MASTER THESIS IN HUMAN FACTORS AND ENGINEERING PSYCHOLOGY

# Exploration of the Communication between Autonomous Vehicles (AVs) and Pedestrians via exterior Human-Machine Interfaces (eHMIs)

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*Note: The results, opinions and conclusions of this work are not necessarily those of Volkswagen AG.*

## Abstract

**Introduction** With the introduction of Autonomous Vehicles (AVs) on public roads, there is a change regarding the communication from vehicles to pedestrians. The conventional bidirectional communication between driver and pedestrian via eye gaze or hand gestures shifts to a human-machine interaction. A resulting challenge for the automotive industry will therefore be to develop new interaction possibilities for AVs, which enable the communication intention of vehicles to pedestrians. One possible way for the external communication of AVs could be an exterior human-machine interface (eHMI), where an explicit, informative message is presented via different technical arrangements outside the vehicle. In this study, six different eHMI concepts were investigated for their comprehensibility and usefulness of the communication intention of an AV. The concepts were previously developed as part of the 'HMI for external communication' research project of Volkswagen Aktiengesellschaft.

**Method** Overall, 24 employees of Volkswagen Aktiengesellschaft took part in a 90-minute Wizard-of-Oz experiment in an industrial area in Wolfsburg. A within-subject design was chosen, where all participants experienced individually six different concepts of an eHMI. For the statistical analysis, an intercept-only Absolute Group Mean (AGM) model with participant-level random effects was used to estimate the design effect of the six eHMI concepts on the evaluation of the User Experience (UX), usability, comprehensibility, sense of security and technical arrangements.

**Results** The results identified a systematic trend in the evaluation of eHMI concepts. Four of the six concepts were rated as useful, understandable and suitable, whereas two of them were not. Participants felt safe in the presence of the AV at all eHMI concepts. The intention of the AV was interpreted most clearly and unambiguously by using a combination of visual, auditory and physical/ kinesthetic modalities. The display technology, acoustic signals, as well as the light bar technology was rated as suitable for the communication of information and the communication of a warning in a safety critical situation. Overall, the attitude of the participants towards AVs improved after the experiment.

**Conclusion** The communication intention of an AV via an eHMI could be a possible way to facilitate and improve the interactions between pedestrians and AVs. Further investigations have to be made in more dynamic traffic situations and by involving a larger number of road users to validate this conclusion. In future, a standardization of the eHMI concepts is recommended to avoid potential ambiguities.

*Keywords:* Autonomous Vehicle (AV); external communication; driver–pedestrian interaction, exterior Human-Machine Interface (eHMI); Wizard-of-Oz experiment; Generalized Linear Models (GLMs)

## Samenvatting

**Inleiding** Met de introductie van Autonome Voertuigen (AV) op de openbare weg is er een verandering in de communicatie tussen voertuigen naar voetgangers. De conventionele tweerichtingscommunicatie tussen bestuurder en voetganger via oog- en/of handbewegingen verschuift naar een mens-machine-interactie. Een resulterende uitdaging voor de auto-industrie is daarom gericht op het ontwikkelen van nieuwe interactiemogelijkheden voor AV, die de communicatie van voertuigen met voetgangers mogelijk maken. Een mogelijke manier voor de externe communicatie van AV zou via een ‘exterior Human-Machine Interface‘ (eHMI) kunnen zijn, waarbij een expliciete, informatieve boodschap wordt gepresenteerd via verschillende technische oplossingen buiten het voertuig. Deze studie onderzocht zes verschillende eHMI-concepten voor hun begrijpelijkheid en bruikbaarheid voor de intentionele communicatie van een AV. Deze concepten werden eerder ontwikkeld in het kader van het onderzoeksproject ‘HMI voor externe communicatie' van Volkswagen Aktiengesellschaft.

**Methode** In totaal namen 24 medewerkers van Volkswagen Aktiengesellschaft deel aan een 90 minuten durende ‘Wizard-of-Oz‘ - experiment op een industrieterrein in Wolfsburg. Een ‘within-subject design‘ werd gekozen, waarbij alle deelnemers individueel zes verschillende concepten van een eHMI hebben ervaren. Voor de statistische analyse is gekozen voor een ‘intercept-only Absolute Group Mean‘ (AGM) model met ‘participant-level random‘ effecten.

**Resultaten** De resultaten identificeerden een systematische trend in de evaluatie van eHMI-concepten. Vier van de zes concepten werden als nuttig, begrijpelijk en geschikt beoordeeld, twee niet. Deelnemers voelden zich veilig in de aanwezigheid van het AV bij alle eHMI-concepten. De bedoeling van de AV wordt het duidelijkst en ondubbelzinnigst geïnterpreteerd door een combinatie van visuele, auditieve en fysieke/ kinesthetische modaliteiten te gebruiken. De weergavetechnologie, akoestische signalen en de lichtbalktechnologie werden beoordeeld als geschikt voor de communicatie van informatie en de communicatie in een veiligheid- kritische situatie. Over het algemeen verbeterde de houding van de deelnemers ten opzichte van AV na het experiment.

**Conclusie** De intentiecommunicatie van een AV via een eHMI zou een mogelijke manier kunnen zijn om de interacties tussen voetgangers en AV te vergemakkelijken en te verbeteren. Verder onderzoek is gedaan naar meer dynamische verkeerssituaties en door een groter aantal weggebruiker te betrekken om deze conclusie te valideren. In de toekomst is een standaardisatie van de eHMI-concepten vereist om mogelijke dubbelzinnigheden te voorkomen.

*Trefwoorden*: Autonome Voertuig (AV); externe communicatie; interactie tussen bestuurder en voetgangers, exterior Human-Machine Interface (eHMI); Wizard-of-Oz experiment; Generalized Linear Models (GLMs)

## Table of Content

**List of Abbreviations**

| Abbrevitation | Meaning |
|---|---|
| ACC | Adaptive Cruise Controle |
| AGM | Absolut Group Mean |
| AV | Autonomous Vehicle |
| eHMI | exterior Human-Machine Interface |
| e.g. | for example |
| GLMs | Generalized Linear Models |
| HMI | Human-Machine Interaction |
| HRI | Human-Robot Interaction |
| i.e. | That is |
| LCD | Liquid Crystal Display |
| m | Meter |
| *max.* | Maximum |
| *min.* | Minimum |
| MLA | Multi-Lens Arrays |
| PRQF | Pedestrian Receptivity Questionnaire for fully AVs |
| *SD* | Standard Deviation |
| SUV | Sport Utility Vehicle |
| UEQ-S | Short form of the User Experience Questionnaire |
| UX | User Experience |
| VMS | Variable Message Signs |

## List of Figures

## List of Tables

## General Introduction

To ensure a successful introduction of Autonomous Vehicles (AVs), crucial challenges have to be overcome. One of the current challenges within the automotive industry is how AVs will interact with pedestrians in their vicinity. Overcoming this challenge seems to be crucial if AVs are to fulfil their potential for traffic safety improvement and to gain public acceptance. In conventional road traffic, the interaction between drivers and pedestrians is governed by human perception, formal rules, social norms, and interpersonal interactions (Owens et al., 2019). In this context, interpersonal interactions are mainly based on non-verbal communication, such as gestures, facial expressions, and eye contact to communicate each other's intention. With the introduction of AVs, this bidirectional human communication has to be taken over by the vehicle to a human-machine interaction, as a human driver will no longer be present. The question, which arises is how AVs can communicate its intention to pedestrians to facilitate the interaction.

New interaction possibilities are yet to be fully explored. The current scope in this field of research is mainly on mastering challenges associated with HMIs inside an AV. These include for example the driver's ability to switch between the transfer and assumption of driving functions. Only a few studies are dealing with the external communication of AVs. A study of Habibovic (2018) showed that pedestrians may gain most from knowing the mode and intent of AVs in terms of perceived sense of security. Further investigations came from studies in Human-Robot Interaction (HRI), which provide a framework to guide the design of the interactions between AVs and pedestrians (Owensby, Tomitsch & Parker, 2018). According to literature, the communication of AVs' intention to pedestrians via external interfaces on the vehicle could be a possible way to guide the behaviour of pedestrians in a way that prevents critical deadlock situations.

The goal of this study was to examine whether the interaction between pedestrians and AVs is positively affected when AVs communicate their intentions to pedestrians via an exterior Human-Machine Interface (eHMI). While this study focused on assessing the User Experience (UX) and usability of six eHMI concepts, it generated some insights into pedestrians' emotions and perceived safety when encountering an AV. The experiment was conducted in real traffic and based on the Wizard of Oz approach to simulate autonomous driving.

**Interaction between Conventional Vehicles and Pedestrians**

A successful interaction between vehicles and pedestrians is primarily responsible for traffic safety in urban environments. In order to be able to guarantee these interactions even with the introduction of AVs, it is crucial to investigate and analyse the underlying factors that contribute to a successful communication between drivers and pedestrians. Regarding the existing literature about the vehicle-pedestrian interaction, there are different conclusions with regard to the common modality of communication between drivers and pedestrians in road traffic.

The first common modality of communication between drivers and pedestrians refers to the bidirectional human communication, which include gestures, facial expressions, and eye contact to communicate each other's intention. Studies conducted by Vinkhuyzen and Cefkin (2016) indicate that the employment of gestures like waving are common practice between drivers and pedestrians while negotiating right of way. Furthermore, both drivers and pedestrians tried to make eye contact to resolve the actual conflict in ambiguous road traffic situations (Müller, Emmenegger and Risto, 2017). Likewise, Šucha (2014) came to the conclusion that 84% sought eye contact with the driver before the road will be crossed. In this context, the study of Malmsten Lundgren et al. (2017) revealed that a lack of eye contact affected road crossing behaviour among pedestrians. Their results show that pedestrians' willingness to cross the street decrease with an inattentive driver, whereas eye contact with the driver leads to calm interaction between vehicles and pedestrians (see Palmeiro, van der Kint, Vissers, Farah, de Winter & Hagenzieker, 2018).

On the contrary, several existing studies emphasize that explicit bidirectional communication between vehicles and pedestrians would not be mandatory or critically important in common traffic situations. For a successful interaction between vehicles and pedestrians, the analysis of motion and behaviour of the vehicle to obtain the vehicle's intention would be more common in traffic coordination. One example is the study of Dey and Terken (2017), whose results show that explicit communication methods like eye contact and gestures are not as significant or important as intuition suggests. In this context, most pedestrians resort to explicit communication only when an expected behaviour of an approaching vehicle did not occur. The knowledge about the intention of the vehicle is inferred from the behavioural indices of the vehicle itself, such as movement patterns and the vehicle's speed, which is why most pedestrians make an informed decision about their crossing behaviour after a momentary glance at an oncoming vehicle (Dey & Terken, 2017; see also. Emmenegger, Risto, Bergen, Norman & Hollan, 2016). In this context, a further addition came from the study of Schmidt, Terwilliger, Aladawy and Fridman (2019), which stated that pedestrians perceived the changes in vehicle motion and speed as a direct reaction to their presence, which gave them a sense of being perceived. Furthermore, the study of Aladawy et al. (2019) demonstrate that over 90% of pedestrians in representative lighting conditions could not determine the gaze of the driver at 15m and see the driver at all at 30m, although pedestrians may believe that they made eye contact with the driver. More specifically, in most traffic situations involving an approaching vehicle, the crossing decision is made by the pedestrian solely based on the kinematics of the vehicle without needing to determine that eye contact by explicitly detecting the eyes of the driver (Aladawy et al., 2019; see also. Risto, Emmenegger, Vinkhuyzen, Cefkin, Hollan, 2017).

A study that considers the bidirectional communication as well as the vehicles kinematic to be relevant for a successful communication between vehicles and pedestrians is that of Schneemann and Gohl (2016). They found out that one of the main influences on the pedestrian’s decision process is to a certain extent the vehicle’s speed and then eye contact. In their study, a driving experiment in real-life traffic was conducted to analyse the interaction between drivers and pedestrians at crosswalks from both, the driver's and the pedestrian's perspective. The results showed that in the majority of interactions (88%), pedestrians fixed their glance on the approaching vehicle to decide if the driver will yield, within a 50 km/h zone. In a 30 km/h zone, 50% of the participants sought the eyes of the driver to clarify each other’s intention, rather than observing the approaching vehicle. These findings suggest that it depends on the initial speed of the vehicle if the pedestrian decides to cross the street, as well as whether the pedestrian looks at the approaching vehicle or the driver himself to get the confirmation that the road can be crossed (see Ackermans, 2019).

As the existing literature about the common modality of the communication between drivers and pedestrians in road traffic is striking, both points of view have to be taken into account in the development process of external communication possibilities for an AV.

**Interaction between AVs and Pedestrians**

After a closer look at the human-to-human communication in conventional road traffic, the question now arises how to implement this background knowledge in such a way that a successful human-machine interaction can be created. Various approaches have been studied to find the most reliable and natural way to communicate between machines and humans. According to the study of Matthews, Chowdhary & Kieson (2017) a successful communication between humans and machines is based on the mutual understanding of each other’s intention, which means that the human not only has to understand the machine but also the other way round. The focus hereby relies on the gesture identification, audio feedback, haptic feedback, as well as other types of HMIs. In this context, Croft (2003) stated that monitoring is important during interpersonal interactions, where non-verbal cues such as eye-gaze direction, facial expression and gestures are frequently exchanged to assess each other's emotional state, focus of attention and intent (Croft, 2003; see also. Wang, Shum, Xu & Zheng, 2001). As human gestures are diverse and ambiguous, gesture identification provides a major challenge for machines (Matthews, Chowdhary & Kieson, 2017). To overcome this challenge, Craft (2003) suggests a more dynamically tracking of the physiological signals of the human, which includes an emotional interface technology, such as facial expression recognition and physiological signal tracking. However, most physiological signals are affected by cognitive and emotional processing, as well as maintaining the equilibrium of bodily functions (homeostasis). Therefore, the measure of approval from robot actions has to be extracted by separating the signal component stemming from homeostasis activities, as well as from emotional and cognitive processing, which is not related to machines' activity. The separation of the signal component, however, represents the next technical challenge (Croft, 2003).

As the technical implementation of a broad understanding of human intentions is quite extensive and difficult, previous literature is more focused on how pedestrians can successfully understand the intention of AVs. The authors Joosse, Lohse and Evers (2014) propose to add some artificially engine noise to AVs to convey their intentions. Their results show that a vehicle approaching with intentional noise (increasing in volume when the vehicle accelerated and decreasing in volume when the vehicle decelerated) was perceived more helpful, and was regarded more positively than without (Joosse, Lohse & Evers, 2014). However, according to Matthews, Chowdhary and Kieson (2017), a problem with this is that the sounds have to be taken in a specific context and humans have to have previous knowledge of the machine or training with the machine, the option of explicit or implicit communication, and the notion of trust.

A further study dealing with the communication intention of AVs came from Habibovic (2018), who stated that pedestrians may gain most from knowing the mode and intent of the AV in terms of a subjectively perceived sense of security. The study investigated how the interaction between pedestrians and AVs might be affected if AVs communicate their intention to pedestrians via an external vehicle interface. This interaction was explored in two experiments using a Wizard of Oz approach to simulate automated driving. During the first experiment, which was carried out at a zebra crossing, the main focus was on assessing the usability of the interface, and pedestrians' emotions and perceived safety when encountering an AV with and without the interface. The second experiment was carried out in a parking lot. The experiment provided some insights of pedestrians' perceived safety when encountering an AV with and without the interface. The results show that pedestrians felt significantly less safe when they encountered the AV without the interface, compared to the conventional vehicle and the AV with the interface. Therefore, according to Habibovic (2018), an external interface showing the actual intention of the AV could contribute to a positive experience and improved perceived safety in pedestrian AVs, which would be important for the general acceptance of AVs.

In this context, the vehicle's awareness and intention should be conveyed through a combination of visual, auditory and physical/ kinesthetic modalities (Mahadevan, Somanath & Sharlin, 2018). The visual modality refers to visual cues like colour, patterns, and text, which pedestrians can perceive, while the auditory modality aims to provide audio feedback through sounds and verbal messages. The physical/ kinesthetic modality refers not only to visual cues but provides also additional feedback through activities, such as braking processes and accelerating of the AV. A further investigation came from Owensby, Tomitsch and Parker (2018), who found out that the more effective design concepts for the external communication of AVs were those that assisted the users in: (1) clearly identifying their vehicle, (2) knowing the vehicle's current status, (3) knowing the vehicle's intent, and (4) knowing the vehicle was aware of them.

Regarding the literature, one possible way for a successful human-machine interaction would therefore be to communicate the intention of AVs to pedestrians through external vehicle interfaces in terms of different technical modalities.

**Further Interaction Challenges between Pedestrians and AVs.** When considering pedestrians' crossing decision, situation awareness plays a crucial role (Palmeiro, van der Kint, Vissers, Farah, de Winter & Hagenzieker, 2018). According to the model of Endsley (1995), pedestrians predict the behaviour of vehicles (Level 3) based on their perception of vehicle and road features (Level 1) and their comprehension of the situation (Level 2) (Figure 1). In this context, AVs' features would include speed and distance as well as cues provided by potential eHMI concepts. Knowledge and expectations about the behaviour of AVs, as well as preconceptions and trust in AVs belong to individual factors. When pedestrians are able to perceive and understand an approaching vehicle's features and the road situation, they are able to make appropriate predictions regarding the behaviour of the vehicle. Subsequently, this leads to accurate crossing decisions and safe crossing behaviour. If pedestrians have inaccurate perception and comprehension about the behaviour of the vehicle, this could lead to potentially wrong predictions, a state of elevated confusion, stress and an unsafe crossing situation (Palmeiro, van der Kint, Vissers, Farah, de Winter & Hagenzieker, 2018).

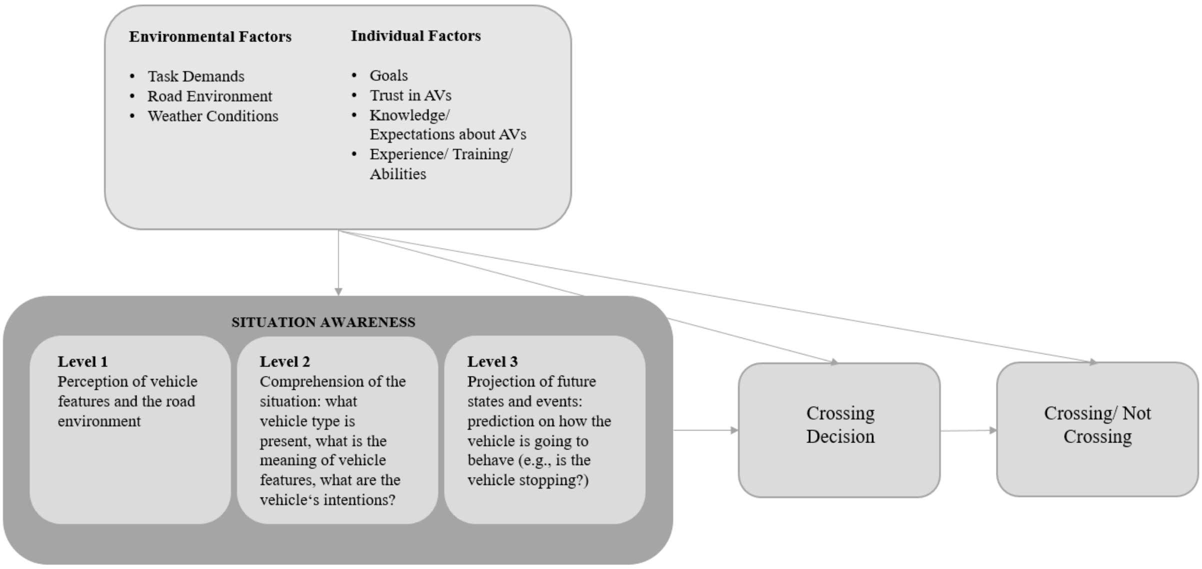


*Figure 1.* Model of situation awareness in dynamic decision making, describing the interaction between a pedestrian and an AV. Own presentation adapted from Palmeiro, van der Kint, Vissers, Farah, de Winter and Hagenzieker (2018).

## Development of the eHMI Concepts

Within the framework of the research project ‘HMI for external communication’ of Volkswagen Aktiengesellschaft the aim was to display an integrated HMI such as the one from the passenger compartment also outside the vehicle to enable mutual recommendations for action between road users and the recognition of intentions. This should enable an optimal adaptation of the HMI to the needs of the pedestrians (Volkswagen Aktiengesellschaft, 2018). The provided test vehicle was a Tiguan, a compact Crossover Utility Vehicle (CUV) of Volkswagen (year of construction 2017). The vehicle was equipped with four different technologies to allow a 360-degree communication. In this context, the visual modality included four large Liquid Crystal Displays (LCD), which were integrated in the doors, as well as in the front and rear sections on the outside of the vehicle, for presenting either information or warnings. Additionally, the vehicle was equipped with a 360-degree LED multicolour bar that interacted in parallel with the LCDs and used animated lighting concepts to support external communication. As a third visual modality, multi-lens arrays (MLA) were mounted in the corner areas of the body and enabled a projection of visual protection and communication information onto the road. The test vehicle was also equipped with acoustic signals, which represent the fourth technology and provided additional sounds for a warning or information. By using different technical modalities to communicate information or warnings, the aim was to implemented and test various possibilities of interaction. The eHMI was intended to build intuitive understanding and confidence in vehicle behaviour and an intuitive prediction of possible driving manoeuvres (Volkswagen Aktiengesellschaft, 2018).

To ensure successful communication between AVs and pedestrians, the communication requirements of pedestrians had to be matched with existing design guidelines regarding the overall design and the representation of information of the eHMI concepts within traffic. In this context, various challenges referring to the design of interfaces, which have to be discernible at the distance of an approaching vehicle, as well as visible and understandable in the context of busy intersections had to be overcome. However, due to the novelty of the topic of external communication methods for AVs via different technical arrangements outside the vehicle, no existing design guidelines or standards could be used so far within the development process. However, the project team of 'HMI for external communication' of Volkswagen Aktiengesellschaft, derived design guidelines for the eHMI concepts with the aid of premises from related subject areas, like the European Catalogue of Principles for HMIs (see EUR-Lex, 2008), the influence of optical displays on distraction, fatigue and concentration (see National Highway Traffic Safety Administration (NHTSA), 2014; Bundesministerium für Verkehr-Innovation und Technologie, 2019), the capturing and processing of optical advertisements (see Erke, Sagberg & Hagman, 2007), as well as design principles for variable message signs (VMS) (see Arbaiza & Lucas-Alba, 2012; Barby, Deml, Hartz & Saighani, 2016). Subsequently, internal design guidelines for the development of the overall design, as well as for the presentation of information of eHMI concepts were compiled (Volkswagen Aktiengesellschaft, 2019).

