Master of science thesis

”MAKE-NO-SOUND”-SOUNDS

Viktor Broo & Anna Tengroth
Supervisor: Fjollë Novakazi & Justyna Maculewicz
Examiner: Lars-Ola Bligård

Department of Industrial and Materials Science
Division Design & Human Factors
Chalmers University of Technology
Gothenburg, Sweden, 2019

Master of Science Thesis (IMSX30)

”Make-no-sound”-sounds

In collaboration with Volvo Cars Corporation

Master’s thesis in Industrial Design Engineering

© Viktor Broo, Anna Tengroth 2019

Chalmers University of Technology

SE-412 96 Göteborg, Sweden

Phone +46(0) 31 - 772 10 00

Cover Image: Kim Palmqvist, PALMQVIST MEDIA

Print: Repro Service Chalmers

ABSTRACT

The automotive industry is moving towards automated driving, this transfers more of the dynamic driving tasks from the driver to the system. While full automation is not available as for now, today's automated driving system such as Adaptive Cruise Control (ACC), which supports in longitudinal control, and Pilot Assist (PA), which supports in both longitudinal and lateral control of the car, is in the forefront of creating a more automated driving experience for drivers. A more automated driving situation creates a need to keep the driver aware and informed of how and when the system is aiding their driving.

This project aimed to improve the user experience of a driver using the two assistive function ACC and PA, through the enhancement of auditory feedback. In order to do so the main goal was first to understand the current user experience of drivers using these functions. The information was gathered through a use study consisting of survey answers, a use test and interviews with both experienced and inexperienced users as well as a benchmark of current vehicles equipped with the same or similar functions.

The result of the project was the introduction of the term "Make-no-sound"-sounds, a new type of auditory feedback to inform the users of their mode status. "Make-no-sound"-sounds are a collection of sounds that guides the user into a behavior that is preferred and provides them with the opportunity to retrieve information without looking away from the road. These sounds were the result of three tests, with their basis in the use study, done to investigate whether the user experience could indeed be enhanced through providing a broader sonic environment for the two functions at focus.

A final concept using these sounds as the only auditory feedback for PA was tested. This resulted in a set of guidelines of how to use subtle auditory feedback to enhance the user experience of driving a second level automated vehicle. These types of sounds should not be used for warnings of high level. Secondly, they are non-intrusive, does not disrupt the driver and can be played multiple times without being considered annoying and as such will enhance the user experience of the driver using the assistive function.

This project was a master thesis written during the spring of 2019 at Chalmers University of Technology and conducted in collaboration with Volvo Cars Corporation.

ACKNOWLEDGEMENTS

Before reading the report it is important to know what made it possible. First, we would like to thank Volvo Cars who have been extremely generous with their time and expertise as well as sharing their venues. With this said we want to give a special thanks to Justyna Maculewicz who was the supervisor from Volvo Cars side throughout this process and gave us the contacts and advice we needed to be able to do this master thesis. Fjollë Novakazi was also a supervisor and was there for the project group during the entire project and helped with whatever was needed and supported us with the report as well as emotionally. Lars-Ola Bligård was the examiner at Chalmers throughout the project and his advice and calmness affected the outcome of this project and mostly the wellbeing of the project group so a big thanks is deserved upon him as well.

We would also like to thank all of the wonderful people who agreed to participate in our tests. Thank you for your feedback and spirit, your contribution was invaluable. Also thank you to our acting coaches where the project group got the opportunity to learn more about a new way of presenting user experience.

Not to forget the enormous thanks that Kim Palmqvist and Palmqvist media deserves for helping create a film that visualizes the final concept!

Finally, what made this thesis possible was the funding from Vinnova Sweden's Innovation Agency who funded the Seamless Efficient and Enjoyable user-vehicle inteRaction (SEER) project which this thesis, 2016-04238, is a part of.

TABLE OF CONTENT

1. INTRODUCTION 6
1.1 AIM AND RESEARCH QUESTIONS 8
1.2 PROJECT SETTING 9
1.3 PROJECT PLANNING AND DEVELOPMENT PROCESS 11

2. LITERATURE REVIEW 14
2.1 FUNCTIONS AND GUIDELINES 15
2.2 RELEVANT THEORETICAL CONCEPTS 20
2.3 AUDIO 22

3. CONTEXT AND PROBLEM DEFINITION 26
3.1 MARKET AND CUSTOMER RESEARCH 27
3.2 RESULT AND ANALYSIS 33

4. CONCEPT DEVELOPMENT 39
4.1 TEST 1 – TESTING SOUNDS THAT ARE NOT REGULAR ON AND OFF SOUNDS 40
4.2 TEST 2 – INTRODUCING “MAKE-NO-SOUND” - SOUNDS 46
4.3 TEST 3 – TESTING A LONG AMBIENT NOISE AS A “MAKE-NO-SOUND” - SOUND 53
4.4 THE FINAL CONCEPT 62
4.5 DISCUSSION OF FINDINGS 65

5. GUIDELINES 67
5.1 WHAT ”MAKE-NO-SOUND”- SOUNDS CAN COMMUNICATE 68
5.2 LOWERING OF VOLUME AS A ”MAKE-NO-SOUND” - SOUND 69
5.3 MUFFLED FEEDBACK AS ”MAKE-NO-SOUND” - SOUND 70
5.4 AMBIENT NOISE AS ”MAKE-NO-SOUND” - SOUND 71
5.5 CATEGORIZING ”MAKE-NO-SOUND” - SOUNDS 72
5.6 WHEN TO USE WHICH ”MAKE-NO-SOUND” - SOUND 73

6. REFLEXIVITY AND FUTURE WORK 74
6.1 REFLECTIONS ON DESIGN APPROACH 75
6.2 FURTHER WORK 77

7. CONCLUSION 79

8. REFERENCES 81

APPENDIX 86

1. INTRODUCTION

There are several forecasts predicting a high availability of high level (level 2-4) automation in cars by 2040. Todays automated driving systems (ADAS) such as ACC and PA will create the backbone of future mobility (Watzenig and Horn, 2017) and a growing interest in driver assistance and automated features is seen in car manufacturers today according to the European Road Transport Research Advisory Council (ERTRAC, 2017). This shift transfers more and more aspects of the driving tasks from the driver to the automated systems in the cars, which further enhances the need to keep the driver vigilant and enable them to make safe assessment regarding the traffic situation that they find themselves in. According to ERTRAC (2017) automated driving must be a part of European transport as a way of creating a sustainable future mobility that contributes to a high quality of life (ERTRAC, 2017). Some of the predicted benefits of a more automated traffic environment are safety, social inclusion, lower emission, better road utilization as well as a better integration of public and private transportation. Automated driving will reduce the human error factor in traffic situations, which creates a safer transport environment and will also optimize traffic flow as well as help elderly and physically impaired with their mobility (Watzenig and Horn, 2017). On the way to full driving automation, lower levels of driving automation are a natural step where the driver has partial control of the dynamic driving task (Feron, 2015), meaning the driver's role changes from being an active driver to a supervisor. Due to the increase of automated features, which relieves the driver of having to be as active as before, there will be inevitable occurrences where the lack of attention may lead to hazardous traffic situations. By providing multi-sensory feedback regarding the current situation to the driver such occurrences can be prevented (Feron, 2015).

Alongside the development of connectivity technology and smartphones the automotive world develops the automated driving support functions like ACC, PA, automatic emergency brake and more systems, which are becoming a standard in current cars on the market. These types of functions are relieving the user of certain driving tasks and due to this their behavior as well as their driving experience is changed. Different studies show that second level of automation functions reduce the number of critical situations in traffic (Malta et. al., 2011) making the movement towards autonomous drive desirable. However, with the increase of automation in the car, the driver might prioritize secondary tasks and decrease in vigilance while driving, creating a hazardous situation where the user looks away from the forward roadway direction.

This master thesis investigates the automated features that exists today, mainly PA and ACC. Further the current behavior of the driver as well as their experience of driving with these functions as a way of understanding their needs is considered during this study. These two functions are evaluated, because of indications that there is a lack of information provided to the drivers making them uncertain of what the automated features are able to do and what the drivers' responsibilities are. Today's cars provide a number of auditory feedback to the driver but lacks range in the auditory environment, meaning that they all sound similar to one another. This thesis digs deeper into the auditory feedback in cars and tries to broaden the sonic environment as a way of enhancing the driving experience and creating a better communication between the automated driving functions and the driver. As a result, design guidelines, where a wider range of auditory feedback is presented as a way of enabling this communication was developed which support the development of future feedback for a better user experience when using PA and ACC.

1.1 AIM

The aim of this master thesis is to improve the user experience of the driver of a vehicle equipped with a second level of automation function by enhancing the audio feedback. The main goal of the thesis is to understand the user experience of the driver when using the assistive functions PA and ACC, as well as determining how to provide feedback to the users to make them aware of when the functions are supporting their driving.

The deliverable of the thesis is a set of design guidelines regarding how the feedback should enhance the user's experience and create an efficient, safe and enjoyable driving situation. Use tests will be performed in order to assure that the different concepts will create the aspired experience and lo-fi prototypes of this redefined experience will be produced for the tests.

1.2 PROJECT SETTING

The master thesis covers 30 ECTS credits and is part of the master's program Industrial Design Engineering at Chalmers University of Technology and is written at the department of Industrial and Material Science. The master thesis is written together with Volvo Cars in Torslanda specifically at the department User Experience Center. Most of the work is conducted at Volvo Torslanda the rest is done at Chalmers Johanneberg. The master thesis is part of the Seamless Efficient and Enjoyable user-vehicle inteRaction projects also called the SEER project which is a collaboration between Volvo Group Trucks Technology Advanced Technology & Research (GTT ATR) together with Volvo Cars Digital User eXperience Development Center, Semcon Sweden AB Design Department /UX group (Semcon) and Viktoria Swedish ICT Göteborg (Viktoria). It is via SEER that this project has been funded and was able to be conducted.

1.2.1 BACKGROUND SEER

SEER stands for Seamless Efficient and Enjoyable user-vehicle inteRaction and is a project that is conducted from January 2017 to September 2019. This thesis is held in cooperation with Volvo Cars Corporation (VCC) which is responsible for User eXperience development in cars, advanced engineer and research. VCC has competencies required for the interactive systems within the car such as UX design, cognitive psychology, user insights, interaction design etc.

Car and truck drivers today have grown accustomed to a certain seamless, connected interaction and infotainment functions with effortless usability from the high-end market with consumer products. With the growing trend of automation within the car industry some of the driving related tasks are taken away from the user, possibly changing their behavior. The result of this change, in terms of user experience and safety, requires investigation.

The SEER project regards the feedback provided to drivers using second level of automation in cars, the level of automation that supports the driver but still demands them to constantly pay attention to the road. Specifically, these cars possess function such as PA that helps the driver to steer as well as to keep the distance from the other surrounding cars and ACC which supports the user in keeping to the speed limit as well as adapting the speed to the car in front of you (NHTSA, 2018). During these kind of driving situations there is a great need to redefine the feedback presented as most of the feedback provided only stimulates the visual sense with sparse supporting auditory and haptic warnings.

The expected outcome of the SEER project is that there should be a set of methods for evaluating secondary tasks in driving scenarios. Human-Machine Interface (HMI) concepts should also be evaluated in realistic driving scenarios and at least six peer reviewed publications should be published in scientific journals as well as five master theses should be issued, one of them being this thesis. Lastly, an HMI design and evaluation recommendation should be formulated.

1.2.2 DEMARCATIONS

This thesis focuses on the feedback provided to the drivers of vehicles equipped with partial assisted and partial automation functions. The user experiences that aims to be enhanced refers to the driver but aims not to make the experience for other users such as passengers worse. Although it is possible that the results of the thesis, potential

concepts, might be implemented into vehicles equipped with a higher and/or lower level of automation, these will not be taken into consideration. The thesis investigates to what extent senses such as, but not limited to, audition and haptics can enhance the user experience. The visual sense is ever-present during research and testing but is not the subject of investigation for the thesis and none of the proposed guidelines is solely focusing on making improvements for this sense. All prototypes created for the thesis is done in a quick-and-dirty manner, meaning used for describing an idea quickly until enough time is given to do a more careful one. None of the prototypes produced can be implement into an existing interface or system without further refinements.

The guidelines produced is taking Human Factors Design Guidance for level 2 and level 3 Automated Driving (National Highway Traffic Safety Administration, NHTSA guidelines) into consideration. The developed guidelines are focusing on enhancing the user experience whether that lie in the scope of these guidelines or not. Further development will be to fully take these guidelines in consideration as to not disable the opportunity to sell cars in the US market where these guidelines are recommended to be followed and sometimes function as laws (NHTSA, 2018).

1.2.3 ETHICAL CONSIDERATIONS

There are several ethical aspects that must be considered during the thesis. Volvo works towards ensuring four of the seventeen Sustainable Development Goals adopted by the United Nations in 2015, more specifically number 3, 9, 11 and 13. (Volvo Group, 2019). The guidelines aimed to be produced during the thesis will be measured and steered towards ensuring the same goals.

Although the thesis aims to improve the experience of users using personal vehicles the aspect of improving an industry that stands for a quarter of Europe's CO2 emissions has not been taken into consideration (Grelier, 2018). The question remains: is it ethically viable to improve the experience in a way that might lead to more frequent use of vehicles that are an environmental hazard?

Further, it should be considered that the use of a low-level automation vehicle, which aids the user in their driving, might reduce the frequency in which drivers have to use the brake rather than come to a slow-down just by releasing the gas pedal. The CO2 emissions from the vehicles increase by sudden acceleration or deceleration and studies suggests that low level automation cars will provide less fluctuating speed effectively contributing to less emissions (Liu et al, 2017).

By improving the experience of the user and creating a more fluent and efficient stream of feedback the societal aspect of edging closer to Vision Zero, that there should be no fatalities or serious injuries involving road traffic, has to be taken into consideration (CityLab, 2014). Any change or improvement in the feedback system needs to bear this in mind and be directed towards achieving this goal.

1.3 PROJECT PLANNING AND DEVELOPMENT PROCESS

The methods included in the project follow the user-centered methods taught in the Industrial Design Engineering education. These methods are part of an iterative process where the focus is first placed on getting to know the user as well as the problem thoroughly. This happens through interviews, observations and research studies, before entering the design and redesign phase. The benefit with the methods used is that they encompass a lot of testing, especially in early phases through quick and dirty tests and low-fidelity prototypes.

The leading research questions guiding the work during the master thesis were the following:
What kind of feedback is needed in a vehicle with second level automation to enhance the driver's user experience?
How could auditory feedback enhance the user experience and inform the driver of the level of automation they are experiencing?
How could subtle auditory feedback nudge the driver to use these functions in the right way?

In general, the double diamond method was used but with a slight modification as the second diamond was redone due to the iterative process (see figure 1). In general, the method consists of four phases where the scope is either broadened and extended or defined and narrowed down (Design Council, 2019).

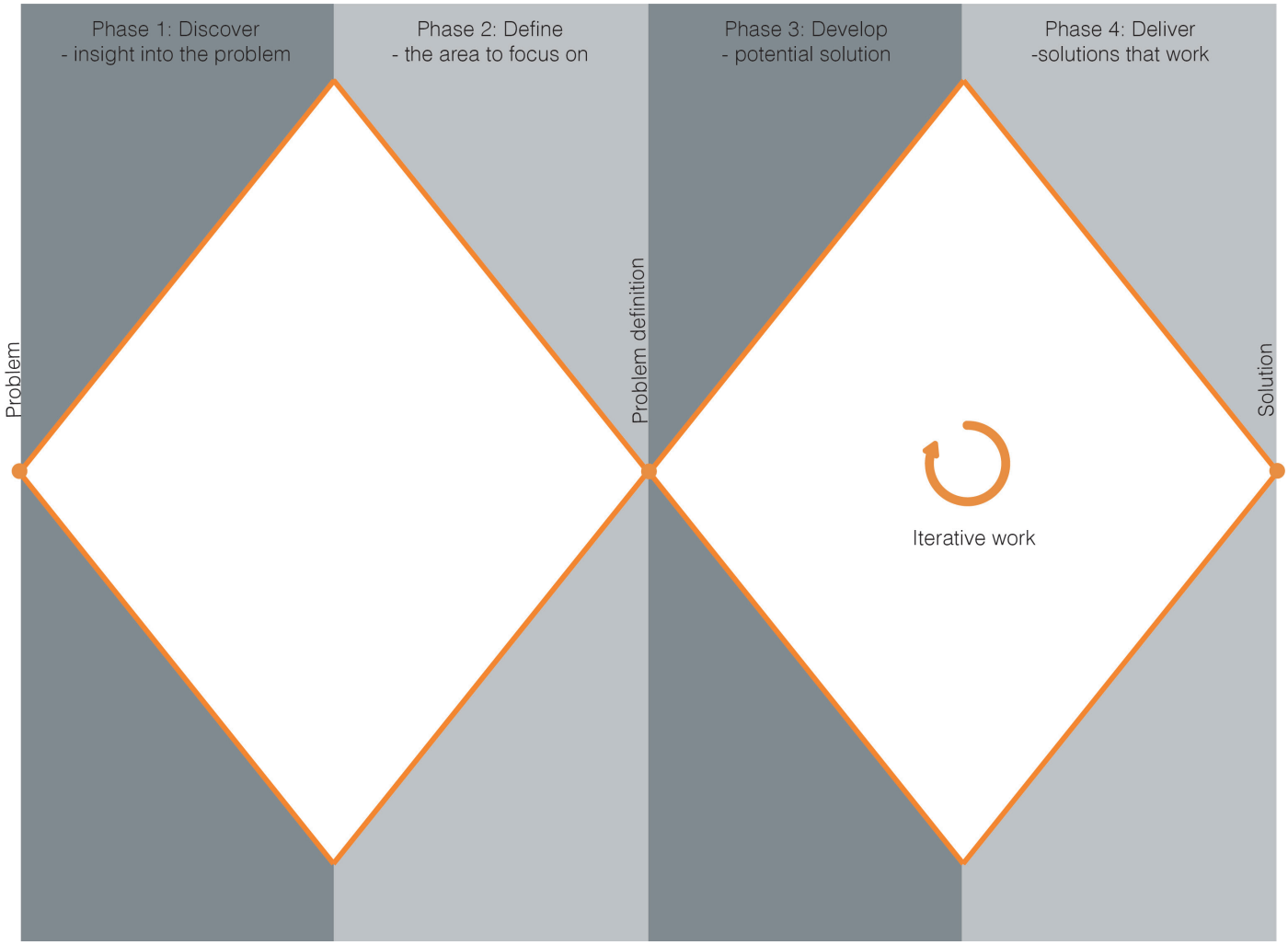


Figure 1: An illustration on the double diamond method that was used during the thesis

The first phase consists of discovering, which broadens the view of the problem and gives the project important insights for the future. It consists of methods that collects information and gave the project group a deeper knowledge of the system, user, vehicles and auditory feedback in general. Because of the great amount of general information and knowledge retrieved from this phase the results from it are presented both in the literature review, the context and problem definition as well as in each respective test where it was deemed relevant. In the first phase the main literature study was conducted where information regarding feedback was received as well as information regarding second level automation in cars and general information of human reaction to stimulus from different senses, with a primary focus on audio. Even though the main part of the literature study took place in the first phase it was complimented and redone when new information was deemed necessary to investigate further.

