 violates the assumption for normally distributed residuals. Thus, generalizing these models should be questioned. For model 5, a transformation of the raw data would be possible, but Field (2012, p. 251) points out that this would not necessarily influence the residuals. Robust regression models would be an option for resolving these violations of the assumptions (Field, 2012; Fahrmeir, Kneib, & Lang, 2009), or training a neural network. For the latter, the disadvantage is that the interpretation is difficult and knowledge about influencing variables is limited.

The indicator, the position of the hands, and the ACC experience had no influence in all six regression models. Naujoks, Purucker, Neukum, Wolter, and Steiger (2015) pointed out that the latter two had no influence on the controllability of partially automated driving functions. For this regression analysis, the indicator was represented by a nominal value. In the future, it should be surveyed whether the real time of the indicator start has an influence on the need or timing of feedback for cutting-in vehicles.

The logistic regression models 1, 2a, and 2b reported the probability of a trigger for feedback and its influences. In all three models, v_{rel} and d_{rel} were included. The probability for a trigger increased the smaller v_{rel} or d_{rel} was. In addition, for model 2a, the type of vehicle as well as whether the ego vehicle was following a PV or not were a predictor. The multiple linear regression models 3, 4, and 5 calculated the timing of the feedback. For the two cutting-in models, d_{rel} as well as the existence of an initial PV were included in the models. For both models it was observed that the further away the PV was, the smaller the lateral distance could be when the feedback occurred. Moreover, the feedback was to take place with a larger lateral distance if the ego vehicle was initially following a PV. v_{rel} as well as the selected time gap in the settling-in phase also influenced the feedback trigger in the model "PV cutting-in from the right". Model 5 ("approaching") included the predictors v_{rel}, type of vehicle, and a_x. The feedback was to occur at a larger distance when the PV was a truck, v_{rel} was smaller, or a_x was bigger.
Overall, it has to be mentioned that the lateral and longitudinal distances to the PV were in relation to the ego vehicle and not the lane markings. Moreover, the accuracy, especially of $d_{y,PV}$, could be improved. Hence, such an analysis could be enhanced with newer sensors and a better perception model. Furthermore, the data should be surveyed via a time-series analysis to better include the change of the predictors/variables over time (Döring & Bortz, 2016).

The vestibular sensory channel was rated as a suitable sensory channel for the representation of the detection of a PV in critical situations. For uncritical situations it was rated partly suitable. However, the statement for this evaluation was phrased really uncritically. Thus, it is expected, and the objective data supports that it is also suitable for less critical situations.

Considering the announcement of a lane change, it was revealed that roll motions were favored. During the driving study, the indicator was illuminated at the time the first experimenter triggered the lane change preparation, whereby the automated vehicle still drove on in the ego lane. The time when the vehicle starts to steer to the target lane, is called the lane change execution. This was at least $2\,s$ later than the begin of the preparation. However, the first experimenter tried to open up gaps on the neighboring lane via triggering the lane change preparation and, thus, the indicator. Many participants got nervous when the vehicle was indicating but not executing the lane change. They mentioned this as well. Some even took over the vehicle guidance and stated that they did not feel comfortable with the lack of knowledge if the automation was still preparing and when it actually starts to execute the lane change. Moreover, several participants pointed out that they want to have a different feedback about the preparation and the execution, and that the indicator is a sign for them for the lane change execution. However, some mentioned that the outside indicator should start at the beginning of the lane change preparation.

Nearly five times more potential participants registered for this driving study than were actually required. Therefore, the gender, technical background, and ACC experience of participants could evenly be distributed in the sample. However, some characteristics of the population might be missing, and only interested persons took part in this study. ACC experience was necessary in order to guarantee that the participants are already used to some ADAS, and avoid them focusing only on the driving behavior of the self-driving vehicle. Accordingly, the participants can focus on their task and evaluate the pitch motions. Moreover, the study limitations of the first driving study (Section 5.4) considering the sample, and existence of, as well as the communication with the experimenters also apply.

Generally speaking, the results of this driving study, combined with the results of a previously conducted driving study (cf. Section 5.3 and 5.4), open up new possibilities for giving feedback to drivers to support their supervising task during partially automated driving. The main advantage is that feedback via pitch motions allows multi-modal feedback. A further study focused on the design of active vehicle roll motions for announcing automated lane changes to the driver as roll motions were rated as most suitable for this (Chapter 7).

7 Driving Study 3

This driving study and its results[3] are prepublished in Cramer and Klohr (2019), and Cramer, Lange, et al. (2017). Some parts of the written text are taken from these papers. Figures, tables, and statistics are adapted for an overall consistent representation throughout this thesis.

7.1 Introduction

The first and second driving study (cf. Chapter 5 and 6) initially investigated active vehicle pitch motions as feedback within partial driving automation. Forward pitch motions were chosen as feedback for detecting a preceding or cutting-in vehicle, and were rated useful, not misleading, and to increase system awareness (cf. Section 5.3.4, 6.3.4, and 6.3.5). This means that vehicle pitch motions can be regarded as suitable for keeping drivers "in-the-loop" as part of a multi-modal feedback. Furthermore, ten participants ($N = 35$) of driving study 1 mentioned on their own initiative that they would prefer active roll motions to announce upcoming lane changes (cf. Section 5.4). In addition, during a further study on vehicle pitch motions, the participants were asked if any and, if so, which rotational vehicle motions were suitable for announcing automated lane changes. Multiple answers were possible. 61 % of the participants rated roll motions as useful and 28 % pitch motions (cf. Section 6.3.13).

As a result, the focus of this driving study was to evaluate roll motions as feedback during partially automated driving within different lane change situations as part of the presented feedback concept (cf. Chapter 3). Pitch motions were not considered for this study. Several roll motions designs were implemented in the automated vehicle. Four selected test scenarios were chosen to evaluate these roll motions as feedback for state transitions and intentions of the automation. First insights were to be gained

---

[3] The driving study was designed and conducted with the assistance of Jana Klohr as part of her Master's thesis (Klohr, 2017). Furthermore, Klohr (2017) analyzed parts of the data as well in her Master's thesis. For this Doctoral thesis, the data was evaluated separately.

concerning the optimal vehicle roll motion design for different driving scenarios and the benefit of vehicle roll motions regarding the driver's monitoring task, as well as understanding of the situation and the system during partially automated driving. The participants had to rate the vehicle roll motions, for example, regarding the items roll direction, intensity, usefulness, and the predictability of the driving behavior. First, the method of the driving study and the design of the roll motions are described. Subsequently, the results are presented.

7.2 Method

In this driving study, active vehicle roll motions were evaluated as feedback for the driver to announce automated lane changes in order to obtain knowledge on the preferred roll motion design. A similar study was conducted previously for pitch motions (cf. Chapter 5). Consequently, the results of that driving study were incorporated. As an example, a degressive profile was used for the roll motions similar to the pitch motion design. The design possibilities of these active vehicle roll motions were, for instance, roll angle and direction. These were selected according to the same reasons as for pitch motions of the first driving study (Section 5.2). Moreover, this time the first impression of the roll motions regarding their intensity should be surveyed to evaluate whether the roll direction, the amplitude, or the driving scenario has an influence on the perceived intensity before selecting their favored roll motion course. Therefore, several roll profiles were implemented (cf. Section 7.2.3) and evaluated in different motorway driving scenarios (Figure 7.1).

Feedback for announcing lane changes should be timely in relation to the maneuver execution (Bubb, Bengler, et al., 2015; European Commission, 1998). Consequently, the announcement time of the lane change should be surveyed. Furthermore, it is necessary for a feedback approach to be perceptible, comprehensible, comfortable, as well as suitable for and accepted by the driver (cf. Section 2.6). System awareness is crucial for the driver during partially automated driving to be "in-the-loop" and be able to take over the vehicle guidance immediately at system limits (Sarter & Woods, 1995). Moreover, similar to the second driving study, the timing for feedback should be investigated for different relative velocities to the PV to gain first insights when a lane change should occur. Consequently, essential research questions were:

- *RQ1*: How do the participants rate the intensity of the roll motions depending on roll angle and direction in different driving scenarios?
- *RQ2*: Which course of the roll motion do the participants prefer in terms of roll direction and amplitude for each driving scenario?

- *RQ3*: How long should the lane change announcement time be?
- *RQ4*: How are different roll profiles assessed for several driving scenarios regarding the items *perceptibility*, *situational context*, and *discomfort*?
- *RQ5*: How is feedback via vehicle roll motions rated for the different driving scenarios regarding *system awareness* and *acceptance*?
- *RQ6*: What is the exact time to announce a lane change if the automation detects a slower preceding vehicle which should be overtaken?

Feedback should not have a negative influence on the driver's well-being. Hence, motion sickness was evaluated as for the driving studies before (cf. Section 5.3.6 and 6.3.11). Furthermore, the participants were asked which sensory channel is suitable to announce lane changes after they experienced lane changes in different scenarios.

The metrics for the evaluation of these research questions are presented in connection with the results in Section 7.3.

7.2.1 Test Setup and Equipment

The driving study took place on the same three-lane oval test track as for the first driving study (Chapter 5). That test track was approximately 1.4 km long. The different driving scenarios were implemented on the straight part of the test track. All participants experienced the same driving scenarios (cf. Section 7.2.2); thus, it was a within-subject design. The automation system, active body control vehicle, as well as the tasks of the experimenter on the passenger seat, and the test equipment are described in Chapter 4. With a video game controller (Wizard controller on the right in Figure 6.1), the experimenter on the passenger seat triggered automated lane changes, which also induced the various roll motions.

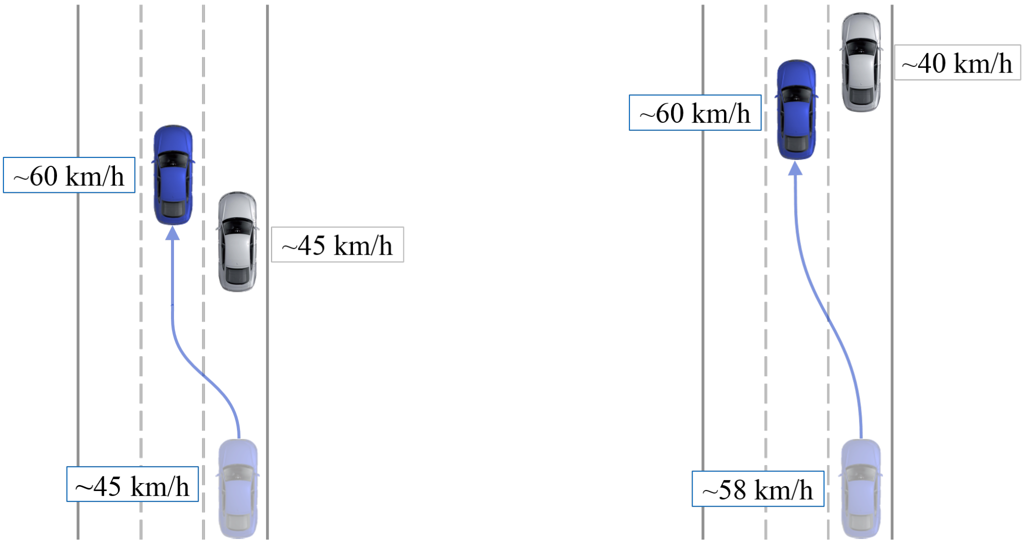
A driver and a scene camera as well as a microphone (cf. Figure 6.1) were installed for the evaluation of the participants' comments. Moreover, vehicle data, internal data of the automation system, and object sensor data were recorded.

7.2.2 Test Scenarios

As mentioned before, the driving study was conducted on a three-lane oval test track. The maximum velocity of the test vehicle was 60 km/h on the straight part and 22 km/h

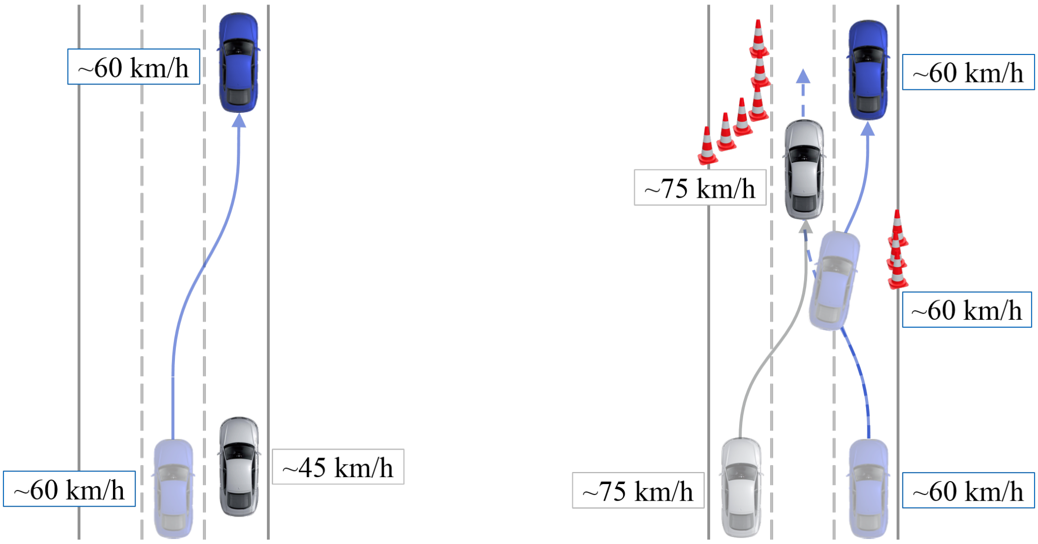
in the curves of the test track. To be able to simulate the driving situations on the test track, another vehicle was present which was driven manually.

Lane changes should be communicated to the driver via active vehicle roll motions (cf. Section 5.4, 6.3.13, and 7.1). Therefore, four different driving scenarios involving lane changes were selected with experts for this driving study (Figure 7.1). These test scenarios were based on motorway driving with the maneuvers *follow lane* and *lane change* with a maximum velocity of 120 km/h (Figure 7.2, cf. Chapter 3).



(a) Scenario 1 "Lane change from following a PV"

(b) Scenario 2 "Lane change when detecting a PV"



(c) Scenario 3 "Lane change to the right"

(d) Scenario 4 "Lane change abort"

Figure 7.1: Test scenarios of the study for announcing lane changes or feeding back lane change aborts to the driver, referring to Cramer and Klohr (2019)

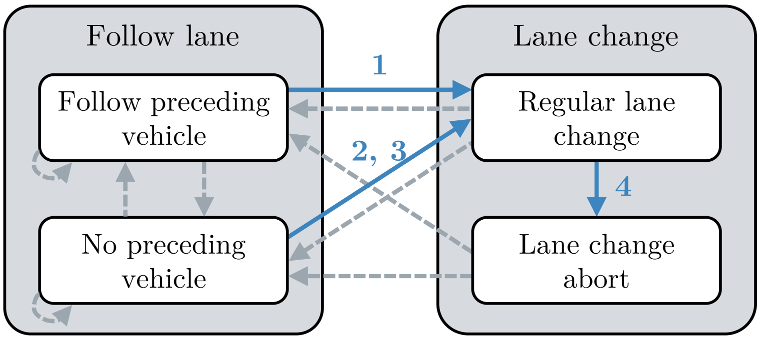


Figure 7.2: Relevant maneuvers and states for motorway driving, referring to Cramer and Klohr (2019)

The set velocity of the ACC was always 60 km/h on the straight for the test vehicle during the driving study. The real velocity varied due to distance control to the PV or the slow build up of the last km/h to the set velocity (cf. Section 5.2.1). Scenario 1 “lane change from following a PV” (Figure 7.1a) and scenario 2 “lane change when detecting a PV” (Figure 7.1b) were similar. In scenario 1 ($\hat{=}$ arrow 1 in Figure 7.2), the test vehicle followed the manually driven vehicle at approximately 45 km/h and was motivated to overtake because of the low velocity of the PV. In scenario 2 ($\hat{=}$ arrow 2 in Figure 7.2, identical to scenario 2 of driving study 1 (Figure 5.2b)), the PV drove approximately 40 km/h and, thus, with a relative velocity of approximately -18 km/h. When the test vehicle detected this slower PV (approximately 79 m distance), it initiated a lane change because of the relative velocity. For both scenarios, the test vehicle pulled out from the right lane to the middle lane of the test track to overtake the manually driven vehicle. This automated lane change was announced via an active vehicle roll motion (cf. Section 7.2.3). Regarding scenario 3 “lane change to the right” (Figure 7.1c), the test vehicle overtook the slower manually driven vehicle and drove back into the right lane. This lane change was also announced via an active vehicle roll motion. As there was no PV in front of the test vehicle in this scenario, it correlates to the change of the automation state which is marked with the arrow 3 in Figure 7.2. To simulate driving scenario 4 “lane change abort” (Figure 7.1d, $\hat{=}$ arrow 4 in Figure 7.2), the test vehicle was initially in the right lane and the manually driven vehicle in the left lane. Three pylons were placed on the right lane marking, which were intended to simulate a vehicle on the hard shoulder. Another six pylons were placed in the left lane to simulate a road closure. The automation system of the test vehicle pulled out in the middle lane but recognized that there was a faster vehicle coming from behind which had to pull out in the middle lane too because of the road closure ahead. Therefore, the automation system of the test vehicle aborted the lane change. This lane change abort to the right lane was intensified by a roll motion.

7.2.3 Design of Roll Motions

The design possibilities for roll motions are similar to those of pitch motions (cf. Section 5.2.2 and 6.2.3). Roll profiles with a maximum angle of 1.5 ° and 3.0 ° and a roll axis in the middle of the vehicle were chosen in a pre-study with experts. These angles are both perceptible and can be clearly distinguished (Cramer, Lange, et al., 2017). Thereby, the left and right wheels moved symmetrically up and down. A roll motion consists of three parts and is schematically presented in Figure 7.3. The first is the increase τ_1 to build up the maximum angle. In a previous study, a degressive course was selected for this part (Cramer, Miller, et al., 2017). The second is the holding phase τ_2 of the maximum angle and last is the return phase τ_3 of the roll angle back to zero (Cramer, Miller, et al., 2017; Cramer, Lange, et al., 2017). Transferring these parts to the chronology of a lane change, the preparation for a lane change starts at the time t_0 and takes until t_2. This time span τ_a is also named the announcement time of a lane change. It was kept constant independent of each roll motion and is the sum of increase τ_1 and holding time τ_2. The latter is not the same for each roll profile and, consequently, was adjusted depending on the increase τ_1 of the roll motion (Cramer, Lange, et al., 2017). During the announcement time, the vehicle drove straight on in its own lane. The execution of the lane change and, thus, the steering of the vehicle towards the new lane started at t_2. The execution of the lane change lasted until t_3 when the middle of the target lane was reached. Simultaneously, the roll motion was proportionally reduced to zero according to the lane change progress from 0 to 100 % (Cramer, Lange, et al., 2017). The return of the roll motion tended to be shaped as a polynomial because the lane change trajectory was polynomial (Heil et al., 2016) and the lane change progress was designed depending on the trajectory.

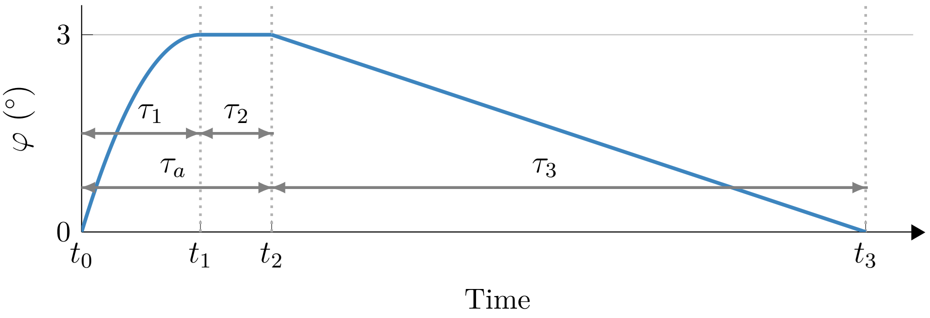


Figure 7.3: Composition of roll motions, referring to Cramer and Klohr (2019)

According to the results of the first driving study (cf. Section 5.4), the time for reaching the maximum angle $t(\varphi_{max})$ determines the perceptibility and discomfort of pitch motions and, hence, the pitch or roll profile. Therefore, the increase of roll profiles (RP) 1 and 3 (Table 7.1, Figure 7.4) is designed with regard to the time aspect and corresponding maximum angle of pitch profile PP1, PP2, and PP3. Consequently, RP1 is identical to PP3, and approximately $0.18\,s$ are added to $t(\varphi_{max})$ for every $0.5\,^\circ$ of φ_{max} (cf. Section 6.2.3, Cramer, Lange, et al. (2017)). The equations used to design the pitch motion increase were also used for roll motion increase (τ_1) and describe in the following the roll angle φ, velocity $\dot{\varphi}$, and acceleration $\ddot{\varphi}$:

$$\varphi(t) = a\,t^2 + b\,t\,; \qquad \dot{\varphi}(t) = 2\,a\,t + b\,; \qquad \ddot{\varphi}(t) = 2\,a \tag{7.1}$$

The increase of RP1 and 3 was rated a bit too dynamic in a pre-study with experts. Because of this, two roll profiles, RP2 and 4, were added and their increase (Table 7.1, Figure 7.4) was designed providing more time $t(\varphi_{max})$ for reaching the maximum angle. Hence, the time difference between reaching φ_{max} of RP3 and 4 is twice as long as between RP1 and 2. The corresponding parameters for the four roll profiles (RP1, RP2, RP3, and RP4) are listed in Table 7.1. Thereby, $t(\varphi_{max}) = \tau_1$ represents the time needed to reach the maximum roll angle.

Table 7.1: Selected roll profiles (RP) (exemplarily for a positive roll angle) as feedback for the driver, referring to Cramer, Lange, et al. (2017)

Profile	φ_{max}	$\ddot{\varphi} = 2\,a$	$t(\varphi_{max})$	b
RP1	$1.5\,^\circ$	$-4.5\,^\circ/s^2$	$0.82\,s$	$3.68\,^\circ/s$
RP2	$1.5\,^\circ$	$-3.0\,^\circ/s^2$	$1.00\,s$	$3.00\,^\circ/s$
RP3	$3.0\,^\circ$	$-3.2\,^\circ/s^2$	$1.36\,s$	$4.38\,^\circ/s$
RP4	$3.0\,^\circ$	$-2.1\,^\circ/s^2$	$1.70\,s$	$3.55\,^\circ/s$

The roll angle φ, velocity $\dot{\varphi}$, and acceleration $\ddot{\varphi}$ of the four roll profiles are presented in Figure 7.4 exemplarily for roll motions with a positive roll angle. Moreover, the roll motions for RP3 and 4 with a positive roll angle were measured with a highly accurate inertial platform (iMAR, 2012) to be sure that the profiles are distinguishable (Figure 7.5). The inertia of the chassis causes the difference between the ideal and the measured roll motions (Cramer, Lange, et al., 2017). The announcement time τ_a varied between 2.0 - 3.0 s. The selection of the time of τ_a is explained in Section 7.2.4 and 7.3.

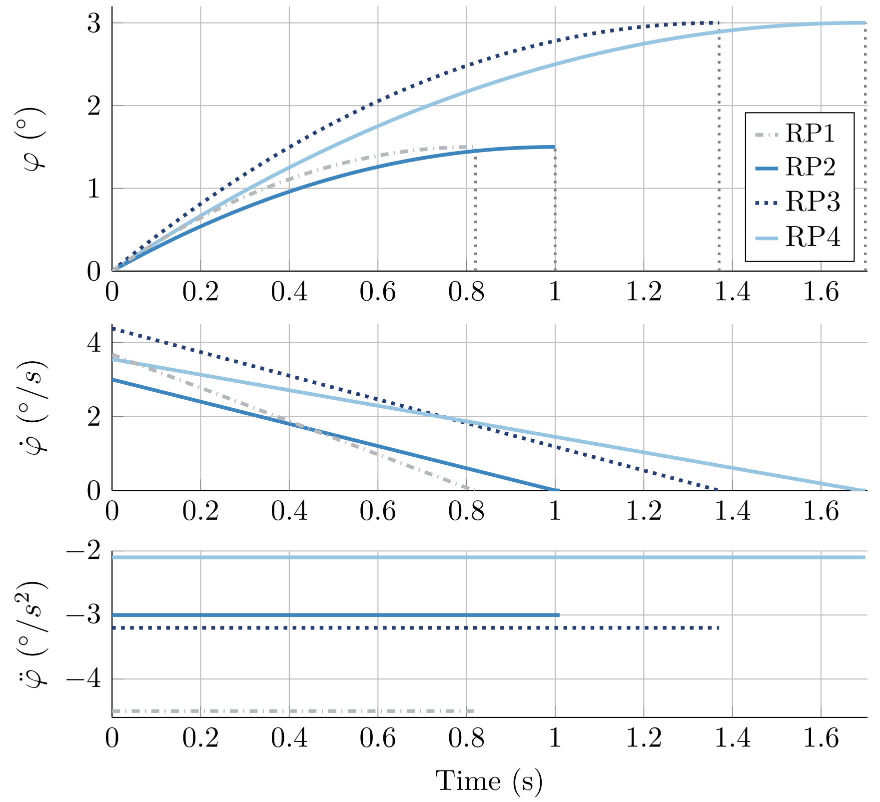


Figure 7.4: Roll angle φ, velocity $\dot{\varphi}$ and acceleration $\ddot{\varphi}$ of the roll profiles, referring to Cramer, Lange, et al. (2017)

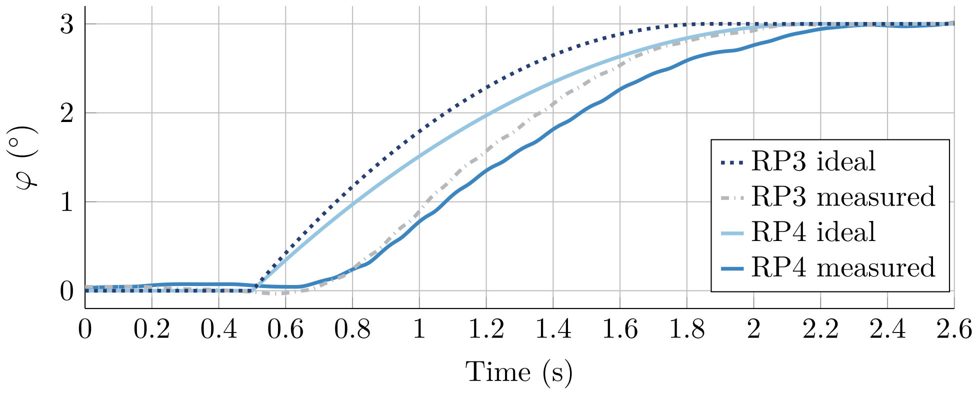


Figure 7.5: Roll angle φ of ideal and measured RP3 and RP4, referring to Cramer, Lange, et al. (2017)

7.2.4 Study Design

The participants received some first notes about the study at the time the appointment was arranged (Appendix D.3). This was due to the same reasons as for the first study (Section 5.2.3). The sequence of the driving study and the duration of each part are shown in Figure 7.6, and the study was conducted in German. After a verbal briefing and a short pre-survey, the participants took their place on the driver's seat

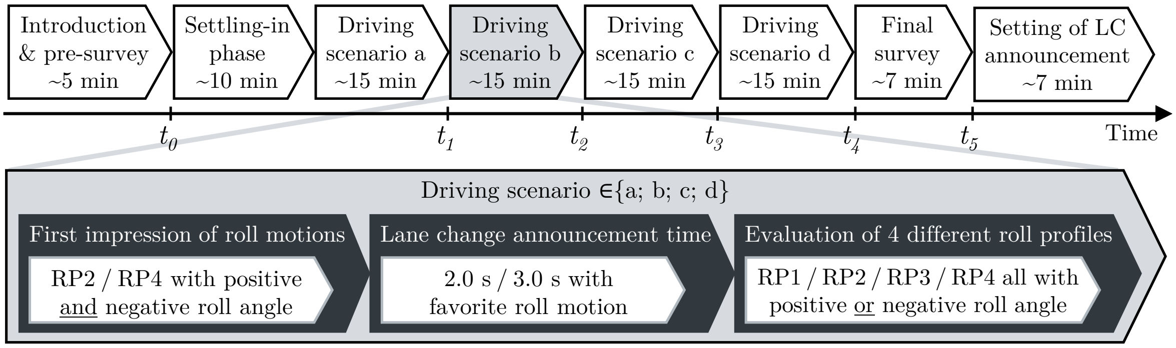


Figure 7.6: Sequence of the third driving study, referring to Cramer and Klohr (2019)

of the test vehicle. During the settling-in phase, the experimenter in the passenger seat explained the technical information, necessary for carrying out the test drive (e. g. how to activate/deactivate the automation system). Furthermore, the participants experienced the roll motions in both directions (positive and negative) and the two different roll angles (1.5 ° and 3.0 °) to get familiar with the automation system and the feedback. Afterwards, the participants ran through the four test scenarios (cf. Figure 7.1) in a randomized order. The sequence of each driving scenario is illustrated in Figure 7.6, exemplarily for driving scenario b. Each test scenario started with a first impression of the roll motions. Therefore, the participants experienced both roll directions and both roll angles. While the participants experienced these four different roll profiles, the experimenter asked them about the intensity of the roll motions on a five-point rating scale from “too weak” to “too strong.” In addition, they were asked whether they felt a difference between the two roll directions and roll angles, and which roll direction and roll angle they would prefer for the respective driving scenario. In the second part of each test scenario, the participants experienced two different lane change announcement times (2.0 s and 3.0 s) with their preferred roll direction and angle (Figure 7.6). The experimenter asked for the perceived length of the announcement time on a five-point rating scale from “too short” to “too long.” Within the scope of part three of each test scenario, the roll angle (1.5 ° and 3.0 °) and the time to reach the maximum roll angle (1.5 °: 0.82 s and 1.00 s; 3.0 °: 1.36 s and 1.70 s) were varied without the participants knowing whether a variation and, if yes, which variations took place (Figure 7.6). Therefore, the four different roll profiles were experienced in a randomized order and evaluated by the participants on a five-point rating scale (from “not at all” to “totally”) regarding the items *perceptibility*, *situational context*, and *discomfort* of the vehicle roll motion. After each test scenario, the participants completed another questionnaire. This included questions and statements about the roll direction, roll angle, and general evaluation of the preferred roll motion of the participants. After all scenarios were carried out, a final survey was completed by the participants in the parked test vehicle (Figure 7.6). Finally, scenario 2 (“Lane change when detecting a PV”, Figure 7.1b) was experienced at least four more times.

Thereby, the participants were asked to trigger when the automated vehicle should start announcing the upcoming lane change. A small hands-off push button (Figure 6.2b) was used by the participants to trigger the lane change announcement with their preferred roll motion; the lane change was executed after finishing the announcement time τ_a. The PV drove either approximately $30\,km/h$ or $40\,km/h$. Both variations were at least experienced twice by each participant, whereby they stated if the trigger time was suitable or not. Thus, at least one suitable trigger time was surveyed for each variation. Overall, the approach of this driving study is similar to the design of a "User-Derived Interface," whereby the users design and evaluate the interface and, thus, create a "natural" interface (Wigdor & Wixon, 2011).

7.2.5 Processing and Evaluation of Data

The data from the questionnaires were surveyed and processed equally to driving study 1 (Section 5.2.4). The data had to be labeled for evaluation of the trigger time for announcing lane changes. This was done in a similar manner as for driving study 2 (Section 6.2.5). To evaluate the data, t-tests, as well as one-way, two-way, and three-way ANOVAs were conducted, and a regression model was set up.

7.2.6 Sample

$N = 39$ participants were available for this study with a mean age of 35.1 years ($SD = 9.1$, $MIN = 24$, $MAX = 63$). The participants consisted of four groups and represented variations of professional background and gender (23.1 % technical female, 25.6 % nontechnical female, 28.2 % technical male, 23.1 % nontechnical male). The groups were formed according to the answers of the pre-questionnaire (Appendix E.5). However, all participants must have had some previous experience with an ACC system. This was necessary in order to guarantee that the participants were already used to some ADAS, and avoid them focusing only on the driving behavior of the self-driving vehicle. Accordingly, the participants could focus on their task and evaluate the roll motions. The median mileage per year was 15,000 - 20,000 km and the mean mileage per week was 381 km (SD =263 km) with an average of 41 % motorway driving. Furthermore, 89.7 % of the participants used LKA and 35.9 % PAD systems (e. g. traffic jam assistance) before. The frequencies of use of ACC, LKA, and PAD systems of the participants who had already used these systems are presented in Figure 7.7. Moreover, the duration of having experience with each driving assistance system is shown in Figure 7.8. For the latter case, not all participants answered all questions. Supplementary information about the sample is presented in Appendix C.

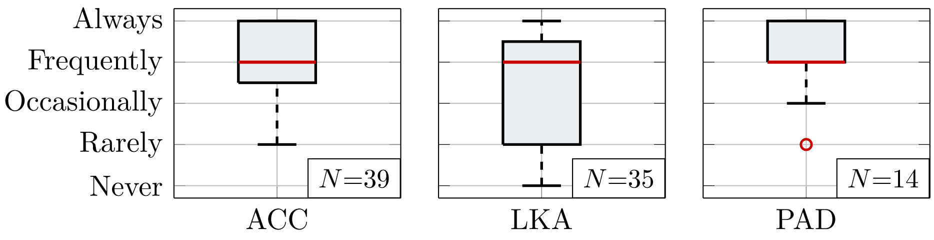


Figure 7.7: Frequency of use of ADAS of the third study's sample, referring to Cramer and Klohr (2019)

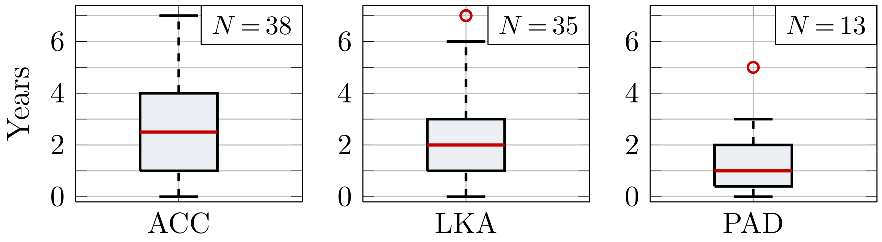


Figure 7.8: Experience with ADAS of the third study's sample, referring to Cramer and Klohr (2019)

7.3 Results

The results of the research questions are presented in the same order as they are introduced at the beginning of Section 7.2. The findings are reported according to the recommendations in Field (2012). The pre-questionnaire and the questionnaire during the driving study are listed in the Appendix E.5 and E.6.

7.3.1 First Impression of the Intensity of Roll Motions

The participants experienced four different roll motions as feedback at the beginning of each driving scenario in a randomized order. These were RP2 (1.5 °) and RP4 (3.0 °) each with positive and negative roll angle (cf. Figure 7.4 and 7.6). The announcement time for a lane change was always 2.5 s. After each roll motion, the participants had to rate its intensity on a five-point rating scale from 1 ≙ "too weak" to 5 ≙ "too strong". The mean values are presented in Figure 7.9 and were on average between 3 (≙ "okay") and 4 (≙ "rather too strong") for the 3.0 ° (RP4) and between 2 (≙ "rather too weak") and 3 (≙ "okay") for the 1.5 ° roll motions (RP2). Furthermore, roll motions with a negative roll angle were on average perceived stronger than with a positive roll angle.

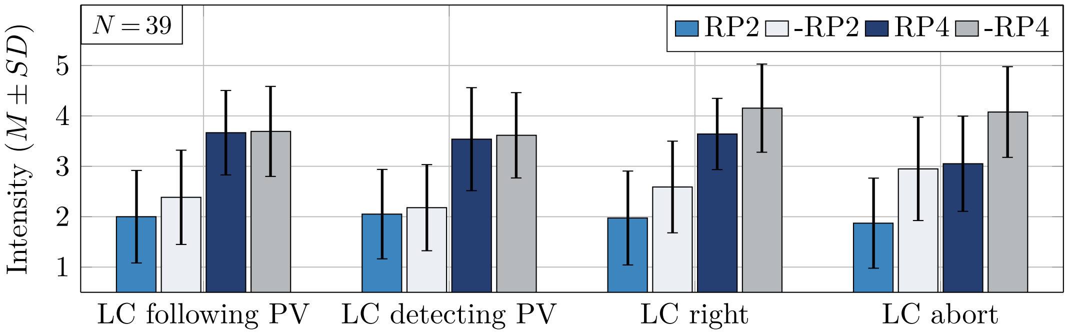


Figure 7.9: Rating of the intensity of roll motions (scale: 1 ≙ "too weak" - 5 ≙ "too strong"), referring to Cramer and Klohr (2019)

A 4 (driving scenario) x 2 (roll angle) x 2 (roll direction) ANOVA with repeated measures indicated no significant main effect for the *driving scenario* but highly significant main effects for *roll angle* and *direction* (Table 7.2). Consequently, 3.0 ° roll motions were perceived significantly stronger than 1.5 ° roll motions, and roll motions with a negative roll angle were also perceived significantly stronger than roll motions with a positive angle. Moreover, significant interaction effects existed for *roll angle* * *driving scenario* and *roll direction* * *driving scenario*. Consequently, contrasts were performed to the baseline scenario 2 (Figure 7.1b). These revealed significant interaction when comparing 3.0 ° and 1.5 ° roll angle for scenario 2 compared to scenario 4 ($F(1,\ 38) = 4.28$, $p = .045$, $r = .32$) and significant interaction when comparing negative and positive roll directions for scenario 2 compared to scenario 4 ($F(1,\ 38) = 35.10$, $p < .001$, $r = .69$) as well as scenario 2 compared to scenario 3 ($F(1,\ 38) = 8.31$, $p = .004$, $r = .42$). Thus, the difference of the intensity of the two roll angles was significantly

Table 7.2: Results of the ANOVA considering the driving scenario, roll angle, and roll direction, referring to Cramer and Klohr (2019)

Main or interaction effect	F	p	η_p^2
Roll angle	$F(1,\ 38) = 447.86$	<.001	.93
Roll direction	$F(1,\ 38) = 57.53$	<.001	.60
Driving scenario	$F(3,\ 114) = 1.34$	.267	.03
Roll angle * driving scenario	$F(3,\ 114) = 3.75$	.013	.09
Roll direction * driving scenario	$F(3,\ 114) = 15.24$	<.001	.29
Roll angle * roll direction	$F(1,\ 38) = 3.53$	.068	.09
Roll angle * roll direction * driving scenario	$F(3,\ 114) = 0.73$	.539	.02

smaller for scenario 4 than scenario 2, and the intensity between negative and positive roll angle was significantly higher for scenario 3 and 4 than scenario 2.

7.3.2 Direction of Roll Motion

After experiencing the four different roll motions (RP2, -RP2, RP4, and -RP4) for each scenario, the participants were asked if they had noticed a difference in the two roll directions and which they would prefer. Only two participants were unable to distinguish between the roll directions for scenario 4. Within the other three scenarios all participants were able to distinguish between the roll directions. For scenario 1, 37 participants favored a positive (94.9 %) and 2 a negative (5.1 %) roll motion, for scenario 2, 38 a positive (97.4 %) and 1 a negative (2.6 %), for scenario 3, 2 a positive (5.1 %) and 37 a negative (94.9 %) and for scenario 4, 27 a positive (73.0 %) and 10 a negative (27.0 %) roll motion (Figure 7.10).

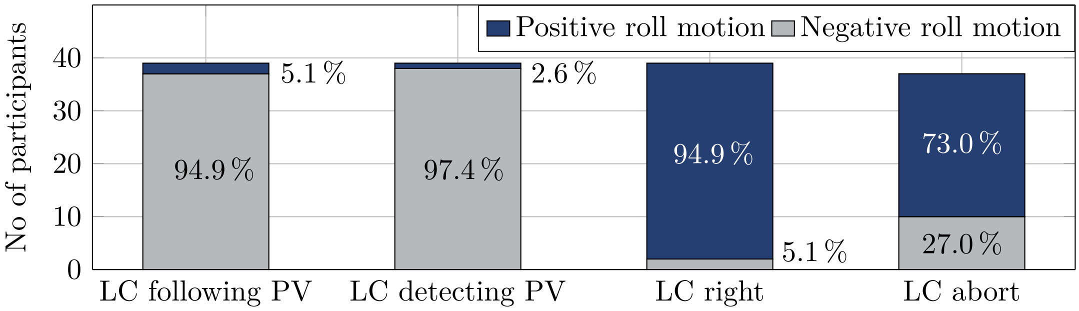


Figure 7.10: Distribution of the preferred roll direction ($N = 39$ for scenarios 1, 2, 3 and $N = 37$ for scenario 4), referring to Cramer and Klohr (2019)

A lot of participants mentioned that it only made sense for them to perceive a roll motion in the direction that the vehicle intends to drive. Some had such a strong opinion that they stated directly at the beginning of the next driving scenario which direction they preferred. Only scenario 4 indicated a not so consistent rating. Some participants liked that a negative roll motion intensified the criticality of the maneuver, and some mentioned that they felt more comfortable if the vehicle rolled to the right and, thus, gave a feeling of safety that the automation detected the other vehicle.

