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# Investigating how different information channels together affect drivers' trust in automated vehicles

Master's thesis in Industrial Design Engineering

JONATHAN FENELIUS  
JONATHAN WAHLUND

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE

DIVISION DESIGN & HUMAN FACTORS

CHALMERS UNIVERSITY OF TECHNOLOGY

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MASTER'S THESIS 2021

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JONATHAN FENELIUS  
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affect drivers' trust in automated vehicles**

Master of Science Thesis

In collaboration with Volvo Car Corporation

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Department of Industrial and Material Science

Chalmers University of Technology

SE-412 96 Göteborg, Sweden

Phone +46(0) 31 - 772 10 00

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## Abstract

The transition towards automated vehicles (AV) is in full motion. When the level of automation increases, cars take over more and more driving tasks. This makes trust a fundamental factor for users to accept and adopt the technology. For users to reap the benefits when using AVs, it is important that users develop an appropriate level of trust (Lee & See, 2004). This project aims to aid users in developing an appropriate level of trust towards AVs by studying how different information channels, such as display, speakers, and driving behaviour, together interact in an information gestalt when forming users' trust. This was studied by identifying the most prominent information channels. The display was shown to be the most prominent information channel when it comes to conveying detailed information and developing an understanding and consequently trust for the AV. Speaker emerged as an information channel that prepared the user, guided the attention to the display and confirmed the information in the display. Driving behaviour was also shown to be important when building trust towards AVs.

To test how the information channels interact when forming trust, three different design concepts, each including a visual interface with matching sounds were designed. Different combinations of the designed display and the speaker information channels were tested in a simulator study (Study 2) and an online study (Study 3). These studies showed that information channels do interact and form an information gestalt and that this can result in increased trust. The results showed that there seems to be an increase in trust towards the AV and an increased sense of safety when users are presented with information from the combination of the display and the speaker information channels compared to being presented with the individual information channels, separately. Different interaction effects between the display and speakers, which could only be seen when the combination of the display and speakers were presented, was also identified. These were:

- Audio information guides the attention to the display.
- Audio information confirms the information in the display.
- The display information channel helps users to understand the audio information.
- Audio information could be played before the car takes action to prepare the user and reduce motion sickness.

Further, 3 design factors that affect users' trust towards AVs have also been identified for the visual and audio information presented through the display and speaker information channels. These are:

- A serious-looking display interface and conventional sounds that the users are familiar with has been shown to increase trust.
- A playful interface will not be taken seriously when it comes to traffic safety.
- Showing a realistic representation of reality in the display will increase the understanding and consequently the trust towards the AV.

These findings, and many more, were summarised in a list of guidelines to aid designers when designing for an appropriate level of trust in AVs.

## Acknowledgements

We want to express our gratitude for those who helped us on this journey, the people we met along the way and the ones who helped us reach our goals.

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## Terminology

IC – Information Channel

AV – Automated Vehicle

DIM – Driver Information Module

The DIM refers to the display that is opposed to the steering wheel from the driver. Where, for manual driving cars, the speedometer, RPM-dial, etc. is shown.

DAW – Digital Audio Workstation

DAW is a computer software that allows the user to record, edit, and mix sounds. DAW software has the option to integrate 3<sup>rd</sup>-party plug-ins that can generate or modify sounds.

VST – Virtual Studio Technologies

A generic term for a plug-in that can be integrated into a DAW software. These can be sound modifiers such as EQ, reverb, or compressors. But also, sound generators such as synthesizers.

VSTi – Virtual Studio Technologies instrument

A more specific term than VST, VSTi refers to only instruments that generate sounds.

EQ – Equalizer

A type of VST plug-in that can be integrated into a DAW. EQ is used to control the volume of individual frequency bands in a sound recording.

WoOz vehicle – Wizard of Oz vehicle


A wizard of oz vehicle is a vehicle used for testing automated driving features with participants. The driver of the vehicle simulates the automated functions while being hidden to the participant, thus creating a realistic experience for the participant (Bengler et al., 2019).

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# 1 Introduction

# 1 Introduction

This chapter gives an introduction to the project by providing a background of the topic, stating the aim and limitations applied. The process used in the project is also explained.

## 1.1 Background

The change towards automated vehicles (AV) within the transportation sector is in full motion. The development of AVs has led to a situation where the driver becomes less involved in the dynamic driving task, handing over more control to the AV, making trust a fundamental factor for the user to accept and adopt the technology. The challenge of transitioning to AV requires that users develop an appropriate level of trust, not having too much or too little trust in the capabilities of the AV as this can lead to misuse or disuse of the system (Lee & See, 2004). The information and feedback presented from the AV to the user about the vehicle processes and performance can help the user form their trust towards the automation (Lee & See, 2004). This type of information can be presented through different information channels. The information channels and their content can be designed to help the user form appropriate trust towards the car and increase the user experience of usage. A study by Fagerlönner et al. (2020), investigated the effect of audio information of the car's perception and intention is being presented through speakers in the car. They found that the audio information could help the user form appropriate levels of trust towards the automation. Ekman et al. (2016) investigated how different levels of transparency of the visual information presented through an in-vehicle display affects user's trust and found that information of what objects the car sees helps users form appropriate trust towards the vehicle. Ekman (2020) has also formulated a model of trust information exchange and gestalt which suggests that all information through different information channels that the user perceives is being interpreted as a whole and the combination of all the information perceived forms an information gestalt. However, studies investigating how users are affected when presented with more than one information channel have (to the authors' knowledge) not been carried out. Therefore, this master thesis project will investigate what are the most prominent information channels are and how their design together affects the user's trust towards the AV.

## 1.2 Aim and Scope

This thesis project aims to help users develop an appropriate level of trust towards AVs. This will be achieved by (i) identifying appropriate and relevant in-vehicle information channels; (ii) investigating how they affect users' trust in the AV; and (iii) evaluating how the different information channels together convey the intended information in a coherent way (i.e., gestalt) and investigating how they affect users' trust. The main focus of the project is the information channels. The role and how the information channels affect users trust will be tested by having the information channels conveying the same information. Guidelines based on the findings will be developed to help the future design of AV information channels.

Research Question (RQ): How does the design of different information channels together affect users' trust towards the AV?

To answer the research questions and fulfil the aim of this thesis, the project has formulated two sub-questions that needs to be answered.

Q1: What are the prominent information channels that affect users' trust?

Q2: How does the integration of multiple information channels affect the users' trust?

### 1.3 Limitations

The project focused on investigating how the design of different information channels together affect users' trust in AVs. To study this, the project developed visual and sound concepts with the sole purpose of being used as a tool in two studies: Study 2 and Study 3. Hence, the project did not try or aim to develop a feasible final design concept that could be used in automated vehicles.

This project was also limited to focus on level 4 automation (LoA4) according to SAE international's classification of automated vehicles (SAE International, 2018). This means that the car is highly automated and handles the driving task itself in most cases. However, there must still be a driver in the car, and he/she could be requested to take over the driving task when the operational conditions for the automated drive are not met. However, the driver could refrain to take over the driving task when being presented with such a request. The automation will then bring the vehicle to a 'minimal risk condition'.

This project has focused only on the driver as a user of the AV. Communication and trust have revolved around the driver and the AV, and not on in-vehicle passengers or pedestrians or drivers of other cars.

Further, the project was limited to look at the in-vehicle display, speakers, and driving behaviour as information channels. For Studies 2 and 3, the project was further limited to look at only in-vehicle display and speakers, due to the restricted use of real cars for testing driving behaviour.

### 1.4 Project Process

The thesis project was divided into three consecutive phases: Prestudy, Study, and Analysis (see figure 1).

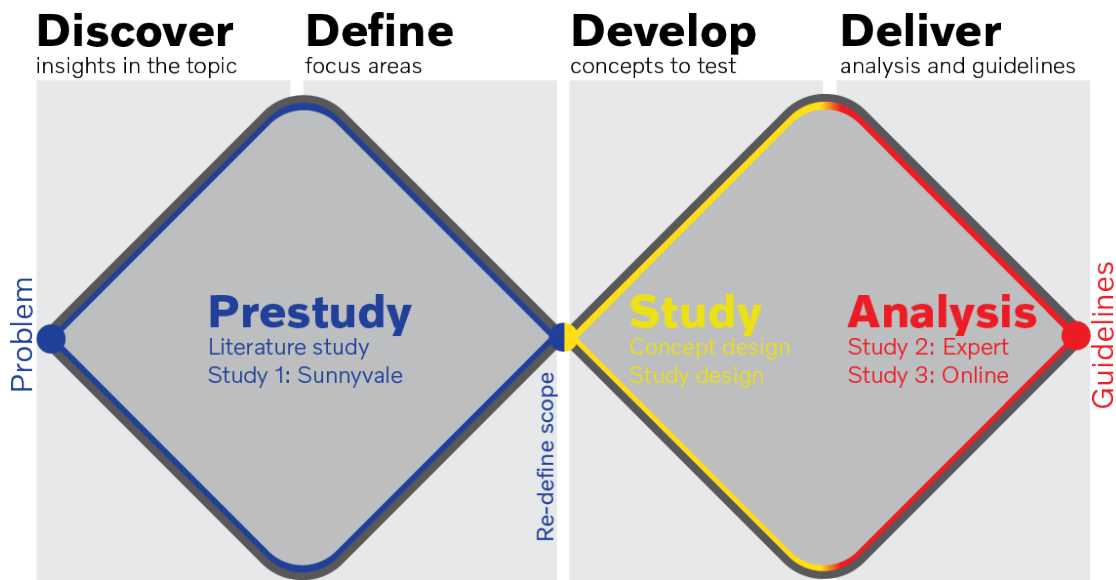


Figure 1. Double Diamond merged with the three phases of the project.

The first phase focused on studying literature within the area of trust, automated vehicles and information channels. An analysis of a previous study by Volvo Cars, Study 1, was also conducted in this phase. The aim for this phase was to create a foundation of

knowledge for the project on topics such as trust, as well as identifying and defining information channels. The second phase, Study, focused on designing and executing two user studies (Study 2 & Study 3) to answer the research question for the project. Before the user studies in this phase, the project also produced visual and sound concepts for Study 2 and Study 3. The last and final phase of the project was Analysis. During this phase the project synthesised the results from the literature study, Study 1, Study 2, and Study 3, to generate guidelines for the design and use of information channels and the information presented through them.

More time was spent in the initial phase than the two later phases. This was due to having access to the previous, so called Sunnyvale study and it was determined that good data could be extracted from the study that would help the thesis project in the later stages as well.

The project structure followed the Double Diamond design model (Design Council, 2015). The main reason this model was chosen was the uncertainty regarding the scope of the project in the early phases. The plan was to, if needed, iterate in the first diamond after analysing Study 2 and performing the literature study. This was not needed when the project reached the middle point of the re-define scope point, resulting in the project having a more linear process. Still, the model enabled the project to explore the areas of interest in the 'discover' phase, narrow down the scope to a concrete research question and plan for the 'develop' and 'deliver' phases in the 'define' phase, developing concepts for Study 2 and Study 3 in the 'develop' phase and synthesizing the findings from the studies in the 'deliver' phase.

The Prestudy phase was laid out to fit in the discover and define stages of the first diamond. The Study phase was the develop stage of the double diamond. The final analysis and guidelines were the last Deliver stage of the double diamond.



# 2 Literature Study

## 2 Literature Study

This chapter describes the aim and method that was used when conducting the literature study as well as the findings that the study resulted in.

### 2.1 Aim

The literature study aimed to deepen the project's knowledge of information channels and how they affect trust.

Some of the specific topics that the project investigated were:

- Trust in automated systems.
- Information channels connected to trust.
- Users' understanding of AVs and its connection to trust.

### 2.2 Method

The literature review was done in several stages to achieve a structured methodology, see figure 2.

1. Search literature: The project gathered and received several articles on the 'trust' theme from researchers in the field. Databases such as Chalmers library and Google scholar were used to find literature using keywords such as 'trust'. Reference lists from already read articles were also used to find relevant literature. The software 'Zotero' was used to manage and organize the literature in the project.

2. Skim Read & Narrow Down: Many articles were scanned by reading the abstract and conclusion. The most interesting articles were picked out for more thorough reading.

3. Read Carefully: The selected articles were read more carefully, and interesting parts were highlighted or commented on. These articles were also grouped in different folders in the software 'Zotero'.

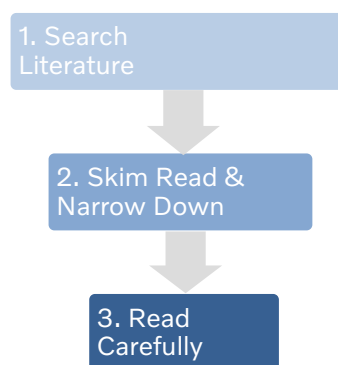


Figure 2. Process of the literature study.

### 2.3 Findings

This chapter presents the findings from the literature study.

#### 2.3.1 Automated Vehicles

The development towards more automated driving functions in the automotive industry is in full motion (*Huawei Wants To Beat Apple In Driverless Car Race*, 2021). Car manufacturers race to provide automated functionality that will increase safety and

comfort for the driver and passengers (*Automated Vehicles for Safety / NHTSA*, n.d.). Currently, though, many automated functionalities are restricted by laws and restrictions in many countries. The automated driving features that exist on the market today are highly conditional, meaning that they can only be used during certain conditions and with the constant supervision of the driver.

To get a structured overview of different driving automation levels and the roles of the driver and driving automation system within each level, the recommended practice J3016 was consulted (SAE International, 2018). SAE International defines six levels of driving automation ranging from 0 - no driving automation to 5 - full driving automation (SAE International, 2018). This thesis project focused on level 4 - high driving automation. Partial driving automation, level 2, is used in new cars today.

#### Level 2 - partial driving automation

Partial driving automation implies that the driving automation system executes some of the driving tasks such as steering the car within a specific lane and keeping a constant speed or distance to the car in front (SAE International, 2018). The driver performs the remaining driving tasks, determines when the system should be turned on/off, supervises the system and is ready to intervene at any time (SAE International, 2018).

#### Level 4 - high driving automation

High driving automation means that the driving automation system manages all driving tasks and monitors that the operational conditions (ODD) for the system are met (SAE International, 2018). The operational design domain (ODD) is defined as the

*“operating conditions under which a given driving automation system or feature thereof is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics” (SAE International, 2018, p. 14).*

If these conditions are not met, if the system fails, if the user requests or if the user fails to respond to an intervention request, the system will bring the vehicle to a minimal risk condition. The system will only disengage when the driver takes over the driving task or when the vehicle reaches a minimal risk condition (SAE International, 2018). The driver determines when the system should be engaged and may be requested by the system to take over the driving task if the system leaves the ODD (SAE International, 2018). The driver may also request a disengagement of the system and become the driver of the vehicle.

Car companies currently offer many different level 2, i.e., partial driving automation, systems that will aid the driver in different traffic situations. Some companies are also developing concept cars that show the possibilities and potential of levels 4 or 5 driving automation systems. One example of this is Volvo Cars' concept 360c which can be seen



Figure 3. Volvo Cars concept 360c.

in figure 3. This is a conceptual automated car that was designed by Volvo Cars to show the benefits and possibilities of automated travel in the future. In contrast to the focus of this thesis, Volvo 360c is a vision of a level 5 automated vehicle that is capable to operate on all roads that could be navigated by a human driver (SAE International, 2018). Level 5 automated cars also create new possibilities when it comes to safety. The technology could be used to communicate and coordinate actions between different automated vehicles (*Koncept 360c | Volvo Car Sverige*, n.d.). This would allow automated vehicles to talk with each other and hereby prevent accidents.

Tesla is another car company that has come relatively far in terms of automated technology. With the technology 'Autopilot', Tesla cars can accelerate, brake and steer automatically to keep the car within the lane and keep the distance to cars in front (*Autopilot*, n.d.). 'Autopilot' can also change lane automatically by engaging the indicator in the desired direction.

According to Tesla, all of their new cars are delivered with the hardware that is required for fully automated driving. In the future, when rules and regulations allow, Tesla aims to upgrade the software in their cars to support fully automated driving and navigation from start to destination (*Autopilot*, n.d.).

### 2.3.2 Trust

To develop user acceptance for AVs, trust is a key issue. Lee and See (2004) define trust as "the attitude that an agent will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability" (p. 54). The agent here could either be automation or another human. There are risks of users misusing or disusing an automated system without an appropriate level of trust towards it. A misuse of an automated system is defined as the user's inappropriate reliance on the automation, an over-trust in the capabilities of the system. Disuse is defined as a user's rejection to utilize

the capabilities of an automated system, a distrust that falls short of the true capabilities of the system.

Lee and See (2004) describe three factors that influence the users' trust in automation: *Performance*, *process*, and *purpose*. *Performance* describes what capabilities the automation has in terms of reliability, predictability, and ability. The performance information is tied to the user's goals for the automation. *Process* information describes how the automation should act, through algorithms and operations specified by the designer. Process-based trust varies depending on the users' understanding of the automated systems' actions and methods used (Hoff & Bashir, 2015). Lastly, *purpose* describes the intended use by the designer and why the automated system was created. So, based on these three factors, a user will tend to trust an automation if:

- the automation can achieve the user's goal reliably,
- the automation's algorithms can be understood by the user and perceived as capable of achieving the user's goal,
- the designer's goals for the automation have clearly been conveyed to the user.

Hoff and Bashir (2015) constructed a trust model based on three layers of trust: *dispositional trust*, *situational trust*, and *learned trust*.

*Dispositional* trust refers to personal attributes the user has, such as culture, age, gender, or personality. An individual's trust may therefore vary depending on these factors.

*Situational* trust consists of two variable dimensions: external and internal. The external dimension involves aspects such as type of system, system complexity, and task difficulty. The internal dimension refers to the user's internal feelings of self-confidence, mood, and attentional capacity.

Lastly, *learned* trust refers to the trust developed based on current or past interactions with the system. Hoff and Bashir (2015) divide learned trust into initial learned trust and dynamic trust. The initially learned trust is affected by the user's attitude, expectation, understanding, and past experience with similar systems. The dynamically learned trust is the trust that is being developed during the interaction and is determined by the system's performance.

Lee and See (2004) provide a list of points to take into consideration when designing for trustable automation. These are the points most relevant for this project:

- Design for appropriate trust, not greater trust than the true capabilities of the automation.
- Show the process and algorithms of the automation by revealing intermediate results in a way that is comprehensible to the operator i.e., the driver of the AV.
- Simplify the algorithms and operation of the automation to make it more understandable.
- Show the purpose of the automation, design basis, and range of applications in a way that relates to the users' goals.

Hoff and Bashir (2015) have developed design recommendations for trustworthy automation. Interesting recommendations are:

- Simplify interfaces to increase ease of use in order to achieve greater trust.
- Consider increased saliency of automation feedback to achieve greater trust.

- Give users accurate feedback on reliability and situational factors that can affect the automation's reliability.
- Evaluate how users interpret system reliability information from different displayed formats.
- Consider increasing the transparency of high-level automation to promote greater trust.

An understandable and easy-to-use interface that can deliver feedback on system reliability, as well as situational factors affecting the automation, seems to be key to help the user trust the automation (Hoff & Bashir, 2015; Lee & See, 2004).

Another factor to consider is transparency. Transparency is defined as the degree to which that the trustor (the user) can interpret and understand the trustee's (the AV's) capabilities and the trustee's processes to achieve the goal of the trustor. This definition of transparency acts as a foundation for trust to be built upon. It involves thus *performance* and *process* as described by Lee and See (2004). Seong and Bisantz (2008) define transparency as "the degree to the extent which the inner workings or logic of the automated systems are known to human operators to assist their understanding about the system" (p. 611). Based on studies highlighted by Hoff and Bashir (2015) a design that provides the user with accurate feedback about the inner workings and reliability of the AV can help the user develop appropriate trust.

Human features of the system, i.e. anthropomorphism, is also something to consider when designing for trust in automation. Different characteristics of the user should be considered when designing anthropomorphic automated systems, such as gender, culture and personality (Hoff & Bashir, 2015). A problem with anthropomorphism that needs to be taken into consideration is the calibration of speech, as small changes to how the systems talks to the user could affect the trust in negative ways (Lee & See, 2004).

### 2.3.3 Information channels

#### Definition

The project decided to define information channels as devices or artefacts inside the AV that can communicate information about the AV to the 'driver'. Examples of such information channels are displays, lights, speakers, driving behaviour, or steering wheel. Information can be communicated by stimuli in one or several modalities for each information channel, see figure 4. The modalities mentioned in this report refers to the five human senses: vision, audition, taction, olfaction and gustation.

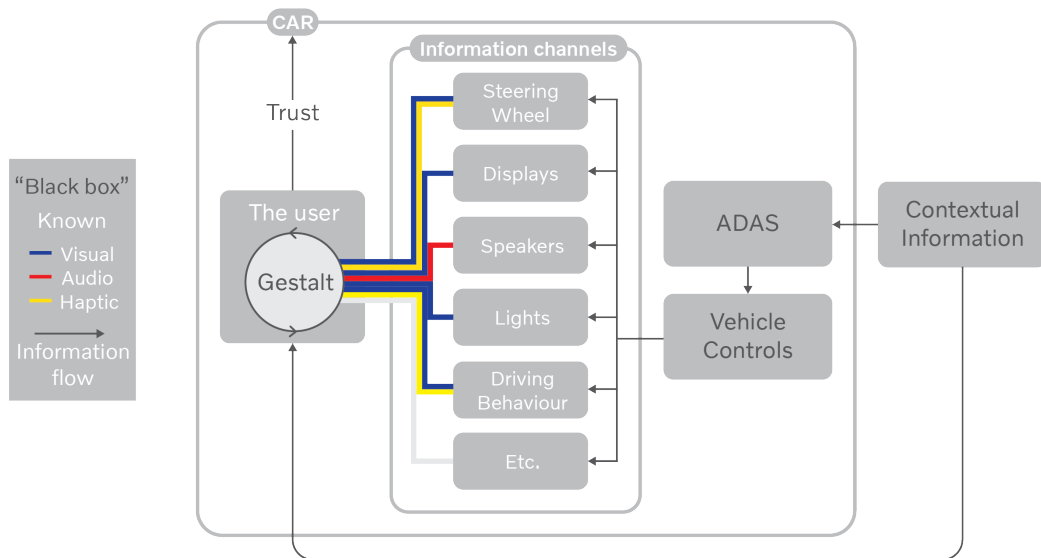


Figure 4. System map over the information channels, modalities and gestalt.