In the second phase of the double diamond methodology the information retrieved from the previous phase was synthesized. This is the phase where the perspective and scope are narrowed down by defining what area to focus on, resulting in a clear problem definition (Design Council, 2019).

In the third phase the perspective was broadened again, and several design proposals and sound ideas were developed from the information retrieved from the first diamond in the model. This phase was the most iterative and a constant literature study was done in order to retrieve new information that was relevant for the specific hypothesis or theory that the current test focused on. Three major tests were done in this phase. Each one testing a different hypothesis that was based on previous tests, on the user study, the system knowledge as well as the literature study, as well as previous studies and the information retrieved through them.

In the fourth phase the results from the tests in phase three were analysed and synthesized into a set of guidelines of how and when to use non-intrusive auditory feedback. A concept of how to implement these guidelines was produced called “Make-no-sound”-sounds.

The designs retrieved from the third phase are defined and synthesized which is the start of the last phase where prototypes are build, tested and evaluated. As this is an iterative process the third and fourth phase was redone until a set of guidelines and concepts were retrieved and analysed. The end of this phase is marked by the last milestone of finishing the study. In this step, the guidelines and a lo-fi prototype are finalised.

With the double diamond methodology in mind an extensive planning of the project was done as to be able to achieve as much as possible with a good quality. In each section of the double diamond milestones were set, as a way of keeping the schedule and timeframe for the project on track. A thorough plan with clear milestones that is shown in the Gantt chart and deadlines creates a project where time is well distributed giving the project group enough time for creating guidelines and analysis of the material both to acquire enough material for the master thesis as well as for the outsourcer, Volvo Cars.

The Gantt chart method is commonly used and shows activities displayed over time (Gantt, 2019). The main time limit was restricted by the final presentations and the report deadline according to Chalmers University which was held in the beginning of June 2019. As seen in the Gantt bellow (see figur 2) the main milestones were regarding the literature study, the user study and a midway presentation was also done with the design team at Volvo Cars. This midway presentation was a way to be able to review information and input for the continuation of the project and change accordingly.

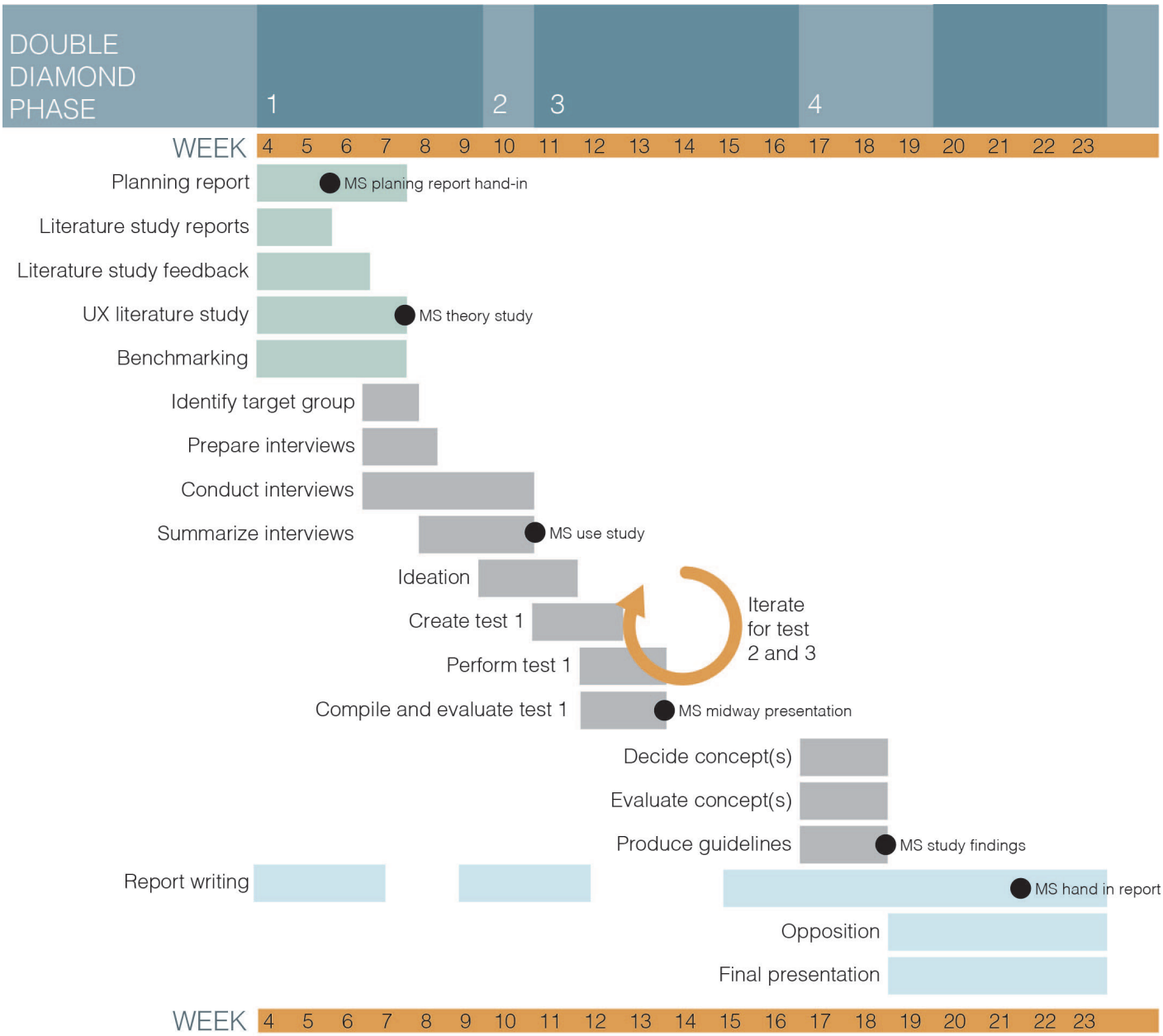


Figure 2: The GANTT chart worked as a method to keep the timeline during the theis

2. LITERATURE REVIEW

Phase 1: Discover

In this section the literature review will be presented, which consists of information retrieved from previous studies and research as well as articles and books. The findings consist of deeper knowledge of the functions as well as theoretical concepts that is relevant for the thesis that will be used further in this report. Most of the literature study was done in the beginning of the thesis but as new information came to light so did the need of new knowledge which is the main idea with this iterative process.

2.1 FUNCTIONS AND GUIDELINES

This part of the literature review describes the functions that is in the cars today as well as terminology that are needed to understand automation in vehicles. The guidelines that the manufactures follow production vehicles (see 2.1.2) was presented as well as how the functions work today (see 2.1.3 & 2.1.4) and what other automation levels exists (see 2.1.1).

2.1.1 SAE LEVELS

The standards organisation Society of Automotive Engineers (SAE) have defined six levels of automation in vehicles which spans from no automation, level zero, to full automation, level five (SAE International, 2014). The different levels define what mechanical technologies the vehicles need to be equipped with, under certain conditions, in order to be classified as a higher level of automation.

Level zero, no automation, means that the human driver is always in full control of the dynamic driving-related tasks, even though the vehicle can be equipped with warning and intervention systems (Campbell et al. 2018). On level one the human driver is still in control of the driving-related tasks but is aided by a driver assistance system of either steering or acceleration/deceleration, however not at the same time. The system uses information of the driving environment to aid the human driver but expects the human driver to perform all other dynamic driving-tasks. As such, the driver still always must be alert and have a high situation awareness with eyes on the road. Level two contains partial automation; the vehicle possesses combined automated functions and can now regulate speed and steering simultaneously. The system still expects the driver to perform all other dynamic driving-tasks, therefore the human driver still must remain engaged in the driving-tasks and continuously monitor the surrounding traffic environment. The third level, conditional automation, demands less of the human drivers' attention as the automated systems in the vehicle now can perform all the driving tasks under certain circumstances. The human driver must be ready to engage in the driving tasks and take over control but will be provided with notice beforehand. This is a key difference between level two and three, in the lower level the human driver might not be given proper notice as to when the assistance systems have been placed in stand-by and therefore must constantly be engaged in the dynamic driving tasks.

The fourth and fifth level, high automation and full automation respectively, differ mainly in the area of option of engaging in driving-tasks. A level four vehicle can perform all driving functions under certain conditions and the driver may have the option to control the vehicle. In level five the human occupant never needs to be involved in the driving task. There are currently no vehicles on the market equipped with level four or five automation. Level two to three is also called supervised driving as the driver must supervise what the car and its automated features are doing at all times. Level four and five is called unsupervised driving as the driver in these scenarios does not need to focus on the driving at all (SAE international, 2014). Figure 3 show the six levels defined by SAE and their differences.

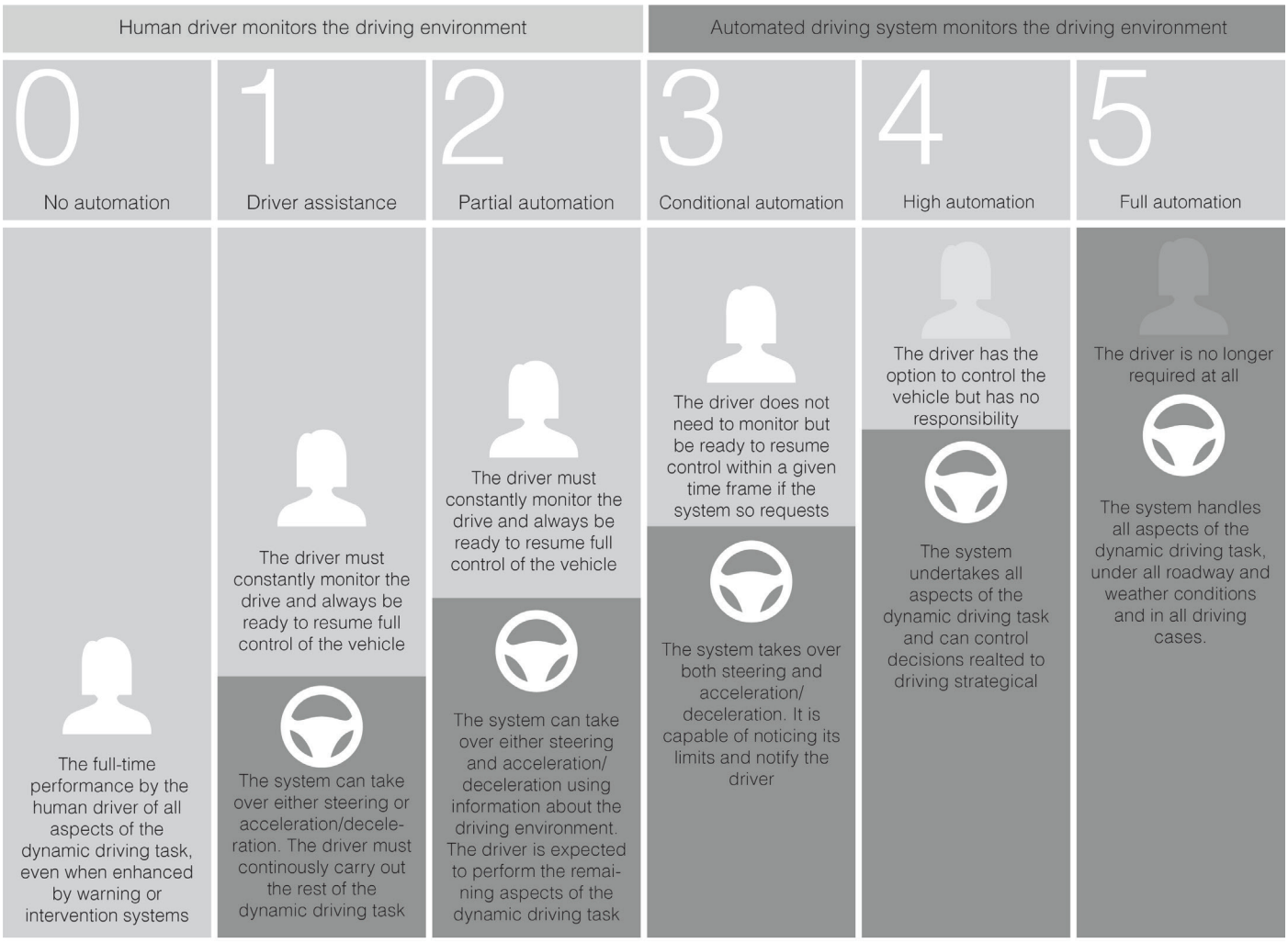


Figure 3: The 6 SAE-levels that show the different levels of automation in cars

2.1.2 NHTSA GUIDELINES

The National Highway Traffic Security Administration (NHTSA) has provided a list of guidelines and recommendations for design and development of Digital Visual Interfaces (DVI) for automated vehicles of second to third level. The list aims to work as guidance for the development of DVIs and does not intend to be viewed as a comprehensive list of rules to follow and in many respects highlight key knowledge gaps and addressing areas where further studies needs to be made (Campbell et al, 2018). The visual interfaces are of primary importance but due to the nature of this thesis the visual guidelines were studied but not of focus. However, presented below is a summary of the key factors mentioned in the guidelines, that are relevant for this study.

The report offers general guidelines for DVIs in level two to three, as well as more specific recommendations divided into chapters regarding visual, auditory and haptic interfaces, message characteristics and drivers input. The general design guidance chapters focus on keeping the driver in the loop of current automation mode, where and how the status of the automation should be presented to them as well as maintaining the driver's mental model. When the

dynamic driving task is shifted more into the automated system the driver needs to be aware of what mode the system is in, meaning the type or level of automation that is active at a particular time. This refers to the specific driving functions that are automated and are relevant for the driver in order to understand the system operation. According to the guidelines the appropriate status feedback regarding automation mode is important for maintaining the driver's situation awareness, communicating if their requests have been received by the system, informing them if the task at hand is performed properly by the system and informing them if there are problems occurring. The guidelines state that this type of information should be provided to the driver through interfaces that are either visual, auditory, haptic or multimodal, meaning it will stimulate more than one sense at the same time.

Regarding message characteristics provided by the system to the driver, the research suggests that safety messages, provided in situations when the driver is not actively monitoring the road, are most effective when they capture the drivers' attention without being distracting, are clear and easily understood, aid the driver in focusing attention on the roadway or the potential hazard, and supports them in making an appropriate response. The guidelines recommend that non-critical messages should be presented in integrated displays. Visual messages are better for providing non-critical messages as the driver may not see them unless they are actively monitoring the road. Auditory and haptic messages work better in providing short and simple messages of quick or immediate action. The guidelines also recommend that both safety and non-critical messages be presented in a multimodal fashion.

The auditory interfaces are useful for capturing and directing the drivers' attention and for presenting information when they are engaging in non-driving related activities. The guideline proposes that auditory interfaces are therefore most useful for presenting the drivers with time-sensitive messages. According to the report, auditory signals can be used for three forms of information: urgency cues, location information and semantic meaning. Urgency cues relates to information provided to the driver regarding the criticality of a situation and/or how quickly the driver has to respond to the warnings. Location information identifies where a hazard is located and where it is coming from. Lastly the semantic meaning regards the implication that the driver attributes to the auditory signal they are provided with, conveying what is happening and which action to take in order to avoid a critical situation. All three forms of information do not necessarily need to be included in one single message, but each of these three components can provide useful information to ensure rapid and correct responses from the driver.

Various characteristics of auditory messages can be modulated to affect the level of salience and obtrusiveness as well as the perception of urgency. The guidelines states that e.g. faster auditory signals (6 pulse/sec), signals that speed up, the use of high fundamental frequencies (1000 Hz) and more urgent words (such as "Danger") will increase the perceived urgency. The trade-off of this is that salient and obtrusive sounds can annoy the driver, instead creating a less desirable user experience. Yet sounds that are not obtrusive or loud enough may go unnoticed. The report presents a masked threshold of about 60 dB at 0-5000 Hz that the auditory feedback should be placed above in a range of 10-30 dB.

The meaning of some auditory signals, e.g. speech messages or auditory icons can be easily understood by the drivers whilst the meaning of other types of sounds, e.g. pure tones, needs to be learned to interpret correctly. It is of importance to keep this in mind when designing auditory feedback.

When it comes to haptic interfaces there are two types that the guidelines approach, vibrotactile and kinesthetic. Vibrotactile interfaces provide information to the driver using vibrations which requires physical contact between the driver and the interface and is therefore best suited for implementation in e.g. seat belts or seat. Kinesthetic interfaces provide information by causing limb or body motion, e.g. the when brake pulse displays cause a sudden jerk motion in the vehicle, causing the driver's body to move. By causing a bodily motion these types of interfaces may help in enhancing awareness of the driver. A common issue when it comes to the haptic interfaces in e.g. the seatbelts is that not every driver uses them and therefore will not be provided with the information they need. As with the auditory interfaces the haptic ones might be deemed as intrusive or disruptive if not implemented in the right way and may risk going undetected if they are not dominant enough.