Overall, 26 (66.7 %) participants chose the roll direction for the four scenarios motion compliant and 13 not (33.3 %, including the 2 participants who could not distinguish between the two roll directions for scenario 4). Motion compliant means that there was one roll direction for driving scenarios to the left and the other for driving scenarios to the right. If overall motion compliant feedback was selected, it was always a roll motion to the left (negative angle) for scenarios to the left (scenario 1 and 2) and a roll motion to the right (positive angle) for scenarios to the right (scenario 3 and 4). Excluding scenario 4 (LC abort), 36 participants (92.3 %) chose a motion compliant feedback (Figure 7.11).

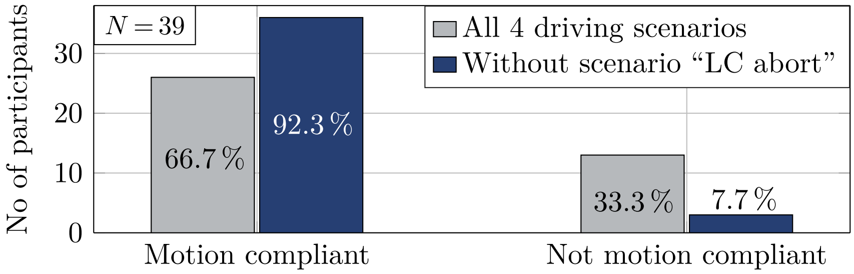


Figure 7.11: Relation of the preferred roll direction for the different driving scenarios of the study, referring to Cramer and Klohr (2019)

7.3.3 Angle of Roll Motion

As for the roll direction, the participants were asked about their preferred roll angle (1.5 ° or 3.0 °) for each driving scenario. The angle of the roll motion could always be distinguished except for 5 participants for scenario 4 (LC abort). For scenario 1, 17 participants favored 1.5 ° (43.6 %) and 22 3.0 ° (56.4 %) roll angle, for scenario 2, 16 1.5 ° (41.0 %) and 23 3.0 ° (59.0 %), for scenario 3, 15 1.5 ° (38.5 %) and 24 3.0 ° (61.5 %), and for scenario 4, 11 1.5 ° (32.4 %), and 23 3.0 ° (67.6 %) roll angle (Figure 7.12).

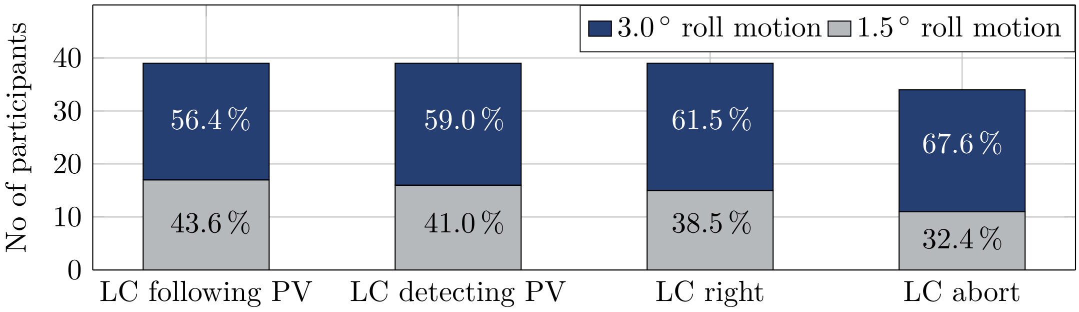


Figure 7.12: Distribution of the preferred roll angle ($N = 39$ for scenarios $1, 2, 3$ and $N = 34$ for scenario 4), referring to Cramer and Klohr (2019)

The general statement of the participants was that they would like to clearly perceive the feedback. For some participants, the 1.5 ° roll angle was much too small. Some would prefer a medium angle between 1.5 ° and 3.0 ° but mentioned that they rather have a bigger angle to clearly perceive the feedback. Moreover, some participants expressed the wish to realize an individual roll angle depending on the sensitivity of the driver.

In total, 6 participants (15.4 %) selected a 1.5 ° roll motion for all four driving scenarios, 9 (23.1 %) always a 3.0 ° roll motion and 24 (61.5 %, including the 5 participants who could not distinguish between the two roll angles for scenario 4) chose different angles for the various driving scenarios. Excluding scenario 4, 10 participants (25.6 %) always selected 1.5 °, 16 (41.0 %) 3.0 °, and 13 (33.4 %) choose no consistent angle (Figure 7.13). Considering the two options roll angle and direction, the distribution of the favored roll profiles is presented in Table 7.3.

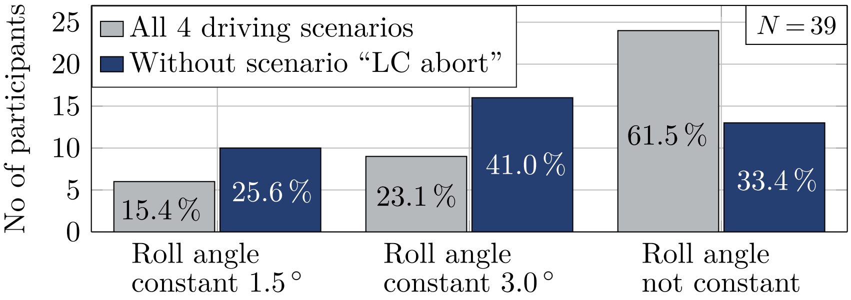


Figure 7.13: Relation of the preferred roll angle for the different driving scenarios, referring to Cramer and Klohr (2019)

Table 7.3: Favored roll motion feedback in each driving scenario, referring to Cramer and Klohr (2019)

Roll profile	RP2	-RP2	RP4	-RP4
Driving scenario				
LC follow. PV	2.6 %	41.0 %	2.6 %	53.8 %
LC detect. PV	2.6 %	38.5 %	0.0 %	58.9 %
LC right	38.5 %	0.0 %	56.4 %	5.1 %
LC abort	27.3 %	6.1 %	45.4 %	21.2 %

7.3.4 Announcement Time for Lane Changes

For scenarios 1, 2, and 3, the participants experienced their preferred roll motion two more times with two variations (2.0 and 3.0 s) of the announcement time for a lane change (Figure 7.6) and evaluated it on a five-point rating scale from 1 ≙ "too short" to 5 ≙ "too long". Generally speaking, the 2.0 s were rated "okay" on average and the 3.0 s "rather too long" (Figure 7.14). Some participants were surprised that the duration of the time is perceived quite differently depending on whether they ensured a safe lane change via control views or not and, as a result, mentioned that 2.0 s are suitable for partially automated driving.

The data did not fulfill the assumptions for parametric tests. A non-parametric equivalent of Mixed-ANOVA does not exist, but methods are available that are robust to violations of assumptions (robust methods, Field, 2012, Field, Miles, & Field, 2012, Wilcox, 2012). Consequently, a 2 (announcement time, repeated measure) x 2 (roll angle) robust analysis using M-estimator and bootstrap for mixed designs was conducted (Field et al., 2012), and results are presented in Table 7.4. The *roll angle* had no significant main effect on the rating of the duration. The *announcement time* of 2.0 *s* was more suitable than the 3.0 *s* for scenario 3 but not significantly. In contrast, the *announcement time* revealed a main effect in scenario 1 and a tendency towards significance in scenario 2. Hence, the 2.0 *s* were perceived considerably shorter than the 3.0 *s* and more suitable for the participants. This was independent of a 1.5 ° or 3.0 ° roll motion. No significant interaction effects existed.

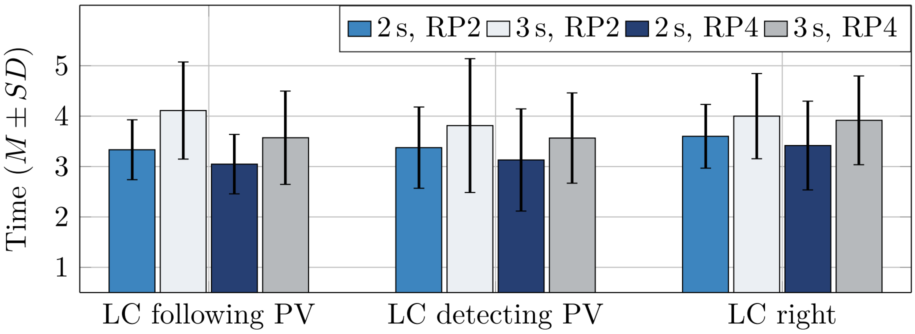


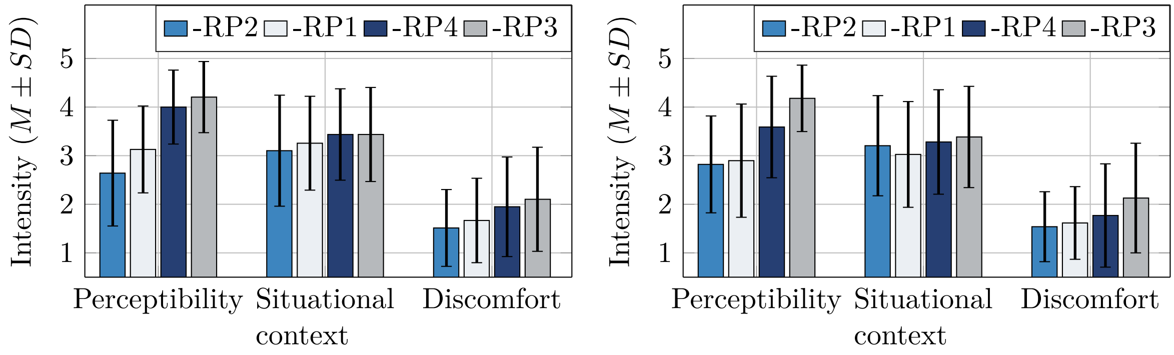
Figure 7.14: Rating of the announcement time for a lane change (scale: 1 ≙ “too short” - 5 ≙ “too long”), referring to Cramer and Klohr (2019)

Table 7.4: Results of the robust analysis considering the main effects *roll angle* and *announcement time* as well as their interaction effect for each scenario

Main effect	$\hat{\psi}$	p
Roll angle		
Scenario 1	0.27	.372
Scenario 2	0.53	.269
Scenario 3	0.34	.352
Announcement time		
Scenario 1	−0.64	.008
Scenario 2	−0.44	.089
Scenario 3	−0.46	.174
Announcement time * roll angle		
Scenario 1	−0.36	.348
Scenario 2	−0.17	.689
Scenario 3	0.10	.823

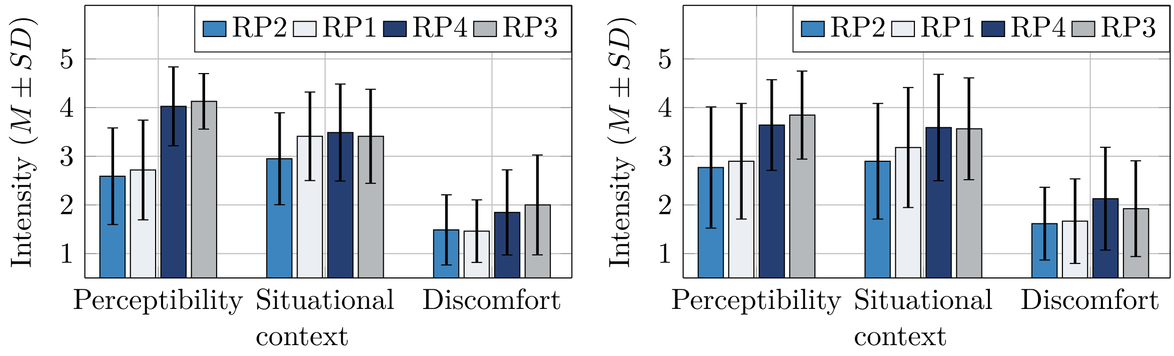
7.3.5 Roll Profiles

The last part for each driving scenario was the evaluation of the four different roll profiles (cf. Figures 7.4 and 7.6) considering the items *perceptibility*, *situational context*, and *discomfort*. For scenario 1, 2, and 3, the announcement time was set to 2.5 s. Moreover, a negative roll angle was selected for scenario 1 and 2, and a positive angle for scenario 3 and 4. This choice was afterwards verified by the favored roll direction in Section 7.3.2. The items were rated on a five-point rating scale from 1 $\widehat{=}$ "not at all" to 5 $\widehat{=}$ "totally" and the results are presented in Figure 7.15.



(a) Scenario 1 "Lane change from following a PV"

(b) Scenario 2 "Lane change when detecting a PV"



(c) Scenario 3 "Lane change to the right"

(d) Scenario 4 "Lane change abort"

Figure 7.15: Evaluation of different roll profiles (RP1 $\widehat{=}$ 1.5 ° fast, RP2 $\widehat{=}$ 1.5 ° slow, RP3 $\widehat{=}$ 3.0 ° fast and RP4 $\widehat{=}$ 3.0 ° slow; scale: 1 $\widehat{=}$ "not at all" - 5 $\widehat{=}$ "totally"; $N = 39$), referring to Cramer and Klohr (2019)

A 2 ($\varphi_{max} \widehat{=}$ maximum roll angle) x 2 ($t(\varphi_{max}) \widehat{=}$ time to reach maximum roll angle) ANOVA with repeated measures was conducted for each item for each driving scenario. The factor scenario could not be considered in the ANOVA because two scenarios (scenario 1 and 2) only included positive and two scenarios (scenario 3 and 4) only negative roll motions. Considering the item *perceptibility* it was rated rather "high" ($\widehat{=}$ 4) for RP3 and RP4, and rather "low" or "moderate" ($\widehat{=}$ 2 - 3) for RP1 and RP2. The roll angle revealed a highly significant main effect for all scenarios and therefore the 3.0 ° was perceived stronger than the 1.5 ° roll angle within each driving scenario. The results are outlined in Table 7.5. The main effect for $t(\varphi_{max})$ was significant for scenario 1 and 2, whereby the roll profiles with the shorter $t(\varphi_{max})$ and, thus, the higher acceleration (RP1 and RP3) were more perceptible. A significant interaction effect of the *roll angle * time to reach maximum angle* only existed for scenario 2. Here, the time to reach the maximum angle had a higher influence on the perceptibility considering the 3.0 ° (RP3 and RP4) than the 1.5 ° (RP1 and RP2) roll profiles.

Table 7.5: Results of the ANOVA for the item *perceptibility* considering the main effects φ_{max} and $t(\varphi_{max})$ as well as their interaction effect, referring to Cramer and Klohr (2019)

Main effect	$F(1, 38)$	p	r
φ_{max}			
Scenario 1	113.3	<.001	.87
Scenario 2	56.74	<.001	.77
Scenario 3	141.11	<.001	.89
Scenario 4	36.18	<.001	.70
$t(\varphi_{max})$			
Scenario 1	15.34	<.001	.54
Scenario 2	10.18	.003	.46
Scenario 3	1.11	.298	.17
Scenario 4	2.40	.130	.24
$t(\varphi_{max}) * \varphi_{max}$			
Scenario 1	2.19	.147	.23
Scenario 2	4.89	.033	.34
Scenario 3	0.02	.893	.02
Scenario 4	0.07	.799	.04

Overall, the *situational context* was scored between "moderate" and "high" ($\widehat{=}$ 3 - 4) and there were mainly no significant results. Only the roll angle revealed a significant main effect for scenario 4 ($F(1, 38) = 16.73$, $p < .001$, $r = .55$) and the interaction effect *roll of angle * time to reach maximum angle* for scenario 3 ($F(1, 38) = 7.72$, $p = .008$, $r = .41$).

Considering the item *discomfort*, the scores were on average between "not at all" and "low" ($\widehat{=}$ 1 - 2). The roll angle showed a significant main effect on the *discomfort* of the roll motion for every driving scenario (Table 7.6). Consequently, the 3.0 ° (RP3 and RP4) caused significantly more discomfort than the 1.5 ° (RP1 and RP2) roll profiles. However, the absolute values were always very low. The *discomfort* of the feedback

Table 7.6: Results of the ANOVA for the item *discomfort* considering the main effects maximum φ_{max} and $t(\varphi_{max})$ as well as their interaction effect, referring to Cramer and Klohr (2019)

Main effect	$F(1, 38)$	p	r
φ_{max}			
Scenario 1	12.47	.001	.50
Scenario 2	6.86	.013	.39
Scenario 3	15.38	<.001	.54
Scenario 4	9.65	.004	.45
$t(\varphi_{max})$			
Scenario 1	4.34	.044	.32
Scenario 2	11.00	.002	.47
Scenario 3	1.49	.230	.19
Scenario 4	0.72	.403	.14
$t(\varphi_{max}) * \varphi_{max}$			
Scenario 1	0.00	1.00	.00
Scenario 2	3.11	.086	.27
Scenario 3	2.42	.128	.24
Scenario 4	1.44	.237	.19

was only significantly influenced by the main effect of $t(\varphi_{max})$ for scenario 1 and 2, whereby the roll profiles with the shorter $t(\varphi_{max})$ and, hence, the higher acceleration (RP1 and RP3) were assessed with more discomfort. No significant interaction effects existed.

7.3.6 System Awareness

The participants answered a questionnaire after each driving scenario (Figure 7.6). Thereby, agreement to the following statements (items written in italics) was surveyed on a five-point rating scale (1 ≙ “does absolutely not apply” - 5 ≙ “does absolutely apply”):

- I find the roll motions *useful.*
- I find the roll motions *misleading.*

- Via the roll motions, I had better awareness of the *driving action* that the vehicle (automation system) is *currently* performing.
- Via the roll motions, I had better awareness of the *driving action* that the vehicle (automation system) *prospectively* intends.
- Via the roll motions, my *comprehension* for the state transition of the automation system is better.
- The roll motions supported me in my *supervising task*.

A visual representation of the evaluated items is presented in Figure 7.16. At first glance, it could be seen that the 6 items were almost always rated differently for the driving scenario 4 (lane change abort) than for the other three scenarios. However, it has to be mentioned that the feedback for each driving scenario was still rated positively. The items *useful*, *prospective driving action*, *comprehensible*, and *supervising task* were on average evaluated with scores over 4 out of 5 ($1 \mathrel{\widehat{=}}$ "does absolutely not apply" - $5 \mathrel{\widehat{=}}$ "does absolutely apply") for the driving scenarios 1, 2, and 3. The item *misleading* received scores between 1 and 2 and the item *current driving action* between 3 and 4 out of 5.

An ANOVA with following post-hoc analysis using Bonferroni correction was conducted and confirmed the first impression of the different ratings of scenario 4. If Mauchly's test for sphericity showed significance, the data was corrected (Greenhouse-Geisser). The results are presented in Table 7.7 and indicated significant main effects for all items except the item *current driving action*.

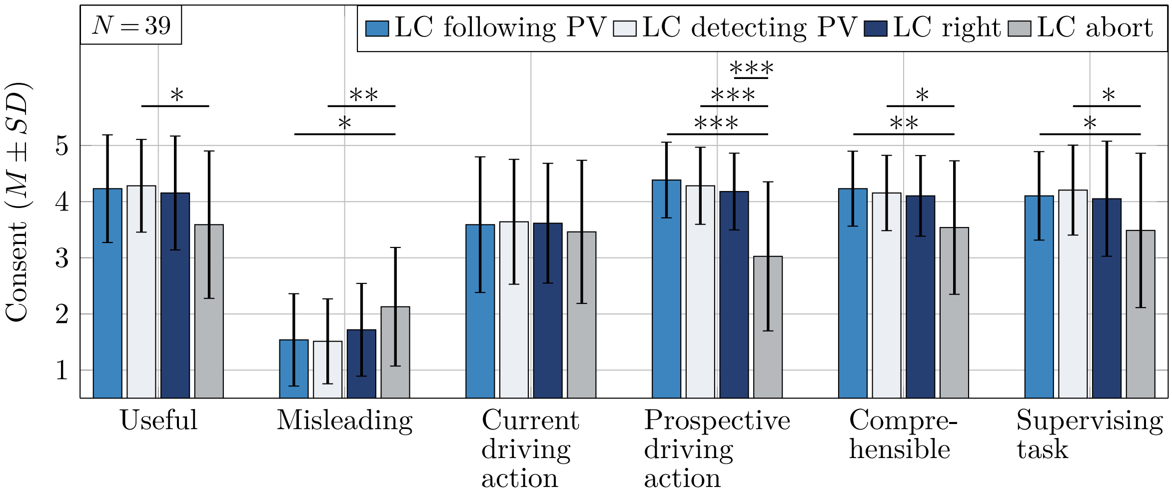


Figure 7.16: Evaluation of the items *useful*, *misleading*, *current driving action*, *prospective driving action*, *comprehensible*, and *supervising task* (scale: $1 \mathrel{\widehat{=}}$ "does absolutely not apply" - $5 \mathrel{\widehat{=}}$ "does absolutely apply"; $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$), referring to Cramer and Klohr (2019)

Table 7.7: Results of the ANOVA considering the items *useful*, *misleading*, *current driving action*, *prospective driving action*, *comprehensible*, and *supervising task* within the driving situations, referring to Cramer and Klohr (2019)

Main effect	F	p	η_p^2
Useful	$F(1.43,\ 54.19) = 6.26$	.008	.14
Misleading	$F(2.00,\ 76.11) = 7.52$	.001	.17
Current driving action	$F(2.41,\ 91.71) = 0.34$	.753	.01
Prospective driving action	$F(1.82,\ 69.03) = 25.06$	<.001	.40
Comprehensible	$F(1.74,\ 66.02) = 8.39$	.001	.18
Supervising task	$F(1.89,\ 71.88) = 6.31$	.004	.14

Post-hoc tests revealed for the item *useful* a significant difference between driving scenario 2 and 4 ($M_{2-4} = 0.69$, $p = .022$) and a tendency towards significance between scenario 1 and 4 ($M_{1-4} = 0.64$, $p = .051$). Considering the item *misleading*, significant results existed between scenario 1 and 4 ($M_{1-4} = -0.59$, $p = .010$) as well as 2 and 4 ($M_{2-4} = -0.62$, $p = .007$). The post-hoc analysis for the item *prospective driving action* indicated significant results for each comparison with scenario 4 ($M_{1-4} = 1.36$, $p < .001$; $M_{2-4} = 1.26$, $p < .001$, and $M_{3-4} = 1.15$, $p < .001$). Moreover, the item *comprehensible* revealed significant different ratings between scenario 1 and 4 ($M_{1-4} = 0.69$, $p = .004$) as well as 2 and 4 ($M_{2-4} = 0.62$, $p = .017$), and a tendency towards significance between scenario 3 and 4 ($M_{3-4} = 0.56$, $p = .052$). In conclusion, the item *supervising task* was rated significantly lower for scenario 4 than scenario 1 ($M_{1-4} = 0.62$, $p = .047$) and scenarios 4 than 2 ($M_{2-4} = 0.72$, $p = .018$). The statistic results reflected the participants' statements in some extent. The roll motion for scenario 4 did not announce an upcoming maneuver but instead intensified the normal vehicle dynamics when detecting the vehicle from behind. Hence, some participants noted that the roll motion in scenario 4 is not as useful and supporting for the driver because the vehicle already reacted to the situation and the participants were somehow confused what this feedback should reflect. An ANOVA without scenario 4 (lane change abort) indicated no significant main effect for any item.

7.3.7 Acceptance

The acceptance of feedback via roll motions was evaluated by the questionnaire of van der Laan et al. (1997) in the German version (Kondzior, n.d.) as it was done for the second driving study (Section 6.3.4). This survey was conducted twice, once before the test drive to assess the expectation of the feedback and once after the test drive as the participants experienced the feedback. The questionnaire measures the items *usefulness* and *satisfying*. Figure 7.17 presents the results of this questionnaire, whereby both items were rated positively.

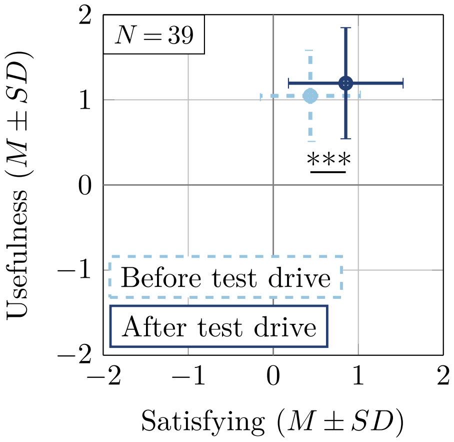


Figure 7.17: Evaluation of the acceptance of the roll motion feedback (scale: five-point semantic differential; ***$p < .001$), referring to Cramer and Klohr (2019)

The item *usefulness* indicated a tendency towards a significantly lower rating (t-test: $t(38) = -1.81$, $p = .079$, $r = .28$) for the expectation ($M = 1.05$, $SE = .09$) compared to after experiencing the roll motions ($M = 1.19$, $SE = .11$). Considering the item *satisfying*, the results revealed a highly significant difference for the expectation ($M = 0.44$, $SE = .10$) compared to experiencing this feedback ($M = 0.85$, $SE = .11$, t-test: $t(38) = -4.58$, $p < .001$, $r = .60$). Some participants supported these finding with their comments that they found the feedback via roll motions much more pleasant and intuitive than they expected it to be.

7.3.8 General Attitude

The agreement to four statements (items written in italics) was surveyed by the participants before and after the test drive on a five-point rating scale ($1 \hat{=}$ "does absolutely not apply" - $5 \hat{=}$ "does absolutely apply"):

- I would like to have *feedback* for state transitions of the automation system during partially automated driving.
- Thanks to roll motion feedback, I had better *awareness* of the state of the automation *system*.
- I would like clearly *noticeable roll motions* to identify prospective driving actions.
- I would prefer rather *small roll motions* to preferably reduce the discomfort.

The ratings are graphically displayed in Figure 7.18 and statistically presented in Table 7.8. After the test drive, the evaluation of all items positively supported the feedback via roll motions to announce lane changes. The first two statements *desired feedback* and *system awareness* were strongly agreed with at both times. Considering the item *noticeable roll motions*, the results indicated a tendency towards a significant difference between the time before and after the test drive. Moreover, the rating of the last statement decreased significantly over time.

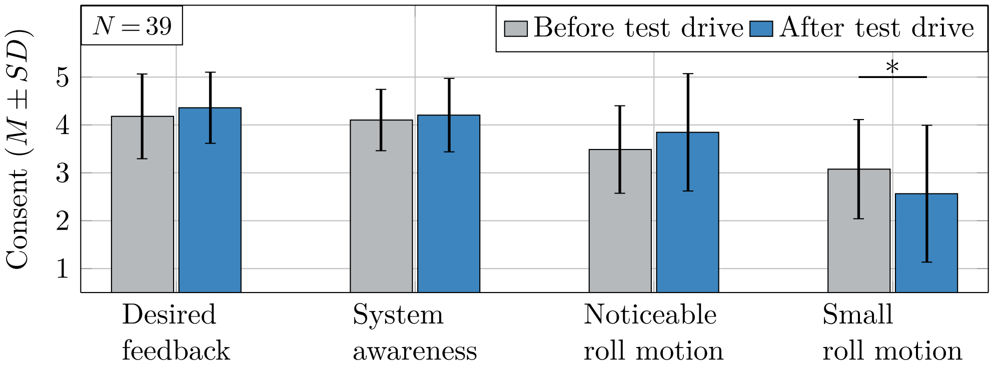


Figure 7.18: Ratings of the items *desired feedback*, *system awareness*, *noticeable* and *small roll motion* (scale: 1 ≙ "does absolutely not apply" - 5 ≙ "does absolutely apply"; $*p < .05$), referring to Cramer and Klohr (2019)

Table 7.8: Results of the t-test considering the items *desired feedback*, *system awareness*, *noticeable roll motion*, *small roll motion* before and after the test drive, referring to Cramer and Klohr (2019)

Metric	$t(38)$	p	r
Desired feedback	−1.36	.181	.22
System awareness	−0.75	.457	.12
Noticeable roll motion	−1.74	.090	.27
Small roll motion	2.36	.023	.36

7.3.9 Timing of the Lane Change Announcement

The participants triggered the announcement of the lane change themselves with a small push-button (Figure 6.2b). This released a $2.5\,s$ lane change announcement with their favorite roll profile followed by the execution of the lane change. Data of one participant was missing due to recording problems. The PV drove either approximately $30\,km/h$ or $40\,km/h$ on the straight of the test track. Consequently, the relative velocity v_{rel} was either $M =$ -26.72 km/h ($SD =$ -1.33 km/h) or $M =$ -17.69 km/h ($SD =$ -0.69 km/h) at the time the button was triggered. The automated vehicle drove similarly in both cases: PV 30 km/h: longitudinal velocity v_x: $M = 55.84\,km/h$, $SD = 0.96\,km/h$, longitudinal acceleration a_x: $M = 0.04\,m/s^2$, $SD = 0.16\,m/s^2$, and PV 40 km/h: v_x: $M = 56.36\,km/h$, $SD = 0.64\,km/h$, a_x: $M =$ -0.02 m/s^2, $SD = 0.09\,m/s^2$. If more than one suitable trigger time was available for one variation, the mean values of the trigger times and their belonging values were generated. The distance to the PV d_{rel} was significantly higher for a PV driving with 30 km/h ($M = 78.30\,m$, $SE = 1.74$) than for the PV driving with 40 km/h ($M = 63.97\,m$, $SE = 1.76$) at the time the button was triggered (cf. Figure 7.19, t-test: $t(37) = -47.97$, $p < .001$, $r = .99$).

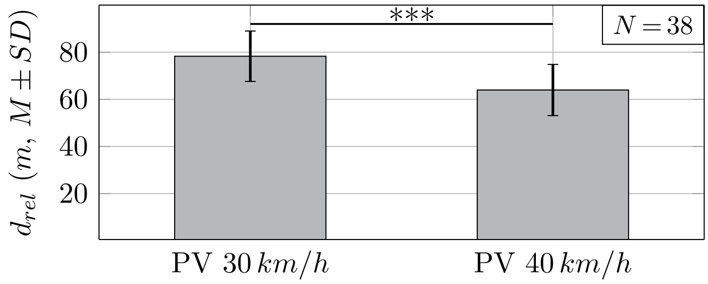


Figure 7.19: Distance d_{rel} to PV when to announce lane changes depending on the relative velocity (**$p < .001$)

Apart from this, a multiple linear regression model was generated with the forced entry method. Two predictors, relative velocity v_{rel} and longitudinal acceleration a_x were chosen as these are significant predictors for the regression model for the similar scenario "approaching" (cf. Figure 6.3a and Section 6.3.10) in driving study 2. The dependent variable was also the longitudinal distance d_{rel}. All assumptions for a linear regression were fulfilled: linearity, homoscedasticity, normally distributed residuals, independent errors (Durbin-Watson statistic = 1.96), and no perfect multicollinearity within data. The regression model revealed that d_{rel} was influenced by v_{rel} and a_x ($F(2,\,73) = 113.63$, $p < .001$). The two predictors accounted for 75% ($R^2 = .75$) of the variation in d_{rel} for announcing lane changes for scenario 2. Further results are presented in Table 7.9 and the regression equation in the following.

Table 7.9: Results of the regression model for the timing of announcing lane changes for scenario 2

	B (SE)	β	p
Step 1			
Constant	44.40 (3.67)		
v_{rel} (km/h)	−1.17 (0.16)	−.42	<.001
a_x (m/s^2)	67.48 (5.71)	.69	<.001

$$d_{rel} = 44.40 - 1.17\,v_{rel} + 67.48\,a_x \tag{7.2}$$

7.3.10 Motion Sickness

It was important to collect data showing whether this feedback or the setting of the study (driving on an oval test track always in the same direction) induced motion sickness. For this reason, the question “Do you have nausea, a headache, or dizziness?” was surveyed five times (t_0, t_1, t_2, t_3, and t_4, Figure 7.6) during the driving study. Mostly, the participants directly stated that they felt well. Only two of the 39 participants answered yes to this question at least once. One participant had “moderate” dizziness and “moderate” nausea (3 on a five-point rating scale from $1 \mathrel{\widehat{=}}$ “very slight” to $5 \mathrel{\widehat{=}}$ “very strong”) at the time t_3 and only very slight nausea at t_4. This participant often had dizziness and nausea on roller coasters and during doing something else when riding as a passenger in vehicles. The other participant had “moderate” and later on a “slight” headache from the time t_2 on until the end of the driving study (3 and 2 on same rating scale). This participant rarely got a headache, dizziness, and nausea as a passenger or on a roller coaster.

7.3.11 Sensory Channels

In the final survey, the participants were asked on a five-point rating scale ($1 \mathrel{\widehat{=}}$ “does absolutely not apply” - $5 \mathrel{\widehat{=}}$ “does absolutely apply”) which sensory channel (vestibular, haptic, visual, and auditory) could be suitable for announcing lane changes. On average, the vestibular feedback gained the highest scores ($M = 4.1$), followed by visual ($M = 3.7$), and haptic as well as auditory ($M = 2.8$) feedback (Figure 7.20).

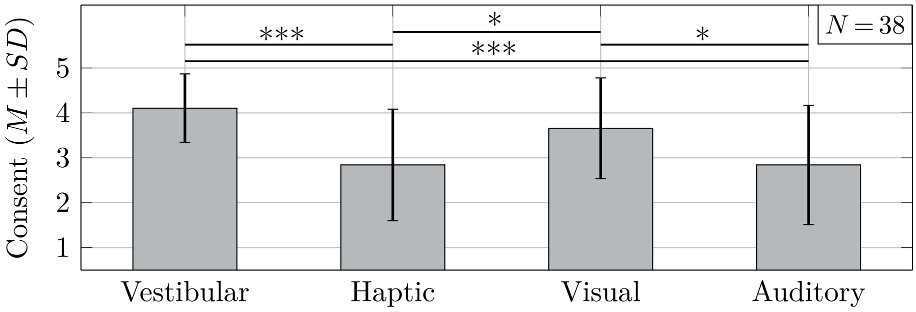


Figure 7.20: Ratings of the suitability of different sensory channels to announce lane changes (scale: $1 \mathrel{\widehat{=}}$ “does absolutely not apply” - $5 \mathrel{\widehat{=}}$ “does absolutely apply”; $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$), referring to Cramer and Klohr (2019)

An ANOVA was conducted and pointed out that the sensory channel has a main effect for transferring this kind of feedback to the driver ($F(3,\ 111) = 11.66$, $p < .001$, $\eta_p^2 = .24$).

Following post-hoc analysis using Bonferroni correction revealed that vestibular and visual feedback were significantly more suitable than auditory and haptic feedback for announcing automated lane changes ($M_{Ve-H} = 1.26$, $p < .001$; $M_{Ve-A} = 1.26$, $p < .001$; $M_{Vi-H} = 0.82$, $p = .043$, and $M_{Vi-A} = 0.82$, $p = .029$).

7.4 Discussion and Conclusion

The general attitude towards feedback on state transitions and intentions of the automation system was already high before even experiencing this kind of feedback. Nevertheless, the ratings increased after experiencing the roll motion feedback. Furthermore, a clearly perceptible feedback was more strongly preferred after the test drive which corresponds to the requirements of feedback (cf. Section 2.6). Moreover, regarding the acceptance, the roll motions for announcing lane changes were expected as *useful* and *satisfying* before even experiencing them. After the test drive, especially the item *satisfying* was assessed higher. Moreover, the roll motions for announcing lane changes (scenario 1, 2, and 3) were strongly approved as supporting the driver in the supervising task as well as providing improvement for the system awareness which is crucial for partially automated driving (Endsley, 1995; Othersen, 2016; Sarter & Woods, 1995; I. Wolf, 2016), and might reduce the reaction time to system failures as Damböck et al. (2012) revealed for presenting additional information about the automation via a contact analogue head-up display. The roll motions as an announcement were also evaluated as useful, comprehensible, and not misleading. However, the ratings revealed that these evaluated items were noticeably less for scenario 4 (“lane change abort”) but were still in the positive range for the feedback.

The 3.0 ° roll angle received a slight majority compared to the 1.5 ° as preferred roll angle regarding the four driving scenarios. The big angle was rated on average between “okay” and “rather too strong” and the small angle between “rather too weak” and “okay”. In many cases, the participants mentioned that a medium roll angle with a tendency towards the 3.0 ° would be the best. The roll angle is recommended to be 2.5 ° and the time to reach the maximum angle should be in the middle of RP3 and RP4 (approximately 1.32 s). Consequently, a clearly perceptible and not discomfort inducing feedback is ensured. Moreover, these results should be evaluated in real traffic, taking account of more road users, road unevenness, and different velocities. Furthermore, the participants were instructed to supervise the system and no secondary tasks were allowed. Nevertheless, drivers tend to do secondary tasks with higher automation levels (Carsten et al., 2012). Hence, the perceptibility could be lower while doing a secondary task.

Considering the preferred roll motion direction for each driving scenario, it appeared that the roll direction should be to the left (negative angle) for maneuvers to the left (scenarios 1 and 2) and to the right (positive angle) for maneuvers to the right (scenarios 3 and 4). As a result, the feedback should be externally compatible with the driving action (Bubb, Bengler, et al., 2015; C. Müller, Siedersberger, et al., 2017). However, it was not as clear for scenario 4 compared to the other scenarios. 27 % favored a negative angle and explained this decision with better suitability for a critical situation because of the higher perceptibility of the roll motion in this direction by supporting the normal vehicle behavior and not reducing it. This was due to the fact, that during this maneuver a negative roll angle already existed because of the normal driving dynamics for the return to the starting lane. Consequently, the added roll profiles with a negative roll angle are summing up to an absolutely bigger roll angle compared to the roll profiles with a positive roll angle which compensated partially the negative roll angle caused by the driving dynamics of the maneuver itself. Other participants wanted a less perceptible roll motion because they already found the normal driving dynamics for such a critical maneuver enough. Some wanted a positive roll motion that overrules the normal driving behavior and, therefore, gives a feeling of safety. In summary, roll motions to feed back a lane change abort were rated ambiguously. Further studies should investigate this feedback in rather critical situations in a dynamic driving simulator. Thereby, the driving scenarios should be critical enough to result in a simulated accident, if the driver does not take over vehicle guidance or if the automation system does not perform an evasive maneuver. These scenarios should not be realized in real world driving studies to not endanger the participants.

Due to the fact that the roll motions as an announcement for an upcoming lane change were rated useful, not misleading, and should be in the direction the vehicle is driving to, the participants often mentioned that this feedback was intuitive for them. The reason for this might be that when a person is riding a bicycle or a motorbike and wants to turn right, the person is tilting with the bicycle to the right, and thus this behavior might be "natural" for the drivers. Consequently, it might be a "natural" interface (Wigdor & Wixon, 2011).

As aforementioned, 1.5 ° roll motions were rated not as intense as 3.0 ° roll motions, and this was mainly independent of the driving scenario. However, the results indicated that the roll motions for the lane change abort were rated differently. The reason for this was pointed out in the previous paragraph. Future research should focus on the influence of road gradients and tilting angles induced by normal driving behavior. Moreover, roll motions to the left were perceived stronger than roll motions to the right for the participants in the driver's seat for the same roll profile. Hence, moving up (positive angle) was perceived weaker than moving down (negative angle). One aspect could be that an acceleration of $1\,G$ is permanently affecting humans and is reduced for the short time when the vehicle is rolling to the left (negative angle). This is emphasized by Weber's law which states that the difference threshold is a constant ratio of the original stimulus and increases with it (Grondin, 2016). During this rating, the participants knew which roll angle and direction they were experiencing. The following analysis about evaluating the *perceptibility*, *situational context*, and *discomfort* of the roll profiles strengthened these results. Thereby, the participants did not know the profile and the roll angle, and the time to reach the maximum angle varied. The latter had only a significant influence on the *perceptibility* for scenarios 1 and 2 which come along with a driving action to the left and, thus, a negative roll angle. Consequently, the participants are more sensitive if they are moving down than up. The same was reported for the item *discomfort*. However, the scores are overall on average between "not at all" and "low". Considering the item *situational context*, the ratings were on average nearly always between "moderate" and "high". Subsequently, the roll profile is not a crucial factor for this item. It is only crucial for scenario 4, where a higher roll angle received better evaluation considering the item *situational context*. This enhances the wish for a stronger feedback in a rather critical driving scenario.