With respect to the internal design guidelines, the eHMI was not intended to be distracting, but to simplify the recognition of the intention. Therefore, static or dynamic icons as well as light elements were used, which were separated by colour coding between information (white) and warnings (orange). The extent of visual cues differed according to content. In the case of information, only the LCD, LED bar and acoustic signals were used, whereas in the case of a warning, an additional floor projection and special warning signals were used. Besides that, the standard lights on the vehicle were always active (Volkswagen Aktiengesellschaft, 2019).

The first of the six developed eHMI concepts, which acted as experimental stimuli, wanted to inform road users about the change of automation levels, for example, the change from a manually operated to a fully autonomous driving vehicle, by means of a turquoise

LED bar, extending along the roof (Figure 2). The colour turquoise was chosen, as this is the universal colour for demonstrating a fully autonomous ride and particularly noticeable, as well as not yet used as signal colour in traffic (Kirchbeck & Lockschen, 2018). Moreover, only one visual modality was chosen for the information mediation to avoid possible distractions in road traffic. According to literature, a key value for a successful interaction with AVs is to know when the vehicle drives completely autonomous and no driver is inside the vehicle, which indicates the relevance of the concept (see Owensby, Tomitsch & Parker, 2018).

*Figure 2.* First experimental stimulus: eHMI concept for showing the current automation level.

A further eHMI concept was designed for illustrating a search for a parking spot. The test vehicle wanted to inform the pedestrian that it was trying to park in the immediate vicinity by displaying the known letter 'P' for parking in white colour with an animated border, as well as by using a white coloured LED bar (Figure 3). The direct parking process was indicated by the letter 'P' with a static border and an LED indicator in white, as well as with MLAs, which allowed a floor projection on the side of the desired parking lot. By communicating its planned driving manoeuvres, the vehicle tried to avoid ambiguities that could arise, for example, from the speed reduction or the braking process of the vehicle, while searching for a parking lot. In addition, a white colour was chosen, as the vehicle only communicated an information about its current status. There were no flashing lights or a change of the pictogram to avoid distractions in road traffic and not to shift the attention of important elements.


*Figure 3.* Second experimental stimulus: eHMI concept for showing a search for a parking spot.

Moreover, there were two eHMI concepts for the stop in front of pedestrians to let them cross the road. One of them illustrated the internal state of the test vehicle by showing an icon for decreasing speed, as well as an acoustic signal (Figure 4). As previously seen in literature, pedestrians perceived the changes in vehicle motion and speed as a direct reaction to their presence, which gave them a sense of being perceived and subsequently a secure feeling to cross the street (Schmidt, Terwilliger, Aladawy and Fridman, 2019; Emmenegger, Risto, Bergen, Norman & Hollan, 2016). The concept attempted to support and clarify the natural deceleration process of the vehicle using the LCD. Acoustic signals were also used to assist pedestrians in alerting to the braking process of the vehicle.


*Figure 4*. Third experimental stimulus: eHMI concept for showing a speed reduction.

The next eHMI concept used an animated walking pedestrian man, a LED bar, whose lights moved from one side to the other and an acoustic signal, to ask the pedestrian to cross the street (Figure 5). The concept tried to replace the missing bidirectional communication between driver and pedestrian by eye contact and gestures, as this is also a common modality in road traffic to communicate (Vinkhuyzen & Cefkin, 2016; Schneemann & Gohl, 2016, Šucha, 2014; Müller, Emmenegger & Risto, 2017). The animated LED bar in the form of step movements, running from one side to the other replaced conventional hand movements, to let pedestrians cross the street. Next to the visual modality, an auditory modality was used, so that pedestrians became aware of the AV.

*Figure 5.* Fourth experimental stimulus: eHMI concept for inviting the pedestrians to cross the street.

Furthermore, there were two eHMI concepts presenting an emergency stop, for example in the event of technical problems, by illustrating an icon of a warning triangle with an exclamation mark and an acoustic warning signal, an orange LED bar, as well as floor projections via MLAs at all four corners of the vehicle (Figure 6). This combination of technical arrangements were used to immediately draw attention to a safety critical situation. The pictogram of the concepts was kept very minimalistic and simple by using a well-known warning sign from the road traffic to provide for a quick understanding.

*Figure 6.* Fifth experimental stimulus: eHMI concept for showing a safety stop by an icon.

On the contrary, the next eHMI concept that represented a safe stop of the vehicle, displayed the text 'Safe Stop' via LCDs and used an acoustic warning signal, an orange LED bar, as well as floor projections via MLAs at all four corners of the vehicle (Figure 7).


*Figure 7*. Sixth experimental stimulus: eHMI concept for showing a safety stop by a text message.

## Purpose and Research Questions

The purpose of the study was to investigate, whether the communication between pedestrians and AVs is successful, user-friendly and supportive by means of the six different eHMI concepts, which convey different intentions and prompts for action. The study also aimed to uncover possible problems and difficulties within the external communication of AVs. In particular, the following research questions were addressed:

*Research Question 1a:* How good is the pedestrians experience in terms of hedonic and pragmatic quality of all six eHMI concepts for the external communication of the AV’s intention to pedestrians?

*Research Question 1b:* Is the communication intention of the AV unambiguously and correctly interpreted on the basis of the eHMI?

*Research Question 1c*: By means of which modalities or combinations of different modalities is the intention of the AV interpreted most clearly and unambiguously?

# Method

## Participants

Overall, 24 participants took part in the study, which were acquired by the Probandenpool of Volkswagen Aktiengesellschaft. The recruitment criteria were an existing driving license, as experiences with traffic regulations and street signs were required, as well as a preferably balanced age distribution of the Volkswagen employees between 25-65 years.

In total, 17 men and seven women took part in this research. The average age was 36.21 years (*min.*=22, *max.*=57, *SD*=10.73).

**Design**

A within-subjects study design was chosen (Table 1). All of the 24 participants experienced six different eHMI concepts for the external communication of an AV that they did not know in advance within an industrial area in Wolfsburg. Participants were blind to the signal, but got the instruction to watch the traffic. Overall, the test vehicle drove past each participants eight times (one trip for each eHMI and two baseline rides) in a randomized order (Appendix C). The evaluation of each use case lasted 10-15 minutes. The entire test duration amounted to 90 minutes per participant. In total, there were six experimental days, on which the participants were tested between 16:00 and 24:00 o'clock.

Table 1

*Illustration of the study design with one within factor (eHMI) that represents six different communication intentions of an AV*

| Automation Level | Parking Search | Pedestrian Icon - Status | Pedestrian Icon - Invitation to act | Safe-Stop - Icon | Safe-Stop - Text |
|---|---|---|---|---|---|
| 24 | 24 | 24 | 24 | 24 | 24 |

**Wizard-of-Oz Approach.** To illustrate an AV, an on-road Wizard-of-Oz approach was conducted by the driver of the test vehicle wearing a seat costume while driving. By considering this approach, participants thought in fact they would interact with an autonomous driving vehicle. This enabled the examination of the suitability of the eHMI for the external communication between pedestrians and AVs on an early stage of the development process (see Kelley, 1984).

**Materials**

**Survey Instrument.** A pen and paper questionnaire was designed, consisting of four main parts (Appendix E). The first part included a preliminary interview, asking about the attitude towards AVs, by using the Pedestrian Receptivity Questionnaire for fully AVs (PRQF) from Deb et al. (2017).

The second part of the questionnaire included a scenario evaluation, consisting of eleven questions based on the first impression and presumption of pedestrians on the intention of the AV to see, whether the communication intention was clear or misleading (see

Owensby, Tomitsch & Parker, 2018; Habibovic, 2018; Malmsten Lundgren et al., 2017). The third part of the questionnaire consisted of 18 questions, asking about the comprehensibility and usefulness of the eHMI concepts, after renewed second presentation and clarification of the intention of the AV. Moreover, the short form of the User Experience Questionnaire (UEQ-S) was used for measuring the subjective impression of users towards the UX of interactive products in terms of pragmatic and hedonic quality (Schrepp, Hinderks & Thomaschewski, 2017).

The last part of the questionnaire included seven questions for the evaluation of the communication technology and the usefulness of the respective modalities of the eHMI, to investigate which modality is best for an external communication (see Mahadevan, Somanath & Sharlin, 2018). A final survey was asking about the attitudes towards AVs via the PRQF again, as well as about demographics. Additionally, in each part of the questionnaire, there were open questions to understand the participants' preferences regarding the eHMI, as well as their point of view in terms of improvements.

**Testing Ground.** For the experiment in real-world traffic, it was chosen for a street within the industrial area of Wolfsburg, as there are real traffic conditions like other vehicles, pedestrians and cyclists, as well as traffic rules. Nevertheless, the industrial area is relatively quiet and manageable in contrast to the overcrowded city center, which is an advantage in terms of safety reasons.

**Measurement**

The PRQF is validated as a potential research tool for designing and improving fully AVs for road-users outside the vehicles and included sixteen survey items. The items were based on attitude, which describes the positive and negative feelings towards fully AVs in general, as well as on social norm that represented the individual perception of what important and influencing people think about fully AVs. Moreover, the PRQF included items for trust, which represented the individual belief that a fully AV will perform its intended task with high effectiveness and items related to compatibility, the degree to which a fully AV is perceived as being consistent with the existing transportation system. Finally, there were items for system effectiveness, which described the extent to which a fully AV successfully detects pedestrians and other obstacles on the road, stops for them and allows safe pathway (Deb et al., 2017; see also. Ackermans, 2017). The questionnaire provided a 7-point Likert scale, ranging from '1' = very positive to '7' = very negative. There was one reverse-scaled item for social norms on the PRQF. Scores $\leq 3$ meant a positive rating of the AV, whereas scores ≥ 5 meant a negative rating. Overall, lower scores represented higher receptivity towards AVs (Deb et al., 2017).

The UEQ concentrated on the measurement of the two meta-dimensions, pragmatic and hedonic quality. In this context, the pragmatic quality was measured in terms of perspicuity, efficiency and dependability of the eHMI concepts, while the hedonic quality was measured in terms of aspects like stimulation and novelty of the eHMI concepts. For each of these dimensions, four items were chosen in the questionnaire. Thus, the short version of the UEQ contained eight items, grouped into two scales, whereby the positive items were marked by a '+3' on the extreme left side and negative items were marked by a '-3' on the extreme right side. The mean value of the eight items gave an overall UX value, whereby values between -0.8 and 0.8 represented a neutral evaluation of the corresponding scale, values ≥ 0,8 represented a positive evaluation and values ≤ -0,8 represented a negative evaluation (Schrepp, Hinderks & Thomaschewski, 2017).

The single items of the developed questionnaire for this study asked about the usability, comprehensibility, sense of security and technical arrangements of the eHMI concepts. The provided answer categories ranged from '1 = applies' to '4 = not applicable', from '1 = very understandable' to '4 = not comprehensible, as well as from '1 = very suitable' to '4 = unsuitable'. Open questions regarding the presumption of the participants about the intention communication of the AV were categorized in 'correct', 'incomplete' and 'incorrect' answers in order to analyze the unambiguity and comprehensibility of the developed eHMI concepts.

**Procedure**

**Greetings & Instructions.** Participants were greeted and thanked for their participation. They received information about the nature of the research and the procedure verbally, as well as via an informed consent (Appendix A), which they had to carefully read and sign at first. After this, participants directly got the preliminary interview (Appendix E), asking about their attitude towards AVs. In this period of time, the test leader was taking notes in the test leader protocol (Appendix B) regarding the actual time and possible abnormalities. Hereafter, participants were placed to a marked spot orthogonal to the road and got the verbal instruction to continuously watch the traffic (Figure 8). When the AV approached the participants, they should try to understand the intention communication of the AV and decide for themselves, whether the test vehicle wanted them to perform a certain action on it. However, they received no instruction regarding the developed eHMI concepts in advance. In case, the participants did not understand the message of the AV, they should simply stop and not take any action. If there were any questions, they were answered carefully.

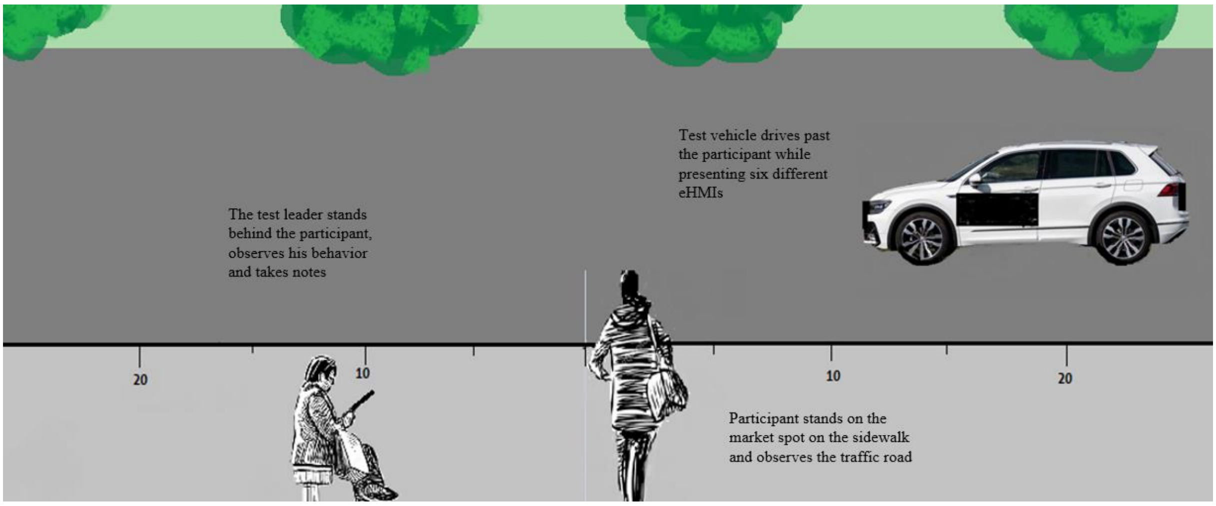


*Figure 8.* Simulation of the experimental setup of this study.

**Execution of the Study.** If everything was prepared, the hidden driver of the test vehicle got a message from the test leader to start. Before carrying out the experiment, the driver received a detailed plan of the sequence of the eHMI concepts to be shown, the directions the test vehicle should be coming from, scheduled baseline rides and information about the process (Table 2) (Appendix C). These were predefined and pseudo randomized before to increase realism and reduce predictability of events.

Moreover, an additional test leader, who sat inside the vehicle, was responsible for the control of the eHMI concepts. In order not to endanger the representation of an autonomous drive, the additional test leader was issued to the participants as a technician who could intervene in the event of a system failure. The LCD and the acoustic signals of the eHMI concepts was turned on at the first marker, 20 meter before the participant. The necessary additional functions, like the MLAs or the LED-bar, were triggered (depending on the eHMI concept) at the corresponding following marking, ten meter before reaching the participant (Appendix D).

Table 2

*Behaviour of the test vehicle per eHMI concept*

| Automation Level | Parking Search | Pedestrian Icon – Invitation to act | Pedestrian Icon - Status | Safe-Stop – Icon | Safe-Stop – Text |
|---|---|---|---|---|---|
| The test vehicle only passed the participant at constant speed. | The test vehicle stopped on the left side of the road for ten seconds to illustrate the parking manoeuvre and then drove on. | The test vehicle stopped in front of the participant and waited ten seconds before continuing. | The test vehicle stopped in front of the participant and waited ten seconds before continuing. | The test vehicle stopped briefly behind the participant at the roadside, waited again ten seconds and then drove off again. | The test vehicle stopped briefly behind the participant at the roadside, waited again ten seconds and then drove off again. |

As soon as the test vehicle had passed the participant or started again after stopping, the eHMI was switched off completely. After each trip with the respective eHMI concept, the questionnaire part 2 was given to the participants (Appendix E). When the participants had completed the questionnaire, the test leader sent again a message to the driver so that he could drive up to the participant for a repeated presentation, as well as for an explanation of the communication intention of the test vehicle in a standing position. After the demonstration of the test vehicle was finished, the questionnaire part 3 was given to the participants (Appendix E). After completion of the questionnaire part 3 and after all six trips, the last questionnaire (part 4) was delivered to the participant (Appendix E).

**Debriefing.** At the end of the study, it was mentioned again that all data would be processed in a confidential and anonymized way by the researcher. The test leader admitted that the test vehicle was not an AV, but was operated manually and that the Wizard of Oz method was used. Finally, participants were thanked for participation and given a small present.

## Statistical Analysis

Overall, participants' responses to the open questions were manually transcribed, encoded and the resulting word frequencies were subsequently analysed to draw conclusions on users' evaluation of the six different eHMI concepts.

The PRQF and UEQ were evaluated according to the validation of the questionnaires. For the PRQF this meant that the mean values of the given answers for each statement, which belonged to one of five categories, were determined. Subsequently, an overall score was determined, where higher scores represent higher receptivity toward AVs. The UEQ was calculated using the UEQ data analysis tool, which provides scores on two meta-dimensions, pragmatic and hedonic quality and an overall UX value (see Schrepp, Hinderks & Thomaschewski, 2017).

For estimating the design effect of the six concepts on the evaluation of the UX, usability, comprehensibility, sense of security and technical arrangements, it was chosen for an intercept only Absolute Group Mean (AGM) model with participant-level random effects. The model has been built with the package ‘rstanram’ of the statistical programming language R (v. 3.5.1.). This general linear model (GLM) included on the one hand the grand mean of the evaluation scores per eHMI concept and on the other hand the inter-individual differences in the evaluation score among participants, relative to the overall group mean. This allowed us to investigate, whether there was a systematic trend in the evaluation of the eHMI concepts. The full R-syntax of the statistical analysis can be found in Appendix F.

**Risk and Ethic Assessment**

Prior to this experiment, an internal risk and ethics assessment at Volkswagen Aktiengesellschaft was conducted. Possible dangers and risks have been minimized during the experiment and research ethics principles have been taken into account. Previously to the experiment, participants were informed about the course of the experiment and their tasks in written form via an informed consent, as well as in oral form. The used Wizard of Oz method was concealed for the time of the experiment. However, during the debriefing, the situation was clarified.

# Results

## Analysis of the UX regarding the six eHMI concepts

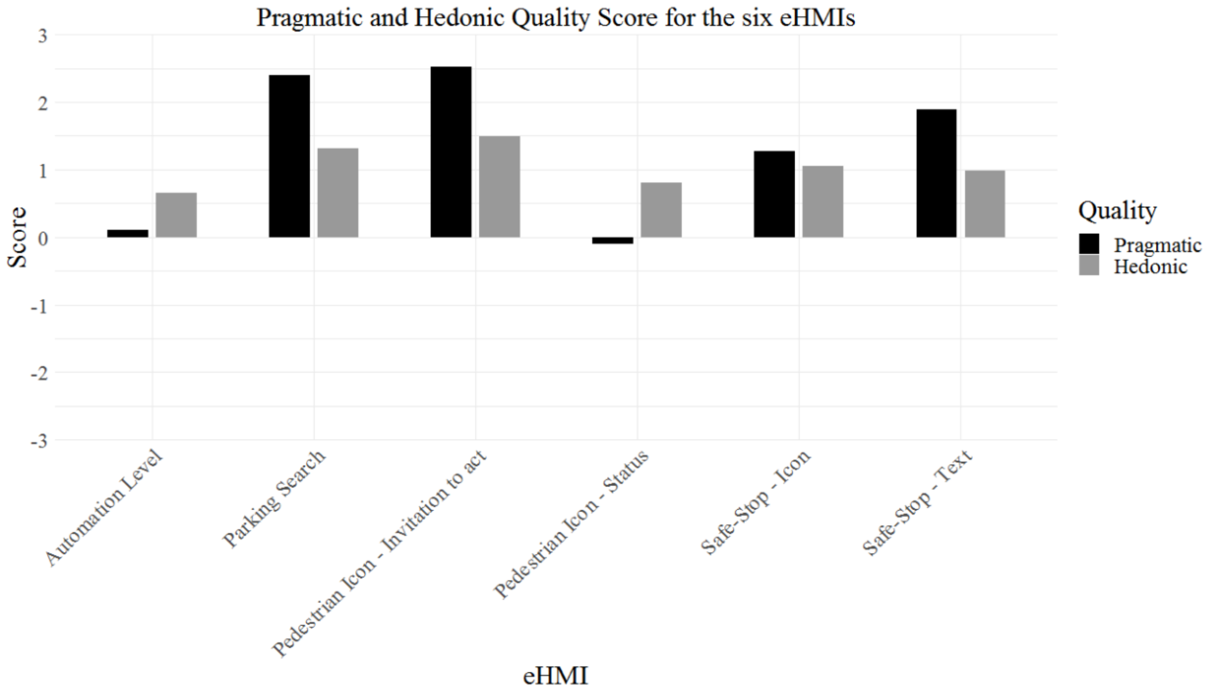


*Figure 9.* Illustration of the pragmatic and hedonic quality score for the six eHMI concepts (scores ≥ 0.8 = positive; scores ≤ -0.8 = negative)

For the analysis of the UEQ, the intercept-only AGM model with participant-level random effects was used, which allowed the evaluation of the grand mean of the pragmatic and hedonic quality score of the six eHMI concepts, and represented the inter-individual differences in the evaluation score among participants.

The results (Table 3) showed that a good pragmatic quality in terms of clarity, efficiency and reliability could be achieved by the 'Pedestrian Icon – Invitation to act' with a score of 2.50 (*95% CI* [2.40; 2.80]). This was closely followed by the 'Parking Search', which represented a nearly identical pragmatic quality score with 2.40 (*95% CI* [2.30; 2.70]). Moreover, the next two eHMI concepts, whose pragmatic quality was also rated positive was the 'Safe-Stop - Text' on the one hand, with a pragmatic quality score of 1.90 (*95% CI* [1.80; 2.20]) and on the other hand, the 'Safe-Stop – Icon', as the pragmatic quality score was 1.30 (*95% CI* [1.20; 1.60]). The two concepts, which need revision, were the 'Automation Level' with a pragmatic quality score of 0.10 (*95% CI* [0.00; 0.40]), as well as at the 'Pedestrian Icon-Status' with a pragmatic quality score of -0.10 (*95% CI* [-0.20; 0.20]).

Regarding the evaluation criteria of the UEQ, it could be stated that the 'Pedestrian Icon – Invitation to act', the 'Parking Search', as well as the two eHMI concepts for demonstrating a safety stop, the ‘Safe-Stop – Icon’, as well as the ‘Safe-Stop – Text’ have been rated positively in terms of perspicuity, efficiency and dependability, as the pragmatic quality scores were greater than 0.8, whereas the ‘Automation Level’ and the ‘Pedestrian Icon – Status’ were rated rather neutral, as the pragmatic quality scores were between -0.8 and 0.8.

In respect of the inter-individual differences (*SD*=0.61), the evaluation of the pragmatic quality for the eHMI concepts did not deviate from the grand overall evaluation.