2.1.3 ADAPTIVE CRUISE CONTROL & PILOT ASSIST (ACC & PA)

ACC also called Active Cruise Control, Intelligent Cruise Control, Autonomous Cruise Control, traffic - aware Cruise Control and Radar Cruise Control is an intelligent cruise control that slows down and speeds up to adapt according to a time-gap set to a leading vehicle (Howard, 2013). This thesis investigates Volvo's function called ACC. By assisting in acceleration and deceleration but leaving the rest of the dynamic driving task to the driver ACC is, according to the SAE, a first level driving assistive function (SAE International, 2014). When using Volvo's ACC, the driver first sets a specific speed that the function keeps, it only works for speeds above 30 km/h. Secondly the system detects a car ahead and adapts the speed to slower moving cars in front of them (Adielsson & Ekman, 2016). Many cars use a radar of some kind but there are also solutions that uses laser and Subaru uses an optical sensor based on stereoscopic cameras to detect vehicles ahead. The radar sensor placed under the bumper or in the grill of the car watches traffic and adapts the speed to a time gap that the driver sets. For the Volvo ACC the time gap that the driver sets vary between two, three, or four seconds behind the leading car. ACC is also often set up with a pre-crash system that alerts the driver and begin to brake in a crash situation (Howard, 2013).

Figure 4: The symbols that appear in the DIM behind the steering wheel for ACC. The right showing when a car has been detected and the left figure showing the symbol for when the function is active

Volvo's PA, assists the driver with steering in addition to acceleration, braking and a set time distance to the vehicle ahead (Volvo Cars, 2019). As it aids in both lateral and longitudinal control at the same time it is a second level partial automation function, according to SAE (SAE International, 2014). The function allows the driver to comfortably follow the flow of traffic by keeping a safety margin towards the vehicle ahead. In addition to keeping an even speed PA positions the vehicle in the center of the lane. PA does not need a leading vehicle for the steering assist to function but requires that the driver keeps their hands on the steering wheel, and control the car at all times. PA sees the lane lines and any vehicle in front of the car with the help of a camera and radar. Through this the vehicle positions itself in the center of the lane and with a sufficient amount of distance behind the lead vehicle (Volvo, 2019). The function cannot handle all traffic situations or weather and road conditions as it loses vision of the lines, when the sight for the sensors or radars is not sufficiently clear. For PA to work properly there need to be clear lines on both sides of the lane and the function might not work when the road is slippery, e.g. during heavy rain or if there is snow on the road. Furthermore, the function might encounter problems in urban traffic or on roads that are too curvy (Volvo, 2019). This information regarding how the functions work are presented to the owner of the car by the car dealer and can always be found in the driver's manual or on Volvo's website (Volvo, 2019).

SCAN THE QR-CODES TO LISTEN TO THE SOUNDS

Apply steering

Cancelled

Photo: Kim Palmqvist

Figure 5: The symbols that appear in the DIM for PA, the green steering wheel is when it is active, the gray is for standby mode, the orange is the first warning for when the hands are not on the steering wheel and the red is when PA is cancelled because no hands were detected on the wheel

2.1.4 HEAD-UP DISPLAY & DRIVER INFORMATION MODULE (HUD & DIM)

In Volvo cars today there are different screens one of them being a Head-Up display (HUD). A Head-Up display is a projection shown in the windshield on the driver's side which enables the driver to retrieve information without averting the eyes from the road. The information shown in the HUD is speed, active assistive functions, an incoming phone call, speed limits etc (Volvo Cars, 2019).

The Driver Information Module (DIM) is the electronic instrument cluster in Volvo vehicles. It is from this display that the driver receives important information of the current status of the vehicle and includes functions such as the speedometer, fuel gauge and tachometer (Schofield, 2019). See figure 6.

Figure 6: The DIM is the information cluster behind the steering wheel and the HUD is the information shown in the windshield.

2.2 RELEVANT THEORETICAL CONCEPTS

In this section relevant theoretical concepts will be presented, such as user experience (2.2.1), situation awareness (2.2.2), mental models (2.2.3), nudging (2.2.4) and mode confusion (2.2.5), theories that will be used frequently during the report.

2.2.1 USER EXPERIENCE

User eXperience (UX) is a term defined as *"a person's perceptions and responses resulting from the use and/or anticipated use of a product, system or service"* (ISO 9241-210:2010). It is a holistic approach to design, meaning dealing with the whole rather than the parts, that puts focus on the human interaction with a system, and occurs before, during and after use. (Roto et al, 2011) The user experience can vary between users and situation but can also change over time as it is dependent on user's skills, personality, attitudes as well as the context in which the product, system or service is used in (Hassenzahl, 2005). When using a product, the user experience includes both, the user and the product. It considers the user's needs, emotions, perceptions, responses, behaviours and accomplishments and the interaction design, information, graphic design, usability and accessibility of the product (Bussolon, 2016).

2.2.2 SITUATION AWARENESS

Situation awareness is defined as *"the perception of the elements in the environment within a volume of space and time, the comprehension of their meaning, and the projection of their future status."* (Endsley, 1995). It deals with understanding the consequences of actions, internal or external, and how events may impact one's goals, either current or future ones. Endsley (1995) has provided a model of situation awareness which consists of three levels of understanding: perception of the elements, comprehending the situation and projecting future status.

To have a high situation awareness while driving is very important, since the driver will be less prone to make mistakes when maintaining awareness over what is happening around them. According to Winsten (2016) 90 % of all traffic accidents are caused by human error and these errors occur due to a lack of situation awareness. The driver should glance left and right, check the rear and side view mirrors and check blind spots every five to eight seconds which often is not done. This issue has increased through the constant use of smartphones which have a large impact on the situation awareness, since they divert the eyes and attention off the road. Despite the laws instituted in many countries the usage of phones behind the wheel is still common. According to Herrera (2014) approximately 80 % use their phones while driving.

2.2.3 MENTAL MODEL

Mental models are the mental representation of entities in the world and the human understanding of it (Johnson-Laird, 1983). The mental models are unstable and incomplete and can develop through time and experience according to Norman (1987). They are also closely related to the systems or products usability and learnability (Norman, 1988). According to Preece (2002) the goals to follow a good mental model are that the artifact is effective to use, efficient to use, safe to use, easy to learn and finally easy to remember how to use. There are, according to Johnson-Laird (1983), two aspects of a mental model; one that is structural and covers hard facts and one functional model that is more dependent on in what context the product is being used in.

2.2.4 NUDGING

Nudging is the idea that you can make people behave in a certain way without them noticing the behavior change or consciously make decisions (Thaler and Sunstein, 2009).

Swedish doctor in psychology William Hagman PhD states that nudging means using psychological mechanisms to frame the decision making in a way that encourages a behavior or decision. Simply put make it easy to do the right thing (Hagman, 2019). According to Hagman the original nudging idea is for the greater good of a single individual, not for a community. But today it is mostly used for pro-social reasons and often when it's both for the greater good of the individual but also the community. Through this type of use corporations can make money out of nudging as long as their customers wants to be nudged.

People who do not have stronger preferences will accept what is presented to them and therefore are more accepting to nudges. Nudging research reasons that what they should be presented with should therefore be the "right" type of information in order to gain the best outcome, whether that be for the individual, the environment or something entirely different.

In his dissertation Hagman presents a model that works as a check-list for the design of a nudge to avoid it being perceived as being manipulation rather than a choice. (Hagman, 2018). Hagman states that the acceptance towards a nudge is controlled by its goal. For example, if one sympathizes with environmental causes one has a higher acceptance level of waste separation. People are more acceptant towards nudges that creates personal gain for them rather than for that for society. A major finding from Hagman is also that the attitude of those behind the idea of the nudge influences how one judges it. For example, it is more likely that one will accept a nudge endorsed by a political party that you belong.

2.2.5 MODE CONFUSION

Mode confusion is referring to the confusion that can arise over the current mode of a certain automation which can lead to a misinterpretation of information or an incorrect action. With the introduction of automated systems in various domains, it can sometimes be difficult for the human operator to track the activities of the system. The result of this can be that the operator is unable to foresee how the system will behave. In short, it is a situation where the system acts in a different way than the user's expectation of the system and has also been called an automation surprise (Sarter et al., 1997). According to previous research and studies this is a serious safety issue within human-machine systems (Bredereke and Lankenau, 2002).

2.3 AUDIO

This chapter is a collection of general information regarding audio. Presented are findings from previous studies of auditory feedback (2.3.1), the impact sound has on the perception of speed (2.3.2), auditory icons (2.3.3), white noise (2.3.4) and how the removal of sounds elicits a reaction (2.3.5). This chapter, as well as results from previous studies, is the background to the three use tests done during the thesis.

2.3.1 AUDITORY FEEDBACK

The human auditory system does not interfere with the visual, and studies show that auditory feedback creates a bigger compliance than just visual alarms (Sodnik et al., 2008, Duffy et al., 2004; Wogalter et al.,1993). A study made by Kang and Montaz (2017) shows that warning systems in cars with auditory feedback increases the driver's attention and improve the driving safety. According to Meng et. al (2016) professional drivers prefers auditory feedback as it can arouse the driver as well as provide information. Studies have shown that the auditory feedback in cars has an important impact on the customer satisfaction (Blauert and Jekosch, 1997). The auditory feedback in vehicles is often used in situations where the drivers risk missing visual signals as well as notifying the driver about impending danger (Edworthy,1994).

SOUND ATTRIBUTES

Sound can be measured and categorized by three different attributes: frequency, amplitude and temporal patterns (Yost, 2009). They all correspond to psychophysical attributes such as pitch, loudness and tempo. A human's experience, expectations and attitude affect their classification of the auditory feedback and therefore a car that has a pleasant sound is often perceived as luxurious (Kuwano et al., 2002).

It has been shown that the sound quality can vary depending on the psychophysical perception of the sound (Lemaitre et. al., 2009). One example of this is the perceived urgency of the sound where if a sound is perceived urgent the user will more easily detect it compared to if it is not. To be able to create a sound that is perceived as urgent it is important to increase the tempo as well as the volume of the feedback (Blauert and Jekosch, 2003). Familiarity also has a great impact on the sound quality, e.g. a sound feedback associated with something else can change the whole perception of the car (North and Hargreaves, 1995). Examples from the study made by Chi et.al. (2016) would be cars with feedback that sounded like alarm clocks or the sound of when a patient's heart stops beating in a hospital. These sounds will be perceived as negative by the user and could therefore not be used for positive feedback.

WARNING SIGNALS

A study by Kim et. al. (2010) resulted in a set of guidelines for designing the warning sounds to accommodate drivers of every age group, including those of greater age which are more likely to suffer from hearing impairments. According to Kim et al (2010) a sound with a frequency of between 3 to 4 kHz will be most effective in terms of physical response i.e. shorter time to brake, indicate a high level of danger and be emotionally preferred by all the age groups tested. The tempo of the warning sound should be about 200 ms to indicate a high level of danger and the intensity level should be 85 dB. In order to differentiate other sounds inside the vehicle from warning sounds Kim et al (2010) suggests a frequency of one kHz and a tempo of 500 ms.

2.3.2 SPEED AND AUDITORY FEEDBACK

It is shown that drivers in general are bad at estimating their own speed which unfortunately is a driving quality of high importance when it comes to accident involvement (Horswill and McKenna, 1999). In a study by Hellier et. al. (2011) where the influence of auditory feedback on speed choice was tested, it was shown that the participants experiencing no noise or low level of engine noise (65 dB) drove at a higher speed compared to the participants experiencing medium to high levels of engine noise (75-85 dB). According to Horswill and Plooy (2008) as little as a change in 5 dB could be noticed by the driver and result in a changing of speed. Despite this it is seen in today's car manufacturing trends to isolate the driver from the engine noise as much as possible hence abandoning these types of auditory feedback. The study by Hellier et. al. (2011) concludes that the engine noise provided by the vehicle does not change the comfort for the user. Isolating the driver from these sounds is an issue. As a large amount of research shows, auditory feedback is crucial for the driver's ability to make decisions regarding their speed (Hellier et. al. 2011). Research has also shown that the drivers in general look towards the auditory feedback from the car and the feedback from the car as well as from the surrounding cars and environment rather than to look at the indicators provided on the screens. This applies even when it comes to seamless displays such as head - up displays (HUD) which have no significant impact on the speed of the driver (Briziarelli and Allen, 1989).

2.3.3 AUDITORY ICONS AND ON AND OFF SIGNALS

According to Chi et.al.'s (2016) study with 21 participants, warning sounds that start with a high intensity and face towards zero is the most preferred by the users. Further according to ISO 7731 (2003) the intensity of the warning sounds inside the vehicle should be around 65 dB to 118 dB. Regarding pitch the auditory warning signals should have a frequency of 1000 Hz to 4000 but according to Chi et. al. (2016), warning sounds with a frequency of more than 2000 Hz were not appreciated by the driver. Further the warning feedback should be composed of four or more different frequency components. This is because a complex sound is much more difficult for the driver to

mask (Patterson, 1982). All warning sounds should also follow the same rhythm, frequency, shape and speed and the number of immediate-action warnings should not exceed five or six in one car. These types of auditory feedback should also be meaningful and make the users react to it and reduce the training needed to understand its meaning (Patterson and Mayfield, 1990).

An auditory icon is deemed the sonic equivalent to visual icons, a sound that the user associates with a particular and strong emotional image. (Gould, 2016) The idea of auditory icons is to support and supplement predominantly visual information with a corresponding sound. The predominant benefit of auditory icons is a tangible confirmation of the action that the user has performed. Auditory icons are most commonly used in the digital world but exists as well in the physical world e.g. the click of a mouse button could be considered an auditory icon. By implementing auditory icons as a complement to visual information the designer can not only add weight to a visual event, but also provide further information about what has happened. Another advantage of auditory icons is the quick transmission of information.

When discussing the different types of auditory icons Gould mentions "metaphorical" icons. These are the sounds that reflect key aspects of an associated action. (Gould, 2016). According to Gould, three short notes going up in scale would largely be heard as a positive statement such as a correct answer, a successful action or an increase in level. Similarly, three short notes stepping down in scale would largely be interpreted as a negative statement. Gould uses the iPhone as an example of different auditory icons and more specifically the Siri-function to demonstrate the characteristics of an on/off sound. Gould states:

"Another mid to high frequency system of sounds that indicate Siri's functionality. This system transforms a double organic ping sound over several pitches to differentiate between information yet maintains a common timbre to denote they belong to the same family."

A typical indication of an "on/off" sound could therefore be interpreted as a shift in pitch in a single sound, a higher pitch for an "on" function accompanied by a lower pitch for turning "off".

2.3.4 WHITE NOISE

According to Green in an article in New York Times (27 December 2018) a white-noise soothes the listener because it replicates an early sound environment. Fred Maher, an audio engineer interviewed in the article, states that *"white noise is one of the first things we hear from our first moments of existence, in the uterus. It is similar to what you hear in a seashell. The shell works as a mechanical filter that focuses and amplifies ambient noise."*

The first white-noise was identified by engineers in the 1920s according to Dr Pigeon (Green, 2018, 27 December) and was defined as the sum of audible frequencies in equal proportions in a single sound.

White-noise and other similar sounds like a car interior, laundromat and air conditioner works as a blanket above other sounds and soothes the listener. It is known to help light sleepers and is also a favored among psychotherapists and among the medical community who seek to mask stressful auditory signals and conversations (Green, 2018, 27 December).

AMBIENT NOISE TOGETHER WITH ACC

In a study done by Larsson et. al. in 2017 an ambient noise created from the sound of wind and waves together with a higher pitch tone was played when ACC was active. The study also tested how the users felt when the ambient noise increased, when the truck was getting closer to the leading vehicle and was lowered if the distance between the two vehicles increased. Finally, a low pitch sound moving right was played when the truck got close to the right lane edge and vice versa for the left. The intensity and direction of the ambient noise was created by using the input from a device that measured the speed of the truck. This test was done with 25 Volvo Truck employees (20 male and 5 female) that drove a truck for 60 – 75 minutes on a highway. From this study it was clear that these drivers enjoyed the ambient noise when a car was detected in front of them which was lowered as the distance increased. It was also shown that low pitch sound adapting to when the truck gets closer to either the left or right edge may have future applications. Having the ambient noise being played constantly when ACC was active was not appreciated but an inverted model where the ambient noise is active when ACC is not, was considered as interesting to investigate, as the hypotheses was that this would be more appreciated. In general, this study gave very mixed answers and few general opinions.

2.3.5 REMOVING SOUND TO ELICIT A REACTION

According to Bizley and Cohen, audition, just as vision, can direct attention towards a particular object through both bottom-up and top-down processes (Bizley and Cohen, 2013). A bottom-up process is a process that is very data-driven and the perception starts with the sensory input. The top-down process, which is defined by the pattern recognition, is highly affected by the context and culture (Sincero, 2013). The disappearance of a sound will in itself not generate a specific reaction through a bottom-up process only but by providing a context a top-down process creates a meaning that could possibly elicit a reaction. In their study Constantino et. al. (2012) show that one detects the appearance of a sound more easily than the disappearance of it. They do however state that this is not true in all cases and that situation and emotional context is of importance, e.g. a discernable reaction to the disappearance of one's child's voice in a crowd.

Phase 2: Define

3. CONTEXT AND PROBLEM DEFINITION

This part of the report will describe the methodology used to define the problem and present the results from the different methods used to get there.

3.1 MARKET AND CUSTOMER RESEARCH

In this section the conducted user and market research will be presented, which serves as a way of understanding the user needs and current market situation. Through this it was possible to detect the research gap concerning the research topic and describe a problem definition.