Overall, these scores emphasize that feedback via roll motions is useful as well as highly accepted by the drivers. Moreover, feedback is needed to maintain or increase the drivers' system awareness of the automation (Sarter & Woods, 1995; Wickens et al., 2013), and the ratings of this study support this. The results further indicated that feedback via roll motions should be clearly perceptible, and thus meet the feedback requirements mentioned in Section 2.6. The discomfort is rated rather "low" for the big roll motion, and hence the feedback is comfortable for the drivers.

The announcement time of $2.0\,s$ is more suitable for the participants than $3.0\,s$ regardless of the experienced roll angle. This is in a similar range as a measured intervention time of Gold, Damböck, Bengler, and Lorenz (2013). Here, the participants drove conditionally automated before they were requested to supervise the automation system and, subsequently, experienced a take-over request. This intervention time was $2.11\,s$. Therefore, an announcement time of $2.0\,s$ might be considered as a sufficient announcement time for the participant for an upcoming lane change maneuver while the vehicle is driving on straight in the starting lane. It has to be mentioned that with the current shape of the lane change path, that follows after the $2.0\,s$ announcement time, there still remain approximately $2\,s$ until the vehicle actually enters the neighboring lane. As a consequence, there are overall about $4\,s$ time from the initial announcement to entering the neighboring lane.

Comparing different sensory channels for announcing lane changes, vestibular and visual feedback were considered suitable by the participants. This is remarkable because vestibular feedback has hardly been scientifically researched or even applied. As a result, the vestibular feedback could be combined with a visual one to accomplish a multi-modal feedback which is more fruitful based on the fact that natural human interaction with the world, for example speech and gesture, is often multi-modal (Bubb, Bengler, et al., 2015; Jain et al., 2011).

Via the online survey, only persons with ACC experience could register and only gender and field of work (technical or non-technical) of the registered persons were reported to the experimenter for an evenly selection of the participants. As a result, some combinations of characteristics might be missing in this sample. Moreover, the study limitations of the first and second driving study (Section 5.4 and 6.4) considering the recruiting of the sample, and existence of, as well as the communication with the experimenters also applied.
The driving study was carried out on a test track with only two vehicles, similar to driving study 1, and thus had the same study limitation considering the test track (Section 5.4).

Vestibular feedback provides a new option for communicating state transitions or intentions of the automation system. This can contribute to a multi-modal feedback. The results of this study and the previous studies (Section 5.3, 5.4, 6.3, and 5.4) support this statement. Feedback on driving actions in the vehicle's longitudinal direction should be via pitch motions and in the vehicle's lateral direction via roll motions with a degressive profile (cf. Section 5.3, 5.4, 6.3, and 5.4).
Until now, the focus has been on the design of pitch and roll motions and their general suitability for different driving scenarios. A fourth study evaluated an overall feedback concept with active pitch and roll motions for announcing maneuvers or feeding back state transition during partially automated motorway driving versus and in combination with visual feedback.

8 Driving Study 4

The first, second, and third driving study (cf. Chapter 5, 6, and 7) initially investigated active vehicle pitch and roll motions as feedback within partial driving automation. Thereby, the design of these pitch and roll motions was evaluated depending on the experienced driving scenario. Pitch motions were chosen for detecting a preceding or cutting-in vehicle, and roll motions for announcing lane changes. Moreover, this feedback was rated useful, not misleading, and supporting the system awareness (cf. Section 5.3, 6.3, and 7.3). Consequently, active pitch and roll motions can be regarded as suitable for keeping drivers "in-the-loop" as part of a multi-modal feedback.

The focus of this driving study was to evaluate a visual-only feedback on state transitions and intentions of the automation compared to a multi-modal feedback of visual and vestibular information. The visual information was the basis and identical for both feedback types (cf. Section 8.1.4). Therefore, a freely programmable instrument cluster was built into the test vehicle. Pitch and roll motions were implemented in the automated vehicle based on the results of the first three diving studies (Section 5.3, 6.3, and 7.3). It was a goal to gain insight on whether vestibular information has added value for the driver considering, for instance, system awareness, perceived safety, trust, and reaction times in case of a system failure. First, the method of the driving study, including research questions and test setup, is described. Subsequently, the design of pitch and roll motions as well as the visual information in the instrument cluster, and the study design are outlined. Concluding, the results are presented.

8.1 Method

In this driving study, a visual-only feedback was evaluated compared to a multi-modal feedback of visual and vestibular information while driving partially automated on a motorway. The design of the vestibular feedback, in the form of pitch and roll motions, is based on the results of the previous studies (Section 5.3, 6.3, and 7.3).
System awareness is essential for the driver during partially automated driving to be "in-the-loop" and able to take over vehicle guidance immediately at system limits (Sarter

& Woods, 1995). Therefore, supervising the vehicle guidance should be appropriately demanding and should not cause many glances away from the road. Moreover, an automation system should convey trust and a feeling of safety (e. g. Ghazizadeh et al., 2012; Muir & Moray, 1996). It is necessary for a feedback approach to be suitable for, accepted by, and not distracting for the driver (cf. Section 2.6). Each sensory channel is limited in its performance (Wickens et al., 2013). Thus, transferring information to the driver via multiple sensory channels is more effective (Bubb, Bengler, et al., 2015). Consequently, essential research questions were:

- *RQ1*: Does the feedback type influence drivers' trust in the automation system?
- *RQ2*: Does the feedback type influence drivers' system awareness of the automation system?
- *RQ3*: Are the drivers' mental, visual, and physical demands as well as their feeling of safety while supervising the automation system perceived differently depending on the feedback type?
- *RQ4*: Does the experienced feedback type influence the drivers' acceptance ratings for the partial driving automation?
- *RQ5*: Do the drivers show a different glance attention ratio away from the road while driving with a visual-only compared to a visual and vestibular feedback?
- *RQ6*: How do the participants assess the situation and rate the perceived safety in case of system failure?
- *RQ7*: Does the experienced feedback type influence drivers' reaction time in case of system failure?

Furthermore, feedback should not have a negative influence on the driver's well-being. Hence, motion sickness should be surveyed, as done for the previous driving studies (cf. Section 5.3.6, 6.3.11, and 7.3.10). Moreover, the participants were asked to rate the feedback types as well as their meanings after the driving study to survey whether announcing lane changes or the feedback for the detection of a PV is more suitable.

The metrics for the evaluation of these research questions are presented in connection with the results in Section 8.2.

8.1.1 Test Setup and Equipment

This driving study setup was equivalent to the second driving study setup (Chapter 6) and, thus, included four parts on the same section of the motorway A9 with a maximum velocity of 120 km/h. The automation system, active chassis, visual feedback for the participant, tasks of the experimenter on the passenger seat, and test equipment are described in Chapter 4. However, the first experimenter triggered the pitch motions via the video game controller, which additionally included the appearance of the visual representation of the PV in the instrument cluster, while the second experimenter triggered the appearance of the visual information for a PV with a little noiseless push-button (Wizard controllers in Figure 8.1). The representation of the PV was removable by the second experimenter by lifting the electric window opener. The reminder for the participants for grabbing the steering wheel was visually realized via the instrument cluster (cf. Section 8.1.4). If the participant had not noticed this and, hence, not touched the steering wheel, a gong sounded as during the previous studies. Besides the new instrument cluster, a prototypical automation button to activate the automation system was installed which was similar to the one in the Audi A8 to activate the “Staupilot” (AUDI AG, 2017a).

The technical setup of the driver’s and first experimenter’s workplace is presented in Figure 8.1. Audio recording, the recording of the driving scenarios via the front camera, the recording of the driver camera, eye-tracking data, and the recording of vehicle data, as well as internal data of the automation system were available for data evaluation.

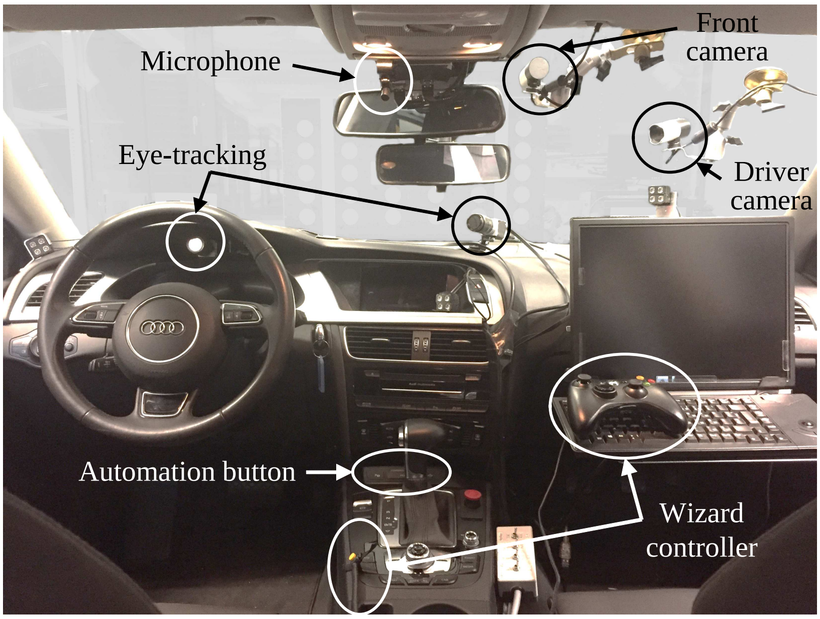


Figure 8.1: Interior for driving study 4

Due to safety issues, a remote two camera eye-tracking system was used (SmartEyePro 7.0, sampling rate 60 Hz) instead of a head-mounted system. It was too critical for the experimenters to drive with a head-mounted eye-tracking system in real traffic because of possible vehicle accidents and, hence, possible airbag releases.

8.1.2 Test Scenarios

Referring to the results of the previous driving studies, several test scenarios, and hence state transitions were selected to be fed back or announced via visual and vestibular feedback. Out of the four driving scenarios of the third study (Section 7.2.2), only the scenario 4 “lane change abort” (Figure 7.1d) was not considered. Moreover, every lane change to the left or right from the maneuver *follow lane* either without or with a PV was announced visually and, in some instances of the driving study, also in vestibular manner. The announcement time for a lane change (lane change preparation phase), while the automated vehicle was driving straight in the lane, was 2.0 s as it was recommended in the third driving study (Section 7.4). The lane change lasted for approximately 7.0 s. Considering the feedback for detecting a PV in the vehicle’s longitudinal direction, the basis is presented in Section 6.2.2 (driving study 2). The visual sign for the PV was always existent if a relevant PV was within the radar range. If the PV changed, the sign was gone for 1 s and showed up again afterwards. In contrast, the vestibular feedback was triggered according to the results of the regression model as well as the descriptive results of the second study (cf. Section 6.3.8 and 6.3.10). Therefore, sometimes a PV was detected and communicated visually only if it was, for instance, further away and driving with a positive relative velocity.

8.1.3 Design of Pitch and Roll Motions

A roll profile with a maximum angle of 2.5 ° with a medium acceleration was implemented as it was suggested in Section 7.4, but a pre-study with experts indicated that this profile was rated rather a bit too weak. As a result, the roll profile RP3 (cf. Section 7.2.3, Figure 7.4) with a maximum angle of 3.0 ° and a roll acceleration of $\ddot{\varphi} =$ -3.2 $°/s^2$ was selected for announcing lane changes. However, the return was designed differently compared to study 3 (cf. Section 7.2.3). When the lane change execution started, the roll angle returned to the horizontal position in 2.5 s. This was chosen in order to avoid tension of the chassis due to a combined pitch and roll angle, as it was otherwise possible for a pitch motion to be induced before the end of the lane change, e.g. if a PV was detected. For the pitch motions, the two profiles PP1 ($\theta_{max} = 1\,°$,

$\ddot{\theta} = -5.0\,^{\circ}/s^2$) and PP2 ($\theta_{max} = 2\,^{\circ}$, $\ddot{\theta} = -4.0\,^{\circ}/s^2$) were chosen (Figure 6.4, Table 6.1) and used depending on the criticality of the driving situation. The bigger angle was selected for more critical driving situations, for instance, a near cutting-in vehicle. The smaller angle was chosen for less critical situations such as, for example, a slower preceding vehicle further away which the ego vehicle was approaching (Section 6.3.8).

8.1.4 Design of Instrument Cluster Display

The prototypical instrument cluster of the Audi A5 was designed in the style of the instrument cluster of the Audi A8, and the automated system displays specifically in the style of the "Staupilot" displays (AUDI AG, 2017a, 2017b). The display for an activated "Staupilot" is presented in Figure 8.2. Herefore, the green small vehicle with the letters AI in the low right corner, the two clasps (left and right in the instrument cluster), as well as the automation button (prototypical in Figure 8.1) are illuminated in green. While driving manually, the r.p.m. counter and tachometer are displayed to the driver. If the "Staupilot" is available to be activated, the clasps appear and blink in white color, and the automation button is illuminated in white as well (AUDI AG, 2017a, 2017b). The same was realized for the prototypical instrument cluster for this driving study, apart from the color green which was replaced by a bluish color.

Figure 8.2: Instrument cluster Audi "Staupilot", taken from AUDI AG (2017a)

For the activated "Staupilot" the display remained in the same configuration as in Figure 8.2, showing only the PV and not the ego vehicle. In contrast, for the automation system of this study, the ego vehicle was represented via a blue triangle and the one relevant PV abstracted via blue rectangles in the particular lane. There are more rectangles drawn in Figure 8.3 only to show some more options. Normally, only the one relevant PV was presented in the darker blue color. This PV was either on one's own lane or turned up on the left or right lane if executing a lane change (darker blue) to the left or right, and detecting the new PV when crossing the lane marking.

A lane change preparation was displayed with a lighter blue text reading “Lane change pending”. When the vehicle arrived in the new lane, the PV moved to its own lane. Moreover, the ego vehicle and the lane markings were static, stayed the same, and did not move when changing lanes. This was explicitly explained to the participants during the settling-in phase.

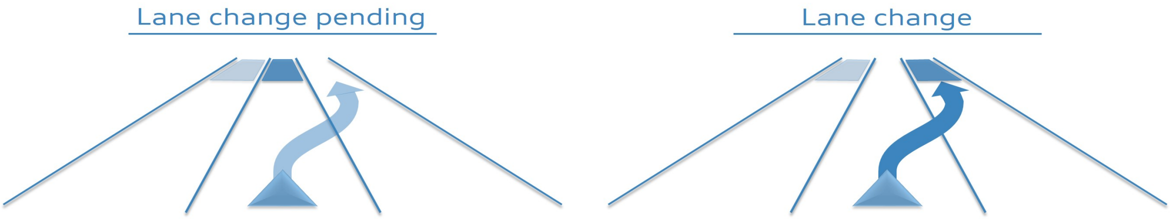


Figure 8.3: Visual feedback in the instrument cluster

The three lanes, the ego vehicle, and the PV were removed if the hands-on reminder appeared. Therefore, a steering wheel with two hands, left and right of it, as well as arrows to show that the hands should be moved on the steering wheel were displayed. The coloring was red, and the clasps were illuminated in red as well.

8.1.5 Study Design

The participants received some first notes about the study at the time the appointment was arranged (Appendix D.4). This was due to the same reasons as for the first study (Section 5.2.3). The sequence of this driving study is presented in Figure 8.4. At the beginning, the participants received a verbal briefing on how to handle the test vehicle and what to expect. It was clearly stated that the vehicle will only drive on the right and middle lane and not left lane or hard shoulder. The participants drove manually onto the motorway to start with the settling-in phase. They activated the automation system with the longitudinal and lateral vehicle guidance by themselves by pressing the automation button in the center console. In the first instance, the participants only received feedback about the activation status of the automation system (cf. Figure 8.2) and an illuminated indicator when the vehicle executed the lane change. After approximately 5 min, the experimenters activated either the visual or the vestibular feedback and added, after approximately another 5 min, the other feedback. This was randomized among the participants. The study was conducted in German.

The first 32 km belonging to the settling-in phase were succeeded by two feedback parts. Group A ($N = 18$) drove with a visual-only feedback in the feedback part 1

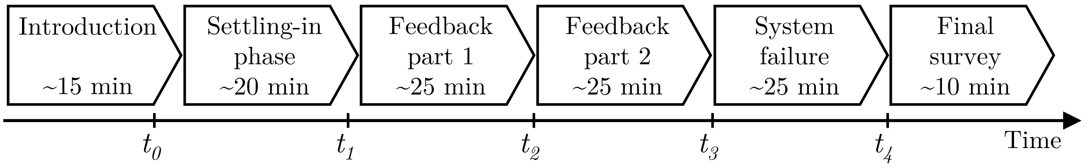


Figure 8.4: Sequence of the fourth driving study

and with a combined visual and vestibular feedback in the feedback part 2 of the driving study (Figure 8.4). Group B ($N = 16$) experienced the feedback in the other order. During each drive, the participants had to supervise the automation system and evaluate the two statements "mental demand" and "feeling of safety" (cf. Section 8.2.3 and 8.2.4) orally approximately every $4\,min$. At the end, the participants answered a questionnaire about, for instance, trust and acceptance (cf. Section 8.2).

Subsequently, the fourth part of the driving study was conducted. Thereby, half of the participants experienced a visual-only feedback (group C, $N = 17$) while the other half experienced a multi-modal feedback (group D, $N = 17$). This was additionally randomized among both groups A and B. The orally surveyed statements changed for the participants (cf. Section 8.2.7). After driving approximately $20\,km$, the first experimenter tried to trigger a lane change to the hard shoulder after following a truck, when the experimenter could ensure that the hard shoulder was free and safe to drive on. This represented a system failure. Hereby, the lane change was announced to the participants in the normal manner for the available feedback type. The participants took over the vehicle guidance by themselves or were invited by the first experimenter to do so when the automation finished the *lane change* and executed the maneuver *follow lane*. Following, the automation system was activated again in the right lane and the automated drive continued as before the system failure until the end of the motorway section. Shortly after activating the automation again, the second experimenter interviewed the participants about their behavior during the system failure and why they reacted that way (cf. Section 8.2.7). Subsequently, the first experimenter explained the participants that it was a triggered system failure. However, the participants were instructed to answer the next questionnaires as if it was a real system failure. Summing up the driving study, a final investigation of the gained impressions took place via questionnaire. During the whole driving study, it was attempted to simulate a "normal" drive with passengers in the vehicle. Thus, conversations were allowed besides the time the participants were interviewed or questioned.

8.1.6 Processing and Evaluation of Data

The data from the questionnaires were surveyed equally to driving study 2 via an online questionnaire, and processed equally to the first driving study (Section 5.2.4). For the eye-tracking data, the literature is not definite for a minimum glance duration that counts for a glance to one area of interest. Kraft, Naujoks, Wörle, and Neukum (2018) refer to a minimum fixation time of at least $100\,ms$ (Rayner, 1998; Young & Sheena, 1975). The International Organization for Standardization (2014-11) points out that a minimum glance duration of $120\,ms$ is necessary to be sure that this glance was planned. The latter was used for the evaluation of this eye-tracking data.

8.1.7 Sample

$N = 36$ participants took part in this driving study, whereby two could not be considered for the evaluation. One had to be excluded because of bad GPS reception and one due to inconsistent answering of the questionnaires. Consequently, $N = 34$ participants were available with a mean age of 33.3 years ($SD = 8.4$, $MIN = 23$, $MAX = 63$). The participants reflected variations of professional background and gender (23.5 % technical female, 26.5 % nontechnical female, 26.5 % technical male, 23.5 % nontechnical male). The groups were formed according to the answers of the pre-questionnaire (Appendix E.7). However, all participants must had used an ACC system before. On the one hand, this was due to safety reasons because the study was conducted in real traffic on the motorway, and on the other hand, in order to guarantee that the participants were already used to some ADAS, to avoid them focusing only on the driving behavior of the self-driving vehicle. Accordingly, the participants were able to focus on their task and evaluate the roll motions. The median mileage per year was 20,000 - 25,000 km and the mean mileage per week was 385 km ($SD = 276\,km$) with an average of 55 % motorway driving. Moreover, 91.2 % of the participants had experienced LKA and 35.3 % PAD systems (e. g. traffic jam assistance) before. The frequencies of use of ACC, LKA, and PAD systems of the participants who had already used these systems are displayed in Figure 8.5. Furthermore, the duration of having experience with each driving assistance system is presented in Figure 8.6. Supplementary information about the sample is presented in Appendix C.

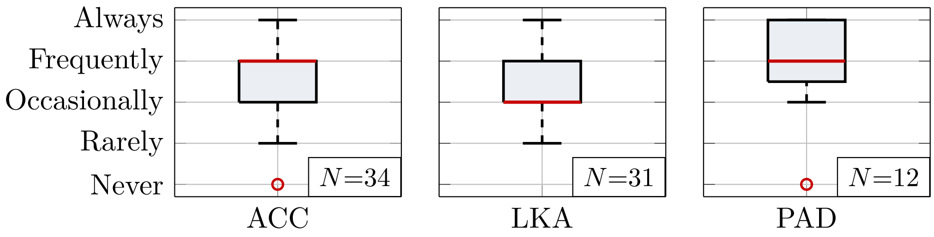


Figure 8.5: Frequency of use of ADAS of the fourth study's sample

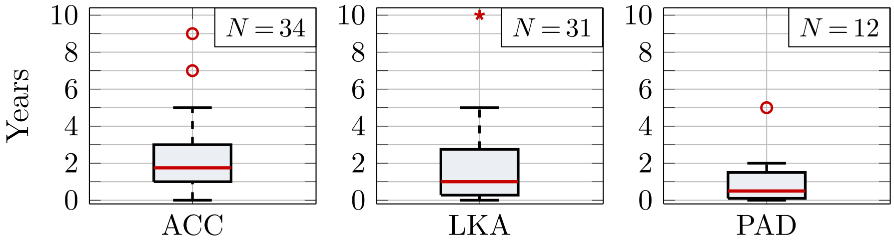


Figure 8.6: Experience with ADAS of the fourth study's sample

8.2 Results

The results of the research questions are presented in the same order as they are introduced at the beginning of Section 8.1. The findings are reported according to the recommendations in Field (2012). The pre-questionnaire and the questionnaire during the driving study are listed in the Appendix E.7 and E.8.

The sequence of experienced feedback (feedback part 1 and 2 in Figure 8.4) was randomized among the participants as mentioned in Section 8.1.5. Group A ($N = 18$) drove with a visual-only feedback at first and group B ($N = 16$) with a combination of visual and vestibular feedback. As described before (Section 8.1.5), the feedback used during the system failure was randomized as well. Group C ($N = 17$) had a visual-only feedback and group D ($N = 17$) a combination of a visual and vestibular feedback in the fourth part of the driving study, the system failure part.

8.2.1 Trust

Trust in the automation system was evaluated by the questionnaire developed by Pöhler, Heine, and Deml (2016), which was translated from the English version created by Jian, Bisantz, and Drury (2000) and was validated afterwards. The original questionnaire has 12 items with 5 items on the mistrust and 7 items on the trust scale. One item from the trust scale had to be removed after the translation and validation. Therefore, the questionnaire was shortened to 11 items (5 for mistrust and 6 for trust) whereby each item is scored on a seven-point rating scale from 1 ≙ "does absolutely not apply" to 7 ≙ "does absolutely apply".

The feedback type had no significant influence neither on the trust (visual-only: $M = 5.53$, $SE = 0.19$, visual & vestibular: $M = 5.51$, $SE = 0.19$; $t(33) = 0.12$, $p = .903$, $r = .03$) nor on the mistrust ratings (visual-only: $M = 1.96$, $SE = 0.16$, visual & vestibular: $M = 1.90$, $SE = 0.13$; $t(33) = 0.67$, $p = .508$, $r = .16$). The results are presented in Figure 8.7.

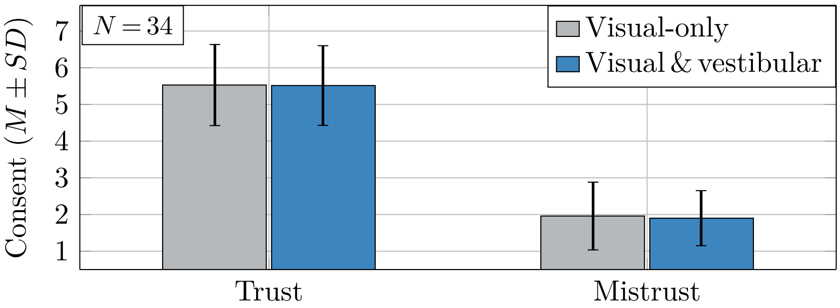


Figure 8.7: Ratings of trust and mistrust for the feedback types (scale: 1 ≙ "does absolutely not apply" - 7 ≙ "does absolutely apply")

The original questionnaire by Jian et al. (2000) measures trust only on one scale, and thus the mistrust items are reversed. This was also done to approximately compare the value to other real driving or driving simulator studies. The mean values are approximately in the range of 5.7 to 5.8 (A: visual-only: $M = 5.69$, $SD = 1.08$; B: visual & vestibular: $M = 5.74$, $SD = 0.69$; A: visual & vestibular: $M = 5.81$, $SD = 0.96$; B: visual-only: $M = 5.84$, $SD = 0.75$).

The same questionnaire was surveyed after the system failure part. The scores for groups C and D after the feedback part as well as after the system failure (SF) are displayed in Figure 8.8. There are two measurements for each group in the feedback part (one for visual-only and one for visual & vestibular) but only one for each group in the system failure part. Consequently, for the following analysis, only the visual-only trust measurement of group C and the visual and vestibular trust measurement of group D from the feedback part were compared with the group's trust measurement after the system failure. The ratings that belong together and, hence, measure the same feedback type before and after the system failure are in the same color but ones with patterns.

Generally speaking, the trust decreased and the mistrust increased on average after the system failure. In detail, the trust decreased significantly for the visual feedback (before SF: $Mdn = 5.7$, after SF: $Mdn = 5.2$, Wilcoxon test: $z = -2.02$, $p = .044$, $r = .35$) but not for the combination of visual and vestibular feedback (before SF: $Mdn = 5.5$,

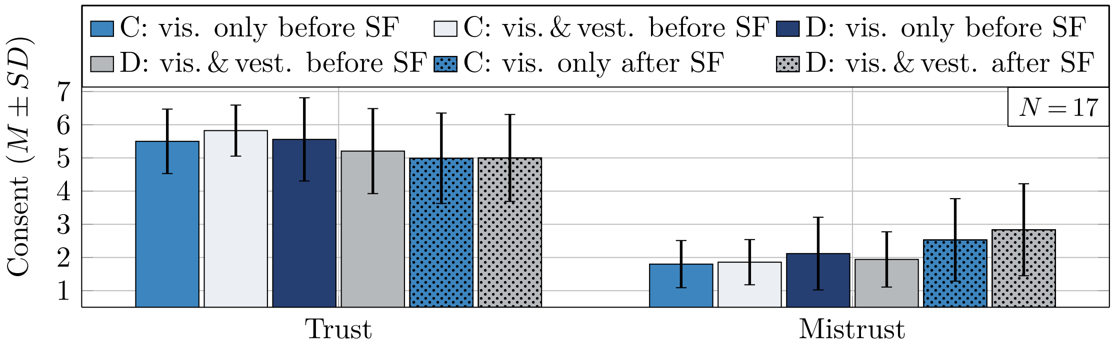


Figure 8.8: Ratings of trust and mistrust for the two groups C and D for the feedback parts of the driving study and after the system failure (SF ≙ system failure; scale: 1 ≙ "does absolutely not apply" - 7 ≙ "does absolutely apply")

after SF: $Mdn = 5.2$, Wilcoxon test: $z = -0.77$, $p = .441$, $r = .13$). In contrast, the mistrust increased significantly for both feedback types after the system failure (visual: before SF: $Mdn = 1.8$, after SF: $Mdn = 2.0$, Wilcoxon test: $z = -2.99$, $p = .003$, $r = .51$; visual and vestibular feedback: before SF: $Mdn = 2.0$, after SF: $Mdn = 2.6$, Wilcoxon test: $z = -3.65$, $p < .001$, $r = .63$). Transferring the trust and mistrust rating to one scale reveals a mean value of 5.21 ($SD = 1.25$) for the visual-only feedback and 5.08 ($SD = 1.24$) for the visual and vestibular feedback after the system failure.

8.2.2 System Awareness

System awareness was measured with the agreement to four self-created statements (items written in italics) on a five-point rating scale (1 ≙ "does absolutely not apply" to 5 ≙ "does absolutely apply"):

- Via the visual / visual and vestibular feedback, I had better awareness of the *driving action* that the vehicle (automation system) is *currently* performing.
- Via the visual / visual and vestibular feedback, I had better awareness of the *driving action* that the vehicle (automation system) *prospectively* intends.
- The visual / visual and vestibular feedback supported me in my *supervising task.*
- I found the *behavior* of the partially automated system *predictable.*

These statements were evaluated after driving with each feedback type. Their ratings with mean values above 3 showed that the feedback supports the driver's system awareness. The item *current driving action* and *prospective driving action* were rated significantly higher for the combination of visual and vestibular compared to the visual-only feedback. The same effect occurred for the items *supervising task* and *predictable behavior*. The results are displayed in Figure 8.9 and Table 8.1.

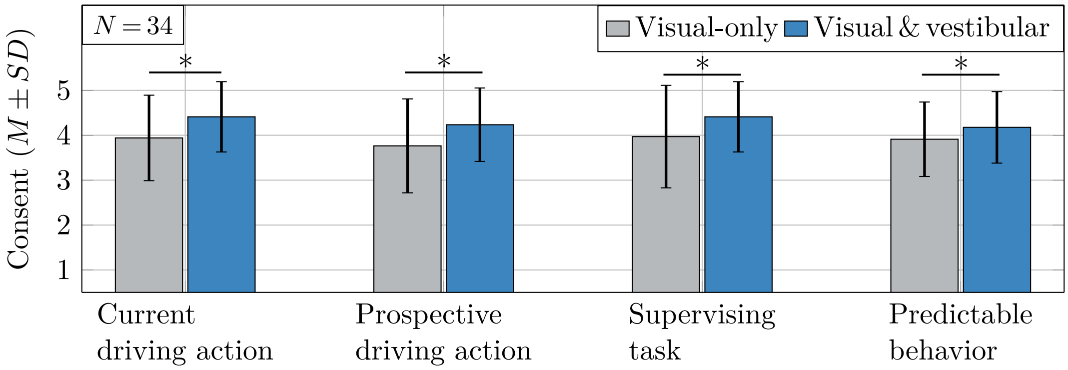


Figure 8.9: Ratings of system awareness (scale: $1 \mathrel{\hat{=}}$ "does absolutely not apply" to $5 \mathrel{\hat{=}}$ "does absolutely apply"; $^*p < .05$)

Table 8.1: Results of the t-tests considering the system awareness of the two feedback types

Metric	Vis. only		Vis. & vest.		$t(33)$	p	r
	M	SE	M	SE			
Current driving action	3.94	.16	4.41	.13	-2.68	.011	.42
Prospective driving action	3.76	.18	4.24	.14	-2.54	.016	.40
Supervising task	3.97	.20	4.41	.13	-2.08	.045	.34
Predictable behavior	3.91	.14	4.18	.14	-2.18	.037	.35

In addition, the *Situation Awareness Rating Technique* (SART) was evaluated which measures three dimensions: *demand* on attentional resources, *supply* of attentional resources, and *understanding* of the situation (Taylor, 1990). For this purpose, the questionnaire was translated into German with the help of an English native speaker (cf. Appendix E.8). The *demand* and *understanding* were not significantly different considering the feedback type (*demand*: visual-only: $M = 3.12$, $SE = .19$, visual & vestibular: $M = 3.12$, $SE = .19$, t-test: $t(33) = 0.00$, $p = 1.00$, $r = .00$; *understanding*: visual-only: $M = 5.22$, $SE = .17$, visual & vestibular: $M = 5.44$, $SE = .12$, t-test: $t(33) = -1.63$, $p = .113$, $r = .27$). However, the dimensions *supply* revealed a strong tendency towards significance (visual-only: $M = 3.88$, $SE = .13$, visual & vestibular: $M = 4.07$, $SE = .09$, t-test: $t(33) = -1.97$, $p = .057$, $r = .32$), and overall the situation awareness ($\hat{=}$ *understanding* - (*demand* - *supply*)) was significantly higher for the multi-modal than the visual-only feedback (t-test: $t(33) = -2.13$, $p = .041$, $r = .35$).

8.2.3 Mental, Visual, and Physical Demand

The participants were asked either orally or via the questionnaire to what extent they experienced mental, visual, and physical demand during automated driving on a seven-point rating scale (1 ≙ "low" to 7 ≙ "high"). The visual and physical demand was surveyed via the questionnaire after each feedback part of the driving study. The visual demand revealed no significantly higher results for the visual-only feedback ($M = 3.59$, $SE = .17$) than the multi-modal feedback ($M = 3.35$, $SE = .24$, t-test: $t(33) = 0.88$, $p = .385$, $r = .15$). Furthermore, the combined feedback was not rated significantly more physically demanding (visual and vestibular: $M = 1.88$, $SE = .14$, visual-only: $M = 1.74$, $SE = .14$, t-test: $t(33) = -1.54$, $p = .134$, $r = .26$). In contrast, the second experimenter orally asked the participant every four minutes during the driving about the extent of their mental demand. The driving on the motorway for each section took approximately 16 - 19 *min*. The statement and the scale were presented to the participants in the center display (Figure 4.2). Consequently, four measures per feedback type were available which were later used to calculate one mean value. A 2 (feedback type, repeated measure) x 2 (sequence) Mixed-ANOVA was conducted. The results are shown in Figure 8.10. The main effect *feedback type* ($F(1, 32) = 0.07$, $p = .794$, $r = .05$) as well as the *sequence* ($F(1, 32) = 1.68$, $p = .204$, $r = .22$) revealed no significant influence. However, the interaction effect *feedback type* * *sequence* was stated significant ($F(1, 32) = 6.30$, $p = .017$, $r = .41$). Simple effect analysis revealed that the ratings of mental demand within group A presented a strong tendency towards being influenced by the type of feedback, while the ratings were not significantly influenced by the type of feedback within group B (group A: $p = .052$, group B: $p = .133$). Moreover, the mental demand ratings considering the type of feedback were significantly different for the two groups for the visual & vestibular feedback ($p = .036$) but not for the visual-only feedback ($p = .784$). Overall, the mean ratings of the mental demand between 2 and 3 reflected that partially automated driving and thereby supervising the automation system requires rather low to moderate mental demand.

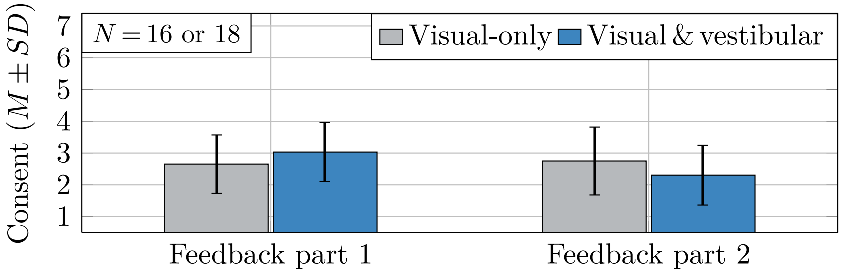


Figure 8.10: Ratings of mental demand (scale: 1 ≙ "low" - 7 ≙ "high")

8.2.4 Feeling of Safety

The feeling of safety while driving partially automated was evaluated the same way as the mental demand (Section 8.2.3) on the same scale (1 ≙ "low" to 7 ≙ "high"). Medium values around 6 revealed that the participants had a rather high feeling of safety in the automation system (Figure 8.11).

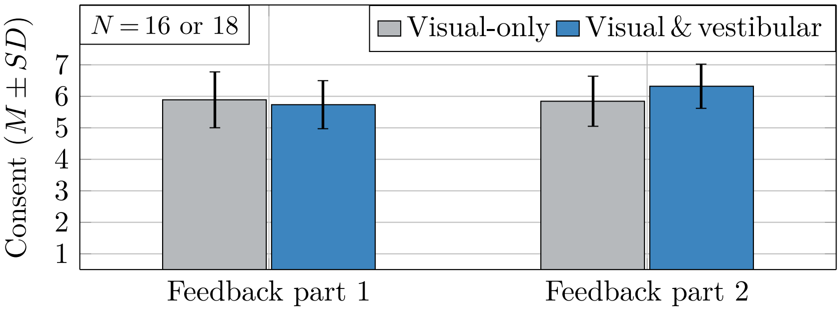


Figure 8.11: Ratings of feeling of safety (scale: 1 ≙ "low" - 7 ≙ "high")

Interestingly, the ratings for the feeling of safety for group B, who experienced the visual and vestibular feedback first, were more or less equal for both feedback types. On the contrary, the feeling of safety increased for group A when they drove part 2 with multi-modal feedback. A 2 (feedback type, repeated measure) x 2 (sequence) Mixed-ANOVA supported these findings. The two main effects *feedback type* ($F(1, 32) = 2.80$, $p = .104$, $r = .28$) and *sequence* ($F(1, 32) = 1.44$, $p = .239$, $r = .21$) were not significant. However, the interaction effect *feedback type* * *sequence* presented significant results ($F(1, 32) = 7.92$, $p = .008$, $r = .45$). Simple effect analysis revealed that the ratings of feeling of safety within group A were significantly influenced ($p = .003$) by the type of feedback. This was not the case for group B ($p = .439$). Moreover, the feeling of safety ratings considering the type of feedback were significantly different for the two groups A and B for the visual & vestibular feedback ($p = .031$) but not for the visual-only feedback ($p = .881$).

8.2.5 Acceptance

Feedback acceptance was surveyed with the questionnaire designed by van der Laan et al. (1997) in the German version (Kondzior, n.d.) as it was for driving study 2 and 3 (Section 6.3.4 and 7.3.7). The corresponding scores for the items *usefulness* and *satisfying* are visualized in Figure 8.12. The scores with positive mean values point out that both feedback types are seen as useful and satisfying. The combination of visual and vestibular feedback ($M = 1.27$, $SE = .10$) was rated more useful than the visual-only feedback ($M = 1.09$, $SE = .10$) but not significantly (t-test: $t(33) = -1.64$, $p = .110$, $r = .27$). Considering the item *satisfying*, the results revealed no significant difference between the two feedback types (visual-only: $M = 1.26$, $SE = .10$, visual and vestibular: $M = 1.15$, $SE = .10$, t-test: $t(33) = 1.17$, $p = .249$, $r = .20$). Regarding the nine items separately, only one item which counts to the *usefulness* scale indicated a significantly higher score for the multi-modal feedback ($M = 0.94$, $SE = .15$) compared to visual-only feedback ($M = 0.44$, $SE = .13$, t-test: $t(33) = -3.14$, $p = .004$, $r = .48$). This item illustrates that combined feedback was better at raising alertness.

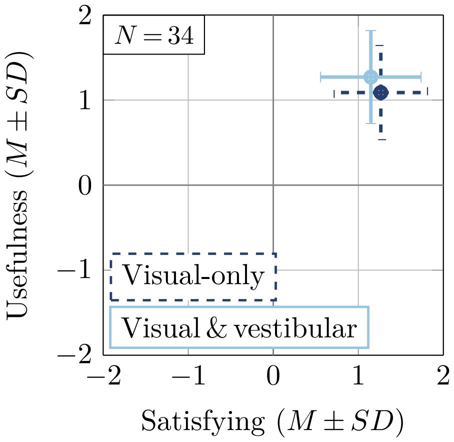


Figure 8.12: Evaluation of the acceptance (scale: five-point semantic differential)

Feedback type acceptance was also evaluated after the system failure, as was evaluated for trust (Section 8.2.1). The statistical results are presented in Table 8.2. On average, both the usefulness and satisfying ratings increased for the multi-modal feedback after the system failure and decreased for the visual-only feedback, but not significantly. Only the combination of visual and vestibular feedback showed a tendency towards significance after the system failure.