Table 3

*Design effect on population- and participant-level for the pragmatic quality score*

| Parameter | Center | Lower | Upper | Fixed Effects SD | Random Effects SD |
|---|---|---|---|---|---|
| Automation Level | 0.10 | 0.00 | 0.40 | 0.20 | 0.61 |
| Parking Search | 2.40 | 2.30 | 2.70 | 0.20 | 0.61 |
| Pedestrian Icon – Invitation to act | 2.50 | 2.40 | 2.80 | 0.20 | 0.61 |
| Pedestrian Icon – Status | -0.10 | -0.20 | 0.20 | 0.20 | 0.61 |
| Safe-Stop – Icon | 1.30 | 1.20 | 1.60 | 0.20 | 0.61 |
| Safe-Stop – Text | 1.90 | 1.80 | 2.20 | 0.20 | 0.61 |

*Note.* Median center estimates with 95% credibility limits

Considering the evaluation of the hedonic quality for the six eHMI concepts (Table 4), it became apparent that the previous evaluation scheme is also reflected in the evaluation of the hedonic quality. A good hedonic quality in terms of stimulation and novelty, was achieved again by the ‘Pedestrian Icon – Invitation to act’, with a score of 1.50 (*95% CI* [1.30; 1.90]). The ‘Parking Search’ with a hedonic quality score of 1.30 (*95% CI* [1.20; 1.70]), as well as the ‘Safe-Stop - Text’ and the ‘Safe-Stop - Icon’ with hedonic quality scores around 1.00 (*95% CI* [0.80; 1.30]) were also rated positive. A neutral evaluation of the hedonic quality score could be find at the ‘Pedestrian Icon - Status’ with a score of 0.80 (*95% CI* [0.70; 1.20]), and the ‘Automation Level’ with a score of 0.60 (*95% CI* [0.50; 1.00]).

According to the evaluation criteria of the UEQ, it could therefore be concluded that the ‘Pedestrian Icon – Invitation to act’, the ‘Parking Search’, as well as the two eHMI concepts for demonstrating a safety stop the ‘Safe-Stop - Text’ and ‘Safe-Stop - Icon’ have been rated positively in terms of stimulation and novelty, as the hedonic quality scores were greater than 0.8. On the contrary, the ‘Pedestrian Icon – Status’, as well as the ‘Automation Level’ were rather rated neutral, as the hedonic quality scores were between -0.8 and 0.8.

In respect of the inter-individual differences (*SD*=0.92), the evaluation of the hedonic quality for the eHMI concepts slightly deviate from the grand overall evaluation. Participants' evaluation of each concept ranged from neutral to positive.

Table 4

*Design effect on population- and participant-level for the hedonic quality score*

| Parameter | Center | Lower | Upper | Fixed Effects SD | Random Effects SD |
|---|---|---|---|---|---|
| Automation Level | 0.60 | 0.50 | 1.00 | 0.20 | 0.92 |
| Parking Search | 1.30 | 1.20 | 1.70 | 0.20 | 0.92 |
| Pedestrian Icon – Invitation to act | 1.50 | 1.30 | 1.90 | 0.20 | 0.92 |
| Pedestrian Icon – Status | 0.80 | 0.70 | 1.20 | 0.20 | 0.92 |
| Safe-Stop – Icon | 1.00 | 0.90 | 1.40 | 0.20 | 0.92 |
| Safe-Stop – Text | 1.00 | 0.80 | 1.30 | 0.20 | 0.92 |

*Note.* Median center estimates with 95% credibility limits

**Analysis of the Attitude towards AVs before and after the Experiment**

The analysis of the PRQF was repeated with the intercept-only AGM model with participant-level random effects. In this context, the GLM was used to investigate, whether the scores on the five factors (Attitude, Social Norm, Trust, Effectiveness and Compatibility), will change after the presentation of the six eHMI concepts.

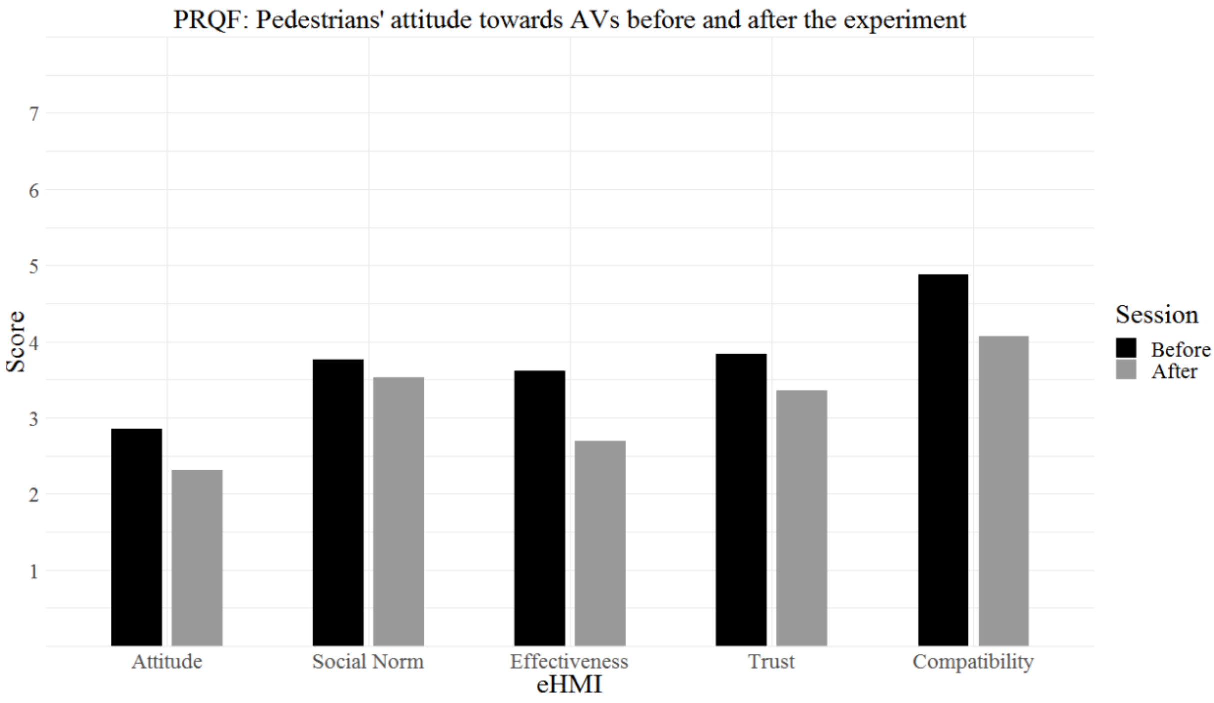


*Figure 10.* Illustration of the pedestrians' attitude towards AVs before and after the experiment (scores ≤ 3 = positive; scores ≥ 5 = negative).

Regarding the score on attitude of the participants towards fully AVs, which was 2.80 (*95% CI* [2.60; 3.30]) before and 2.30 (*95% CI* [2.10; 2.80]) after the experiment, it could be stated that the attitude improved by 0.5 points (Table 5). In general, participants had rather positive feelings towards fully AVs as the scores were ≥ 3. On participants level, the score on attitude showed a great inter-individual variation (*SD*=1.23) (Table 5). Participants' ratings ranged from a very positive to a neutral evaluation of the attitude towards AVs before and after the experiment compared to the grand overall evaluation.

Analysis of the score for social norm, which was 3.70 (*95% CI* [3.60; 4.00]) before and 3.50 (*95% CI* [3.40; 3.80]) after the experiment, it could be assumed that the individual perception of how people think about fully AVs improved by 0.2 points (Table 5). However, the scores show rather a neutral evaluation. Regarding the participant level, inter-individual variation could be recognised (*SD*=1.00), as the evaluation of social norm ranged from positive to neutral among participants before and after the experiment compared to the grand overall evaluation (Table 5).

The score on effectiveness, which was 3.60 (*95% CI* [3.40; 4.00]) before and 2.70 (*95% CI* [2.50; 3.10]) after the experiment, improved by 0.90 points (Table 5). Thus, the pedestrians believed more in the ability of the AV to successfully recognise pedestrians and other obstacles in road traffic after the experiment. Overall, the evaluation of effectiveness of AVs changed from rather neutral to positive. Regarding the participant level, inter-individual variation could be recognised (*SD*=1.01), as the evaluation of effectiveness ranged from positive to negative before the experiment and from positive to rather neutral after the experiment compared to the grand overall evaluation (Table 5).

In respect to the score on trust of the participants, which was 3.80 (*95% CI* [3.60; 4.40]) before and 3.30 (*95% CI* [3.10; 3.90]) after the experiment, it could be determined that the trust in AVs improved by 0.5 points after the experiment (Table 5). In particular this meant, that the belief of the participants that a fully AV will perform its intended task with high effectiveness increased positively. The score, however showed rather a neutral evaluation. Regarding the participant level, a great inter-individual variation could be recognised (*SD*=1.38), as the evaluation of trust ranged from positive to negative before and after the experiment compared to the grand overall evaluation (Table 5).

The last factor that affects pedestrians' receptivity towards fully AVs was the compatibility. The compatibility score represents the degree to which a fully AV is perceived as being consistent with the existing transportation system. By analysing the scores of compatibility of the participants, which were before 4.80 (*95% CI* [4.70; 5.20]) and after the experiment 4.00 (*95% CI* [3.90; 4.40]), it could be assumed that the score on compatibility improved by 0.8 points. However, the score on compatibility showed rather a neutral evaluation. Regarding the participant level, inter-individual variation could be recognised (*SD*=1.00), as the evaluation of compatibility ranged from negative to neutral before the experiment and from neutral to positive after the experiment compared to the grand overall evaluation (Table 5).

Table 5

*Changes in attitude towards AVs after the presentation of the six eHMI concepts*

| Parameter | Center | Lower | Upper | Fixed Effects SD | Random Effects SD |
|---|---|---|---|---|---|
| Attitude: Before | 2.80 | 2.60 | 3.30 | 0.30 | 1.23 |
| Attitude: After | 2.30 | 2.10 | 2.80 | 0.30 | 1.23 |
| Social Norm: Before | 3.70 | 3.60 | 4.00 | 0.20 | 1.01 |
| Social Norm: After | 3.50 | 3.40 | 3.80 | 0.20 | 1.01 |
| Effectiveness: Before | 3.60 | 3.40 | 4.00 | 0.20 | 1.01 |
| Effectiveness: After | 2.70 | 2.50 | 3.10 | 0.20 | 1.01 |
| Trust: Before | 3.80 | 3.60 | 4.40 | 0.30 | 1.38 |
| Trust: After | 3.30 | 3.10 | 3.90 | 0.30 | 1.38 |
| Compatibility: Before | 4.80 | 4.70 | 5.20 | 0.20 | 1.00 |
| Compatibility: After | 4.00 | 3.90 | 4.40 | 0.20 | 1.00 |

*Note.* Median center estimates with 95% credibility limits

**Subjective Evaluation of the six eHMI Concepts**

For analysing the design effect in the responses to the single items of the questionnaire, it was chosen for the intercept-only AGM model with participant-level random effects. In this context, the GLM was used to compare the grand mean of the chosen answer categories per eHMI concept by considering also the inter-individual differences.

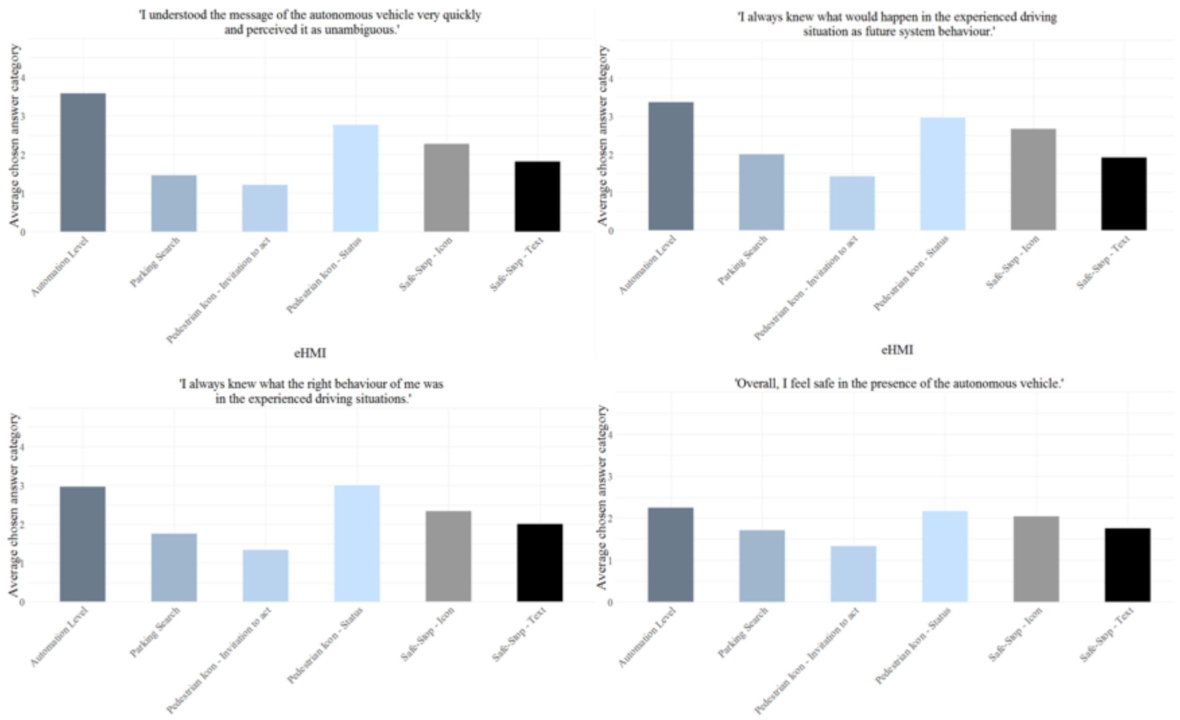


*Figure 11.* Evaluation of the understandability, knowledge about the future system behaviour, as well as about the right behaviour of the pedestrians and the feeling of safety in the presence of AVs (answer categories are ranging from '1 = applies' to '4 = not applicable')

Regarding the design effects of the four single items (Figure 11), it could be seen that the concept 'Pedestrian Icon - Invitation to act' 1.20 (*95% CI* [1.10; 1.60]), as well as the 'Parking Search' 1.50 (*95% CI* [1.30; 1.80]), was understood most quickly and unequivocally by the participants (Table 6). Participants knew best what would happened in the experienced driving situation as future system behaviour at the 'Pedestrian Icon - Invitation to act' 1.39 (*95% CI* [1.30; 1.80]) and at the 'Parking Search' 1.97 (*95% CI* [1.80; 2.40]) (Table 7). In addition, participants knew best how to behave in the experienced driving situation at the 'Pedestrian Icon - Invitation to act' 1.31 (*95% CI* [1.20; 1.70]) and at the 'Parking Search' 1.73 (*95% CI* [1.60; 2.10]) (Table 8). Finally participants felt the safest in the presence of the AV, when encountering the concept 'Pedestrian Icon – Invitation to act' 1.31 (*95% CI* [1.20; 1.60]) or the 'Parking Search' 1.63 (*95% CI* [1.60; 2.00]) (Table 9).

Hereafter, the two eHMI concepts for a safety stop, the 'Safe-Stop – Text' and the 'Safe-Stop – Icon' followed. The message of the AV was understood quickly and unequivocally by the participants at the 'Safe-Stop – Text' 1.80 (*95% CI* [1.70; 2.20]), as well as at the 'Safe-Stop – Icon' 2.30 (*95% CI* [2.10; 2.60]) (Table 6). Furthermore, participants knew what would happened in the experienced driving situation as future system behaviour at the 'Safe-Stop – Text' 1.89 (*95% CI* [1.80; 2.40]). However, the average chosen answer category of 2.64 (*95% CI* [2.50; 3.00]) at the ‘Safe-Stop – Icon’ showed uncertainties about the future system behaviour (Table 7). Despite this, participants knew what an adequate behaviour of them was in the experienced driving situation at the ‘Safe-Stop – Text’ 1.98 (*95% CI* [1.80; 2.40]), as well as at the ‘Safe-Stop – Icon’ 2.31 (*95% CI* [2.20; 2.80]) (Table 8). It could be seen that the participants felt safe in the presence of the AV, while presenting the concept ‘Safe-Stop – Text’ 1.73 (*95% CI* [1.60; 2.10]), as well as the ‘Safe-Stop – Icon’ 2.02 (*95% CI* [1.90; 2.30]) (Table 9).

The two last eHMI concepts, the ‘Pedestrian Icon – Status’, as well as the ‘Automation Level’ were rated less positive. The results stated that the communication intention of the ‘Pedestrian Icon – Status’ 2.80 (*95% CI* [2.60; 3.10]), and especially the ‘Automation Level’ (intercept) 3.60 (*95% CI* [3.40; 3.90]) were rather slowly and not clearly understood (Table 6). Participants were not sure about the future system behaviour in the experienced driving situation at the ‘Pedestrian Icon – Status’ 2.93 (*95% CI* [2.80; 3.30]) and at the ‘Automation Level’ 3.34(*95% CI* [3.20; 3.80]) (Table 7). Furthermore, they rather did not know what an adequate behaviour of them was in the experienced driving situation at both concepts, the ‘Pedestrian Icon – Status’ 2.97 (*95% CI* [2.80; 3.40]) and at the ‘Automation Level’ 2.90 (*95% CI* [2.80; 3.40]) (Table 8). Nevertheless, participants felt safe in the presence of the AV when presenting the ‘Pedestrian Icon – Status’ 2.14 (*95% CI* [2.00; 2.50]) and at the ‘Automation Level’ (intercept) 2.22 (*95% CI* [2.10; 2.60]) (Table 9).

Regarding the participant level, it could be seen that in the evaluation of the comprehensibility of the six eHMI concepts (*SD*=0.17) (Table 6), the knowledge of the future system behaviour (*SD*=0.50) (Table 7), the right behaviour in the experienced driving situation (*SD*=0.52) (Table 8), as well as the sense of security in the presence of the AV, while demonstrating the six eHMI concepts (*SD*=0.45) (Table 9), there was very small inter-individual variation. The evaluation of the eHMI concepts among participants only slightly deviate from the grand overall evaluation.

Table 6

*Design effect of the eHMI concepts on population- and participant-level for the first single item*

| Parameter | Center | Lower | Upper | Fixed Effects SD | Random Effects SD |
|---|---|---|---|---|---|
| Automation Level | 3.60 | 3.40 | 3.90 | 0.20 | 0.17 |
| Parking Search | 1.50 | 1.30 | 1.80 | 0.20 | 0.17 |
| Pedestrian Icon – Invitation to act | 1.20 | 1.10 | 1.60 | 0.20 | 0.17 |
| Pedestrian Icon – Status | 2.80 | 2.60 | 3.10 | 0.20 | 0.17 |
| Safe-Stop – Icon | 2.30 | 2.10 | 2.60 | 0.20 | 0.17 |
| Safe-Stop – Text | 1.80 | 1.70 | 2.20 | 0.20 | 0.17 |

*Note.* Median center estimates with 95% credibility limits

Table 7

*Design effect of the eHMI concepts on population- and participant-level for the second single item*

| Parameter | Center | Lower | Upper | Fixed Effects SD | Random Effects SD |
|---|---|---|---|---|---|
| Automation Level | 3.34 | 3.20 | 3.80 | 0.20 | 0.50 |
| Parking Search | 1.97 | 1.80 | 2.40 | 0.20 | 0.50 |
| Pedestrian Icon – Invitation to act | 1.39 | 1.30 | 1.80 | 0.20 | 0.50 |
| Pedestrian Icon – Status | 2.93 | 2.80 | 3.30 | 0.20 | 0.50 |
| Safe-Stop – Icon | 2.64 | 2.50 | 3.00 | 0.20 | 0.50 |
| Safe-Stop – Text | 1.89 | 1.80 | 2.30 | 0.20 | 0.50 |

*Note.* Median center estimates with 95% credibility limits

Table 8

*Design effect of the eHMI concepts on population- and participant-level for the third single item*

| Parameter | Center | Lower | Upper | Fixed Effects SD | Random Effects SD |
|---|---|---|---|---|---|
| Automation Level | 2.90 | 2.80 | 3.40 | 0.20 | 0.52 |
| Parking Search | 1.73 | 1.60 | 2.10 | 0.20 | 0.52 |
| Pedestrian Icon – Invitation to act | 1.31 | 1.20 | 1.70 | 0.20 | 0.52 |
| Pedestrian Icon – Status | 2.97 | 2.80 | 3.40 | 0.20 | 0.52 |
| Safe-Stop – Icon | 2.31 | 2.20 | 2.80 | 0.20 | 0.52 |
| Safe-Stop – Text | 1.98 | 1.80 | 2.40 | 0.20 | 0.52 |

*Note.* Median center estimates with 95% credibility limits

Table 9

*Design effect of the eHMI concepts on population- and participant-level for the fourth single item*

| Parameter | Center | Lower | Upper | Fixed Effects SD | Random Effects SD |
|---|---|---|---|---|---|
| Automation Level | 2.22 | 2.10 | 2.60 | 0.20 | 0.45 |
| Parking Search | 1.68 | 1.60 | 2.00 | 0.20 | 0.45 |
| Pedestrian Icon – Invitation to act | 1.31 | 1.20 | 1.60 | 0.20 | 0.45 |
| Pedestrian Icon – Status | 2.14 | 2.00 | 2.50 | 0.20 | 0.45 |
| Safe-Stop – Icon | 2.02 | 1.90 | 2.30 | 0.20 | 0.45 |
| Safe-Stop – Text | 1.73 | 1.60 | 2.10 | 0.20 | 0.45 |

*Note.* Median center estimates with 95% credibility limits

After the renewed presentation of the eHMI concepts and the explanation of the communication intention, participants interpreted each concept as understandable in the respective driving situation (Figure 12). The most understandable concept was still the ‘Pedestrian Icon – Invitation to act’ 1.31 (*95% CI* [1.20; 1.60]), as well as the ‘Parking Search’ 1.68 (*95% CI* [1.60; 2.00]) (Table 15). These concepts were closely followed by the ‘Safe-Stop – Text’ 1.72 (*95% CI* [1.60; 2.00]) and the ‘Safe-Stop – Icon’ 2.01 (*95% CI* [1.90; 2.30]). The ‘Pedestrian Icon – Status’ 2.13 (*95% CI* [2.00; 2.50]), as well as the ‘Automation

Level' 2.13 (*95% CI* [2.00; 2.50]), were rated less positive compared to the other four eHMI concepts, but the communication intention of these two were still considered as understandable.

Regarding the evaluation of the eHMI concepts on participant level, a small inter-individual variation could be recognised (*SD*=0.45). These findings suggest that the evaluation of the eHMI concepts among participants only slightly deviate from the grand overall evaluation (Table 10).