In other words, the information channel 'display' could communicate information (e.g., about the car's intention and perception) through visual stimuli. Another example is the information channel 'steering wheel' that could communicate information (e.g., about different levels of driving automation) through visual and haptic stimuli.

## Displays

According to Hoff and Bashir (2015), research has shown that the design of automated systems can affect the users' trust. Since "interfaces are often the primary visual component of systems", it is important to design them thoughtfully to build trust towards the system (Hoff & Bashir, 2015, p. 422). An article written by Ekman et al. (2016) describes how the presentation of object recognition feedback of other vehicles around the AV, presented through an in-vehicle display, can increase trust in level 3 automated cars. The study designed three object recognition concepts with different levels of system transparency, namely: the sensor indicator concept (low transparency), the ring concept (medium transparency) and the God view concept (high transparency), see figure 5. These concepts were tested by 8 participants in a WoOz vehicle setup. The results showed that the participants had more trust in the ring and God view concepts. Some participants in the study stated that they did not need to see what kind of object was close to the car, only that it was there. When it comes to orientation, however, the God view concept was considered more suitable since it was easier to compare objects in the environment with the interface. Participants in the study also stated that they would be less forgiving to the God view concept than to the ring concept since errors would be more apparent in the God view concept that provided more detailed object recognition feedback. The study concluded that presenting object recognition feedback increased trust and that users preferred a level of feedback that was not too much or too little. However, the preferred level of feedback could change over time, depending on individual user needs and different situations. Thus, the study recommends having a flexible approach when it comes to the level of feedback, letting the user decide based on his/her preferences.

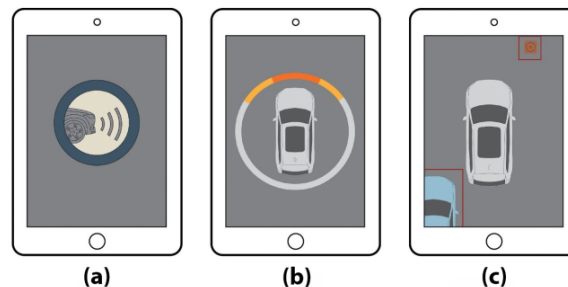


Figure 5. a - sensor indicator concept, b - ring concept and c - God view concept (Ekman et al., 2016).

## Speakers

The relation between sound and trust in automated cars was studied in the research project 'Sonic Interaction in Intelligent Cars' (SIIC) (SIIC, n.d.). As part of that study, Fagerlönn et al. (2020) studied if auditory displays (speakers) could increase users' trust and if such a speaker would be accepted by users of automated cars. The study focused on designing audio information that conveyed "the Intention and Perception layers since [...] these are the most crucial ones when it comes to increasing trust" (Fagerlönn et al., 2020, p.6). The perception layer conveys what the car sees in the surrounding environment and the intention layer presents what the car is going to do, its intended behaviour.

The design approach that was used in the study tried to develop intention sounds that were supposed to be played a couple of seconds before the actual event took place to prepare the driver. The perception sounds were designed to sound like the objects that

were perceived, e.g., a pedestrian was represented by a footstep sound. The study also tried to move away from traditional salient sounds that are used in cars today and “investigate[d] if it is possible to design a very subtle and pleasant but still efficient, useful and intuitive display” (Fagerlönn et al., 2020). The sounds that were designed were tested in a virtual environment where the participants experienced a driving scenario containing different events.

The results from the study showed that the audio information was considered useful and pleasant. The trust ratings also increased when playing the car’s intention and perception as sounds compared to a scenario without audio information. Specifically, the results showed that the intention sounds were easier to understand. The intention sounds were also the most effective when it comes to trust-building. Another finding from the study was that the audio information helped the drivers to anticipate the car’s behaviour (Fagerlönn et al., 2020).

### Driving Behaviour

Driving behaviour is another information channel that is interesting to look at when it comes to trust in automated vehicles. A study by Ekman et al. (2021) aimed to see if the car’s driving behaviour in different everyday traffic situations had an effect on the trust towards the car. The study tested this by letting 18 participants experience two different driving behaviours, a defensive and an aggressive, in a WoOz car encountering different driving situations. The trust ratings and interviews showed that the participants trusted the defensive driving behaviour more than the aggressive one (Ekman et al., 2021). The reason for this was that the calmer movements of the defensive driving behaviour were appreciated, but it was also easier to discern the car’s intention i.e., what the car was going to do next. The aggressive driving behaviour was considered more unpredictable. Presenting the intention of the car makes it more predictable, which relates to the trust affecting factors of *performance* and *process* stated by Lee and See (2004).

Further, it can be seen that the driving behaviour was more critical with regards to creating trust in some situations than in others. In driving situations where the difficulty was perceived to be low, the driving behaviour did not matter as much, in regards to trust, as in driving situations that were perceived to be difficult to handle (Ekman et al., 2021). In situations with a high perceived risk, the respective driving behaviours (defensive and aggressive) amplified the perceived risk. In those situations, the participants perceived the defensive driving behaviour as being too sluggish or slow and the aggressive having too aggressive or sudden movements (Ekman et al., 2021). In those situations, both driving behaviours got a low trust score. Thus, it can be seen that introducing a moderate amount of risk is important to generate realistic trust ratings.

Thus, it can be concluded that introducing a moderate amount of risk will help participants to take a stand and say what they really think about the driving behaviour in relation to trust.

### 2.3.4 Gestalt

In order to develop an appropriate level of trust, it is believed that each information channel needs to be designed with the other information channels in mind so that a good interplay or ‘Gestalt’ can be achieved. Gestalt is defined as “an arrangement of parts which appears and functions as a whole that is more than the sum of its parts” (Monö, 1997). According to Monö (1997), the term ‘Gestalt’ can be applied to more than forms or physical products. Thus, this concept could also be applied to information channels. Monö

writes that every system that means something more than only the sum of the components constitutes a gestalt, a meaningful whole. To aid designers in creating a clear gestalt, Monö presents eight factors to take into consideration (1997). The factors that were considered most relevant for this project were:

- Similarity: If objects have a similar appearance, it makes it easier to see that they have similar properties or functions.
- Experience: This factor requires us to have experience within a specific domain in order to recognise the gestalt. An example of this is the gestalt ‘technical drawing’ that requires experience within the technical domain in order to be understood correctly.

This thesis will focus on the interplay between different information channels to create an information gestalt that is experienced as a whole, rather than separate information channels (cf. Ekman, 2020). The information gestalt should be designed to help the driver to develop an appropriate level of trust towards the AV.

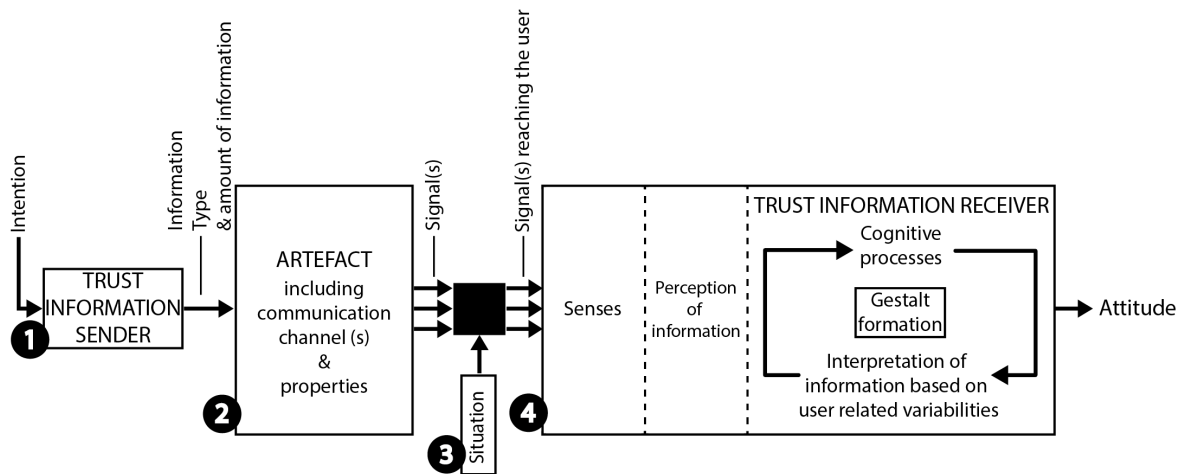


Figure 6. Model of trust information exchange and gestalt by Ekman (2020).

The model of trust information exchange and gestalt created by Ekman (2020) is used to explain how trust towards an AV is formed, see figure 6. The information generating an appropriate level of trust starts as an intended message in the mind of the developers (Ekman, 2020), in this case, the authors of this report. This intention is then transferred to the user via different communication channels, in this report referred to as information channels. The information channels send out signals that according to Monö (1997) can be defined as an action that gives directive in a specific situation. These signals are sent out in the context where the automated vehicles operate. That context may contain disturbances such as traffic noise (external) or tiredness (internal), resulting in the intended message not being interpreted or perceived correctly by the driver (the information receiver) (Ekman, 2020). The signals that reach the user, together with the disturbances, are perceived and interpreted by the driver’s sensory organs, i.e., vision, audition, olfaction, gustation, and taction (Ekman, 2020). This interpretation forms the information gestalt of the AV that the driver will base his/her attitude and trust on (Ekman, 2020). This model will be used to understand how users build an appropriate level of trust based on the intended message that is communicated through the information channels.

## 2.4 Conclusions and Implications

From the literature study, it can be concluded that it is important to design for an appropriate level of trust as too much or too little trust will lead to *misuse* or *disuse* (Lee & See, 2004). Three aspects are important for users to trust automated systems; namely *performance*, *process* and *purpose*. Trust is also affected by personal attributes, the system and tasks that should be carried out with the system, feelings of self-confidence, earlier experience and learning (Hoff & Bashir, 2015).


When designing trustworthy automation, it is important to consider the users' understanding of the system's reliability as well methods and algorithms for how the system acts. The algorithms need to be designed so that users can understand them, and how they help the user achieve their goals for using the automation (Hoff & Bashir, 2015; Lee & See, 2004). As a level 4 AV is considered high automation, the suggestion from Hoff and Bashir (2015), that an increased degree of transparency should be considered when designing a higher automated system should be taken into account for this project.

In this project, information channels were defined as devices or artefacts inside the AV that can communicate information about the AV to the 'driver'. Each information channel can communicate information through one or several modalities. The concept of information that is communicated through information channels (such as displays and speakers) was believed to be easier to understand and talk about for the users than the concept of information communicated through different modalities (such as vision). Therefore, the project chose to work mainly with information channels. The project believes that an information gestalt, that conveys something more than the isolated information channels, is formed when several information channels are communicating information at the same time. The gestalt creating factors of *similarity* and *experience* (Monö, 1997) were considered important to create a gestalt when working with information channels.

When it comes to specific information channels, it can be concluded that showing a moderate amount of information about object recognition (the car's perception of other cars and objects around it) in the display channel will increase trust in automated vehicles (Ekman et al., 2016). Further, this information should be adapted depending on the situation and individual user needs. Intention and perception sounds presented to the user have also been shown to increase trust (Fagerlönn et al., 2020). When it comes to driving behaviour, it can be concluded that a calm and defensive driving behaviour can convey the intentions of, and develop trust towards, automated cars (Ekman et al., 2021).

However, it has also been seen that the perceived risk and difficulty in different traffic situations will affect the trust ratings. Participants will generally demand more of the driving behaviour in order to trust it in situations with high difficulty and risk. It can therefore be concluded that it is important to introduce a moderate amount of risk to help users take a stand and say what they think of the information channels with regards to trust.





# 3 Study 1: The Sunnyvale study

### 3 Study 1: The Sunnyvale Study

This chapter is based on an analysis of a study previously conducted by Volvo Cars.

#### 3.1 Introduction

The Sunnyvale study was conducted in 2019 by Volvo Cars in California, USA. The study tested the human-machine interaction between the car and the user during automated driving. The study used a WoOz vehicle with features from a Level 2 partial automated vehicle and a Level 4 highly automated vehicle respectively.

The thesis project had access to video recordings and transcripts from the study and carried out an analysis of the data collected, more specifically the video files and transcripts connected to them.

#### 3.2 Aim

The goal for the analysis of Study 1 was to answer the first sub-question (Q1) as well as two additional questions formulated for this study:

Q1: What are the prominent information channels that affect users' trust?

- How do users interact with the respective information channels?
- Do the users understand the information presented through the channels?

#### 3.3 Method

The first part of this chapter, 3.2.1, summarises the method that was used by Volvo Cars when conducting the Sunnyvale study in 2019. The second part of the chapter, 3.2.2, explains the method that was used by this thesis project when analysing the results from Study 1.

##### 3.3.1 Materials

This section describes the study setup designed by Volvo Cars, the equipment that was used and the participants who participated in the study.

The car

This test was conducted in real traffic conditions with a modified version of the Volvo XC90 car. The car was equipped with level 2 partial automated features (pilot assist), lane assist and adaptive cruise control as well as a simulated level 4 high automation system (autopilot) (SAE International, 2018). The autopilot functions were simulated using a test driver in the back seat who could take over control of the car during the test. The autopilot function was offered to the participants in traffic jam situations with slow-moving traffic. When these conditions were no longer met, the participants were requested to take back control.

The level 2 pilot assist (PA) function was always accessible to the participants, but they were not encouraged to use it when driving in populated areas. The level 2 PA function helps the user maintain a constant distance to the car ahead as well as assists the user to stay inside the lane. For the car to allow the user to access the level 4 autopilot function, certain criteria had to be met, such as the car had to be on the freeway and below a certain speed. The participants were free to accept or decline the car's suggestion of activating autopilot. When the operational conditions for the level 4 autopilot functions were no longer met, the car asked the participant to resume the control of the car.

## The Information Channels

The car had two main display information channels, the driver information module (DIM) display showing speed, fuel, and automation system information, and a large tablet in the centre console that was used for GPS and entertainment control. The displays were used to deliver information about the PA and AP systems. The car was also equipped with a speaker information channel that notified and alerted the participants with different kinds of beeping sounds and human voice sounds. Lastly, the car also alerted the participants through the seatbelt, through a pulling motion. Some of the events that triggered messages through the different information channels were:

### PA

- PA activated
- PA deactivated
- Keep hands on the steering wheel

### AP

- AP available
- AP activated
- Failure of activation
- Take over (from AP to manual drive)
- Failure of deactivation (take over)

## The task

Each participant was tasked to drive around a predetermined stretch that was pre-programmed in the built-in GPS, see figure 7. Each test drive took approximately 90 minutes to complete and was conducted during rush hour. During the drive, the participants were free to use the level 2 automation system (PA) whenever they wanted but were only allowed to use the level 4 automation system (autopilot) when the car presented that the feature was available.

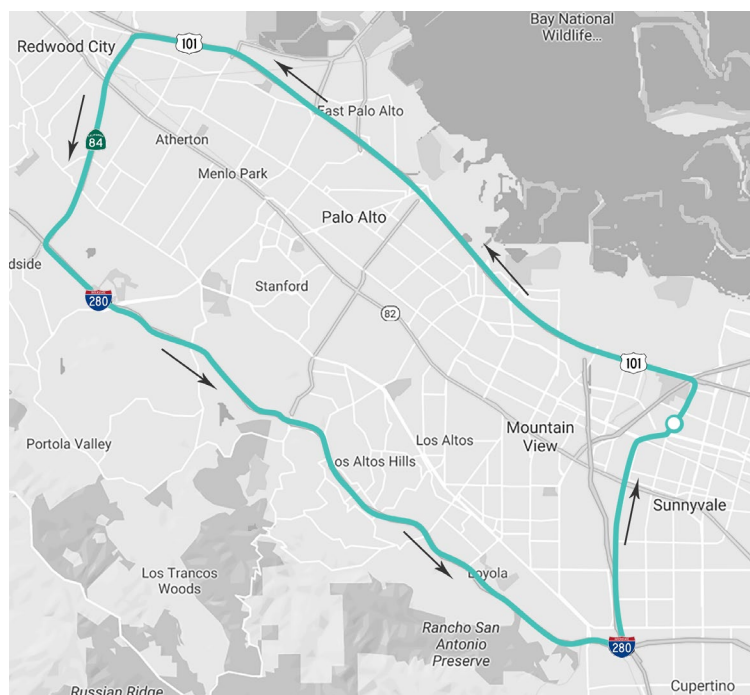


Figure 7. The route the participants were driving during the study (Novakazi, 2020).

## Participants

The total number of participants in the test was 20, of which 11 females and 9 males. Their age ranged between 22 and 62 years. All participants of the test held valid driving licenses and experience of using cars with common cruise control and automatic gearbox. For this thesis project, 16 (7 female and 9 male) of the video recordings with corresponding transcripts were analysed.

### 3.3.2 Study Design

The analysis method was a predominantly an inductive approach to thematic analysis (cf. Braun & Clarke, 2012). The videos and the transcripts from the test were coded in the coding software NVivo. The first round of coding started with a pre-defined codebook and four coders from two different master's thesis projects. The codes were reviewed and modified whilst the coders collectively coded two videos. This was done so that the codes would fit both project groups. The codes of the first round of coding can be found in **Appendix A**. Whilst the coders coded the two first videos together, they were supported by two supervisors, these did not participate in the remaining coding. Near the end of the first round of coding the inter-rated reliability between the coders was tested to ensure the reliability of codes (cf. Lombard et al., 2010). NVivo's built-in calculation for determining the kappa coefficient between two testers was used. The mean value for the kappa coefficient between all coders was 0.62. According to McHugh (2012), a kappa coefficient between 0.61-0.80 can be interpreted as a substantial agreement that the project deemed good.

The second round of coding also used a predominantly inductive approach to the codebook. The project generated a new codebook that focused on identifying if the users understood the information provided in the information channels and their emotional reaction to its content, as well as their general trust towards the car. These codes can be found in **Appendix B**. The codes were applied to situations where the participants explicitly expressed emotions, understanding, or confusion towards an information channel.

Apart from trust, the project also chose to focus on user's understanding of the AV's *process* and *performance* information since this has been identified as one important factor to build trust in automation (Lee & See, 2004). The 'Understood' and 'Not Understood' codes were applied where the participants' actions could be considered a direct and immediate consequence of the information presented to them through the information channels. The 'Understood' code was applied when the participants took the right action and the 'Not Understood' code was applied when the participants took the wrong action. In other words, the participants were considered to understand the information if they took the correct action based on the presented information.

The codes used in the second round of coding were based on interesting trends that emerged during the first round of coding. Only the two persons who participated in this thesis project took part in the second round of coding. Based on the positive results from the previous inter-rated reliability test where the two coders in this thesis project had a kappa coefficient of 0.67, the project decided that the previous test was enough to safely determine good reliability of coding.

After the two rounds of coding, both post-it notes with direct quotations and descriptions of how participants acted were added to the web-based whiteboard software Mural. The

post-its were put in clusters based on the underlying theme, problem, or probable cause of the participants' reactions.

### 3.4 Findings

The findings of this analysis focus on the users' understanding of information presented and interaction with the information channels and how these were judged to affect the users' trust in the car. The analysis mainly focuses on the level 4 automation aspects of the test.

The participants in the Sunnyvale study were seldom affected by information in a single information channel. Throughout the test, the participants were presented and notified by information through multiple information channels when, for instance, an action was required. The user was constantly affected by the car's driving behaviour and the display. However, this analysis has tried to separate the individual information channels to figure out how participants are affected by a single information channel.

#### 3.4.1 Information channels

How relevant or prominent the different information channels can be seen from many different perspectives. The information channels that the participants received the most concrete information from, and mentioned most times, were the display and the speaker information channels. The reason why these channels were mentioned so often was probably that they were the primary information channels that were used to deliver information in the test that was analysed. Information shown in displays also has the inherent property of being able to deliver more detailed information than other information channels such as seatbelt or steering wheel. The display information channel is often chosen to deliver more information, both when it comes to quantity and level of detail, making it one of the most relevant information channels for this project.

The information that was presented through the display and the speaker information channels were the least understood based on the analysis, compared to the other information channels in the AV.

- 66% expressed an understanding of the beeping sounds.
- 89% expressed an understanding of the human voice sounds.
- 69% expressed an understanding of the visual information presented (text, icons and graphical elements) in the display.

The expressed understanding of the messages presented through the display or speakers was determined based on if the participant took the correct action or not. It can be questioned though if this measure of understanding gave a realistic picture of the participants' understanding of the information channels. Further, the speaker and display information channels often worked together when presenting information in the test and it is therefore hard to determine exactly which information channel lacked.

What can be seen, though, is that the participants tended to show more understanding of the human voice than the beeping sounds. A human voice can convey and carry more information than a beeping sound. Connected to this, Hoff and Bashir (2015) state that increased anthropomorphism of automation will promote trust.