Table 8.2: Results of the Wilcoxon tests considering the acceptance ratings before and after the system failure, $N = 17$

Metric	Mdn before	Mdn after	z	p	r
Satisfying vis	1.25	1.25	-0.84	.401	.14
Satisfying visvest	1.25	1.25	-0.88	.380	.15
Usefulness vis	1.40	1.20	-0.11	.916	.02
Usefulness visvest	1.40	1.40	-1.84	.066	.32

8.2.6 Visual Behavior

Eye-tracking data was recorded from participant seven on and, thus, for 28 participants. However, the availability of eye-tracking data was rather poor. On the one hand, the system crashed several times during the driving study. Therefore, it was necessary to restart it when the experimenter noticed it. On the other hand, the gaze vectors were lost often. This was due to high frequency road unevenness, the participants looking around a lot outside of the possible gaze detection area, e. g. large head turns to the left or to the right to try to see what the experimenters were doing or to talk to them. Moreover, SmartEye tries to capture certain markers, for instance, nostrils, earlobe, or corners of the mouth to build a head model and, hence, support and stabilize gaze detection. Very surprisingly, the participants did not leave their hands to rest on their legs when not needed on the steering wheel. As a consequence, however, their hands very often touched their faces, especially in the mouth region. Furthermore, the study took place on some very sunny days. Consequently, in one direction, good eye-tracking quality was available, while in the other direction, when the sun was shining from behind, the quality was very poor. When looking at the recorded eye-tracking data and the video of the driver and the road, all these aspects were identified when gaze detection was lost. As a consequence, two data sets were kept to be analyzed as well as compared. In the first data set, data of the visual-only and the visual and vestibular feedback for 19 participants were forthcoming. Therefore, gaze detection was accessible for at least 25 % of the automated driving time. If one feedback part had less than 25 % gaze detection and the other one more, both parts and hence, the participant, was excluded for evaluation. Overall, eye-tracking data were available on average for $M = 56.63\,\%$ ($SD = 20.61\,\%$) of the automated driving time. Considering data set 2, the limit was 50 % for eye-tracking accessibility for each part during the automated drive. Accordingly, only 6 participants remained for data set 2 with an overall $M = 69.10\,\%$ ($SD = 11.92\,\%$) eye-tracking data availability. Kraft et al. (2018) presented similar data accessibility with $M = 63.37\,\%$ ($SD = 16.71\,\%$) for a real driving study. Six areas of interest (AOIs) were defined: “left” (left mirror plus driver window), “road” (windscreen), “instrument cluster” (display with system’s state information), “interior mirror”, “center display” (location for scales for orally asked questions), and “right” (right mirror and passenger window). However, it has to be mentioned that the detection of the AOIs “left” and “right” were limited due to the viewing area of the two cameras. The distribution of glance duration to certain AOIs is presented in Figure 8.13 for both data sets as well as both feedback types.

The results were similar for all feedback types for each data set and AOI. No significant differences existed between the two feedback types (‘road”: data set 1, t-test:

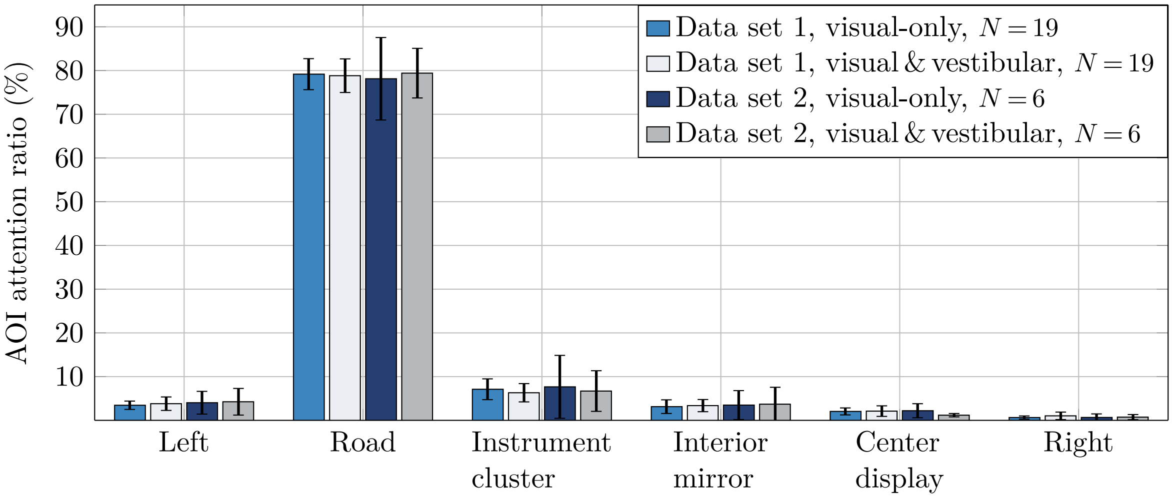


Figure 8.13: Percent time on AOI

$t(18) = 0.21$, $p = .839$, $r = .05$; data set 2, Wilcoxon tests: $z = -0.31$, $p = .753$, $r = .13$; "instrument cluster": data set 1, Wilcoxon tests: $z = -1.29$, $p = .198$, $r = .30$; data set 2, Wilcoxon tests: $z = -0.734$, $p = .463$, $r = .30$). The percentage values for glance duration on "road" and "instrument cluster" were nearly identical to the equivalent ones presented by Kraft et al. (2018) for the participants with prior ACC experience. The glance rate to the "instrument cluster" was $0.15\,n/s$ ($9.07\,n/min$) for the visual and vestibular feedback, and $0.16\,n/s$ ($9.77\,n/min$) for the visual-only feedback for data set 1, and thus did not differ significantly ($z = -0.68$, $p = .494$, $r = .16$). Moreover, the participants often mentioned that they only rarely looked at the instrument cluster because they trusted the system.

8.2.7 System Failure Situation

The system failure happened in the last driving part of the study (Figure 8.4) and was an announced (either visual-only or a combination of visual and vestibular feedback) lane change to the hard shoulder (cf. Section 8.1.5). 21 (61.8 %) participants took over the vehicle guidance on their own before the lane change was finished and 13 (38.2 %) participants had to be invited by the first experimenter to take over the vehicle guidance and drive the vehicle back to a normal lane. The two groups were rather equally distributed with regard to the feedback type: 11 participants took over the vehicle guidance on their own while experiencing a multi-modal feedback and 10 participants while experiencing the visual-only feedback. Hence, 6 participants with the visual and vestibular feedback had to be invited to take over and 7 for the visual-only feedback.

Assessment of the Situation

The participants had to assess the consent to the following four statements on a five-point rating scale (1 ≙ “does absolutely not apply” - 5 ≙ “does absolutely apply”) after the system failure:

- I have *quickly overviewed* the entire situation.
- I perceived the situation as *demanding*.
- I *reacted well* to the situation.
- I assessed the situation as *critical*.

The statements were created referring to questions of Othersen (2016, p. 298) which were answered by her participants after experiencing a critical situation while driving partially automated in a simulator. The participants were separated in two groups: the ones who took over the vehicle guidance on their own and the ones who had to be invited to take over. The results are visualized in Figure 8.14.

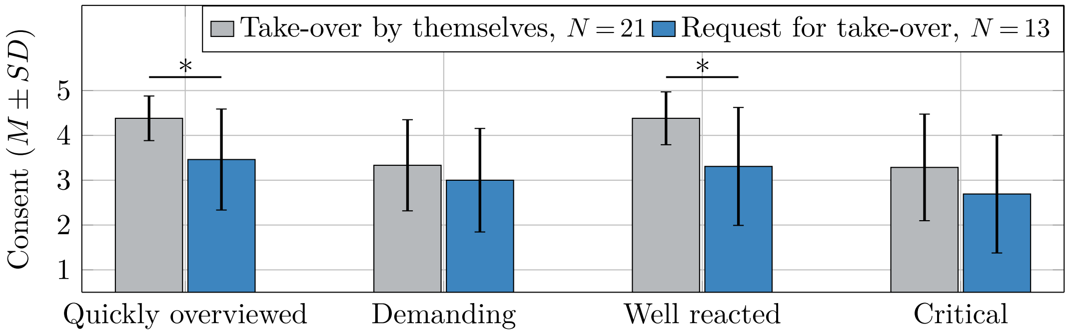


Figure 8.14: Rating of several items considering the system failure (scale: 1 ≙ “does absolutely not apply” - 5 ≙ “does absolutely apply”; $^*p < .05$)

The participants who took over by themselves had *overviewed* the entire situation significantly quicker than the participants who needed a request to take over. The statistical results are presented in Table 8.3. Moreover, the participants who had to be invited to take over showed an ambivalent opinion if they had *reacted well* to the situation or not. In contrast, the participants who took over by themselves were stating that they *reacted well* which presented a significant difference. The ratings for the items *demanding* and *critical* showed a similar picture. The participants who had to receive a request for taking over the vehicle guidance assessed the situation as less *demanding* and *critical* than the ones who did it on their own but not significantly.

Perceived Safety

The participants rated the feeling of safety (Section 8.2.4) and the mental demand (Section 8.2.3) orally four times during the feedback parts 1 and 2 (Figure 8.4). In

Table 8.3: Results of Mann-Whitney test for several items considering the system failure, $N = 21,\ 13$

Metric	Mdn Self	Mdn Request	U	z	p	r
Quickly overviewed	4.0	4.0	73.0	-2.52	.012	.43
Demanding	3.0	3.0	113.0	-0.87	.386	.15
Well Reacted	4.0	3.0	70.5	-2.49	.013	.43
Critical	4.0	3.0	100.5	-1.32	.188	.23

contrast, during the last driving part, the participants were asked to answer the questions relating to perceived safety found in the Godspeed questionnaire (Bartneck, Kulić, Croft, & Zoghbi, 2009) in the German version (Foster & Giuliani, 2012). This included three statements on a five-point semantic differential scale from 1 to 5: *anxious - relaxed*, *agitated - calm*, and *quiescent - surprised*. These were surveyed four times (t_{C1}, t_{C2}, t_{C3}, and t_{C4}) with approximately four minutes difference. However, the third time was chosen to be directly after the system failure, consequently the time difference sometimes needed to be extended due to traffic. An ANOVA with following post-hoc analysis using Bonferroni correction was conducted for each item for t_{C2}, t_{C3}, and t_{C4}. The results are presented in Figure 8.15.

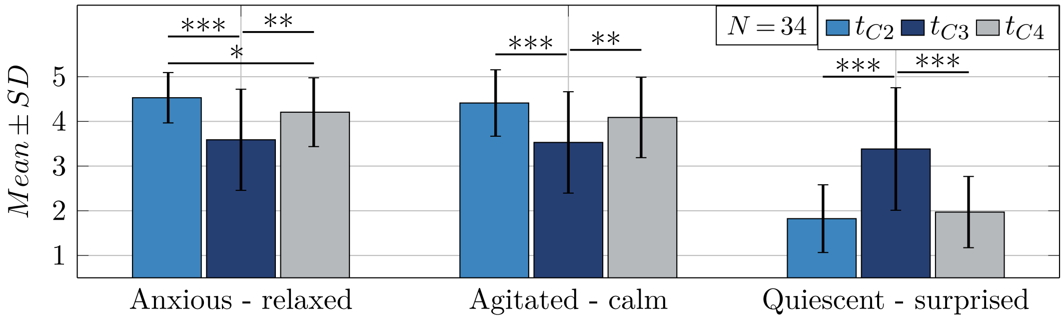


Figure 8.15: Ratings of perceived safety according to the Godspeed questionnaire (Bartneck et al., 2009; scale: five-point semantic differential; $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$))

Overall, the participants were rather *relaxed*, *calm*, and *quiescent*. However, the system failure at t_{C3} raised or lowered their ratings to an approximately centered score on the semantic differential. The factor *time* revealed a significant main effect for all three items (*anxious - relaxed*: $F(2,\ 66) = 19.90$, $p < .001$, $\eta_p^2 = .38$; *agitated - calm*: $F(2,\ 66) = 18.80$, $p < .001$, $\eta_p^2 = .36$; *quiescent - surprised*: $F(1.40,\ 46.06) = 39.93$, $p < .001$, $\eta_p^2 = .55$). Post-hoc tests indicated that the participants felt significantly more *relaxed* at t_{C2} and t_{C4} than t_{C3} ($M_{C2-C3} = 0.94$, $p < .001$; $M_{C3-C4} = -0.62$, $p = .001$) and even at t_{C2} compared to t_{C4} ($M_{C2-C4} = 0.32$, $p = .042$). Furthermore, the participants felt significantly more *calm* before the system failure and close to the end of the driving study than directly after the system failure ($M_{C2-C3} = 0.88$, $p < .001$; $M_{C3-C4} = -0.56$, $p = .004$). A tendency towards significance considering the item *calm* for t_{C2} compared to t_{C4} is existent ($M_{C2-C4} = 0.32$, $p = .058$). The participants were significantly more *surprised* directly after the system failure compared to the other two measured times ($M_{C2-C3} = -1.56$, $p < .001$; $M_{C3-C4} = 1.41$, $p < .001$). If the ratings of the last item were reversed, and considering all three items together, a significant main effect for the *time* ($F(1.61, 53.16) = 35.35$, $p < .001$, $\eta_p^2 = .52$) was revealed as well as a significant difference for all three Post-hoc tests ($M_{C2-C3} = 1.13$, $p < .001$; $M_{C2-C4} = 0.26$, $p = .038$; $M_{C3-C4} = -0.86$, $p < .001$).

First Reaction and Reaction Times

The data were labeled manually by the experimenters subsequent to the driving study. The cycle time of the driver camera recording pictures was 100 ms and the audio recording was played in parallel. After triggering a lane change to the hard shoulder, the first reaction of the participants was labeled as well as its starting time. First reactions were either that the participants moved their hands towards the steering wheel, questioned the experimenter what was happening, or a verbal expression of astonishment (e. g. “Eh?”). No laughing (1 participant) or facial expression (2 participants) counted as a first reaction. 21 participants directly moved their hands towards the steering wheel whereby these were mostly the ones who took over the vehicle guidance by themselves (Figure 8.16). 7 participants first asked the experimenter what was going on or if they should do something. Moreover, 4 participants reacted with a verbal expression of astonishment, und 2 (one for each feedback type) did not show any of the reactions mentioned before.

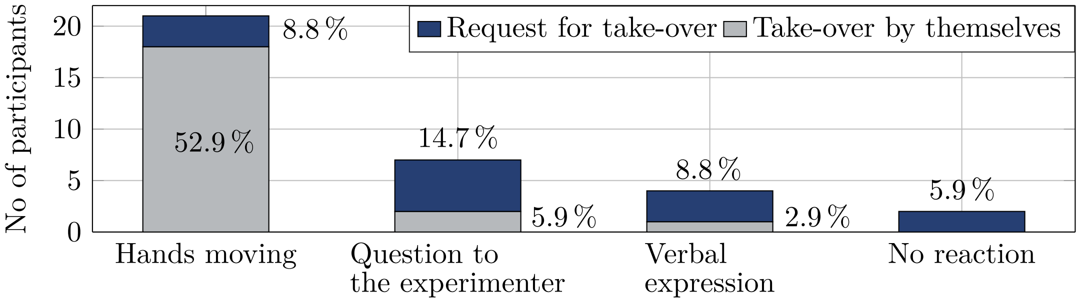
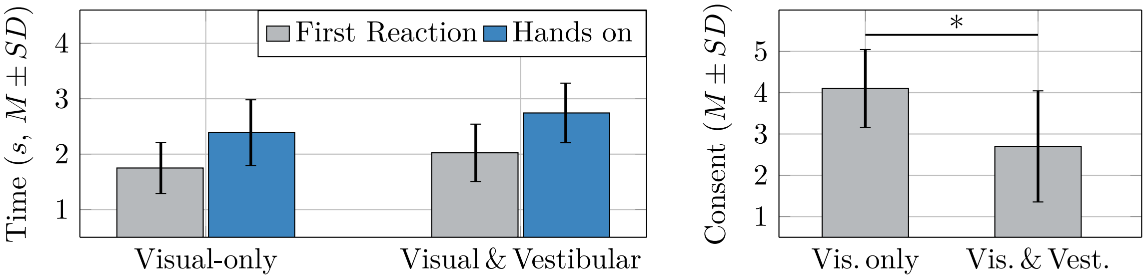


Figure 8.16: First reactions of the participants at the system failure

Out of the 21 participants who took over the vehicle guidance on their own, 18 participants moved their hands towards the steering wheel as a first reaction. The other three either asked the experimenter (one for visual-only and one for visual and vestibular feedback) or showed a verbal expression (one for multi-modal feedback) and, therefore, needed a bit longer to put the hands on the steering wheel. Another participant, who experienced a visual and vestibular feedback, needed considerably longer than the other participants who took over on their own and, thus, was excluded for the statistical tests. The requirements for parametric tests are fulfilled for the reaction times. The graphical results are presented in Figure 8.17a. The reaction time began with the starting of the lane change execution (active steering to the neighboring lane). The duration until the first reaction indicated no significant difference between the visual-only ($M = 1.75$, $SE = .15$) and the visual and vestibular feedback ($M = 2.02$, $SE = .17$; t-test: $t(18) = -1.19$, $p = .250$, $r = .27$). Furthermore, the results for the hands-on time were similar (visual-only: $M = 2.39$, $SE = .20$, visual and vestibular: $M = 2.74$, $SE = .18$; t-test: $t(18) = -1.33$, $p = .200$, $r = .30$).



(a) Reaction times labeled by the experimenter *(b)* Quiescent - surprised (*$p < .05$)

Figure 8.17: Evaluation of reactions times and parts of the perceived safety (cf. Section 8.2.7) considering the two different feedback types ($N = 10$ for each)

Comparing the perceived safety (Godspeed questionnaire (Bartneck et al., 2009)) of the two feedback type groups, the participants were calmer and more relaxed after the system failure with the visual and vestibular feedback, but not significantly (*Anxious - relaxed*: vis.: $Mdn = 3.5$, vis. & vest.: $Mdn = 4.0$, Mann-Whitney test: $U = 33.0$, $z = -1.34$, $p = .180$, $r = .30$; *agitated - calm*: vis.: $Mdn = 3.0$, vis. & vest.: $Mdn = 4.0$, Mann-Whitney test: $U = 42.0$, $z = -0.63$, $p = .532$, $r = .14$). Moreover, the ratings of the item *quiescent - surprised* indicated that the participants who took over vehicle guidance on their own with a visual-only feedback ($M = 4.1$, $SE = 0.31$) were significantly more surprised than the ones experiencing visual and vestibular feedback ($M = 2.7$, $SE = 0.45$; t-test: $t(18) = 2.56$, $p = .020$, $r = .52$, Figure 8.17b).

Out of the 21 participants who took over vehicle guidance on their own, 28.6 % mentioned that they would have reacted faster without a safety driver, 19.0 % stated that this system failure was not critical, and 2 directly claimed that the first experimenter had triggered the system failure. Similar statements were reported by the 13 participants who had to be invited to steer back to the right lane. Therefore, 46.2 % thought that the system was right and it was allowed to drive on the hard shoulder, 69.2 % mentioned that it was not critical at all and they were really relaxed, and some said that they reacted well but did not react at all. Furthermore, 69.2 % stated that they did not react because of the safety driver. Either they said the safety driver was the fall-back level or that the safety driver showed no panic behavior or that they did not want to disturb the driving study by interrupting the automation. Moreover, a lot of participants reported that the automation system was driving in such a controlled and calm manner, that it was not critical or gave the feeling of a system failure.

8.2.8 Motion Sickness

As it was done before for the driving studies 2 (Section 6.3.11) and 3 (Section 7.3.10), the question “Do you have nausea, a headache, or dizziness?” was surveyed after each part (t_0, t_1, t_2, t_3 and t_4) of the driving study (Figure 8.4). Only one participant answered this question with yes, which felt very slightly dizzy, had a very slight headache (1 on a five-point rating scale from $1 \mathrel{\widehat{=}}$ very slight to $5 \mathrel{\widehat{=}}$ very strong), and had slight nausea (2 on the same rating scale) only at t_2. All of these motion sickness symptoms were gone after the next driving part. The participants often directly responded to the question that they were feeling really good.

8.2.9 Type of Feedback

In the final survey, the participants were asked how useful they found the type and the meaning of feedback on a five-point rating scale ($1 \mathrel{\widehat{=}}$ “does absolutely not apply” - $5 \mathrel{\widehat{=}}$ “does absolutely apply”). The meaning represented either the detection of a PV or announcing an upcoming lane change. The variations were a combination of a visual-only, vestibular only, or combination of visual and vestibular feedback, and whether the feedback presented the detection of a preceding vehicle or announced a lane change. The results are visualized in Figure 8.18 and point out that in total the feedback is rated as useful with mean values between 4 and 5.

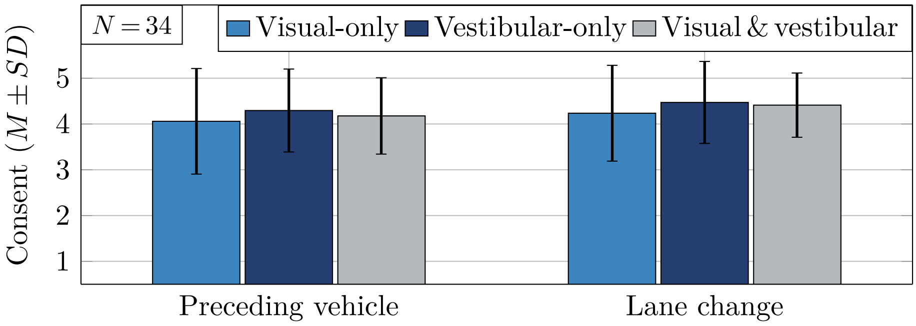


Figure 8.18: Rating of usefulness of the type and meaning of feedback (scale: $1 \mathrel{\widehat{=}}$ “does absolutely not apply” - $5 \mathrel{\widehat{=}}$ “does absolutely apply”)

A 3 (feedback type) x 2 (feedback meaning) ANOVA with repeated measures was conducted. The degrees of freedom were corrected using the Greenhouse-Geisser correction if this was necessary. The main effect for feedback type ($F(1.36, 44.82) = 1.02$, $p = .343$, $\eta_p^2 = .03$) as well as the interaction effect of feedback type * feedback meaning ($F(1.33, 43.88) = 0.45$, $p = .956$, $\eta_p^2 = .001$) indicated no significant effects. However, the main effect feedback meaning reveals significant results ($F(1, 33) = 5.86$, $p = .021$, $r = .71$). Therefore, the announcement of a lane change is rated significantly more useful than the feedback for the detection of a preceding vehicle.

8.3 Discussion and Conclusion

The visual display during partially automated driving was rather simple and focused on the communication of the same information as the vestibular feedback, in order to compare the ratings. Participants rated the visual display for automated driving as nor or rather not pleasant. Main points were that the information on other objects and the representation via a square is not detailed enough, and that they would like to have more information about fuel status, traffic signs, and target velocity. Furthermore, some pointed out that a head-up display would be more suitable. This was unfortunately not possible in this test vehicle, but should be considered in further studies.

The trust in the automation system was high and the mistrust low. Thereby, the type of feedback had no or only little effect on these ratings during the feedback parts of the driving study. After the system failure, the mistrust increased for both feedback types with a large effect. In contrast, the system failure had a fairly substantial effect on the trust ratings for the visual feedback but not for the multi-modal feedback. Compared to a driving study conducted by Lange (2018), the trust ratings on one scale (5.4 - 5.6) are in the same range. However, the trust ratings of this thesis are even higher after the feedback parts and lower after the system failure compared to the results of Lange (2018). Gold, Körber, Hohenberger, Lechner, and Bengler (2015) reported trust ratings between approximately 4.6 - 5.5 for a simulator study. However, the existence of a safety driver on the passenger seat might have influenced these ratings.

The additional vestibular feedback had a medium to large positive effect on the system awareness of the participants. The same effect existed for usefulness rating, especially increasing more alertness. However, the visual-only feedback had a positive small effect on the item satisfying. After the system failure, the ratings for acceptance raised for the multi-modal feedback with a small to moderate effect, and decreased for the visual-only feedback with a slight effect.

The scores for the feeling of safety were rather high, and increased significantly in the second feedback part when experiencing the visual-only feedback first, and stayed the same when experiencing the combined feedback first. Thus, added value of the vestibular feedback exceeded the familiarization effect.

Considering the mental demand, it was evaluated rather low to moderate. Moreover, the mental demand rather decreased over time and even more if the multi-modal feedback was experienced after the visual-only feedback.
On average, the physical demand was rather low and the visual demand rather moderate. The added vestibular feedback increased the physical demand and decreased the visual demand with a small effect. Eye-tracking data supported the latter findings in that, on average, the participants glanced towards the instrument cluster more with the visual-only feedback with a moderate effect. At most, the feedback type had only little effect on the glance duration on the road. The attention ratios to the AOI “road” and “instrument cluster” were similar to the ones of Kraft et al. (2018) for the participants with ACC experience during a partially automated driving study. Moreover, the attention ratios were absolut 1 - 2 % higher as the ones of Othersen (2016) during a partially automated driving study when the participants had a similar task, but it should be considered that the participants received visual information via the head-up display as well. For manual driving, the attention ratio is definitely smaller to the “instrument cluster” and higher to the “road” compared to the partial diving automation of this study (Kraft et al., 2018; Othersen, 2016). However, it has to be mentioned that the quality of the eye-tracking data was rather poor. This evaluation should be repeated when quality of eye-tracking in real driving condition is improved.

Overall, the active pitch and roll motions do not cause motion sickness as it was revealed in former studies (cf. Section 6.4, 7.4, and 8.3). Furthermore, the participants evaluated the pitch and roll motions as well as their corresponding visual display highly useful for announcing lane changes or feeding back the detection of a PV. Interestingly, a vestibular-only feedback was surveyed more useful than a multi-modal (visual & vestibular) feedback. This might rather indicate that the visual feedback has no added value when a vestibular feedback exists. Though, the announcement of lane changes was rated more useful than the detection of a PV with a fairly substantial effect.

Regarding the system failure, it was surprising that only 61.8 % of the participants took over the vehicle guidance by themselves and that the other participants had to be invited to do so. The latter did not overview the situation nor did they react as quickly as the participants who took over the vehicle guidance on their own. This was indicated with a moderate to large effect. Moreover, they rated the system failure not as demanding and critical. The perceived safety was evaluated considerably more anxious, agitated, and surprised directly after the system failure compared to earlier and later in the driving study. Because the ratings taken after the system failure were between two anchors, the participants were still somehow relaxed, calm, and quiescent directly after the system failure. The participants with a visual-only feedback reacted faster with a medium effect compared to the participants with a visual and vestibular feedback. The experimenters had the impression that the group experiencing multi-modal feedback was not so surprised by the system failure and, hence, was calmer. This was supported by the ratings of the perceived safety comparing the two feedback type groups, and hence the participants with a visual-only feedback were definitely more surprised. This presents a large effect. Thereby, moving the hands towards the steering wheel was only a first reaction in 61.7 % of the cases. In the other cases, they asked the experimenter, presented a verbal expression, or showed no reaction. These findings should be seriously questioned due to the fact that several participants mentioned that this situation was not critical and that they felt safe because of the safety driver. Evoking a more critical situation is too risky in real traffic driving studies. A consequence of this is that it is not possible to test driver reaction during system failures in real traffic with a safety driver on the passenger seat. Perhaps a dynamic driving simulator or a driving study on the test track might be useful for testing system failures. However, then the participants might also not react as quickly due to the simulated situation. Therefore, it is suggested to move the safety driver to the rear seat for testing system failures.

Overall, some participants mentioned that the roll motions could be more intense. Consequently, the maximum acceleration or the maximum angle could be increased. Furthermore, it was often pointed out that the perceptibility of the pitch and roll motions depends on the velocity, the road gradient, as well as the unevenness of the road. These influences should also be surveyed in future studies. The return of the roll angle was realized within 2,5 s after the execution of the lane change started. Some participants mentioned that the return should be smoother. This is due to the fact that the trajectory (polynomial of fifth degree) starts with a slow lateral offset at the beginning, which is seen as driving on in the start lane where the roll angle is already returning. Consequently, the return should be according to the percentage of the lane change progress within approximately the first 40 % of the lane change. Reaching the horizontal position earlier than finishing the lane change is necessary to allow a pitch motion during the lane change for the detection of a PV without tensioning the chassis.

Via an online survey, persons with ACC experience could register for this driving study as it was done for driving study 3. Moreover, the study limitations of the first, second, and third driving study (Section 5.4, 6.4, and 7.4) considering the recruiting of the sample, and existence of as well as the communication with the experimenters also applied.

Summing up, active vehicle pitch and roll motions provide a new possibility for communicating state transitions or intentions of the automation system in advance in a multi-modal manner to the driver.

9 Conclusion and Outlook

During partially automated driving, feedback on state transitions and intentions of the automation (e. g. current and prospective maneuver) is indispensable for drivers in order to obtain, as well as increase their system awareness and, thus, fulfill their supervising task sufficiently (Beggiato et al., 2015; Bubb, Bengler, et al., 2015; Itoh & Inagaki, 2004; Norman, 1990; Sarter & Woods, 1995; Wickens et al., 2013). System awareness means that drivers have a suitable mental model of the vehicle's automation system, know in which state the automation system is, and anticipate prospective state transitions (Boer & Hoedemaeker, 1998; Lange, Albert, et al., 2015; Norman, 1990).

In this thesis, feedback is communicated to the driver via active vehicle pitch and roll motions, and not visually as is usually the case (Bubb, Bengler, et al., 2015; Knoll, 2016). The rotational motions are mainly perceived via the vestibular sensory channel; the haptic and visual sensory channel contribute to this perception. Therefore, state transitions and intentions are communicated in a multi-modal manner, and hence the feedback is more effective (Bubb, Bengler, et al., 2015; Othersen, 2016).

The design of the active pitch and roll motions was developed in this thesis via four driving studies. The results are mainly discussed in the conclusions of each driving study (Section 5.4, 6.4, 7.4, and 8.3). For future applications, feedback for driving actions in the longitudinal vehicle direction (e. g. detection of a preceding vehicle (PV)) should be realized via pitch motions, and for driving actions in the lateral direction (announcing lane changes) via roll motions. Pitch motions should be designed in the direction the normal driving behavior would be. That means that the detection of a PV should be communicated with a forward pitch motion. The roll motions should be in the direction the vehicle is driving to. Thus, the roll motions are externally compatible (Bubb, Bengler, et al., 2015; C. Müller, Siedersberger, et al., 2017). The increase of the pitch and roll motions should be degressive to gain alertness at the beginning, but finish comfortably. In contrast, the return should rather be designed in a slow linear profile. 1 ° and 2 ° pitch motions are necessary to give a more intense feedback to the driver in more critical situations. This is mainly dependent on the relative velocity and distance to the PV. Roll motions should be 3 ° for both lane changes to the left and right. In general, rotational motions as feedback did not cause motion sickness or discomfort in any of the conducted studies, and should be designed clearly perceptible.

The pitch and roll motions are surely suitable and useful for giving feedback about the detection of a PV while approaching the latter, for cutting-in vehicles (except cutting-in vehicles with a large relative distance or a high positive velocity), and for announcing lane changes. For static objects, for instance speed signs, it is not useful as it would confuse the driver in situations with dynamic and static objects. The scenario "lane change abort" should be further evaluated to survey whether a vestibular feedback is useful. Moreover, the acceptance and comprehensibility is high for a feedback via active pitch and roll motions, and contribute positively to the driver's system awareness. Some participants mentioned that they liked that the feedback was not visual as they found the displays to be too overloaded. This statement is supported by Fisher et al. (2016) and van den Beukel et al. (2016). Compared to a visual-only feedback, an added value does exist. However, system failures and eye-tracking data should be evaluated further to rate this feedback's performance completely. The trust and feeling of safety was directly rated high after driving the automated vehicle for only a short period of time.

This thesis was a first step in evaluating whether active rotational vehicle motions are useful for feedback on state transitions and intentions of the automation system. As this question can be positively answered, future studies should focus on the perceptibility of active rotational motions considering different aspects. First, it should be surveyed if the ego velocity and acceleration as well as road gradients and viewing direction of the driver have an influence on the perceptibility. Moreover, the acceptance of the rotational motions regarding the front- and rear-seat passengers should be evaluated, and how the design of the rotational motions might be adjusted.

Besides using the active rotational vehicle motions as a communication channel for state transitions or intentions of the automation to the driver, future research should also focus on communicating the intentions of the automated vehicle to other vehicles or to pedestrians. Beggiato, Witzlack, and Krems (2017), and Kauffmann, Winkler, and Vollrath (2018) presented approaches to communicating to other road users via longitudinal and lateral vehicle movements of the automated vehicle.

Concluding, vehicle movements are suitable to feed back information to the driver during automated or assisted driving in advance before the automation system initiates the maneuver or driving action. Lange et al. (2014), Lange, Albert, et al. (2015), and C. Müller, Siedersberger, et al. (2017) support this proposition by their results. Furthermore, Sivak and Schoettle (2015) mention that vehicle motion for anticipating the direction of motion should be improved in self-driving vehicles. Several participants stated that the driving behavior on maneuver and trajectory layer has big influence on the well-being in an automated vehicle. Hence, this should be investigated in the future. Additionally, vehicle movements can add up to a multi-modal feedback.

References

Albert, M., Lange, A., Schmidt, A., Wimmer, M., & Bengler, K. (2015). Automated Driving - Assessment of Interaction Concepts Under Real Driving Conditions. In *6th International Conference on Applied Human Factors and Ergonomics and the Affiliated Conferences, AHFE 2015* (pp. 2832–2839). doi: 10.1016/j.promfg.2015.07.767

Ardelt, M., Coester, C., & Kaempchen, N. (2012). Highly Automated Driving on Freeways in Real Traffic Using a Probabilistic Framework. *IEEE Transactions on Intelligent Transportation Systems*, *13*(4), 1576–1585.

Arndt, S. (2010). *Evaluierung der Akzeptanz von Fahrerassistenzsystemen* (Doctoral thesis). Technische Universität Dresden.

AUDI AG. (2017a, September 07). *Automated driving at a new level: the Audi AI traffic jam pilot.* Retrieved May 20, 2018, from https://www.audi-mediacenter.com/en/press-releases/automated-driving-at-a-new-level-the-audi-ai-traffic-jam-pilot-9300

AUDI AG. (2017b, September 07). *Footage Audi A8: Audi AI traffic jam pilot.* Retrieved May 20, 2018, from https://www.audi-mediacenter.com/en/audimediatv/video/footage-audi-a8-audi-ai-traffic-jam-pilot-3785

Bainbridge, L. (1983). Ironies of Automation. *Automatica*, *19*(6), 775–779.

Baloh, R. W., Honrubia, V., & Kerber, K. A. (2011). *Clinical Neurophysiology of the Vestibular System* (4th ed., Vol. 77). New York: Oxford University Press.

Bär, M. (2014). *Vorausschauende Fahrwerkregelung zur Reduktion der auf die Insassen wirkenden Querbeschleunigung* (Doctoral thesis). Rheinisch-Westfälischen Technischen Hochschule Aachen.

Bär, M., Siedersberger, K.-H., & Meitinger, K.-H. (2011). Predictive chassis control to reduce lateral acceleration on passengers. In *20. Aachen Colloquium Automobile and Engine Technology 2011* (pp. 1513–1526).

Bartels, A., Berger, C., Krahn, H., & Rumpe, B. (2009). Qualitätsgesicherte Fahrentscheidungsunterstützung für automatisches Fahren auf Schnellstraßen und Autobahnen. In *10. Braunschweiger Symposium Automatisierungssysteme, Assistenzsysteme und eingebettete Systeme für Transportmittel (AAET).*

Bartels, A., Meinecke, M.-M., & Steinmeyer, S. (2016). Lane Change Assistance. In H. Winner, S. Hakuli, F. Lotz, & C. Singer (Eds.), *Handbook of Driver Assistance Systems* (pp. 1235–1257). Springer Reference.

Bartels, A., Rohlfs, M., Hammel, S., Saust, F., & Klauske, L. K. (2016). Lateral Guidance Assistance. In H. Winner, S. Hakuli, F. Lotz, & C. Singer (Eds.), *Handbook of Driver Assistance Systems* (pp. 1207–1233). Springer Reference.

Bartneck, C., Kulić, D., Croft, E., & Zoghbi, S. (2009). Measurement Instruments for the Anthropomorphism, Animacy, Likeability, Perceived Intelligence, and Perceived Safety of Robots. *International Journal of Social Robotics*, *1*(1), 71–81. doi: 10.1007/s12369-008-0001-3

Becker-Carus, C., & Wendt, M. (2017). *Allgemeine Psychologie: Eine Einführung* (2. ed.). Springer.

Beggiato, M., Hartwich, F., Schleinitz, K., Krems, J., Othersen, I., & Petermann-Stock, I. (2015). What would drivers like to know during automated driving? Information needs at different levels of automation. In *7. Tagung Fahrerassistenz.*

Beggiato, M., Witzlack, C., & Krems, J. F. (2017). Gap Acceptance and Time-To-Arrival Estimates as Basis for Informal Communication between Pedestrians and Vehicles. In S. Boll, B. Pfleging, & B. Donmez (Eds.), *AutomotiveUI 2017* (pp. 50–57). New York: Association for Computing Machinery. doi: 10.1145/3122986.3122995

Bengler, K., Dietmayer, K., Färber, B., Maurer, M., Stiller, C., & Winner, H. (2014). Three Decades of Driver Assistance Systems: Review and Future Perspectives. *Intelligent Transportation Systems Magazine, IEEE*, *6*(4), 6–22. doi: 10.1109/MITS.2014.2336271

Bengler, K., Pfromm, M., & Bruder, R. (2016). Input Devices for DAS. In H. Winner, S. Hakuli, F. Lotz, & C. Singer (Eds.), *Handbook of Driver Assistance Systems* (pp. 813–828). Springer Reference.

Benson, A. J., Hutt, E. C., & Brown, S. F. (1989). Thresholds for the perception of whole body angular movement about a vertical axis. *Aviation, space & environmental medicine*, *60*(3), 205–213.

Bitterberg, U. (1999). *Wissensbasiertes Verfahren zum Neigen von Wagenkästen bei Schienenfahrzeugen* (Doctoral thesis). Universität Hannover.

Blümle, A. (2003). *Interaktion der visuellen, somatosensorischen und vestibulären Sinnessysteme bei der Gleichgewichtskontrolle* (Doctoral thesis). Albert-Ludwigs-Universität Freiburg.

Boer, E. R., & Hoedemaeker, M. (1998). Modeling Driver Behavior with Different Degrees of Automation: A Herarchical Decision Framework of Interacting Mental Models. *Human Decision Making and Manual Control*, 63–72.

Bortz, J., & Schuster, C. (2010). *Statistik für Human- und Sozialwissenschaftler* (7., vollständig überarbeitete und erweiterte Auflage ed.). Berlin, Heidelberg: Springer-Verlag. doi: 10.1007/978-3-642-12770-0

Brackstone, M., Waterson, B., & McDonald, M. (2009). Determinants of following headway in congested traffic. *Transportation Research Part F: Traffic Psychology and Behaviour*, *12*(2), 131–142. doi: 10.1016/j.trf.2008.09.003

Bruder, R., & Didier, M. (2016). Design of Human-Machine-Interfaces for DAS. In H. Winner, S. Hakuli, F. Lotz, & C. Singer (Eds.), *Handbook of Driver Assistance Systems* (pp. 797–811). Springer Reference.

Bubb, H. (2015a). Das Regelkreisparadigma der Ergonomie. In H. Bubb, K. Bengler, R. E. Grünen, & M. Vollrath (Eds.), *Automobilergonomie* (pp. 27–65). Wiesbaden, Germany: Springer Fachmedien.

Bubb, H. (2015b). Einleitung. In H. Bubb, K. Bengler, R. E. Grünen, & M. Vollrath (Eds.), *Automobilergonomie* (pp. 1–25). Wiesbaden, Germany: Springer Fachmedien.

Bubb, H., & Bengler, K. (2015). Fahrerassistenz. In H. Bubb, K. Bengler, R. E. Grünen, & M. Vollrath (Eds.), *Automobilergonomie* (pp. 525–582). Wiesbaden, Germany: Springer Fachmedien.

Bubb, H., Bengler, K., Breuninger, J., Gold, C., & Helmbrecht, M. (2015). Systemergonomie des Fahrzeugs. In H. Bubb, K. Bengler, R. E. Grünen, & M. Vollrath (Eds.), *Automobilergonomie* (pp. 259–344). Wiesbaden, Germany: Springer Fachmedien.