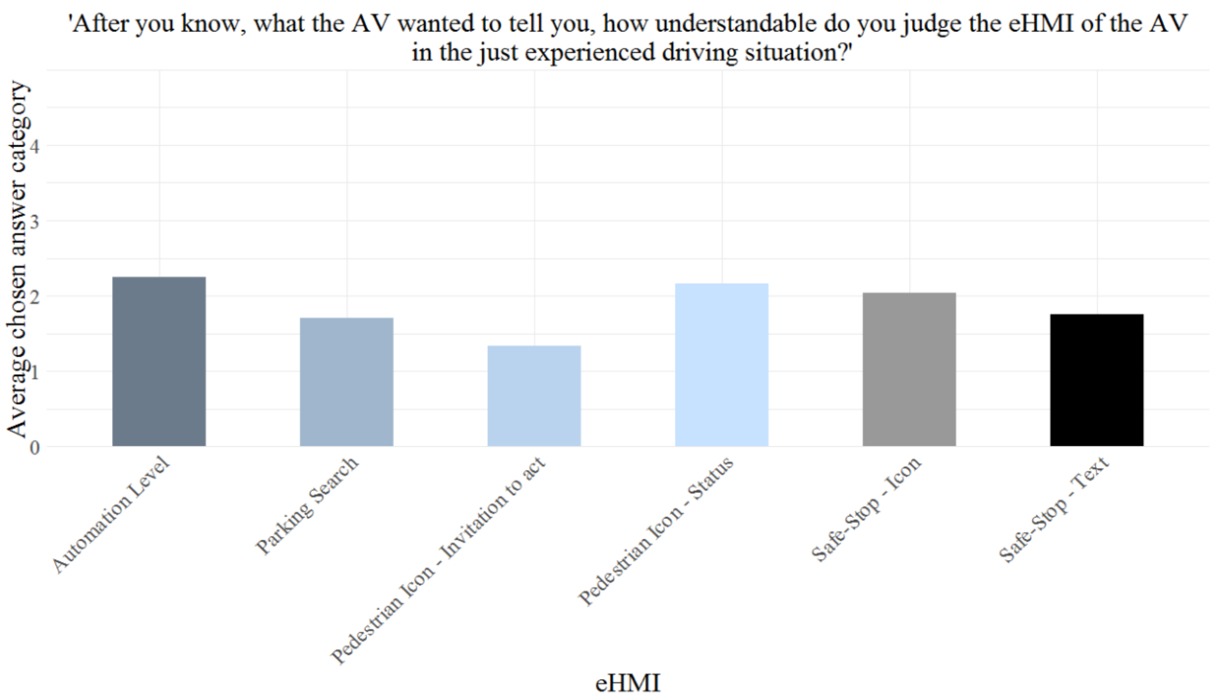


*Figure 12*. Evaluation of the understandability of the six eHMI concepts, after the repeated presentation and explanation of the six eHMI concepts (answer categories are ranging from 1 = 'very understandable' to 4 = 'incomprehensible')

Table 10

*Design effect of the eHMI concepts on population- and participant-level for the fifth single item*

| Parameter | Center | Lower | Upper | Fixed Effects SD | Random Effects SD |
|---|---|---|---|---|---|
| Automation Level | 2.21 | 2.10 | 2.50 | 0.20 | 0.45 |
| Parking Search | 1.68 | 1.60 | 2.00 | 0.20 | 0.45 |
| Pedestrian Icon – Invitation to act | 1.31 | 1.20 | 1.60 | 0.20 | 0.45 |
| Pedestrian Icon – Status | 2.13 | 2.00 | 2.50 | 0.20 | 0.45 |
| Safe-Stop – Icon | 2.01 | 1.90 | 2.30 | 0.20 | 0.45 |
| Safe-Stop – Text | 1.72 | 1.60 | 2.00 | 0.20 | 0.45 |

*Note.* Median center estimates with 95% credibility limits.

**Evaluation of the Communication Media**

The evaluation of suitable modalities for a successful external communication with an AV was examined using the intercept-only AGM model with participant-level random effects. In this context, the GLM was used to compare the grand mean of chosen answer categories for the single items of the questionnaire, which ranged from 1 = ‘very suitable’ to 4 = ‘unsuitable’.

Regarding Figure 13, it can be seen that participants found the display technology (LCD) for the communication of information of an AV 1.22 (*95% CI* [1.10; 1.60]), as well as for sending a warning message in a safety critical situation 1.26 (*95% CI* [1.20; 2.20]), most suitable. However, acoustic signals for the information communication of an AV 1.88 (*95% CI* [1.80; 2.20]) and for procuring warnings in safety critical situations 1.51 (*95% CI* [1.40; -0.90]), as well as light bar technology for the communication of information 1.84 (*95% CI* [1.70; 2.20]) and for the communication of warnings 2.00 (*95% CI* [1.90; 2.30]) were also rated as suitable.

In respect of the inter-individual differences in the evaluation of the communication media (*SD*=0.53) only a slightly deviation from the grand overall evaluation could be recognised (Table 11).

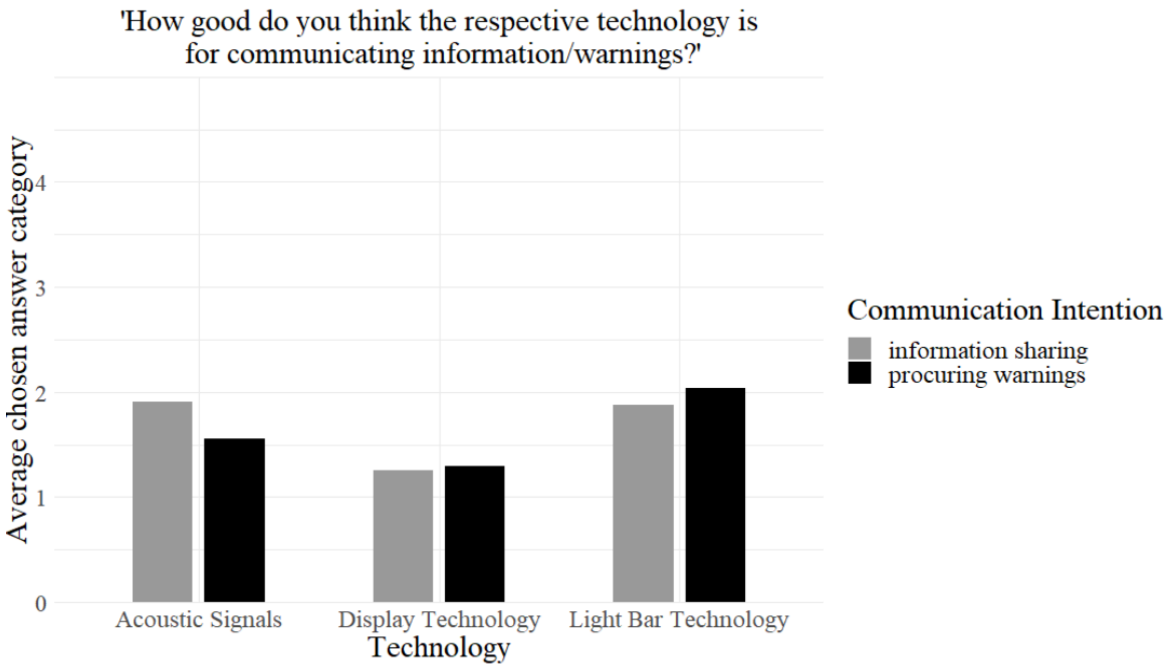


*Figure 13.* Evaluation of the communication media (answer categories are ranging from 1 = 'very suitable' to 4 = 'unsuitable').

Table 11

*Design effect of the eHMI concepts on the evaluation of the communication media on population- and participant-level*

| Parameter | Center | Lower | Upper | Fixed Effects SD | Random Effects SD |
|---|---|---|---|---|---|
| Acoustic Signals – Information | 1.88 | 1.80 | 2.20 | 0.20 | 0.53 |
| Acoustic Signals – Warning | 1.51 | 1.40 | 1.80 | 0.20 | 0.53 |
| Display Technology – Information | 1.22 | 1.10 | 1.60 | 0.20 | 0.53 |
| Display Technology – Warning | 1.26 | 1.20 | 2.20 | 0.20 | 0.53 |
| Light Bar Technology – Information | 1.84 | 1.70 | 2.20 | 0.20 | 0.53 |
| Light Bar Technology – Warning | 2.00 | 1.90 | 2.30 | 0.20 | 0.53 |

*Note.* Median center estimates with 95% credibility limits

The analysis of the preferred modality for the communication intention of an AV showed that overall, 75% of the participants preferred a combination of visual, auditory and physical/ kinesthetic modalities, to understand the intention of the AV most clearly and unambiguously. In addition, 17% of the participant would prefer only visual modalities in terms of LCD and LED bars, whereas no one would prefer only auditory modalities. A minority of participants (8%) preferred only physical/ kinesthetic modalities, in terms of the vehicle's kinematic.

**Evaluation of the Optical Recognisability of the eHMI Concepts**

In respect to the optical recognition of the eHMI concepts (Figure 14), it could be seen that the 'Parking Search' was best recognised by the participants, as the average chosen answer category was 1.03 (*95% CI* [0.90; 1.10]), (Table 12). Likewise, the 'Pedestrian Icon - Status' with an average chosen answer category of 1.07 (*95% CI* [1.00; 1.20]), as well as the 'Pedestrian Icon - Invitation to act' with 1.20 (*95% CI* [1.10; 1.30]) was optically well recognised by the participants. Moreover, the communication intention of the eHMI concepts 'Safe-Stop - Text' with an average chosen answer category of 1.33 (*95% CI* [1.20; 1.40]), as well as 'Safe-Stop – Icon' with 1.33 (*95% CI* [1.20; 1.40]), were optically good recognisable. The 'Automation Level' with an average chosen answer category of 1.44 (*95% CI* [1.40; 1.50]) seemed to be the eHMI that the participants could most poorly recognise optically, however, it was nevertheless still evaluated as well recognisable.

Regarding the participant level, it could be seen that there was a very small inter-individual variation noticeable (*SD*=0.12) (Table 12), which meant that the evaluation of the recognisability among participants did not deviate from the grand overall evaluation.

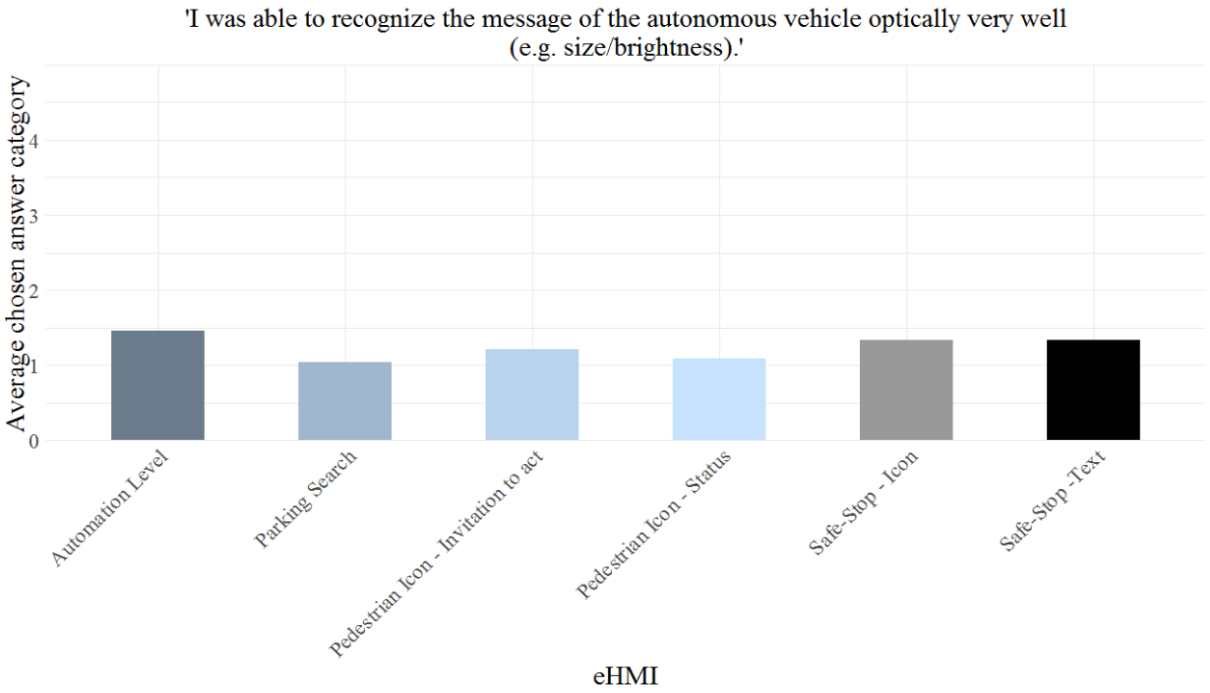


*Figure 14.* Evaluation of the recognisability of the six eHMI concepts (answer categories are ranging from 1 = 'applied' to 4 = 'not applicable').

Table 12

*Design effect on the evaluation of the recognisability of the six eHMI concepts on population- and participant-level*

| Parameter | Center | Lower | Upper | Fixed Effects SD | Random Effects SD |
|---|---|---|---|---|---|
| Automation Level | 1.44 | 1.40 | 1.50 | 0.10 | 0.12 |
| Parking Search | 1.03 | 0.90 | 1.10 | 0.10 | 0.12 |
| Pedestrian Icon – Invitation to act | 1.20 | 1.10 | 1.30 | 0.10 | 0.12 |
| Pedestrian Icon – Status | 1.07 | 1.00 | 1.20 | 0.10 | 0.12 |
| Safe-Stop – Icon | 1.33 | 1.20 | 1.40 | 0.10 | 0.12 |
| Safe-Stop – Text | 1.33 | 1.20 | 1.40 | 0.10 | 0.12 |

*Note.* Median center estimates with 95% credibility limits.

### Evaluation of the Open Questions regarding the Comprehensibility of the Communication Intention of the six eHMI Concepts

To represent the participants' answers regarding the interpretation of the AV's communication intention based on the six eHMI concepts, these were previously coded and quantified. Afterwards, the coded statements were assigned to a total of three categories: ‘correct’, ‘incomplete’ and ‘incorrect’ interpretation. In this context, correct interpretations included all statements, which included the exact meaning of the eHMI concepts, whereas incomplete interpretation reflected only a part of the right meaning. All other interpretations that were not related to the correct meaning of the eHMI concepts, were classified under incorrect interpretation (Figure 15).

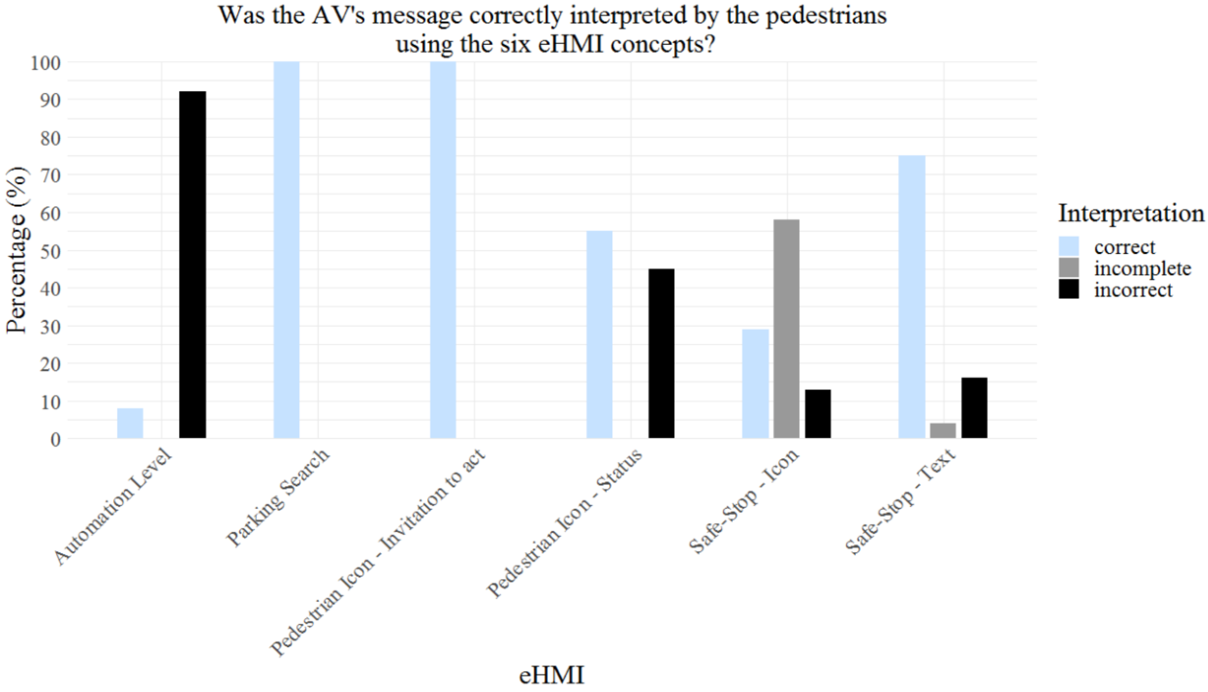


*Figure 15.* Illustration of the correct interpretation of the AV’s communication intention via the six eHMI concepts

**Automation Level.** Regarding the concept ‘Automation Level’ it could be recognised that only (8%) of the participants had interpreted the communication intention of the AV correctly as an indication of the vehicle that it drives fully autonomous. However, (92%) of misinterpreted the eHMI or did not understand it. In this context, the misinterpretations included the assumption that the AV wanted to tell the pedestrians that it had registered them, pedestrians have to be careful, as the vehicle just wanted to pass them, the vehicle must refuel, as well as that the vehicle wanted to be visually more recognisable.

In respect of participants’ assessment as to whether the concept ‘Automation Level’ represented a system status or an invitation to act, (44%) of the participants interpreted the message of the eHMI correctly as a communication of the systems status. Almost a third of the participants (32%) suspected that the concept represented an invitation to act and (8%) of them thought, the concept illustrated both, the system status, as well as an invitation to act. Overall, (16%) of the participants could not determine the communication intention at all.

Regarding the positive aspects of the concept, (32%) of the participant noticed the bright colour of the LED bar. The remaining part of the participants (68%) did not gave any statement. However, (36%) of the participants mentioned some negative aspects of the concept ‘Automation Level’. In this context, (24%) of these participants criticized the unclear communication intention of the eHMI and (12%) of participants criticized the poor visibility of the LED bar in direct sunlight.

**Parking Search.** The eHMI for illustrating a parking search was correctly interpreted by all participants. Additionally, the message of the concept ‘Parking Search’ was correctly interpreted as a communication of the system status of the AV by (60%) of the participants, whereas (32%) rather interpreted the message as an invitation to act. Another (8%) of the participants understood the message as both, a communication of the system status, as well as an invitation to act.

Regarding the positive and negative aspects of the concept ‘Parking Search’, (32%) of the participants mentioned that the message was very understandable and unambiguous due to the already known 'P' for parking space. Another (8%) of the participants specified the floor projection as very helpful. Further (8%) mentioned the adequate speed of the AV and the good visibility of the eHMI. Overall, (52%) of the participants did not gave any statement.

However, (12%) of the participants stated that the direction indicator was too inconspicuous, between the display, light bar and sensor technology, (8%) mentioned the uncertainty about, whether they as pedestrians need to perform an action or not and (4%) criticized the colours of the visual modalities, which dazzled too much in the dark.

**Pedestrian Icon – Invitation to act.** The message of the ‘Pedestrian Icon - Invitation to act’ was also correctly interpreted by all participants. In addition, (84%) of the participants correctly recognized a request for action, whereas (12%) interpreted the concept as a communication of the system status. One participant (4%) understood the message as both, a communication of the system status, as well as an invitation to act. However, all participants crossed the street in front of the AV.

Regarding the positive aspects of the concept, (32%) of the participants mentioned the already known traffic light manikin, as easy to understand, (16%) found the timely speed reduction very pleasant, and (8%) mentioned the running light as direction indicator, as very helpful. Further (8%) specified the combination of acoustic signals, display animations, and the pleasant sound of the acoustic signals. The remaining part of the participants (36%) did not gave any statement.

On the contrary, (12%) of the participants criticized the poor recognition of the eHMI concept in direct sunlight, another (12%) mentioned that the rolling of the vehicle created uncertainty, (8%) specified the acoustic signals as disturbing and (4%) mentioned that the walking motion of the traffic light manikin should adapt to the walking movement of the pedestrian. In total, (64%) did not make a statement.

**Pedestrian Icon – Status.** Regarding the eHMI concept 'Pedestrian Icon – Status, (56%) of the participants interpreted the communication intention correctly in terms of an indication for speed reduction. However, they did not understand that the vehicle reduced the speed, because it wanted to let them cross the road. Almost half of the participants (44%) misinterpreted or did not understand the message of the concept. In this context, (16%) of the participants interpreted the speedometer display as a fuel gauge and thought that the vehicle had to refuel accordingly, whereas (8%) of the participants thought that the speedometer display would illustrate a countdown and participants would have to hurry up, if they wanted to cross the street. Another (4%) mentioned that the vehicle wanted to illustrate its brake readiness and (4%) interpreted the speedometer display as an illustration for the Adaptive Cruise Control (ACC). In total, (12%) of the participants did not understand the message of the eHMI.

The concept was correctly interpreted as a communication of the system status by (64%) of the participants, whereas (24%) of the participants interpreted the message as an invitation to act. In total, (12%) of the participants interpreted the message as both, a communication of the system status, as well as an invitation to act. Only, (8%) of the participants crossed the street in front of the AV.

With respect to the positive aspects of the 'Pedestrian Icon – Status', (12%) of the participants mentioned the pleasant sound of the acoustic signals, as well as the combination of acoustic signals and display technology and the good visibility of the concept. On the other hand, (16%) of the participants mentioned that the symbol of the display technology was not understandable.

**Safe-Stop - Icon.** The concept 'Safe-Stop – Icon' was correctly interpreted by (32%) of the participants, whereas (56%) of the participants interpreted the eHMI only partly correctly. In this context, (36%) of the participants interpreted the communication intention of the AV correctly as a warning, but did not know what the vehicle wanted to warn about and what to do in the situation. Furthermore, (20%) of the participants understood the message as a warning of arriving vehicles. In total, (12%) of the participants wrongly thought that the vehicle wanted to tell them that it recognised them at the street, or they recognised the message wrongly as an indication to keep distance to the vehicle.

Overall, (44%) of the participants interpreted the message of the AV correctly as a communication of the system status, whereas (32%) of the participants interpreted the message as an invitation to act. Another (24%) mentioned that the message of the AV was both, a communication of the system status, as well as an invitation to act.

Regarding to the positive and negative aspects of the eHMI 'Safe-Stop – Status', (32%) of the participant specified the floor projection as pleasant and helpful. Additionally, (8%) liked the symbol of the already known warning triangle for a quick understanding and another (8%) mentioned that the orange colour is very well suited for a warning. There were 3 individual notifications (12%) with regard to negative aspects of the concept. The missing specification of the warning was mentioned and the blinking of the floor projection was defined as disturbing, as well as irritating.