Participants also tended to express a lack of understanding when talking about the display. Generally, the participants understood the written information presented in the display, although they had greater problems understanding the information presented through the display in both the level 2 and 4 systems. This might be the lead cause to why

they more often expressed a lack of understanding for the information from the display rather than for the speakers (specifically the audio information presented as a human voice), driving behaviour, seatbelt, and steering wheel. One participant talked about the 'autopilot available' message and stated that:

*"It said on the screen, it said "auto pilot available" or "AP available"."*  
(TP 10, Study 1)

However, it can still be argued that participants based most of their understanding on the information presented in the display and the speaker information. The claim is based on the large quantity of information that was presented through the display and the speaker information channels in the test. There is also evidence in the literature that the display and the speaker information channels support the building of understanding and consequently trust. Lee and See (2004) state that "the content and format of the [display] interface have a powerful effect on trust" (p. 73). The study by Fagerlönner et al. (2020) has shown that sounds conveying the car's intention have a positive effect on trust.

### Driving Behaviour

Another theme that emerged during the analysis was that users develop their trust based on how they experience the driving behaviour of the automated car. The analysis showed that users' trust is built when participants experience that the car behaves in a safe manner according to the users' preferences. The idea that driving behaviour can affect the user's trust towards AVs is also stated in the literature. In the study done by Ekman et al. (2021), it was concluded that a defensive driving behaviour increased the trust towards the car.

Therefore, driving behaviour was also identified as a prominent information channel that can support the building of trust in this study. It can be argued that understanding the car's driving behaviour through the capabilities and limitations in different traffic situations can result in participants generating an appropriate level of trust towards the car. One participant mentioned that:

*"I can feel it braking, I can see that it is going faster and slowing down when it needs to".* (TP 2, Study 1)

Another participant stated that:

*"I trust it here [points at the traffic]. You know, when I've experienced that it can speed up and slow down and whatever".* (TP 18, Study 1)

These statements help shape the picture of how the participants understanding of driving behaviour, and consequently trust towards the car, is being shaped in the test. The participants felt that they had to experience critical situations and through those situations form an understanding which they use to generate an appropriate level of trust towards the car.

### 3.4.2 Learning

Understanding of the information presented through the information channels is not only based on the current information presented to the participant, but also on the instruction, training, mental model, and preconceptions the participants had before the test. Some participants in the study knew from the first interaction which action was required by them, others did not understand it at all. It is important to understand that the

participants' understanding, and consequently their trust towards the car, is affected by the information flow from the first touchpoint with the (idea of the) car, all the way through the use.

### 3.4.3 Saliency

The user interacts and receives information differently from different information channels. The analysis showed that salient notifications such as alarming sounds and seatbelt tensioning directed the user's attention to the DIM display which can present more detailed information. The analysis also showed that these audio notifications often resulted in participants expressing stress and feelings of unease. One participant expressed this experience as follows:

*"Um... It [seatbelt] choked me a little bit [Laughter] Um... Yeah, that kind of really startled me, to be honest [Laughter] But like, yeah so, I'm not sure. That was kind of scary [Laughter] That part! Um... And then I guess that beeping and that I had to like read it [on the display]. So, um, I wasn't really sure what happened there. (TP 19, Study 1)*

Usually, the purpose of information transmitted through the speakers is to primarily alert and notify the user. What has been identified, though, is that the participants do not understand what is required from them when hearing these notifications. Since the speaker information channel works in tandem with the display in most cases, it can be concluded that it is the display and not the speakers that fail to convey its intended message, so that the participant understands it. This is supported by the fact that many participants failed to understand that they needed to hold the steering wheel whilst using the pilot assist function. The participants often understood that their attention was needed when they were alerted through the speakers but failed to understand what action was required of them. This situation can be illustrated by the following quote:

*"[Pling!] What does it [message hold hands on wheel] tell me to do? To hold on? [Pling!] Does it tell me to hold on?". (TP 13, Study 1)*

Similar to the situation described above, the salient and notifying information that is carried by the seatbelt, in combination with the display and speakers, often led to the right intent but wrong action by the participant. Although some participants did not know how to deactivate the autopilot, they at least prepared themselves to take over by grabbing the wheel, signalling that they had understood that they needed to take over. The speakers were either used to notify the user that the autopilot function was available, or to warn the participant that they should take certain actions, such as taking back control over the car when the autopilot was disengaged.

### 3.4.4 Control

The analysis also showed that some participants were unsure of the limits and capabilities in the operational design domain (ODD) of the PA and AP systems in the automated vehicle. These participants expressed confusion about when the different systems were available and when the take over-message was shown, they were surprised that they needed to take over. One way to solve this problem would be to design for more predictable decisions by the AP and clearer instructions on different actions, such as activation/deactivation, that users are required to take. One participant stated:

*"Why is it telling me to take over, is it because it's a lot of traffic everywhere?" (TP 8, Study 1)*

Connected to this, many participants also mentioned that it was hard to know the difference between the two systems, PA and AP, and who is in control over different functions, such as steering and braking, in the respective systems. One participant stated:

*"Um... I don't know. I didn't think it [PA] was this good! Um... [...] I guess... [sigh] Maybe AP does do more!". (TP 16, Study 1)*

Generally, the control distribution between driver and car was more unclear in the PA system than in the AP system. This could be explained by the distribution of control in the respective systems. The PA system is a level 2 automated system and has a more equal control distribution between the driver and the car compared to the level 4 system (AP) that gives almost 100% control to the car within its ODD. Since PA has a shared control distribution, it could be easier to misunderstand who has control in the PA system compared to the AP system.

To give more attention to other topics that were identified in the analysis, the project chose to exclude the control scope from the following phases of the project. In addition, earlier studies, such as Erhardsson and Lidander (2020), have already been conducted within the area of control. This decreased the need to dive deeper within the area in this project.

### 3.4.5 Vigilance

Connected to what has been said earlier, it has become evident that the participants who experienced the level 4 automated driving systems felt that they had to remain vigilant of the traffic and how the car behaves in different critical situations. How the car handles these critical situations, together with users' personal preferences of driving style, is believed to form the basis on which trust is built during usage. There are strong reasons to believe that the introduction of information about the car's perception and intention could decrease the need to stay vigilant. One participant stated that:

*"[I] would have liked to see some display saying that it recognized the bus, maybe slow down a little bit. (...) Just so I know the car sees the bus and it is going to react to it". (TP 10, Study 1)*

Another participant stated that:

*"My biggest concern is, like right now when there's traffic if it'll actually going to stop or not". (TP 12, Study 1)*

Both quotes support the idea that information about perception and intention will decrease the need to stay vigilant and help the user anticipate what action the car will take through its driving behaviour so that users can feel more relaxed when riding in automated drive. Since these aspects were considered important, the project will continue working with intention and perception when designing visual and sound concepts in the concept development phase.

## 3.5 Conclusions and Implications

The majority of the information presented to the user in the Sunnyvale study was conveyed through the display and the speaker information channels as well as through

the driving behaviour. The analysis indicated that trust is developed when users experience that the car can handle different traffic situations in a safe way. The display has the inherent property of being able to convey detailed information that can aid the user in understanding and consequently trust the system. The audio information has been shown to notify the user and guide the user's attention to the display.

According to Lee and See (2004) understanding the automation is an important factor to build trust. Further, Lee and See (2004) state that the design of the display has an effect on trust and the study by Fagerlönn et al. (2020) have shown that intention sounds will increase trust towards AVs. There is also evidence that a defensive driving behaviour will increase trust (Ekman et al., 2021). Because of the ongoing pandemic, the project considered it difficult to test and evaluate different driving behaviours. This would require a WoOz car with four people (including test participant, test leader, test driver and interface controller) sitting in the same car during the test. Based on this, the project chose to continue working with the display and the speaker information channels when developing the concepts. The findings regarding driving behaviour were nevertheless used when formulating design guidelines for the use of information channels in AVs, see chapter 6.

From the analysis, it also became evident that participants felt the need to stay vigilant of the traffic around the car. When the participants mentioned this, they also mentioned that they wanted to know what the car was 'seeing' and what the car was 'planning' to do. The article by Fagerlönn et al. (2020) argues that the perception and intention layers are important to convey in order to increase trust. Lee and See (2004) explain the importance of the trust affecting aspect *process*, explaining the automation's algorithms to the user. Based on this, there are strong reasons to believe that showing the intention and perception of the vehicle will increase users' trust in AVs. In the next phase, the project will design the information content to be communicated in the display and the speaker information channels to present the intention and perception of the car.

Many participants in the study expressed confusion about who is in control, over what functions and when. This confusion was believed to be a result of the unclear control distribution in the level 2 PA system. In a level 4 automated system, the car has most of the control, thus making the control distribution easier to understand. However, an important guideline to help users understand who is in control and when is to design the information in the display to show a clear control distribution.

Many participants also reacted negatively to the audio information in the study. This was believed to be connected with the beeping, alarming and intrusive properties of the sounds in the study. Since the project decided to develop perception sounds to be played every time the car perceives another vehicle in the concept development phase, it was decided that a scenario with moderate to calm traffic conditions should be used in the coming studies. This was decided since too heavy traffic conditions could lead to negative reactions caused by information overload of perception sounds.

Another theme that became evident during the analysis of Study 1 was that the audio information guided the attention to the display, rather than conveyed any information. The theme that audio guides attention and the negative reactions were believed to be connected to the short and alarming beeping sounds only. In the concept development phase, the project, therefore, tried to design longer, softer sounds containing more information to investigate if the speakers could be designed to carry as much information as the display.





# 4 Concept Development

## 4 Concept Development

Based on the findings from Study 1 and the literature review, the two designers in the project (the authors of this report) decided to narrow down the selection of information channels to the display (DIM) and speaker information channels.

### 4.1 Implications from Study 1

The findings from the literature study and Study 1 showed that there are connections between visualising the car's intention and perception in a display (DIM) and an increased level of trust towards the AD. Therefore, the project chose to design the content in the display and sounds to show the intention and perception of the car.

By presenting both the AV's intention and perception, a higher degree of transparency could be achieved, which is something that should be considered when designing high-level automated systems (Hoff & Bashir, 2015). A higher degree of transparency will help the user understand the logic and inner workings of the system (Seong & Bisantz, 2008). Two of the factors influencing trust that Lee and See (2004) defined are: *Performance* and *process*. They continue to explain that performance information describes what the automation does and how well it can achieve the user's goal through the competency and expertise of the automation. How the automation operates are described by the process information (Lee & See, 2004). The user will then tend to trust the automation if automation performs in a manner that reliably achieves the user's goal, and if the automation's algorithms can be understood and seem capable of achieving the user's goals (Lee & See, 2004, p. 59). Information of the AV's intention and perception gives the user insights into how the algorithms of the AV work and what the AV is currently doing in the current situation.

Anthropomorphic features were not chosen to be included in the concept development even though both the literature and results from Study 1 suggested that users' trust for the system could be increased. The reason for not including anthropomorphic features was that the gender, culture, and personality of the user should be considered when designing anthropomorphic features as these features can affect diverse users differently (Hoff and Bashir, 2015). This could lead to test results might be skewed if test participants would, due to different personalities etc., be affected differently depending on how the anthropomorphic features were designed.

***Based on these findings, the project decided to develop ideas on how to convey the car's intention and perception through the DIM display and speakers in the car.***

The theme that audio guides attention, and the negative comments about sound, were believed to be connected to the short, beeping sounds. In the concept development phase, the designers in the project, therefore, tried to design longer, softer sounds that were supposed to be more relaxing, to see if these could contain more information and if they would be met with more positive comments. Since the sounds were supposed to be longer, the designers in the project also saw the opportunity to tell a story of what is happening with the car, through the sounds. In the sound design process, the project was inspired by the sounds designed in the SIIC (Sonic Interaction in Intelligent Cars) project ('Application: Trust', 2020).

## 4.2 Process

The concept development phase used a rapid prototyping approach (*Rapid Prototyping, Faking It Until You Make It in a UX Driven World*, 2020). This meant that the designers in the project worked with the three phases: prototype, review and refine. The prototyping of visual and audio ideas was followed by a review and a refinement of the prototypes based on the review. These phases were repeated in the three iterations that were conducted in the project.

During the prototype phase, the designers developed ideas and prototypes for the sound and visuals. The visual prototypes consisted of sketches created in the web-based tool Mural or Adobe photoshop. The sketches were then brought into Mural where the prototypes could be discussed in project internal reviews. To create the initial ideas and prototypes of sounds, the designers tried out and experimented with different digital audio workstations (DAWs). After trying a couple of different software, the designers continued working with Reaper. To create the actual sounds, the designers experimented with different virtual studio technologies (VSTs) such as instruments, equalizers (EQs), compressors, pitch change, panning (left-right) and volume etc. The finished sounds were saved in the project's Microsoft teams folder where the sounds could be played during the internal reviews.

During the review phase, the designers had review sessions both internally in the project team and with external experts. The internal review session was done within the project, where the two designers in the project presented ideas and concepts to each other, reviewed the ideas and concepts and discussed which ideas should be developed further and which ideas that should be excluded. The external review sessions were done with experts in the field of UX/sound design, trust research as well as with another master student within industrial design engineering. For the external reviews, the project prepared a PowerPoint presentation with different combinations of visual and sound ideas on different slides. Each combination slide consisted of one visual idea and several sound ideas that conveyed the same information as the visual idea. This way, the experts could examine a visual idea and at the same time listen to the sounds that were supposed to be related to that visual idea. This setup meant that the experts could compare, and comment on, different combinations of visual and sound ideas. In total, three external review sessions were conducted.

In the refine phase, the prototypes were refined based on the feedback from the internal and external review sessions.

### 4.2.1 The first iteration

This iteration started by designing lo-fi prototypes for the sound and visuals. The visual prototypes were sketches, and the earliest sound prototypes started with voice recordings where the designers used their own voices to generate volume and pitch changes to highlight certain intentions and perceptions. These sounds were also imported and edited in the DAW 'Reaper'. The intention sounds that was developed in the first iteration can be listened to on <https://soundcloud.com/user-464723432/sets/intention-iteration-1> and the perception sounds from the first iteration can be listened to on <https://soundcloud.com/user-464723432/sets/perception-iteration-1>. The goal for the lo-fi prototypes was to determine the layout and structure of the visuals, the desired tone and pitch shift of the sound and what type of feeling should be conveyed through the overall design.

Before the first expert review session, the ideation work started with Braindumping (Dam & Siang, 2020) sessions where the designers individually generated ideas and then discussed them together.

To explore the design space, these short sessions focused on the chosen information content: the intention and perception of the car. During the first parts of this phase, the sounds and visuals were ideated separately from each other. The early goal was to generate as many ideas as possible and explore the design space for how one could visualize intention, perception, and the context in which those two would be presented, see figure 8. The visual ideation explored colours, symbols and different visualisations for different intentions and the perception of the car. The ideas were later placed into a space where they could be categorized based on the extent/detail of the information. For perception, this ranged from informing the user that an object has been detected, to more detailed information of what the car sees (a car, a bicycle, etc.) and what the distance to that object is.



Figure 8. Initial sketches ordered after type of event and extent of information conveyed.

The ideation then continued with Brainwriting (Dam & Siang, 2020) This enabled the designers to be creative and develop ideas within a specific area. The designers chose a given focus point, e.g., the intention of acceleration, and spent a couple of minutes drawing ideas for how that could be visualized. The sketches were then sent to the other designer who sketched new ideas in the same file, drawing inspiration from the other designer's previous sketches.

The early sound ideation had a similar goal as the visual ideation, the goal was to explore the possibilities and generate as many ideas as possible. The first sound ideas explored the different sound generating and modification tools within the DAW (Digital Audio Workstation) Reaper and what these types of modification can be associated with. Still using lo-fi sound prototypes, the designers explored tools such as pitch shifts of sounds to try and simulate the sounds a gas-driven car would make during acceleration and deceleration.

Together with the ideation of visual and sound ideas, the designers also ideated on how much of the car's perception should be presented to the user through the display and

speakers. As well as ideating on different events that could be important to show the intention of through the display or speakers in the AV. Examples of such intention events that were included in the ideation were: acceleration, braking, lane change to the left and lane change to the right. To be able to create concepts on how to present the intention and perception of the car, the designers had to decide how the scenario in the coming studies should look like. Since the scenario should have low to moderate traffic conditions, it was decided that the scenario should take place on a highway and not in the city.

After the first prototyping and ideating of both sound and visuals, the first expert review took place. The early prototypes were tested with an expert that worked as a UX/sound designer. The ideas were presented in the form of a PowerPoint presentation where different sketches of the same intention and perception events were shown on each slide, such as perception of a car to the side and intention of overtaking, each accompanied by multiple sounds that also should convey the same event.

The first review gave feedback on which types of sounds could generate associations to the perception and intention of the car. The length of sounds was also discussed during the review. The feedback on the visuals helped the project pick out clear and understandable graphics as well as suitable colours and symbols. Signal colours such as red, yellow and orange should be avoided as this would be associated with warnings in car interfaces. The discussions also revolved around what type of feelings that both the visuals and sounds generate. The expert recommended that the project should develop a couple of design paths to distinguish the different designs from each other.

#### 4.2.2 The second iteration

Based on the feedback from the UX/sound designer, the second iteration started with ideating different design paths. The initial ideas for these design paths grew from the review session in the first iteration. Mood boards were used to help visualize each path. Desired feelings and expressions for each path, as well as guiding words for how sounds should be designed, was included in the mood boards. For one of the design paths, music was added to help get a feel for the sounds that should be created. The three paths were named:

- 'Modern'
- 'Retro'
- 'Classic'

Together with the development of the design paths, the intention events and amount of information about the car's perception that should be included in the highway scenario and consequently in the design paths and final concept were also decided. The intention events that were picked out from the first iteration were:

- A lane change to the left.
- A lane change to the right.
- Braking.

These intention events were chosen since they were considered to be the most common events that take place on a highway. The amount of perception information that the display and speakers should present in the design paths and final concept was also decided. To decrease the time spent on creating variations of perception information to

fit every possible situation, the designers decided to design the display and speakers to only convey perception information about:

- Vehicles to the left of the AV.
- Vehicles to the right of the AV.
- Vehicles in front and to the left of the AV.
- Vehicles in front and to the right of the AV.
- Vehicles in front of the AV.

## Modern

The 'Modern' design path should express a brave and powerful feeling when it comes to showing the intention of the car. The intention of the car should be visualized with a transparent path showing where the car is going to position itself on the road. The perception around the car should be shown with white 'ghosts' with a fading colour that goes from white to transparent. That will bring a soft expression to the interface. The interface should have ingredients for telling a story about driving. The sounds should be longer than notification sounds, powerful but still round and soft in their design. The mood board that was created for the 'Modern' design path can be seen in figure 9.

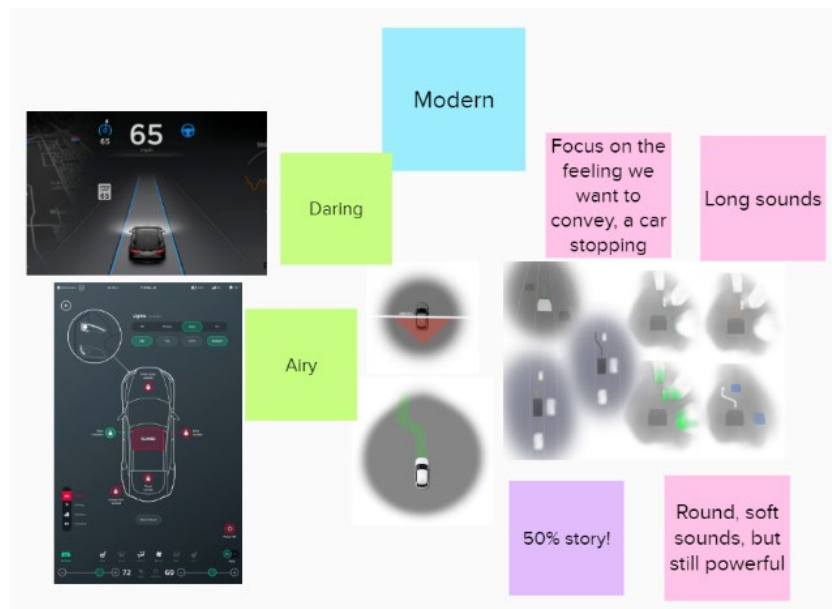


Figure 9. Mood board for the Modern design path.