Bubb, H., Vollrath, M., Reinprecht, K., Mayer, E., & Körber, M. (2015). Der Mensch als Fahrer. In H. Bubb, K. Bengler, R. E. Grünen, & M. Vollrath (Eds.), *Automobilergonomie* (pp. 67–162). Wiesbaden, Germany: Springer Fachmedien.

Carsten, O., Lai, F. C. H., Barnard, Y., Jamson, A. H., & Merat, N. (2012). Control Task Substitution in Semiautomated Driving: Does It Matter What Aspects Are Automated? *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *54*(5), 747–761. doi: 10.1177/0018720812460246

Choi, J. K., & Ji, Y. G. (2015). Investigating the Importance of Trust on Adopting an Autonomous Vehicle. *International Journal of Human-Computer Interaction*, *31*(10), 692–702. doi: 10.1080/10447318.2015.1070549

Comprehensible. (n.d.). Retrieved July 15, 2018, from https://www.merriam-webster.com/dictionary/comprehensibility

Continental AG. (2015, January 29). *Continental Mobility Study 2015.* Retrieved July 27, 2018, from https://www.continental-corporation.com/resource/blob/7634/01710d3ab830c117db35aeb4d79ca1e0/mobility-study-2015-data.pdf

Cook, R. D., & Weisberg, S. (1982). *Residuals and influence in regression.* New York: Chapman & Hall.

Cramer, S., Kaup, I., & Siedersberger, K.-H. (2018). Comprehensibility and Perceptibility of Vehicle Pitch Motions as Feedback for the Driver During Partially Automated Driving. *IEEE Transactions on Intelligent Vehicles*, *4*(1), 3–13. (© 2018 IEEE) doi: 10.1109/TIV.2018.2886691

Cramer, S., & Klohr, J. (2019). Announcing Automated Lane Changes: Active Vehicle Roll Motions as Feedback for the Driver. *International Journal of Human–Computer Interaction*, *35*(11), 980–995. doi: 10.1080/10447318.2018.1561790

Cramer, S., Lange, A., & Bengler, K. (2015). Path Planning and Steering Control Concept for a Cooperative Lane Change Maneuver According to the H-Mode Concept. In *7. Tagung Fahrerassistenz.*

Cramer, S., Lange, A., Bültjes, S., & Klohr, J. (2017). Design Possibilities for Vehicle Roll Motions as Feedback for the Driver during Automated Driving. In A. Löcken et al. (Eds.), *Proceedings of 9th International ACM Conference on Automotive User Interfaces and Interactive Vehicular Applications* (pp. 152–157). doi: 10.1145/3131726.3131746

Cramer, S., Miller, B., Siedersberger, K.-H., & Bengler, K. (2017). Perceive the Difference: Vehicle Pitch Motions as Feedback for the Driver. In *IEEE International Conference on Systems, Man, and Cybernetics* (pp. 1699–1704). (© 2017 IEEE) doi: 10.1109/SMC.2017.8122860

Cramer, S., Siedersberger, K.-H., & Bengler, K. (2017). Active Vehicle Pitch Motions as Feedback-Channel for the Driver during Partially Automated Driving. In Uni-DAS e. V (Ed.), *11. Workshop Fahrerassistenz und automatisiertes Fahren* (pp. 74–83).

Dambier, M. (2010). *Adaptive Information Flow Control: Recognition and Prediction of Factors Contributing to Driver's Stress* (Doctoral thesis). Universität der Bundeswehr München.

Damböck, D. (2013). *Automationseffekte im Fahrzeug – von der Reaktion zur Übernahme* (Doctoral thesis). Technische Universität München.

Damböck, D., Weißgerber, T., Kienle, M., & Bengler, K. (2012). Evaluation of a Contact Analog Head-Up Display for Highly Automated Driving. In *4th International Conference on Applied Human Factors and Ergonomics.* San Francisco.

Darms, M. (2016). Data Fusion of Environment-Perception Sensors for ADAS. In H. Winner, S. Hakuli, F. Lotz, & C. Singer (Eds.), *Handbook of Driver Assistance Systems* (pp. 549–566). Springer Reference.

Dietmayer, K. (2016). Predicting of Machine Perception for Automated Driving. In M. Maurer, J. C. Gerdes, B. Lenz, & H. Winner (Eds.), *Autonomous Driving* (pp. 407–424). Heidelberg, Germany: Springer Open.

Donges, E. (1982). Aspekte der aktiven Sicherheit bei der Führung von Personenkraftwagen. *Automobil-Industrie*, *27*(2), 183–190.

Donges, E. (1999). A Conceptual Framework for Active Safety in Road Traffic. *Vehicle System Dynamics*, *32*(2-3), 113–128. doi: 10.1076/vesd.32.2.113.2089

Donges, E. (2016). Driver Bahavior Models. In H. Winner, S. Hakuli, F. Lotz, & C. Singer (Eds.), *Handbook of Driver Assistance Systems* (pp. 19–33). Springer Reference.

Döring, N., & Bortz, J. (Eds.). (2016). *Forschungsmethoden und Evaluation in den Sozial- und Humanwissenschaften* (5. ed.). Berlin and Heidelberg: Springer. doi: 10.1007/978-3-642-41089-5

Endsley, M. R. (1987). SAGAT: A methodology for the measurement of situation awareness. (NOR DOC 87-83).

Endsley, M. R. (1988). Situation awareness global assessment technique (SAGAT). In *Proceedings of the IEEE 1988 National Aerospace and Electronics Conference* (pp. 789–795). IEEE. doi: 10.1109/NAECON.1988.195097

Endsley, M. R. (1995). Toward a Theory of Situation Awareness in Dynamic Systems. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *37*(1), 32–64.

Endsley, M. R., & Kiris, E. O. (1995). The Out-of-the-Loop Performance Problem and Level of Control in Automation. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *37*(2), 381–394. doi: 10.1518/001872095779064555

Ericsson, K. A., & Simon, H. A. (1980). Verbal Reports as Data. *Psychological Review*(87(3)), 215–251.

Ersoy, M., Elbers, C., Vortmeyer, J., & Wegener, D. (2017). Elektronische Systeme im Fahrwerk. In M. Ersoy & S. Gies (Eds.), *Fahrwerkhandbuch* (pp. 793–876). Wiesbaden: Springer Vieweg.

European Commission. (1998). *European Statement of Principles on Human Machine Interface for In-Vehicle Information and Communication Systems.* Brussels, Belgium.

Eysel, U. (2010). Sehen und Augenbewegungen. In R. F. Schmidt, F. Lang, & M. Heckmann (Eds.), *Physiologie des Menschen* (pp. 345–385). Berlin: Springer.

Fahrmeir, L., Kneib, T., & Lang, S. (2009). *Regression: Modelle, Methoden und Anwendungen* (2. ed.). Berlin, Heidelberg: Springer-Verlag Berlin Heidelberg. doi: 10.1007/978-3-642-01837-4

Federal Ministry of Transport and Digital Infrastructure. (2015, September). *Strategy for Automated and Connected Driving: Remain a lead provider, become a lead market, introduce regular operations.* Retrieved February 12, 2018, from https://www.bmvi.de/SharedDocs/EN/publications/strategy-for-automated-and-connected-driving.pdf?__blob=publicationFile

Feldhütter, A., Segler, C., & Bengler, K. (2017). Does Shifting Between Conditionally and Partially Automated Driving Lead to a Loss of Mode Awareness? In N. A. Stanton (Ed.), *Advances in Human Aspects of Transportation* (pp. 730–741). Springer International Publishing.

Field, A. (2012). *Discovering Statistics Using SPSS* (3. ed., repr ed.). Los Angeles, USA: Sage.

Field, A., Miles, J., & Field, Z. (2012). *Discovering Statistics Using R.* Los Angeles: Sage.

Fisher, D. L., Lohrenz, M., Moore, D., Nadler, E. D., & Pollard, J. K. (2016). Humans and Intelligent Vehicles: The Hope, the Help, and the Harm. *IEEE Transactions on Intelligent Vehicles*, *1*(1), 56–67. doi: 10.1109/TIV.2016.2555626

Flemisch, F., Adams, C., Conway, S., Goodrich, K., Palmer, M., & Schutte, P. (2003). *The H-Metaphor as a Guideline for Vehicle Automation and Interaction: NASA/TM—2003-212672.*

Flemisch, F., Bengler, K., Bubb, H., Winner, H., & Bruder, R. (2014). Towards cooperative guidance and control of highly automated vehicles: H-Mode and Conduct-by-Wire. *Ergonomics*, *57*(3), 343–360. doi: 10.1080/00140139.2013.869355

Flemisch, F., Winner, H., Bruder, R., & Bengler, K. (2016). Cooperative Guidance, Control, and Automation. In H. Winner, S. Hakuli, F. Lotz, & C. Singer (Eds.), *Handbook of Driver Assistance Systems* (pp. 1471–1481). Springer Reference.

Foster, M. E., & Giuliani, M. (2012, June 25). *German version of The Godspeed Questionnaire.* Retrieved November 17, 2017, from http://www.bartneck.de/2012/06/25/german-version-of-the-godspeed-questionnaire-series-available/

Freundt, D., & Lucas, B. (2008). LRR3 von Bosch - Long Range Radar Sensor für den stark wachsenden Markt der Fahrerassistenzsysteme. In *Integrierte Sicherheit und Fahrerassistenzsysteme* (pp. 55–68). Düsseldorf: VDI-Verlag.

Fuchs, H., Hofmann, F., Löhr, H., & Schaaf, G. (2016). Vehicle-2-X. In H. Winner, S. Hakuli, F. Lotz, & C. Singer (Eds.), *Handbook of Driver Assistance Systems* (pp. 663–684). Springer Reference.

Gasser, T. M., Arzt, C., Ayoubi, M., Bartels, A., Bürkle, L., Eier, J., … Vogt, W. (2012). *Rechtsfolgen zunehmender Fahrzeugautomatisierung: Gemeinsamer Schlussbericht der Projektgruppe* (Vol. F 83). Bergisch Gladbach: Wirtschaftsverlag NW and Wirtschaftsverl. NW Verl. für neue Wissenschaft.

Gasser, T. M., Arzt, C., Ayoubi, M., Bartels, A., Eier, J., Flemisch, F., … Vogt, W. (2012). Ergebnisse der Projektgruppe Automatisierung: Rechtsfolgen zunehmender Fahrzeugautomatisierung. In *5. Tagung Fahrerassistenzsysteme.* München.

Gasser, T. M., Seeck, A., & Smith, B. W. (2016). Framework Conditions for the Development of Driver Assistance Systems. In H. Winner, S. Hakuli, F. Lotz, & C. Singer (Eds.), *Handbook of Driver Assistance Systems* (pp. 35–68). Springer Reference.

Gasser, T. M., & Westhoff, D. (2012). BASt-study: Definitions of Automation and Legal Issues in Germany. In Transportation Research Board (Ed.), *Road Vehicle Automation Workshop.*

Ghazizadeh, M., Lee, J. D., & Boyle, L. N. (2012). Extending the Technology Acceptance Model to assess automation. *Cognition, Technology & Work*, *14*(1), 39–49. doi: 10.1007/s10111-011-0194-3

Göhrle, C. (2014). *Methoden und Implementierung einer vorausschauenden Fahrwerksregelung für aktive und semi-aktive Federungssysteme* (Doctoral thesis). Universität Stuttgart.

Gold, C. (2016). *Modeling of Take-Over Performance in Highly Automated Vehicle Guidance* (Doctoral thesis). Technische Universität München, München.

Gold, C., Damböck, D., Bengler, K., & Lorenz, L. (2013). Partially Automated Driving as a Fallback Level of High Automation. In TÜV (Ed.), *6. Tagung Fahrerassistenz.*

Gold, C., Damböck, D., Lorenz, L., & Bengler, K. (2013). Take over! How long does it take to get the driver back into the loop? *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *57*(1), 1938–1942. doi: 10.1177/1541931213571433

Gold, C., Happee, R., & Bengler, K. (2017). Modeling take-over performance in level 3 conditionally automated vehicles. *Accident Analysis and Prevention.* doi: 10.1016/j.aap.2017.11.009

Gold, C., Körber, M., Hohenberger, C., Lechner, D., & Bengler, K. (2015). Trust in Automation – Before and After the Experience of Take-over Scenarios in a Highly Automated Vehicle. In *6th International Conference on Applied Human Factors and Ergonomics and the Affiliated Conferences, AHFE 2015* (pp. 3025–3032). doi: 10.1016/j.promfg.2015.07.847

Goldstein, E. B. (2010). *Sensation and Perception* (8. ed.). Wadsworth Cengage Learning.

Gottmann, F., Böhm, M., & Sawodny, O. (2017). Integrated Trajectory and Path Tracking of under-actuated and over-actuated Cars up to the Handling Limits. In *2017 American Control Conference (ACC)* (pp. 954–960). Piscataway, NJ: IEEE. doi: 10.23919/ACC.2017.7963076

Gotzig, H. (2016). Parking Assistance. In H. Winner, S. Hakuli, F. Lotz, & C. Singer (Eds.), *Handbook of Driver Assistance Systems* (pp. 1077–1092). Springer Reference.

Gotzig, H., & Geduld, G. (2016). Automotive LIDAR. In H. Winner, S. Hakuli, F. Lotz, & C. Singer (Eds.), *Handbook of Driver Assistance Systems* (pp. 405–430). Springer Reference.

Green, M. (2000). How Long Does It Take to Stop? Methodological Analysis of Driver Perception-Brake Times. *Transportation Human Factors*, *2*(3), 195–2016.

Grondin, S. (2016). *Psychology of Perception.* New York, USA: Springer.

Guedry, F. E. (1974). Psychophysics of Vestibular Sensation. In H. H. Kornhuber (Ed.), *Handbook of Sensory Physiology* (pp. 3–154). Berlin, Heidelberg: Springer.

Gundry, A. J. (1978). Experiments on the Detection of Roll Motion. *Aviation, Space and Environmental Medicine*, *57*(5), 657–664.

Handwerker, H. O. (2006). Somatosensorik. In R. F. Schmidt, H.-G. Schaible, & N. Birbaumer (Eds.), *Neuro- und Sinnesphysiologie* (pp. 203–228). Berlin, Heidelberg: Springer Medizin Verlag Heidelberg.

Handwerker, H. O., & Schmelz, M. (2010). Allgemeine Sinnesphysiologie. In R. F. Schmidt, F. Lang, & M. Heckmann (Eds.), *Physiologie des Menschen* (pp. 251–271). Berlin: Springer.

Harvey, C., Stanton, N. A., Pickering, C. A., McDonald, M., & Zheng, P. (2011). In-Vehicle Information Systems to Meet the Needs of Drivers. *International Journal of Human-Computer Interaction*, *27*(6), 505–522. doi: 10.1080/10447318.2011.555296

Heerspink, H. M., Berkouwer, W. R., Stroosma, O., van Paassen, M. M., Mulder, M., & Mulder, J. A. (2005). Evaluation of Vestibular Thresholds for Motion Detection in the SIMONA Research Simulator. In *AIAA Modeling and Simulation Technologies Conference and Exhibit.*

Heil, T., Lange, A., & Cramer, S. (2016). Adaptive and Efficient Lane Change Path Planning for Automated Vehicles. In IEEE Intelligent Transportation Systems Society (Ed.), *19th International Conference on Intelligent Transportation Systems (ITSC)* (pp. 479–484).

Heißing, B., Kudritzki, D., Schindlmaister, R., & Mauter, G. (2000). Menschengerechte Auslegung des dynamischen Verhaltens von PKW. In H. Bubb (Ed.), *Ergonomie und Verkehrssicherheit* (pp. 1–31). München: Herbert Utz Verlag.

Hoberock, L. L. (1976). *A Survey of Longitudinal Acceleration Comfort Studies in Ground Transportation Vehicles* (Research Report). University of Texas at Austin.

Hoc, J.-M., Young, M. S., & Blosseville, J.-M. (2009). Cooperation between drivers and automation: implications for safety. *Theoretical Issues in Ergonomics Science*, *10*(2), 135–160. doi: 10.1080/14639220802368856

Hoffmann, J. (2008). *Das Darmstädter Verfahren (EVITA) zum Testen und Bewerten von Frontalkollisionsgegenmassnahmen* (Doctoral thesis). Technischen Universität Darmstadt.

Hohm, A., Lotz, F., Fochler, O., Lueke, S., & Winner, H. (2014). Automated Driving in Real Traffic: from Current Technical Approaches towards Architectural Perspectives. In *SAE 2014 World Congress & Exhibition.*

IBM Corp. (2016). IBM SPSS Statistics for Windows (Version 24.0) [Computer software]. Armonk, NY.

iMAR. (2012, Februar). *Datenblatt iTraceRT-F400-E.* Retrieved January 08, 2017, from http://imar-navigation.de/downloads/TraceRT-F400_de.pdf

International Organization for Standardization. (2010-04-15). *Intelligent transport systems - Adaptive Cruise Control systems - Performance requirements and test procedures (ISO 15622:2010)* (No. ISO 15622:2010).

International Organization for Standardization. (2011-12). *Road vehicles - Vehicle dynamics and road-holding ability - Vocabulary (ISO 8855:2011)* (No. ISO 8855:2011).

International Organization for Standardization. (2014-11). *Road vehicles - Measurement of driver visual behaviour with respect to transport information and control systems - Part 1: Definitions and parameters (ISO 15007-1:2014)* (No. ISO 15007-1:2014).

Itoh, M., & Inagaki, T. (2004). A Microworld Approach to Identifying Issues of Human-Automation Systems Design for Supporting Operator's Situation Awareness. *International Journal of Human-Computer Interaction*, *17*(1), 3–24. doi: 10.1207/s15327590ijhc1701{\textunderscore}2

Jain, J., Lund, A., & Wixon, D. (2011). The Future of Natural User Interfaces. In D. Tan, S. Amershi, B. Begole, W. A. Kellogg, & M. Tungare (Eds.), *Proceedings of the 2011 Annual Conference Extended Abstracts on Human Factors in Computing Systems - CHI EA '11* (p. 211). New York, USA: ACM Press. doi: 10.1145/1979742.1979527

Jian, J.-Y., Bisantz, A. M., & Drury, C. G. (2000). Foundations for an Empirically Determined Scale of Trust in Automated Systems. *International Journal of Cognitive Ergonomics*, *4*(1), 53–71.

Josten, J., Schmidt, T., Philipsen, R., Eckstein, L., & Ziefle, M. (2017). What to Expect of Automated Driving: Expectations and Anticipation of System Behavior. In N. A. Stanton (Ed.), *Advances in Human Aspects of Transportation.* Springer International Publishing.

Josten, J., Zlocki, A., & Eckstein, L. (2016). *Untersuchung der Bewältigungsleistung des Fahrers von kurzfristig auftretenden Wiederübernahmesituationen nach teilautomatischem, freihändigem Fahren* (No. 289). Berlin.

Kammel, S., Ziegler, J., Pitzer, B., Werling, M., Gindele, T., Jagzent, D., ... Stiller, C. (2009). Team AnnieWAY's Autonomous System for the DARPA Urban Challenge 2007. In M. Buehler, K. Iagnemma, & S. Singh (Eds.), *The DARPA Urban Challenge* (pp. 359–391). Berlin, Heidelberg: Springer-Verlag.

Katriniok, A., Maschuw, J. P., Christen, F., Eckstein, L., & Abel, D. (2013). Optimal Vehicle Dynamics Control for Combined Longitudinal and Lateral Autonomous Vehicle Guidance. In *European Control Conference (ECC), 2013* (pp. 974–979). Piscataway, NJ: IEEE.

Kauffmann, N., Winkler, F., & Vollrath, M. (2018). What Makes an Automated Vehicle a Good Driver? In R. Mandryk, M. Hancock, M. Perry, & A. Cox (Eds.), *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems - CHI '18* (pp. 1–9). New York, USA: ACM Press. doi: 10.1145/3173574.3173742

Kaup, I. (2017). *Teilautomatisiertes Fahren: Unterstützung des Fahrers durch ein vestibuläres Feedback* (Master's thesis). Technische Universität München.

Kerschbaum, P., Lorenz, L., & Bengler, K. (2015). A transforming steering wheel for highly automated cars. In *2015 IEEE Intelligent Vehicles Symposium (IV)* (pp. 1287–1292). Piscataway, NJ: IEEE. doi: 10.1109/IVS.2015.7225893

Kingdom, F. A. A., & Prins, N. (2010). *Psychophysics: A Practical Introduction* (1. ed.). Amsterdam: Elsevier.

Klanner, F., & Ruhhammer, C. (2016). Backend Systems for ADAS. In H. Winner, S. Hakuli, F. Lotz, & C. Singer (Eds.), *Handbook of Driver Assistance Systems* (pp. 685–700). Springer Reference.

Kleine-Besten, T., Behrens, R., Pöchmüller, W., & Engelsberger, A. (2016). Digital Maps for ADAS. In H. Winner, S. Hakuli, F. Lotz, & C. Singer (Eds.), *Handbook of Driver Assistance Systems* (pp. 647–661). Springer Reference.

Klohr, J. (2017). *Evaluation aktiver Fahrzeugwankbewegungen als Rückmeldung beim teilautomatisierten Fahren* (Master's thesis). Technische Universität Darmstadt.

Knapp, A. (2018). Code of Practice for AD-Functions. In *25th ITS World Congress.* Retrieved November 10, 2018, from https://l3pilot.eu/fileadmin/user_upload/Downloads/ITSWC2018_SIS45_presentation_Andreas_Knapp_20180919.pdf

Knoll, P. M. (2016). Information Visualization for DAS. In H. Winner, S. Hakuli, F. Lotz, & C. Singer (Eds.), *Handbook of Driver Assistance Systems* (pp. 829–856). Springer Reference.

Kondzior, M. (n.d.). *Akzeptanzskala - Methode zur Erfassung der Akzeptanz eines Systems.* Retrieved May 07, 2017, from http://www.hfes-europe.org/accept/accept_de.htm

König, W. (2016). Guidelines for User-Centered Development of DAS. In H. Winner, S. Hakuli, F. Lotz, & C. Singer (Eds.), *Handbook of Driver Assistance Systems* (pp. 781–796). Springer Reference.

Koo, J., Kwac, J., Ju, W., Steinert, M., Leifer, L., & Nass, C. (2015). Why did my car just do that? Explaining semi-autonomous driving actions to improve driver understanding, trust, and performance. *International Journal on Interactive Design and Manufacturing (IJIDeM)*, *9*(4), 269–275. doi: 10.1007/s12008-014-0227-2

Körber, M., Baseler, E., & Bengler, K. (2018). Introduction matters: Manipulating trust in automation and reliance in automated driving. *Applied ergonomics*, *66*, 18–31. doi: 10.1016/j.apergo.2017.07.006

Kraft, A.-K., Naujoks, F., Wörle, J., & Neukum, A. (2018). The impact of an in-vehicle display on glance distribution in partially automated driving in an on-road experiment. *Transportation Research Part F: Traffic Psychology and Behaviour*, *52*, 40–50. doi: 10.1016/j.trf.2017.11.012

Kyriakidis, M., de Winter, J. C. F., Stanton, N., Bellet, T., van Arem, B., Brookhuis, K., … Happee, R. (2017). A human factors perspective on automated driving. *Theoretical Issues in Ergonomics Science*, *53*, 1–27. doi: 10.1080/1463922X.2017.1293187

Lachenmayer, B., Buser, A., Keller, O., & Berger, J. (1996). Sehstörungen als Unfallursache. *Berichte der Bundesanstalt für Straßenwesen, Mensch und Sicherheit*(M 65).

Lange, A. (2018). *Gestaltung der Fahrdynamik beim Fahrstreifenwechselmanöver als Rückmeldung für den Fahrer beim automatisierten Fahren* (Doctoral thesis). Technische Universität München.

Lange, A., Albert, M., Siedersberger, K.-H., & Bengler, K. (2015). Ergonomic Design of the Vehicle Motion in an Automated Driving Car. In *6th International Conference on Applied Human Factors and Ergonomics and the Affiliated Conferences, AHFE 2015* (pp. 2761–2768). doi: 10.1016/j.promfg.2015.07.710

Lange, A., Maas, M., Albert, M., Siedersberger, K.-H., & Bengler, K. (2014). Automatisiertes Fahren - So komfortabel wie möglich, so dynamisch wie nötig. In VDI Wissensforum GmbH (Ed.), *30. VDI-VW-Gemeinschaftstagung Fahrerassistenz und Integrierte Sicherheit* (pp. 215–228). Düsseldorf, Germany: VDI Verlag.

Lange, A., Müller, C., Reichel, M., & Albert, M. (2015). *Method for Operating a Driver Assistance System of a Motor Vehicle and Motor Vehicle* (No. WO 2015/055297 A1).

Langlois, S., & Soualmi, B. (2016). Augmented reality versus classical HUD to take over from automated : an aid to smooth reactions and to anticipate maneuvers. In IEEE Intelligent Transportation Systems Society (Ed.), *19th International Conference on Intelligent Transportation Systems (ITSC)* (pp. 1571–1578). doi: 10.1109/ITSC.2016.7795767

Lategahn, H. (2013). *Mapping and Localization in Urban Environments Using Cameras* (Doctoral thesis). Karlsruher Institut für Technologie.

Lavrakas, P. (2008). *Encyclopedia of Survey Research Methods.* 2455 Teller Road, Thousand Oaks California 91320 United States of America: Sage Publications, Inc. doi: 10.4135/9781412963947

Lee, S. C., Hwangbo, H., & Ji, Y. G. (2016). Perceived Visual Complexity of In-Vehicle Information Display and Its Effects on Glance Behavior and Preferences. *International Journal of Human-Computer Interaction*, *32*(8), 654–664. doi: 10.1080/10447318.2016.1184546

Löcken, A., Buhl, H., Heuten, W., & Boll, S. (2015). TactiCar: Towards Supporting Drivers During Lane Change Using Vibro-Tactile Patterns. In G. Burnett, J. Gabbard, P. Green, & S. Osswald (Eds.), *Adjunct Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications - AutomotiveUI '15* (pp. 32–37). ACM Press. doi: 10.1145/2809730.2809758

Löcken, A., Heuten, W., & Boll, S. (2016). AutoAmbiCar. In P. Green, B. Pfleging, A. L. Kun, Y. Liang, A. Meschtscherjakov, & P. Fröhlich (Eds.), *Proceedings of the 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications Adjunct - Automotive'UI 16* (pp. 57–62). New York, New York, USA: ACM Press. doi: 10.1145/3004323.3004329

Löper, C., Kelsch, J., & Flemisch, F. (2008). Kooperative, manöverbasierte Automation und Arbitrierung als Bausteine für hochautomatisiertes Fahren. In *Automatisierungs-, Assistenzsysteme und eingebettete Systeme für Transportmittel* (pp. 215–237).

Lüke, S., Fochler, O., Schaller, T., & Regensburger, U. (2016). Traffic Jam Assistance and Automation. In H. Winner, S. Hakuli, F. Lotz, & C. Singer (Eds.), *Handbook of Driver Assistance Systems* (pp. 1287–1302). Springer Reference.

Martens, M. H., & van den Beukel, A. P. (2013). The road to automated driving: dual mode and human factors considerations. In *16th International IEEE Conference on Intelligent Transportation Systems (ITSC), 2013* (pp. 2262–2267). Piscataway, NJ: IEEE. doi: 10.1109/ITSC.2013.6728564

Matthaei, R. (2015). *Wahrnehmungsgestützte Lokalisierung in fahrstreifengenauen Karten für Assistenzsysteme und automatisches Fahren in urbaner Umgebung* (Doctoral thesis). Technische Universität Braunschweig.

Matthaei, R., Reschka, A., Rieken, J., Dierkes, F., Ulbrich, S., Winkle, T., & Maurer, M. (2016). Autonomous Driving. In H. Winner, S. Hakuli, F. Lotz, & C. Singer (Eds.), *Handbook of Driver Assistance Systems* (pp. 1519–1556). Springer Reference.

Maurer, M. (2009). Entwurf und Test von Fahrerassistenzsystemen. In H. Winner, S. Hakuli, & G. Wolf (Eds.), *Handbuch Fahrerassistenzsysteme* (pp. 43–54). Vieweg + Teubner.

Merat, N., Jamson, A. H., Lai, F. C. H., & Carsten, O. (2012). Highly Automated Driving, Secondary Task Performance, and Driver State. *Human Factors*, *54*(5), 762–771. doi: 10.1177/0018720812442087

Miller, B. (2016). *Wirkweise und Akzeptanz von Nick- und Wankbewegungen als Feedback-Kanal beim automatisierten Fahren* (Master's thesis). Technische Universität Darmstadt.

Mörbe, M. (2016). Vehicle Dynamics Sensors for DAS. In H. Winner, S. Hakuli, F. Lotz, & C. Singer (Eds.), *Handbook of Driver Assistance Systems* (pp. 279–302). Springer Reference.

Muir, B. M., & Moray, N. (1996). Trust in automation. Part II. Experimental studies of trust and human intervention in a process control simulation. *Ergonomics*, *39*(3), 429–460. doi: 10.1080/00140139608964474

Müller, C., Sieber, M., Siedersberger, K.-H., Popp, M., & Färber, B. (2017). Aktives Wanken als Kommunikationskanal informierender und warnender Querführungssassistenten. In Uni-DAS e. V (Ed.), *11. Workshop Fahrerassistenz und automatisiertes Fahren* (pp. 84–93).

Müller, C., Siedersberger, K.-H., Färber, B., & Popp, M. (2017). Aktive Aufbauneigung als Rückmeldekanal bei Querführungsassistenz über entkoppelte Lenkaktorik. *Forschung im Ingenieurwesen*, *81*(1), 41–55. doi: 10.1007/s10010-017-0212-6

Müller, T. (2015). *Ermittlung vestibulärer Wahrnehmungsschwellen zur zielgerichteten Gestaltung der Fahrzeug-Längsdynamik* (Doctoral thesis). Technische Universität München.

Münster, M., Mair, U., Gilsdorf, H.-J., & Thomä, A. (2009). Electromechanical Active Body Control. *ATZ worldwide*, *111*(9), 44–48. doi: 10.1007/BF03225316

Muragishi, Y., Fukui, K., Ono, E., Kodaira, T., Yamamoto, Y., & Sakai, H. (2007). Improvement of Vehicle Dynamics Based on Human Sensitivity (First Report) - Development of Human Sensitivity Evaluation System for Vehicle Dynamics. In *SAE World Congress & Exhibition.* SAE International. doi: 10.4271/2007-01-0448

Nagel, H.-H., Enkelmann, W., & Struck, G. (1995). FhG-Co-Driver: From Map-Guided Automatic Driving by Machine Vision to a Cooperative Driver Support. *Mathematical and Computer Modelling*, *22*(4-7), 185–212.

Naujoks, F., Purucker, C., Neukum, A., Wolter, S., & Steiger, R. (2015). Controllability of Partially Automated Driving functions – Does it matter whether drivers are allowed to take their hands off the steering wheel? *Transportation Research Part F: Traffic Psychology and Behaviour*, *35*, 185–198. doi: 10.1016/j.trf.2015.10.022

Nesti, A., Barnett-Cowan, M., Macneilage, P. R., & Bülthoff, H. H. (2014). Human sensitivity to vertical self-motion. *Experimental brain research*, *232*(1), 303–314. doi: 10.1007/s00221-013-3741-8

Nesti, A., Masone, C., Barnett-Cowan, M., Giordano, P. R., Bülthoff, H. H., & Pretto Paolo. (2012). Roll rate thresholds and perceived realism in driving simulation. In *Driving Simulation Conference.*

Nesti, A., Nooij, S., Losert, M., Bülthoff, H. H., & Pretto, P. (2016). Roll rate perceptual thresholds in active and passive curve driving simulation. *SIMULATION*, *92*(5), 417–426. doi: 10.1177/0037549716637135

NHTSA. (2013). *Preliminary Statement of Policy Concerning Automated Vehicles.* Retrieved January 21, 2017, from http://www.nhtsa.gov/staticfiles/rulemaking/pdf/Automated_Vehicles_Policy.pdf

Noll, M., & Rapps, P. (2016). Ultrasonic Sensors for a K44DAS. In H. Winner, S. Hakuli, F. Lotz, & C. Singer (Eds.), *Handbook of Driver Assistance Systems* (pp. 303–323). Springer Reference.

Norman, D. A. (1990). The Problem of Automation: Inappropriate Feedback and Interaction, not Over-Automation. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *327*(1241), 585–593.

Normark, C. J. (2015). Design and Evaluation of a Touch-Based Personalizable In-Vehicle User Interface. *International Journal of Human-Computer Interaction*, *31*(11), 731–745. doi: 10.1080/10447318.2015.1045240

Othersen, I. (2016). *Vom Fahrer zum Denker und Teilzeitlenker: Einflussfaktoren und Gestaltungsmerkmale nutzerorientierter Interaktionskonzepte für die Überwachungsaufgabe des Fahrers im teilautomatisierten Modus* (Doctoral thesis, Technische Universität Braunschweig). doi: 10.1007/978-3-658-15087-7

Parasuraman, R., & Riley, V. (1997). Humans and Automation: Use, Misuse, Disuse, Abuse. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *39*(2), 230–253.

Parasuraman, R., & Wickens, C. D. (2008). Humans: Still Vital After All These Years of Automation. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *50*(3), 511–520. doi: 10.1518/001872008X312198

Perceptible. (n.d.). Retrieved July 15, 2018, from https://www.merriam-webster.com/dictionary/perceptibility

Petermeijer, S. M., Abbink, D. A., & de Winter, J. C. F. (2015). Should Drivers Be Operating Within an Automation-Free Bandwidth? Evaluating Haptic Steering Support Systems With Different Levels of Authority. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *57*(1), 5–20. doi: 10.1177/0018720814563602

Petermeijer, S. M., Abbink, D. A., Mulder, M., & de Winter, J. C. F. (2015). The Effect of Haptic Support Systems on Driver Performance: A Literature Survey. *IEEE transactions on haptics*, *8*(4), 467–479. doi: 10.1109/TOH.2015.2437871

Petermeijer, S. M., Cieler, S., & de Winter, J. C. F. (2017). Comparing spatially static and dynamic vibrotactile take-over requests in the driver seat. *Accident; analysis and prevention*, *99*(Pt A), 218–227. doi: 10.1016/j.aap.2016.12.001

Pfannmüller, L., Kramer, M., Senner, B., & Bengler, K. (2015). A comparison of display concepts for a navigation system in an automotive contact analog head-up display. In *6th International Conference on Applied Human Factors and Ergonomics and the Affiliated Conferences, AHFE 2015* (pp. 2722–2729).

Pöhler, G., Heine, T., & Deml, B. (2016). Itemanalyse und Faktorstruktur eines Fragebogens zur Messung von Vertrauen im Umgang mit automatischen Systemen. *Zeitschrift für Arbeitswissenschaft*, *70*(3), 151–160. doi: 10.1007/s41449-016-0024-9

PReVENT. (2009). *Code of Practice for the Code of Practice for the Design and Evaluation of ADAS.* Response 3 - a PReVENT Project. Retrieved November 10, 2018, from https://www.acea.be/uploads/publications/20090831_Code_of_Practice_ADAS.pdf (V5.0)

Punke, M., Menzel, S., Werthessen, B., Stache, N., & Höpfl, M. (2016). Automotive Camera (Hardware). In H. Winner, S. Hakuli, F. Lotz, & C. Singer (Eds.), *Handbook of Driver Assistance Systems* (pp. 431–460). Springer Reference.

Rasmussen, J. (1983). Skills, Rules, and Knowledge: Signals, Signs, and Symbols, and Other Distinctions in Human Performance Models. In *IEEE Transactions on Systems, Man, and Cybernetics* (Vol. SMC-13(3), pp. 257–266).

Rayner, K. (1998). Eye Movements in Reading and Information Processing: 20 Years of Research. *Psychological bulletin*, *124*(3), 372–422.

Reimann, G., Brenner, P., & Büring, H. (2016). Steering Actuator Systems. In H. Winner, S. Hakuli, F. Lotz, & C. Singer (Eds.), *Handbook of Driver Assistance Systems* (pp. 745–777). Springer Reference.

Remfrey, J., Gruber, S., & Ocvirk, N. (2016). Hydraulic Brake Systems for Passenger Vehicles. In H. Winner, S. Hakuli, F. Lotz, & C. Singer (Eds.), *Handbook of Driver Assistance Systems* (pp. 703–730). Springer Reference.

Rhiu, I., Kwon, S., Bahn, S., Yun, M. H., & Yu, W. (2015). Research Issues in Smart Vehicles and Elderly Drivers: A Literature Review. *International Journal of Human-Computer Interaction*, *31*(10), 635–666. doi: 10.1080/10447318.2015.1070540

Rieken, J., Reschka, A., & Maurer, M. (2016). Development Process of Forward Collision Prevention Systems. In H. Winner, S. Hakuli, F. Lotz, & C. Singer (Eds.), *Handbook of Driver Assistance Systems* (pp. 1177–1206). Springer Reference.

Robert Bosch GmbH. (2009). *Fernbereichsradarsensor LRR3: Long-Range Radar, 3. Generation.* Retrieved October 04, 2017, from http://produkte.bosch-mobility-solutions.de/media/db_application/pdf_2/de/LRR3_Datenblatt_DE_2009.pdf

Rockwell, T. H. (1971). *Eye Movement Analysis of Visual Information Acquisition in Driving: An Overview* (No. 3). Raleigh.

Rodenburg, M., Stassen, H. P., & Maas, A. J. (1981). The Threshold of Perception of Angular Acceleration as a Function of Duration. *Biological cybernetics*, *39*(3), 223–226.

SAE. (2014). *Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems* (2014-01-16 ed.) (No. J3016).

SAE. (2016). *Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles* (2016-09 ed.) (No. J3016).

Saffarian, M., de Winter, J. C. F., & Happee, R. (2012). Automated Driving: Human-Factors Issues and Design Solutions. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *56*(1), 2296–2300. doi: 10.1177/1071181312561483

Sarter, N. B., & Woods, D. D. (1995). How in the World Did We Ever Get into That Mode? Mode Error and Awareness in Supervisory Control. *Human Factors*, *37*(1), 5–19.

Sauer, W., Kramer, K., & Ersoy, M. (2017). Fahrkomfort. In M. Ersoy & S. Gies (Eds.), *Fahrwerkhandbuch* (pp. 207–243). Wiesbaden: Springer Vieweg.

Schiffman, H. R. (2001). *Sensation and Perception: An Integrated Approach* (5. ed.). New York: Wiley.

Schimmel, C. (2010). *Entwicklung eines fahrerbasierten Werkzeugs zur Objektivierung subjektiver Fahreindrücke* (Doctoral thesis). Technische Universität München.

Schmidt, G., Kiss, M., Babbel, E., & Galla, A. (2008). The Wizard on Wheels: Rapid Prototyping and User Testing of Future Driver Assistance Using Wizard of Oz Technique in a Vehicle. In *FISITA 2008 World Automotive Congress.*

Schmidt, R. F. (2001). *Physiologie kompakt.* Berlin, Heidelberg: Springer Berlin Heidelberg. doi: 10.1007/978-3-642-56501-4

Schmidt, R. F., Lang, F., & Heckmann, M. (Eds.). (2010). *Physiologie des Menschen: mit Pathophysiologie* (31. Auflage ed.). Berlin: Springer.

Sieber, M., Siedersberger, K.-H., Siegel, A., & Färber, B. (2015). Automatic Emergency Steering with Distracted Drivers: Effects of Intervention Design. In *2015 IEEE 18th International Conference on Intelligent Transportation Systems* (pp. 2040–2045). IEEE. doi: 10.1109/ITSC.2015.330

Sirkin, D., Fischer, K., Jensen, L., & Ju, W. (2016). Eliciting Conversation in Robot Vehicle Interactions. In *Proceedings of the Association for the Advancement of Artificial Intelligence (AAAI) Spring Symposium Series* (pp. 164–171).

Sivak, M., & Schoettle, B. (2015). *Motion Sickness in Self-Driving Vehicles: UMTRI-2015-12* (Bericht). University of Michigan, Ann Arbor, USA.