3.1.1 EXPERT CONSULTATION

In order to gain insights into the current situation of how auditory feedback in constructed in vehicles today, consultations were held with experts within this field. The experts were Pontus Larsson and Fredrik Hagman who are sound designers at Volvo Cars as well as Jens Ahren, associate professor at Applied Acoustics at Chalmers University. The variety in expertise gave a larger picture about the sounds implemented in human's everyday life in general as well as to give insights in how Volvo works with sound more specifically. The thesis authors were new to designing sounds and insights regarding this were crucial for the following work steps. Because of the lack of background information and knowledge about sounds, as well as how to design and work with it, the interviews during the consultations were loose and unstructured so the questions asked were depending on what information was brought up and what was considered relevant and fruitful for the project. Furthermore, Larsson was also present when the third test was going to be conducted. He assisted in the sound design and gave instructions in a program called PureData. In PureData the ambient sound in the car can be induced with input from the car regarding speed. This was done as an attempt to use the sound that is already existing in the car in Test 3. Larsson further pointed out previous conducted tests and gave valuable information regarding the test and hypothesis, which was a great support in understanding results and methods.

According to Ahren, a sound that is to be used to alert a user should be high pitched and fast paced, just as in music the user will perceive the sound as fast paced if it is of a higher tempo than the heartbeat at rest. Sounds and auditory warnings can be recognised intuitively and Ahren was of the opinion that one should not use sounds that contradicts said intuitive recognition. However, some types of sounds have to be learnt to understand and Ahren gave examples of the many possibilities in which sounds could be used to improve the user's experience of their surroundings e.g. usage of sound in architecture to enhance the experience of rooms and buildings.

The sound designers, Pontus Larsson and Fredrik Hagman, were of interest because of their vast knowledge of the impact of sounds in user experience but also because, as they work at Volvo Cars, are experts on the current and future models of Volvo vehicles. There are 53 different sounds used in today's Volvo vehicles and the most important one's are those related to safety, which is a major aspect of the Volvo brand strategy. Whilst Volvo are currently using sounds emanating from instruments for feedback in the vehicles, they have incorporated sounds from nature in the past. One example that was mentioned as a source directly from nature was the fir twig that is recorded, edited and used for the blinker sound in Volvo cars. The fir shows a connection to Scandinavian nature and the Scandinavian heritage of Volvo.

The two also described auditory icons. These are sounds that humans react instinctively to or that have been learned from an early age. Such sounds are useful as they create an almost subconscious reaction, but when used as

warning sounds startle people, and may create the desired reaction but impact the user experience negatively. These sounds are also only effective in the right context and can easily be interpreted as "comical" when they have been processed by a synthesizer. The context of any sound always needs to be considered so as not to create a contradictory response from the driver. The location of the sound is equally important depending on where the sound emanates from, the driver will direct their attention towards that source. The most important use in a vehicle for this is to prepare the driver for an impending collision, either to enable them to avert it or to position them in the right way to cause as little bodily harm as possible. Furthermore, two of the most important features to consider in order to enhance the sense of urgency of a sound is sharpness and loudness.

When it comes to voice control the pair was convinced that this will be more common in vehicles in the future, due to the introduction of it in so many other contexts, like cellphones and households. They stressed that utilizing sounds to convey messages will still be present and work as both complementary to voice control but also on its own in many situations. For example, a voice message should not be repeated many times over if the driver needs a continuous flow of information. Instead a non-sound would be better at conveying the message and urgency in these kinds of situations. They also noted that there are still many pitfalls that needs to be avoided, an example being a correct translation of the messages for each language to continue to be a force on a worldwide market.

VOLVO'S EXPLANATION TO THE DESIGN OF PA

A consultation with Mikael Ljung-Aust, a technical expert within Safety and Strategy at Volvo, provided an explanation for why PA is designed the way it is.

When creating the first generation of PA it was understood that drivers could experience confusion as to what the function could and could not do. The function was programmed with a focus on staying in the middle of the lane regardless of what was in the lane next to the car. This is because PA is a system that sees the road in a very two-dimensional way where surroundings are not taken in consideration for the positioning. For example, when driving next to a truck one would rather position the vehicle closer to the other side of the lane. Another potential shortcoming was that the function could suddenly lose vision of the lane markings or mistake something else for lane markings and position itself according to this. This in return led to the issue of over-trust in the system that needed to be avoided. The decision to not implement any auditory feedback for standby mode was made to avoid over trust by designing PA so that the driver has to be alert at all times.

The biggest issue was that the system could not handle all situations, e.g. sharp turns where the markings would be detected but the system would be unable to turn quickly enough. Because of this the decision was made to not add feedback for stand-by mode as this indicates that the car will always tell the driver when PA is deactivated which was not the case. The development is now taking another direction as the PA function gets better at knowing when it is working and not and will therefore communicate more with the driver.

3.1.2 PREVIOUS CUSTOMER RESEARCH

In a study conducted by Ihlström et. al. (2018) in depth interviews with three end users were performed. The study regards the use of automated features with a focus on PA. The participants were of different ages and had different driving experience as well as knowledge regarding the system. The test was done with Volvo cars from 2017 as PA had been implemented as standard equipment in these then recent cars. The participants were interviewed before they used the car, when they got the car delivery from the car dealership, after one week with the car and finally after four months.

Two of the participants in this study had little faith in the system as they did not understand it resulting in a poor mental model regarding the usage of this function. Having trouble with PA from the start might block future use and result in a poorer development of their mental model of the system. One participant mentioned that according to his mental model the activation of PA looked like a volume button and felt a bit unsafe and pointed out that it was possible to activate the function by mistake. Another participant did not know that PA existed even after driving the car for four months. Two of the participants drew pictures of the sensors when trying to describe their understanding of the system. Even with a good understanding of how PA worked many felt that using the function meant handing over some of the control to the car which made them feel uncomfortable. However, one of the users used PA daily simply because it was available. Still he was uncertain of how and when it was supposed to be used and despite the frequent use of the system, he did not fully trust it. The display in his opinion was good, but he wished to see a better graphical representation of how the function works. The third user had no problem to rely on and use PA frequently. However, he felt that the system lacked a confirmation that would assure him that it was being used correctly.

Overall, the participants felt the need of better understanding how PA worked to remove the fear of using it and to obtain trust in the system (Ihlström et. al., 2018). However, mental models are a simplification and these complex automation systems could only be represented in ways where they resemble the actual system (Norman 1987; Johnson-Laird, 1983).

According to the study (Ihlström et. al. 2018) a more solid theoretical understanding is crucial to be able to use PA, when starting with practical experience the mental model is not as clear and the user does not trust the system as much as they would if the users had obtained some previous knowledge before using it.

3.1.3 BENCHMARKING

A benchmark of other original equipment manufacturers solutions was performed to gain insight into the current market situation and to avoid any biases. Both Volvo and Tesla were tested to better get to know the systems of these cars and understand the differences as well as understanding the car and brand in focus – Volvo. Tesla was chosen as it is in the forefront when it comes to autonomous drive and was considered a good source of inspiration for future work. For the benchmark a Volvo V60, equipped with the latest update of PA, and Tesla Model X equipped with Autopilot see figure 7, were tested by the project group members and another master thesis student. The benchmark was conducted on highways and rural roads between Torslanda and Lerum, two suburbs of Gothenburg. Both rides were conducted on the same route in order to maintain a consistent comparison between the two models. After the ride the tested functions were evaluated against how well they followed the NHTSA design guidelines for level one and two automation.

The focus was put on the general guidelines rather than the specific sensory guidelines in order to keep the benchmark more explorative. The decision to evaluate the cars against these guidelines was done as they are instated as laws in some countries and very strictly followed in other countries. To be able to evaluate the cars in a structured way the NHTSA guidelines were advantageous so as not to miss anything when looking into the systems and driving the cars. The driver recorded their answers in a questionnaire where they rated how well they felt that the functions followed the guidelines on a scale from one to five. There was also space for the driver to provide a more detailed reasoning for their rating. The questionnaire can be found in Appendix 1. The results from the questionnaire was analysed and compiled in a PUGH matrix, presented below. A PUGH matrix is originally a method used to weight concepts against one another (Wikberg-Nilsson et al., 2015, s. 186). In the matrix the requirements, in this case the NHTSA guidelines, are evaluated and each concept, here the two cars, are graded on how well they achieve these. This results in a final grade that can be evaluated and compared with the other concepts. This results in an easily readable and understandable matrix, making it a good method for comparing the results of a benchmark.

The benchmark resulted in a better understanding of the solutions present in today's vehicles. As can be seen in Appendix 1 the models scored very evenly. The Tesla Autopilot scored just a bit higher than the Volvo PA whereas the Volvo's ACC received a higher mark than that of the Tesla. Overall the assistive functions found in the Volvo V60 scored a total of 115 out of a possible 170 and the Tesla Model X scored 113.

Figure 7: Tesla Model X and Volvo V60 the two car models that were tested in the benchmarking.

The major differences between PA and Autopilot For full PUGH score (see Appendix 2) , was that the latter made use of more screen space ultimately scoring higher on such requirements as providing the driver with information of successful transfer between modes, with distinct notifications. However, PA reacted more instantly to a driver's command and the take command instructions were easier to comprehend and follow. PA was found to be more streamlined and did not enable any unnecessary interaction features in comparison to the Autopilot which made use of multiple functions that distracts the driver and takes their focus away from the roadway.

Both assistive functions scored relatively high on providing system status and for using multiple modalities to alert the driver in "take control" situations except when the functions went into standby mode automatically. They both made use of multiple visual warnings that enhanced the sense of urgency by utilizing differentiation in color (going from blue to orange and later a red hue) , as well as complementing auditory warnings in the final escalation level before the function turned itself off. A major difference between the two functions became clear when the driver had to resume full control of the vehicle. PA and Autopilot made use of the same visual message "Apply steering",

which with PA translated into the action of placing one's hand on the steering wheel. When using Autopilot in the Tesla this action was not enough to alert the system that the driver had resumed control, the driver had to "wiggle" the steering wheel in order to continue using the function. This was not intuitive nor explained by the message. The auditory feedback was experienced equal in terms of tone, both were easy to hear over the sound of the car and surrounding traffic.

ACC also scored fairly equally between the two brands with the Volvo being the preferred. The bars used to indicate the distance from the leading vehicle in Volvos system is constantly shown on the screen whereas in the Tesla it is only shown for a brief period of time. The function doesn't provide the driver with a lot of feedback and while driving, a loss of vigilance was experienced. By having a constant reminder of the distance, the driver is provided with a quick reminder that the function is active and which setting has been chosen. The Volvo therefore scored higher than the Tesla on this requirement.

Overall ACC scored lower than PA and Autopilot, this was due to the fact that the driver is provided with less information and feedback from the function. The requirements that the functions were weighed against, were specifically chosen with a focus on feedback and therefore it is not surprising that ACC would score lower. It should be noted, that the function has been present in cars long before either PA or Autopilot (in the form of regular Cruise Control), and due to the normalization of it, the driver's may not need to be provided with as much information as with PA or Autopilot. ACC also scored lower since four of the requirements could not be evaluated as they would require the driver to initiate a situation in which the function would not work, therefore receiving a neutral score of three in these cases.

Due to the limited timeframe given for the benchmark, the weather conditions might not have been optimal for the assistive functions to work properly, as it was snowing and raining during the drives. This is an additional issue with the functions, since no information regarding what weather conditions the function is available in is communicated to the driver. However, the weather conditions were similar during both drives, so the results were still comparable to one another.

3.1.4 USE TEST

In order to gain insight into the user's current experience, internal surveys of Volvo customers were studied first. But to gain a more holistic view a use test was conducted as the design and future solution should have a user focus and fit into the mental model of today's drivers. To be able to enhance the experience of the user, the knowledge of the user today and what he or she feels is crucial so as not to remove something enjoyable but also know where and when the user has an undesirable feeling. The test was also performed to gain insight into the overall experience of the users when driving with the assistive functions.

The use test was conducted with four frequent users of ACC and PA at a test track inside the VCT area at Volvo Torslanda. Each participant started driving with ACC active for 10 to 15 minutes and then with PA for another 10 to 15 minutes, all of which was recorded for a later analysis, so the test leader could be more present during the test. As ACC needs a leading vehicle one group member drove the leading car and the test leader and participant followed in the test car. During the drive, the participants answered open questions regarding how the car

communicated with them and how their experience of the feedback was. It was an open and semi structured interview with a semi structured script (see Appendix 3) to probe the participant to talk freely about the functions and their experiences of them. After the interview for each respective function a User Experience Questionnaire (UEQ) was filled out by the participants (see Appendix 4) The UEQ is a method first created in Germany in 2005 and is a seven-stage scale with opposite words on each side of the scale to elicit if the product conveys a positive or negative user experience (Schrepp, 2019). The method was used to measure how the users felt as well as to be able to compare it with a final concept.

All results from the use test were compiled in a KJ-analysis as a way to elicit what was most common regarding the user experience. A KJ- analysis is a method that groups similar findings to see patterns that could lead to guidelines, requirements or a common view on the problem (Wikberg-Nilsson et al., 2015, s. 68-69). The comments in the KJ-analysis were divided into four sub-sections for each function, the positive and negative aspects of the function as well as the positive and negative function of the feedback provided from each function.

The positive aspects of ACC were the trust it instilled in the user, the comfort they felt in using it and its learnability. The positive feedback that ACC provides lies in the natural response the driver has that it turns off when the user brakes by themselves, indicating that they no longer are interested in using the function. The negative aspects were that the function does not match the driving style of the user's fully in particular the braking, which was either considered too late or too harsh. The negative aspects of the feedback were that there was too little of it, the users expressed that during long rides where they had to intervene by themselves, they would sometimes forget if the function was active or not. The function only provides visual feedback to the user and in order to set the speed and space the user must look away from the road and at the DIM. Therefore, the users expressed the desire of multi-modal feedback or an enhancement of the visuals provided.

When it came to PA the users felt that the function was likable and gave them a relaxed driving experience when used in the right environment, where the lines were clear and the speed limit allowed the function to be active. It was perceived as intelligent and a step towards a fully autonomous driving experience, which was desirable. It was however perceived as less intelligent than ACC and not as easily used. The negative aspects of the function were that it did not feel fully developed yet and did not live up to their initial expectations of the situations it should be able to handle. Examples of this is when it went into standby mode automatically even though the lines seemed to be visually clear enough to the user or that the car positioned the car too far to one side. Therefore, the function was not as trustworthy as ACC. Like ACC, PA did not match the users driving style placing itself too close to the middle line. The use of multi-modal feedback was deemed positive by the users, the haptic feedback in combination with the visual feedback when the system activated was clear and easily understood. However, the instructions provided for when and how the user had to apply steering was more difficult to understand and became frustrating to the users. They also expressed confusion as to why the function went into stand-by mode in certain situation when they were of the impression that the road conditions were such that the function should be able to handle them. The users also found it peculiar that the function provided multi-modal feedback only when the driver needs to apply steering rather than when it deactivates. This particular issue was considered to be one of the biggest issues with PA.

The users view PA as being a child with a lot of potential it is a big step towards autonomous drive but it is not fully grown yet. It however describes clearly the fact that the users expected the function to be able to handle more situations and therefore thought that there is room for development in this area. Many of the users enjoyed PA as it was a high-tech solution that they expressed as being cool which was the main reason why they used it rather than the fact that it was helpful and made driving more effortless. There was an exceptionally high acceptance for the function which in itself is positive.

Overall, it was said that there was a need for more feedback especially when it comes to knowing if the function is active or not. A majority of the participants felt the need of more multi-modal feedback and encouraged more of audio feedback in the features. All participants did however show concerns regarding the fact that there already exist many warning sounds in cars today and to implement more might be annoying and disturb their driving experience.

After analyzing the UEQ results (see Appendix 5) it was confirmed that ACC was the most appreciated function as its results were overall more positive. PA scored lower in terms of being viewed as clear, efficient and safe. PA was also in general not considered as enjoyable as ACC and when compared did not meet the user's expectations. Still, both functions were considered equally friendly and attractive.

The fact that all the users that the test is based on were Volvo employees has to be taken into account. Even though they were not designers of the function it self the bias of an employee towards their company products and services could influence their critical view. Many of the users tested were additionally to this very interested in new technologies especially when it came to automation in vehicles. This might have resulted in comments that were overly positive as they enjoyed technology which other users might consider too complicated or difficult. The test was also relatively short. The user drove for about 10 to 15 minutes with each assistive function which might be too short to be able to really get into how the users feel and elicit deeper thoughts and opinions. This was however necessary to be able to get participants to do the test. The UEQ was a good way to keep the conversation going and to be able to do measurements enabling a comparison between the two functions. The words presented in the UEQ were considered somewhat difficult to understand, as it was not translated from English to the users' native language, which might have affected their answers. English was however chosen to be able to accommodate non-Swedish speaking test participants. This margin of error is considered small because the results seen in the UEQ are similar from all participants and there are no big deviations indicating that the results are valid.

3.2 RESULT AND ANALYSIS

In this section the results from the market and customer research will be presented and an analysis regarding these findings is incorporated in the result presentation.

3.2.1 HTA

A Hierarchical Task Analysis (HTA) was conducted. With this method the main goal of the task is divided into smaller subtasks to be able to understand the performance and necessary actions taken by the user. It also enables the possibility to find critical parts in the system and generate a discussion regarding how and in what order the system is used (Hornsby, 2010).

Two HTA's were constructed, one where the main goal was to drive with ACC and one for when driving with PA (see Appendix 6). It was done with the information that was retrieved from the benchmarking as well as the use test.

From the HTA for PA one critical use case was identified, when the user unwillingly has to go from a semi-automated drive back to manual. This happens when the function loses sight of the lane markings resulting in it going into stand-by mode. When this happens, the user receives a small amount of visual feedback as the PA symbol changes color from green to gray. If the driver's car is not equipped with a HUD, the user has to glance away from the surrounding traffic environment to acquire the information from the DIM.