## Retro

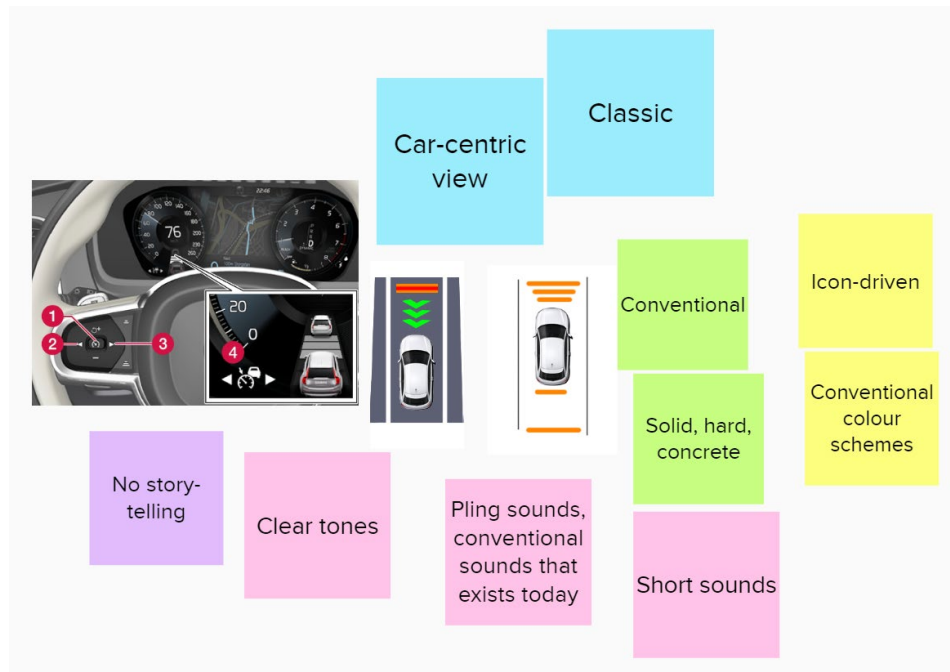
The 'Retro' path should go far beyond what is conventional now by gamifying the interface and bringing the thoughts to arcade games and action movies from the eighties and nineties. The 80s colour scheme that was used in this design path was also used to some extent in the release of the new Volvo C40. In this design path, the intention and perception should be shown in a fun way. The sounds should have influences from distorted synths, space sounds, and sounds from arcade racing games. The mood board that was created for the 'Retro' concept can be seen in figure 10.



Figure 10. Mood board for the Retro design path.

## Classic

The 'Classic' design path should be designed to look conventional, using icons and colours that are used in today's cars. In other words, the interface should use classic components that are adapted to show the perception and intention in automated cars. The sounds should have clear tones and short conventional notification sounds should be used. The mood board that was created for the 'Classic' concept can be seen in figure 11.



*Figure 11. Mood board for the Classic design path.*

The evaluation of the second iteration focused on how the sound and visuals worked together in the different design paths. The expert that participated in this review was a researcher focusing on trust. The goal for the design paths was that they should feel congruent in terms of feeling and tonality, aiming for similarity (cf. Monö, 1997) between the two information channels.

At the end of this second iteration, the designers chose which of the three design paths should be used as the main concept for Study 2 and Study 3, where the information channels and information gestalt were the focus. The concept to be used in the user tests should: (i) show the car's perception and intention in a clear way; (ii) have an aesthetics and style that should not be too salient and take too much focus from the information channels themselves. The first criterion was chosen as it was assumed that having an understandable presentation of the information would yield clearer results in the user study. The clearer the information, and that the visual and audio information could convey both the perception and intention on their own in an understandable way, was assumed to help evaluate the roles of the information channels as well. The second criterion was chosen as the user study should mainly focus on the information channels, and the project wanted to reduce the risk of having strong reactions towards an aesthetics that would affect the results of the user study.

Based on these criteria, the 'Modern' concept was chosen as the main concept for Study 2 and Study 3. The 'Modern' concept shows the intention and perception of the car in a

clear way, the intention is shown by a green transparent path on the road and the car's perception is shown by white 'ghosts' around the AV. The aesthetics are 'modern' and dark like many other in-car interfaces on the market. Thus, the 'Modern' design path does not take the focus from the information channels themselves.

#### 4.2.3 The third iteration

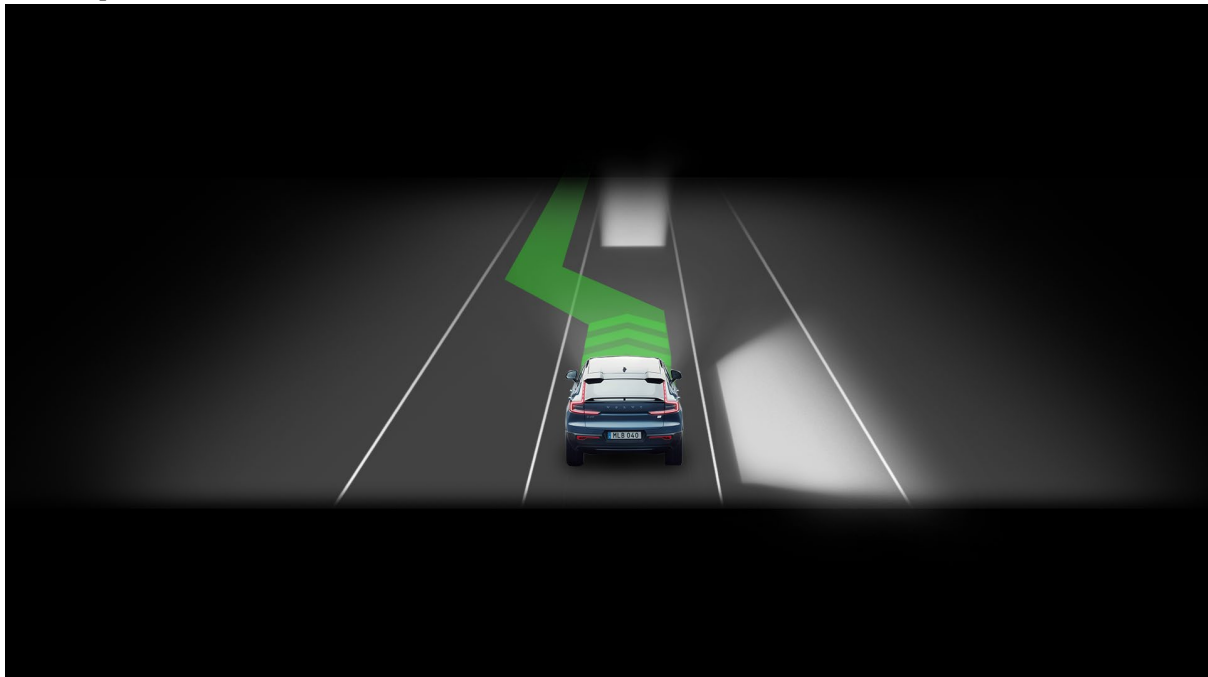
For the last iteration, the designers continued to refine the 'Modern' design path that should be used to study the information channels and information gestalt in Study 2 and Study 3. The designers worked on the similarity between visuals and sounds and developed the tonality of the sounds. The designers also refined the 'Retro' and 'Classic' design paths to achieve the same level of detail between the three design paths and to achieve the desired expressions and feelings. This was done since the 'Retro' and 'Classic' design paths should also be used in Study 3, to test if the aesthetics of the information channels influenced trust.

The 'Modern' sounds (before the last review session) can be listened to on <https://soundcloud.com/user-464723432/sets/modern-iteration-2>. The last review with a master's student tested different sounds connected to the different intentions and perception of the car. Based on the feedback from the review, the project changed minor details in the sounds such as starting pitch, tonality etc. At the end of the third iteration, the visual and sound prototypes were considered to be hi-fi prototypes that were of such quality that they could be used in the user studies.

#### Final Design Paths

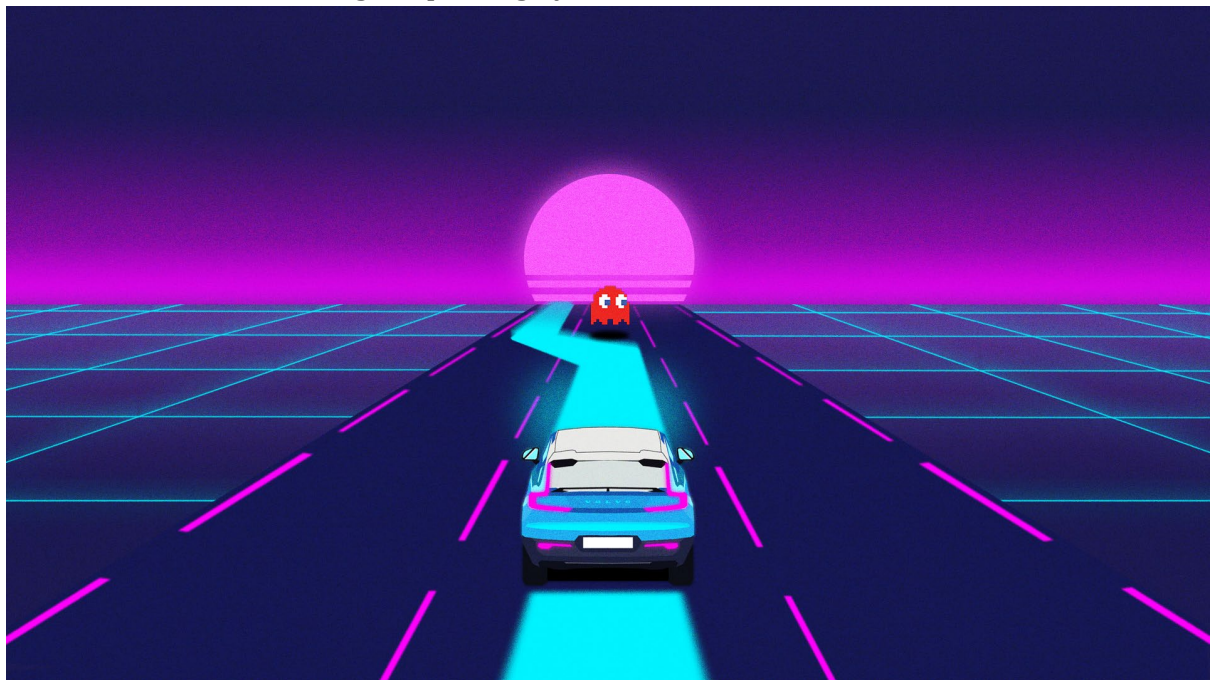
The 'Modern' design path was refined so that it could be used in Study 2 and Study 3 as explained earlier. The 'Retro' and 'Classic' design paths were refined so that they could be used in Study 3. However, the 'Modern' concept was chosen to be the main concept to study the information channels and information gestalt in both Study 2 and Study 3; it is explained further in 4.2. Final Concept.

The 'Modern' design path (can be watched on <https://www.youtube.com/watch?v=pq7mWGF3vBw>), shown in figure 12, is considered to have a brave, powerful but still soft expression. The car's intention is shown with a transparent path that tells a story about which path the car is going to drive, which makes it easy to see what the car is going to do. The perception is shown with white 'ghosts', visible without requiring too much attention from the user. The intention sounds in this design path are around 5 seconds long to be able to convey the same amount of information as in the display. The sounds have a powerful but still soft expression, with influences from powerful gasoline-driven cars with an electronic touch. The volume of all sounds in this design path fades out in the end which also results in a soft expression. The perception sounds consist of soft chime sounds with a positive vibe. The volume of these sounds is faded at the start and end which gives the soft expression.



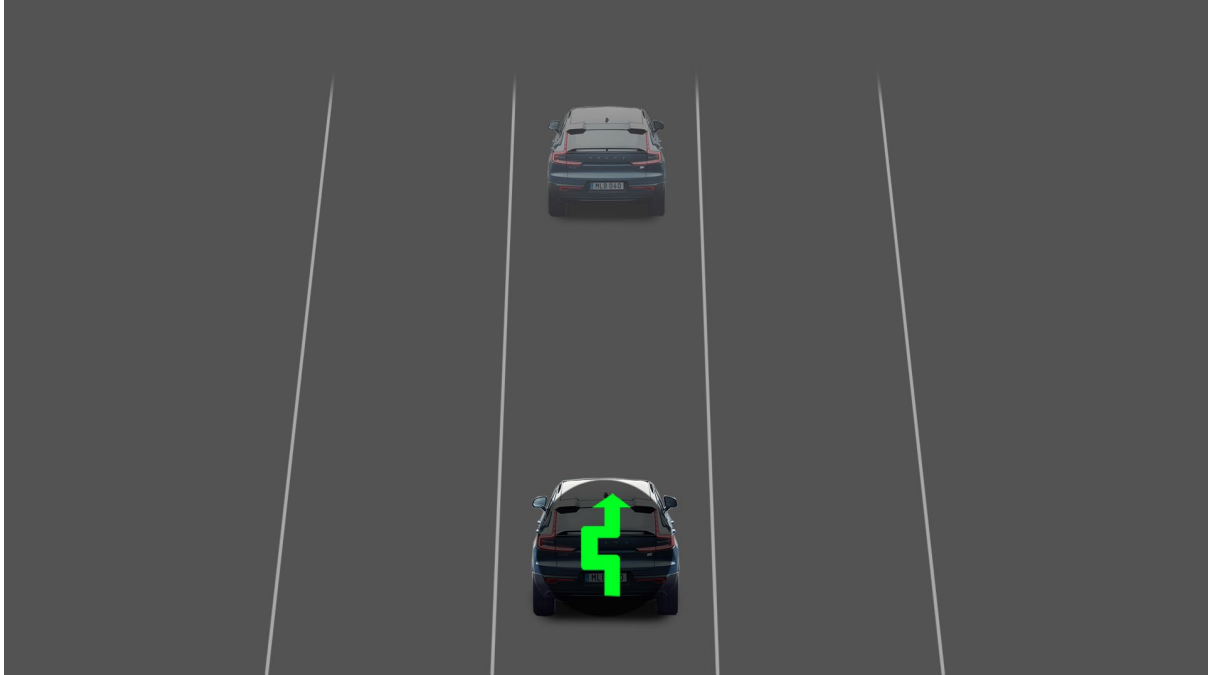
*Figure 12. Modern concept showing the overtake intention.*

The 'Retro' path (can be watched on <https://www.youtube.com/watch?v=EUDMAWSqE8k>), shown in figure 13, is designed to be unconventional. Influences were gathered from arcade and racing games to make the sounds and visuals playful and fun to interact with. To get the 'retro' feeling, this design path was also inspired by the retro games, vibrant colours and the release of the new Volvo C40. In this design path, the intention and perception are shown in the same way as the 'Modern' design paths, the white 'ghosts' being Pacman monsters in this concept. The changes in volume and pitch in the 'Retro' sounds have a similar profile as the 'Modern' concept's, which are described later in this chapter. The intention sounds sound like a racing car with influences of distorted synths. Sounds from arcade games have also been included to confirm different intentions even more. The perception sounds sound like a racing car passing by.



*Figure 13. Retro concept showing the overtake intention.*

The 'Classic' design path (can be watched on <https://www.youtube.com/watch?v=SX0wS44Ghbs>), shown in figure 14, was designed with conventional interfaces in mind. The 'Classic' design path uses icons and colours that are already used in cars today. The overtake intention of the car is shown by a green overtaking symbol on top of the car and the braking intention is shown by two blue arrows pointing down. Unlike the other design paths, other cars are shown as real cars in the interface. The intention and perception sounds in this concept consist of clear tones and short conventional notification sounds.



*Figure 14. Classic concept showing the overtake intention.*

## 4.3 Final Concept

This chapter explains the details in the 'Modern' design path that was chosen to be the final concept to be used in the user test.

### 4.3.1 Visual Information for the Display

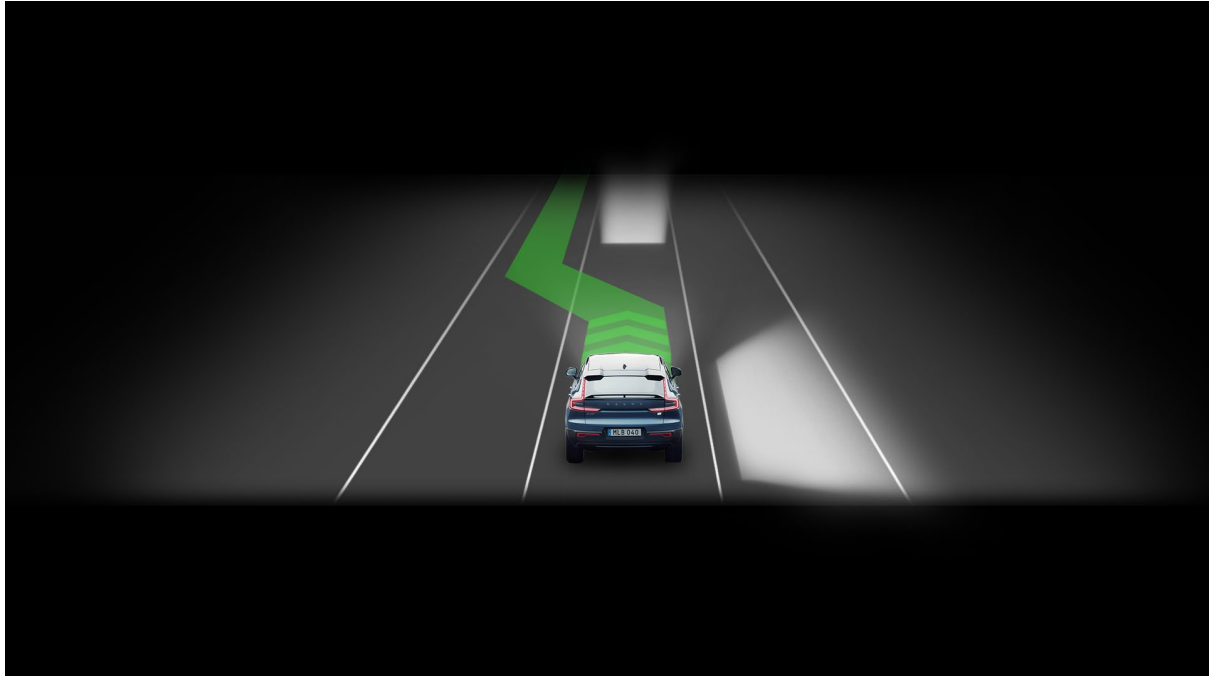
The purpose of the interface in the DIM is that it should show the car's perception of its surroundings and its intention. The final concept that was developed from the 'Modern' design path shows the perception through white 'ghosts' around the car, see figure 15. The 'ghosts' shows the outer contours of the vehicles around the car, like radar detecting objects, and casting a white 'radar shadow' behind them. The transition between the white 'ghost' and the grey surrounding visualizes the accuracy of the object recognition system by showing a sharp transition (high accuracy) close to the car and a softer transition (low accuracy) further away from the car.

This way of showing the AV and other surrounding vehicles is similar to the 'God view' and 'ring' concepts in the study done by Ekman et al. (2016). The 'ring' and 'God view' concepts have been shown to increase trust and the 'God view' concept was also shown to be good for orientation. Therefore, the project believes that the final concept developed in this project will also have these attributes.

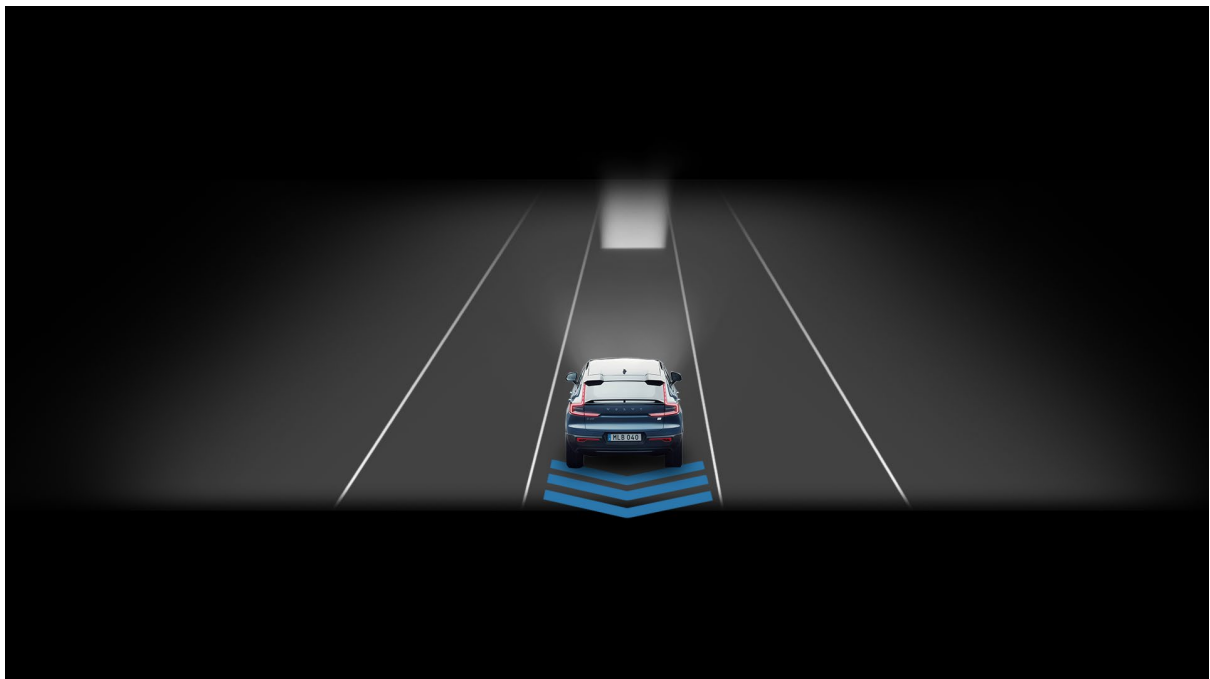


*Figure 15. Perception of objects around the car in the final concept.*

The lane change intention of the final concept is shown by a green transparent path in front of the car showing where the car is going to drive, see figure 16. During overtakes to the left of other cars, green arrows indicating acceleration are also shown on the green transparent path. When the car brakes, the intention is shown by blue arrows behind the car in the DIM, see figure 17. The blue colour was chosen since it is commonly used in interface concepts for automated cars and would not be associated with warnings.



*Figure 17. Intention: Overtake/lane change to the left in the final concept.*



*Figure 16. Intention: braking in the final concept.*

### 4.3.2 Sounds for the Speakers

The sounds were designed to convey the perception and intention of the car with the modern expression explained earlier. The sound visualizations in figures 18-21 show the approximate change in pitch and volume on the y-axis and the length of the sound in seconds on the x-axis.