Sommer, K. (2013, December 12). *Continental Mobility Study 2013.* Retrieved January 20, 2016, from https://www.continental-corporation.com/resource/blob/7380/6cddc571cd3d3b5cacd279fe0d1a00c1/mobistud-2013-dl-data.pdf

Stadtler, R. (2015, September 09). *Im Internet der Ringe: Wie Audi das Auto vernetzt.* Frankfurt. Retrieved July 22, 2018, from https://www.audi-mediacenter.com/de/publikationen/reden/rede-carit-kongress-225

Stanton, N. A., & Young, M. S. (2005). Driver behaviour with adaptive cruise control. *Ergonomics*, *48*(10), 1294–1313. doi: 10.1080/00140130500252990

Steinhardt, N., & Leinen, S. (2016). Data Fusion for Precise Localization. In H. Winner, S. Hakuli, F. Lotz, & C. Singer (Eds.), *Handbook of Driver Assistance Systems* (pp. 605–646). Springer Reference.

Stern, J. (1999). *Akzeptanz verkehrssicherheitsfördernder Maßnahmen bei jungen Fahranfängern* (Diploma thesis). Technische Universität Dresden.

Stevens, J. P. (2002). *Applied Multivariate Statistics for the Social Sciences: Chapter 3* (4. ed.). New York.

Taylor, R. M. (1990). Situational Awareness Rating Technique (SART): The developement of a tool for aircrew systems design. *Situational Awareness in Aerospace Operations (AGARD Conference Proceedings)*(478), 3.1–3.17.

The MathWorks, Inc. (2015). MATLAB R2015b [Computer software]. Natick, Massachusetts, Unites States.

Thomä, A., Gilsdorf, H.-J., Münster, M., Mair, U., Müller, C., Hippe, M., & Hoffmann, J. (2008). Electromechanical Active Body Control: F2008-03-057. In *FISITA 2008 World Automotive Congress.*

Tomaske, W. (2001). Der Einfluss von Wahrnehmungsschwellwerten auf die Auslegung von Bewegungssystemen in der Fahrsimulation. *Deutsche Gesellschaft für Luft- und Raumfahrt e.V. (DGLR)*(2001-06).

Treede, R.-D. (2010). Das somatosensorische System. In R. F. Schmidt, F. Lang, & M. Heckmann (Eds.), *Physiologie des Menschen* (pp. 272–297). Berlin: Springer.

Ulbrich, S., & Maurer, M. (2015). Towards Tactical Lane Change Behavior Planning for Automated Vehicles. In *IEEE Conference on Intelligent Transportation Systems (ITSC)* (pp. 989–995).

Ulbrich, S., Menzel, T., Reschka, A., Schuldt, F., & Maurer, M. (2015). Defining and Substantiating the Terms Scene, Situation, and Scenario for Automated Driving. In *2015 IEEE 18th International Conference on Intelligent Transportation Systems (ITSC)* (pp. 982–988). IEEE. doi: 10.1109/ITSC.2015.164

Unger, A. (2012). *Serientaugliche quadratisch optimale Regelung für semiaktive Pkw-Fahrwerke* (Doctoral thesis). Technische Universität München.

van den Beukel, A. P., van der Voort, M. C., & Eger, A. O. (2016). Supporting the changing driver's task: Exploration of interface designs for supervision and intervention in automated driving. *Transportation Research Part F: Traffic Psychology and Behaviour*, *43*, 279–301. doi: 10.1016/j.trf.2016.09.009

van der Laan, J. D., Heino, A., & de Waard, D. (1997). A Simple Procedure for the Assessment of Acceptance of Advanced Transport Telematics. *Transportation Research Part C: Emerging Technologies*, *5*(1), 1–10. doi: 10.1016/S0968-090X(96)00025-3

VDA. (2015). Automation: From Driver Assistance Systems to Automated Driving. *VDA Magazin - Automatisierung*. Retrieved June 18, 2018, from https://www.vda.de/dam/vda/publications/2015/automation.pdf

Wan, J., & Wu, C. (2017). The Effects of Vibration Patterns of Take-Over Request and Non-Driving Tasks on Taking-Over Control of Automated Vehicles. *International Journal of Human-Computer Interaction*, *41*(1), 1–12. doi: 10.1080/10447318.2017.1404778

Warm, J. S., Dember, W. N., & Hancock, P. A. (1996). Vigilance and Workload in Automated Systems. In R. Parasuraman & M. Mouloua (Eds.), *Human factors in transportation. Automation and human performance: Theory and applications* (pp. 183–200). Hillsdale, NJ: Lawrence Erlbaum Associates.

Weinberger, M. (2001). *Der Einfluß von Adaptive Cruise Control Systemen auf das Fahrerverhalten* (Doctoral thesis). Technische Universität München.

Weller, G., & Schlag, B. (2016). Behavioral Aspects of Driver Assistance Systems. In H. Winner, S. Hakuli, F. Lotz, & C. Singer (Eds.), *Handbook of Driver Assistance Systems.* Springer Reference.

Werling, M. (2010). *Ein neues Konzept für die Trajektoriengenerierung und -stabilisierung in zeitkritischen Verkehrsszenarien* (Doctoral thesis). Karlsruher Institut für Technologie.

Wickens, C. D., Hollands, J. G., & Parasuraman, R. (2013). *Engineering Psychology and Human Performance* (4th ed.). London, New York: Routledge Taylor & Francis Group.

Wigdor, D., & Wixon, D. (2011). *Brave NUI World: Designing Natural User Interfaces for Touch and Gesture.* Amsterdam, Netherlands: Morgan Kaufmann/Elsevier.

Wilcox, R. R. (2012). *Introduction to Robust Estimation and Hypothesis Testing* (3. ed.). Elsevier/Academic Press.

Wimmer, M. (2014). *Entwicklung und Erprobung von Mensch-Maschine-Systemen zur automatisierten Fahrzeugführung.* (Doctoral thesis). Universität der Bundeswehr München.

Winner, H. (2016). Automotive RADAR. In H. Winner, S. Hakuli, F. Lotz, & C. Singer (Eds.), *Handbook of Driver Assistance Systems* (pp. 325–403). Springer Reference.

Winner, H., Hakuli, S., Bruder, R., Konigorski, U., & Schiele, B. (2006). Conduct-by-Wire - ein neues Paradigma für die Weiterentwicklung der Fahrerassistenz. In *4. Workshop Fahrerassistenzsysteme.*

Winner, H., & Schopper, M. (2016). Adaptive Cruise Control. In H. Winner, S. Hakuli, F. Lotz, & C. Singer (Eds.), *Handbook of Driver Assistance Systems* (pp. 1093–1148). Springer Reference.

Wolf, H. J. (2009). *Ergonomische Untersuchung des Lenkgefühls an Personenkraftwagen* (Doctoral thesis). Technische Universität München.

Wolf, I. (2016). The Interaction Between Humans and Autonomous Agents. In M. Maurer, J. C. Gerdes, B. Lenz, & H. Winner (Eds.), *Autonomous Driving* (pp. 103–124). Heidelberg, Germany: Springer Open.

Young, L. R., & Sheena, D. (1975). Survey of eye movement recording methods. *Behavior Research Methods & Instrumentation*, *7*(5), 397–429. doi: 10.3758/BF03201553

Zaichik, L., Rodchenko, V., Rufov, I., Yashin, Y., & White, A. (1999). Acceleration Perception. In *Modeling and Simulation Technologies Conference and Exhibit.* Reston, Viriginia: American Institute of Aeronautics and Astronautics. doi: 10.2514/6.1999-4334

Zenner, H.-P. (2010a). Der Gleichgewichtssinn und die Bewegungs- und Lageempfindung des Menschen. In R. F. Schmidt, F. Lang, & M. Heckmann (Eds.), *Physiologie des Menschen* (pp. 336–344). Berlin: Springer.

Zenner, H.-P. (2010b). Die Kommunikation des Menschen: Hören und Sprechen. In R. F. Schmidt, F. Lang, & M. Heckmann (Eds.), *Physiologie des Menschen* (pp. 315–335). Berlin: Springer.

Zhang, L., Helander, M. G., & Drury, C. G. (1996). Identifying Factors of Comfort and Discomfort in Sitting. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *38*(3), 377–389. doi: 10.1518/001872096778701962

Ziegler, J., Bender, P., Schreiber, M., Lathegahn, H., Strauss, T., & Stiller, C. (2014). Making Bertha Drive: An Autonomous Journey on a Historic Route. *IEEE Intelligent Transportation Systems Magazine*, *6*(2), 8–20.

List of Figures

List of Tables

Acronyms

ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance Systems
ADTF	Automotive Data and Time-Triggered Framework
ANOVA	ANalysis Of VAriance
AOI	Area Of Interest
BASt	Bundesanstalt für Straßenwesen
CAN	Controller Area Network
CL	Complete Logic, participants who identified the complete logic
DGPS	Differential Global Positioning System
eABC	Electromechanical Active Body Control
ESC	Electronic Stability Control
HMI	Human-Machine Interface
LC	Lane Change
LKA	Lane Keeping Assistance
NCL	Not Complete Logic, participants who needed at least some explanation of the feedback logic
NHTSA	National Highway Traffic Safety Administration
PAD	Partially Automated Driving
PP	Pitch Profile
PV	Preceding Vehicle
RP	Roll Profile
RQ	Research Question
SAE	Society of Automotive Engineers

SF	System Failure
VDA	Verband der Automobilindustrie e.V.

Symbols

φ	Roll angle
$\dot{\varphi}$	Roll velocity
$\ddot{\varphi}$	Roll acceleration
φ_{max}	Maximum roll angle
ψ	Yaw angle
τ_1	Increase phase of pitch or roll profile
τ_2	Holding phase of pitch or roll profile
τ_3	Return phase of pitch or roll profile
τ_a	Announcement of a lane change
θ	Pitch angle
$\dot{\theta}$	Pitch velocity
$\ddot{\theta}$	Pitch acceleration
θ_{max}	Maximum pitch angle
a_x	Longitudinal acceleration
a_y	Lateral acceleration
a_z	Vertical acceleration
d_{rel}	Relative distance
$d_{x,PV}$	Longitudinal distance to the preceding vehicle
$d_{y,PV}$	Lateral distance to the preceding vehicle
t	Time
v_{rel}	Relative velocity
v_x	Longitudinal velocity

Appendix

A Results of Normal Distribution Tests

Table A.1: Results of Kolmogorov–Smirnov tests for normal distribution of variables with $N \leq 30$ of driving study 1

		Profile	D	p
Scenario "PV to follow"				
	Perceptibility	Lin. 1 °	$D(26) = .42$	$< .001$
		Degr. 1 °	$D(26) = .26$	$< .001$
		Poly. 1 °	$D(26) = .29$	$< .001$
	Situational context	Lin. 1 °	$D(26) = .20$	.009
		Degr. 1 °	$D(26) = .23$	.001
		Poly. 1 °	$D(26) = .25$	$< .001$
	Discomfort	Lin. 1 °	$D(26) = .20$	.009
		Degr. 1 °	$D(26) = .24$	.001
		Poly. 1 °	$D(26) = .27$	$< .001$
Scenario "PV to overtake"				
	Perceptibility	Lin. -1 °	$D(21) = .36$	$< .001$
		Degr. -1 °	$D(21) = .29$	$< .001$
		Poly. -1 °	$D(21) = .28$	$< .001$
	Situational context	Lin. -1 °	$D(21) = .22$	.007
		Degr. -1 °	$D(21) = .24$	.002
		Poly. -1 °	$D(21) = .25$	.001
	Discomfort	Lin. -1 °	$D(21) = .21$	.014
		Degr. -1 °	$D(21) = .27$	$< .001$
		Poly. -1 °	$D(21) = .25$	.002

	Profile	D	p
Scenario “cutting-in vehicle”			
Perceptibility	Lin. 1°	$D(14) = .29$	003
	Degr. 1°	$D(14) = .33$	$< .001$
	Poly. 1°	$D(14) = .33$	$< .001$
	Lin. 2°	$D(12) = .37$	$< .001$
	Degr. 2°	$D(12) = .31$	.002
	Poly. 2°	$D(12) = .30$	.004
Situational context	Lin. 1°	$D(14) = .32$	$< .001$
	Degr. 1°	$D(14) = .27$	.006
	Poly. 1°	$D(14) = .24$	.031
	Lin. 2°	$D(12) = .30$	004
	Degr. 2°	$D(12) = .40$	$< .001$
	Poly. 2°	$D(12) = .40$	$< .001$
Discomfort	Lin. 1°	$D(14) = .26$	.009
	Degr. 1°	$D(14) = .25$	.020
	Poly. 1°	$D(14) = .27$	.009
	Lin. 2°	$D(12) = .28$	010
	Degr. 2°	$D(12) = .20$	.200
	Poly. 2°	$D(12) = .21$	.163
Scenario “speed limit”			
Perceptibility	Lin. 1°	$D(27) = .28$	$< .001$
	Degr. 1°	$D(27) = .26$	$< .001$
	Poly. 1°	$D(27) = .27$	$< .001$
Situational context	Lin. 1°	$D(27) = .23$	.001
	Degr. 1°	$D(27) = .26$	$< .001$
	Poly. 1°	$D(27) = .22$	.002
Discomfort	Lin. 1°	$D(27) = .25$	$< .001$
	Degr. 1°	$D(27) = .23$	.001
	Poly. 1°	$D(27) = .22$	.002

Table A.2: Results of Kolmogorov–Smirnov tests for normal distribution of variables with $N \leq 30$ of driving study 2

		D	p
Acceptance			
Satisfying	CL	$D(26) = .17$	.065
	NCL	$D(10) = .20$	.200
Usefulness	CL	$D(26) = .19$	.021
	NCL	$D(10) = .22$	.191

Table A.3: Results of Kolmogorov–Smirnov tests for normal distribution of variables with $N \leq 30$ of driving study 3

		D	p
Announcement time			
LC following PV	$2\,s$, RP2	$D(18) = .44$	$< .001$
	$3\,s$, RP2	$D(18) = .27$	.002
	$2\,s$, RP4	$D(21) = .44$	$< .001$
	$3\,s$, RP4	$D(21) = .22$	.009
LC detecting PV	$2\,s$, RP2	$D(16) = .24$	.013
	$3\,s$, RP2	$D(16) = .25$	.008
	$2\,s$, RP4	$D(23) = .20$	.015
	$3\,s$, RP4	$D(23) = .35$	$< .001$
LC right	$2\,s$, RP2	$D(15) = .30$	.001
	$3\,s$, RP2	$D(15) = .22$	.061
	$2\,s$, RP4	$D(24) = .35$	$< .001$
	$3\,s$, RP4	$D(24) = .20$	.011

Table A.4: Results of Kolmogorov–Smirnov tests for normal distribution of variables with $N \leq 30$ of driving study 4, (SF $\widehat{=}$ system failure, TO $\widehat{=}$ take-over)

		D	p
Trust/mistrust system failure			
Visual-only	Trust	$D(17) = .22$	.036
	Mistrust	$D(17) = .22$	.036
Vis. & vest.	Trust	$D(17) = .16$	.200
	Mistrust	$D(17) = .22$	.036

		D	p
Mental demand			
Part 1	Vis.-only	$D(18) = .12$	.200
	Vis. & vest.	$D(16) = .18$	.190
Part 2	Vis.-only	$D(16) = .19$	.129
	Vis. & vest.	$D(18) = .13$	.200
Feeling of Safety			
Part 1	Vis.-only	$D(18) = .16$	.200
	Vis. & vest.	$D(16) = 20$	.104
Part 2	Vis.-only	$D(16) = .14$	.200
	Vis. & vest.	$D(18) = .20$	.067
Acceptance system failure			
Visual-only	Satisfying	$D(17) = .28$	.001
	Usefulness	$D(17) = .19$	.105
Vis. & vest.	Satisfying	$D(17) = .34$	$< .001$
	Usefulness	$D(17) = .28$	.001
Visual Behavior			
Road	AOI ratio	$D(19) = .13$	.200
Instrument cluster	AOI ratio	$D(19) = .20$	.043
Assessment of the situation			
Quickly overviewed	TO themselves	$D(21) = .40$	$< .001$
	TO request	$D(13) = .30$	.002
Demanding	TO themselves	$D(21) = .22$	.009
	TO request	$D(13) = .19$	.200
Well reacted	TO themselves	$D(21) = .31$	$< .001$
	TO request	$D(13) = .16$	.200
Critical	TO themselves	$D(21) = .25$	.001
	TO request	$D(13) = .16$	.200
Reaction times			
Visual-only	First reaction	$D(10) = .20$	.200
	Hands on	$D(10) = .22$	.173
Vis. & vest.	First reaction	$D(10) = .16$	.200
	Hands on	$D(10) = .16$	.200

		D	p
Perceived safety, TO themselves			
Quiescent-surprised	Vis.-only	$D(10) = .26$	.054
	Vis. & vest.	$D(10) = .22$	.200
Anxious-relaxed	Vis.-only	$D(10) = .30$	.010
	Vis. & vest.	$D(10) = .26$	.060
Agitated-calm	Vis.-only	$D(10) = .28$	.023
	Vis. & vest.	$D(10) = .23$	.127

B Results of Homogeneity of Variance Tests

Table A.5: Results of Levene's tests for homogeneity of variance of variables of driving study 2

		F	p
Acceptance			
Satisfying	CL / NCL	$F(1,\ 34) = 0.23$	.631

Table A.6: Results of Levene's tests for homogeneity of variance of variables of driving study 4 (TO $\widehat{=}$ take-over)

		F	p
Assessment of the situation			
Quickly overviewed	TO themselves/request	$F(1,\ 32) = 19.55$	$< .001$
Demanding	TO themselves/request	$F(1,\ 32) = 0.22$	.644
Well reacted	TO themselves/request	$F(1,\ 32) = 13.77$	.001
Critical	TO themselves/request	$F(1,\ 32) = 0.11$	.748
Reaction times			
First reaction	Vis.-only / vis. & vest.	$F(1,\ 18) = 0.18$	.676
Hands on	Vis.-only / vis. & vest.	$F(1,\ 18) = 1.05$	.318
Perceived safety,TO themselves			
Quiescent-surprised	Vis.-only / vis. & vest.	$F(1,\ 18) = 1.34$	.263
Anxious-relaxed	Vis.-only / vis. & vest.	$F(1,\ 18) = 1.82$	.194
Agitated-calm	Vis.-only / vis. & vest.	$F(1,\ 18) = 4.69$	.044

C Supplementary Information about the Samples

C.1 Driving Style

Table A.7: Driving style: “Compared to other drivers, I mainly drive ...” according to Stern (1999) as cited in Arndt (2010)

Driving style	Study 1 $N = 35$		Study 2 $N = 36$		Study 3 $N = 39$		Study 4 $N = 34$	
	M	SD	M	SD	M	SD	M	SD
Slow - fast (1 - 5)	3.9	0.6	3.7	0.8	3.9	0.7	4.0	0.7
Anxious - courageous (1 - 5)	3.7	0.7	3.8	0.7	3.7	0.8	3.9	0.7
Defensive - offensive (1 - 5)	3.2	0.8	3.2	0.9	3.1	1.0	3.3	0.9
Cautious - risk-taking (1 - 5)	2.8	0.7	2.9	0.8	2.9	0.7	2.9	0.6
Relaxed - sporty (1 - 5)	3.6	0.7	3.5	0.9	3.6	0.9	3.7	0.9
Total (5 - 25)	17.2	2.4	17.0	3.3	17.3	3.1	17.8	2.5

C.2 Questionnaire of the Continental Mobility Study

Table A.8: Evaluation of statements of the Continental Mobility Study 2015 (Continental AG, 2015) for each driving study (MSG ≙ Mobility Study 2015 results of Germany; n/a ≙ not applicable)

	Study 1 $N = 35$	Study 2 $N = 36$	Study 3 $N = 39$	Study 4 $N = 34$	MSG $N = 1{,}800$
Automated driving can relieve me of the driving task in monotonous or stressful driving situations.					
"I tend to agree"	100 %	89 %	100.0 %	97 %	68 %
"I tend to object"	0.0 %	0.0 %	0.0 %	0.0 %	n/a
"I am unable to say"	0.0 %	11 %	0.0 %	3 %	n/a
Automated driving can prevent serious accidents.					
"I tend to agree"	94%	83 %	87 %	85 %	63 %
"I tend to object"	3 %	0.0 %	3 %	3 %	n/a
"I am unable to say"	3 %	17 %	10 %	12 %	n/a
I don't believe that it will ever function reliably.					
"I tend to agree"	0.0 %	3 %	0.0 %	6 %	47 %
"I tend to object"	91 %	94 %	92 %	94 %	n/a
"I am unable to say"	9 %	3 %	8 %	0 %	n/a
When the car drives itself I could do other things.					
"I tend to agree"	82 %	69 %	64 %	88 %	46 %
"I tend to object"	9 %	25 %	21 %	6 %	n/a
"I am unable to say"	9 %	6 %	15 %	6 %	n/a
Automated driving scares me.					
"I tend to agree"	6 %	8 %	0.0 %	0.0 %	43 %
"I tend to object"	88 %	72 %	92 %	94 %	n/a
"I am unable to say"	6 %	20 %	8 %	6 %	n/a

D Information for the Driving Studies

D.1 Notes Driving Study 1

Fahrversuch zu Fahrzeugnickbewegungen als Feedback-Kanal für den Fahrer beim automatisierten Fahren

Instruktion für Versuchspersonen

Herzlich Willkommen zur Probandenstudie mit dem Thema „Wirkweise und Akzeptanz von Fahrzeugnickbewegungen als Feedback-Kanal für den Fahrer beim automatisierten Fahren“.

Sie haben sich bereit erklärt, als Versuchsperson an dieser Studie teilzunehmen, wofür wir Ihnen herzlich danken.

Bitte nehmen Sie sich Zeit die folgenden Hinweise zu lesen, um etwas über den Versuch und dessen Ablauf zu erfahren. Falls während des Lesens der Instruktion oder im Laufe des Versuchs Fragen entstehen, zögern Sie nicht diese Ihrem Versuchsleiter zu stellen.

Wir bitten Sie sich klar zu machen, dass es sich bei dem in diesem Versuch eingesetzten Fahrzeug um einen Prototyp handelt.

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.

Neben den von Ihnen getätigten Angaben in den Fragebögen werden während des Versuchs Messdaten des Fahrzeugs, ein Portraitvideo sowie der Ton im Fahrzeug aufgezeichnet. Die Daten werden ausschließlich für die wissenschaftliche Auswertung im Rahmen des Versuchs verwendet. Die Daten bilden die Grundlage zur Ableitung statistisch evaluierter Ergebnisse, die keine Rückschlüsse auf einzelne Personen zulassen. Des Weiteren steht es Ihnen natürlich frei den Versuch ohne Angaben von Gründen jederzeit abzubrechen.

Fahrzeug und Funktionen des teilautomatisierten Assistenzsystems

Das Fahrzeug ist ein Audi A5 Prototyp und Eigentum der AUDI AG. Darin ist eine teilautomatisierte Fahrfunktion integriert, welches selbstständig die Längs- (Bremsen und Beschleunigen) und Querführung (Lenken) des Fahrzeugs ausführen kann. Es fährt mit einer maximalen Geschwindigkeit von 60 km/h. Über ein aktives Fahrwerk kann der Prototyp dabei gezielte Fahrzeugnickbewegungen zur Rückmeldung der Änderung des Systemzustands, wie beispielsweise der Wechsel von einer Freifahrt hin zu einer Folgefahrt hinter einem langsameren Vorderfahrzeug, realisieren.

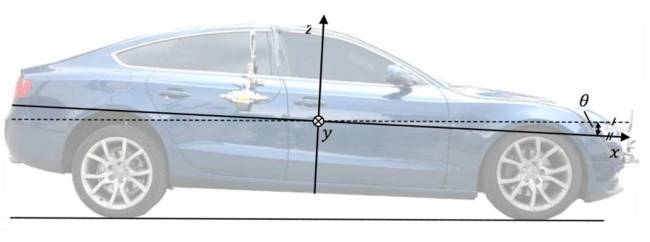


Abbildung 1: Versuchsfahrzeug - aktives Nicken

Da es sich bei dem getesteten System um ein teilautomatisiertes System handelt, sind Sie jederzeit in der Verantwortung und müssen das System sowie Ihr Umfeld dauerhaft überwachen.

Sie dürfen während der Fahrt keine Nebenaufgaben ausführen und müssen jederzeit bereit sein die Fahraufgabe wieder zu übernehmen. In diesem Fall wird Sie entweder das Fahrzeug selbst oder der Versuchsleiter zur Übernahme auffordern. Folgen Sie dieser Anweisungen bitte augenblicklich!

Falls Sie selbst das Gefühl haben, dass das System einen Fehler macht oder die Situation Ihnen zu gefährlich wird, können Sie das System übersteuern.

Deaktiviert wird das System durch folgende Bedienhandlungen:

- Drücken des Automationsknopfes (diesen wird Ihnen der Versuchsleiter zeigen)
- Betätigung des Bremspedals
- Betätigung des Gaspedals
- Aufbringung eines größeren Lenkmoments

Die Deaktivierung des Systems wird Ihnen visuell im Kombi-Instrument des Fahrzeugs sowie akustisch, durch einen Gong zurückgemeldet.

Sollte es vorkommen, dass sich das System durch die oben genannten Bedienhandlungen nicht deaktivieren lässt, kann durch **Betätigung des Notschalters in der Mittelkonsole eine Abschaltung des Systems ausgelöst werden.** Dies ist allerdings nur im Notfall zu tun, da es einen Neustart des gesamten Fahrzeugs notwendig macht.

Grundsätzlich wird das Fahrzeug je nach Fahrbahnbeschaffenheit und Situation ruhiger oder unruhiger fahren. Unruhiges Fahrverhalten macht sich z.B. durch leicht schwingende Lenkbewegungen bemerkbar. Dies ist an sich kein Grund zur Sorge. Durch Ungenauigkeiten in der Lokalisierung des Fahrzeugs kann es außerdem vorkommen, dass das Fahrzeug zeitweise nicht ganz mittig im Fahrstreifen fährt. Dies ist ebenfalls keine Fehlfunktion.

Sollte Ihnen das Verhalten jedoch zu irgendeinem Zeitpunkt zu unsicher werden, dürfen Sie das System jederzeit deaktivieren.

Ablauf des Versuchs

Abbildung 2: Ablauf Studie

Oben dargestellt sehen Sie in Abbildung 2 den geplanten Ablauf des Versuchs. Das Versuchsgelände bildet die FASIS Teststrecke des Audi Driving Experience Center in Neuburg an der Donau mit einer Gesamtlänge von 1400 Metern (siehe Abbildung 3).

Abbildung 3: Luftaufnahme Testgelände

Die Studie beginnt mit einer kurzen Instruktion durch den Versuchsleiter. Danach beginnt eine Eingewöhnungsphase, bei der Sie die Gelegenheit bekommen sich an das teilautomatisierte Fahren, die aktiven Fahrzeugnickbewegungen und die Bedienung des Automationssystems zu gewöhnen. Des Weiteren erlernen Sie die Methode, mit denen Sie im weiteren Verlauf die Nickbewegungen bewerten werden.

Den Hauptteil des Versuches bilden vier definierte Fahrsituationen. Unser Ziel ist es hierbei herauszufinden, welche Fahrzeugnickbewegungen für Sie als Fahrer in der jeweiligen Fahrsituation sinnvoll ist. Die Fahrsituationen spielen sich ausschließlich auf den Geraden des Kurses ab. Die Fahrzeugnickbewegungen kündigen hierbei die Änderung des Zustands der Automation an. Diese vier Fahrsituationen werden Sie erleben:

- Fahrsituation 1 : Versuchsfahrzeug identifiziert Vorderfahrzeug und setzt zur Folgefahrt an (analog ACC)
- Fahrsituation 2 : Versuchsfahrzeug identifiziert ein Vorderfahrzeug und setzt zum Fahrstreifenwechsel an
- Fahrsituation 3 : Ein anderes Fahrzeug überholt das Versuchsfahrzeug und schert ein
- Fahrsituation 4: Versuchsfahrzeug erkennt eine Geschwindigkeitsbegrenzung und passt seine Geschwindigkeit an

Während der Fahrt wird Ihr Urteil zu den Nickbewegungen abgefragt. Außerdem werden die Nickbewegungen anhand Ihres Urteils innerhalb gewisser Grenzen angepasst.

Falls Sie noch offene Fragen haben, zögern Sie nicht diese Ihrem Versuchsleiter persönlich noch vor Beginn des Versuchs zu stellen.

Wir bedanken uns bereits im Voraus für Ihre Teilnahme.

D.2 Notes Driving Study 2

Realfahrzeugstudie zum teilautomatisierten Fahren
Gestaltung des Feedbacks für den Fahrer

Herzlich Willkommen zur Probandenstudie zum Thema „Gestaltung des Feedbacks für den Fahrer beim teilautomatisierten Fahren“. 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

Wir bitten Sie sich klar zu machen, 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 den Verlauf des Fahrstreifens mittig zu folgen)
  - Das Fahrzeug kann eigenständig einen Fahrstreifenwechsel durchführen

---

Ein aktiviertes Automationssystem ist durch die grün leuchtenden Lampen des ACC- und des Querführungssystems im Kombi-Instrument erkenntlich (siehe Abbildung 1).


Automationssystem aktiv

Abbildung 1: Aktiviertes Automationssystem, Kombi-Instrument des Audi A5 Prototyps

Die Position Ihrer Hände variiert je nach Versuchsteil. In einem Versuchsteil werden Sie Ihre Hände wie gewohnt am Lenkrad haben. In einem anderen Versuchsteil befinden sich Ihre Hände nicht dauerhaft am Lenkrad. Sie müssen das Lenkrad aber in Zeitintervallen von ca. 60 Sekunden kurz berühren. Sie werden dazu durch ein gelbes Blinken der Querführungssystem-Lampe (siehe Abbildung 1, rechtes Symbol) aufgefordert. Gegebenenfalls wird Sie die Versuchsleiterin daran erinnern.

Im Normalfall müssen Sie das Fahrgeschehen nicht aktiv beeinflussen, jedoch jederzeit zu einer vollständigen Übernahme der Fahrzeugführung bereit sein. Ihre Aufgabe ist es demnach, das Automationssystem und Ihr Umfeld dauerhaft zu überwachen und zu eruieren, ob Ihr Eingreifen notwendig ist.

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

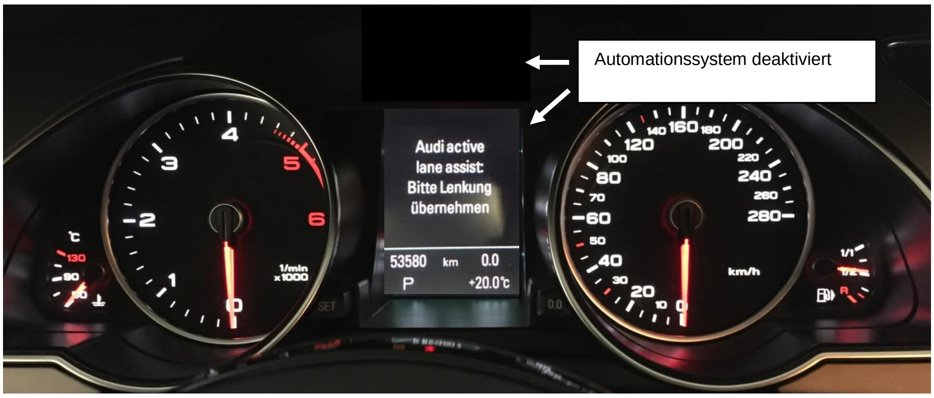
Potentiell kritische Situationen
Hier sollten Sie besonders aufmerksam sein:

- 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 einem Fahrstreifenwechsel mit einer deutlich höheren Geschwindigkeit von hinten annähern und Fahrzeuge, die sich während einem Fahrstreifenwechsel im Zielfahrstreifen befinden oder sich dort hin bewegen
  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. Darüber hinaus können Sie auch über das Kombi-Instrument im Fahrzeug (siehe Abbildung 2) oder die Versuchsleiterin zu einer sofortigen Übernahme aufgefordert werden. Folgen Sie dieser Anweisung bitte augenblicklich!


[redacted]

Automationssystem deaktiviert

Audi active lane assist: Bitte Lenkung übernehmen

Abbildung 2: Übernahmeaufforderung, Kombi-Instrument des Audi A5 Prototyps

Übernahme der Fahrzeugführung / Deaktivierung des Automationssystems

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

Ein deaktiviertes System ist durch die erloschenen Lampen des ACC- und des Querführungssystems (Abbildung 2, oben) im Kombi-Instrument erkenntlich. Zusätzlich erscheint der Hinweis „Bitte Lenkung übernehmen“ (Abbildung 2, unten) und ein Gong ertönt.

Sollte es vorkommen, dass sich das Automationssystem durch die oben genannten Bedienhandlungen nicht deaktivieren lässt, kann durch Betätigung des Notschalters 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.

Die Versuchsleiterin 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).

Aufnahme und Verwertung der Daten

Neben den von Ihnen getätigten Angaben in den Fragebögen (vor, während und nach dem Versuch), werden während des Versuchs Messdaten des Fahrzeugs, ein Portraitvideo sowie der Ton im Fahrzeug aufgezeichnet. Die Daten werden ausschließlich für die wissenschaftliche Auswertung im Rahmen des Versuchs verwendet. Die Daten bilden die Grundlage zur Ableitung statistisch evaluierter Ergebnisse, die keine Rückschlüsse auf einzelne Personen zulassen.

Inhalt und Ablauf des Versuchs

Im Versuch fahren Sie die Strecke zwischen Lenting und Holledau zwei Mal. Wir werden sowohl an der Raststätte in Holledau, als auch an einem Pendlerparkplatz in Lenting halten. Damit ist der Versuchsstrecke in 4 Abschnitte unterteilt (siehe Abbildung 3).

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 Versuchsleiterinnen zu stellen.

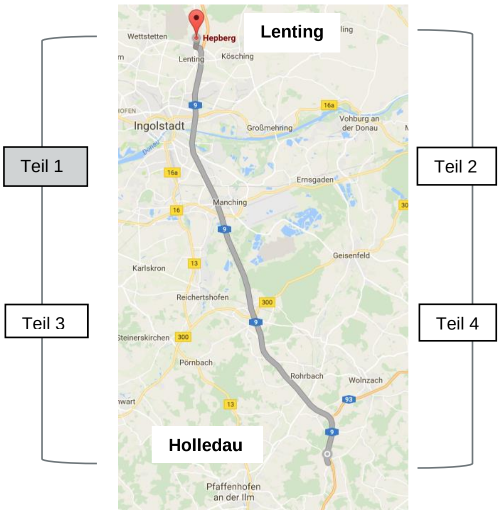


Abbildung 3: Versuchsstrecke A9

Der erste Teil des Versuchs dient zur Eingewöhnung. Zunächst machen Sie sich mit dem Fahrzeug vertraut, indem Sie ca. 5 Minuten mit einem Abstandsregeltempomat (ACC) fahren. Die Bedienung des ACC im Fahrzeug wird Ihnen zuvor gezeigt.

Nach Aktivierung des Automationssystems durch den Versuchsleiter wird in eine teilautomatisierte Fahrt gewechselt, wobei das Fahrzeug zusätzlich die Querführung übernimmt.

Sie haben auch hier die Gelegenheit sich mit dem Automationssystem vertraut zu machen. Sie werden von der Versuchsleiterin aufgefordert ihre Hände zeitweise vom Lenkrad zu nehmen. In Holledau werden Sie von der Autobahn abfahren. Dort werden Ihnen die weiteren Schritte des Versuchs erklärt.

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.

Zur Teilnahme an diesem Versuch ist noch eine Erklärung notwendig, die Sie auf der nächsten Seite 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 im Voraus.

D.3 Notes Driving Study 3

Realfahrzeugstudie zum teilautomatisierten Fahren
Aktive Fahrzeugwankbewegungen als Feedback für den Fahrer

Herzlich Willkommen zur Probandenstudie zum Thema „Aktive Fahrzeugwankbewegungen als Feedback für den Fahrer beim teilautomatisierten Fahren“. Vorab schon einmal vielen Dank, dass Sie an dieser Studie teilnehmen! Bitte nehmen Sie sich Zeit die folgenden Hinweise zu lesen, um mehr über den Versuch und dessen Ablauf zu erfahren.

Funktionen des Fahrzeugs und Ihre Aufgaben als Fahrer

Wir bitten Sie sich klar zu machen, 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 bewusst ist, dass ein Fahrfehler des Automationssystems oder Ihrerseits auftreten kann.

Funktionen des Automationssystems

- Längsführung (eigenständiges Bremsen und Beschleunigen)
  - Die maximale Geschwindigkeit im Versuch beträgt 60 km/h und es erfolgt eine Anpassung der Geschwindigkeit an den Streckenverlauf
  - 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

Ein aktiviertes Automationssystem ist durch die grün leuchtenden Lampen des ACC- und des Querführungssystems im Kombi-Instrument erkenntlich (siehe Abbildung 1).

Abbildung 1: Aktiviertes Automationssystem, Kombi-Instrument des Audi A5 Prototyps

Während der Versuchsfahrt befinden sich Ihre Hände nicht dauerhaft am Lenkrad. Sie müssen das Lenkrad aber in Zeitintervallen von ca. 60 Sekunden kurz berühren. Dazu werden Sie durch ein gelbes Blinken der Querführungssystem-Lampe (siehe Abbildung 1, rechtes Symbol) aufgefordert. Gegebenenfalls wird Sie die Versuchsleiterin daran erinnern.

Im Normalfall müssen Sie das Fahrgeschehen nicht aktiv beeinflussen, jedoch jederzeit zu einer vollständigen Übernahme der Fahrzeugführung bereit sein. Ihre Aufgabe ist es demnach, das Automationssystem und Ihr Umfeld dauerhaft zu überwachen und zu eruieren, ob Ihr Eingreifen notwendig ist.

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 oder seitlich sehr nahe kommende Fahrzeuge
  Grund: Diese Fahrzeuge werden möglicherweise nicht oder zu spät erkannt
- Fahrzeuge, welche sich während eines Fahrstreifenwechsels mit einer deutlich höheren Geschwindigkeit von hinten annähern und Fahrzeuge, welche sich während eines Fahrstreifenwechsels im Zielfahrstreifen befinden oder sich dort hin bewegen
  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 Ihnen die Situation zu gefährlich wird, können Sie das Automationssystem übersteuern, d.h. selbst die Fahrzeugführung übernehmen. Darüber hinaus können Sie auch über das Kombi-Instrument im Fahrzeug (siehe Abbildung 2) oder die Versuchsleiterin zu einer sofortigen Übernahme aufgefordert werden. Folgen Sie dieser Anweisung bitte augenblicklich.


[redacted]

Automationssystem deaktiviert
Fahrzeugführung übernehmen!

Audi active lane assist: Bitte Lenkung übernehmen

Abbildung 2: Übernahmeaufforderung, Kombi-Instrument des Audi A5 Prototyps

Übernahme der Fahraufgabe / Deaktivierung des Automationssystems

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

Ein deaktiviertes System ist durch die erloschenen Lampen des ACC- und des Querführungssystems (Abbildung 2, oben) im Kombi-Instrument erkenntlich. Zusätzlich erscheint der Hinweis „Bitte Lenkung übernehmen“ (Abbildung 2, unten) und ein Gong ertönt.

Sollte es vorkommen, dass sich das Automationssystem durch die oben genannten Bedienhandlungen nicht deaktivieren lässt, kann durch Betätigung des Notschalters 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.

Die Versuchsleiterin 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, können Sie jederzeit die Fahrzeugführung übernehmen (Deaktivierung des Automationssystems).

Aufnahme und Verwertung der Daten

Neben den von Ihnen getätigten Angaben in den Fragebögen (vor, während und nach dem Versuch), werden während der Versuchsfahrt Messdaten des Fahrzeugs, ein Portraitvideo sowie der Ton im Fahrzeug aufgezeichnet. Die Daten werden ausschließlich für die wissenschaftliche Auswertung im Rahmen des Versuchs verwendet. Die Daten bilden die Grundlage zur Ableitung statistisch evaluierter Ergebnisse, die keine Rückschlüsse auf einzelne Personen zulassen.

Aktive Fahrzeugwankbewegungen als Feedback für den Fahrer

Um Ihnen zu verdeutlichen was mit aktiven Fahrzeugwankbewegungen gemeint ist, sind in den folgenden Abbildungen (Abb. 3 – Abb. 5) die aktiven Fahrzeugwankbewegungen dargestellt, welche im Versuch zum Einsatz kommen. Diese Wankbewegungen werden mithilfe eines aktiven Fahrwerks des Prototyps realisiert. Im Rahmen dieser Studie kündigen diese Fahrzeugwankbewegungen Fahraktionen der Automation als Feedback für den Fahrer an. Dies kann beispielsweise die Ankündigung eines Fahrstreifenwechsels sein.