**Safe-Stop - Text.** Regarding the 'Safe-Stop – Text', (80%) of the participants were able to interpret the communication intention correctly. Another (4%) stated that the communication intention of the AV was to warn pedestrian about arriving vehicles. However, (16%) of the participants wrongly interpreted the message of the concept as an indication that it would be safe to cross the street, as the vehicle will stop, based on the presented text 'Safe Stop'. The message of the concept was correctly interpreted as a communication of the system status by (60%) of the participants, whereas (24%) of the participants thought, it would be an invitation to act. In total, (16%) of the participants interpreted the message as both, a communication of the system status, as well as an invitation to act. However, (16%) of the participants crossed the street in front of the AV, even though that was not the intention of the AVs communication, when presenting the concept 'Safe-Stop – Text'.

Regarding the positive aspects of the eHMI, (32%) of the participants specified the very clear and understandable display technology and (8%) of the participants indicated that the flashing floor projection was pleasant and helpful. There were three single notifications (12%). The combination of acoustic signals and display animation was considered as very comprehensible, it had a good legibility despite direct sunlight, and the orange colour was mentioned as suitable for presenting a warning. On the contrary, (4%) criticized the text message in English, as people without English skills would not understand the communication intention of the AV. Another (4%) mentioned the difficulty for children who cannot read yet or dyslexics and therefore, they proposed an additional display animation. Finally, it was mentioned that the text was very difficult to read when the sun was shining by (4%) of the participants.

### Suggestions to improve regarding the eHMI concepts

Overall, 18 participants gave a suggestion for the improvement of the eHMI in general. A total of 39% of these participants proposed a brighter and multi-coloured LED bar, as the current LED bar was partly difficult to see with increasing brightness. Moreover, 22% of the participants suggested to show text and picture message in alternation, for a more comprehensive understanding. In the following, 11% of the participants worried about the size of the designs, as they would be rather expensive and unstylish. In addition, further 11% of the participants wanted a floor projection in the form of a zebra crossing strip for crossing the road to be even more certain that the AV would stop for them so that they could cross the road. Finally, one participant would prefer to use less technology for the communication intention of the AV, one suggested to never display only a light bar and a further participant proposed to display the message in English and in German to achieve an international understanding of the intention of the AV.

## Discussion

Currently, only a few studies are dealing with the introduction of AVs in road traffic and the resulting challenges regarding a successful communication between pedestrians and AVs. This study elucidated this topic from a human factors perspective and examined an eHMI, which communicates the intention of an AV in six different situations. The goal of the study was to investigate participants' preferences regarding the UX, usability, comprehensibility, sense of security and technical arrangements of the concept ideas, as well as their suggestions regarding improvements.

### Explanation of the Results and Design Recommendation

The results of the UEQ indicated that the concept 'Pedestrian Icon – Invitation to act', the 'Parking Search', as well as the two eHMI concepts for demonstrating a safety stop, the 'Safe-Stop - Text' and 'Safe-Stop - Icon' have been rated positively in terms of perspicuity, efficiency, dependability, stimulation and novelty in this order. The concept 'Automation Level' and the 'Pedestrian Icon – Status' were rated rather negatively. This trend could also be seen in the evaluation of the single items of the questionnaire. Participants stated that they understood the message of the eHMI concepts ‘Pedestrian Icon – Invitation to act’, ‘Parking Search’, ‘Safe-Stop - Text’ and ‘Safe-Stop - Icon’ very quickly and unambiguous. These statements predominantly agreed with their assumptions about the communication intention of the respective eHMI concepts. In addition, they knew what the future system behaviour was, and also what an adequate and correct behaviour of them would be in the experienced driving situations. The two eHMI concepts that were not evaluated as unambiguous and understandable by the participants and which could be also seen in the participants' assumptions about the communication intention of the respective concepts, were the ‘Pedestrian Icon – Status’ and the ‘Automation Level’. In addition, participants found the future system behaviour of these two eHMI concepts rather unpredictable and they did not know how to behave in the respective driving situations.

Overall, it could be seen that the participants felt safe in the presence of the AV, regardless which concept was presented. Moreover, all eHMI concepts were purely optically well detected by the participants. However, participants criticized the poor recognisability of the ‘Automation Level’, the ‘Pedestrian Icon – Invitation to act’, as well as of the ‘Parking Search’ with increasing brightness. Regarding the suggestions for improvement for the eHMI concepts, more than a third of the participant (39%) proposed a brighter and multi-coloured LED bar, whereas a fifth of the participants (22%) suggested to show text and picture message in alternation for a more comprehensive understanding. Further 11% of the participants worried about the size of the designs, as they would be rather expensive and unstylish and another 11% of the participants wanted a floor projection in the form of a zebra crossing.

When analysing the well recognisable design effect in the evaluation of the six eHMI concepts, it could be suspected that the cause for this is the incomprehensibility of the communication intention of the concept ‘Automation Level’, as well as the ‘Pedestrian Icon – Status’. According to Palmeiro et al. (2018), an inaccurate perception and comprehension about the behaviour of vehicle could lead to wrong predictions, a state of elevated confusion and stress and unsafe traffic situation. Although, participants could optically recognised the vehicle and the eHMI concepts well, they did not understood the communication intention and were unsure about the future system behaviour. According to Endsley (1995), this lack of understanding about the future action of the vehicle and the overall driving situation leads to a reduced situational awareness, which may be responsible for the striking evaluation of the concepts.

Regarding the design of the concept ‘Automation Level’ the cause for the incomprehensibility of the communication intention could be the presentation of a single LED bar, without any indications or references to the vehicle's intention. Especially, as the concept for indicating an AV is novel and no known symbols could be used, presenting only one visual modality may be not sufficient for a comprehensive understanding. However, as it could be seen in the results, after a renewed presentation and an explanation of the 'Automation Level', the concept was rated positively by the participant, which could be the results of a learning effect. A learning effect is the effect of a test resulting from the repetition of the same or similar tasks. Newly acquired knowledge about a type of task can lead to better test results at later examination times than at the initial examination (Stangl, 2019). In addition, current literature showed the relevance for pedestrians to know the current automation level of a vehicle, which shows the relevance of the concept 'Automation Level' (see Owensby, Tomitsch & Parker, 2018). Consequently, this would mean that there should be either a general instruction before the concept is introduced, or the concept would have to be extended in the sense of further technical modalities to clarify the communication intention.

In this context, the display technology could be used as a further visual modality, representing a static text like 'NO DRIVER' (Figure 16), as it could be seen that the concept 'Safe-Stop - Text' was positively evaluated and additionally better understood than the 'Safe-Stop - Icon'. As the concept only mediates an information about the current level of automation, the text should be represented in static form, as well as in white colour, according to the internal design principles. However, in the long run, after a familiarisation phase, the LED bar may be sufficient for indicating an autonomous drive.


*Figure 16.* Adapted concept of the 'Automation Level'.

Considering the 'Pedestrian Icon - Status', half of the participants did not interpreted the concept as an indication for a speed reduction. In this context, one possible explanation would be that the speed reduction of the vehicle was indeed recognised through the vehicles kinematics (see Aladawy et al., 2019; Dey and Terken, 2017; Schmidt, Terwilliger, AlAdawy and Fridman, 2019), but the communication intention of the concept ‘Pedestrian Icon – Status’ was not understood, as the design was not sufficient. On the other hand, there could be the possibility that the participants indeed interpreted the concept as an indication for a speed reduction, but the vehicle’s kinematics did not fit, which is why they were confused and unsure about the AV’s intention. The lack of potential to assess the situation and the behaviour of the vehicle could therefore lead to wrong predictions, and a state of elevated confusion and stress, which could explain why only 8% of the participants crossed the street (Palmeiro et al., 2018). This shows the high relevance of the correspondence of vehicle movement and communication intention on the basis of the eHMI for a mutual understanding. Additionally, this gives an indication that in the road-crossing scenario, an invitation for action may be the better alternative for the pedestrians’ decision making process from a subjective point of view of the study participants.

A further reason for the participants’ preference towards the eHMI concepts ‘Pedestrian Icon – Invitation to act’, ‘Parking Search’ and the two concepts for a safety stop could be that these concepts represented already known symbols. In this regard, the known traffic light manikin at the ‘Pedestrian Icon – Invitation to act’, the ‘P’ for illustrating a parking space at the ‘Parking Search’, as well as the hazard warning light and the warning triangle have been used within the study. This could be explained by the mere-exposure effect, which is a psychological phenomenon by which people tend to develop a preference for things merely because they are familiar with them (Gordon & Holyoak, 1983).

Moreover, it was also seen in the results that although only the eHMI ‘Pedestrian Icon – Invitation to act’ communicates an invitation to act, the participants interpreted each eHMI as an invitation to action. This became dangerous at the ‘Safe-Stop – Text’, as 17% of the participants thought, it would be safe to cross the street in front of the AV, because it will stop, due to the text message ‘Safe Stop’. This phenomenon could be traced back to the fact that the test leaders instructed the participants to watch the traffic, as an AV tries to communicate with them and it may be that they have to perform an action. Moreover, the traffic situation could be to blame for the fact that the participants project any behaviour of the AV on themselves, since apart from them almost no other road user was present within the experiment. Within a more dynamic traffic situation adapted to the eHMI, the distinction between a request for action and the notification of a status may be better distinguished.

Finally, the results of the communication technology evaluation supported the findings of Mahadevan, Somanath and Sharlin (2018), as the participants stated that the communication intention of the AV was most understandable and clearest by using visual, auditory and physical/ kinesthetic modalities in combination. Furthermore, the results show that the acoustic signals, display technology, as well as light bar technology were evaluated as suitable for the information communication on the one hand, and for the communication of a warning in a safety critical situation on the other hand. However, within the internal design guidelines, it was stated that in contrast to the mediation of warnings, the mediation of information should not distract road users from information with higher relevance in road traffic. Therefore, the concepts for the information mediation should be rather simple and reserved without any flashing lights or dynamic display, such as at the 'Automation Level'. As participants preference was to use a combination of several visual modalities (i.e. display and LED bar technology), as well as an acoustic modality for a comprehensive understanding of the vehicle's intention, and because the 'Automation Level' was not understood by demonstrating only a LED bar, the design guidelines should be further adapted. In this context, it should be considered in the future that using just a single technical modality might not lead to sufficient knowledge of the intention of the AV.

Overall, the results suggest that an external vehicle interface, which communicates the AV's intention to pedestrians via an eHMI may create a positive experience in the interaction and increases pedestrians' perceived safety, which is in line with the results of Habibovic (2018). People are still largely sceptical towards AVs (Nielsen & Haustein, 2018), which is in line with the results of the PRQF, as the participants tended to be somewhat closed and unsafe towards AVs and its capabilities before the experiment. In this context, it is important to gain positive experiences in dealing with AVs to build trust and acceptance (Habibovic, 2018). For the time when AVs were introduced to the traffic, pedestrians may not necessarily have realistic assumptions or beliefs about the actual capabilities and possibilities of these vehicles. They may underestimate the abilities of AVs, and consequently become too cautious when interacting with such vehicles, which can in turn lead to critical deadlock situations and traffic inefficiency. On the other hand, pedestrians may overestimate capabilities of AVs, and behave in a risky manner due to incorrect assumptions (Habibovic, 2018). However, by representing the actual and future behaviour of the AV, there is a great chance to mitigate these issues, which could be also confirmed by the results of the PRQF after the experiment. The participants' score in compatibility, which represents the degree to which a fully AV is perceived as being consistent with the existing transportation system, increased. Likewise, the belief of the participants that a fully AV will perform its intended task with high effectiveness increased. Furthermore, participants believed more in the ability of the AV to successfully recognise pedestrians and other obstacles in road traffic, after the experiment. Finally, the individual perception of what important and influencing people think about fully AVs changed positively. Therefore, it can be stated that after getting experienced in dealing with an AV, participants were able to better assess their possibilities and abilities and subsequently their attitude towards AVs improved.

## Limitations

**Methodological Limitations.** Only a limited number of participants (24) were involved in the experiment and all of them were employees of Volkswagen Aktiengesellschaft, which is why they may have a higher affinity towards technology. Moreover, participants had no physical or mental limitations, they had a driver's license and thus experiences with traffic rules and signs and they were not illiterate. The representation of the general population is therefore limited.

Moreover, there was only a limited number of other road users during the experiment within the industrial area in Wolfsburg. The test vehicle was predominantly the only vehicle on road, which meant that real traffic conditions were only available to a limited extent.

One question about the clarity of the acoustic signals had to be removed, as it was not clear, whether the participants had chosen for the answer category ‘4 = not applicable’, because they did not hear any acoustic signal at all, or whether they only did not found it suitable in terms of the volume and frequency.

Due to technical failures, some test runs had to be repeated. On the one hand there were problems with the acoustic signals, which were partly missing and on the other hand the displays were shown too late due to a distorted signal transmission, which may have affected the evaluation of the respective eHMI concept.

## Further research

Further studies should explore the value of external communication via an eHMI in more dynamic traffic situations and with a more heterogeneous participant pool with different physical impairments and experiences in road traffic. It would be also of interest to investigate, whether children and even illiterate people who cannot read, uzh.ji443eecould understand the intention of the AV. Moreover, it would be recommended to investigate the comprehensibility of the concept ‘Automation Level’ with the additional visual modality. Furthermore, it would be recommended to continue exploring, whether the brightness of the visual modalities and the acoustic signals of the eHMI concepts are still suitable within the overcrowded city centre at day and night. In this context, it would have to be tested subsequently, whether the intention of the vehicle can be distinguished between a status message or an action request. Overall, it would be important in the long run to see if pedestrians' wishes and requirements change after a familiarisation phase with an AV and accordingly to what extent the eHMI concepts would have to be adapted.

## Conclusion

The study implies that the communication intention of an AV via an eHMI could be sufficient to improve interactions between pedestrians and AVs by creating an extensive knowledge of the current and future system behaviour and accordingly by creating higher perceived safety for pedestrians.

Overall, four of the six use case scenarios: the 'Pedestrian Icon - Invitation to act', 'Parking Search', Safe-Stop - Text' and 'Safe-Stop - Icon' displayed a good hedonic and pragmatic quality, participants were able to quickly and clearly understand the message, predict the future system behaviour and they knew what adequate behaviour was on their part in the experienced driving situation. This was not the case for the use case scenario 'Automation Level' and 'Pedestrian Icon – Status'. The study revealed that a single technical modality for the intention mediation of an AV might not be sufficient to understand it in every condition, which is why it would be recommended to focus also on a baseline ride without an eHMI to test the need for additional elements. Furthermore, it is clear that a direct call to action in crossroads situations is preferred by the participants of this study. Overall, the attitude towards AVs has changed positively after the experiment. The communication intention is most successful by a combination of the visual, auditory and physical/ kinesthetic modalities. Furthermore, the information message and the notification of warnings by means of acoustic signals, display and lightning technologies is considered as suitable. All concepts were recognised optically well. Nevertheless, the subjects mentioned that some of the concepts were not well visible in sunlight, which is why an adjustment of the brightness in dependence of the environment seems to make sense in the future. Further investigations in more dynamic traffic situations and by involving also other road users such as cyclists, cars and trucks to validate this conclusion, is suggested. Finally, it should be noted that the eHMI of AVs may require standardization in future to avoid potential ambiguities.

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Appendix A

**Informed Consent**

VOLKSWAGEN

AKTIENGESELLSCHAFT

**Consent to data processing for a study investigating the communication of autonomous vehicles (AV) with pedestrians.**

**Consent to data processing**

**☐ I agree that the following personal data may be processed by Volkswagen AG for the following purposes:**

Gender; age; nationality; type of residential area; typical behaviour in road traffic; current fatigue; statements on (the communication of) AV and personality, which are queried and recorded by means of questionnaires; notes on actions and statements during the experiment

I am participating in a study investigating the communication between AV and pedestrians. The aim is to test and evaluate the communication techniques developed in advance. The above-mentioned data will be evaluated and analysed in order to process the problem areas in the broader research context.

The following methods are used by Volkswagen AG:

- I will participate in an experiment and express my opinion on the communication of an AV with pedestrians by means of a questionnaire.
- During the study, the investigators take notes (e.g. statements and actions) that relate to the objectives of the experiment.
- The study is recorded during two partial experiments by means of a video recording in order to be able to retrieve the information at a later time. The personal reference to the data is deleted one month after the end of the experiment.

**Withdrawal**

You can, of course, revoke your consent at any time without giving reasons to Volkswagen AG, Berliner Ring 2, 38440 Wolfsburg, for example by sending an e-mail to info-datenschutz@volkswagen.de with effect for the future. Your revocation does not affect the legality of the processing of your data on the basis of your consent until revocation.

With my consent, I confirm that I have reached at least sixteen years of age.

**Wolfsburg, ________________________________________________**

**(Place) (Date) (Signature)**

Appendix B

**Test leader protocol**

Date: ______________________________________________

Time: ______________________________________________

Subject: _________

Weather conditions:

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

Notes:

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Appendix C

**Instruction to the driver of the test vehicle**

The following document is a brief description of how the journey under real road conditions is planned from the point of view of the test vehicle driver. In the following, you will find a detailed sequence of eHMI concepts, empty trips and directions from which the vehicle will start each trip.

Your starting position will be communicated to you in advance. Via a communication channel (WhatsApp or similar) you will get your driving license. Here it is important that you have switched on the sound of your mobile phone. You will then drive the specified route at 20 km/h as accurately as possible. The road traffic regulations must be observed during the entire journey. You can see the direction from the overview below. In the case of the eHMI 'Pedestrian Icon', you must stop in front of the participant at the defined mark and wait for his reaction. Then you can continue the ride. If there is no reaction, the ride continues after about 20 seconds.

The selected route is ring-shaped. Please always turn on the opposite side/street or outside the field of vision of the participant. You can see the route in the picture below.

An empty trip means that no eHMI is presented. Therefore, drive past the participant, turn or drive along the ring and then perform the following ride.

After each eHMI/trip, the respondent will fill out a questionnaire. During this time you will have the opportunity to stretch your legs briefly. You will then receive another notification to take the vehicle to the participant. You will be informed of the designated location in advance. Here the eHMI will be demonstrated again. Please remain seated as calmly as possible. We will send you another message. You should recognise it by the sound and drive away with as few movements as possible.

As soon as you see passers-by in your field of vision, please do not drive off and give us a short feedback. We will also not give you permission to start as long as passers-by are in your field of vision.

The well-being of the participants and all other participants is our top priority. The decision as to whether the test has to be aborted lies with you as the driver. Each trip can be repeated.

After the last drive you can look for a place outside the field of vision of the participants and stretch your legs.

## <u>Day 1</u>

| **eHMI/ Empty trip** | **While driving** | **Direction** |
|---|---|---|
| Pedestrian Icon - Invitation to act | ○ Start on notification<br>○ Stop briefly in front of participant<br>○ Wait for reaction<br>○ Start again<br>○ Return to respondent for renewed demonstration after notification | **left** |
| **Empty trip** | ○ Start on notification<br>○ Drive past the participant<br>○ No notification for the next trip follows<br>○ Direct transition to the next trip | **left** |
| Pedestrian Icon - Status | ○ Start on notification<br>○ Stop briefly in front of participant<br>○ Wait for reaction<br>○ Start again<br>○ Return to respondent for renewed demonstration after notification | **right** |
| Parking Search | ○ Start on notification<br>○ Drive past the participant<br>○ Park for a moment<br>○ Return to respondent for renewed demonstration after notification | **right** |
| Automation Level | ○ Start on notification<br>○ Drive past participant<br>○ Return to participant for renewed demonstration after notification | **left** |
| **Empty trip** | ○ Start on notification<br>○ Drive past the participant<br>○ No notification for the next trip follows<br>○ Direct transition to the next trip | **left** |
| Safe-Stop - Icon | ○ Start on notification<br>○ Stop shortly after the participant<br>○ Wait five seconds and then continue<br>○ Return to respondent for renewed demonstration after notification | **right** |
| Safe-Stop - Text | ○ Start on notification<br>○ Stop shortly after the participant<br>○ Wait five seconds and then continue<br>○ Return to respondent for renewed demonstration after notification | **right** |

**Day 2**

| **eHMI/ Empty trip** | **While driving** | **Direction** |
|---|---|---|
| Parking Search | ○ Start on notification<br>○ Drive past the participant<br>○ Park for a moment<br>○ Return to respondent for renewed demonstration after notification | **right** |
| **Empty trip** | ○ Start on notification<br>○ Drive past the participant<br>○ No notification for the next trip follows<br>○ Direct transition to the next trip | **left** |
| Pedestrian Icon - Invitation to act | ○ Start on notification<br>○ Stop briefly in front of participant<br>○ Wait for reaction<br>○ Start again<br>○ Return to respondent for renewed demonstration after notification | **right** |
| Safe-Stop - Icon | ○ Start on notification<br>○ Stop shortly after the participant<br>○ Wait 5 seconds and then continue<br>○ Return to respondent for renewed demonstration after notification | **left** |
| Automation Level | ○ Start on notification<br>○ Drive past participant<br>○ Return to participant for renewed demonstration after notification | **right** |
| **Empty trip** | ○ Start on notification<br>○ Drive past the participant<br>○ No notification for the next trip follows<br>○ Direct transition to the next trip | **right** |
| Safe-Stop - Text | ○ Start on notification<br>○ Stop shortly after the participant<br>○ Wait 5 seconds and then continue<br>○ Return to respondent for renewed demonstration after notification | **left** |
| Pedestrian Icon - Status | ○ Start on notification<br>○ Stop briefly in front of participant<br>○ Wait for reaction<br>○ Start again<br>○ Return to respondent for renewed demonstration after notification | **left** |

**Day 3**

| **eHMI/ Empty trip** | **While driving** | **Direction** |
|---|---|---|
| Pedestrian Icon - Status | ○ Start on notification<br>○ Stop briefly in front of participant<br>○ Wait for reaction<br>○ Start again<br>○ Return to respondent for renewed demonstration after notification | **left** |
| Automation Level | ○ Start on notification<br>○ Drive past participant<br>○ Return to participant for renewed demonstration after notification | **right** |
| **Empty trip** | ○ Start on notification<br>○ Drive past the participant<br>○ No notification for the next trip follows<br>○ Direct transition to the next trip | **left** |
| Safe-Stop - Text | ○ Start on notification<br>○ Stop shortly after the participant<br>○ Wait 5 seconds and then continue<br>○ Return to respondent for renewed demonstration after notification | **right** |
| Parking Search | ○ Start on notification<br>○ Drive past the participant<br>○ Park for a moment<br>○ Return to respondent for renewed demonstration after notification | **left** |
| Pedestrian Icon – Invitation to act | ○ Start on notification<br>○ Stop briefly in front of participant<br>○ Wait for reaction<br>○ Start again<br>○ Return to respondent for renewed demonstration after notification | **right** |
| **Empty trip** | ○ Start on notification<br>○ Drive past the participant<br>○ No notification for the next trip follows<br>○ Direct transition to the next trip | **right** |
| Safe-Stop - Icon | ○ Start on notification<br>○ Stop shortly after the participant<br>○ Wait 5 seconds and then continue<br>○ Return to respondent for renewed demonstration after notification | **left** |