The perception sounds had a constant pitch with a varying volume, see figure 18. The change in volume relative to time is intended to create the feeling of a car passing by. The perception sounds were panned to the left or right to indicate the perception of a vehicle on the left (listen on: <https://soundcloud.com/user-464723432/perception-modern-car-left?in=user-464723432/sets/modern-final>) or right side (listen on: <https://soundcloud.com/user-464723432/perception-modern-car-right?in=user-464723432/sets/modern-final>) of the car. The perception of a vehicle in front of the car was indicated by the perception sound being played in stereo with an equal balance between left and right (listen on: <https://soundcloud.com/user-464723432/perception-modern-car-front?in=user-464723432/sets/modern-final>).



Figure 18. Perception sound.

The designers also developed several intention sounds to indicate the car's intention. When the car was about to change lane to the left, one intention sound was played (listen on: <https://soundcloud.com/user-464723432/intention-modern-lane-change-1?in=user-464723432/sets/modern-final>). A lane change to the left is often associated with an overtake of another vehicle. Thus, this sound had an increase in pitch over time which was meant to indicate the acceleration that is commonly connected with overtakes, see figure 19. The sound had a constant volume with a volume dip in the end. This dip was placed to achieve a soft ending of the sound when the car has reached the new lane.

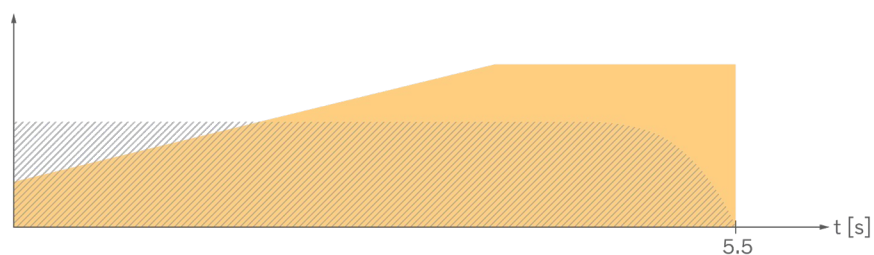


Figure 19. Sound indicating a lane change to the left.

When the car was about to change lane to the right, another intention sound was played (listen on: <https://soundcloud.com/user-464723432/intention-modern-lane-change?in=user-464723432/sets/modern-final>). This sound was longer than the left lane change sound and had a slight decrease in pitch over time. The decrease in pitch was intended to indicate a lane change to a lane with a slower traffic flow. The volume of this sound had a pulsating pattern in order to create the feeling of a turning signal when changing lanes, see figure 20. Apart from the pulses in volume, this sound had a constant volume with a volume dip in the end. This dip created a soft ending of the sound, indicating that the car has 'landed safely' in the new file.

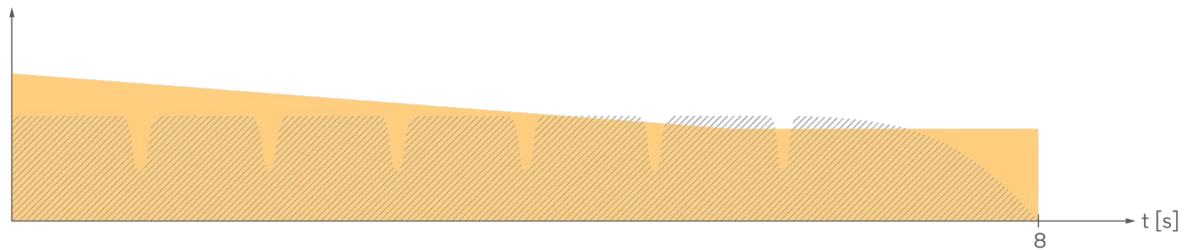


Figure 20. Sound indicating a lane change to the right.

The designers also developed a sound that indicated when the car braked (listen on: <https://soundcloud.com/user-464723432/intention-modern-brake-jf?in=user-464723432/sets/modern-final>). This sound had a decrease in pitch over time to indicate that the car slowed down. The volume of this sound was constant with a dip in the end to achieve a soft ending when the car had finished braking, see figure 21.

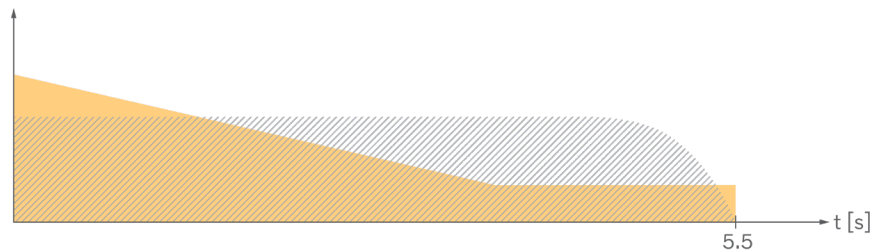


Figure 21. Braking sound.



# 5 Study 2 and 3: Evaluation of Final Concept

## 5 Studies 2 and 3: Evaluation of Final Concept

This chapter gives a walkthrough of the methods that were used in the two studies carried out to evaluate the final concept as well as the findings from the studies. Study 2 was a simulator study with experts. Study 3 was an online study carried out in two versions, a qualitative version (called Study 3 Qualitative) and a quantitative version (called Study 3 Quantitative).

### 5.1 Aim

This study aimed to answer the main research question and the second sub-question asked in the aim for the thesis.

RQ: How does the design of different information channels together affect users' trust towards the AV?

Q2: How does the integration of multiple information channels affect the users' trust?

Based on the finding that showing the car's intention and perception could help the user develop appropriate trust, a third question was also asked in this study:

- Does presenting the car's intention and perception through the display and speakers help users develop appropriate trust?

### 5.2 Method

The tests that were conducted each followed an A/B/n testing structure (Young, 2014) where the participants got to experience three different scenarios. The three scenarios presented the car's perception and intention through audio information in the speakers, or visual information in the DIM display, or both at the same time. This structure, which can be seen in figure 22, was believed to be effective when studying the information gestalt and its effect on trust.

	Display	Speakers
A	●	●
B	●	
C		●

Figure 22. The chosen A/B/n setup for the studies.

The information gestalt is believed to form when several information channels present information at the same time. The project, therefore, deemed it necessary to study the trust that is formed when the display and speakers present information simultaneously (scenario A in figure 22). To see if this information gestalt creates something more than just the sum of the information from the display and the speakers, the display and speaker information channels were also studied in isolation (scenario B & C in figure 22).

To see if the design of information channels had an effect on trust, the project also included the 'Classic' and 'Retro' concepts in Study 3.

To be able to determine how trust is affected by the individual information channels and the information channels in combination, the method of having both information channels showing the same content and amount of information was chosen. This meant that the display, when it was presented in scenario A & B, and the speakers, when they were presented in scenario A & C, conveyed the same information about perception and intention. The information that was shown was:

- Perception of a vehicle in the lane to the left of the AV (approx. 2 s before the vehicle was passing by until the vehicle was approx. 60 m ahead of the AV).
- Perception of a vehicle in the lane to the right of the AV (approx. 2 s before the vehicle was passing by until the vehicle was approx. 60 m ahead of the AV).
- Perception of a vehicle in the same lane as the AV (approx. 60 m ahead of the AV).
- The intention of changing lane to the left.
- The intention of changing lane to the right.
- The intention of braking.

This setup of having both information channels showing the same content and amount of information was deemed to have fewer variables that could lead to errors in the test.

Some of the other setups that were considered were having setup A, where both information channels had the responsibility of showing 50% of the information of perception and intention, then for the B and C setups, each information channel would convey 100% of the information. Variations of this were considered where in B and C the balance of information should be 30/70. The introduced sources of errors for these two latter methodologies are that it would be more difficult to discern if the change in trust and understanding would have been caused by a design flaw or by the different amounts of information included in each information channel. It would also be harder to evaluate how much each of the information channels affected the trust separately and if the combination is actually better at helping the user generate an appropriate level of trust than the individual parts. During the scenarios, the participants are notified of the car's intention and perception according to the previous bullet list, these notifications are referred to here as events.

- Other cars enter the vicinity of the test car.
- The test car is being overtaken.
- A slow-moving car ahead is being approached.
- A strong deceleration of the test car.
- The test car changing lanes.

### 5.2.1 Study 2: The Expert study

To study the concept of information gestalt of the information channels and evaluate the design of the content of the display and speakers connected to trust, an expert study was made. Because of the ongoing pandemic, the project could not test the display and speakers in a WoOz vehicle with a demographically representative user group as this would have required four people to be in the WoOz car at the same time during each test. Instead, the project decided to do a smaller simulator study with participants that were already present at the Volvo Cars' office in Torslanda. This enabled the project to reduce the risk of spreading any infection during the tests.

However, since many of the experts that participated in the study were already familiar with and had a lot of knowledge within UX or sound design connected to AVs, it can be questioned if these experts were suitable for the task to evaluate trust towards AVs when being presented with the information channels display and speaker. Since these experts had a lot of knowledge within the area, they were probably more suitable for the task to evaluate and discern the feasibility of the information presented through the information channels.

#### Preparation

In preparation for Study 2, the project borrowed two cars that were used to film driving videos on the highways in the Gothenburg area. The driving videos were created to introduce realism and risk in the study since the project could not test the concepts in a WoOz setup. A GoPro camera mounted on top of the dashboard in one of the cars were used to record the videos as well as the noise coming from the car and surrounding traffic. The other car helped stage the events:

- Other cars enter the vicinity of the test car.
- The test car is being overtaken.
- A slow-moving car ahead is being approached.
- A strong deceleration of the test car.
- The test car changing lanes.

The videos that were recorded were later cut to three different driving videos with approximately the same length and number of events. The video editing was done in the software Adobe Premier Pro. The same three driving videos were later used in Study 2 and Study 3.

To create the interface shown in the display (DIM), a photoshop file containing all necessary components on different layers was imported into Adobe Premier Pro. The layers of the photoshop file that was imported could then be turned on or off (visible or invisible) to match the events in the driving video.

For Study 2, each of the scenarios were roughly the same length, around 8 minutes, with approximately the same number of events (between 30-36).

#### Participants

The participants for this test were 5 experts from Volvo Cars. Their expertise was in interaction design research, sound design, UX design, transitions between AD and manual drive, and complete vehicle testing. The participants' age span was between 25 and 52 years with a mean of 38 years. The participants had varying degrees of experience working with automated drive as well as varied attitudes towards AD in general.

## Study design

In this chapter, the specific setup for the Expert Study is presented.

### *The simulator*

The physical simulator consisted of a car cut in half. The participant sat in the driving seat of the car, with a real interior including a steering wheel and pedals, see figure 23.



*Figure 23. View from inside the simulator showing the outside TV screens and the DIM display.*

Two TV screens were placed in front of the simulator car. The TV screens showed the highway driving videos that were recorded and edited in the preparation phase. Two external speakers were placed to the left and right of the driver, slightly behind the seat. A smaller display was also placed in front of the steering wheel, to simulate the DIM display. The external speakers and DIM display were controlled from a computer outside the car. The two TV screens were controlled by a second computer outside the car.

### *The interfaces*

The two tv-screens showed a pre-recorded video of a car driving around on highways in Gothenburg, Sweden. The video also had car and traffic noise that was synchronised with the video. The TV screens were placed so that they took up most of the participant's field of view.

### *The procedure*

Before the test started, the surfaces in the car interior were wiped with disinfectant. The room had boundaries for where the participant could move around before the test, to ensure a safe distance between the participants and the test leaders. All parties wore face masks during the test to reduce the risk of any spread of Covid-19.

The order of the display only, speakers only, and combination scenario were predefined and evenly distributed over the participants. This was done to avoid the risk that the order of scenario would affect the overall results of the study. For each scenario, the participants sat in the car and held their hands on the steering wheel. A few seconds after the scenario started playing, they were told by the test leader that they had now entered automated driving. The participants were not tasked with any secondary task during the test.

The participants were asked questions such as if they trusted the car in the shown scenario if they understood what the car tried to tell them, as well as if they felt the need to stay vigilant during the scenario. Following each question, the participants were encouraged to elaborate their answers and the test leader probed the participants as well. After the participants had experienced all three scenarios, they were asked an open question of how they had experienced the different scenarios where they were encouraged and asked to elaborate on how it felt to be presented information through only the display, speakers, or both in combination. The complete test structure can be seen in **Appendix C**. As stated previously, the project had chosen this A/B setup as it was assumed to convey the same amount of information from both information channels. Therefore, the participants were asked if they perceived the information presented as equal between the speakers and the display.

No data was recorded during the test. During the test, there was one person dedicated to taking notes, as well as the test leader writing down keywords from the interview with the participants. Immediately following a test, the notes were compared with the keywords as well as discussed to elucidate any uncertainties in the notes. The discussion that followed each test acted as an initial analysis of the data while and some deeper analysis went into clarifying underlying topics or attitudes the participants had.

### 5.2.2 Study 3: The Online study

To complement Study 2 and gather data from more participants (potential users), an online study was done. The online study enabled the project to test the concept of information gestalt connected to trust as well as different visual and sound concepts and their effect on trust. Since the study was done online, the project could recruit many participants and at the same time conduct the tests in a safe way according to the regulations and general guidelines to prevent any spread of Covid-19.

In addition to the questions asked in the aim for both Studies 2 and 3, an additional question was prompted in Study 3:

How are users' trust towards AVs affected by the aesthetics of the information presented in the speaker and display information channels?

This question was added to complement the answers to the other questions on design factors affecting trust when answering the main research question.

#### The Platform

The platform [usertesting.com](https://www.usertesting.com) (*UserTesting*, n.d.) was used to create and send out the online tests. This platform allows companies to create and send out online user tests to users around the world. The platform is structured so that users are encouraged to speak out their comments and opinions loud during the test, in other words, a kind of think-aloud procedure. The platform also allows written responses and rating scales etc. The incentive for users to complete tests is that they get paid for each test they complete. For each completed 20 minutes of tests, the participant earns \$10. This results in companies getting many respondents in a short period of time.

#### The Tests

On the platform, the number of participants to receive the test was specified. It was also specified that only participants using computers should be allowed to start the test.

The test that was sent out on [usertesting.com](https://www.usertesting.com) consisted of a qualitative and a quantitative part. The project deemed it necessary to have 90 participants in the quantitative part to achieve a statistical significance. On the quantitative part, however, the project chose to restrict the number of participants to 18. Eighteen participants were considered enough to distinguish the major trends and elicit the most important takeaways from the qualitative data. The choice to restrict the number of participants in the qualitative part of the study was also made to limit the amount of qualitative data that needed to be processed and analysed.

To get 90 participants in the quantitative part and 18 participants in the qualitative part of the online test, the project needed to create four qualitative subtests (Quali 1, Quali 2, Quali 3 & Quali 4) and 6 quantitative subtests (Quan 1, Quan 2, Quan 3, Quan 4, Quan 5 & Quan 6). This was done because of the restricted number of maximum participants on each test decided by [usertesting.com](https://www.usertesting.com). An overview of these subtests, the number of participants participating in each subtest and the order of the scenarios in each subtest can be seen in table 1. In total, 10 subtests were created to test all orders of the scenarios in both a qualitative and a quantitative way.

Table 1. Overview of tests within Study 3. S – Speakers, D – Display, and Both – Speakers and Display, C – Classic, R – Retro.

	Participants	Order of Scenarios
Quali 1	3	S-D-Both-C-R
	3	D-S-Both-C-R
Quali 2	3	S-Both-D-C-R
Quali 3	3	D-Both-S-C-R
Quali 4	3	Both-S-D-C-R
	3	Both-D-S-C-R
Quan 1	15	S-D-Both-C-R
Quan 2	15	D-S-Both-R-C
Quan 3	15	S-Both-D-C-R
Quan 4	15	D-Both-S-R-C
Quan 5	15	Both-S-D-C-R
Quan 6	15	Both-D-S-R-C

### The Scenarios

In the test, five different scenario videos were presented to the participants. When the scenario videos were presented, the screen was divided horizontally to fit the driving video at the top and the DIM display at the bottom of the screen, see figure 24 and figure 25. Car and traffic noise were also included in all scenario videos to increase realism.

The first three scenarios showed a drive on a highway together with visual information, audio information or both at the same time presented through display and speakers. These scenarios were approx. 3 minutes long. The two remaining scenarios showed a drive on a highway together with other ways to present the visual and audio information, namely the ‘Classic’ and the ‘Retro’ concept. These scenarios were included to answer the question:

How are users’ trust towards AVs affected by the aesthetics of the information presented in the speaker and display information channels?

The ‘Retro’ and ‘Classic’ scenarios were about 40 seconds long and contained one overtake event and one event where the car was overtaken.

### The participants

In total, 108 people participated in Study 3. The number of females was 52 (48%) and 56 (52%) were males. Their age spanned from 18 to 57 years with an average of 27.2 years. Participants were also prompted to have a valid driver’s licence and use headphones in order to start the test. However, the project discovered that participants could start the test even though they did not fulfil these requirements. This was taken into consideration when the project analysed the qualitative data from Study 3 Qualitative. In total, 91% of all participants answered that they held a valid driver’s licence and 74% answered that they used headphones. The participants were also asked to rate their general attitude towards technology on a scale from 1 (Very sceptical) to 7 (Very trusting). The participants rated themselves with an average of 5.8 and a variance ranging from 4 to 7.

### Setup Qualitative

The following test structure was used for Study 3 Qualitative. The complete test structure can also be found in **Appendix D**. The order of the scenarios was varied so that all

possible orders of the speaker and the display information channels were tested with three participants testing each order.

First, the participants answered three initial questions, these were:

- Are you using headphones? [Yes/No]
- Do you have a valid driver's license? [Yes/No]
- Rate your general attitude towards technology [7-point Rating Scale: Very sceptical to Very trusting]

The participants were then presented with the first scenario.

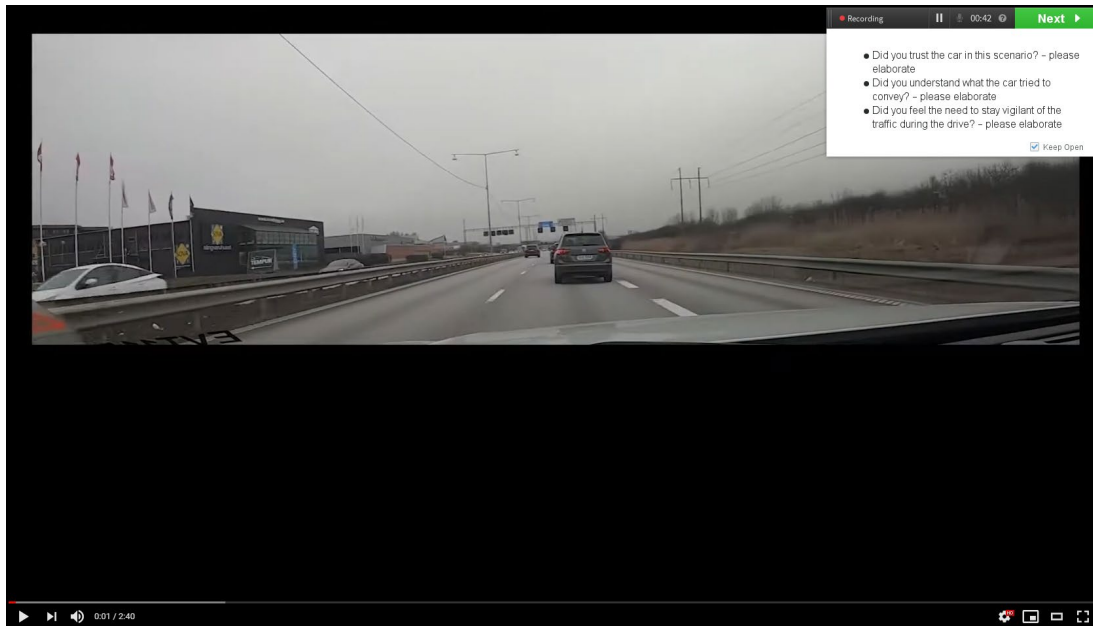


Figure 24. Qualitative version showing a scenario with only sound.

After each scenario, the participants got to answer three questions about the scenario, these were:

- Did you trust the car in this scenario? – please elaborate
- Did you understand what the car tried to convey? – please elaborate
- Did you feel the need to stay vigilant of the traffic during the drive? – please elaborate

After that, the second and third scenario was played. The participants were then asked to answer some questions regarding all three scenarios, these questions were:

- How was your experience of the different scenarios?
- How did it feel to only be presented with information through visual or audio?
- How did you feel being presented with information from both the display and speakers?
- Did the display and speakers present the content equally?