What makes the use case critical is that at any other moment when the user goes from semi-automated driving back to manual, they do so by providing input to the system. The system provides feedback to the user if they are not applying steering therefore eliciting an input from the driver. However, when the function goes into stand-by through a system initiation (see figure 5 and 8) , it does not provide similarly clear feedback as to how the user should react, there is no explanatory text, as in the previous case nor any signal that will inform the user that they have to provide input by steering man---11--

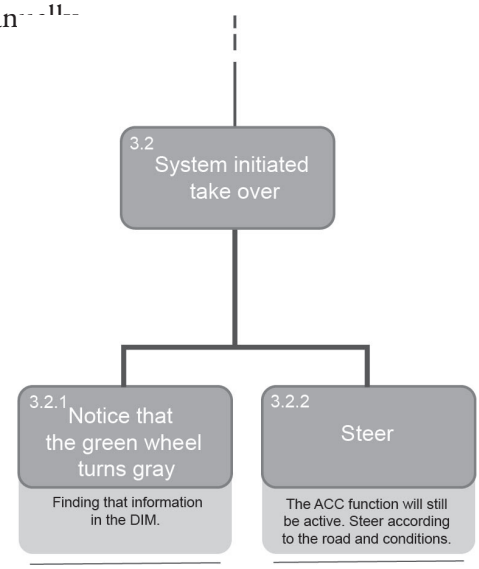


Figure 8: Standby mode shown in the in HTA, for full HTA see Appendix 6

3.2.2 ECW AND PUEA

In order to understand the different situations that the user perceives as critical about the system an Enhanced Cognitive Walkthrough (ECW) and Predictive Use Error Analysis (PUEA) was performed. These methods are used to get a better view of the possible errors and mistakes that might occur in the system today (Bligård & Osvalder, 2010).

The ECW and PUEA showed that there is a high probability that the driver will be able to register that PA has entered stand-by, as they are required to have full focus on the forward roadway and keep their hands on the wheel (see Appendix 7). However, the driver is only provided with visual feedback when this is happening, which is that the wheel goes from green to gray in the DIM. If the car is equipped with a HUD the green steering wheel will

disappear from it. This visual cue is easily missed by the driver and forces them to look down at the DIM. This should not put the user in any immediate danger, as the function is not designed to handle a situation where it must steer all by itself. The problem lies in the impact that the mode confusion has on the user experience. When using the assistive function, the driver should be able to drive in what they perceive to be a comfortable and safe way with the function aiding them in reaching that goal. The feedback that they are provided with will interfere with the desired safety and comfort thus creating a problematic situation for the driver.

Two identified use errors which the driver is unlikely to notice are that PA has entered stand-by mode or that they do not understand what stand-by mode correlates to, and how they should act when the situation arises. The error types lie within message transmission and whether the driver will be able to obtain and make sense of the information they are provided with. The information that is provided is limited. The driver is only provided with the notion that something has disappeared, the removal of the symbol in the HUD or the change of color in the DIM. It is up to the driver to either feel confident in knowing that this symbolizes stand-by and not that the function has turned itself off completely. If the driver was to make this assumption and then press the button to activate PA, the function would turn off completely. The driver should already have this information presented to them, either by the car dealer or by reading the manual. However, if they have failed to acquire this information the situation is non-intuitive for the user. Therefore, the user might not feel sure that they have made the right assessment of the situation or which mode they are actually driving in.

The immediate consequences of this is that the user will not drive in their desirable way rather than the error will inflict any life-threatening injuries, though of course this could happen if the driver has an over-trust in the system as well.

In order to prevent the errors from happening the drivers is in need of clearer, multi-modal feedback for stand-by mode as well as providing the driver with more information regarding the function's possibilities and limitations.

3.2.3 PERSONAS AND EXPRESSION ASSOCIATION WEB

In this study it is also important to understand what feelings are desired and from the customer research, personas was created as a way of analysing and understanding the Volvo users of today. A persona is an effective way of describing a target group and is also a good way of discussing the typical user as an actual person which could be more relatable (Staunstrup, 2017). Two personas were created based on customer research done by Volvo which identifies customer behavior and desires, these are presented below (figure 9).

Yvette is a 28-year-old architect that lives in a big city with her dog. She lives her life in the fast lane, juggling a busy work life with hanging out with friends and colleagues and therefore wants everything around her to work seamlessly. Yvette doesn't shy away from new technology, as long as it is intuitive and easy to learn she is willing to try anything. Because of her living situation Yvette does not own a car but on rainy days she often uses a car-sharing service. When doing so Yvette wants to feel active and that she can use her time in the car in an efficient way and therefore wants the car to enable her to stay connected during the ride.

Marcel is 35 years old and lives with his son in a small house in the suburbs. For the past six years Marcel has worked at a PR-company in the city and commutes with his own car every day, both to drop of his son at kindergarten but also to be able to travel during the day for work. Due to his limited time for himself and the hectic schedule that he has at his job from time to time, Marcel uses his time in the car to be able to relax and have some private time. He sees each ride as a time to get some relaxation and time for reflection.

Photo: Adobe Stock

Figure 9: Pictures of the personas that were used during the thesis

When a foundation of the user was built an Expression Association Web (EAW) was created to be able to get an overview of what the users need and hope for when driving with PA and ACC in a Volvo car. This web is a cloud of adjectives that summaries the users wished feelings and values when it comes to the use of second level autonomous cars (Krippendorff, 2005).

The EAW is a summarisation of the words used by the users in the use test and the customer feedback as a way of visualising what is important for the drivers to feel in a driving situation with automated features (see figure 10). As seen in this cluster of words the user wants to feel safe and want the car to be kind to them in the interaction. Related to this the users also want to feel calm when using assistive functions and will achieve this if the function is trustworthy, smooth and intelligent.

Figure 10: An EAW to elicit what feelings the users wanted to feel and what they wanted the car to feel like when driving with PA and ACC

3.3 PROBLEM DEFINITION

From the evaluation of the today's systems, from a function and user perspective, it is clear that there is room for improvements, regarding the feedback that the drivers receive from the assistive functions ACC and PA.

The use case that this thesis will focus on is when PA enters stand-by mode, when the green steering wheel turns gray. The users are only provided with visual feedback in either the HUD or DIM when this happens, and therefore seems like the most critical aspect of the interaction.

From the customer research and use test it was evident that the users felt that PA function needs to provide clearer, multi-modal feedback for this specific use case. The negative aspects of the small-scale use test mirror the customer feedback thus validating the claim. However, the users were aware that the implementation of sounds might be

overstimulating, especially since similar warning signals already are used for the different functions. It became apparent that providing multi-modal feedback through the adding of audition needs to be non-intrusive so as not to over-stimulate the driver but still catch their attention.

According to the NHTSA guidelines visual messages are better for providing non-critical messages (NHTSA, 2018). As the driver is expected to actively monitor the road and have their hands on the wheel when using PA, one can argue that the message of stand-by isn't a critical one per se. The driver should not rely solely on the function to steer the vehicle. However, for the user experience of the driver, the uncertainty of whether the function is active and what stand-by means is critical. From the customer research and use test the drivers expressed confusion, irritation and a lack of trust in the function because of the lack of feedback. In order to create a seamless and satisfactory user experience the drivers should trust in the function and feel aided by them.

The NHTSA guidelines also recommend that both safety and non-critical messages should be presented in multi-modal fashion, which they are not done in the use case (NHTSA, 2018). Neither haptic nor auditory messages are used, even though they are established to work well in providing short and simple messages of quick and immediate action (NHTSA, 2018). By providing multi-modal feedback to the use case of when PA goes into stand-by mode the drivers would feel less uncertain which mode the function is in and build better trust in what the system is capable of, thus enhancing their experience of driving with them activated.

4. CONCEPT DEVELOPMENT

Phase 3: Develop

In this section the studies that forms the basis to the guidelines and their respective results and methodology will be presented.

4.1 TEST 1 – TESTING SOUNDS THAT ARE NOT REGULAR ON AND OFF SOUNDS

Through the ECW and the PUEA it became clear that a lack of distinct feedback could potentially lead to a use error, as the driver might not know when PA goes into stand-by mode. The results from the use test showed that users experienced this to be confusing and unsafe for them. By adding a sound to indicate that the function had entered or returned from stand-by mode the drivers would be provided with multimodal feedback thus making them more aware that it has happened. Therefore, it was decided that testing sounds for an on/off function would be the starting point.

As the group had never worked solely with sound design before, the test worked as an introduction to how one could ideate with sound. From the consultation with two of Volvo's sound designers the group learned that the sound used for the blinkers in Volvo cars came from braking a fir twig in half, which was done to harken back to Swedish nature and the Scandinavian heritage of the company, which is why the group chose to use sounds inspired by nature. Another reason for choosing nature as a source of inspiration was that when is in nature, one usually feels calm and undisturbed by the sounds that are present. Therefore, sounds from nature that do not share the same pitchy character of most warning signals, became the main inspiration for the type of sounds that was used in the test.

Adding another high-pitched signal to the car was deemed undesirable for two reasons. For one, the different systems in the car make use of such signals to notify the user. Adding a sound for stand-by mode would have to compete with the auditory signal used when the function turns itself off, because the driver hasn't applied steering. These two events may seem very much the same for the driver, yet when PA de-activates they have to restart it manually. Adding the same or a similar signal for stand-by mode would risk confusing them even more as to which mode they are driving in. Secondly, the eventuality of PA going back and forth between stand-by and active mode might occur several times during one drive, if the road or weather conditions aren't up to par. Therefore, adding a high-pitched signal for this would risk disturbing the driver and take their focus off the forward roadway.

With this in mind, the decision was made to aim to create a sound that would not share the characteristic of established signals but would still be able to convey that same functional meaning to the driver. The sounds that were used for the test, were sounds of nature captured at the coastline outside of Gothenburg. Prominently featured among the collected sounds were sounds of water crashing against cliffs, rocks thrown into water and similar. After being recorded, the sounds were edited using the sound-editing software Audacity.

The sounds were edited into short clips to be used for indicating sounds and some mixed with pre-existing royalty-free sound effects to create a variety of sounds for different interpretations. This test also has a base in the literature review regarding auditory icons, on and off signals, as well as the information retrieved from the expert consultations regarding the inspiration from nature and the input regarding how to design sound alerts

4.1.1 AIM AND HYPOTHESIS

The aim of the first test was to create a framework and get familiar with the vocabulary users have for describing sounds and what, in their opinion, characterized an "on" or "off" sound. With this information future sounds and ideas could be measured by how well they would follow these rules set by the users themselves.

The other aim was to get an idea about which sounds, which are not regular on and off sounds, are preferred and clear to the user. The sounds created were made to see whether they could convey meaning thus opening up for more possibilities to think outside the box for future tests, in terms of what sounds could be used.

The hypothesis, which had its foundation within literature and previous studies, was that sounds that do not share the characteristics of established on and off-sounds could still convey the same functional meaning to users

4.1.2 TEST SET-UP

The first test focused on the on and off sounds, a technical product could have. 11 sounds were developed with the help of brainstorming and inspiration from nature. Each test participant was presented to the sounds out of context, sitting by a table, and had to decide whether they thought that the sound they had heard was an on or off sound. They were later placed in a driving simulator to listen to their favorite on and off sounds. They were continuously probed to think-out-loud as a way of retrieving information regarding their thought process. It was also important to extract adjectives from the participants that described sounds and retrieve what was desirable features for an on versus an off sound.

The 11 sounds were developed as follows:

1. A speed pin swung in the air
2. Water that poured
3. Knock on a table
4. Open palm knock on a table
5. A medium sized rock thrown in the ocean
6. A small sized rock thrown in the ocean
7. Two rocks thrown in the ocean
8. A big rock that is thrown in the ocean
9. A stick swung in the air
10. A hand stroking a surface
11. Nails scratching a surface

SCAN THE QR-CODES TO LISTEN TO THE SOUNDS

1. 2. 3. 4. 5. 6.

7. 8. 9. 10. 11.

These sounds were later adjusted and mixed in different ways in Audacity, which created a large variety of sounds. Some were closer to todays on and off sounds, e.g. sounds 6, 9 and 1, and some were designed to be more difficult to discern as on or off sounds, which was mainly the longer sounds, e.g. sound 10 and 11.

The test took place at the UX-Lab at Chalmers Johanneberg with a total of five participants between the ages of 23 and 28, two male and three females. The participants had little to no experience of driving with the assistive functions. As the aim was to get an understanding of users' way of talking about sounds and to elicit emotions regarding them, experience of the function was not considered to be of importance.. The duration of the test was about 35 minutes.

Each participant was introduced to the background and scope of the thesis and was asked if they would allow the test to be recorded. After their approval they were introduced to the procedure of the test and told that if they at any time felt as though they wanted to leave the test, they were free to do so.

Each participant listened to 11 sounds one at a time, and was asked whether they would categorize the sound as "on" or "off". They were probed to explain their reasoning behind the choice and were asked to describe the sound in their own words. After this, they were asked to rank the congruency of the sound in its ability to mediate an on and off characterization. Each participant was presented with a scale (see figure 11) to indicate their choice, which was then written down on a separate paper by the mediator. The participant was allowed to listen repeatedly, and could return to a specific sound if needed.

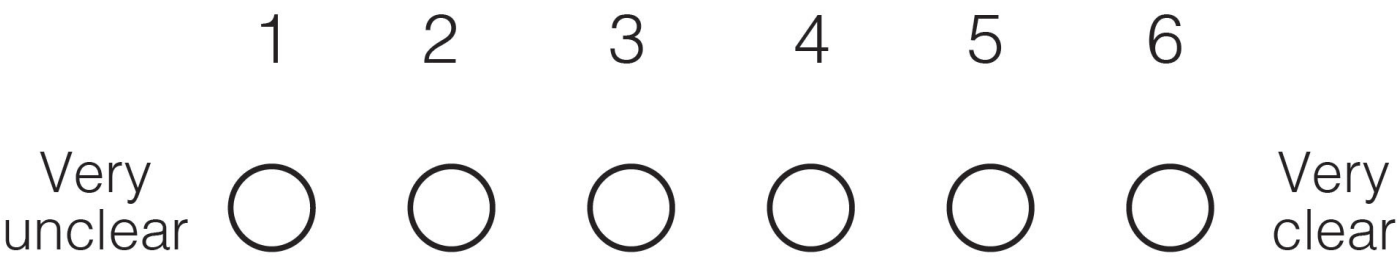


Figure 11: Scale used to rank the sounds on how well the sounds were percieved as either on or off

When all the 11 sounds had been played the test leader presented the participants top ranked "on" and "off" sound and played it for them in sequence. If the participant had two or more sounds with the same rank, they were played their choices and got to pick one that they favored for "on" and for "off".

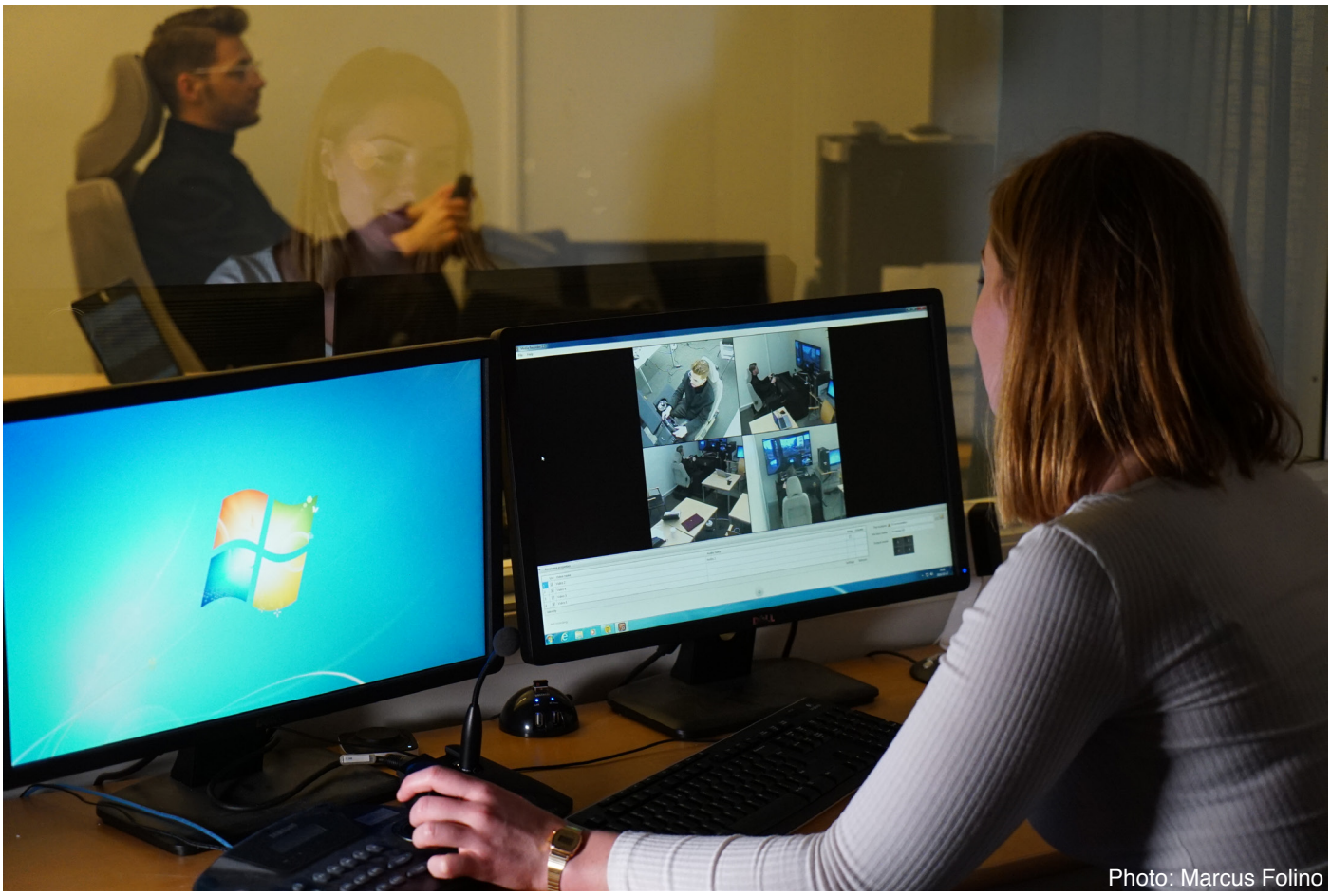


Figure 12: The simulator set-up used during test 1.