**Day 4**

| **eHMI/ Empty trip** | **While driving** | **Direction** |
|---|---|---|
| Automation Level | ○ Start on notification<br>○ Drive past participant<br>○ Return to participant for renewed demonstration after notification | **left** |
| Safe-Stop - Icon | ○ Start on notification<br>○ Stop shortly after the participant<br>○ Wait 5 seconds and then continue<br>○ Return to respondent for renewed demonstration after notification | **left** |
| **Empty trip** | ○ Start on notification<br>○ Drive past the participant<br>○ No notification for the next trip follows<br>○ Direct transition to the next trip | **left** |
| Pedestrian Icon - Status | ○ Start on notification<br>○ Stop briefly in front of participant<br>○ Wait for reaction<br>○ Start again<br>○ Return to respondent for renewed demonstration after notification | **right** |
| Safe-Stop - Text | ○ Start on notification<br>○ Stop shortly after the participant<br>○ Wait 5 seconds and then continue<br>○ Return to respondent for renewed demonstration after notification | **left** |
| Parking Search | ○ Start on notification<br>○ Drive past the participant<br>○ Park for a moment<br>○ Return to respondent for renewed demonstration after notification | **right** |
| **Empty trip** | ○ Start on notification<br>○ Drive past the participant<br>○ No notification for the next trip follows<br>○ Direct transition to the next trip | **left** |
| Pedestrian Icon - Invitation to act | ○ Start on notification<br>○ Stop briefly in front of participant<br>○ Wait for reaction<br>○ Start again<br>○ Return to respondent for renewed demonstration after notification | **right** |

**Day 5**

| **eHMI/ Empty trip** | **While driving** | **Direction** |
|---|---|---|
| Safe-Stop - Icon | ○ Start on notification<br>○ Stop shortly after the participant<br>○ Wait 5 seconds and then continue<br>○ Return to respondent for renewed demonstration after notification | **right** |
| **Empty trip** | ○ Start on notification<br>○ Drive past the participant<br>○ No notification for the next trip follows<br>○ Direct transition to the next trip | **right** |
| Parking Search | ○ Start on notification<br>○ Drive past the participant<br>○ Park for a moment<br>○ Return to respondent for renewed demonstration after notification | **left** |
| Automation Level | ○ Start on notification<br>○ Drive past participant<br>○ Return to participant for renewed demonstration after notification | **left** |
| **Empty trip** | ○ Start on notification<br>○ Drive past the participant<br>○ No notification for the next trip follows<br>○ Direct transition to the next trip | **right** |
| Safe-Stop - Text | ○ Start on notification<br>○ Stop shortly after the participant<br>○ Wait 5 seconds and then continue<br>○ Return to respondent for renewed demonstration after notification | **right** |
| Pedestrian Icon - Invitation to act | ○ Start on notification<br>○ Stop briefly in front of participant<br>○ Wait for reaction<br>○ Start again<br>○ Return to respondent for renewed demonstration after notification | **left** |
| Pedestrian Icon - Status | ○ Start on notification<br>○ Stop briefly in front of participant<br>○ Wait for reaction<br>○ Start again<br>○ Return to respondent for renewed demonstration after notification | **left** |

**Day 6**

| eHMI/ Empty trip | While driving | Direction |
|---|---|---|
| Safe-Stop - Text | ○ Start on notification<br>○ Stop shortly after the participant<br>○ Wait 5 seconds and then continue<br>○ Return to respondent for renewed demonstration after notification | **right** |
| Pedestrian Icon - Status | ○ Start on notification<br>○ Stop briefly in front of participant<br>○ Wait for reaction<br>○ Start again<br>○ Return to respondent for renewed demonstration after notification | **left** |
| Parking Search | ○ Start on notification<br>○ Drive past the participant<br>○ Park for a moment<br>○ Return to respondent for renewed demonstration after notification | **left** |
| **Empty trip** | ○ Start on notification<br>○ Drive past the participant<br>○ No notification for the next trip follows<br>○ Direct transition to the next trip | **right** |
| Safe-Stop - Icon | ○ Start on notification<br>○ Stop shortly after the participant<br>○ Wait 5 seconds and then continue<br>○ Return to respondent for renewed demonstration after notification | **right** |
| **Empty trip** | ○ Start on notification<br>○ Drive past the participant<br>○ No notification for the next trip follows<br>○ Direct transition to the next trip | **right** |
| Automation Level | ○ Start on notification<br>○ Drive past participant<br>○ Return to participant for renewed demonstration after notification | **right** |
| Pedestrian Icon - Invitation to act | ○ Start on notification<br>○ Stop briefly in front of participant<br>○ Wait for reaction<br>○ Start again<br>○ Return to respondent for renewed demonstration after notification | **Left** |

Appendix D

**Instruction to the test leaders**

## 1. Comments prior to the investigation

Test leader 1 is responsible for the entire execution of the study and communication with the participants. The second test leader is responsible for controlling the eHMI within the test vehicle.

The arrows in this document stand for handing over the corresponding materials to the participants. These include the informed consent and the respective parts of questionnaires.

The italic print refers to the direct address of the respondent. The rest of the text describes general information regarding the expiration of the study.

A total of six different eHMI concepts are tested. Each day, four participants are tested, who will view each eHMI. Moreover, there are two empty trips at each passage/participant.

The weather conditions and possible abnormalities are also recorded in this protocol.

The markings must be made with the help of chalk during preparation. The eHMI concepts are switched on at these corresponding marks, which can be seen in the experimental setup.

For the pedestrian icon – invitation to act this means that the acoustic signal and the traffic light manikin will be switched on 20 meters before the participant. As soon as the vehicle stops before the participant, the animated LED bar is switched on. The acoustic signal, as well as the display indication for the pedestrian icon – status is already switched on 20 meters before the participant. Furthermore, the symbol ‘P’ for the parking search is also switched on 20 meters before the participant, but the direction indicator and the blinking LED bar is switched on only 10 meters before the participant is reached. The LED bar for displaying the automation level, as well as the LED bar, the acoustic signal and the display concept for the Safe-Stop is switched on 20 meters in front of the participant.

**<u>Assignment of questionnaires per eHMI</u>**

| eHMI | Order of the respective parts of the questionnaire | | | |
|---|---|---|---|---|
| | Preliminary to the experiment | After the first presentation of the respective eHMI | After the repeated presentation of the respective eHMI | At the end of the study |
| Safe Stop - Text | Questionnaire 1 | Questionnaire 2 | Questionnaire 3 | Questionnaire 4 |
| Safe Stop - Icon | Questionnaire 1 | Questionnaire 2 | Questionnaire 3 | Questionnaire 4 |
| Pedestrian Icon - Status | Questionnaire 1 | Questionnaire 2 | Questionnaire 3 | Questionnaire 4 |
| Pedestrian Icon – Invitation to action | Questionnaire 1 | Questionnaire 2 | Questionnaire 3 | Questionnaire 4 |
| Parking Search | Questionnaire 1 | Questionnaire 2 | Questionnaire 3 | Questionnaire 4 |
| Automation Level | Questionnaire 1 | Questionnaire 2 | Questionnaire 3 | Questionnaire 4 |

## 2. Welcoming the subject

*Welcome,*
*Thank you very much for your participation in our study. This gives you the opportunity to actively shape the future!*

*We are students of Volkswagen Group Innovation in the field of HMI Augmentation and write our theses on the basis of this study. We concentrate on the communication with an autonomously driving vehicle of level 5. This means that the vehicle drives independently and does not require a driver, a steering wheel or pedals. Every person in the vehicle becomes a passenger.*

*Please read this Informed Consent carefully and sign it afterwards.*

➔ **Informed Consent**

*Now we start directly with the first questionnaire, which you have to fill out. We will then discuss the next steps with you.*

➔ **Questionnaire Part 1**

## 3. After filling in the informed consent + questionnaire part 1 and before the presentation of the eHMI

*Thank you very much! Next, we would like to ask you to position yourself at the marked spot on the side of the road and watch the traffic. You will see an autonomous vehicle. This vehicle will communicate with you. Your task is to raise your hand when you have understood what the vehicle wants to tell you. If you feel that the vehicle requires an action on your part, please take it as soon as you feel safe. You can lift your hand and perform the action at the same time.*

## 4. Comments for implementation

The participant is placed on the marked spot on the roadside. It must be ensured that no direction is given to him and he is orthogonal to the road.
If everything is prepared, the driver of the test vehicle gets a message (WhatsApp or similar) to start. The driver receives a detailed plan of the directions and scheduled empty runs.

The test leader 2 inside the vehicle takes control of the eHMI concepts. The eHMI is turned on at the first marker. The necessary additional functions are triggered at the corresponding following markings. As soon as the test vehicle is passed the participant or starts again after stopping, the eHMI is switched off completely (with the corresponding button).
After each trip with the respective eHMI the questionnaire part 2 will be filled in (a total of 6 times).

➔ **Questionnaire part 2**

## 5. After completing the questionnaire part 2

After the participant has completed the questionnaire part 2, please send a message to the driver so that he can drive up to the participant again. Each eHMI is shown again individually. After the demonstration is finished, another message must be sent to the driver so that he knows that he can drive away again. After each demonstration the questionnaire part 3 is filled out (a total of 6 times).

*Thank you very much. Next, we would like to show you the autonomous vehicle once again and explain the message of the vehicle to you. You will then receive another questionnaire, which you should carefully read and complete.*

**Explanation of the eHMI:**

**General (unique):** Here you can see the autonomous vehicle at a standstill. There are four displays all around with different eHMI concepts to enable the external communication between you and the vehicle.

**Pedestrian Icon – Invitation to act:** Here you see once again the autonomous vehicle at a standstill. In this case, the vehicle tries to inform you that you can cross the road as a pedestrian, as the vehicle has recognised you and takes you into consideration accordingly. It is a request for action from the autonomous vehicle to you.

**Pedestrian Icon - Status:** Here you can see the autonomous vehicle again. In this case, the vehicle tries to tell you that it has noticed you and will brake accordingly to let you cross the road. The vehicle wants to tell you its intention and intention to act.

**Parking Search:** Here you can see the autonomous vehicle once again. In this case, the vehicle tries to inform you that it has the intention to look for a parking space in the immediate vicinity.

**Automation Level:** Here you can see the autonomous vehicle again. The colour change of the LED bar indicates the change of automation levels. For example, from semi-automated to fully automated driving.

**Safe-Stop - Icon:** Here you can see the autonomous vehicle once again. In this case, the vehicle tries to inform you that it has the intention to stop safely, e.g. in case of technical malfunctions.

**Safe-Stop - Text:** Here you can see the autonomous vehicle again. In this case, the vehicle tries to inform you that it has the intention to keep safe, e.g. in case of technical malfunctions.

➔ **Questionnaire part 3, after each repeated presentation of the eHMI concepts**

## 6. After completion of the questionnaire part 3 and after all six trips

*Thank you very much for your effort! Finally, I would ask you once again to complete a final questionnaire.*

➔ **Questionnaire part 4**

## 7. Goodbye

This brings us to the end of the study and I would like to thank you very much for your participation! As compensation you can choose one of the vouchers.

➔ **Handing over the present**

## 8. Dismissal of the participant

Appendix E

**Survey Instrument**

**Part 1 - Preliminary Survey**

An Autonomous Vehicle (AV) is driven by technology instead of by a human. An AV is equipped with radars, cameras, and sensors which can detect the presence, position, and speed of other vehicles or road-users. With this information, the AV can then respond as needed by stopping, decelerating and/or changing direction.

As you consider this, how much would you agree or disagree with the following statements. Please tick the appropriate box. **1 stands for perfect agreement** and **7 for complete rejection**. By the values in between you can gradate your opinion.

| | Statements | ++<br>1 | 2 | 3 | 4 | 5 | 6 | --<br>7 |
|---|---|---|---|---|---|---|---|---|
| 1 | AVs will enhance the overall transportation system. | O | O | O | O | O | O | O |
| 2 | AVs will make the roads safer. | O | O | O | O | O | O | O |
| 3 | I would feel safe to cross roads in front of AVs. | O | O | O | O | O | O | O |
| 4 | It would take less effort from me to observe the surroundings and cross roads if there are AVs involved. | O | O | O | O | O | O | O |
| 5 | I would find it pleasant to cross the road in front of AVs. | O | O | O | O | O | O | O |
| 6 | People who influence my behaviour would think that I should cross roads in front of AVs. | O | O | O | O | O | O | O |
| 7 | People who are important to me would not think that I should cross roads in front of AVs. | O | O | O | O | O | O | O |
| 8 | People who are important to me and/or influence my behaviour trusts AVs (or has a positive attitude towards AVs). | O | O | O | O | O | O | O |
| 9 | Interacting with the system would not require a lot of mental effort. | O | O | O | O | O | O | O |
| 10 | An AV can correctly detect pedestrians on streets | O | O | O | O | O | O | O |
| 11 | I would feel comfortable if my child, spouse, parents – or other loved ones – cross roads in the presence of AVs. | O | O | O | O | O | O | O |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 12 | I would recommend my family and friends to be comfortable while crossing roads in front of AVs. | O | O | O | O | O | O | O |
| 13 | I would feel more comfortable doing other things (e.g., checking emails on my smartphone, talking to my companions) while crossing the road in front of AVs | O | O | O | O | O | O | O |
| 14 | The traffic infrastructure supports the launch of AVs. | O | O | O | O | O | O | O |
| 15 | An AV is compatible with all aspects of transportation system in my area. | O | O | O | O | O | O | O |
| 16 | AVs will be able to effectively interact with other vehicles and pedestrians. | O | O | O | O | O | O | O |

## Part 2 - Scenario evaluation

1. You just saw a vehicle driving autonomously. Can you imagine what the AV wanted to tell you? If you are not sure, please describe the presumption you think is most likely.

____________________________________________________________

____________________________________________________________

____________________________________________________________

____________________________________________________________

____________________________________________________________

____________________________________________________________

____________________________________________________________

2. Did you interpret the message as communication of the system status of the AV, or as an invitation to pedestrian to take action?

o as a communication of the system status of the AV

o as an invitation to pedestrians to take action

o both

o other: ____________________________________________

3. I understood the message of the AV very quickly.

o applies

o applies predominantly to

o applies in part

o not applicable

4. I perceived the AVs message as clear and easy to understand.

o applies

o applies predominantly to

o applies in part

o not applicable

5. I could see the message of the AV very well (e.g. size/brightness).

o applies

o applies predominantly to

o applies in part

o not applicable

6. If you heard an audible signal: Were you able to perceive the message from the AV (e.g. volume/ frequency).

o applies

o applies predominantly to

o applies in part

o not applicable

7. In the just experienced driving situation, I knew what would happen as future system behaviour.

o applies

o applies predominantly to

o applies in part

o not applicable

8. In the just experienced driving situation, I knew how to behave correctly.

o applies

o applies predominantly to

o applies in part

o not applicable

9. Overall, I felt very safe in the situation I had just experienced and in the presence of the AV.

o applies

o applies predominantly to

o applies in part

o not applicable

10. Have you noticed certain aspects of the AV in a very positive light?

______________________________

______________________________

______________________________

______________________________

______________________________

______________________________

11. Have you noticed certain aspects of the AV in a very negative way?

______________________________

______________________________

______________________________

______________________________

______________________________

______________________________

**Part 3 - Scenario evaluation after renewed presentation**

| |
|---|
| 12. After the repeated demonstration of the AV, did you notice certain aspects of the eHMI, which you had not noticed before during the first journey? |

- ○ Yes, namely: ______________________________________________
  ______________________________________________
- ○ No

| |
|---|
| 13. Would these aspects have been important for the comprehensibility of the eHMI and should therefore be presented more clearly? |

- ○ Yes
- ○ No

| |
|---|
| 14. If you answered "Yes" to the previous question: Do you have any idea how to present these aspects more clearly? |

- ○ Yes, namely: ______________________________________________
  ______________________________________________
- ○ No

| |
|---|
| 15. Do you have derived additional information from the message of the AV, which did not fit the intention of the vehicle just described? |

- ○ Yes
- ○ No

| |
|---|
| 16. If you answered "Yes" to the previous question: What additional information did you derive from the message and what was responsible for providing the additional information? |

______________________________________________

______________________________________________

______________________________________________

17. After you know what the AV wanted to tell you, how understandable do you judge the eHMI of the AV in the just experienced driving situation?

o very understandable

o somewhat understandable

o hardly understandable

o incomprehensible

18. Please enter the following word pairs to indicate how you perceived the eHMI. Please indicate in each line a position between the adjectives that you consider most appropriate. I consider the eHMI to be...

| | | 3 | 2 | 1 | 0 | -1 | -2 | -3 | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | supportive | ○ | ○ | ○ | ○ | ○ | ○ | ○ | obtrusive |
| 2 | easy | ○ | ○ | ○ | ○ | ○ | ○ | ○ | complicated |
| 3 | efficient | ○ | ○ | ○ | ○ | ○ | ○ | ○ | inefficient |
| 4 | clear | ○ | ○ | ○ | ○ | ○ | ○ | ○ | confusing |
| 5 | exiting | ○ | ○ | ○ | ○ | ○ | ○ | ○ | boring |
| 6 | interesting | ○ | ○ | ○ | ○ | ○ | ○ | ○ | not interesting |
| 7 | inventive | ○ | ○ | ○ | ○ | ○ | ○ | ○ | conventional |
| 8 | leading edge | ○ | ○ | ○ | ○ | ○ | ○ | ○ | usual |

19. Which suggestions for improvement do you have for the design of the eHMI?

○ following:
______________________________________________
______________________________________________
______________________________________________
______________________________________________
______________________________________________
______________________________________________

○ none

## Part 4 - Evaluation of the communication media + final survey

20. How good do you think display technology is for communicating information?

o very suitable

o suitable

o hardly suitable

o unsuitable

21. How good do you think display technology is to communicate a warning in a safety critical situation?

o very suitable

o suitable

o hardly suitable

o unsuitable

22. How good do you think the light bar technology is to communicate information?

o very suitable

o suitable

o hardly suitable

o unsuitable

23. How good do you think the light bar technology is to communicate a warning in a safety critical situation?

o very suitable

o suitable

o hardly suitable

o unsuitable

24. How good do you think the acoustic signals are for communicating information?

o very suitable

o suitable

o hardly suitable

o unsuitable

25. How good do you think the acoustic signals are for communicating a warning in a safety critical situation?

o very suitable
o suitable
o hardly suitable
o unsuitable

26. If you think back to the eHMI, is there a preferred modality for you, or a combination of several modalities?

o visual only (i.e. Liquid Crystal Display (LCD), LED bar)
o auditory only (i.e. acoustic signals)
o physical/ kinesthetic only (i.e. vehicle's kinematic)
o combination of the following modalities:
________________________________________

27. Are you missing important information to understand the message of the AV faster and better?

- Yes, namely:
  ________________________________________
  ________________________________________
- No

28. Are there certain aspects of the eHMI that you would like to improve?

- Yes, namely:
  ________________________________________
  ________________________________________
- No

29. Is there anything else you would like to tell us about the eHMI of the AV?

________________________________________________
________________________________________________
________________________________________________
________________________________________________
________________________________________________

30. An AV is driven by technology instead of by a human. It is equipped with radars, cameras, and sensors which can detect the presence, position, and speed of other vehicles or road-users. With this information, the AV can then respond as needed by stopping, decelerating and/or changing direction. As you consider this, how much would you agree or disagree with the following statements.
Please tick the appropriate box. **1 stands for perfect agreement** and **7 for complete rejection**. By the values in between you can gradate your opinion.

| | Statements | ++<br>1 | 2 | 3 | 4 | 5 | 6 | --<br>7 |
|---|---|---|---|---|---|---|---|---|
| 1 | AVs will enhance the overall transportation system. | O | O | O | O | O | O | O |
| 2 | AVs will make the roads safer. | O | O | O | O | O | O | O |
| 3 | I would feel safe to cross roads in front of AVs. | O | O | O | O | O | O | O |
| 4 | It would take less effort from me to observe the surroundings and cross roads if there are AVs involved. | O | O | O | O | O | O | O |
| 5 | I would find it pleasant to cross the road in front of AVs. | O | O | O | O | O | O | O |
| 6 | People who influence my behaviour would think that I should cross roads in front of AVs. | O | O | O | O | O | O | O |
| 7 | People who are important to me would not think that I should cross roads in front of AVs. | O | O | O | O | O | O | O |
| 8 | People who are important to me and/or influence my behaviour trusts AVs (or has a positive attitude towards AVs). | O | O | O | O | O | O | O |
| 9 | Interacting with the system would not require a lot of mental effort. | O | O | O | O | O | O | O |
| 10 | An AV can correctly detect pedestrians on streets | O | O | O | O | O | O | O |
| 11 | I would feel comfortable if my child, spouse, parents – or other loved ones – cross roads in the presence of AVs. | O | O | O | O | O | O | O |
| 12 | I would recommend my family and friends to be comfortable while crossing roads in front of AVs. | O | O | O | O | O | O | O |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 13 | I would feel more comfortable doing other things (e.g., checking emails on my smartphone, talking to my companions) while crossing the road in front of AVs | O | O | O | O | O | O | O |
| 14 | The traffic infrastructure supports the launch of AVs. | O | O | O | O | O | O | O |
| 15 | An AV is compatible with all aspects of transportation system in my area. | O | O | O | O | O | O | O |
| 16 | AVs will be able to effectively interact with other vehicles and pedestrians. | O | O | O | O | O | O | O |

31. Please enter your age:

Age: ___________

32. Please indicate your sex:

o male

o female

o diverse

**Appendix F**

R-Script (Markdown)

# Realfahrtstudie_Auswertung

Lisa MÃ¼hrmann

25 Juni 2019

## Install Packages

```
library(ggplot2)
library(tidyverse)

## -- Attaching packages --------------------------------------- tidyv
erse 1.2.1 --

## v tibble  2.0.1     v purrr   0.2.5
## v tidyr   0.8.2     v dplyr   0.7.8
## v readr   1.3.1     v stringr 1.3.1
## v tibble  2.0.1     v forcats 0.3.0

## -- Conflicts ------------------------------------------ tidyverse_c
onflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()

library(tidyr)
library(readxl)
library(tidyverse)
library(rstanarm)

## Loading required package: Rcpp

## rstanarm (Version 2.18.2, packaged: 2018-11-08 22:19:38 UTC)

## - Do not expect the default priors to remain the same in future rs
tanarm versions.

## Thus, R scripts should specify priors explicitly, even if they are
just the defaults.

## - For execution on a local, multicore CPU with excess RAM we recom
mend calling

## options(mc.cores = parallel::detectCores())

## - Plotting theme set to bayesplot::theme_default().

library(devtools)
```

### Evaluation of the UEQ (Pragmatic/Hedonic)(H1)

### Reading and cleaning data

```
UEQ_1 <- read_excel("C:\\Users\\x\\Desktop\\Auswertung_Realfahrt_Long
.xlsx", sheet = "UEQ_1") %>%
  mutate(Score = as.numeric(Score))

summary(UEQ_1)
```