Abbildung 3: Keine aktive Fahrzeugbewegung

Abbildung 4: Aktive Fahrzeugwankbewegung nach links

Abbildung 5: Aktive Fahrzeugwankbewegung nach rechts

Inhalt und Ablauf des Versuchs

Die Versuchsfahrt wird auf dem Gelände des Audi Driving Experience Centers in Neuburg an der Donau stattfinden. Dort werden Sie von den zwei Versuchsleiterinnen empfangen, welche Sie durch den Versuch begleiten werden. In Abbildung 6 können Sie die ovale, dreispurige Teststrecke mit einer Gesamtlänge von 1400 Metern sehen. Diese wird im Rahmen der Studie abgefahren.

Abbildung 6: Luftaufnahme Testgelände

Die Studie beginnt mit einer kurzen Instruktion durch die Versuchsleiterinnen. Danach beginnt eine Eingewöhnungsphase, in der Sie die Gelegenheit bekommen sich an das teilautomatisierte Fahren, die aktiven Fahrzeugwankbewegungen und die Bedienung des Automationssystems zu gewöhnen. Des Weiteren erlernen Sie, wie Sie die aktiven Fahrzeugwankbewegungen im weiteren Verlauf bewerten werden.

Den Hauptteil des Versuches bilden verschiedene Fahrsituationen wie:

- Fahrstreifenwechsel nach links um ein vorausfahrendes Fahrzeug zu überholen,
- Fahrstreifenwechsel nach rechts um vor einem anderen Fahrzeug einzuscheren,
- Abbruch eines Überholvorgangs

Unser Ziel ist es herauszufinden, welche Fahrzeugwankbewegungen für Sie als Fahrer in der jeweiligen Fahrsituation als sinnvoll erachtet werden. Während und nach der Fahrt wird Ihr Urteil zu den Wankbewegungen abgefragt. In Abbildung 7 ist der geplante Ablauf des Versuchs dargestellt.

Abbildung 7: Ablauf Studie

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 Versuchsleiterinnen zu stellen.

Gerne können Sie alle versuchsbezogenen Fragen während des Versuchs 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.

Zur Teilnahme an diesem Versuch sind noch zwei Erklärungen notwendig, welche Sie auf den nächsten Seiten finden. Bringen Sie diese bitte unterschrieben zum Versuch mit. Des Weiteren steht es Ihnen natürlich frei den Versuch ohne Angabe von Gründen jederzeit abzubrechen.

Im Voraus nochmals vielen Dank für Ihre Teilnahme!

D.4 Notes Driving Study 4

Realfahrzeugstudie zum teilautomatisierten Fahren

Aktive Fahrzeugaufbaubewegungen und visuelle Anzeige als Feedback für den Fahrer

Herzlich Willkommen zur Probandenstudie zum Thema „Aktive Fahrzeugaufbaubewegung und visuelle Anzeige als Feedback für den Fahrer beim teilautomatisierten Fahren“. Vorab schon einmal vielen Dank, dass Sie an dieser Studie teilnehmen! Bitte nehmen Sie sich Zeit die folgenden Hinweise zu lesen, um mehr über den Versuch und dessen Ablauf zu erfahren.

Funktionen des Fahrzeugs und Ihre Aufgaben als Fahrer

Wir bitten Sie sich klar zu machen, 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 bewusst ist, dass ein Fahrfehler des Automationssystems oder Ihrerseits auftreten kann.

Funktionen des Automationssystems

- Längsführung (eigenständiges Bremsen und Beschleunigen)
  - Die maximale Geschwindigkeit im Versuch beträgt 120 km/h und es erfolgt gegebenenfalls 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

Ein aktiviertes Automationssystem ist durch das Leuchten des Automationstasters in der Mittelkonsole und die Anzeige (Siehe Abbildung 1) auf dem Kombi-Instrument erkenntlich. Während der Versuchsfahrt befinden sich Ihre Hände nicht dauerhaft am Lenkrad. Sie müssen das Lenkrad aber in Zeitintervallen von ca. 60 Sekunden kurz berühren. Dazu werden Sie durch eine Anzeige im Kombi-Instrument (Siehe Abbildung 2) aufgefordert. Gegebenenfalls wird Sie die Versuchsleiterin daran erinnern.

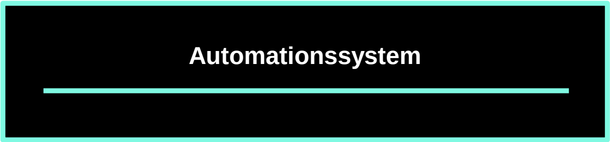


Abbildung 1: Schematische Darstellung der Anzeige des aktivierten Automationssystems

Abbildung 2: Schematische Darstellung der Aufforderung zum Lenkrad berühren

Im Normalfall müssen Sie das Fahrgeschehen nicht aktiv beeinflussen, jedoch jederzeit zu einer vollständigen Übernahme der Fahrzeugführung bereit sein. Ihre Aufgabe ist es demnach, das Automationssystem und Ihr Umfeld dauerhaft zu überwachen und zu eruieren, ob Ihr Eingreifen notwendig ist.

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. bei Autobahnauffahrten) oder seitlich sehr nahe kommende Fahrzeuge
  Grund: Diese Fahrzeuge werden möglicherweise nicht oder zu spät erkannt
- Fahrzeuge, welche sich während eines Fahrstreifenwechsels mit einer deutlich höheren Geschwindigkeit von hinten annähern und Fahrzeuge, welche sich während eines Fahrstreifenwechsels im Zielfahrstreifen befinden oder sich dort hin bewegen
  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 Ihnen die Situation zu gefährlich wird, können Sie das Automationssystem übersteuern, d.h. selbst die Fahrzeugführung übernehmen. Darüber hinaus können Sie auch über das Kombi-Instrument im Fahrzeug oder die Versuchsleiterin zu einer sofortigen Übernahme aufgefordert werden. Folgen Sie dieser Anweisung bitte augenblicklich.

Übernahme der Fahraufgabe / Deaktivierung des Automationssystems

- Drücken des Automationstasters (diesen wird Ihnen die Versuchsleiterin zeigen)
- Betätigung des Bremspedals
- Betätigung des Gaspedals
- Aufbringung einer starken Lenkbewegung

Ein deaktiviertes System ist durch das Ertönen eines Gongs und durch den Hinweis „Bitte Hände ans Lenkrad!“ (Siehe Abbildung 2) erkenntlich. Zusätzlich erlischt das Licht des Automationstasters in der Mittelkonsole.

Sollte es vorkommen, dass sich das Automationssystem durch die oben genannten Bedienhandlungen nicht deaktivieren lässt, kann durch Betätigung des Notschalters 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.

Die Versuchsleiterin 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, können Sie jederzeit die Fahrzeugführung übernehmen (Deaktivierung des Automationssystems).

Aufnahme und Verwertung der Daten

Neben den von Ihnen getätigten Angaben in den Fragebögen (vor, während und nach dem Versuch), werden während der Versuchsfahrt Messdaten des Fahrzeugs, ein Portraitvideo sowie der Ton im Fahrzeug aufgezeichnet. Außerdem werden Ihre Blickdaten mithilfe eines „Eye-Tracking“-Systems erfasst.

Die Daten werden für die wissenschaftliche Auswertung im Rahmen des Versuchs sowie für die Weiterentwicklung eines Blickerfassungssystems verwendet. Die Daten werden soweit möglich pseudonymisiert gespeichert und bilden die Grundlage zur Ableitung statistisch evaluierter Ergebnisse.

Inhalt und Ablauf des Versuchs

Die Versuchsleiterinnen werden Sie am Parkplatz gegenüber der Esso-Tankstelle an der Autobahnauffahrt Lenting empfangen (Adresse: Am Sportplatz, 85120 Lenting). Anschließend 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 Versuchsleiterinnen zu stellen.

Im Versuch fahren Sie die Strecke zwischen Lenting und Holledau zwei Mal. Wir werden sowohl an der Raststätte in Holledau, als auch an einem Pendlerparkplatz in Lenting halten. Damit ist der Versuchsstrecke in 4 Abschnitte unterteilt (Siehe Abbildung 3).

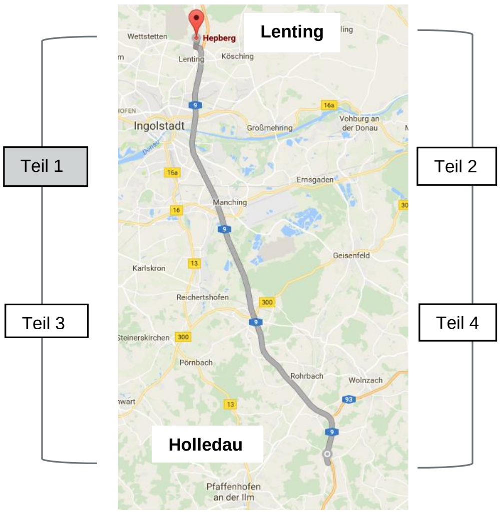


Abbildung 3: Versuchsstrecke A9

Der erste Teil des Versuchs dient zur Eingewöhnung. Zunächst machen Sie sich mit dem Fahrzeug vertraut, indem Sie ca. 5 Minuten mit einem Abstandsregeltempomat (ACC) fahren. Die Bedienung des ACC im Fahrzeug wird Ihnen zuvor gezeigt.

Nach Aktivierung des Automationssystems durch den Versuchsleiter wird in eine teilautomatisierte Fahrt gewechselt, wobei das Fahrzeug zusätzlich die Querführung übernimmt.

Sie haben auch hier die Gelegenheit sich mit dem Automationssystem vertraut zu machen. Sie werden von der Versuchsleiterin aufgefordert ihre Hände zeitweise vom Lenkrad zu nehmen. In Holledau werden Sie von der Autobahn abfahren. Dort werden Ihnen die weiteren Schritte des Versuchs erklärt.

Zur Teilnahme an diesem Versuch sind noch die Erklärungen notwendig, die wir Ihnen ebenfalls zugeschickt haben. Bringen Sie diese bitte unterschrieben zum Versuch mit. Es steht Ihnen natürlich frei den Versuch ohne Angaben von Gründen jederzeit abzubrechen.

Im Voraus nochmals vielen Dank für Ihre Teilnahme!

E Questionnaires of the Driving Studies

E.1 Pre-Questionnaire Driving Study 1

Nickbewegungen als Feedback-Kanal für den Fahrer beim automatisierten Fahren

Liebe Interessentinnen und Interessenten,

Wir möchten Sie herzlich zur Teilnahme an einer Probandenstudie zum Thema „Wirkweise und Akzeptanz von Fahrzeugnickbewegungen als Feedback-Kanal für den Fahrer beim automatisierten Fahren“ einladen. Die Studie findet im Rahmen eines Promotionsprojektes statt.

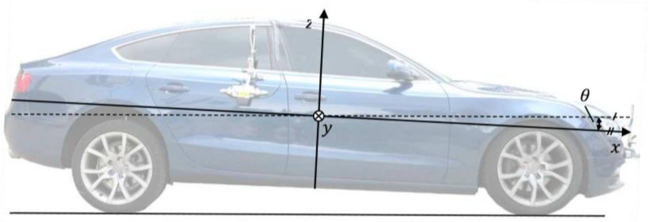


Abbildung: Versuchsfahrzeug –aktive Fahrzeugnickbewegungen

Sie werden in einem Versuchsfahrzeug der AUDI AG verschiedene Ausprägungen von Fahrzeugnickbewegungen zur Rückmeldung der Änderung des Systemzustands (beispielsweise Freifahrt ↔ Folgefahrt) bei teilautomatisierter Fahrt auf dem Prüfgelände in Neuburg fahren. Dabei haben Sie Gelegenheit ein prototypisches Automationssystem zu erleben, welches unter Ihrer Aufsicht die Längs- und Querführung des Fahrzeugs für eine gewisse Zeit übernehmen kann.

Für die wissenschaftliche Untersuchung werden objektive Fahrdaten des Fahrzeugs und Ihre subjektiven Eindrücke mit Hilfe eines Fragebogens erfasst sowie ein Portraitvideo mit Tonaufnahme von Ihrer Fahrt aufgezeichnet.

Wenn Sie Interesse haben an diesem Versuch teilzunehmen, füllen Sie bitte den folgenden Fragebogen aus. Dieser fragt bereits einige Informationen wie Alter, Fahrpraxis und Erfahrung mit Fahrerassistenzsystemen ab. Wenn Ihr Profil zu unseren Versuchsanforderungen passt, werden wir uns im Anschluss mit Ihnen in Verbindung setzen, um einen Termin für die Versuchsfahrt zu vereinbaren. Details zur Probandenstudie finden Sie im Folgenden:

Wer: - Sichere und geübte Autofahrer
- Im Besitz eines eigenen Fahrzeugs oder regelmäßige Nutzung von Dienstfahrzeugen
- Mindestens Erfahrung mit Tempomat, idealerweise auch mit ACC und Spurhalteassistent

Wann: - Im Zeitraum vom 29.08.2016 - 16.09.2016
- Dauer des Versuchs: ca. 90 min
- Termine: 09:00-10:30 Uhr, 11:00-12:30 Uhr, 13:30-15:00 Uhr und 15:30-17:00 Uhr
- Die An- und Abreisezeit ist in der Versuchsdauer nicht berücksichtigt

Wo: - Audi Driving Experience Center- Neuburg a.d. Donau
- Wir bitten Sie, die Anfahrt selbst zu organisieren

Vielen Dank für Ihre Unterstützung!

Demographie

Ihr Alter:.	_______________ Jahre
Ihr Geschlecht:	☐ weiblich ☐ männlich
Jährliche Gesamt-Kilometerleistung:	ca.: _______________ km

Ihr Fahrstil

Im Vergleich zu anderen Autofahrern fahre ich überwiegend…						
schnell	☐	☐	☐	☐	☐	langsam
ängstlich	☐	☐	☐	☐	☐	mutig
offensiv	☐	☐	☐	☐	☐	defensiv
vorsichtig	☐	☐	☐	☐	☐	risikobereit
sportlich	☐	☐	☐	☐	☐	gemütlich

Ihre Erfahrungen mit Fahrerassistenzsystemen

Welche der folgenden Assistenzsysteme haben Sie bereits als Fahrer erlebt?		
Teilautomatisierte Systeme (z.B. Stauassistenz)	☐ Ja	☐ Nein
Aktiver Spurhalteassistent (mit Lenkeingriff)	☐ Ja	☐ Nein
Adaptive Geschwindigkeitsregelung (ACC)	☐ Ja	☐ Nein

Wenn Sie diese in Ihrem eigenen Fahrzeug oder Ihrem Dienstwagen haben oder hatten, wie oft haben Sie diese verwendet oder verwenden diese?					
	nie	selten	gelegentlich	oft	immer
Teilautomatisierte Systeme (z.B. Stauassistenz)	☐	☐	☐	☐	☐
Aktiver Spurhalteassistent (mit Lenkeingriff)	☐	☐	☐	☐	☐
Adaptive Geschwindigkeitsregelung (ACC)	☐	☐	☐	☐	☐

Ihre Einstellung zum automatisierten Fahren

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

E.2 Questionnaire Driving Study 1

Fragebogen vor dem Fahrversuch

Bitte beschreiben Sie Ihre Erwartungshaltung an die Fahrzeugnickbewegungen.						
	Trifft ganz und gar nicht zu	Trifft nicht zu	Trifft eher nicht zu	Trifft eher zu	Trifft zu	Trifft voll und ganz zu
Ich wünsche mir keine Dynamik durch ein aktives Nicken des Fahrzeugs.	☐	☐	☐	☐	☐	☐
Ich möchte so wenig Dynamik wie möglich, um einen möglichst geringen Diskomfort zu erreichen.	☐	☐	☐	☐	☐	☐
Ich wünsche mir eine deutlich spürbare Dynamik, um die Zustandsänderung der Automation zu erkennen.	☐	☐	☐	☐	☐	☐

Erleben Sie gerade Übelkeit, Kopfschmerzen oder Schwindel? Wenn ja, wie stark?						
gar nicht	sehr schwach	schwach	etwas	ziemlich	stark	sehr stark
☐	☐	☐	☐	☐	☐	☐

Fragebogen während jeder Fahrsituation (mündliche Befragung)

Nickprofil		**gar nicht 0**	**sehr gering 1**	**gering 2**	**mittel 3**	**hoch 4**	**sehr hoch 5**
1☐ **-1**☐ **4**☐ **-4**☐	Wahrnehmbarkeit	☐	☐	☐	☐	☐	☐
	Situationsbezug	☐	☐	☐	☐	☐	☐
	Diskomfort	☐	☐	☐	☐	☐	☐
2☐ **-2**☐ **5**☐ **-5**☐	Wahrnehmbarkeit	☐	☐	☐	☐	☐	☐
	Situationsbezug	☐	☐	☐	☐	☐	☐
	Diskomfort	☐	☐	☐	☐	☐	☐
3☐ **-3**☐ **6**☐ **-6**☐	Wahrnehmbarkeit	☐	☐	☐	☐	☐	☐
	Situationsbezug	☐	☐	☐	☐	☐	☐
	Diskomfort	☐	☐	☐	☐	☐	☐

Fragebogen nach jeder Fahrsituation

	nach vorne	nach hinten
Für die folgende Nickbewegungsrichtung habe ich mich entschieden:	☐	☐

	Großer Winkel	Kleiner Winkel
Ich bevorzuge den folgenden maximalen Nickwinkel:	☐	☐

	„Schnelle“ Rückführung	„Langsame“ Rückführung
Nach der aktiven Nickbewegung bevorzuge ich die folgende Rückführung des Fahrzeugs zurück in die horizontale Lage:	☐	☐

Ihre Einschätzung der Nickbewegungen						
	Trifft ganz und gar nicht zu	Trifft nicht zu	Trifft eher nicht zu	Trifft eher zu	Trifft zu	Trifft voll und ganz zu
Die Nickbewegungen finde ich sinnvoll.	☐	☐	☐	☐	☐	☐
Die Nickbewegungen sind irreführend.	☐	☐	☐	☐	☐	☐
Durch die Nickbewegungen habe ich die Zustandsänderung der Automation wahrgenommen.	☐	☐	☐	☐	☐	☐
Durch die Nickbewegungen wurde die Systemtransparenz und mein Systembewusstsein für die Automation erhöht.	☐	☐	☐	☐	☐	☐
Die Nickbewegungen waren nachvollziehbar und der Fahrsituation eindeutig zuordenbar.	☐	☐	☐	☐	☐	☐

Erleben Sie gerade Übelkeit, Kopfschmerzen oder Schwindel? Wenn ja, wie stark?						
gar nicht	sehr schwach	schwach	etwas	ziemlich	stark	sehr stark
☐	☐	☐	☐	☐	☐	☐

Anmerkungen: Haben Sie Anmerkungen zur Fahrzeugnickbewegung und/oder der Fahrsituation? *Bitte geben Sie diese hier an.*

Fragebogen nach dem Fahrversuch

Einschätzung der Dynamik der Nickbewegungen nach dem Fahrversuch.						
	Trifft ganz und gar nicht zu	Trifft nicht zu	Trifft eher nicht zu	Trifft eher zu	Trifft zu	Trifft voll und ganz zu
Ich wünsche mir keine Dynamik durch ein aktives Nicken des Fahrzeugs.	☐	☐	☐	☐	☐	☐
Ich möchte so wenig Dynamik wie möglich, um einen möglichst geringen Diskomfort zu erreichen.	☐	☐	☐	☐	☐	☐
Ich wünsche mir eine deutlich spürbare Dynamik, um die Zustandsänderung der Automation zu erkennen.	☐	☐	☐	☐	☐	☐

Ihre Einschätzung des Automationssystems						
	Trifft ganz und gar nicht zu	Trifft nicht zu	Trifft eher nicht zu	Trifft eher zu	Trifft zu	Trifft voll und ganz zu
Das Automationssystem gab mir ein Gefühl von Sicherheit.	☐	☐	☐	☐	☐	☐
Ich kann dem Automationssystem vertrauen.	☐	☐	☐	☐	☐	☐
Durch die Nickbewegungen habe ich die Logik des Automationssystems besser nachvollziehen können.	☐	☐	☐	☐	☐	☐

Anmerkungen
Haben Sie noch Anmerkungen zu dem Fahrversuch, den Fragebögen oder allgemeine Anmerkungen? *Bitte geben Sie diese hier an.*

E.3 Pre-Questionnaire Driving Study 2

Fahrversuch zum Thema „Gestaltung des Feedbacks für den Fahrer beim teilautomatisierten Fahren“

Liebe Interessentinnen und Interessenten,

wir möchten Sie herzlich zur Teilnahme an der Probandenstudie zum Thema „Gestaltung des Feedbacks für den Fahrer beim teilautomatisierten Fahren“ einladen. Die Studie findet im Rahmen eines Promotionsprojektes statt.

In der teilautomatisierten Fahrt übernimmt das Automationssystem die Längs- und Querführung. Der Fahrer überwacht das System dabei dauerhaft und ist somit zu jedem Zeitpunkt zu einer möglichen Übernahme der Fahraufgabe bereit. Voraussetzung für eine erfolgreiche Übernahme der Fahraufgabe ist, dass der Fahrer fortlaufend sowohl über das Geschehen um das Fahrzeug, als auch über den Zustand und die Absichten der Automation informiert ist. Um dieser Anforderung gerecht zu werden, wurde eine neuartige Form der Rückmeldung entwickelt und in einem Versuchsfahrzeug der AUDI AG umgesetzt. Nachdem eine erste Studie auf einem Prüfgelände stattfand, besteht nun die Möglichkeit dieses prototypische Automationssystem auf der Autobahn A9 zu testen und einen Beitrag zu dessen Weiterentwicklung zu leisten.

Voraussetzung für Ihre Teilnahme: Sie sind ein sicherer und geübter Autofahrer. Sie sind im Besitz eines eigenen Fahrzeugs oder nutzen regelmäßig Dienstfahrzeuge. Besonders weibliche Probanden werden zu einer Teilnahme ermutigt.

Details zur Studie:
Zeitraum: 23.01.2017 bis 24.02.2017
Termine (Mo – Fr): 8:30 - 10.30 Uhr, 11:00 - 13:00 Uhr, 14:00 - 16:00 Uhr
Treffpunkt: Esso Tankstelle Autobahnauffahrt Lenting

Zur wissenschaftlichen Auswertung des Versuchs werden objektive Fahrdaten des Fahrzeugs und Ihre subjektiven Eindrücke mit Hilfe eines Fragebogens erfasst sowie ein Portraitvideo mit Tonaufnahme von Ihrer Fahrt aufgezeichnet.

Wenn Sie Interesse haben an diesem Versuch teilzunehmen, füllen Sie bitte den folgenden Fragebogen aus. Dieser fragt bereits einige Informationen wie Angaben zu Ihrer Person, Ihre Fahrgewohnheiten und Ihre Erfahrungen mit Fahrerassistenzsystemen ab. Die Beantwortung der Fragen wird ca. 10 Minuten in Anspruch nehmen.

Leider kann nur eine begrenzte Anzahl an Personen an diesem Versuch teilnehmen. Sofern Ihr Profil zu unseren Versuchsanforderungen passt, werden wir uns im Anschluss mit Ihnen in Verbindung setzen, um einen Termin für die Versuchsfahrt zu vereinbaren.

Vielen Dank für Ihre Unterstützung!

Demographie

Ihr Alter:	_____________ Jahre
Ihr Geschlecht:	☐ weiblich ☐ männlich
In welchem Tätigkeitsfeld arbeiten Sie?	☐ Technisches Tätigkeitsfeld ☐ Nicht-technisches Tätigkeitsfeld

Ihre Fahrgewohnheiten

Legen Sie Ihren Arbeitsweg mit dem Auto zurück?	☐ Ja ☐ Nein	
Wie hoch ist Ihre wöchentliche Kilometerleistung durch den Arbeitsweg?	ca. ________________ Kilometer	
Wie verteilt sich Ihr Arbeitsweg (in km) auf folgende Straßentypen (gesamt 100%)? *Falls Sie einen Straßentypen nicht nutzen, tragen Sie bitte Null ein.*	Stadt (%)	
	Land-/Bundesstraße (%)	
	Autobahn (%)	
Legen Sie sonstige Strecken (privat oder dienstlich) mit dem Auto zurück?	☐ Ja ☐ Nein	
Wie hoch ist Ihre wöchentliche Kilometerleistung durch sonstige Fahrten?	ca. ________________ Kilometer	
Wie verteilen sich Ihre sonstigen Fahrten (in km) auf folgende Straßentypen (gesamt 100%)? *Falls Sie einen Straßentypen nicht nutzen, tragen Sie bitte Null ein.*	Stadt (%)	
	Land-/Bundesstraße (%)	
	Autobahn (%)	
Wie hoch ist Ihre jährliche Kilometerleistung (inkl. Urlaubsfahrten, etc.) insgesamt? *Geben Sie bitte den Bereich an.*	bis 10.000 km	☐
	10.001 – 15.000 km	☐
	15.001 – 20.000 km	☐
	20.001 – 30.000 km	☐
	30.001 – 40.000 km	☐
	über 40.000 km	☐

Ihr Fahrstil

Markieren Sie die Position zwischen den Wortpaaren, die Ihrem Fahrstil am besten entspricht. *Machen Sie in jeder Zeile ein Kreuz.*						
Im Vergleich zu anderen Autofahrern fahre ich überwiegend…						
schnell	☐	☐	☐	☐	☐	langsam
ängstlich	☐	☐	☐	☐	☐	mutig
offensiv	☐	☐	☐	☐	☐	defensiv
vorsichtig	☐	☐	☐	☐	☐	risikobereit
sportlich	☐	☐	☐	☐	☐	gemütlich

Ihre Erfahrungen mit Fahrerassistenzsystemen

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

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

Teilautomatisiertes System (in Serienfahrzeugen ist aktuell nur der Stauassistent verfügbar)					
Sind Sie bereits (privat oder dienstlich) mit einem teilautomatisierten System (z. B. Stauassistent) gefahren?	☐ Ja ☐ Nein				
Wie viele Jahre sind Sie insgesamt mit Fahrzeugen gefahren, die mit einem teilautomatisierten System ausgestattet waren?	ca. _____________ Jahre				
Wenn Sie mit einem Fahrzeug fahren, welches mit einem teilautomatisierten System ausgestattet ist, wie häufig schalten Sie dieses auf der Autobahn ein (sofern die Voraussetzungen dafür erfüllt sind, z. B. Stau)?	nie	selten	gele-gentlich	oft	immer
	☐	☐	☐	☐	☐

Ihre Einstellung zum automatisierten Fahren

Man kann verschiedene Meinungen zum automatisierten Fahren haben. Daher hätten wir gerne Ihre Reaktionen auf die folgenden Aussagen.
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
Automatisiertes Fahren kann mich in monotonen oder stressigen Fahrsituationen entlasten.	☐	☐	☐
Automatisiertes Fahren kann schwere Unfälle verhindern.	☐	☐	☐
Ich glaube nicht, dass es jemals zuverlässig funktionieren wird.	☐	☐	☐
Wenn das Auto selber fährt, kann ich andere Dinge tun.	☐	☐	☐
Automatisiertes Fahren macht mir Angst.	☐	☐	☐

E.4 Questionnaire Driving Study 2

Fragebogen nach der Eingewöhnungsfahrt

Mündliche Befragung: Erleben Sie gerade Übelkeit, Kopfschmerzen oder Schwindel?	☐ Ja ☐ Nein

Fragebogen nach dem Interpretationsteil

Mündliche Befragung: Erleben Sie gerade Übelkeit, Kopfschmerzen oder Schwindel?	☐ Ja ☐ Nein

Im ersten Teil des Versuchs sind Sie nach der ACC-Fahrt mit dem Automationssystem gefahren, es gab jedoch keine aktive Nickbewegung, die einen Wechsel von einer Freifahrt in eine Folgefahrt kommuniziert hat.
In dem darauffolgenden Versuchsteil haben Sie eine aktive Nickbewegung zur Kommunikation des Wechsels erlebt.
Geben Sie bitte an, inwieweit die folgenden Aussagen auf Sie zutreffen. Die Nickbewegung ist immer in der von Ihnen präferierten Richtung und Intensität gemeint.

	Trifft absolut nicht zu	Trifft eher nicht zu	Weder noch	Trifft eher zu	Trifft absolut zu
Ich kann dem Automationssystem (ohne aktive Nickbewegungen) vertrauen.	☐	☐	☐	☐	☐
Ich kann dem Automationssystem (mit aktiven Nickbewegungen) vertrauen.	☐	☐	☐	☐	☐
Durch die Nickbewegungen hatte ich ein besseres Bewusstsein darüber, welche Fahraktion das Fahrzeug/Automationssystem **gerade** ausführt.	☐	☐	☐	☐	☐
Durch die Nickbewegungen hatte ich ein besseres Bewusstsein darüber, welche Fahraktion das Fahrzeug/Automationssystem **gerade** ausführt.	☐	☐	☐	☐	☐
Die Nickbewegungen gaben mir ein Gefühl von Sicherheit.	☐	☐	☐	☐	☐
Die Wahrnehmbarkeit der Nickbewegungen nahm mit zunehmender Versuchsdauer ab.	☐	☐	☐	☐	☐

Beurteilung des Automationssystems mit aktiver Nickbewegung						
Die von mir präferierte Nickbewegung als eine Rückmeldung des Wechsels von einer Freifahrt in eine Folgefahrt finde ich…						
nützlich	☐	☐	☐	☐	☐	nutzlos
angenehm	☐	☐	☐	☐	☐	unangenehm
schlecht	☐	☐	☐	☐	☐	gut
nett	☐	☐	☐	☐	☐	nervig
effizient	☐	☐	☐	☐	☐	unnötig
ärgerlich	☐	☐	☐	☐	☐	erfreulich
hilfreich	☐	☐	☐	☐	☐	wertlos
nicht wünschenswert	☐	☐	☐	☐	☐	wünschenswert
aktivierend	☐	☐	☐	☐	☐	einschläfernd

Fragebogen nach dem Gestaltungsteil I

Mündliche Befragung: Erleben Sie gerade Übelkeit, Kopfschmerzen oder Schwindel?	☐ Ja	☐ Nein

Haben Sie den Nickwinkel variiert?	☐ Ja
	☐ Nein, ich habe ausschließlich den kleinen Nickwinkel gewählt.
	☐ Nein, ich habe ausschließlich den großen Nickwinkel gewählt.

Fragebogen nach dem Gestaltungsteil II

Mündliche Befragung: Erleben Sie gerade Übelkeit, Kopfschmerzen oder Schwindel?	☐ Ja	☐ Nein

Haben Sie den Nickwinkel variiert?	☐ Ja
	☐ Nein, ich habe ausschließlich den kleinen Nickwinkel gewählt.
	☐ Nein, ich habe ausschließlich den großen Nickwinkel gewählt.

Im ersten Teil des Versuchs sind Sie nach der ACC-Fahrt mit dem Automationssystem gefahren, es gab jedoch keine aktive Nickbewegung, die einen <u>Wechsel von einer Freifahrt in eine Folgefahrt</u> kommuniziert hat. In den letzten zwei Versuchsteilen haben Sie eine aktive Nickbewegung zur Kommunikation des Wechsels selbst eingestellt. *Geben Sie bitte an, inwieweit die folgenden Aussagen auf Sie zutreffen. Die Nickbewegung ist immer in der von Ihnen präferierten Richtung und Intensität gemeint.*					
	Trifft absolut nicht zu	Trifft eher nicht zu	Weder noch	Trifft eher zu	Trifft absolut zu
Ich kann dem Automationssystem (ohne aktive Nickbewegungen) vertrauen.	☐	☐	☐	☐	☐
Ich kann dem Automationssystem (mit aktiven Nickbewegungen) vertrauen.	☐	☐	☐	☐	☐
Durch die Nickbewegungen hatte ich ein besseres Bewusstsein darüber, welche Fahraktion das Fahrzeug/Automationssystem **gerade** ausführt.	☐	☐	☐	☐	☐
Durch die Nickbewegungen hatte ich ein besseres Bewusstsein darüber, welche Fahraktion das Fahrzeug/Automationssystem **gerade** ausführt.	☐	☐	☐	☐	☐
Die Nickbewegungen gaben mir ein Gefühl von Sicherheit.	☐	☐	☐	☐	☐
Die Wahrnehmbarkeit der Nickbewegungen nahm mit zunehmender Versuchsdauer ab.	☐	☐	☐	☐	☐

Beurteilung des Automationssystems mit aktiver Nickbewegung						
Die von mir präferierte Nickbewegung als eine Rückmeldung des <u>Wechsels von einer Freifahrt in eine Folgefahrt</u> finde ich…						
nützlich	☐	☐	☐	☐	☐	nutzlos
angenehm	☐	☐	☐	☐	☐	unangenehm
schlecht	☐	☐	☐	☐	☐	gut
nett	☐	☐	☐	☐	☐	nervig
effizient	☐	☐	☐	☐	☐	unnötig
ärgerlich	☐	☐	☐	☐	☐	erfreulich
hilfreich	☐	☐	☐	☐	☐	wertlos
nicht wünschenswert	☐	☐	☐	☐	☐	wünschenswert
aktivierend	☐	☐	☐	☐	☐	einschläfernd

Eine Rückmeldung zu Kommunikation eines Wechsels von einer Freifahrt in eine Folgefahrt kann über verschiedene Sinneskanäle erfolgen. Bitte geben Sie an, inwieweit Sie die folgenden Sinneskanäle in Abhängigkeit der Kritikalität der Situation geeignet fänden.

Beispiel: Inwieweit fänden Sie eine vestibuläre Rückmeldung geeignet, wenn es sich

a) um eine UNKRITISCHE Situation handelt (Annähern an ein Fahrzeug mit nur etwas geringerer Geschwindigkeit).
b) um eine KRITISCHE Situation handelt (ein nahe einscherendes Fahrzeug nach einer Autobahnauffahrt).

	Trifft absolut nicht zu	Trifft eher nicht zu	Weder noch	Trifft eher zu	Trifft absolut zu
Vestibulär (z.B. durch Nickbewegungen): a) In einer UNKRITISCHEN Situation	☐	☐	☐	☐	☐
Vestibulär (z.B. durch Nickbewegungen): b) In einer KRITISCHEN Situation	☐	☐	☐	☐	☐
Haptische (z.B. durch Vibrationen): a) In einer UNKRITISCHEN Situation	☐	☐	☐	☐	☐
Haptische (z.B. durch Vibrationen): a) In einer KRITISCHEN Situation	☐	☐	☐	☐	☐
Visuell: a) In einer UNKRITISCHEN Situation	☐	☐	☐	☐	☐
Visuell: a) In einer KRITISCHEN Situation	☐	☐	☐	☐	☐
Auditiv: a) In einer UNKRITISCHEN Situation	☐	☐	☐	☐	☐
Auditiv: a) In einer KRITISCHEN Situation	☐	☐	☐	☐	☐

Eine vestibuläre Rückmeldung zu Kommunikation anderer Fahrsituationen ist ebenfalls denkbar. *Sofern Sie einen Vorschlag als sinnvoll erachten, kreuzen Sie diesen bitte an (Mehrfachantworten sind möglich). Sie haben auch die Möglichkeit eigene Vorschläge einzubringen.*

☐ Ankündigung eines Fahrstreifenwechsels durch eine Nickbewegung des Fahrzeugs nach vorne

☐ Ankündigung eines Fahrstreifenwechsels durch eine Nickbewegung des Fahrzeugs nach hinten

☐ Ankündigung eines Fahrstreifenwechsels nach links durch eine Wankbewegung des Fahrzeugs nach links

☐ Ankündigung eines Fahrstreifenwechsels nach links durch eine Wankbewegung des Fahrzeugs nach rechts

☐ Vorschlag für weitere Fahrsituation: ________________________________

☐ Vorschlag für weitere Fahrsituation: ________________________________

Anmerkungen
Haben Sie noch abschließende Anmerkungen zu dem Fahrversuch, den Fragebögen oder allgemeine Anmerkungen?

E.5 Pre-Questionnaire Driving Study 3

Fahrversuch zu aktiven Fahrzeugbewegungen als Feedback für den Fahrer beim teilautomatisierten Fahren

Liebe Interessentinnen und Interessenten,

wir möchten Sie herzlich zur Teilnahme an der Probandenstudie zum Thema „Evaluation von aktiven Fahrzeugbewegungen als Feedback für den Fahrer beim teilautomatisierten Fahren“ einladen. Die Studie findet im Rahmen eines Promotionsprojektes statt.

In der teilautomatisierten Fahrt übernimmt das Automationssystem die Längs- und Querführung. Der Fahrer überwacht das System dabei dauerhaft und ist somit zu jedem Zeitpunkt zu einer möglichen Übernahme der Fahraufgabe bereit. Voraussetzung für eine erfolgreiche Übernahme der Fahraufgabe ist, dass der Fahrer fortlaufend sowohl über das Geschehen um das Fahrzeug, als auch über den Zustand und die Absichten der Automation informiert ist. Um dieser Anforderung gerecht zu werden, wurde eine neuartige Form der Rückmeldung entwickelt und in einem Versuchsfahrzeug der AUDI AG umgesetzt. Im Rahmen der Studie haben Sie nun die Möglichkeit dieses prototypische Automationssystem auf einem Prüfgelände zu testen und damit einen Beitrag zu dessen Weiterentwicklung zu leisten.

Ihre Teilnahme setzt voraus, dass Sie ein sicherer und geübter Autofahrer sind, ein eigenes Fahrzeug besitzen oder regelmäßig Dienstfahrzeuge nutzen.

Details zur Studie:
Zeitraum: 08.07.2017 – 22.07.2017
Termine: 8:00 - 9.30 Uhr, 10:00 - 11:30 Uhr, 12:30 - 14:00 Uhr, 14:30 - 16:00 Uhr, 16:30 - 18:00 Uhr
Treffpunkt: Audi Driving Experience Center (Heinrichsheimstraße 200, Neuburg/Donau)

Zur wissenschaftlichen Auswertung dieser Studie werden objektive Fahrdaten des Fahrzeugs und Ihre subjektiven Eindrücke mit Hilfe eines Fragebogens erfasst sowie ein Portraitvideo mit Tonaufnahme von Ihrer Fahrt aufgezeichnet.

Wenn Sie Interesse haben an diesem Versuch teilzunehmen, füllen Sie bitte den folgenden Fragebogen aus. Dieser fragt bereits einige Informationen wie Angaben zu Ihrer Person, Ihre Fahrgewohnheiten und Ihre Erfahrungen mit Fahrassistenzsystemen ab. Die Beantwortung der Fragen wird ca. 10 Minuten in Anspruch nehmen.

Leider kann nur eine begrenzte Anzahl an Personen an diesem Versuch teilnehmen. Sofern Ihr Profil zu unseren Versuchsanforderungen passt, werden wir uns im Anschluss mit Ihnen in Verbindung setzen, um einen Termin für die Versuchsfahrt zu vereinbaren.

Vielen Dank für Ihre Unterstützung!