Finally, the participants were presented with the 'Classic' and 'Retro' scenarios in that order to see if the design of the information channels changed the result. After each of these scenarios, the participants were asked:

- Did you trust the car in this scenario? – please elaborate

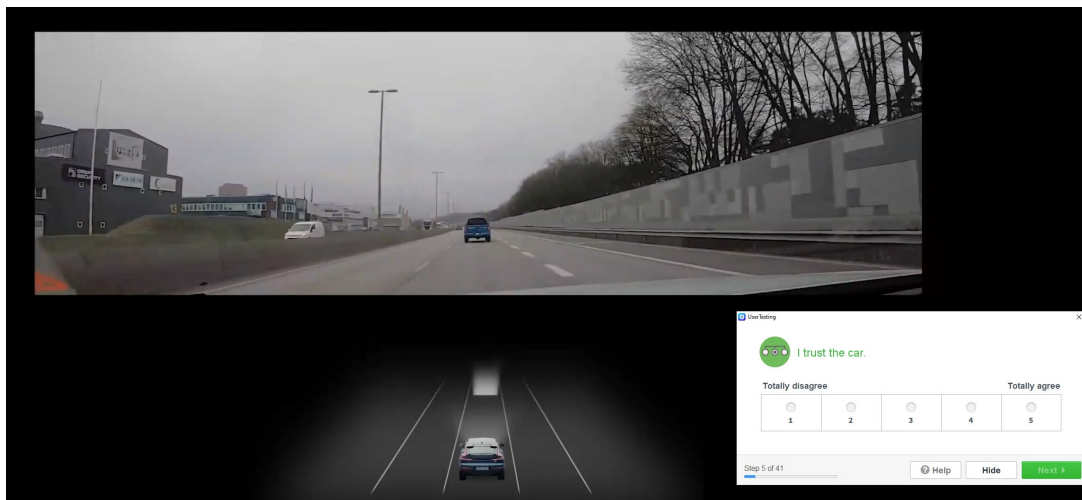
## Setup Quantitative

A similar test structure was used for Study 3 Quantitative. The order of the scenarios was varied so that all possible orders of the speaker and the display information channels were tested with 15 participants testing each order. The full test structure can be found in **Appendix E**.

First, the participants answered three initial questions, these were:

- Are you using headphones? [Yes/No]
- Do you have a valid driver's license? [Yes/No]
- Rate your general attitude towards technology [7-point Rating Scale: Very sceptical to Very trusting]

The participants were then presented with the first scenario.



*Figure 25. Quantitative version showing the DIM display.*

After each scenario, the participants rated the scenario on ten items on a scale which ranged from 1 - 5 (Totally disagree to Totally agree). These items were:

- I trust the car.
- I perceived the information presented as useful.
- I perceived the information presented as sufficient.
- I perceived the information presented as reliable.
- I perceived the information presented as too much.
- I understood what the car planned to do.
- I understood what the car saw.
- I felt the need to stay vigilant.
- I perceived the information presented as accurate.
- The information helped me relax.

After that, the second and third scenario was played. Each scenario was followed by the ten items presented above. The participants were then presented with the 'Classic' and 'Retro' scenarios to investigate if the design of the information channels changed the result. After these scenarios, the participants got to rate the concepts from 1 – 5 (Totally disagree to Totally agree) on the item 'I trust the car'. 45 participants were presented with the 'Classic' scenario first and 45 participants with the 'Retro' scenario first.

### 5.2.3 Analysis

Since Study 2 and Study 3 aimed to answer approximately the same questions and had a similar study structure, it was decided that the qualitative parts of Study 2 and Study 3 should be analysed together in one analysis. The quantitative parts of the respective studies were analysed separately since they were slightly different.

#### Quantitative Data

The quantitative data from Study 2 was brought into Excel where different diagrams and graphs were created. The same was also done with the results from Study 3 Quantitative but in a separate document. Each statement on the rating scale of Study 3 Quantitative was compared between the different scenarios (display only, speakers only, and combination) using a Kruskal-Wallis test in SPSS. This was done in order to determine whether there are statistically significant differences between the different scenarios and the participants' agreements on the corresponding rating scales for that scenario. The decision to use Kruskal-Wallis was due to the ranked ordinal data from the three scenario groups (Linebach et al., 2014).

#### Qualitative Data

The qualitative data was gathered by taking notes on the voice and screen recordings from Study 3 Qualitative. The notes from Study 2 and Study 3 were then coded with predefined codes (i.e. deductive approach) (Braun & Clarke, 2012). These codes were developed from interesting results in the project's earlier studies (the literature study and Study 1). Codes were also adapted and added during the coding. The codes that were used were:

- Vigilance decreases with 2 information channels
  - Audio catches attention
- Trust comes with experience/learning (short term)
- You always have to be vigilant sitting in the driver's seat
- Audio
- 2 modalities are better than 1
  - 2 modalities = better understanding
  - 2 modalities = more trust?
- Participants base majority of their trust based on Driving behaviour.
- Design implications
  - Conventional sound and visuals = more trust?
  - Serenity
  - Higher fidelity in display = more trust? /Reflecting on reality compared to information channels
  - Retro concept

### *Thematic Analysis*

The qualitative data in the studies conducted in this project were analysed using thematic analysis, see figure 26. Thematic analysis is a method that can be used to analyse qualitative data by clustering the data into themes that is relevant to answer the research question in the study (Braun & Clarke, 2012).



*Figure 26. Thematic analysis in Mural.*

The project became familiar with the data by reading and coding the notes from Study 2 and Study 3 using the previously mentioned codes. The different codes are represented by different colours in figure 26. Familiarizing and coding were the first two phases of the thematic analysis. When all notes had been coded, the coded notes were added to the web-based platform Mural, see figure 26. The data was initially categorised based on the codes specified above. When the data had been added to Mural in the respective categories, the project started clustering the data into initial themes that were believed to be meaningful to answer the research question in the project, this was done by moving the individual post-it notes. This was the third phase of the thematic analysis. The initial themes were then reviewed a second time by moving individual post-it notes and updating the labels of the themes, this was the fourth phase of the thematic analysis. The last phase created distinct and clear themes that formed the findings of the qualitative parts of Study 2 and Study 3. The final themes can be seen as clusters in figure 26. The final themes (bullet list) can also be seen in **Appendix F**.

## 5.3 Findings

In this chapter, the findings and analysis of Study 2 and Study 3 will be presented.

### 5.3.1 Synergy of information channels

In Study 3 Quantitative, the combination of using both speakers and display gained an “I trust the car” score average of 4.31 compared to speakers only scenario which received an average score of 3.36 and display only scenario which scored 4.27. Here, we can see a much greater increase in trust when introducing the display information channel. Still, there is not enough of a difference between display only and the combination to determine if the combination increases the trust towards the car if we only look at the quantitative data. The statistical analysis found that there is no statistical significant difference ( $\alpha=0.05$ , Kruskal-Wallis  $\sigma_{\text{trust}}=0.719 > \alpha$ ) between trust scores when presented with the combination compared to only the display only scenario.

The participants’ answers in Study 3 Quantitative on how they perceived the information presented is consistent with the results of the trust scores. As can be seen in figure 27, the participants perceived the information as more useful, sufficient, reliable, and accurate when presented with the combination and display only scenarios than with the speakers only scenario. Histograms of each of the questions in each of the scenarios can be seen in **Appendix G**. There was no statistical significance between the speakers and combination scenario when participants of Study 3 Quantitative were asked if they perceived the information as useful, sufficient, reliable, or accurate ( $\alpha=0.05$ ,  $\sigma_{\text{useful}}=0.544$ ,  $\sigma_{\text{sufficient}}=0.051$ ,  $\sigma_{\text{reliable}}=0.665$ ,  $\sigma_{\text{accurate}}=0.441$ ). There is a slightly larger difference in average score between the combination and display only scenarios when participants were asked to indicate their agreement with the statement: “I perceived the information presented as sufficient”. Still, this difference is not great enough to state that it is statistically significant. The participants in the quantitative study perceived that the information in all the 3 scenarios was not too much and disagreed with the statement.

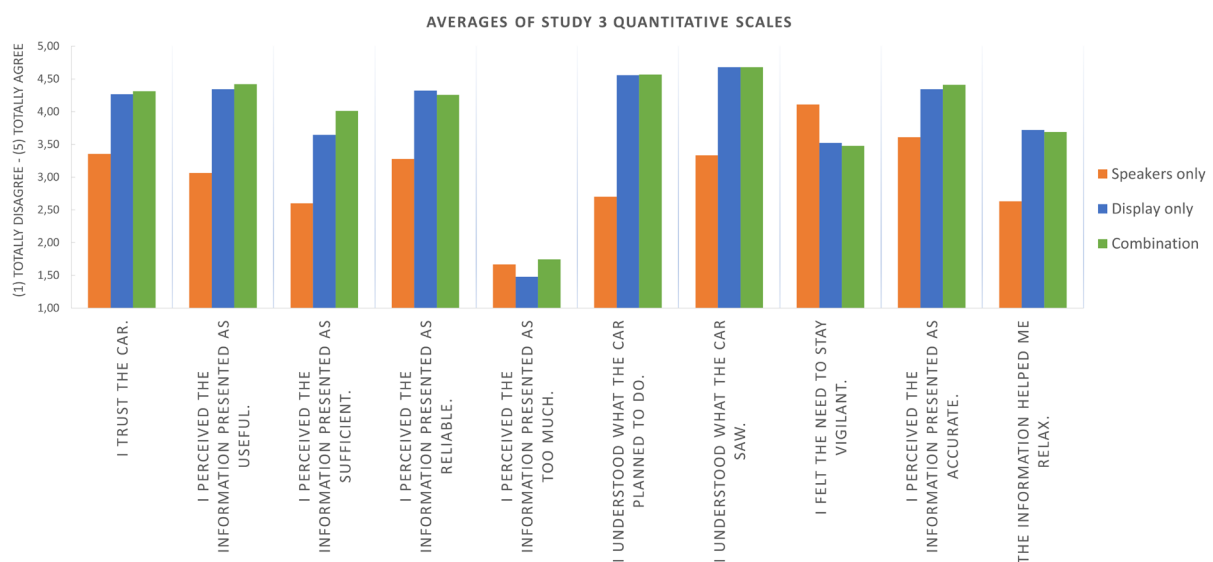


Figure 27. Averages for each question on the scale from the quantitative study.

In Study 3 Quantitative, we can see an order effect, the group of participants who experienced the speakers only scenario first rated it higher on the trust scale than the participant groups who experienced the other scenarios before the speakers only as seen in figure 28. The assumption was that the results for the speakers only scenario would be similar to the results from a previous study by Fagerlönn et al. (2020), with an average of “I trust the car” around 4 rather than 3.36. The average score for the trust scale for the speakers only first participant group was 4.2. The reason why the other participant groups rated the speakers lower might be that they compared it more to the other two scenarios. This order effect is only present in the trust scale of the speaker only scenario and not in any of the other scenarios or scales.

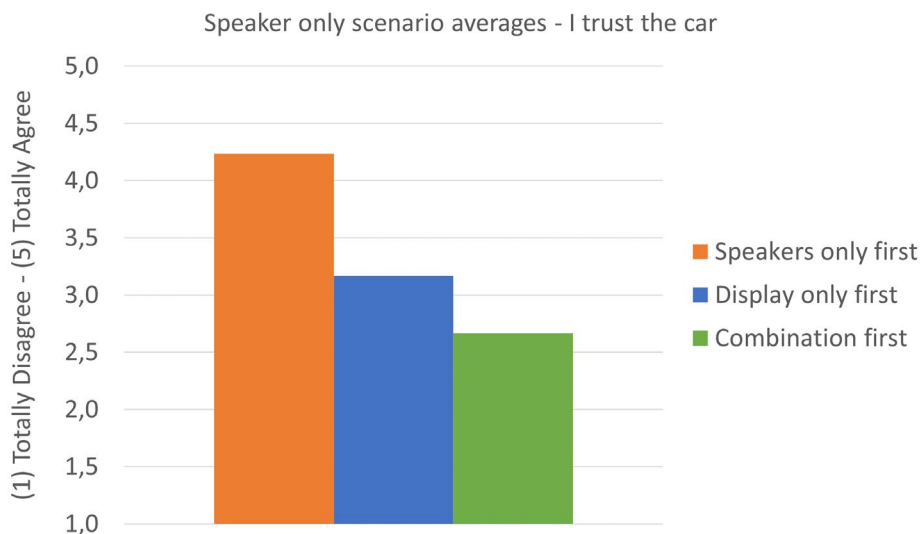


Figure 28. Average plot of the trust scale for the audio only scenario showing the difference depending on which scenario participants experienced first.

Contrary to the quantitative results, the qualitative analysis indicates that there are benefits of using both the display and the speakers to help users build trust towards the AV. More than half (12/23) of participants in Study 2 and Study 3 Qualitative expressed that the dual information channel setup helped them trust the car.

*“Yeah, I trusted the car in this scenario, more than the other two.” (TP 1E, Study 3 Qualitative)*

Nine participants explicitly stated that the dual information channel setup helped them understand what the car tried to tell them.

*“It is evident more than the first few scenarios that the car knows what it is conveying is correct and that I can understand that, and I do.” (TP 1C, Study 3 Qualitative)*

Twelve participants also stated positive attitudes towards the dual information channel setup in general, such as that they preferred the combination setup over the other ones, that the combination setup was the best, and that the experience was the best in the combination scenario.

*“Overall, the combination of both visual and audio was the best one so far.” (TP 1G, Study 3 Qualitative)*

As for why the participants appreciated the combination scenario more than the other two, this seems to be related to an increased sense of safety.

*“I liked the first [combination] scenario best, having the noise and the dashboard showing the cars surrounding us, that felt a lot safer.” (TP 4D, Study 3 Qualitative)*

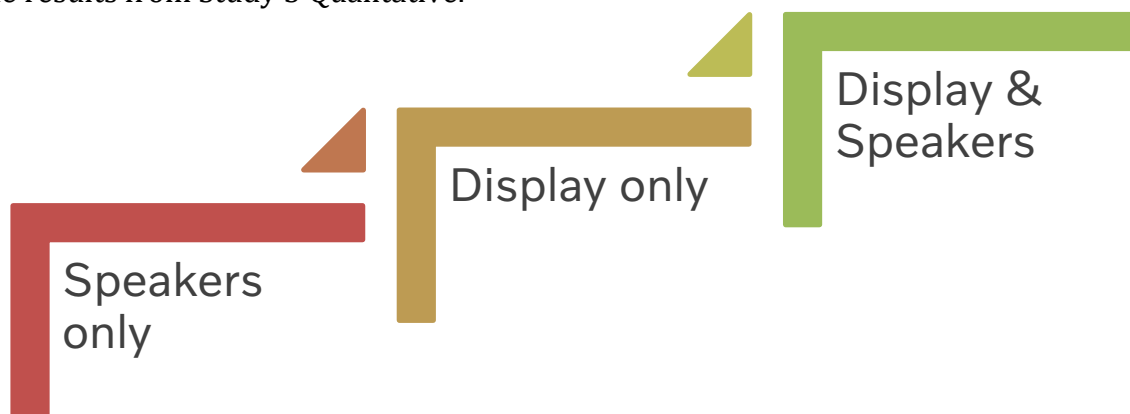
Participants expressed that having both the speakers and display conveying information increased their feeling of being safe and that the combination helped them understand that the car saw and reacted to its surrounding.

*“This creates a full sense of security, things are working, I am safe. Without those [both display and speakers] I’ll be less secure.” (TP 4A, Study 3 Qualitative)*

They also said that the combination scenario felt safer due to the lowered risk of them missing information, that the redundant information presented through the information channels was positive. Having the information presented through both display and speakers reassured them that they would not miss information about what the car is doing.

*“Having the best of both worlds in terms of seeing what the car is planning to do, and also be able to hear it if you are not looking at the screen.” (TP 1G, Study 3 Qualitative)*

Even though the results from Study 3 Quantitative did not show an as clear distinction between the combination scenario and display scenario in terms of trust and understanding as Study 2 and Study 3 Qualitative, there seems to be an increase in user’s trust in, and understanding of the AV when presented with the combination scenario. One of the expert participants in Study 2 expressed that even though the display had a major part in the trust-building, the speakers helped push the trust one step further, explaining it as a sort of logical trust stair, see figure 29. This parable can also be used to describe the results from Study 3 Qualitative.



*Figure 29. Trust stair as explained by one of the experts.*

The increased sense of safety, as well as the participants feeling the car being more in control of its environment when presented with the combination scenario, might be a result of the information gestalt (cf. Ekman, 2020). As the intention of the concepts for

the test was to convey the same information about the car's perception and intentions through the speakers and display information channels, the information gestalt formation might be expressed by the participants as the increased sense of safety.

### 5.3.2 Display

When comparing the speaker information channel and the display information channel, the display seems to be, based on the study, the most important information channel in order to lower users' need to stay vigilant as well as helping them generate more trust in the AV.

*"I understand because there were visuals, I am a visual person. I think that, that is a clear message how the car is thinking, and the decisions being made. I saw them on the screen, so I understood the message and what the car was trying to convey." (TP 4E, Study 3 Qualitative)*

This might be due to the display's inherent ability to convey very detailed information. Participants mentioned that the display conveyed clearer information with a low risk of misinterpretation of the information.

*"There are no misinterpretations in the visuals." (TP 2, Study 2)*

The participants also stated that it is faster to understand and grasp what the car is trying to convey when presented with information through the display information channel.

*"It goes faster to assimilate the graphics." (TP 1, Study 2)*

### 5.3.3 Speakers

Even though the project tried to design longer sounds that aimed to contain more information, the participants' understanding of the message conveyed in the speakers only scenario was lower in all studies (Study 2, Study 3 Qualitative, and Study 3 Quantitative). In the quantitative study, as stated previously, the averages for each item in terms of perceiving the information scored lower than those of the combination and the display only scenario (see figure 27). This trend can also be seen in the results from Study 2 and Study 3 Qualitative. In those studies, 9 participants in total expressed that they either did not understand or that it was harder to understand what the audio information in the speakers only scenario tried to convey. Participants stated this after experiencing the speakers only scenario.

*"This [speakers only] is even worse. I don't have a feeling of what's happening, I just see that the cars are switching lanes. This is not for me." (TP 4E, Study 3 Qualitative)*

Participants in both Studies 2 and 3 voiced concerns that the amount of audio information used through the speaker information channel could be annoying and result in an information overload during longer driving sessions. The scenario lengths for Study 2 were around 8 minutes whereas for Study 3 the scenario length was 3 minutes. Still, the project's sounds seemed to guide the participants' attention towards the outside video or the display, similar to Study 1 (see chapter 3). The audio information generally needed more explanation to understand what the car tried to convey, similar to the quote above. Participants in Studies 2 and 3 said that the display helped them to understand the information presented through the speakers.

*“The noise is just now reaffirmation that the display that we see is correct and the car is reacting to its environment.” (TP 1C, Study 3 Qualitative)*

A few participants mentioned that there was a misfit between the car’s action and the sound when changing lane to the right. The sound played in the ‘Modern’ scenarios had a pitch shift downwards, indicating a deceleration. The participants did not feel that the deceleration sound matched what the car actually did, which were more of a constant speed and merge to the right.

*“When it changes lane to the right, I was a bit confused cause I thought it slowed down, which did not match up with what I saw on the screen.” (TP 2D, Study 3 Qualitative)*

#### 5.3.4 Realistic representation of reality

In Studies 2 and 3, the participants expressed the need to verify what they saw on the DIM and what they heard from the car with “reality”, the outside video. The participants felt a need to confirm that there was actually a car or object where the car signalled it to be. In relation to this, the participant expressed positive reactions towards the ‘Classic’ concept, especially towards the representation of the surrounding cars as cars in the DIM. The theme ‘realistic representation of reality’ was added during the analysis sessions due to participants positive comments towards the more “real” representation of objects in the ‘Classic’ concept. They expressed that they would want the display to show a semi-truck, construction work, etc. if that was what the car perceived rather than having the white, “ghost-like”, perception boxes that were used in the three initial scenarios. The realistic representation of objects surrounding the car seemed to help the participants generate more trust towards the system in comparison to the previous scenarios. This was stated in relation to the ‘Classic’ scenario where the nearby cars on the DIM were shown as “real” cars rather than the white ghosts:

*“Yes, I trusted the car. [...] you could clearly see what the other vehicles were.” (TP 1D, Study 3 Qualitative)*

The participants saw the graphics in the ‘Classic’ scenario as an improvement over the ‘Modern’ concept which led them to express trust towards the car.

*“The visuals are better as well. Much better. Yes, I did trust the car. Maybe more than the other [scenarios] ones.” (TP 1E, Study 3 Qualitative)*

During the test when participants reached the ‘Classic’ concept, they expressed that they preferred the sounds in the ‘Classic’ concept rather than the initial three scenarios. In the ‘Classic’ scenario there were two types of sounds; the overtake sound that used the sound that an ordinary turn signal on a car uses, and a perception sound that is a more conventional notification ‘pling’. The turn signal sound was appreciated by the participants who stated that it was easier to understand than the other scenarios.

*“It was obvious with the chime and it turned the [turn] signal on, and it made the manoeuvre.” (TP 1G, Study 3 Qualitative)*

Some participants also appreciated the ‘pling’ sounds in the ‘Classic’ scenario over the initial scenarios, stating that it alerted them, and conveyed the sense of urgency that they wanted. There are thus conflicting ideas between the designers and the user here. The designers intended to convey the perceptive information without alerting the user, to convey that the car has seen the object and that you, the user, do not need to react to that. The participants misunderstood the intended message from the designers. In the test, some participants thought that the intent of the test was to help them be more vigilant on the road.

*“This [classic] is perfect. This is what I’ve been saying from the first video. The audio is now a bling and there is a sense of urgency. Hey, you need to react to this.” (TP 1C, Study 3 Qualitative)*

The ‘Retro’ concept was met with a lower trust score than the other concepts as can be seen in figure 30, with a similar trust score as the speakers only scenario.