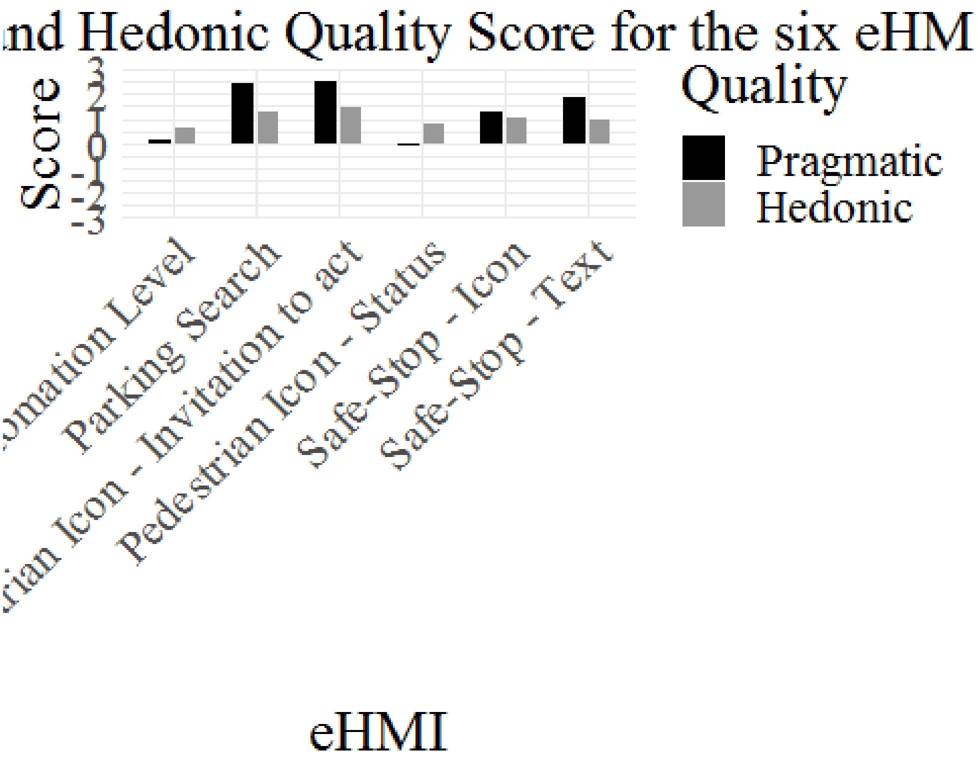
```
##       eHMI             Quality              Score
##  Length:12          Length:12          Min.   :-0.100
##  Class :character   Class :character   1st Qu.: 0.770
##  Mode  :character   Mode  :character   Median : 1.160
##                                        Mean   : 1.199
##                                        3rd Qu.: 1.590
##                                        Max.   : 2.520
```

```
str(UEQ_1)
```

```
## Classes 'tbl_df', 'tbl' and 'data.frame':    12 obs. of  3 variabl
es:
##  $ eHMI   : chr  "Automation Level" "Parking Search" "Pedestrian Icon -
Invitation to act" "Pedestrian Icon - Status" ...
##  $ Quality: chr  "Pragmatic" "Pragmatic" "Pragmatic" "Pragmatic" ...
##  $ Score  : num  0.11 2.4 2.52 -0.1 1.27 1.89 0.65 1.32 1.49 0.81 ...
```

### Explorative data analysis

```
UEQ_1$Quality <- factor(UEQ_1$Quality, levels = c("Pragmatic", "Hedon
ic"), ordered = TRUE)

UEQ_1$eHMI <- factor(UEQ_1$eHMI, levels = c("Automation Level", "Parking S
earch", "Pedestrian Icon - Invitation to act", "Pedestrian Icon - Status",
"Safe-Stop - Icon", "Safe-Stop - Text"), ordered = TRUE)

UEQ_1 %>%
  ggplot(aes(x = eHMI, y = Score, fill = Quality)) +
  geom_bar(stat = "identity", position = position_dodge(0.6), width = 0.5)
+
  scale_fill_manual("Quality", values = c("Pragmatic" = "black", "Hedonic"
= "#999999")) +
  ggtitle("Pragmatic and Hedonic Quality Score for the six eHMIs") +
  labs(x = "eHMI", y = "Score") +
  theme_classic() +
  theme_minimal() +
  scale_y_continuous(expand = c(0, 0), limits = c(-3, 3), breaks = c(-3, -
2, -1, 0, 1, 2, 3)) +
  theme(plot.title = element_text(hjust = 0.5, color = "black", size = 22)
) +
  theme(text = element_text(
    family = "serif"
  )) +
  theme(text = element_text(size = 22))+
  theme(axis.text.x = element_text(angle = 45, hjust = 1))
```




**Analysis UEQ**

```
      # Pragmatic

UEQ <- read_excel("C:\\Users\\X\\Desktop\\Auswertung_Realfahrt_Long.xlsx",
sheet = "UEQ")

UEQ_analysis_1 <-
  UEQ %>%
  stan_glmer(Pragmatic_Score ~ 0 + Scenario_Name + (1 | Part),
    data = .
  )

      fixef(UEQ_analysis_1)

      ranef(UEQ_analysis_1)

      summary(UEQ_analysis_1)



      # Hedonic

UEQ_analysis_2 <-
  UEQ %>%
  stan_glmer(Hedonic_Score ~ 0 + Scenario_Name + (1 | Part),
    data = .
  )

      fixef(UEQ_analysis_2)

      ranef(UEQ_analysis_2)
```

```
summary(UEQ_analysis_2)
```

**Evaluation of the attitude towards AVs (H1)**

**Reading Data**

```
PRQF <- read_excel("C:\\Users\\X\\Desktop\\Auswertung_Realfahrt_Long.
xlsx", sheet = "PRQF")

summary(PRQF)
```

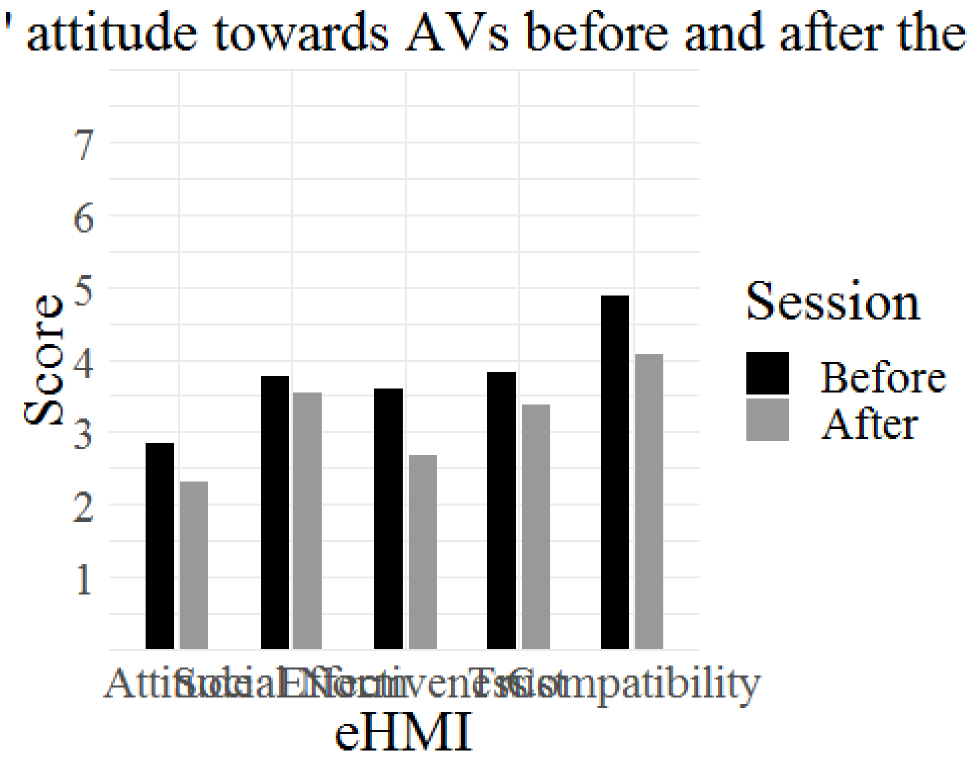
```
##      PRQF             Session              Score      
##  Length:10          Length:10          Min.   :2.310  
##  Class :character   Class :character   1st Qu.:2.978  
##  Mode  :character   Mode  :character   Median :3.570  
##                                        Mean   :3.489  
##                                        3rd Qu.:3.812  
##                                        Max.   :4.880
```

```
str(PRQF)
```

```
## Classes 'tbl_df', 'tbl' and 'data.frame':    10 obs. of  3 variabl
es:
##  $ PRQF   : chr  "Attitude" "Social Norm" "Effectiveness" "Trust" ...
##  $ Session: chr  "Before" "Before" "Before" "Before" ...
##  $ Score  : num  2.85 3.76 3.61 3.83 4.88 2.31 3.53 2.69 3.36 4.07
```

**Explorative data analysis**

```
PRQF$Session <- factor(PRQF$Session, levels = c("Before", "After"), o
rdered = TRUE)

PRQF$PRQF <- factor(PRQF$PRQF, levels = c("Attitude", "Social Norm", "Effe
ctiveness", "Trust", "Compatibility"), ordered = TRUE)

PRQF %>%
  ggplot(aes(x = PRQF, y = Score, fill = Session)) +
  geom_bar(stat = "identity", position = position_dodge(0.6), width = 0.5)
+
  scale_fill_manual("Session", values = c("Before" = "black", "After" = "#
999999")) +
  ggtitle("PRQF: Pedestrians' attitude towards AVs before and after the ex
periment") +
  labs(x = "eHMI", y = "Score") +
  theme_classic() +
  theme_minimal() +
  scale_y_continuous(expand = c(0, 0), limits = c(0, 8), breaks = c(1, 2,
3, 4, 5, 6, 7)) +
  theme(plot.title = element_text(hjust = 0.5, color = "black", size = 22)
) +
  theme(text = element_text(
    family = "serif"
  )) +
  theme(text = element_text(size = 22))
```




**Analysis of the PRQF by using the GLM**

**Attitude**

```
      # Reading Data
PRQF_A <- read_excel("C:\\Users\\X\\Desktop\\Auswertung_Realfahrt_Long.xls
x", sheet = "PRQF_A")

# Analysis
PRQF_AA <-
  PRQF_A %>%
  stan_glmer(Score ~ 0 + Session + (1 | Part),
    data = .
  )

      fixef(PRQF_AA)

      ranef(PRQF_AA)

      summary(PRQF_AA)
```

**Social Norm**

```
      # Reading Data
PRQF_SN <- read_excel("C:\\Users\\X\\Desktop\\Auswertung_Realfahrt_Long.xl
sx", sheet = "PRQF_E")

# Analysis
PRQF_SNA <-
  PRQF_SN %>%
  stan_glmer(Score ~ 0 + Session + (1 | Part),
```

```
    data = .
  )

      fixef(PRQF_SNA)

      ranef(PRQF_SNA)

      summary(PRQF_SNA)
```

**Effectiveness**

```
      # Reading Data
PRQF_E <- read_excel("C:\\Users\\X\\Desktop\\Auswertung_Realfahrt_Long.xls
x", sheet = "PRQF_E")

# Analysis
PRQF_EA <-
  PRQF_E %>%
  stan_glmer(Score ~ 0 + Session + (1 | Part),
    data = .
  )

      fixef(PRQF_EA)

      ranef(PRQF_EA)

      summary(PRQF_EA)
```

**Trust**

```
      PRQF_T <- read_excel("C:\\Users\\X\\Desktop\\Auswertung_Realfahrt_Lon
g.xlsx", sheet = "PRQF_T")


PRQF_TA <-
  PRQF_T %>%
  stan_glmer(Score ~ 0 + Session + (1 | Part),
    data = .
  )

      fixef(PRQF_TA)

      ranef(PRQF_TA)

      summary(PRQF_TA)
```

**Compatibility**

```
      # Reading Data

PRQF_C <- read_excel("C:\\Users\\X\\Desktop\\Auswertung_Realfahrt_Long.xls
x", sheet = "PRQF_C")

# Analysis
PRQF_CA <-
  PRQF_C %>%
```

```
  stan_glmer(Score ~ 0 + Session + (1 | Part),
    data = .
  )

      fixef(PRQF_CA)

      ranef(PRQF_CA)

      summary(PRQF_CA)
```

### Evaluation of the single items (H2)

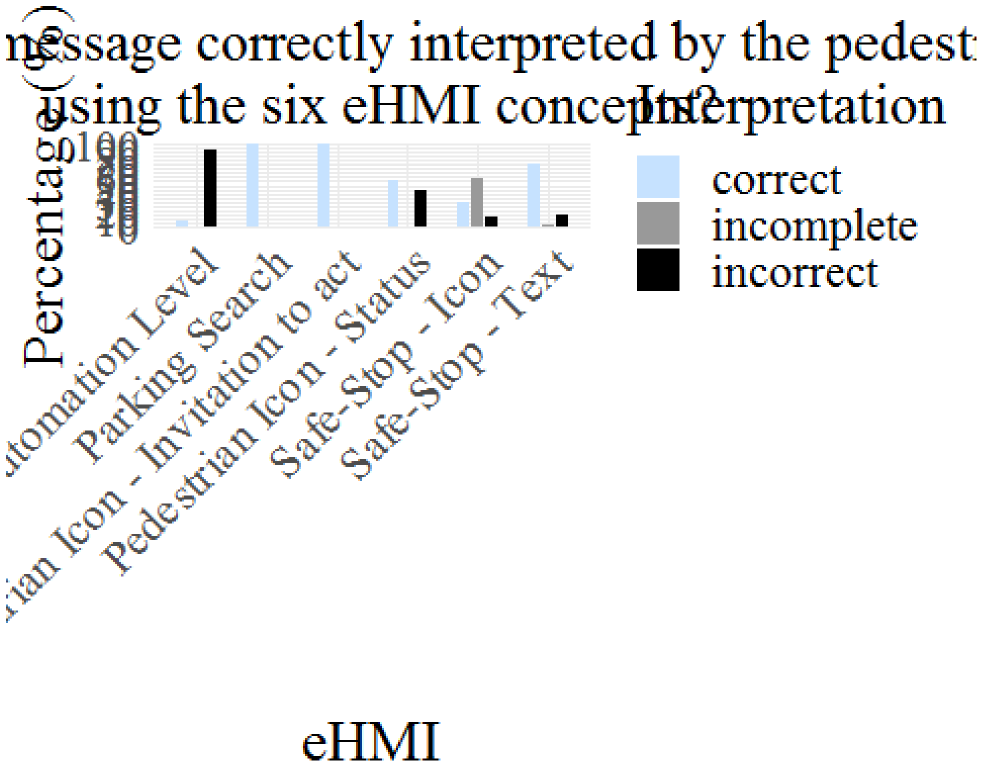
### Reading Data

```
      Single_Item1 <- read_excel("C:\\Users\\X\\Desktop\\Auswertung_Realfah
rt_Long.xlsx", sheet = "Single_Item")

summary(Single_Item1)
```

### Explorative Analysis

### Single Item 1

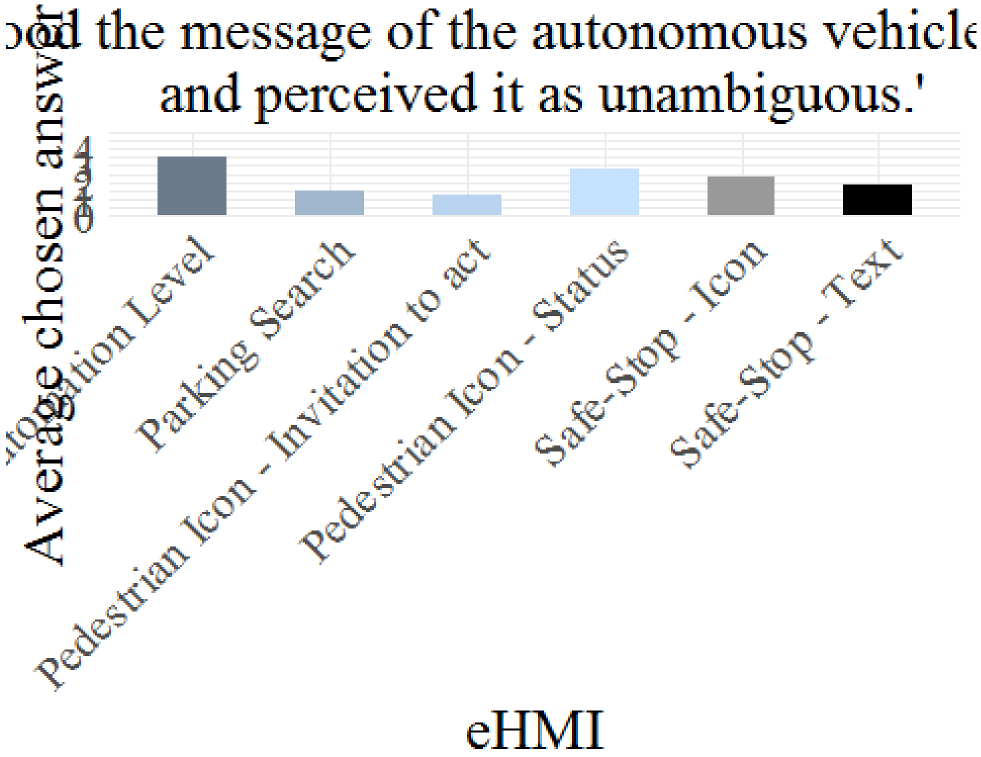
```
      Single_Item1$Answer <- factor(Single_Item1$Answer, levels = c("correc
t", "incomplete", "incorrect"), ordered = TRUE)

Single_Item1$eHMI <- factor(Single_Item1$eHMI, levels = c("Automation Leve
l", "Parking Search", "Pedestrian Icon - Invitation to act", "Pedestrian I
con - Status", "Safe-Stop - Icon", "Safe-Stop - Text"), ordered = TRUE)

Single_Item1 %>%
  ggplot(aes(x = eHMI, y = Frequency, fill = Answer)) +
  geom_bar(stat = "identity", position = position_dodge(0.6), width = 0.5)
+
  scale_fill_manual("Interpretation", values = c("correct" = "slategray1",
"incomplete" = "#999999", "incorrect" = "Black")) +
  ggtitle("Was the AV's message correctly interpreted by the pedestrians\n
using the six eHMI concepts?") +
  labs(x = "eHMI", y = "Percentage (%)") +
  theme_classic() +
  theme_minimal() +
  scale_y_continuous(expand = c(0, 0), limits = c(0, 100), breaks = c(0, 1
0, 20, 30, 40, 50, 60, 70, 80, 90, 100)) +
  theme(plot.title = element_text(hjust = 0.5, color = "black", size = 22)
) +
  theme(text = element_text(
    family = "serif"
  )) +
 theme(text = element_text(size = 22))+
  theme(axis.text.x = element_text(angle = 45, hjust = 1))
```




**Single Item 2**

```
    # Reading Data

Single_Item2 <- read_excel("C:\\Users\\X\\Desktop\\Auswertung_Realfahrt_Lo
ng.xlsx", sheet = "Frage2")

# Explorative Analysis

Single_Item2 %>%
  group_by(Scenario_Name) %>%
  summarize(avg_Answers = mean(Answers)) %>%
  ggplot(aes(x = Scenario_Name, y = avg_Answers, fill = Scenario_Name)) +
  geom_bar(stat = "identity", position = position_dodge(0.6), width = 0.5)
+
  scale_fill_manual("eHMI", values = c("Automation Level" = "slategray4",
"Parking Search" = "slategray3", "Pedestrian Icon - Invitation to act" = "
slategray2", "Pedestrian Icon - Status" = "slategray1", "Safe-Stop - Icon"
= "#999999", "Safe-Stop - Text" = "Black")) +
  ggtitle("'I understood the message of the autonomous vehicle very quickl
y\n and perceived it as unambiguous.'") +
  labs(x = "eHMI", y = "Average chosen answer category") +
  theme_classic() +
  theme_minimal() +
  scale_y_continuous(expand = c(0, 0), limits = c(0, 5), breaks = c(0, 1,
2, 3, 4)) +
  theme(plot.title = element_text(hjust = 0.5, color = "black", size = 22)
) +
  theme(text = element_text(
    family = "serif"
  )) +
```

```
  theme(text = element_text(size = 22)) +
  theme(legend.position = "none")+
  theme(axis.text.x = element_text(angle = 45, hjust = 1))
```



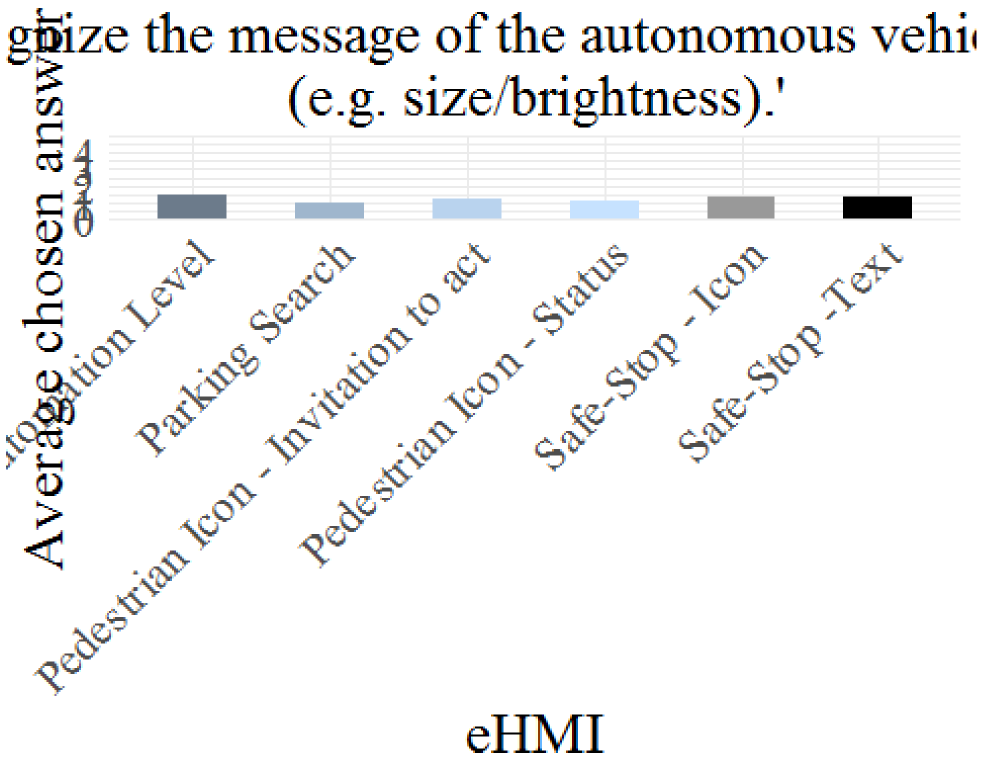

**Analysis Single Item 2**

```
      # Reading Data

Item2_Analysis <-
  Single_Item2 %>%
  stan_glmer(Answers ~ 0 + Scenario_Name + (1 | Part),
    data = .
  )

      fixef(Item2_Analysis)

      ranef(Item2_Analysis)

      summary(Item2_Analysis)
```