The participant was then introduced to the simulator (see figure 12) and was asked to familiarize themselves with the software, Euro Truck Simulator 2, before the actual test began. Once they felt comfortable, they were introduced to the test procedure where they were asked to use voice control to activate the Pilot Assist function. When doing so they were played their chosen "on" sound and let go of the steering wheel as one of the test leaders took over the steering for them as a pilot assist assistant. After a while they were asked to cancel the function, again through voice control. Their chosen "off" sound was played and the subject regained control over the steering. The participants were asked if they were content with their choice or if they would like to try again with different sounds. In that case they were played their second choice for favorite sounds. The participants also had the choice to have their least favorite sounds played to them.

The simulator part of the test ended when the participant was content with both their sounds for the "on" and "off" function. After the simulation a short interview was conducted to elicit how realistic the simulator was and if they changed their minds in the simulator, why they think they did so and was asked general questions regarding their choice of "on" and "off" sounds.

In the test set-up described below (figure 13) the following shortenings are used:

F: Female
M: Male
TP: Test Participant
TL: Test leader
PAA: Pilot Assist Assistant, one TL simulating PA by intervening and steering the truck from behind the drivers seat

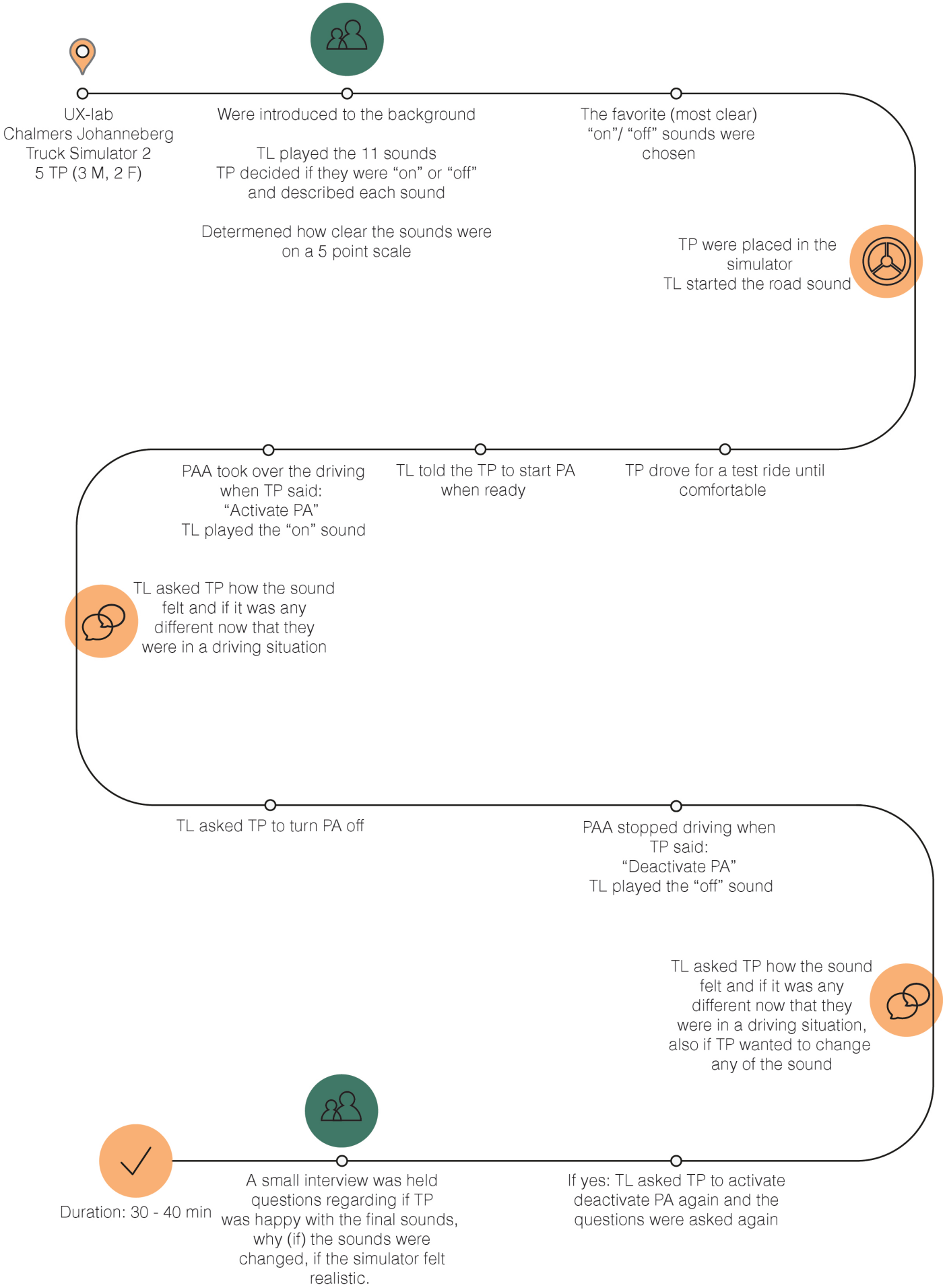


Figure 13: Test 1 timeline and summary of the test set-up

4.1.3 RESULT AND ANALYSIS

The participants' categorization and comments of the sounds were transcribed which formed the basis of the analysis. The majority of the participants stood by their original choice of favorite sounds after entering the simulator and being tested in the driving situation. However, those who changed their minds did so because of the driving context, since the sounds did not mediate the function properly in that context. Overall the participants agreed that the driving context heavily influenced their feelings towards their chosen sounds in a positive way, enhancing their meaning. When exposed to the sounds in a non-driving scenario the participants felt that the on and off function was difficult to imagine, by placing them in context it became more palpable and prominent.

According to the participants an "off" sound is characterized as short, chopped off, muffled, pitchy and dark. Short was the most used adjective, re-appearing nine times in the participants reactions. Muffled was also prominent, chosen as a descriptive six times. Out of the 11 sounds used in the test, five were chosen as "off" sounds by all the participants with sound 1 and 8 most often being chosen as the participants' favorites (see figure 14).

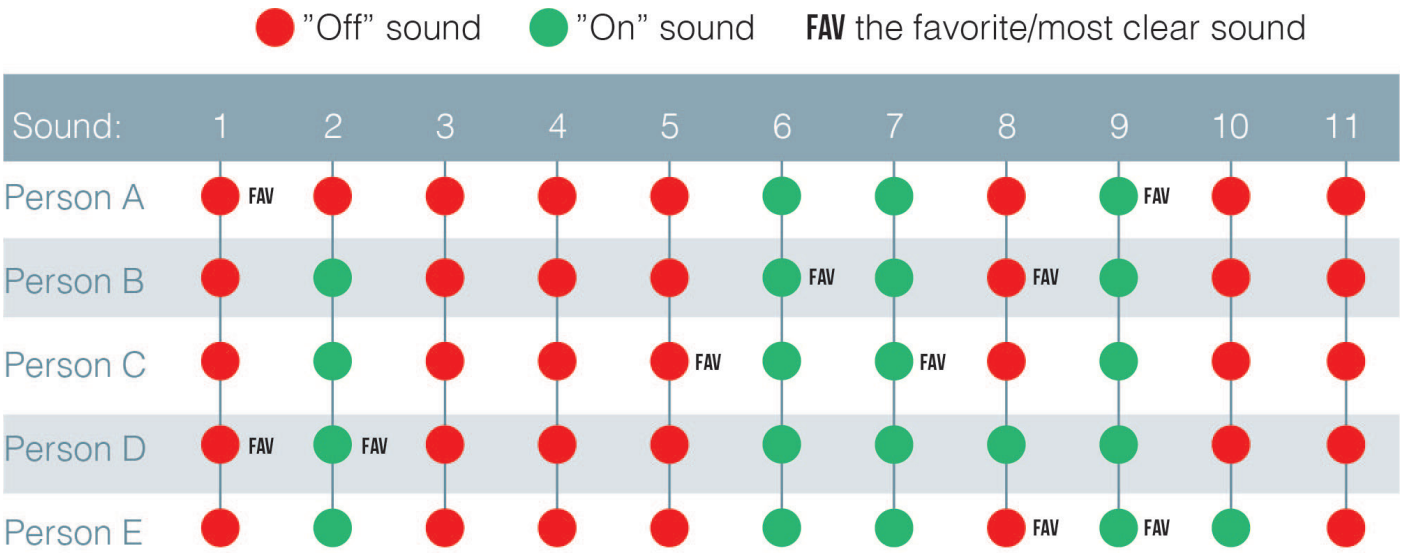


Figure 14: Results from test 1. Showing what sounds were percieved as on and what was percieved as off as well as informataion regarding which sound was the favorite after entering the car simulator.

In contrast, an "on" sound was characterized as happy or light and indicated that something was finished or mediating a function that "keeps on going". Only three of the sounds used in the test were unanimously deemed as "on" sounds, sound 9 was most often chosen as the participants' favorite sound.

When discussing the "on" and "off" sounds that had a character that was far away from today's warning sounds, sounds 1, 3, 4, 5, 6, 7, 8, 10 and 11, were perceived as nicer and were informative in a kinder way compared to today's auditory feedback in cars. Many of the participants in the test compared todays audio feedback with someone screaming and yelling at them what to do but the muffled low pitch sounds presented in the test were compared to someone kindly informing you of the status of the car.

The participants often used associations to make sense of the sounds that they heard and seemingly had a strong influence on their choices of favorite sounds. The associations could influence the experience positively as well as negatively. When the participant associated the sound with something that agreed with their mental model of what

the sound conveyed, e.g. a closing door with an off sound, it gave a positive reaction to the sound. In the cases of a mismatch of the mental model, the sound distracted the subject. One participant had made an association with a flushing toilet, and when the sound was played in the driving situation it was distracting the subject. It therefore becomes of importance to make use of sounds that matches the mental models of the users and strengthen a connected association to the functionality.

4.1.4 DISCUSSION

Four of the participants had never used PA before and one participant that had only done so once. As the function does not use any auditory feedback for the on and off function today (an auditory warning appears in special occasion when the function is turned off), this should not influence the result to a greater extent. However, two participants expressed that the "on" sound was the more important feedback for them in the driving scenario, as they felt that this information was more relevant for them. The results from the benchmarking would suggest otherwise, that the driver would want feedback when the function was deactivated. Further investigation is needed, preferably with experienced users, to determine which function needs more prominent multi modal feedback.

The limitations of the software required the test to be performed by a Wizard of Oz technique and did not mirror a real driving situation. The participants did not have to keep their hands on the wheel when they had activated PA, and they still had to use the pedals to keep the speed. There was also no button or lever used to activate the function, but it was activated by voice control. These deviations from the actual driving situation could possibly have influenced the participants' responses. However, they had little to no prior contact with PA and therefore would not have a clear mental model of how the interaction should happen, thus enabling them to focus more on the auditory feedback. Using more experienced PA users might have caused them to focus more on the staged Wizard of Oz-situation, as it did not match the interaction that they are accustomed to.

Most of the sounds that were used for the test were re-designed from their original form to conform to fit with the "accepted" rules for on/off sounds. These could have made for a mismatch in the participants mental models as some of the sounds were in line with what is often regarded an on or off sound, an in- or decrease in pitch or the use of digital beeps, whilst some deviated from those established rules entirely. Although the introduction of out-of-context sounds and taking a step away from the use of beeps to mediate functions is the focus of the thesis, these types of sounds needs to be more polished in order to be appealing for drivers and for them to accept them as mediating a function.

4.2 TEST 2 – INTRODUCING "MAKE-NO-SOUND" - SOUNDS

From the first use test it was found that users would not mind auditory feedback to complement the visual feedback that they received when PA goes into stand-by. They were however weary of adding another high-pitched signal as they were of the notion that there already are a multitude of auditory warnings implemented in the car system. From this, the idea sprung of implementing sounds that would not make a sound to catch the drivers' attention. Adding a more discernable sound for low level warnings would risk being perceived as intrusive. As such, a sound working within the same dB levels as the ambient noise in the car, or from media, would not be intrusive for the driver but would still generate a reaction.

"Make-no-sound"- sounds were first introduced in this test. From use study it became clear that the audio environment needed to be widened as the "beep" and "pling" signals used in today's cars are too intrusive, and to implement more signals like this would be perceived as annoying. The definition of "Make-no-sound" sounds are sounds that inform the user that something has happened, and they need to take action but in a subtle way, just enough to be heard. In contrast to warning signals that are designed to be intrusive "Make-no-sound"-sounds are designed, so that the driver can block them out if they wish to rely on other type of feedback. If a warning signal used today is someone screaming at you to take action a "Make-no-sound"-sound is someone kindly informing you that you should take action. The goal with "Make-no-sound" -sounds is that they should in a kind way push the user into a behavior that is preferred and give the driver the opportunity to retrieve information without looking away from the road or giving them a warning signal.

Three "Make-no-sound" -sounds were created for the test. The first was one of the sounds from the previous test that conveyed an off-function in the best way according to the subjects, sound number eight. This short muffled sound is approximately the same length as todays warning signals, which lasts between 200 –500 ms. However, it has a different character when it comes to pitch and intensity. The sound is lower and muffled and has a character that lay in the spectrum of the surrounding car sound but with a higher dB. It could be compared with a beat of a drum or someone tapping on a microphone. The sound was made from digitally distorting the sound of a rock hitting a water surface. The sound was thought to be the most discernable sound out of the three sounds tested. In order to become a "Make-no-sound" -sound it was tested in different volumes to test whether the subjects would find it noticeable at lower levels.

The second sound was a two-second-long snippet of a white noise that faded in and out. The reasoning for using a white noise was that they are designed for listeners to be able to block them out if they find them to be disturbing – further details are described in the literature review describing white noise. As PA might activate and deactivate stand-by mode multiple times if there are troubling conditions a signal for this has to be able to be blocked out by the driver if they feel confident in relying on other type of feedback when this happens. The second reason for using white noise was to see if such a low-frequency sound would be noticed by the subjects at all.

The third "Make-no-sound" -sound was a two-second-long change of volume used when media is being played. The reasoning for inducing an inverse of a warning signal was that it would generate a reaction that was not as disruptive for the driver. The test was also based on the findings from the literature study mostly from the sections 2.3.4 and 2.3.5. It was also built upon input from the use test.

4.2.1 AIM AND HYPOTHESIS

The aim of test two was to retrieve information about how little auditory feedback the drivers needed to be provided with for it to still be heard and understood. By integrating the feedback sounds into different forms of media the test also aimed to investigate which sounds were suitable for which type of media. The comments users made about their feelings regarding the subtle auditory feedback was used to write requirements, which would be he source for creating the guidelines.

The hypothesis for this use test was that a subtle auditory feedback will be noticed by the user and the user will act upon this feedback according to instructions.

4.2.2 TEST SET-UP

The second test also took place at the UX-Lab on the Chalmers Johanneberg Campus (see figure 12 &15). Seven participants between the ages 21 to 54, three male and four females participated. The participants were students and people who worked close by Johanneberg Campus, the only requirement was that the participants should have a driving license. Since the sound in a driving situation was the important part to test it was considered to be less important if the participants had tested automated functions or not. Each test session was about 45 minutes. The media sounds that were being used were two podcasts (Skäringer & Mannheimer, She Kills), one radio station (Mix Megapol) and three songs (Sunflower by Post Malone, 7 rings by Ariana Grande, September by Earth, Wind & Fire). 7 rings and Sunflower as well as Skäringer och Mannheimer were chosen as they were among the most popular songs and podcasts in Sweden at the time, the song September was chosen as it is considered to be a song that is recognizable. She Kills was chosen as it is an English-speaking podcast to see if there is a different reaction to a podcast that does not use the participants' native language. During the test the participants were asked to call a colleague and a prerecorded phone call was played. Unfortunately, the colleague does not answer and a voice mail is played. As seen in the list below the edited and un-edited media was mixed to avoid creating a pattern which the participant could follow regardless if he or she heard the feedback or not. Each media was played for about 2,5 minutes. The order for when the different sounds and media were played was as follows:

1. *Skäringer & Mannheimer* podcast edited to include the white noise and the "off" sound
2. *Mix Megapol* radio edited to include a change of volume and the "off" sound
3. Ambient noise of the car driving adding the "off" sound and white noise
4. *7 rings* song with Ariana Grande un-edited
5. *Sunflower* song with Post Malone edited to include the white noise
6. *She Kills* podcast edited to include a change of volume and the "off" sound
7. *September* song with Earth, Wind & Fire edited to include the "off" sound
8. A big rock that is thrown in the ocean
9. Answering machine with a lowering of the volume implemented

SCAN THE QR-CODES TO LISTEN TO THE SOUNDS

1. 2. 3. 4.

5. 6. 7. 8.

SCAN THE QR-CODES TO LISTEN TO THE SOUNDS

White noise

Muffled sound

Figure 15: The test simulator at Chalmers University used for test 1 and 2.

Before the drive, the participants were asked to fill in a few questions regarding their car habits and also what they usually listen to while in the car, to be able to elicit exclusive verbatims from the drivers who usually listen to e.g. music. The participants were introduced to the test settings and were informed that they would be driving in a simulator and identify subtle feedback sounds. They were then introduced to the scenario, which was as following: The participant is driving their daily commute to work, using Cruise Control (CC). During the ride they listen to several different types of media, and at a point, that they decide themselves, they will make a phone call. The Cruise Control should be set to 70 km/h and the entire ride to work is on a highway. The test session was filmed with the approval of the subjects, so that the videos could later be used for the analysis.

The participants were told that the Cruise Control needs to be re-assured that the driver is alert, and it would provide auditory feedback to generate a reaction from them otherwise it would turn itself off. In order to re-assure the CC that they were alert the subjects were asked to "wiggle" the steering wheel whenever they thought that the function had provided them with the auditory feedback. If the participant missed the feedback one of the test-leaders would turn the function off from behind a panel, thus forcing the participant to realize that they were driving manually. When they switched to manual mode the CC symbol in the DIM would disappear and the vehicle would stop accelerating, which could be noticed by watching the decline speed in the speedometer.