Ihre Erfahrungen mit Fahrerassistenzsystemen

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

Spurhalteassistenten (z. B. Audi Active Lane Assist)					
Sind Sie bereits (privat oder dienstlich) mit einem aktiven Spurhalteassistenten gefahren?	☐ Ja ☐ Nein				
Wie viele Jahre sind Sie insgesamt mit Fahrzeugen gefahren, die mit einem aktiven Spurhalteassistenten ausgestattet waren?	ca. ______________ Jahre				
Wenn Sie mit einem Fahrzeug fahren, welches mit einem aktiven Spurhalteassistenten ausgestattet ist, wie häufig schalten Sie diesen auf der Autobahn ein?	nie	selten	gelegentlich	oft	immer
	☐	☐	☐	☐	☐

Teilautomatisiertes System (in Serienfahrzeugen ist aktuell nur der Stauassistent verfügbar)					
Sind Sie bereits (privat oder dienstlich) mit einem teilautomatisierten System (z. B. Stauassistent) gefahren?	☐ Ja ☐ Nein				
Wie viele Jahre sind Sie insgesamt mit Fahrzeugen gefahren, die mit einem teilautomatisierten System ausgestattet waren?	ca. ______________ Jahre				
Wenn Sie mit einem Fahrzeug fahren, welches mit einem teilautomatisierten System ausgestattet ist, wie häufig schalten Sie dieses auf der Autobahn ein (sofern die Voraussetzungen dafür erfüllt sind, z. B. Stau)?	nie	selten	gelegentlich	oft	immer
	☐	☐	☐	☐	☐

Ihre Fahrgewohnheiten

Legen Sie Ihren Arbeitsweg mit dem Auto zurück?	☐ Ja ☐ Nein	
Wie hoch ist Ihre wöchentliche Kilometerleistung durch den Arbeitsweg?	ca. ________________ Kilometer	
Wie verteilt sich Ihr Arbeitsweg (in km) auf folgende Straßentypen (gesamt 100%)? *Falls Sie einen Straßentypen nicht nutzen, tragen Sie bitte Null ein.*	Stadt (%)	
	Land-/Bundesstraße (%)	
	Autobahn (%)	
Legen Sie sonstige Strecken (privat oder dienstlich) mit dem Auto zurück?	☐ Ja ☐ Nein	
Wie hoch ist Ihre wöchentliche Kilometerleistung durch sonstige Fahrten?	ca. ________________ Kilometer	
Wie verteilen sich Ihre sonstigen Fahrten (in km) auf folgende Straßentypen (gesamt 100%)? *Falls Sie einen Straßentypen nicht nutzen, tragen Sie bitte Null ein.*	Stadt (%)	
	Land-/Bundesstraße (%)	
	Autobahn (%)	
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	☐

Ihr Fahrstil

Markieren Sie die Position zwischen den Wortpaaren, die Ihrem Fahrstil am besten entspricht. *Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Machen Sie in jeder Zeile ein Kreuz.*						
Im Vergleich zu anderen Autofahrern fahre ich überwiegend…						
schnell	☐	☐	☐	☐	☐	langsam
ängstlich	☐	☐	☐	☐	☐	mutig
offensiv	☐	☐	☐	☐	☐	defensiv
vorsichtig	☐	☐	☐	☐	☐	risikobereit
sportlich	☐	☐	☐	☐	☐	gemütlich

Ihre Einstellung zum automatisierten Fahren

Man kann verschiedene Meinungen zum automatisierten Fahren haben. Daher hätten wir gerne Ihre Reaktionen auf die folgenden Aussagen.
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
Automatisiertes Fahren kann mich in monotonen oder stressigen Fahrsituationen entlasten.	☐	☐	☐
Automatisiertes Fahren kann schwere Unfälle verhindern.	☐	☐	☐
Ich glaube nicht, dass es jemals zuverlässig funktionieren wird.	☐	☐	☐
Wenn das Auto selber fährt, kann ich andere Dinge tun.	☐	☐	☐
Automatisiertes Fahren macht mir Angst.	☐	☐	☐

Demographie

Ihr Alter:	<31	31-40	>40
Geben Sie bitte den Bereich an, in dem sich Ihr Alter befindet.	☐	☐	☐
Ihr Geschlecht:	☐ weiblich		☐ männlich
Welchen beruflichen Hintergrund (z. B. Ausbildung oder Studium) haben Sie?	☐ technischer Hintergrund ☐ nicht-technischer Hintergrund		

E.6 Questionnaire Driving Study 3

Fragebogen vor dem Fahrversuch

Erwartungshaltung an das Automationssystem mit aktiven Wankbewegungen						
Wie würden Sie aktive Fahrzeugwankbewegungen als Rückmeldung über die Zustandsänderung der Automation finden? *Bitte lesen Sie jedes Wortpaar aufmerksam und machen Sie jeweils ein Kreuz pro Zeile.*						
nützlich	☐	☐	☐	☐	☐	nutzlos
angenehm	☐	☐	☐	☐	☐	unangenehm
schlecht	☐	☐	☐	☐	☐	gut
nett	☐	☐	☐	☐	☐	nervig
effizient	☐	☐	☐	☐	☐	unnötig
ärgerlich	☐	☐	☐	☐	☐	erfreulich
hilfreich	☐	☐	☐	☐	☐	wertlos
nicht wünschenswert	☐	☐	☐	☐	☐	wünschenswert
aktivierend	☐	☐	☐	☐	☐	einschläfernd

Erwartungshaltung an die Wankbewegungen					
	Trifft absolut nicht zu	Trifft eher nicht zu	Weder noch	Trifft eher zu	Trifft absolut zu
Ich wünsche mir eine Rückmeldung über die Zustandsänderung der Automation während einer teilautomatisierten Fahrt.	☐	☐	☐	☐	☐
Mein Bewusstsein für den Zustand der Automation verbessert sich durch eine Rückmeldung in Form einer Wankbewegung.	☐	☐	☐	☐	☐
Ich wünsche mir eine deutlich spürbare Wankbewegung, um die zukünftige Fahraktion der Automation zu erkennen.	☐	☐	☐	☐	☐
Ich wünsche mir eine eher schwache Wankbewegung, um einen möglichst geringen Diskomfort zu erreichen.	☐	☐	☐	☐	☐

Fragebogen während jeder Fahrsituation (mündliche Befragung)

	zu schwach	eher zu schwach	in Ordnung	eher zu stark	zu stark	Kann ich nicht sagen
Wankprofil **1** (klein, rechts)	☐	☐	☐	☐	☐	☐
Wankprofil **-1** (klein, links)	☐	☐	☐	☐	☐	☐
Wankprofil **2** (groß, rechts)	☐	☐	☐	☐	☐	☐
Wankprofil **-2** (groß, links)	☐	☐	☐	☐	☐	☐

Wankprofil		zu kurz	eher zu kurz	in Ordnung	eher zu lang	zu lang	Kann ich nicht sagen
2 ☐ **1** ☐ **-1** ☐ **-2** ☐	Ankündigungsdauer (kurz)	☐	☐	☐	☐	☐	☐
2 ☐ **1** ☐ **-1** ☐ **-2** ☐	Ankündigungsdauer (lang)	☐	☐	☐	☐	☐	☐

	Ja	Nein	Kann ich nicht sagen
Ich habe einen Unterschied zwischen den beiden Richtungen der Wankbewegung gespürt?	☐	☐	☐
Ich habe einen Unterschied zwischen den beiden Wankwinkeln gespürt?	☐	☐	☐
Ich habe einen Unterschied zwischen den beiden Ausprägungen der Ankündigungsdauer des Fahrstreifenwechsels gespürt?	☐	☐	☐

Fragebogen während jeder Fahrsituation (mündliche Befragung)

Wank-profil		**gar nicht** **0**	**gering** **1**	**mittel** **2**	**hoch** **3**	**völlig** **4**
1 ☐	Wahrnehmbarkeit	☐	☐	☐	☐	☐
	Situationsbezug	☐	☐	☐	☐	☐
-1 ☐	Diskomfort	☐	☐	☐	☐	☐
2 ☐	Wahrnehmbarkeit	☐	☐	☐	☐	☐
	Situationsbezug	☐	☐	☐	☐	☐
- 2 ☐	Diskomfort	☐	☐	☐	☐	☐
3 ☐	Wahrnehmbarkeit	☐	☐	☐	☐	☐
	Situationsbezug	☐	☐	☐	☐	☐
-3 ☐	Diskomfort	☐	☐	☐	☐	☐
4 ☐	Wahrnehmbarkeit	☐	☐	☐	☐	☐
	Situationsbezug	☐	☐	☐	☐	☐
-4 ☐	Diskomfort	☐	☐	☐	☐	☐

Fragebogen nach jeder Fahrsituation

Für welche Wankbewegungsrichtung haben Sie sich entschieden?	nach links	nach rechts
	☐	☐

Für welchen maximalen Wankwinkel haben Sie sich entschieden?	Kleiner Winkel	Großer Winkel
	☐	☐

Einschätzung der bevorzugten Wankbewegung als Rückmeldung über die Zustandsänderung der Automation in der gerade erlebten Fahrsituation					
	Trifft absolut nicht zu	Trifft eher nicht zu	Weder noch	Trifft eher zu	Trifft absolut zu
Die Wankbewegungen finde ich sinnvoll.	☐	☐	☐	☐	☐
Die Wankbewegungen finde ich irreführend.	☐	☐	☐	☐	☐
Durch die Wankbewegungen hatte ich ein besseres Bewusstsein darüber, welche Fahraktion das Fahrzeug bzw. Automationssystem **gerade** ausführt.	☐	☐	☐	☐	☐
Durch die Wankbewegungen hatte ich ein besseres Bewusstsein darüber, welche Fahraktion das Fahrzeug bzw. Automationssystem **zukünftig** vorhat.	☐	☐	☐	☐	☐
Durch die Wankbewegungen konnte ich die Zustandsänderung der Automation besser nachvollziehen.	☐	☐	☐	☐	☐
Die Wankbewegungen unterstützten mich bei meiner Überwachungsaufgabe.	☐	☐	☐	☐	☐

Erleben Sie gerade Übelkeit, Kopfschmerzen oder Schwindel?	☐ Ja ☐ Nein
	Falls ja, melden Sie sich bitte bei Ihrer Versuchsleiterin.

Anmerkungen
Haben Sie Anmerkungen zur den Fahrzeugwankbewegungen und/oder der gerade erlebten Fahrsituation? *Bitte geben Sie diese hier an.*

Fragebogen nach dem Fahrversuch

Einstellung gegenüber den Wankbewegungen					
	Trifft absolut nicht zu	Trifft eher nicht zu	Weder noch	Trifft eher zu	Trifft absolut zu
Ich wünsche mir eine Rückmeldung über die Zustandsänderung der Automation während einer teilautomatisierten Fahrt.	☐	☐	☐	☐	☐
Mein Bewusstsein für den Zustand der Automation verbessert sich durch eine Rückmeldung in Form einer Wankbewegung.	☐	☐	☐	☐	☐
Ich wünsche mir eine deutlich spürbare Wankbewegung, um die zukünftige Fahraktion der Automation zu erkennen.	☐	☐	☐	☐	☐
Ich wünsche mir eine eher schwache Wankbewegung, um einen möglichst geringen Diskomfort zu erreichen.	☐	☐	☐	☐	☐

Beurteilung des Automationssystems mit aktiven Wankbewegungen						
Wie finden Sie aktive Wankbewegungen als Rückmeldung über die Zustandsänderung der Automation? *Bitte lesen Sie jedes Wortpaar aufmerksam und machen Sie jeweils ein Kreuz pro Zeile.*						
nützlich	☐	☐	☐	☐	☐	nutzlos
angenehm	☐	☐	☐	☐	☐	unangenehm
schlecht	☐	☐	☐	☐	☐	gut
nett	☐	☐	☐	☐	☐	nervig
effizient	☐	☐	☐	☐	☐	unnötig
ärgerlich	☐	☐	☐	☐	☐	erfreulich
hilfreich	☐	☐	☐	☐	☐	wertlos
nicht wünschenswert	☐	☐	☐	☐	☐	wünschenswert
aktivierend	☐	☐	☐	☐	☐	einschläfernd

Rückmeldung über verschiedene Sinneskanäle					
Eine Rückmeldung zur Kommunikation eines Wechsels von einer Frei- oder Folgefahrt zu einem Fahrstreifenwechsel kann über verschiedene Sinneskanäle erfolgen. *Bitte geben Sie an, inwieweit Sie die folgenden Sinneskanäle geeignet fänden.*					
	Trifft absolut nicht zu	Trifft eher nicht zu	Weder noch	Trifft eher zu	Trifft absolut zu
Vestibulär (z. B. durch Wankbewegungen)	☐	☐	☐	☐	☐
Haptisch (z. B. durch Vibrationen)	☐	☐	☐	☐	☐
Visuell (z. B. durch eine Anzeige im Kombiinstrument)	☐	☐	☐	☐	☐
Auditiv (z. B. durch einen Ton)	☐	☐	☐	☐	☐

Anmerkungen
Haben Sie noch Anmerkungen zu dem Fahrversuch, den Fragebögen oder allgemeine Anmerkungen? *Bitte geben Sie diese hier an.*

E.7 Pre-Questionnaire Driving Study 4

Fahrversuch zum Thema „Aktive Fahrzeugaufbaubewegung und visuelle Anzeige als Feedback für den Fahrer beim teilautomatisierten Fahren“

Liebe Interessentinnen und Interessenten,

wir möchten Sie herzlich zur Teilnahme an der Probandenstudie zum Thema „Aktive Fahrzeugaufbaubewegung und visuelle Anzeige als Feedback für den Fahrer beim teilautomatisierten Fahren“ einladen. Die Studie findet im Rahmen eines Promotionsprojektes statt.

In der teilautomatisierten Fahrt übernimmt das Automationssystem die Längs- und Querführung. Der Fahrer überwacht das System dabei dauerhaft und ist somit zu jedem Zeitpunkt zu einer möglichen Übernahme der Fahraufgabe bereit. Voraussetzung für eine erfolgreiche Übernahme der Fahraufgabe ist, dass der Fahrer fortlaufend sowohl über das Geschehen um das Fahrzeug, als auch über den Zustand und die Absichten der Automation informiert ist. Um dieser Anforderung gerecht zu werden, wurde eine neuartige Form der Rückmeldung entwickelt und in einem Versuchsfahrzeug der AUDI AG umgesetzt. Im Rahmen der Studie haben Sie nun die Möglichkeit dieses prototypische Automationssystem auf der Autobahn A9 zu testen und damit einen Beitrag zu dessen Weiterentwicklung zu leisten.

Ihre Teilnahme setzt voraus, dass Sie ein sicherer und geübter Autofahrer sind, ein eigenes Fahrzeug besitzen oder regelmäßig Dienstfahrzeuge nutzen.

Details zur Studie:
Zeitraum: 27.11.2017 bis 20.12.2017
Termine (Mo – Fr): 8:30 - 10.30 Uhr, 11:00 - 13:00 Uhr, 14:00 - 16:00 Uhr
Treffpunkt: Esso Tankstelle Autobahnauffahrt Lenting

Zur wissenschaftlichen Auswertung dieser Studie werden objektive Fahrdaten des Fahrzeugs und Ihre subjektiven Eindrücke mit Hilfe eines Fragebogens erfasst sowie ein Portraitvideo mit Tonaufnahme von Ihrer Fahrt aufgezeichnet.

Wenn Sie Interesse haben an diesem Versuch teilzunehmen, füllen Sie bitte den folgenden Fragebogen aus. Dieser fragt bereits einige Informationen wie Angaben zu Ihrer Person, Ihre Fahrgewohnheiten und Ihre Erfahrungen mit Fahrerassistenzsystemen ab. Die Beantwortung der Fragen wird ca. 10 Minuten in Anspruch nehmen.

Leider kann nur eine begrenzte Anzahl an Personen an diesem Versuch teilnehmen. Sofern Ihr Profil zu unseren Versuchsanforderungen passt, werden wir uns im Anschluss mit Ihnen in Verbindung setzen, um einen Termin für die Versuchsfahrt zu vereinbaren.

Vielen Dank für Ihre Unterstützung!

Ihre Erfahrungen mit Fahrerassistenzsystemen

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

Spurhalteassistenten (z. B. Audi Active Lane Assist)					
Sind Sie bereits (privat oder dienstlich) mit einem aktiven Spurhalteassistenten gefahren?	☐ Ja ☐ Nein				
Wie viele Jahre sind Sie insgesamt mit Fahrzeugen gefahren, die mit einem aktiven Spurhalteassistenten ausgestattet waren?	ca. _______________ Jahre				
Wenn Sie mit einem Fahrzeug fahren, welches mit einem aktiven Spurhalteassistenten ausgestattet ist, wie häufig schalten Sie diesen auf der Autobahn ein?	nie	selten	gelegentlich	oft	immer
	☐	☐	☐	☐	☐

Teilautomatisiertes System (in Serienfahrzeugen ist aktuell nur der Stauassistent verfügbar)					
Sind Sie bereits (privat oder dienstlich) mit einem teilautomatisierten System (z. B. Stauassistent) gefahren?	☐ Ja ☐ Nein				
Wie viele Jahre sind Sie insgesamt mit Fahrzeugen gefahren, die mit einem teilautomatisierten System ausgestattet waren?	ca. _______________ Jahre				
Wenn Sie mit einem Fahrzeug fahren, welches mit einem teilautomatisierten System ausgestattet ist, wie häufig schalten Sie dieses auf der Autobahn ein (sofern die Voraussetzungen dafür erfüllt sind, z. B. Stau)?	nie	selten	gelegentlich	oft	immer
	☐	☐	☐	☐	☐

Ihre Fahrgewohnheiten

Legen Sie Ihren Arbeitsweg mit dem Auto zurück?	☐ Ja ☐ Nein	
Wie hoch ist Ihre wöchentliche Kilometerleistung durch den Arbeitsweg?	ca. _________________ Kilometer	
Wie verteilt sich Ihr Arbeitsweg (in km) auf folgende Straßentypen (gesamt 100%)? *Falls Sie einen Straßentypen nicht nutzen, tragen Sie bitte Null ein.*	Stadt (%)	
	Land-/Bundesstraße (%)	
	Autobahn (%)	
Legen Sie sonstige Strecken (privat oder dienstlich) mit dem Auto zurück?	☐ Ja ☐ Nein	
Wie hoch ist Ihre wöchentliche Kilometerleistung durch sonstige Fahrten?	ca. _________________ Kilometer	
Wie verteilen sich Ihre sonstigen Fahrten (in km) auf folgende Straßentypen (gesamt 100%)? *Falls Sie einen Straßentypen nicht nutzen, tragen Sie bitte Null ein.*	Stadt (%)	
	Land-/Bundesstraße (%)	
	Autobahn (%)	
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	☐

Ihr Fahrstil

Markieren Sie die Position zwischen den Wortpaaren, die Ihrem Fahrstil am besten entspricht. *Überlegen Sie nicht, sondern antworten Sie aus dem Bauch heraus. Machen Sie in jeder Zeile ein Kreuz.*						
Im Vergleich zu anderen Autofahrern fahre ich überwiegend…						
schnell	☐	☐	☐	☐	☐	langsam
ängstlich	☐	☐	☐	☐	☐	mutig
offensiv	☐	☐	☐	☐	☐	defensiv
vorsichtig	☐	☐	☐	☐	☐	risikobereit
sportlich	☐	☐	☐	☐	☐	gemütlich

Ihre Einstellung zum automatisierten Fahren

Man kann verschiedene Meinungen zum automatisierten Fahren haben. Daher hätten wir gerne Ihre Reaktionen auf die folgenden Aussagen. *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
Automatisiertes Fahren kann mich in monotonen oder stressigen Fahrsituationen entlasten.	☐	☐	☐
Automatisiertes Fahren kann schwere Unfälle verhindern.	☐	☐	☐
Ich glaube nicht, dass es jemals zuverlässig funktionieren wird.	☐	☐	☐
Wenn das Auto selber fährt, kann ich andere Dinge tun.	☐	☐	☐
Automatisiertes Fahren macht mir Angst.	☐	☐	☐

Demographie

Ihr Alter: *Geben Sie bitte den Bereich an, in dem sich Ihr Alter befindet.*	<31	31-40	>40
	☐	☐	☐
Ihr Geschlecht:	☐ weiblich		☐ männlich
Welchen beruflichen Hintergrund (z. B. Ausbildung oder Studium) haben Sie?	☐ technischer Hintergrund ☐ nicht-technischer Hintergrund		

E.8 Questionnaire Driving Study 4

Fragebogen vor dem Fahrversuch

Erste Einschätzung zur Akzeptanz						
Zu Beginn möchten wir gerne Ihre **erste Einschätzung** hören: Wie fänden Sie es, wenn das Automationssystem Zustandsänderung (Ankündigen eines Spurwechsels, Erkennen eines Vorderobjekts) während einer teilautomatisierten Fahrt zurückmeldet? *Bitte lesen Sie jedes Wortpaar aufmerksam und machen Sie jeweils ein Kreuz pro Zeile.*						
nützlich	☐	☐	☐	☐	☐	nutzlos
angenehm	☐	☐	☐	☐	☐	unangenehm
schlecht	☐	☐	☐	☐	☐	gut
nett	☐	☐	☐	☐	☐	nervig
effizient	☐	☐	☐	☐	☐	unnötig
ärgerlich	☐	☐	☐	☐	☐	erfreulich
hilfreich	☐	☐	☐	☐	☐	wertlos
nicht wünschenswert	☐	☐	☐	☐	☐	wünschenswert
aktivierend	☐	☐	☐	☐	☐	einschläfernd

Fragebogen nach der Eingewöhnungsfahrt

Mündliche Befragung: Erleben Sie gerade Übelkeit, Kopfschmerzen oder Schwindel?	☐ Ja ☐ Nein

Fragebogen während der Fahrt mit rein visueller oder visueller und vestibulärer Rückmeldung (mündliche Befragung)

Wie hoch waren Ihr Sicherheitsempfinden und Ihre mentale Beanspruchung während der letzten 4 min?								
Sicherheitsempfinden								
	1	2	3	4	5	6	7	
gering	☐	☐	☐	☐	☐	☐	☐	hoch
Mentale Beanspruchung								
	1	2	3	4	5	6	7	
gering	☐	☐	☐	☐	☐	☐	☐	hoch

Fragebogen während der Fahrt mit rein visueller oder visueller und vestibulärer Rückmeldung

Mündliche Befragung: Erleben Sie gerade Übelkeit, Kopfschmerzen oder Schwindel?	☐ Ja ☐ Nein

Die nachfolgenden Fragen beziehen sich **ausschließlich** auf den **zuletzt erlebten Versuchsteil.** Dabei bewerten Sie das Automationssystem sowie die **visuelle** Rückmeldung über die Zustandsänderungen der Automation (Ankündigung eines Spurwechsels, Erkennen eines Vorderobjekts).

Bitte lesen Sie jede Frage und jedes Wortpaar aufmerksam und beantworten Sie diese möglichst zügig, ohne lange zu überlegen.

Beanspruchung

Die nachfolgenden Fragen erfassen den Grad Ihrer Beanspruchung.
Bitte machen Sie jeweils ein Kreuz pro Zeile.

Visuelle Beanspruchung
Wie schätzen Sie das Ausmaß Ihrer visuellen Beanspruchung (sehen, beobachten, optische Darstellungen erfassen, etc.) während der letzten Fahrt ein?

	1	2	3	4	5	6	7	
gering	☐	☐	☐	☐	☐	☐	☐	hoch

Physische (körperliche) Beanspruchung
Wie schätzen Sie das Ausmaß Ihrer körperlichen Beanspruchung (bewegen, Kräfte ausgleichen etc.) während der letzten Fahrt ein?

	1	2	3	4	5	6	7	
gering	☐	☐	☐	☐	☐	☐	☐	hoch

Situations- und Systembewusstsein

Die folgenden Fragen erfassen Ihr Situationsbewusstsein.
Bitte machen Sie jeweils ein Kreuz pro Zeile.

Änderten sich die Fahrsituationen plötzlich bzw. waren diese veränderlich oder waren diese gleichbleibend?

	1	2	3	4	5	6	7	
gleichbleibend	☐	☐	☐	☐	☐	☐	☐	veränderlich

Wie war die Komplexität der Fahrsituationen?

	1	2	3	4	5	6	7	
einfach	☐	☐	☐	☐	☐	☐	☐	komplex

Auf wie viele „Dinge“ mussten Sie während der Fahrsituationen achten?

	1	2	3	4	5	6	7	
wenige	☐	☐	☐	☐	☐	☐	☐	viele

Wie aktiviert und handlungsbereit waren Sie während der Fahrsituationen?

	1	2	3	4	5	6	7	
wenig aktiviert	☐	☐	☐	☐	☐	☐	☐	sehr aktiviert

Wie viel Konzentration haben Sie während der Fahrsituationen aufbringen müssen?

	1	2	3	4	5	6	7	
wenig	☐	☐	☐	☐	☐	☐	☐	viel

Wie war Ihre Aufmerksamkeit während der Fahrsituationen?

	1	2	3	4	5	6	7	
gerichtet	☐	☐	☐	☐	☐	☐	☐	geteilt

Wie viel mentale Kapazität hatten Sie während der Fahrsituationen noch zur Verfügung?

	1	2	3	4	5	6	7	
keine	☐	☐	☐	☐	☐	☐	☐	viel

Wie viele relevante Informationen haben Sie während der Fahrsituationen erhalten und verstanden?

	1	2	3	4	5	6	7	
keine	☐	☐	☐	☐	☐	☐	☐	viele

Wie war die Qualität und Relevanz der Informationen, die Sie während der Fahrsituationen erhalten haben?

	1	2	3	4	5	6	7	
gering	☐	☐	☐	☐	☐	☐	☐	hoch

Wie vertraut waren die Fahrsituationen für Sie?

	1	2	3	4	5	6	7	
ungewohnt	☐	☐	☐	☐	☐	☐	☐	vertraut

Fragebogen bei rein visueller Rückmeldung

Allgemeine Einschätzung der Rückmeldeart des Automationssystems
Geben Sie bitte an, inwieweit die folgenden Aussagen auf Sie zutreffen und machen Sie bitte jeweils ein Kreuz pro Zeile.

	Trifft absolut nicht zu	Trifft eher nicht zu	Weder noch	Trifft eher zu	Trifft absolut zu
Durch die **visuelle** Rückmeldung hatte ich ein besseres Bewusstsein darüber, welche Fahraktion das Fahrzeug bzw. Automationssystem **gerade** ausführt.	☐	☐	☐	☐	☐
Durch die **visuelle** Rückmeldung hatte ich ein besseres Bewusstsein darüber, welche Fahraktion das Fahrzeug bzw. Automationssystem **zukünftig** vorhat.	☐	☐	☐	☐	☐
Die **visuelle** Rückmeldung unterstützt mich bei meiner Überwachungsaufgabe.	☐	☐	☐	☐	☐
Ich war mir jederzeit bewusst, welche Fahraktion das Fahrzeug bzw. Automationssystem ausführt.	☐	☐	☐	☐	☐
Das Verhalten des teilautomatisierten Systems empfand ich als vorhersehbar.	☐	☐	☐	☐	☐

Fragebogen bei visueller und vestibulärer Rückmeldung

Allgemeine Einschätzung der Rückmeldeart des Automationssystems *Geben Sie bitte an, inwieweit die folgenden Aussagen auf Sie zutreffen und machen Sie bitte jeweils ein Kreuz pro Zeile.*					
	Trifft absolut nicht zu	Trifft eher nicht zu	Weder noch	Trifft eher zu	Trifft absolut zu
Durch die **visuelle und vestibuläre** Rückmeldung hatte ich ein besseres Bewusstsein darüber, welche Fahraktion das Fahrzeug bzw. Automationssystem **gerade** ausführt.	☐	☐	☐	☐	☐
Durch die **visuelle und vestibuläre** Rückmeldung hatte ich ein besseres Bewusstsein darüber, welche Fahraktion das Fahrzeug bzw. Automationssystem **zukünftig** vorhat.	☐	☐	☐	☐	☐
Die **visuelle und vestibuläre** Rückmeldung unterstützt mich bei meiner Überwachungsaufgabe.	☐	☐	☐	☐	☐
Ich war mir jederzeit bewusst, welche Fahraktion das Fahrzeug bzw. Automationssystem ausführt.	☐	☐	☐	☐	☐
Das Verhalten des teilautomatisierten Systems empfand ich als vorhersehbar.	☐	☐	☐	☐	☐

Vertrauen in das Automationssystem								
Die folgenden Fragen erfassen Ihr Vertrauen in das Automationssystem. *Bitte machen Sie jeweils ein Kreuz pro Zeile.*								
Das System ist irreführend.								
	1	2	3	4	5	6	7	
trifft gar nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft völlig zu
Das System verhält sich undurchsichtig.								
	1	2	3	4	5	6	7	
trifft gar nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft völlig zu
Ich misstraue den Entscheidungen des Systems.								
	1	2	3	4	5	6	7	
trifft gar nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft völlig zu
Ich muss vorsichtig im Umgang mit dem System sein.								
	1	2	3	4	5	6	7	
trifft gar nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft völlig zu
Die Handlungen des Systems haben negative Auswirkungen zur Folge.								
	1	2	3	4	5	6	7	
trifft gar nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft völlig zu

Das System bietet Sicherheit.								
	1	2	3	4	5	6	7	
trifft gar nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft völlig zu
Das System arbeitet tadellos.								
	1	2	3	4	5	6	7	
trifft gar nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft völlig zu
Das System ist verlässlich.								
	1	2	3	4	5	6	7	
trifft gar nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft völlig zu
Das System ist vertrauenswürdig.								
	1	2	3	4	5	6	7	
trifft gar nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft völlig zu
Ich kann dem System vertrauen.								
	1	2	3	4	5	6	7	
trifft gar nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft völlig zu
Ich kenne mich mit dem System aus.								
	1	2	3	4	5	6	7	
trifft gar nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft völlig zu

Fragebogen für Akzeptanz bei rein visueller Rückmeldung

Akzeptanz						
Wie finden Sie die **visuelle** Rückmeldung über die Zustandsänderung der Automation (Ankündigung eines Spurwechsels, Erkennen eines Vorderobjekts)? *Bitte machen Sie jeweils ein Kreuz pro Zeile.*						
nützlich	☐	☐	☐	☐	☐	nutzlos
angenehm	☐	☐	☐	☐	☐	unangenehm
schlecht	☐	☐	☐	☐	☐	gut
nett	☐	☐	☐	☐	☐	nervig
effizient	☐	☐	☐	☐	☐	unnötig
ärgerlich	☐	☐	☐	☐	☐	erfreulich
hilfreich	☐	☐	☐	☐	☐	wertlos
nicht wünschenswert	☐	☐	☐	☐	☐	wünschenswert
aktivierend	☐	☐	☐	☐	☐	einschläfernd

Fragebogen für Akzeptanz bei visueller und vestibulärer Rückmeldung

Akzeptanz						
Wie finden Sie die **visuelle und vestibuläre** Rückmeldung über die Zustandsänderung der Automation (Ankündigung eines Spurwechsels, Erkennen eines Vorderobjekts)? *Bitte machen Sie jeweils ein Kreuz pro Zeile.*						
nützlich	☐	☐	☐	☐	☐	nutzlos
angenehm	☐	☐	☐	☐	☐	unangenehm
schlecht	☐	☐	☐	☐	☐	gut
nett	☐	☐	☐	☐	☐	nervig
effizient	☐	☐	☐	☐	☐	unnötig
ärgerlich	☐	☐	☐	☐	☐	erfreulich
hilfreich	☐	☐	☐	☐	☐	wertlos
nicht wünschenswert	☐	☐	☐	☐	☐	wünschenswert
aktivierend	☐	☐	☐	☐	☐	einschläfernd

Anmerkungen
Haben Sie noch Anmerkungen zu dem Fahrversuch, den Fragebögen oder allgemeine Anmerkungen? *Bitte geben Sie diese hier an.*

Fragebogen während der Fahrt mit dem Systemfehler (mündliche Befragung)

Bitte bewerten Sie Ihren emotionalen Zustand auf diesen Skalen.						
	1	2	3	4	5	
ängstlich	☐	☐	☐	☐	☐	entspannt
	1	2	3	4	5	
aufgewühlt	☐	☐	☐	☐	☐	ruhig
	1	2	3	4	5	
still	☐	☐	☐	☐	☐	überrascht

Fragebogen nach dem Systemfehler (mündliche Befragung)

Einschätzung der Situation. *Die folgenden Aussagen beziehen sich auf den gerade erlebten Spurwechsel.*					
	Trifft absolut nicht zu	Trifft eher nicht zu	Weder noch	Trifft eher zu	Trifft absolut zu
Ich habe die gesamte Situation schnell überblickt.	☐	☐	☐	☐	☐
Ich empfand die Situation als beanspruchend.	☐	☐	☐	☐	☐
Ich habe gut auf die Situation reagiert.	☐	☐	☐	☐	☐
Ich schätze die Situation als kritisch ein.	☐	☐	☐	☐	☐

Fragebogen nach der Fahrt mit dem Systemfehler

Mündliche Befragung: Erleben Sie gerade Übelkeit, Kopfschmerzen oder Schwindel?	☐ Ja ☐ Nein

Die nachfolgenden Fragen beziehen sich **ausschließlich** auf den **zuletzt erlebten Versuchsteil.** Dabei bewerten Sie das Automationssystem sowie die Rückmeldung über die Zustandsänderung der Automation (Ankündigung eines Spurwechsels, Erkennen eines Vorderobjekts).

Bitte lesen Sie jede Frage und jedes Wortpaar aufmerksam und beantworten Sie diese möglichst zügig, ohne lange zu überlegen.

Vertrauen in das Automationssystem

Die folgenden Fragen erfassen Ihr Vertrauen in das Automationssystem.
Bitte machen Sie jeweils ein Kreuz pro Zeile.

		1	2	3	4	5	6	7	
Das System ist irreführend.	trifft gar nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft völlig zu
Das System verhält sich undurchsichtig.	trifft gar nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft völlig zu
Ich misstraue den Entscheidungen des Systems.	trifft gar nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft völlig zu
Ich muss vorsichtig im Umgang mit dem System sein.	trifft gar nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft völlig zu
Die Handlungen des Systems haben negative Auswirkungen zur Folge.	trifft gar nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft völlig zu

Das System bietet Sicherheit.								
	1	2	3	4	5	6	7	
trifft gar nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft völlig zu
Das System arbeitet tadellos.								
	1	2	3	4	5	6	7	
trifft gar nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft völlig zu
Das System ist verlässlich.								
	1	2	3	4	5	6	7	
trifft gar nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft völlig zu
Das System ist vertrauenswürdig.								
	1	2	3	4	5	6	7	
trifft gar nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft völlig zu
Ich kann dem System vertrauen.								
	1	2	3	4	5	6	7	
trifft gar nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft völlig zu
Ich kenne mich mit dem System aus.								
	1	2	3	4	5	6	7	
trifft gar nicht zu	☐	☐	☐	☐	☐	☐	☐	trifft völlig zu

Fragebogen für Akzeptanz bei rein visueller Rückmeldung während der Fahrt mit dem Systemfehler

Wie finden Sie die **visuelle** Rückmeldung über die Zustandsänderung der Automation? *Bitte machen Sie jeweils ein Kreuz pro Zeile.*						
nützlich	☐	☐	☐	☐	☐	nutzlos
angenehm	☐	☐	☐	☐	☐	unangenehm
schlecht	☐	☐	☐	☐	☐	gut
nett	☐	☐	☐	☐	☐	nervig
effizient	☐	☐	☐	☐	☐	unnötig
ärgerlich	☐	☐	☐	☐	☐	erfreulich
hilfreich	☐	☐	☐	☐	☐	wertlos
nicht wünschenswert	☐	☐	☐	☐	☐	wünschenswert
aktivierend	☐	☐	☐	☐	☐	einschläfernd

Fragebogen für Akzeptanz bei visueller und vestibulärer Rückmeldung während der Fahrt mit dem Systemfehler

Wie finden Sie die **visuelle und vestibuläre** Rückmeldung über die Zustandsänderung der Automation? *Bitte machen Sie jeweils ein Kreuz pro Zeile.*						
nützlich	☐	☐	☐	☐	☐	nutzlos
angenehm	☐	☐	☐	☐	☐	unangenehm
schlecht	☐	☐	☐	☐	☐	gut
nett	☐	☐	☐	☐	☐	nervig
effizient	☐	☐	☐	☐	☐	unnötig
ärgerlich	☐	☐	☐	☐	☐	erfreulich
hilfreich	☐	☐	☐	☐	☐	wertlos
nicht wünschenswert	☐	☐	☐	☐	☐	wünschenswert
aktivierend	☐	☐	☐	☐	☐	einschläfernd

Anmerkungen
Haben Sie noch Anmerkungen zu dem Fahrversuch, den Fragebögen oder allgemeine Anmerkungen? *Bitte geben Sie diese hier an.*

Abschließender Fragebogen

Die nachfolgenden Fragen beziehen sich auf die gesamte Versuchsfahrt und alle dabei erlebten Rückmeldearten. *Bitte lesen Sie jede Frage aufmerksam und beantworten Sie diese möglichst zügig, ohne lange zu überlegen.*

Abschließende Einschätzung der Rückmeldearten					
Geben Sie bitte an, inwieweit die folgenden Aussagen auf Sie zutreffen und machen Sie bitte jeweils ein Kreuz pro Zeile.					
	Trifft absolut nicht zu	Trifft eher nicht zu	Weder noch	Trifft eher zu	Trifft absolut zu
Die **Nickbewegungen** sind sinnvoll, um dem Fahrer das Erkennen eines Vorderfahrzeugs zurückzumelden.	☐	☐	☐	☐	☐
Die **Wankbewegungen** sind sinnvoll. um dem Fahrer einen Spurwechsel anzukündigen.	☐	☐	☐	☐	☐
Die **visuellen Anzeigen auf dem Display** sind sinnvoll, um dem Fahrer das Erkennen eines Vorderfahrzeugs zurückzumelden.	☐	☐	☐	☐	☐
Die **visuellen Anzeigen auf dem Display** sind sinnvoll, um dem Fahrer einen Spurwechsel anzukündigen.	☐	☐	☐	☐	☐
Die **Kombination aus Nickbewegungen und visuellen Anzeigen** ist sinnvoll, um dem Fahrer das Erkennen eines Vorderfahrzeugs zurückzumelden.	☐	☐	☐	☐	☐
Die **Kombination aus Wankbewegungen und visuellen Anzeigen** ist sinnvoll, um dem Fahrer einen Spurwechsel anzukündigen.	☐	☐	☐	☐	☐
Die **visuellen Anzeigen** haben mir gut gefallen.	☐	☐	☐	☐	☐

Anmerkungen für die visuellen Anzeigen im Display
Haben Sie Anmerkungen zu den visuellen Anzeigen? Wurden zu viele oder zu wenige Informationen dargestellt? *Bitte geben Sie diese hier an.*

Anmerkungen
Haben Sie noch abschließende Anmerkungen zu dem Fahrversuch, den Fragebögen oder allgemeine Anmerkungen? *Bitte geben Sie diese hier an.*

F Accuracy Regression Models

Table A.9: Accuracy of the different logistic regression models

Criteria*	Basis of decision-making for positive assessment	Model 1	Model 2a	Model 2b
Standardized residual	$\leq 5\,\%$ of the values $> \pm 1.96$, $\leq 1\,\%$ of the values $> \pm 2.58$	✓3.5 % of the values $> \pm 1.96$, ✓0.0 % of the values $> \pm 2.58$	× 5.3 % of the values $> \pm 1.96$, × 2.1 % of the values $> \pm 2.58$	✓3.8 % of the values $> \pm 1.96$, × 2.3 % of the values $> \pm 2.58$
Cook's Distance	< 1[†]	✓	✓	✓
Standardized DFBeta	< 1	✓	✓	✓
Leverage	100 % of the values $\leq (3(k+1)/N) = l$[§]	× 98.5 % of the values $\leq l$	× 97.1 % of the values $\leq l$	× 97.7 % of the values $\leq l$
	Nagelkerke's R^2	.560	.417	.358

[*] Field (2012)

[†] Cook and Weisberg (1982) as cited in Field (2012)

[§] Stevens (2002) as cited in Field (2012), k: number of predictors

Table A.10: Accuracy of the different multiple regression models

Criteria[*]	Basis of decision-making for positive assessment	Model 3	Model 4	Model 5	Model Study 3
Standardized residual	$\leq 5\,\%$ of the values $> \pm 1.96$, $\leq 1\,\%$ of the values $> \pm 2.58$	× 5.4 % of the values $> \pm 1.96$, × 1.5 % of the values $> \pm 2.58$	× 6.5 % of the values $> \pm 1.96$, × 1.6 % of the values $> \pm 2.58$	× 8.5 % of the values $> \pm 1.96$, × 2.8 % of the values $> \pm 2.58$	× 5.2 % of the values $> \pm 1.96$, ✓0.0 % of the values $> \pm 2.58$
Cook's Distance	< 1[†]	✓	✓	✓	✓
Standardized DFBeta	< 1	✓	✓	✓	✓
Leverage	100 % of the values $\leq (3(k+1)/N) = l$[§]	✓ 100 % of the values $\leq l$	× 98.8 % of the values $\leq l$	× 98.4 % of the values $\leq l$	✓100 % of the values $\leq l$
	R^2 Adjusted R^2	.237 .212	.197 .190	.526 .521	.757 .750

[*] Field (2012)

[†] Cook and Weisberg (1982) as cited in Field (2012)

[§] Stevens (2002) as cited in Field (2012), k: number of predictors