**Single Item 3:**

```
      # Reading Data

Single_Item3 <- read_excel("C:\\Users\\X\\Desktop\\Auswertung_Realfahrt_Long.xlsx", sheet = "Frage3")

# Explorative Analysis

Single_Item3 %>%
  group_by(Scenario_Name) %>%
  summarize(avg_Answers = mean(Answers)) %>%
```

```
  ggplot(aes(x = Scenario_Name, y = avg_Answers, fill = Scenario_Name)) +
  geom_bar(stat = "identity", position = position_dodge(0.6), width = 0.5)
+
  scale_fill_manual("eHMI", values = c("Automation Level" = "slategray4",
"Parking Search" = "slategray3", "Pedestrian Icon - Invitation to act" = "
slategray2", "Pedestrian Icon - Status" = "slategray1", "Safe-Stop - Icon"
= "#999999", "Safe-Stop -Text" = "Black")) +
  ggtitle("'I was able to recognize the message of the autonomous vehicle
optically very well\n(e.g. size/brightness).'") +
  labs(x = "eHMI", y = "Average chosen answer category") +
  theme_classic() +
  theme_minimal() +

  scale_y_continuous(expand = c(0, 0), limits = c(0, 5), breaks = c(0, 1,
2, 3, 4)) +
  theme(plot.title = element_text(hjust = 0.5, color = "black", size = 22)
) +
  theme(text = element_text(
    family = "serif"
  )) +
  theme(text = element_text(size = 22)) +
  theme(legend.position = "none")+
  theme(axis.text.x = element_text(angle = 45, hjust = 1))
```



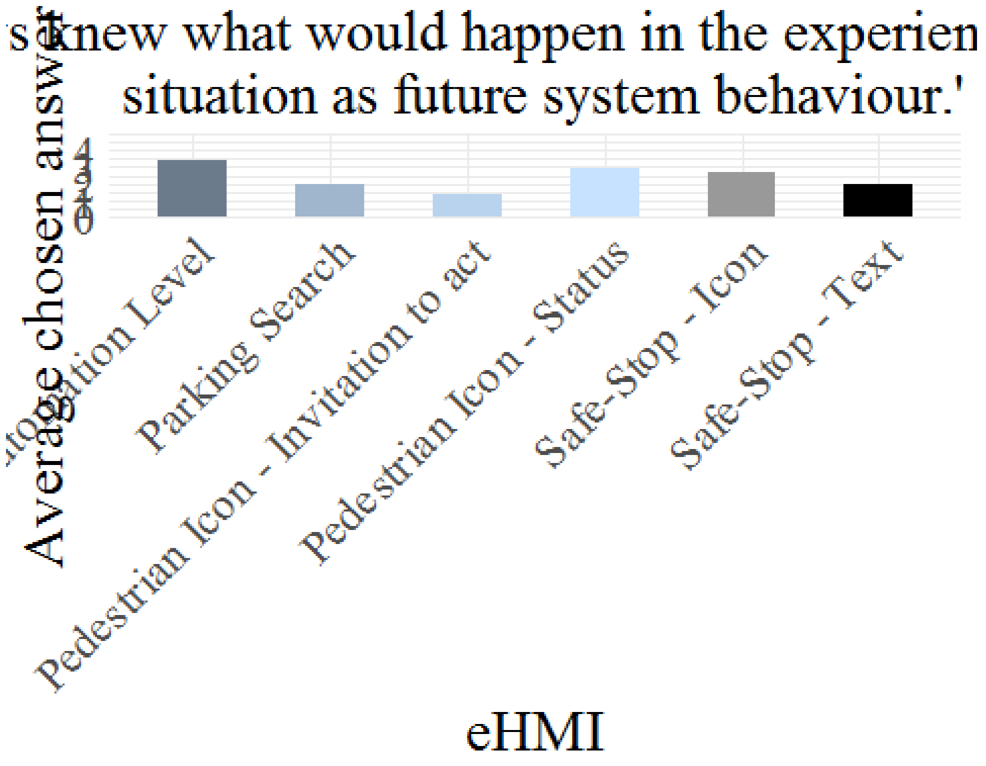

**Analysis Single Item 3**

```
  # Reading Data

Item3_Analysis <-
  Single_Item3 %>%
  stan_glmer(Answers ~ 0 + Scenario_Name + (1 | Part),
```

```
    data = .
  )

     fixef(Item3_Analysis)

     ranef(Item3_Analysis)

     summary(Item3_Analysis)
```

**Single Item 4:**

```
     # Reading Data

Single_Item4 <- read_excel("C:\\Users\\X\\Desktop\\Auswertung_Realfahrt_Lo
ng.xlsx", sheet = "Frage4")

# Explorative Analysis

Single_Item4 %>%
  group_by(Scenario_Name) %>%
  summarize(avg_Answers = mean(Answers)) %>%
  ggplot(aes(x = Scenario_Name, y = avg_Answers, fill = Scenario_Name)) +
  geom_bar(stat = "identity", position = position_dodge(0.6), width = 0.5)
+
  scale_fill_manual("eHMI", values = c("Automation Level" = "slategray4",
"Parking Search" = "slategray3", "Pedestrian Icon - Invitation to act" = "
slategray2", "Pedestrian Icon - Status" = "slategray1", "Safe-Stop - Icon"
= "#999999", "Safe-Stop - Text" = "Black")) +
  ggtitle("'I always knew what would happen in the experienced driving\n s
ituation as future system behaviour.'" ) +
  labs(x = "eHMI", y = "Average chosen answer category") +
  theme_classic() +
  theme_minimal() +

  scale_y_continuous(expand = c(0, 0), limits = c(0, 5), breaks = c(0, 1,
2, 3, 4)) +
  theme(plot.title = element_text(hjust = 0.5, color = "black", size = 22)
) +
  theme(text = element_text(
    family = "serif"
  )) +
  theme(text = element_text(size = 22)) +
  theme(legend.position = "none")+
    theme(axis.text.x = element_text(angle = 45, hjust = 1))
```




#Analysis

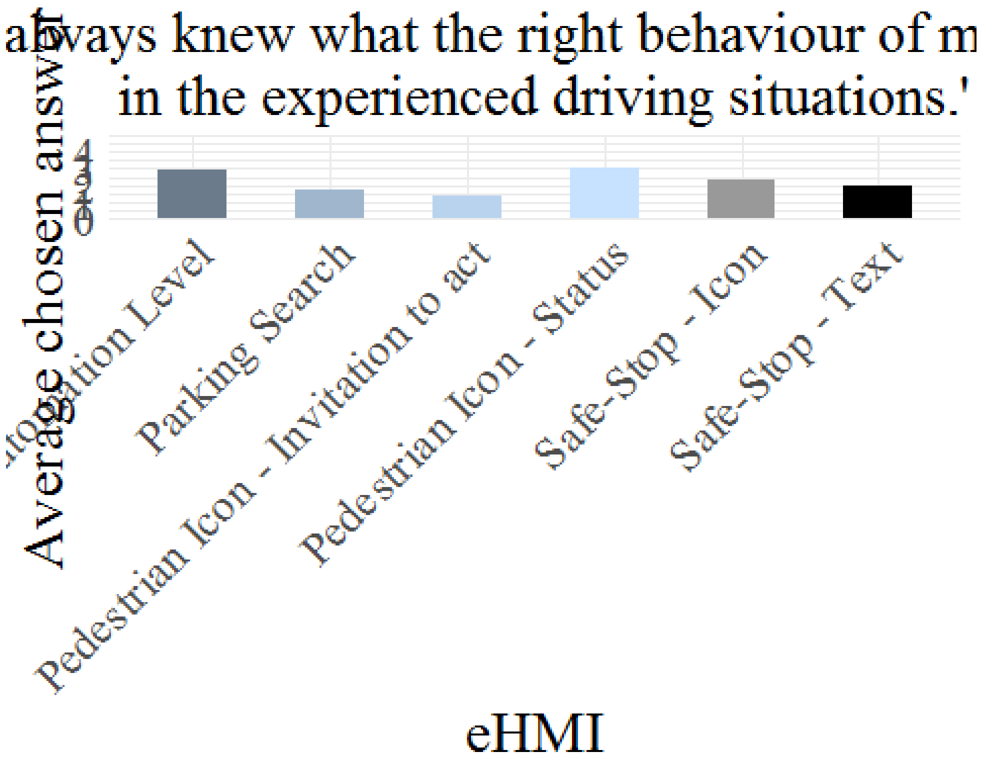
Single Item 4

```
# Reading Data

Item4_Analysis <-
  Single_Item4 %>%
  stan_glmer(Answers ~ 0 + Scenario_Name + (1 | Part),
    data = .
  )

fixef(Item4_Analysis)

ranef(Item4_Analysis)

summary(Item4_Analysis)
```

**Single Item 5**

```
# Reading Data

Single_Item5 <- read_excel("C:\\Users\\X\\Desktop\\Auswertung_Realfahrt_Lo
ng.xlsx", sheet = "Frage5")

# Explorative Analysis

Single_Item5 %>%
  group_by(Scenario_Name) %>%
  summarize(avg_Answers = mean(Answers)) %>%
  ggplot(aes(x = Scenario_Name, y = avg_Answers, fill = Scenario_Name)) +
  geom_bar(stat = "identity", position = position_dodge(0.6), width = 0.5)
+
  scale_fill_manual("eHMI", values = c("Automation Level" = "slategray4",
```

```
"Parking Search" = "slategray3", "Pedestrian Icon - Invitation to act" = "
slategray2", "Pedestrian Icon - Status" = "slategray1", "Safe-Stop - Icon"
= "#999999", "Safe-Stop - Text" = "Black")) +
  ggtitle("'I always knew what the right behaviour of me was\n in the expe
rienced driving situations.'") +
  labs(x = "eHMI", y = "Average chosen answer category") +
  theme_classic() +
  theme_minimal() +
  scale_y_continuous(expand = c(0, 0), limits = c(0, 5), breaks = c(0, 1,
2, 3, 4)) +
  theme(plot.title = element_text(hjust = 0.5, color = "black", size = 22)
) +
  theme(text = element_text(
    family = "serif"
  )) +
  theme(text = element_text(size = 22)) +
  theme(legend.position = "none")+
  theme(axis.text.x = element_text(angle = 45, hjust = 1))
```



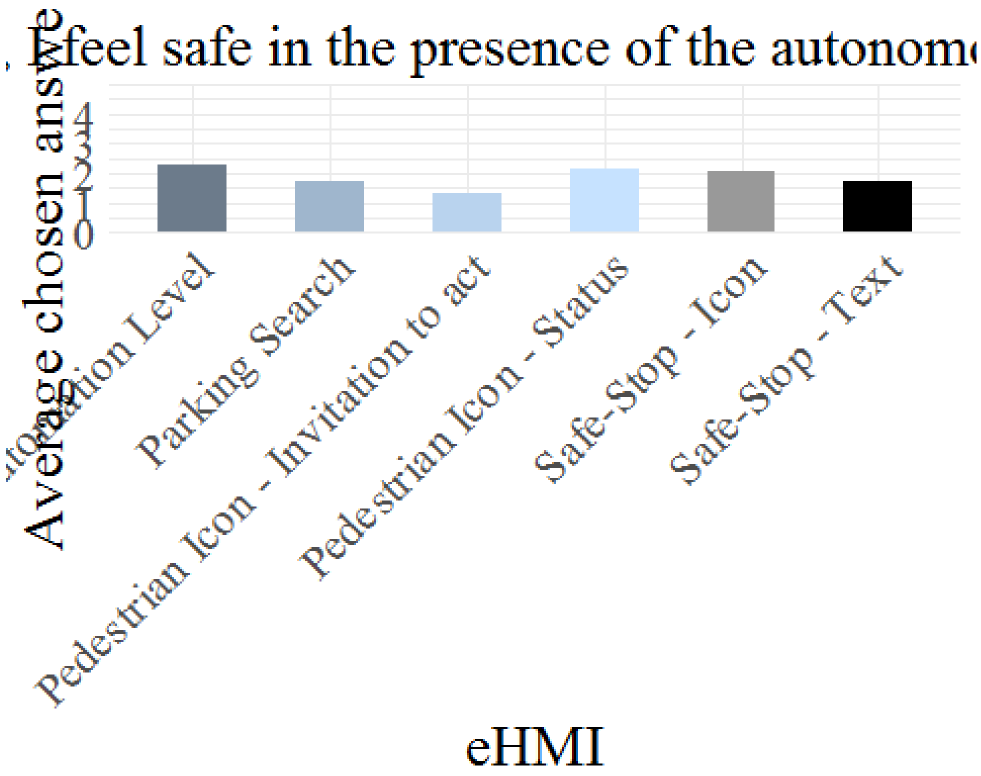

**Analysis Single Item 5**

```
    # Reading Data

Item5_Analysis <-
  Single_Item5 %>%
  stan_glmer(Answers ~ 0 + Scenario_Name + (1 | Part),
    data = .
  )

    fixef(Item5_Analysis)

    ranef(Item5_Analysis)
```

```
summary(Item5_Analysis)
```

**Single Item 6**

```
# Reading Data

Single_Item6 <- read_excel("C:\\Users\\X\\Desktop\\Auswertung_Realfahrt_Lo
ng.xlsx", sheet = "Frage6")

# Explorative Analysis

Single_Item6 %>%
  group_by(Scenario_Name) %>%
  summarize(avg_Answers = mean(Answers)) %>%
  ggplot(aes(x = Scenario_Name, y = avg_Answers, fill = Scenario_Name)) +
  geom_bar(stat = "identity", position = position_dodge(0.6), width = 0.5)
+
  scale_fill_manual("eHMI", values = c("Automation Level" = "slategray4",
"Parking Search" = "slategray3", "Pedestrian Icon - Invitation to act" = "
slategray2", "Pedestrian Icon - Status" = "slategray1", "Safe-Stop - Icon"
= "#999999", "Safe-Stop - Text" = "Black")) +
  ggtitle("'Overall, I feel safe in the presence of the autonomous vehicle
.'") +
  labs(x = "eHMI", y = "Average chosen answer category") +
  theme_classic() +
  theme_minimal() +
  scale_y_continuous(expand = c(0, 0), limits = c(0, 5), breaks = c(0, 1,
2, 3, 4)) +
  theme(plot.title = element_text(hjust = 0.5, color = "black", size = 22)
) +
  theme(text = element_text(
    family = "serif"
  )) +
  theme(text = element_text(size = 22)) +
  theme(legend.position = "none")+
   theme(axis.text.x = element_text(angle = 45, hjust = 1))
```



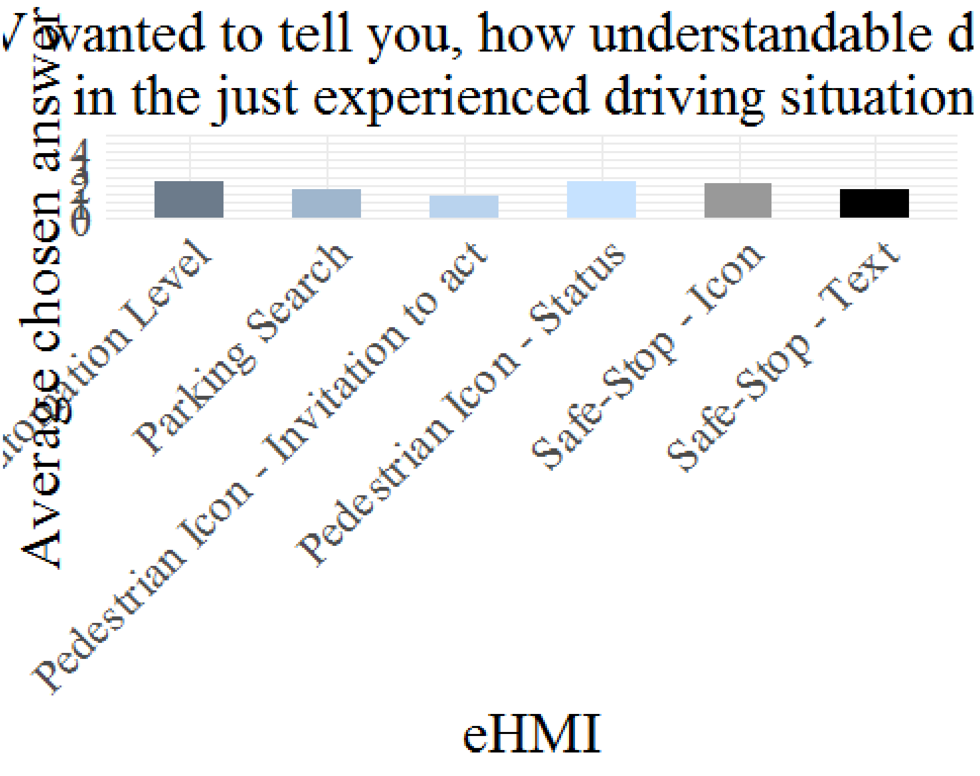

**Analysis Single Item 6**

```
# Reading Data

Item6_Analysis <-
  Single_Item6 %>%
  stan_glmer(Answers ~ 0 + Scenario_Name + (1 | Part),
    data = .
  )

fixef(Item6_Analysis)

ranef(Item6_Analysis)

summary(Item6_Analysis)
```

**Single Item 7**

```
# Reading Data

Single_Item7 <- read_excel("C:\\Users\\X\\Desktop\\Auswertung_Realfahrt_Long.xlsx", sheet = "Frage6")

# Explorative Analysis

Single_Item7 %>%
  group_by(Scenario_Name) %>%
  summarize(avg_Answers = mean(Answers)) %>%
  ggplot(aes(x = Scenario_Name, y = avg_Answers, fill = Scenario_Name)) +
  geom_bar(stat = "identity", position = position_dodge(0.6), width = 0.5)
+
  scale_fill_manual("eHMI", values = c("Automation Level" = "slategray4",
```

```
"Parking Search" = "slategray3", "Pedestrian Icon - Invitation to act" = "
slategray2", "Pedestrian Icon - Status" = "slategray1", "Safe-Stop - Icon"
= "#999999", "Safe-Stop - Text" = "Black")) +
  ggtitle("'After you know, what the AV wanted to tell you, how understand
able do you judge the eHMI of the AV\n in the just experienced driving sit
uation?'" ) +
  labs(x = "eHMI", y = "Average chosen answer category") +
  theme_classic() +
  theme_minimal() +
  scale_y_continuous(expand = c(0, 0), limits = c(0, 5), breaks = c(0, 1,
2, 3, 4)) +
  theme(plot.title = element_text(hjust = 0.5, color = "black", size = 22)
) +
  theme(text = element_text(
    family = "serif"
  )) +
  theme(text = element_text(size = 22)) +
  theme(legend.position = "none")+
  theme(axis.text.x = element_text(angle = 45, hjust = 1))
```



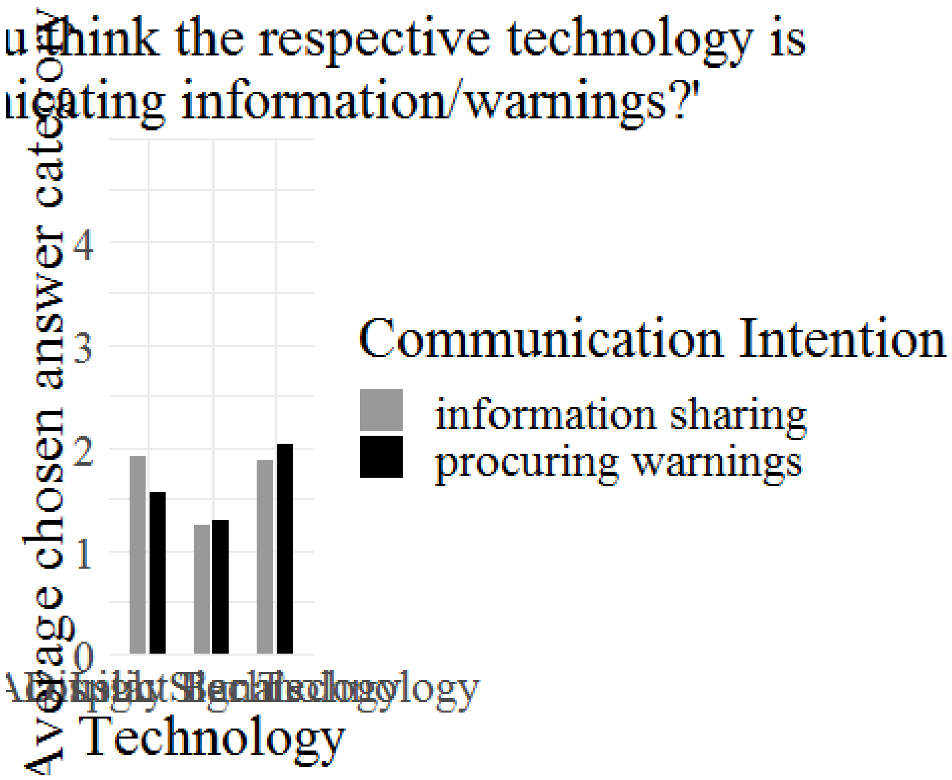

**Analysis Single Item 7**

```
    # Reading Data

Item7_Analysis <-
  Single_Item7 %>%
  stan_glmer(Answers ~ 0 + Scenario_Name + (1 | Part),
    data = .
  )

    fixef(Item7_Analysis)
```

```
ranef(Item7_Analysis)

summary(Item7_Analysis)
```

**Evaluation of the Communication Media**

```
# Reading Data

Gesamt1 <- read_excel("C:\\Users\\X\\Desktop\\Auswertung_Realfahrt_Long.xl
sx", sheet = "Gesamt1")

# Explorative Analysis

Gesamt1 %>%
  group_by(Technology) %>%
  ggplot(aes(x = Technology, y = Answers, fill = Communication)) +
  geom_bar(stat = "identity", position = position_dodge(0.6), width = 0.5)
+
  scale_fill_manual("Communication Intention", values = c("information sha
ring" = "#999999", "procuring warnings" = "Black")) +
  ggtitle("'How good do you think the respective technology is\n for commu
nicating information/warnings?'") +
  labs(x = "Technology", y = "Average chosen answer category") +
  theme_classic() +
  theme_minimal() +
  scale_y_continuous(expand = c(0, 0), limits = c(0, 5), breaks = c(0, 1,
2, 3, 4)) +
  theme(plot.title = element_text(hjust = 0.5, color = "black", size = 22)
) +
  theme(text = element_text(
    family = "serif"
  )) +
  theme(text = element_text(size = 22))
```




**Analysis Communication Media**

```
# Reading Data
Gesamt <- read_excel("C:\\Users\\X\\Desktop\\Auswertung_Realfahrt_Long.xlsx", sheet = "Gesamt")

Communication_Analysis <-
  Gesamt %>%
  stan_glmer(Answers ~ 0 + Technology + (1 | Part),
    data = .
  )

fixef(Communication_Analysis)

ranef(Communication_Analysis)

summary(Communication_Analysis)
```