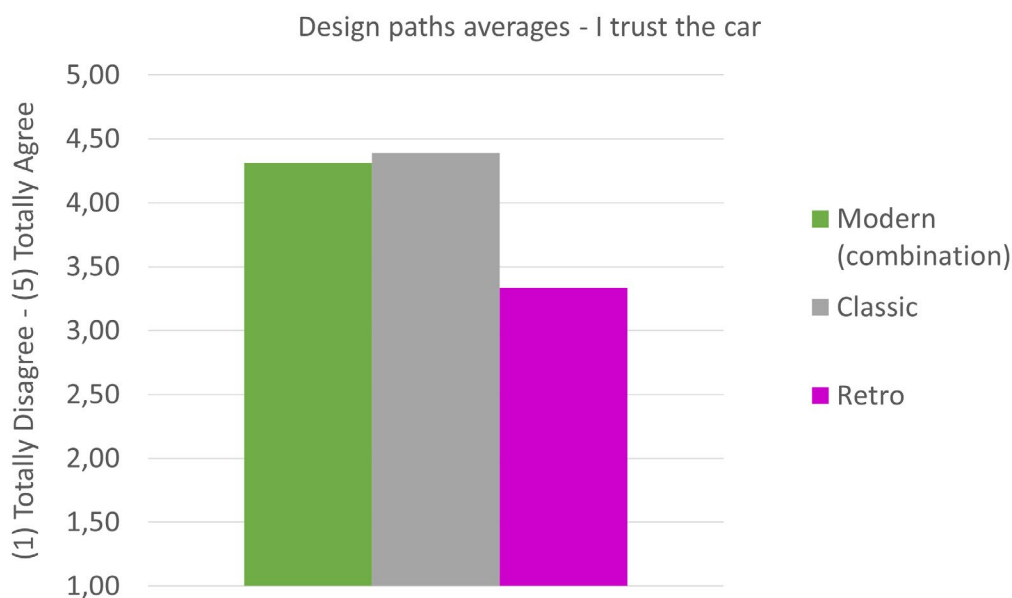


Figure 30. Averages on the trust scale for each of the design path.

The qualitative study showed that participants felt that the more playful graphics trivialized their safety, that driving is something serious and it should be taken seriously, something that they did not think the aesthetics of the ‘Retro’ concept did. Some participants still recognized that the ‘Retro’ scenario conveyed the same information about the car’s perception and intentions as the previous scenarios, but still expressed lower trust towards the ‘Retro’ concept. Still, there seemed to be something fun with the ‘Retro’ concept as participants often started laughing during the scenario.

### 5.3.5 Driving Behaviour & Vigilance

Similar to findings in Ekman et al. (2021) and the previous Study 1, Studies 2 and 3 showed that driving behaviour had a major impact on the participants' expressed trust with the car. Many participants based much of their trust on how the car drove and handled obstacles on the road, such as keeping a good speed and distance to the cars ahead.

*"I can see that the car is maintaining a good distance to the car ahead. [...] Yes I did [trust the car in this scenario], I felt the car maintained a good speed, and the car was aware of its environment." (TP 2C, Study 3 Qualitative)*

In total, 10 out of the 23 participants expressed that the driving in the scenarios was safe and expressed positive comments in relation to the car's driving behaviour.

Roughly half of the participants expressed that you should always stay vigilant when you are in traffic, even though the car is self-driving.

*"Yes, you always have to stay vigilant during a drive." (TP 2B, Study 3 Qualitative)*

Self-driving cars are still in the early stages, you still must be vigilant in case anything happens.

*"Well, I am always vigilant, so that's how I am. But now that you are telling me that it is a completely AD, but I always keep my eye on the road. I will stay vigilant of the traffic as we are in the early stages of self-driving and you never know how a car could react." (TP 2C, Study 3 Qualitative)*

## 5.4 Discussion

The results from the study conducted by Fagerlönn et al. (2020) lead the project to assume that the speaker only scenario would have a greater impact on users' trust than the quantitative results showed. The mean value on their rating scale between 1 ("not at all") to 7 ("completely") was 6.0 when asking the participants to indicate their agreement with the statement: "The sounds contributed to a feeling that I could trust the car to behave safely in traffic". This can be compared with the lower mean value from Study 3 Quantitative of 3.36 on a 5-point scale for the speakers only scenario.

As stated earlier in the results of Study 3, it can be seen that participant tended to give the speakers only scenario a higher score on the trust scale, if it was the first scenario that they experienced in the test (mean value of 4.2). Based on the previous statement, the decision of dividing which order the participants got to experience the scenarios in Studies 2 and 3 was correct. One reason for the deviation, on the trust scale in the quantitative study, could be that the participants rated the information channel scenarios in comparison to each other, rather than rating how much they agree with the statement on trust for that specific scenario. The choice of a 5-point scale could also have an impact on the deviation. If the participants compared the information channels, their initial rating for the first scenario would be their point of reference, do they trust the next scenario more or less than the previous one. The 5-point scale only allows for two scores for agree, 4 and 5. So if the participant still felt that they agreed with the statement of trusting the car and selected 4 for the display only scenario, they would be forced to select a 3 for the speakers only, if they want to highlight that they trusted the speakers only scenario less than the display only scenario. If a more sensitive, 7-point scale had been used instead, the participant of the quantitative study might have been able to express the increase in trust and understanding that can be seen in the qualitative study. This is also supported by the fact that in the qualitative and expert studies, the participant still expressed that they trusted the car in the speakers only scenario, and not stating that they did not trust or were neutral, which are the options in the rating scale.

The chosen content for the information channels was the car's intention and perception of other vehicles. Based on the article by Lee and See (2004) it can be said that if the user understands the automations algorithms, the user will tend to trust the automation. Therefore, the results from Study 3 Quantitative on the two scales, "I understood what the car planned to do" and "I understood what the car saw" can be seen as supporting and strengthening the validity of the users expressed trust in the trust scale.

Based on the shorter scenarios that were used in these studies, as well as that participants expressed concerns that the sounds could get annoying over time the role of the speaker information channel should be further investigated. The speakers might have a role to play in the early parts of a drive, to give the user an extra verification that the car is in control and reacts to its environment. After a while on the highway, however, the speaker could take a more passive role and mainly highlight the car's intention and the perception(s) that are directly connected with the car's intention and actions. This complies with the findings in the study by Ekman et al. (2016) that recommend having a flexible approach based on the users' needs when it comes to the extent of information that should be presented to the user.

Based on the results from Study 1, it was believed that the guiding properties of sound, as well as the negative comments towards the sound, were connected to short and alarming sounds only. The project, therefore, designed longer, softer, and more relaxing

sounds, for Studies 2 and 3, to see if these could convey more information and trigger more positive comments. What can be seen in the results in Studies 2 and 3, however, is that many participants still did not understand what the sounds meant. Some participants stated that the display helped them to understand the sounds. A few participants mentioned that there was a misfit between the project's sounds and the car's actions. It was also noted that the attention guiding properties of sound was not changed by designing longer, softer, and more relaxing sounds.

It is important to note that the haptic sensation of the driving behaviour was missing and perhaps, more importantly, the participants did not experience any risk associated with the car's actions. When comparing the participants' reactions between Studies 1, 2, and 3, it is quite clear that all participants in this test were more relaxed and did not have the same visceral reactions as observed in Study 1 where risk and driving behaviour were present factors.

The Study 3 test setup did not allow for follow up questions. There might be more to find as to reasons behind why the participants thought the combination scenario was the better one, but the test method only allowed for the participants to answer pre-defined questions. They were free to comment freely, but as the participants recorded themselves answering the questions without the presence of an interviewer, no follow-up question could be asked.

The participants learned and gained a better understanding of the system throughout the three initial scenarios. The qualitative data points to that the participants who experienced the combination scenario before the speaker only scenario stated that they understood the speaker only scenario quite quickly. This trend is not seen in the quantitative data, and it is not obvious from the data that this would have any major effect on the results.

#### 5.4.1 Design Implications

Based on the results from Studies 2 and 3, it can be seen that the visual 'Modern' interface would have built more trust if it had shown the objects around the car with a more realistic representation instead of showing all vehicles and objects like white 'ghosts'. To do this, some inspiration could be taken from the 'Classic' concept that was met with positive comments when it comes to a more realistic representation. Based on the results from Ekman et al. (2016), it was assumed that the 'Modern' concept would have a transparency level somewhere between their 'Ring' concept and 'God view' concept. As the participant in their study preferred the 'Ring' concept over the 'God view' the assumption for this study was that 'Modern' would be preferred over the 'Classic'.

Participants also mentioned that a serious expression was trusted more than a playful one, something that the 'Classic' concept was also appreciated for compared to 'Retro'. However, when the market for automated vehicles matures, it is believed that users will also want to be entertained in the car, possibly creating a need for more playful interfaces like the 'Retro' concept, where the user can get a more playful and possibly fun experience when using an automated car.

The intention sounds could be redesigned to better match the respective intentions that they are supposed to convey. This has to do with matching the pitch change to the acceleration or deceleration of the car. When the car brakes, the sound should change from a higher to a lower pitch and when the car accelerates, the pitch should increase, from a lower to a higher pitch. When the car changes lanes without accelerating or

decelerating, this has to be conveyed with a sound without any pitch increases/decreases like the ones used in sounds for acceleration or deceleration. For example, when indicating lane changes, the sound conveying a right lane change in the 'Modern' concept could be used, without the decreasing pitch.

# 6 Guidelines for Information Channels in AVs

## 6 Guidelines for Information Channels in AVs

The guidelines are based on the findings from the literature, Study 1, Study 2 and Study 3. The guidelines aim to give an overview of all the findings and help the future design of information channels in AVs.

### 6.1 Method

The first stage of the development of the guidelines was to summarize the findings from the executed studies. The findings were formulized into an initial draft of the guidelines. The draft was discussed during an expert review together with a PhD-student. The feedback revolved around the formulization and structure of the guidelines. The guidelines were then refined based on the feedback.


### 6.2 Results

These guidelines focus on the roles of the information channels, how they should work together as well as what type of information is suitable to present through them.

IC	Guideline (what)	Effect (why)	Source
Display	Use a display to show information with a high degree of detail.	Increase understanding of the car's perception of other vehicles and the car's intention. Create a feeling that the car 'understands' and reacts to its environment.	Study 1, Study 3 & (Ekman et al., 2016).
Display	Use a display to help users learn the audio information.	Decrease the learning curve and increase the understanding of the audio information presenting the car's intention and perception. Decreased need for the user to stay vigilant.	Study 2 & Study 3.
Display & Speakers	Design the information in the ICs to support good guessability and learnability for first time users.	Decrease the learning curve and prevent disuse.	Discussion.
Display & Speakers	Adapt the information presented through the speakers and display over time as the user learns the system.	Decrease the risk of information overload.	Study 2 & Study 3.
Speakers	Use audio information through the speakers to direct attention to the display.	Decrease the risk of missing visual information.	Study 1 & Study 3.
Speakers	Present audio information through speakers before the car takes action.	Prepare the user and reduce motion sickness.	Study 2 & (Fagerlön et al., 2020).
Display & Speakers	Use multiple ICs to convey critical information. Redundancy is good if the situation is critical.	Increase the chance of paying attention to information.	Study 1 & Study 3.
Speakers	Design the sounds to be congruent with the actions and information of the other ICs.	A better understanding of information. Positive user experience.	Study 2, Study 3 &

			(Monö, 1997).
Display	Show the distances between the AV and other vehicles through the display.	Increase trust as users understands the car's capabilities and performance.	Study 3 & (Lee & See, 2004).
Speakers	Use perception sounds to convey events that have a more immediate effect on the car's intention and actions.	Reduce the risk of annoyance/information overload.	Study 2 & Study 3.
Display	The visuals in the display should have a realistic representation of the vehicles around the AV.	Enhance understanding and confidence in the system.	Study 3.
Display & Speakers	Present visual and audio information of what the car sees and intends to do.	Increase the trust in the AV.	Study 1, Study 3 & (Fagerlönn et al., 2020; Lee & See, 2004)
Display	Show information about who is in control, over what functions and when.	Could build trust in the AV.	Study 1 & (Erhardsson & Lidander, 2020).
Driving Behaviour	Use defensive and calm driving behaviour.	Increase the trust in the AV.	Study 1, Study 2, Study 3 & (Ekman et al., 2021).
Display & Speakers	Design sounds and visuals to create a comfortable and relaxed driving experience.	Decrease the need to stay vigilant of traffic, a relaxed experience.	Study 1, Study 2 & Study 3.
Display & Speakers	Design the content of the ICs to express the seriousness of driving safely.	Increase the sense of safety and trust in the AV.	Study 3.
Speakers	Use sounds that the users are familiar with, at least initially.	Greater understanding and lower risk of misinterpretation.	Study 3.
Speakers	Design sounds to be clear and relaxing but still distinct enough to be noticeable and not eerie.	Prevents a stressful experience, informs the user about the car's intention and perception.	Study 1, Study 2 & Study 3.





# 7 Discussion

## 7 Discussion

This part of the report discusses the results, fulfilment of the aim, important findings and methods in the thesis project. Societal, environmental, and ethical considerations are also discussed in this chapter.

### 7.1 Results

To answer the research question, the project set up two sub-questions to be answered:

Q1: What are the prominent information channels that affect users' trust?

Q2: How does the integration of multiple information channels affect the users' trust?

Based on literature and Study 1, it can be determined that driving behaviour, display, and speakers have an impact on the users trust in an automated vehicle (Ekman et al., 2016, 2021; Fagerlönn et al., 2020). From Study 1, it can be seen that user's base their trust on how the car handles critical driving situations. This is similar to what Ekman et al. (2021) found that the AVs driving behaviour has a greater impact on users trust in situations the user perceives as a more difficult traffic situation.

The results further imply that, out of the information channels tested in this thesis, the display seems to be the main information channel in terms of building an understanding of the AV. The results also imply that the user gains the most understanding of what the car is going to do, and what actions are required from the user from visual information presented in the display. Based on the work by Lee and See (2004), the assumption here is that through the understanding of the car's perception and intention, the user will tend to trust the AV. Users also tend to look for information in the display when they feel that they need more information in a situation. This can also be seen in Studies 2 and 3 where participants expressed a lack of understanding and information gaps when they were only presented with audio information through the speakers. The role of the speakers seems to help the user prepare for what the car is doing, something also stated by Fagerlönn et al. (2020), as well as guaranteeing that they will not miss information.

For the second sub-question, there seems to be an increase in trust and understanding when users were presented with information through the combination of display and speakers. This is supported by the results from Study 2 and the results of Study 3 Qualitative. The combination of information channels helped the users feel safe in the test.

The main research question:

RQ: How does the design of different information channels together affect users' trust towards the AV?

The answer to the main research question can be seen as two parts, first how the design of the information channels affect trust, and the latter part, how they together affect users' trust. The answer to the last part of the main question is similar to the answer to Q2. Design factors for how to design the information within the individual channels as well as an integrated whole have been identified throughout this project and formulated in the guidelines. As this project decided to test the speaker and the display information channels, the main design factors for integrating audio and visual information in the information channels are: (i) Representation of reality, where the participants expressed that they would trust a system with a more realistic visual representation of the car's perception (Studies 2 and 3). This is something that was not expected as the visual

information presented in Studies 2 and 3 was similar to the God view concept from Ekman et al. (2016) with a high level of system transparency, and the participants of that study preferred a lower level of system transparency whereas in Studies 2 and 3 participants requested a higher level of system transparency. (ii) When designing the content of the information channels, consider a more serious representation of the audio and visuals (Studies 2 and 3), at least initially when introducing a user to automated driving, in order to help them form appropriate trust.

In Studies 2 and 3, we can see that people appreciated more conventional sounds and visuals, with a higher level of realism of objects around the car. The role of the information channels should be considered depending on what type of events occur during a drive, such as conveying the car's intention before the action is taken, to ensure that the user is prepared, even though they might not pay attention to the display. Furthermore, the role of the information channels, how they are used over a longer time is something that should be investigated. From Studies 2 and 3, we can see that the amount of audio information that the users were exposed to could lead to information overload, but there were still participants who felt that the redundant and high amount of audio information was good, at least of the early and initial parts of an automated car ride.

### 7.1.1 Representation

The study performed by Ekman et al. (2016) developed three different object recognition interfaces, the God view concept is similar to the visual information presented in the display that was developed in this project. The former study showed that the God view concept was considered to simplify orientation and that participants could compare objects in the environment with what is shown in the interface (Ekman et al., 2016). The participants also stated that errors in the God view concept would be more obvious than in the other concepts. This project has developed and tested visual information similar to the God view concept. Study 2 and Study 3 show similar results as the study by Ekman et al. (2016), users want to see the vehicles around them represented in the display. When the connection between environment and display was lacking in Study 2 and Study 3, participants expressed that they wanted a more realistic representation of the reality in the information presented through the display.

Based on the studies conducted in this project and the study done by Ekman et al. (2016), it can be concluded that introducing visual information showing the vehicles and objects around the car could create a need in users to see this representation of the surrounding environment with a high level of realism. In other words, for this kind of interface to be accepted by users, it must represent the reality (cars shown as cars, trucks shown as trucks) and be synchronized without any glitches (distance and position of other vehicles matching reality).

A similar theme connected to the audio information was also identified. In Study 2, some participants mentioned that there was a mismatch between the sound and the vehicle's actions during left and right lane changes. This mismatch could be connected to one of the factors, namely *similarity*, to help designers when designing for a clear gestalt (Monö, 1997). In the situations where the mismatch was expressed, the sound indicated a deceleration or an acceleration when the car moved sideways to another lane. The fact that the speaker and driving behaviour did not convey similar information in this situation is believed to have formed the mismatch.

### 7.1.2 Gestalt

From the data of Study 3 Qualitative, we can see that there is an increase in trust when presented with multiple information channels at the same time. However, determining if the meaning when presenting the combination of information channels is greater than the sum of meanings when presenting the individual information channels in isolation is hard. The project would still argue that gestalt could be seen when presenting the combination of display and speakers to users.

In Study 3, the gestalt could be seen as an increased sense of safety when participants were presented with the combination of information channels. The participants expressed that the increased sense of safety was a result of an increased understanding of the system; understanding what the car saw and understanding what the car was going to do. Participants in the studies also mentioned that the audio information guides the attention to the display, and confirms the information shown in the display. Thus, redundancy of information could also be a part of creating the understanding that contributed to the gestalt: an increased sense of safety. Connected to this, the project has also identified a couple of interaction effects between the information channels that was seen in the studies. These are:

- Audio information presented through the speaker channel guides the attention to the display. (Study 1 & Study 3)
- Audio information presented through the speaker channel confirms the information in the display. (Study 3)
- The display information channel helps users to understand the audio information. (Study 2 & Study 3)
- Audio information could be played before the car takes action to prepare the user and reduce motion sickness. (Study 2 & (Fagerlönn et al., 2020))

Since these interaction effects could only be seen when the display and the speaker information channels were presented together, not in isolation, they form a gestalt. As stated before, the display was identified as an information channel that could be used to convey detailed information to the user. With this in mind, a gestalt consisting of interaction effects where the information channels had different roles and helped clarify each other was identified.

## 7.2 Method Adaptations

As the implementation of AVs is still in the very early stages, the ideal participants of Studies 2 and 3 would be people who would have low knowledge of AVs, as it would give input from someone that would resemble a first-time user. Because of the ongoing pandemic, the project had to adapt the choice of participants, strategies, and methodologies to comply with current regulations and general guidelines stated by the government and other Swedish authorities.

Initially, the project planned to develop concept designs of different information channels and test them in a study utilizing a WoOz vehicle on a test track or in real traffic. This setup would have tested the concepts in a realistic setting with risk included. However, this setup was not possible to realize since it would have required four people to be in the same car during the test. Instead, the project conducted a smaller simulator study (Study 2) with five participants at Volvo Cars in Torslanda as well as an online study (Study 3) with 108 participants. The simulator setup enabled the project to prevent the

spread of Covid-19 as much as possible by keeping a safe distance, wearing face masks and disinfecting surfaces inside the car before each test. At the same time, the project could test the concepts inside a real car interior with a driving scenario being played in front of the car. This was considered a good trade-off between the safety and realism of the test setting. Still, the participants of Study 2 were experts on the topic of AV, and it can be assumed that their trust in the automation would not be equal to a participant with low knowledge of AVs as the experts have greater insights into how the AV works.

Still, Study 2 gave good insights as the user's interaction with the information channels were similar to a real car. The speakers were placed on either side of the participant, the driving video was shown outside the windshield, and the display was placed over the DIM. The user had to look down from the outside video to see what happened in the display. The user's interaction with the information channels in Study 3 was more skewed. As the participants were presented with both the outside video and display on a computer screen it was easier for them to look at both videos at the same time.

The project could not expect reliable trust ratings from the simulator study, due to the lack of risk as well as that the participants were experts working with AVs. Hence, the focus was shifted slightly. Earlier in the project, understanding of the automation was identified to be an important aspect to build trust (Lee & See, 2004). Since understanding was considered easier to get reliable results on than trust in a simulator setup the project also focused on identifying when participants expressed an understanding of the information presented in the information channels. As stated previously, this is based on that users will tend to trust automation that can in a reliable manner achieve the user's goals and that the algorithms of the automation can be understood by the user (Lee & See, 2004). However, understanding does not give the whole (trust affecting) picture, it is just one of many aspects that can lead to trust. Therefore, in this project, understanding was used as a complement to the trust scales and questions, adding data to answer the main research question.

As stated before, since Studies 2 and 3 were conducted online and in a simulator, it is evident that the studies lacked the realism and risk that would be needed to get reliable results on trust. Connected to what Ekman et al. (2021) write about perceived risk and task difficulty, it could be argued that a more realistic setting with more risk such as WoOz car would have triggered the participants to evaluate the information channels (such as driving behaviour) more critically with regards to trust. This could have resulted in even higher trust ratings for the combinations of information channels that were already met with a positive attitude and in even lower trust ratings for combinations of information channels that were already met with a negative attitude with regards to trust.