After each media session the participants were asked in what way the car had tried to communicate with them, how the auditory feedback made them feel, how they interpreted it and finally if they ever had felt uncertain as to whether the car actually had tried to communicate with them. When the participant had arrived at their destination, they were asked whether they could identify the three "Make-no-sound" -sounds and which one was preferable. They were also asked which "Make-no-sound"-sound would fit best into their own driving situation, depending on what type of media they usually would listen to, and whether they thought that they would accept this type of notification sound (for full script see Appendix 8). In the test set-up described below (figure 16) the following shortenings are used:

CC: Cruise Control
MNSS: "Make-no-sound" - sound
FB: Feedback
TL2: A test leader playing the sound and canceling the CC

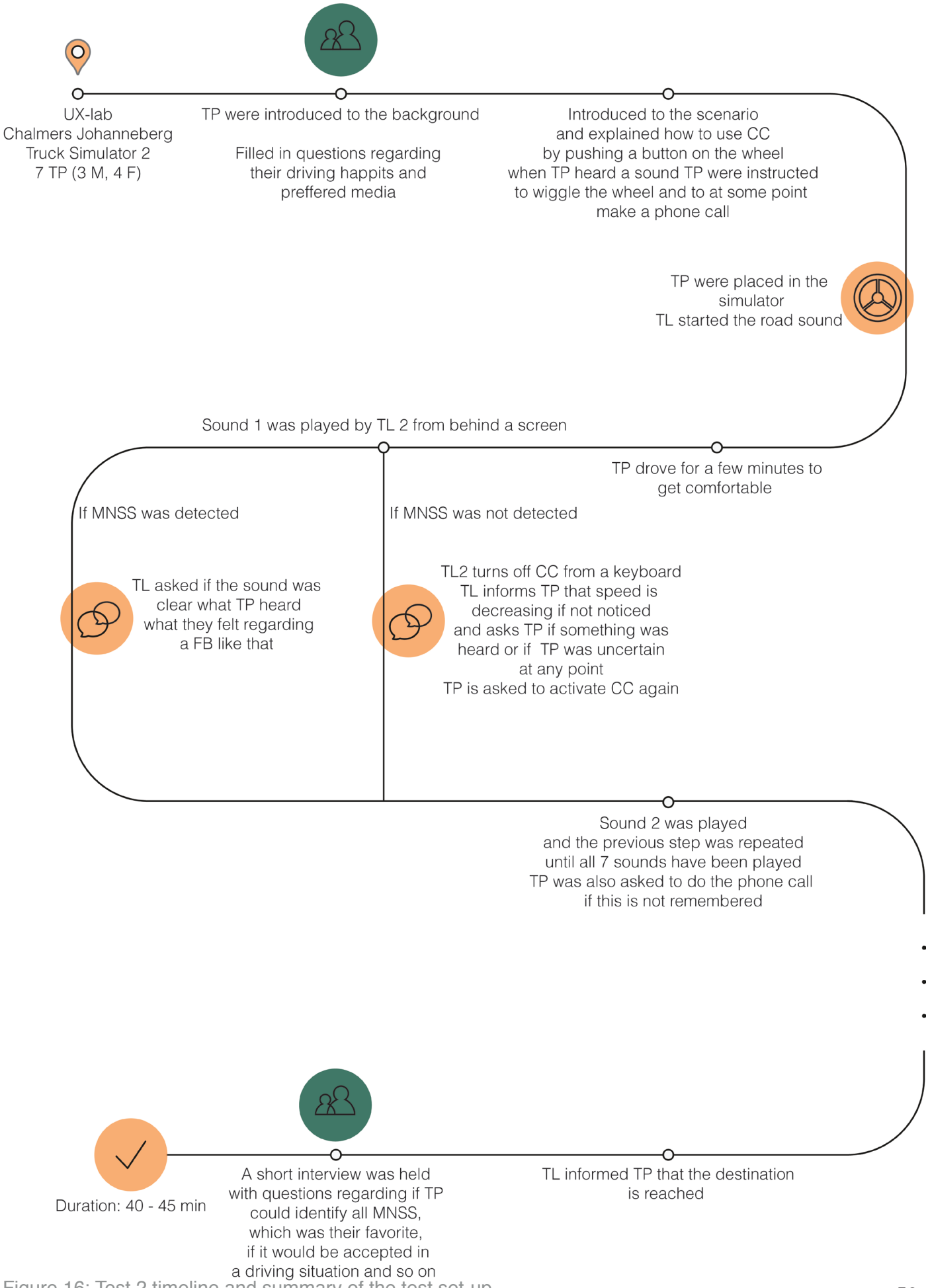


Figure 16: Test 2 timeline and summary of the test set-up

4.2.3 RESULT AND ANALYSIS

The participants' reactions and comments of the "Make-no-sound"-sounds were transcribed from reviewing the videos of the tests. The transliterations formed the basis for the KJ-analysis used to synthesize the participants' opinions about the different feedback sounds (see Appendix 9).

The results show that the short-muffled sound was the most noticeable sound and the one that the participants considered as their favorite out of the three. Five out of the seven participants named it their favorite sound, because it was "easily understandable", "it stood out from the surrounding noise" and "a friendly push in the right direction". All participants found it to be discernable from every other form of media that it was played with and it also had the highest learnability. After the first exposure to it, where four out of seven took notice of the sound, every participant reacted upon hearing it for the remainder of the test. The sound was played in different volumes depending on the media it was integrated in and the results show that no matter the volume it was noticeable for the participants every time. By the end of the test the participants started to actively look for the sound, one participant commented *"I recognized it from before even though it was even lower this time".* All of the seven participants could identify the off-sound when asked which three sounds they had heard, when the simulator ride was over.

The participants found the short-muffled sound to be the clearest warning signal but once again it was perceived as being kinder than other warning signals heard in today's cars. Many participants referred to the sound as "the drum sound" or that it sounded as if someone was testing a microphone. One participant commented that although personally a subtle signal was preferable *"I think that the drum (the short-muffled sound) would be the best discrete sound if you are driving for a long time, because I believe that tinkling sounds would be disruptive"*. However, one participant commented that depending on the music that was playing that the short-muffled sound could be misinterpreted as part of a drum-solo or something of that sort and had that happened the participant would not have reacted to it.

The white noise had a high acceptance level among the participants, only few of them found it to be intrusive or disruptive to their driving. According to the participants, because the sounds differed from the signaling sounds used in the car system today, the white noise stood out. This was why it felt as if it was designed to capture their attention. Due to its rustling nature the participants didn't feel startled by it, and one participant stated that after hearing it two times it started to feel *"as if it became part of the overall sounds in the car".*

The negative aspect of the white noise was that it was less noticeable when media was being played. When the participants were played the sound with only the ambient noise coming from the car and motor everyone identified the sound and reacted upon it. However, when it was played during a podcast or a song four out of the seven participants did not register the sound. One participant associated the rustling of the white noise with a disturbance in reception, stating *"The scratching sound could be interpreted as something wrong with the radio reception".* Overall the participants had many different names for the sound, from the rustling of leaves or birch twigs to the sound of splashing water. All the participants could identify the white noise as one of the three sounds that they were supposed to have heard, when asked after the simulator drive was over.

One of the positive aspects of the lowering of volume was that it matched the mental models of the participants of how an indicating sound should work. Many test participants related it to the situation they had had of getting a notification on their phone when listening to media which causes the volume to lower for a short period. By matching this existing solution, the volume change was accepted and understood by many subjects.

However, the participants struggled with identifying the change of volume in the media. When played during the radio segment, only one participant reacted to the volume change and understood its meaning. It fared better when it was used during a podcast where all but one of the participants reacted upon it. A comment on "Make-no-sound" -sounds during a podcast or radio was that it was difficult to register when the media had natural pauses in it.

The change of volume was also used during the phone call that the participants had to make while driving. In this context no participant reacted to the "Make-no-sound" -sound at all and were surprised when they realized that the CC had disengaged after they heard the voice mail. The phone call was another type of media that had natural pauses within it, both when the colleague talked in the voice mail but also during the ring tones, which might be one reason for why the participants did not respond to the feedback. Another reason may have been that when tasked with making a phone call the participants felt as though it was too much going on and therefore overlooked the volume change. The volume change proved to be more difficult for the participants to identify after the simulator ride had ended, three subjects did not identify it as one of the three sounds used in the test.

The type of subtle feedback sounds, or "Make-no-sound"-sounds, that have been tested should not be used for high level warnings. The subtle feedback is designed to be non-intrusive for the drivers and therefore it could be either overlooked or ignored by them. The sounds are suitable for nudging the users, since they do perceive them as being a kind push. Further studies are needed to explore whether these sounds could be played for the driver's multiple times, and still be perceived as kind. It was found that the sounds had a high learnability and that the participants could make sense of them after just a few times of exposure. To liken the sounds to a visual representation these "Make-no-sound" -sounds are heard by the peripheral hearing, meaning that the drivers notice them, but they become part of the entire sonic scene rather than taking center stage. It is because of this that they work better for lower level warnings, as they become less intrusive for the user who might choose to block them out if they find them annoying.

These types of sounds do however run the risk of being missed entirely by the driver and therefore "Make-no-sound"-sounds should be used as a compliment to visual feedback. In themselves the sounds don't convey a specific action, but need feedback connected to other senses, to work as a guidance towards a source of information.

Lastly, a short and muffled auditory feedback will be detected and reacted upon. This type of sound is non-intrusive and is not categorized as annoying. Therefore, it could be used as an alternative to a high-pitched warning signal, as it matches the mental models of drivers of how to react upon such a sound. Even in its short nature it is informative in a similar way as a warning signal and triggers a more immediate response than the other "Make-no-sound"-sounds. This type of feedback can be used in many different types of media with different volumes and still be discernable.

4.2.4 DISCUSSION

There were factors that could have affected the result, but it is believed that these were relatively small and that the result from the test are still valid. When using a simulator and not a field test, there are issues regarding the similarity with real trafic situations. During the test the participants had a hard time with the graphics of the game and mentioned that the trees among other things made it difficult for them to focus, since they looked unrealistic. In two scenarios the participants also mentioned that they thought they saw the hood moving or some other visual interference and thought it was part of the test and perceived this to be feedback from the Cruise Control. The simulator only had one screen, making it unrealistic with periphery vision and usual driving reflexes, like the lack of blinkers or the shoulder-check. All of these factors created a less real experience, but many participants mentioned that when they had driven for a while, they got into it and on a regular straight high way the lack of periphery vision and blinkers was not as present as it would be in inner city traffic.

Other aspects regarding test errors could be that the participants were asked to listen to feedback. One participant said: *"it affects me that I know that I am sitting here trying to hear audio feedback".* Since the test description made the participants listen carefully for sounds it was also difficult for some to understand the audio input that was lowering the volume. Another participant mentioned: *"I heard that the volume was lowered but you said to listen for sounds and I did not hear a sound".* These aspects did affect the user experience, but were considered to be necessary to steer the user into focusing on the auditory feedback, as this was the focus of the test. For the future tests it was made clearer to the participants that the auditory feedback would not necessarily have to be a sound, but could be a change in the sonic environment. To tell the user that there should be an auditory signal to listen to was told as there was no other visual feedback in the simulator. Without the visual feedback it was considered to be much more difficult for the user to connect the sound to a function. It would require a longer learning process that there was no time for in the test and longer compared to how it would be in reality when the visual feedback is present. Therefore this was considered to have little to no influence on the result for the test.

4.3 TEST 3 – TESTING A LONG AMBIENT NOISE AS A "MAKE-NO-SOUND" - SOUND

The results from the previous tests showed that drivers noticed signals that deviates from standard high-pitch warnings. However, most of the sounds tested in Test 2 were like todays warning sounds, relatively short. Hence, a longer lasting sound was tested in Test 3. Longer sounds with an ambient character have been used before as a way of blocking other sounds and are known to have a soothing effect. An ambient noise, enhancing the volume of the surrounding car sound, that is played when the function is not active would be noticed but is also easily blocked out until it disappears or reappears. The change in volume will notify the user that something is happening and require their attention. A change in volume when listening to different media is already implemented in a driving context to alert the driver about an upcoming notification. An example being when a phone is connected to the speaker and the volume of the media changes for a text-message notification.

The "Make-no-sound"-sound used in the test was taken from a previous recording of the interior sound of a car driving in 90 km/h. Initially a recording made of the interior sound of a car driving on the TT-track at Volvo Torslanda was made. The reasoning for this was that as the TT-track was going to be the test location, the recording

would resemble the interior sound inside the test car the most. In order to simulate the perception of having the sound already present to be either raised or lowered it was desirable to have the closest possible version of that sound being used. However, the recording was deemed too noisy and when played during a trial run, it became apparent that it did not enhance the interior sound. The contrary, the two sounds combined created a roaring sound and therefore this was discarded. A cleaner recording provided from the Lean UX design team was utilized instead. Several recordings at different speeds were provided and tested. Ultimately, the interior sound at 90 km/h was chosen as it became more distinct than the sound created at lower speeds, yet not noisy enough to be apparent.

The initial idea was to have an ambient noise being played when PA is active but after a midway presentation with the User Experience Center design team it was clear that the driver might benefit more from and would more easily connect the change in volume with PA, if it is quiet when the function is active instead. The design team also mentioned a similar study done at Volvo Trucks, as seen in the literature review, where an ambient noise had been played during use. From that study it was concluded that having the function create silence instead when activated might create a better user experience. This test was also designed according to information retrieved in the literature study regarding white noise, speed, auditory feedback as well as information regarding bottom-up and top-down processes.

4.3.1 AIM AND HYPOTHESIS

The aim of this test was to retrieve verbatims and opinions about the users' experience of constant ambient noise as a feedback method instead of the regular warning sounds e.g. "beeps". Futher, the test aimed to get input on how well the ambient noise was noticed, as well as if and how it would fit into the entire driving experience. By introducing and removing a continuous sound the test aimed to help the driver realize that their support in the driving task has disappeared, and they needed to direct full attention to the steering.

The hypothesis was that adding a continuous ambient noise when PA is not active and removing that sound when it is active will generate a reaction from the driver when the sounds reappears. The reappearance of the sound should alert the driver that they needed to regain full control of the dynamic driving task. This ambient noise is created through enhancing the sound of the engine, road and wind that are already present when driving. By creating a quiet sonic environment when the function is being used it was hypothesized that the function would appear more attractive to users.

4.3.2 TEST SET-UP

The third test took place on the TT-track, a test track at Volvo Torslanda using a Volvo XC60 and a Volvo S90 with the latest software update equipped with PA and an automatic shift gear. 10 participants between the ages of 21-51 (six male and four females) took part in the test, all were Volvo employees in different roles and departments, none of which was part of the designing of the function. Half of the participants were beginners in using PA, with the other half describing themselves as frequent users. The participants were asked when applying for the test what media they usually listen to when driving, so this could be prepared before the test started. The speaker system in the car was used to play the ambient noise and the media that was played during parts of the test was played via a Bluetooth speaker. To be able to elicit as much as possible and to be able to be present for the test the situation was filmed and recorded with the participants approval.

The ambient noise used in the test is a recording of a car driving in 90 km/h which was considered to be closest to the real situation at the TT-track.

SCAN THE QR-CODES TO LISTEN TO THE SOUNDS

Ambient noise

The participants got picked up from PVP at Volvo Torslanda and then got the test described to them and drove for approximately 40 minutes at the TT-track with PA turned on and off in different situations. When the participant got picked up at PVP the ambient noise was playing in the speaker system as a way of testing if it was noticed by the participants from the start. PA was not used by the test leader on the way to the test track, to stay consistent with the concept idea of having the ambient noise active when the function is not active. When arriving at the TT-track the participants entered the driving seat and were introduced to the test. Those who had rarely or never used PA before were introduced to how to activate and deactivate the function and how it works. Since most of the participants had also never visited the TT-track, everyone was given an introduction to it. The TT-track has speed limits of 90 km/h and 130 km/h, but the participants were told to keep a speed of 70-80 km/h as a safety precaution and to enable them to focus on the feedback as much as possible. The less experienced users were given a test lap to familiarize themselves with the function before the start of the actual test.

When comfortable, the participants were asked to enter the TT-track and asked to activate PA by pressing the button on the steering wheel and letting them drive on side A (see figure 17) . When PA was activated the ambient noise was removed by the test leader positioned in the back seat. The ambient noise had by that time been played during the entire time from when the participants left Volvo which is for approximately 15 minutes. In the end of side A before the curve the participants were asked to turn PA off and the ambient noise reappeared.

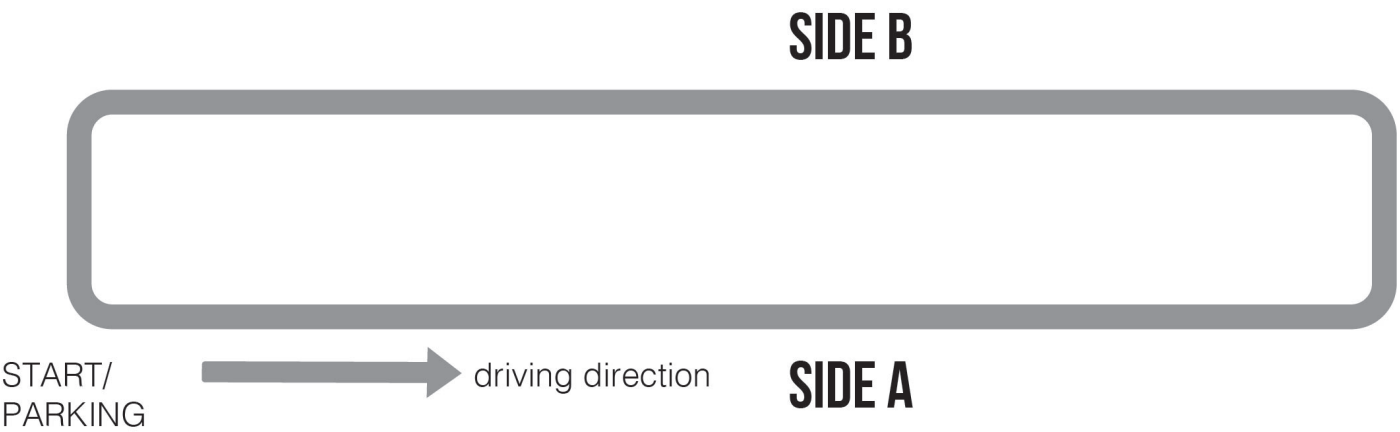


Figure 17: TT-track illustration showing the start point where the preparation and final interview was held as well as the side A and B whih are refered to in the test description.