If one assumes that a trust rating of 3 (middle point in scale) can be considered as neutral when it comes to trust, this means that the combination of display and speakers as well as having the display only could have been rated higher with regards to trust in a WoOz study with more risk present. Having speakers only could have been rated the same or with a slight increase with regards to trust. The 'Classic' concept could have been rated higher and the 'Retro' concept could also have been rated slightly higher with regards to trust.

This study has not looked at how speakers and display could work together with driving behaviour, due to the limitations of using a simulator and an online study. However, based on the visual aspects of the driving behaviour, participants did describe the driving

as safe and good in both Studies 2 and 3. It can be assumed that the driving behaviour would not affect the results of the study in a negative way, but the positive results might also be due to the participants basing a large portion of their trust on the car's driving behaviour, something that is mentioned in Studies 1, 2, and 3. When filming the scenario videos for Study 2 and Study 3, the project tried to simulate calm driving behaviour. In a WoOz study, however, it would also have been possible to study the haptic effects of driving behaviour in combination with the display and the speaker information channels. How the information channels affect each other and contribute to an information gestalt in that setup is still unknown.

### 7.3 Considerations

Trust will be a critical factor in the introduction and dissemination of AVs. The ethical, societal, and ethical consequences that the dissemination of AVs may have are discussed in this chapter.

#### 7.3.1 Ethical Considerations

Multiple ethical problems might arise with the implementation of AVs, and in extension, the results of this thesis. Responsibility is something that is already discussed globally. Is the driver or the car manufacturer responsible when an accident occurs? This project looks to design guidelines for an appropriate level of trust. An accident can and probably will occur if a user has an inappropriate level of trust towards the AV. The transparency of information between the driver and the AV is also something that can cause ethical problems. How much information should be conveyed to the driver, and what information does the driver have a right to see? Another aspect to take into consideration is if the user has complete control of which roads the car will take to the destination, as well as if someone else, government or company, can override the route for the car and re-route it.

#### 7.3.2 Societal Considerations

There will be many societal changes given the implementation of highly automated vehicles, some positive and others more problematic. As cars reach higher levels of automation, jobs such as taxi drivers might decrease which in turn might lead to unemployment. People might have the incentive to use automated cars for longer travels that they today would use either train or flight for, which might have positive or negative effects depending on which type of transportation they replace. Another positive societal change will probably be the opportunity for increased mobility for elderly people or people with certain function variations.

Another positive argument for automated cars is the claim that they can decrease the number of traffic accidents. As 10-40% of all traffic accidents in Sweden is related to tired drivers (VTI, 2020). An AV that is unaffected by tiredness have the possibility to take over the driving task on longer routes and during certain times where drivers are more prone to fall asleep behind the wheel. The importance here is that the user has trust in the AV to hand over control and not risk driving in situations where the drivers are unfit to drive.

A positive effect that AVs could have on society could be the option to re-route traffic if emergency services need to get through or an accident happens on a road. As discussed previously, this could be seen as an ethical problem since the user's control over the AV is restricted or removed completely.

### 7.3.3 Environmental Considerations

The introduction of AVs opens for a major change in the whole personal mobility sector where we can transition to mobility as a service, ordering your ride instead of driving your own car. Rather than owning a car, you share the service with multiple people. This would reduce the number of cars on our streets and demand less resources for manufacturing. Companies like *M (Sustainability, n.d.)* and *Lync & co (Sharing | Lync & Co, n.d.)* already have market offers that is based on these ideas. As car-sharing platforms will be used by many different users, designers must take into consideration that many users will be first time users or users that have only used the car a few times. Therefore, designing for a trustworthy and understandable automation is important factors for user acceptance of the AV. The participants of Studies 1 and 3 of this thesis are had low or almost no knowledge of AVs, the insights from the studies can be seen as similar comments and reactions that a first-time user would express. Therefore, the guidelines presented in this report will help designers when designing how information channel should work together and what information should be presented through them during the introduction of AVs.

Transitioning to AVs and mobility as a service would also lead to pedestrians reclaiming the cityscape. Parking space could be reduced and instead turned into parks or recreational areas. These parks would allow for more vegetation in the cities, increasing the CO<sub>2</sub> absorption capacity and creating relaxing and joyful experiences for the inhabitants. Another major ecological benefit in relation to the introduction of AVs is the simultaneous electrification of the drivetrain. The development of automated driving systems goes hand in hand with electrified drivetrains. One example of this is the electric car manufacturer *Tesla* that is at the forefront when it comes to developing automated driving systems as well as electrified drivetrains (*Autopilot, n.d.*).





# 8 Conclusions and Recommendations

## 8 Conclusions and Recommendations

The main research question that was formulated for this thesis project was:

RQ: How does the design of different information channels together affect users' trust towards the AV?

To answer the main research question, the project also formulated two sub-questions, these were:

Q1: What are the prominent information channels that affect users' trust?

Q2: How does the integration of multiple information channels affect the users' trust?

Study 1 and the literature study helped determine that the prominent, in building trust, and commonly used information channels were the display, speakers and driving behaviour. The display information channel was identified to be the main information channel when it comes to building an understanding of the AV. The speakers prepare the user for what the car is going to do, guides user's attention to the display and confirms the information shown in the display. The driving behaviour has been identified to be an important component when building trust towards AVs. A defensive driving behaviour was shown to build trust in the study done by Ekman et al. (2021). Even though the project could not test the haptic aspects of driving behaviour in the studies, it could be seen that the visual dimension of the defensive driving behaviour that was present in Studies 2 and 3 was perceived as safe and good, similar to Ekman et al. (2021).

For the sub-question of how the integration of multiple information channels affect the user's trust, there seems to be an increase in trust towards the AV when the users are presented with the combination of the display and the speaker information channel compared to being presented with the individual information channels respectively based on Study 3. The project would also argue that an information gestalt could be seen when presenting the combination of display and speakers to users in Study 3. The information gestalt emerged as an increased sense of safety when users were being presented with the combination of display and speakers compared to the individual ICs in isolation. When the combination of display and speakers were presented, different interaction effects between the ICs could also be identified. These were:

- Audio information presented through the speaker channel guides the attention to the display. (Study 1 & Study 3)
- Audio information presented through the speaker channel confirms the information in the display. (Study 3)
- The display information channel helps users to understand the audio information. (Study 2 & Study 3)
- Audio information could be played before the car takes action to prepare the user and reduce motion sickness. (Study 2 & (Fagerlönn et al., 2020))

These effects could only be seen when the combination of the display and speakers were presented. Since the combination of ICs conveyed something more than the sum of each IC, these interaction effects can also be seen as an information gestalt.


Factors for how the design of different information channels together affect users' trust towards automated vehicles have been identified for the display and speaker information channels. A serious-looking display interface and conventional sounds that the users are familiar with has been shown to increase trust. A playful interface will not be taken

seriously when it comes to traffic safety. The project has also concluded that showing a realistic representation of reality in the display will increase the understanding and consequently the trust towards the AV.

From the findings of this thesis, there are still topics that need further investigations. Both Studies 2 and 3 were conducted in risk-free environments, opposed to being in a car in real traffic. The trust a user feels towards the automation might differ if this was conducted in a real driving car. A similar study could also evaluate the role of driving behaviour in contribution to gestalt formation.

Another topic that needs to be further investigated is how users are affected by the perception and intention sounds that were tested in Studies 2 and 3 over a longer time period. Overall, investigations of the roles of the information channels over a longer time horizon and if their roles will change over time are required. Studies 2 and 3 as well as the earlier study conducted by Fagerlönn et al. (2020) were relative short tests. Investigating the roles of the information channels over a longer time horizon and if their roles shall adapt over the time of usage. Further research on how to integrate audio information but still enable the user to distinguish the sounds whilst listening to radio or music is also needed.





# 9 References

## 9 References

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# 10 Appendices

Appendix A – First codebook (Study 1)

Appendix B – Trust codebook (Study 1)

Appendix C – Expert test structure (Study 2)

Appendix D – Online qualitative test structure (Study 3)

Appendix E – Online quantitative test structure (Study 3)

Appendix F – Final themes in thematic analysis

Appendix G – Histogram of likert-scales from online study (Study 3)

## 10 Appendices

### 10.1 Appendix A

# First codebook

(As it looked after the first round of coding)

- Pilot Assist (PA)
    - PA Start
    - PA End
    - PA Comment
  - Traffic Jam Pilot (TJP)
    - TJP start
    - TJP end
    - TJP Interference
    - TJP Comment
  - Interface
  - Errors
    - Mode Confusion
    - Comission (surprise)
    - Omission
    - Failure
  - Trust
  - Error
  - Question
- Main code
  - Sub-code

## 10.2 Appendix B

# Trust codebook

(As it looked after the second round of coding)

- Information channels
  - Displays
  - Steering Wheel
    - SW PA
    - SW TJP
  - Audio (Artificial)
  - Audio (Human Voice)
  - Seatbelt
  - Driving Behaviour
- Trust
  - Do trust
  - Do not trust
  - Misuse
  - Disuse
- Reaction
  - Positive
  - Negative
  - Neutral
  - Understood
  - Not Understood

- Main code
- Sub-code
- 3<sup>rd</sup> level code

## 10.3 Appendix C

# Expert test structure (Translated from Swedish)

[SANITIZE EQUIPMENT]

We will not record anything during the test, your answers and comments will remain anonymous after the test.

### Initial questions

1. What is your area of expertise?
2. How old are you?

Now you are welcome to sit in the simulator car and put on the seatbelt.

### Intro

You will now experience a scenario where you drive on a stretch of highway and receive information through the display or audio speakers or both at the same time. The scenario will start when you are entering the highway and stop when you are exiting the highway. Most of the driving will be spent in automated drive, then the car is driving by itself and you can just sit back and enjoy the drive.

### Show first scenario

For the start of the scenario we want you to put your hands on the steering wheel like you were driving by yourself.

[START SCENARIO]

10 s into the scenario: The car has now entered automated driving, you can let go of the steering wheel, sit back and enjoy the ride.

[SCENARIO ENDS]

Rating Scales:

[PARTICIPANTS SCAN QR CODE AND FILL IN THE SCALES IN THE QUESTIONNAIRE]

- I trust the car. [5-point Rating Scale: Totally disagree, Somewhat disagree, Neutral, Somewhat agree, Totally agree]
- I perceived the information presented as useful. [5-point Rating Scale: Totally disagree, Somewhat disagree, Neutral, Somewhat agree, Totally agree]
- I perceived the information as reliable. [5-point Rating Scale: Totally disagree, Somewhat disagree, Neutral, Somewhat agree, Totally agree]
- I felt that I understood the information that was presented. [5-point Rating Scale: Totally disagree, Somewhat disagree, Neutral, Somewhat agree, Totally agree]
- The information helped me relax. [5-point Rating Scale: Totally disagree, Somewhat disagree, Neutral, Somewhat agree, Totally agree]

Trust questions:

- Did you trust the car in this scenario?
- Did you understand what the car tried to convey?
- Did you feel the need to stay vigilant during drive?

### **Show second scenario**

For the start of the scenario we want you to put your hands on the steering wheel like you were driving by yourself.

[START SCENARIO]

10 s into the scenario: The car has now entered automated driving, you can let go of the steering wheel, sit back and enjoy the ride.

[SCENARIO ENDS]

Rating Scales:

[PARTICIPANTS SCAN QR CODE AND FILL IN THE SCALES IN THE QUESTIONNAIRE]

Same scales as before.

Trust questions:

Same questions as before.

### **Show third scenario**

For the start of the scenario we want you to put your hands on the steering wheel like you were driving by yourself.

[START SCENARIO]

10 s into the scenario: The car has now entered automated driving, you can let go of the steering wheel, sit back and enjoy the ride.

[SCENARIO ENDS]

Rating Scales:

[PARTICIPANTS SCAN QR CODE AND FILL IN THE SCALES IN THE QUESTIONNAIRE]

Same scales as before.

Trust questions:

Same questions as before

[REMIND THEM TO SEND IN QUESTIONNAIRE]

### **Post scenario interview**

1. How was your experience of the different scenarios?
2. How did it feel to only be presented with information through the visual or audio?
3. How did you feel being presented with information from both the display and the speakers?
4. Did the information channels present the content equally?
5. Do you have some other thoughts?

## 10.4 Appendix D

# Online qualitative test structure

### Initial questions

- Are you using headphones? [Yes/No]
- Do you have a valid driver's license? [Yes/No]
- Rate your general attitude towards technology
- [7-point Rating Scale: Very sceptical to Very trusting]

### Show first scenario

You will now experience a scenario. View it and keep your comments until the questions in the next step.

- Did you trust the car in this scenario? – please elaborate [Verbal response]
- Did you understand what the car tried to convey? – please elaborate [Verbal response]
- Did you feel the need to stay vigilant of the traffic during the drive? – please elaborate [Verbal response]

### Show second scenario

You will now experience a scenario. View it and keep your comments until the questions in the next step.

- Did you trust the car in this scenario? – please elaborate [Verbal response]
- Did you understand what the car tried to convey? – please elaborate [Verbal response]
- Did you feel the need to stay vigilant of the traffic during the drive? – please elaborate [Verbal response]

### Show third scenario

You will now experience another scenario. View it and keep your comments until the questions in the next step.

- Did you trust the car in this scenario? – please elaborate [Verbal response]
- Did you understand what the car tried to convey? – please elaborate [Verbal response]
- Did you feel the need to stay vigilant of the traffic during the drive? – please elaborate [Verbal response]

### Post scenario questions

You will now be asked to answer some questions regarding all three previous scenarios.

- How was your experience of the different scenarios? [Verbal response]
- How did it feel to only be presented with information through the visual or audio? [Verbal response]
- How did you feel being presented with information from both the display and speakers? [Verbal response]
- Did the display and speakers present the content equally? [Verbal response]

Show Classic scenario

You will now experience a different scenario. View it and keep your comments until the questions in the next step.

- Did you trust the car in this scenario? – please elaborate [Verbal response]

Show Retro scenario

You will now experience the last scenario. View it and keep your comments until the questions in the next step.

- Did you trust the car in this scenario? – please elaborate [Verbal response]

## 10.5 Appendix E

# Online quantitative test structure

### Initial questions

- Are you using headphones? [Yes/No]
- Do you have a valid driver's license? [Yes/No]
- Rate your general attitude towards technology
- [7-point Rating Scale: Very sceptical to Very trusting]

### Show first scenario

You will now experience a scenario. View it and answer the scales after the video. You do not need to speak out loud for this test.

- I trust the car. [5-point Rating Scale: Totally disagree to Totally agree]
- I perceived the information presented as useful. [5-point Rating Scale: Totally disagree to Totally agree]
- I perceived the information presented as sufficient. [5-point Rating Scale: Totally disagree to Totally agree]
- I perceived the information presented as reliable. [5-point Rating Scale: Totally disagree to Totally agree]
- I perceived the information presented as too much. [5-point Rating Scale: Totally disagree to Totally agree]
- I understood what the car planned to do. [5-point Rating Scale: Totally disagree to Totally agree]
- I understood what the car saw. [5-point Rating Scale: Totally disagree to Totally agree]
- I felt the need to stay vigilant. [5-point Rating Scale: Totally disagree to Totally agree]
- I perceived the information presented as accurate. [5-point Rating Scale: Totally disagree to Totally agree]
- The information helped me relax. [5-point Rating Scale: Totally disagree to Totally agree]

### Show second scenario

You will now experience a scenario. View it and answer the scales after the video. You do not need to speak out loud for this test.

Same scales as before.

### Show third scenario

You will now experience a scenario. View it and answer the scales after the video. You do not need to speak out loud for this test.

Same scales as before.

### Show Classic or Retro scenario

You will now experience a different scenario. View it and answer the scales after the video. You do not need to speak out loud for this test.

- I trust the car. [5-point Rating Scale: Totally disagree to Totally agree]

Show Classic or Retro scenario

You will now experience the last scenario. View it and answer the scales after the video.  
You do not need to speak out loud for this test.

- I trust the car. [5-point Rating Scale: Totally disagree to Totally agree]

## 10.6 Appendix F

# Final themes in thematic analysis

- Multimodal is good
  - Multimodal increase understanding
  - Multimodal increase trust
  - Display presents clear information
  - The visual explains the sounds
  - People appreciate to see what is around the car
  - People appreciate to see what the car is going to do
  - Visual is key for reducing vigilance
  - Audio and visual together helps reducing vigilance
  - Display is better than Audio, remarks when the display is not there
  - Always needs to stay vigilant when driving
- 
- Representation of reality, a truck should be shown as a truck
  - Small details are important
  - Less information results in participants thinking that the car has more capabilities than it has
  - Likes sounds that is close to reality
  - People want to confirm sounds (sounds fill the role of vestibular forces) with reality
- 
- Audio intention, Acc/Decc should match reality
  - Audio perception, the sound and display has different roles
  - The animation did not suffice
  - Display conveys information over a longer time horizon, sounds should be played before the event happens, sounds should have clear rules (when they are played)

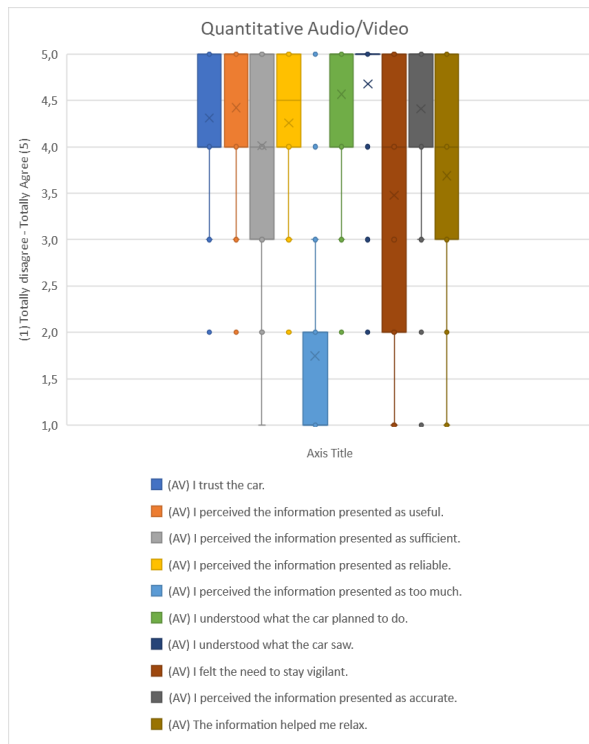
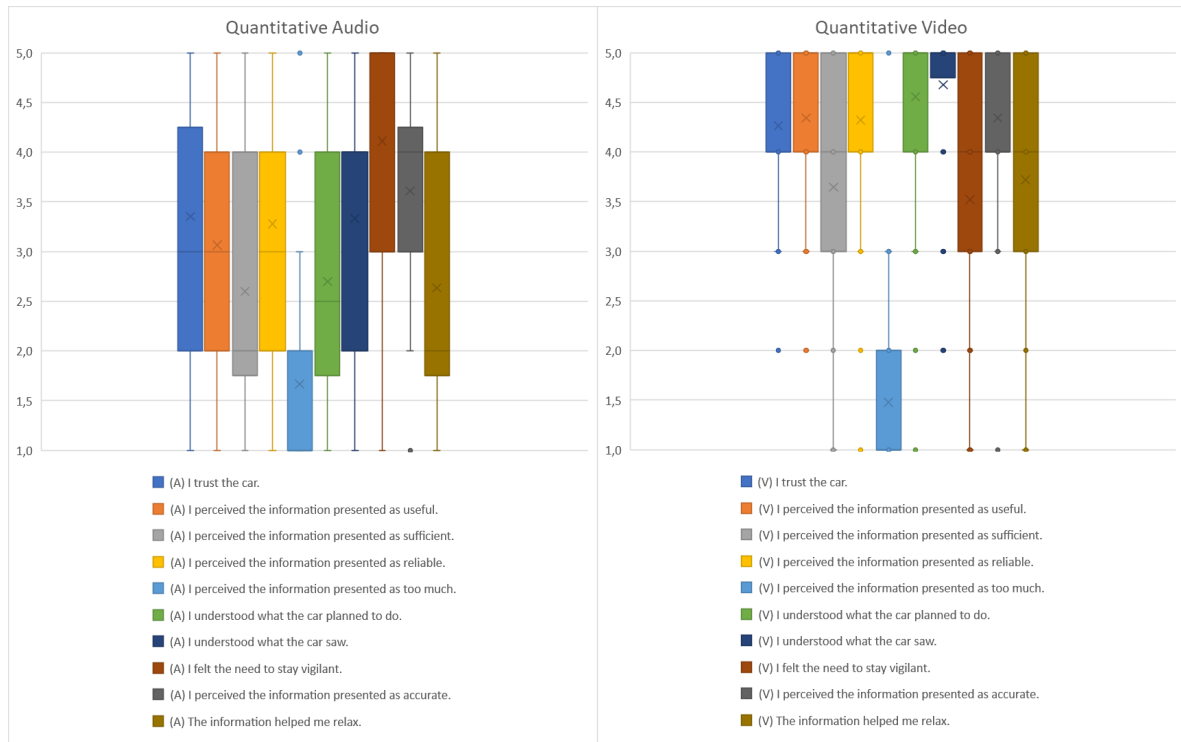
### Sounds:

- Do not understand
  - No trust
  - Audio is bad
  - Uneasy/negative feelings
  - Audio is good
  - Relaxing/calming
  - Sounds grab attention
  - Information overload, all perception sounds is too much information
  - Sounds should be able to turn on/off
  - Display retains the attention
- 
- Good driving behaviour
  - Driving behaviour is a fundamental part of building trust

- It's the same
- Funny
- Serious interfaces creates trust
- Trust comes by learning in the short-term perspective

## 10.7 Appendix G

# Histogram of rating scales from the online study







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