During the entire test, the participants were asked to think out loud and questions were asked to help the participants to describe their experience easier. The questions asked during the ride, were about the audibility of the sound, and if it was disturbing. The participants were also inquired about their feelings towards the sound and if there were any associations made. The procedure was repeated on side B of the test track.

For the second lap, the participants were asked to activate PA when the test leader told them to. However, the participants would not be told when to turn it off. They had to search for the auditory feedback, which was the disappearance of the ambient noise, to tell them to deactivate the function. The second test leader would turn the ambient noise off from the back seat sometime before the curve, and the participant were once again questioned about their experience. The procedure was repeated on side B.

For the third lap the participants were informed that they would get no instructions from the test leader about when to activate or deactivate the function. They had to rely solely on the auditory feedback, either that the ambient noise disappeared telling them to activate PA or vice versa. The ambient noise was turned off and on by the second test leader two times during the third lap. The last two laps were performed in the same manner but with the addition of the participants choice of media being played from the Bluetooth speaker as well. For these laps the participants were also asked whether they felt that the ambient noise was disrupting their chosen media.

At the end of the fifth lap the participants were asked to return to the parking spot where the test started, and a short interview was conducted. For this interview the participants were questioned regarding how the sound was perceived compared to the regular “beeps” that exists in today’s cars. The participants were also asked if they would feel differently if the sound was applied to when the function went into standby mode as well as if it motivated them to use PA. The script used for the test can be found in the Appendix 10.

After the interview the participants were asked to answer a UEQ with regards to PA with the sound incorporated. This was done as a way of eliciting the last thoughts of the sound together with the function (see Appendix 4). The test set-up is also described in figure 18.

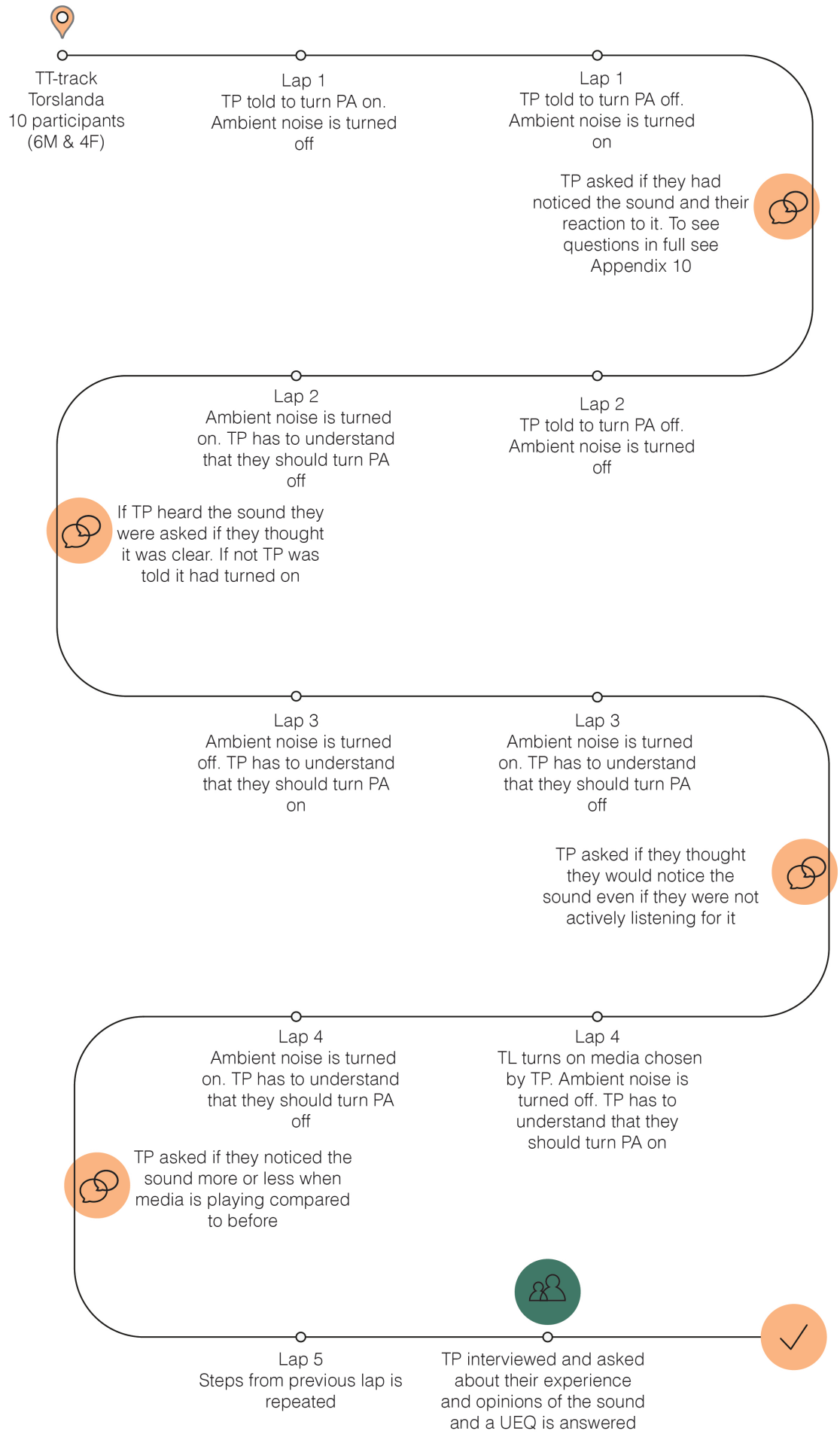


Figure 18: Test 3 timeline and summary of the test set-up

4.3.3 RESULTS AND ANALYSIS

After organizing the test, interviews and comments into a KJ-analysis many answers were shown to be similar and connected to each other. From this patterns and results could be retrieved.

In general, the participants thought the sound was annoying and disrupted their driving experience. Some participants questioned the point of adding a sound, since they associated it with a broken car. One participant felt that it was insulting to the NVH department (Noise and Vibration Center) at Volvo Cars who works very hard on getting the cars to be as quiet as possible. The participants associated the sound with things that were negative to them, such as a car window or door being open, that something was wrong with the car or the road they drove on. Many participants said that they found these types of sounds extra disturbing and identified themselves as being overly sensitive to them. Yet, none of the participants took notice of the sound until it had been removed at least once. Each of these participants would at least at one point incorrectly claim that the sound was not there because they did not feel annoyed anymore.

A common opinion amongst the participants was that the sound was easy to get used to even if found annoying, when first noticed. How long it took to get used to the sound differed between the participants. Some said that it depended on the speed as they claimed that the sound was more annoying in lower speeds, because the ambient noise did not match the speed they were driving at. Some said that it would take a couple of minutes to get used to and that it depends on how often it is turned on and off.

Although a majority thought the sound itself was annoying and disturbing when noticed, also positive comments were retrieved. A few participants associated it with a sound they would fall asleep to as children and due to this found it to be calming and relaxing. A few participants mentioned that it would be supportive in the long run and once you get used to the sound it was no longer bothersome. Six out of ten participants mentioned that it is a natural sound one can expect to exist in a car which makes it less intrusive. However, once the sound disappeared and they could hear how quiet it got, they felt annoyed and felt cheated by Volvo as this would actively create a less pleasant driving experience.

None of the participants noticed the sound when leaving Volvo for the seven minutes ride to the TT – track and were not disturbed by it at all. Conclusion can be drawn that the sound itself is not annoying, but it is the knowledge that it could be quiet instead that is aggravating and frustrating. The participants were able to identify different sounds from the ambient noise, an engine sound, a wind sound, a road sound and a squeaky sound. A majority noticed a squeaky sound which all explained was the worst thing about the ambient noise, but the participants that felt like they noticed a wind sound felt like that was very pleasant and wanted only that sound to be played.

As for the understanding and learnability many claimed that they would need a lot of information regarding the feedback, because it is not as easy to understand as todays warning signals in cars. They felt that it needed some explanation otherwise people would not notice it, or they would think that something is wrong with the car, instead of connecting the feedback to the PA function. One participant also mentioned that users will need an explanation and she did not believe that car sellers would be able to make it understandable for customers. The

sound was noticed more often than not. The issue with it was rather that the test participants did not connect it to PA being active. Whether they noticed the sound or not was affected by the fact that the participants actively listened to the sound which would not be the case in a real driving situation.

Compared to today's signals this ambient sound was a lot more difficult to understand according to the users. Further, it was mentioned that for this specific case a regular signal might not work as the goal is to inform the driver of when PA is active. Some stated that the ambient noise might be less annoying if the function is turned on and off several times as it is not as intrusive as a regular warnings signal. It was also asked how the regular beeps would be implemented if they were to show that the function is active, a constant "beep-beep-beep" would not work according to the participants. This ambient noise was considered less efficient than today's beeps but there were mixed feelings regarding if it should be efficient or if an efficient sound would be more intrusive and therefore annoying. One participant stated: *"It is a balance between being too intrusive and bother the driver but yet be clear enough to be able to understand and take notice of"* . This statement represents a nice summary of the mixed emotions regarding the ambient noise and its efficiency.

As confirmed with previous tests there was a concern that already too many warning signals exist in cars as it is, and another type of feedback might be a good idea, although this specific ambient noise was not noticed all the time and when noticed it was perceived as annoying. Almost every participant in the test said that even if this ambient noise is subtle and difficult to detect it might be a good compliment to some sort of haptic feedback and would create something that is less annoying than today's warning signals yet as noticeable and understandable.

A majority of the participants said that it was satisfying when PA was on, as the silence made them feel more relaxed. They did not understand why it was quieter just because PA was active. One participant phrased it as *"It seems like the car wants me to have PA activated but why does the car spur me to that?"*. This confusion was common, and many wondered if maybe it is safer to have PA on, and whether this was the reason why the driving experience was more pleasant when it was active. A few participants mentioned that they were feeling kindly pushed or nudged into using PA which they accepted but did not understand why.

When PA was not active the sound was described as annoying, awful and overall unlikable until the participants were able to block it out and/or thought that the test leader had turned it off. When it was quiet the experience was perceived as calming and relaxing and made the participants feel safer and happier about their car experience. One participant was reminded of noise canceling head phones, another metaphor was that it felt like catching a fly. The participants described it with an exhalation while leaning back and lowering their shoulders. Some described it as a relief that someone had closed that window or door that has been open for a while. Overall the participants preferred it when the car was silent compared to when the ambient noise was on.

The effect was the same even when listening to media the participants mentioned that, since they are used to a specific song for example, they know what is supposed to be there or not. Many said that it did not disturb them, and it did not feel more annoying just because the music was playing. The only thing that was different to when no media was playing was that two participants felt like they listened to two different sounds, both the media and the ambient noise and this felt more difficult than before. Some participants felt that when listening to their media

it demanded more of their concentration to be able to hear the ambient noise and said that they would not have noticed it if they were not actively searching for the ambient sound. The media masked some of the ambient noise feedback and made it more difficult to hear. Mainly the participants took notice of a kind of squeaky sound that was part of the ambient noise which they did not hear when their media was playing. They were left with a pleasant ambient noise as the squeaky part of the sound was the least liked part. The ambient noise that was remaining was compared with the wind blowing against the window which was much more appreciated.

As confirmed by the use test the drivers demand more feedback when the car goes into standby mode. For this test the participants were asked to actively turn PA on or off, the majority mentioned that it was confusing that this action needed a sound as it was enough feedback for them to press the button to receive the visual feedback of PA icon in the DIM. When explained that this was supposed to work as an indication of when it automatically goes into standby mode the participants changed their opinion. Many stated that there is a need of a sound in those situations and, as confirmed before, a more subtle sound would be appreciated as there already is too many signals used in the car. Most of the participants were positive towards the hypothesis of the test and thought that it has a lot of potential. They felt that the way the sound was implemented was innovative and helpful but the sound itself should be changed into something less annoying and disturbing. The participants could not describe what such a sound should sound like, but a majority suggested that the sound should come from nature, since you are seldom bothered by nature sounds or other types of ambient noises. In conclusion the ambient noise used for the test is in need of development and would not, as one participant mentioned, help sell a car as it is now. However, the idea to nudge the driver and to implement a longer sound was perceived as kinder and an idea that could be work in a different setting and manner.

Figure 19: One paricipant on test 3, filmed when driving on side A listening to his own choice of media

4.3.4 DISCUSSION

This test had some issues regarding the reality of how the sound was implemented and how it was supposed to be implemented but a lot of good input and reflections was gained from it. One interesting aspect that should be taken in consideration was that the test was done solely on Volvo employees, not working with the design of the functions, but still people who have a personal interest and connection towards the brand. Half of the participants mentioned that PA is not supposed to work on all kinds of road conditions and that the infrastructure should change because PA will not work as flawlessly on bad roads with little to no lines. This could be interpreted as these participants felt like Volvo has developed PA in the best way possible and leaves the rest of the responsibility to the government and the infrastructure to make the function work in all conditions. With this said Volvo employees might have high thoughts of Volvo cars the way they are produced today and due to this feel like it is not only PA that should change but the infrastructure as well. Parts of the results might therefore be affected by the fact that Volvo employees is proud of the current state of the Volvo cars.

Another issue that was mentioned during the test is that this ambient sound is supposed to indicate when PA goes into standby mode automatically. The initial plan was to use prototype cars where the standby mode and the function could be controlled by the test leader. However just before the test this prototype experienced malfunction and the test had to be conducted in regular cars, where the use case regarding PA going into standby mode automatically could not be simulated. Due to this all participants felt confused when they had to turn it on and off by pressing a button and did not see the need of added feedback for this. When the initial test idea, where PA goes into standby mode, was explained the participants viewed the sound in a different way and was more positive towards the sound. How well the users took notice of the sound and their emotional response to it would how ever be the same regardless of whether the participants actively turned on and off the function or if it was done automatically.

The test was relatively short, and a majority of the participants said that the sound might be easier to get used to and be less bothersome if used during a longer ride, on a highway for example. All participants got used to the sound when activated for a few minutes, but some said that it was a bit annoying as the sound did turn on and off relatively often, and it therefore was more difficult to block out. In a regular car situation when using PA, the participants probably would not keep turning the function on if it turned off this frequently.

Half of the participants had never or only a few times tried PA. This might affect their feeling of insecurity, as it takes some practice to feel completely confident with the function itself. Despite this it was considered to have very little effect on how the sound itself was interpret and results from these participants are valued and analyzed the same way.

Lastly the test results were affected by the fact that the participants were very aware that they were in a test situation. Even though they brought their own music and or podcast which made them feel more at home many mentioned that they would not notice the sound if they did not know to look for it. This affects the results whether the participants heard the ambient sound or not. However, it does not affect the comments retrieved regarding how the sound made them feel and how they reacted upon it which makes it a relatively small issue.

4.4 THE FINAL CONCEPT

The outcome of the previous tests resulted in a final concept. The concept was to include “Make-no-sound”-sounds into PA to enhance the user experience of the use case that has been the focus for the thesis, when PA enters stand-by mode. However, the concept also replaced the auditory feedback for the “Apply steering” command with a “Make-no-sound”-sound as well.

When PA automatically deactivates or goes into stand-by mode the driver is played sound 8 from Test 1, the short-muffled sound also used for Test 2. The sound originated from a larger rock hitting the ocean surface. The sound was described as “dark” and “muffled” by participants and was both named the best sound to convey an “off” function as well as being the most discernable “Make-no-sound”-sound from Test 2.

When PA reactivates itself from stand-by mode, when the road lines are detected again, an edited version of sound 5 from Test 1 is played. The sound originated from the sound of a medium sized rock hitting the ocean surface and was chosen as the sound that the participants thought mediated the “on” function in the best way. They described the sound as “happy” and “light”. It was edited to become shorter as the participants thought that it sounded like two different sounds wrapped into one.

From Test 1 it was made clear that if two different sounds were to be used for the same function turning “on” or “off” they needed to share characteristics both for the users to connect them to the same function but also to become less annoying. Thus, it was important to use two sounds that could share some likeness to one another. This was the reason for editing sound 5 into a shorter version but also as it was deemed the sound that shared the most characteristics of sound 8 which had already been proven to be effective.

From the use test it was shown that the users found it strange that they were provided with such strong multi-modal feedback for the “Apply steering”-situation in proportion to the relatively small feedback they received for stand-by mode. Thus, it was decided to replace the warning signal with a “Make-no-sound”-sound to create a more holistic user experience of PA.

The sound that was chosen for the command was a version of the longer ambient noise used for Test 3. However, as the participants disliked that the ambient noise was constantly playing the sound was altered to start at a very low and slowly be raised in volume until the driver applied steering, which results in the sound disappearing. The reasoning for this was that the participants in Test 3 stated that they understood that the ambient noise was guiding them into a behavior but did not understand the reason for it guiding them into using PA. By providing them with a clear reason, that steering needs to be applied, the drivers would understand why they were being nudged and perceive this as being a kinder indication than a warning signal.

On the next page (figure 20) the sounds could be listened to and there is also a QR-code to scan showing a film where the final concept is implemented which was created by PALMQVIST media.

SCAN THE QR- CODES TO LISTEN TO THE SOUNDS

PA standby mode

PA re-activated

Apply steering

Figure 20: The final concept shown in pictures, sound and film. The symbols together with the sounds show what could be used when PA goes into standby mode, turns gray, when it re-activates, turnes green and when the driver needs to apply steering, the orange symbol.

4.4.1 SWOT – ANALYSIS

A SWOT-analysis was made in order to further analyse the final concept and as a way of determining its flaws as well as defining the concepts strengths. In a SWOT - analysis Strengths, Weaknesses, Opportunities and Threats are defined, Strengths and Weaknesses often are internal to the organization and Opportunities and Threats are often external. Because of this a SWOT-analysis is often called an internal-external analysis as well (Mindtools, 2019).

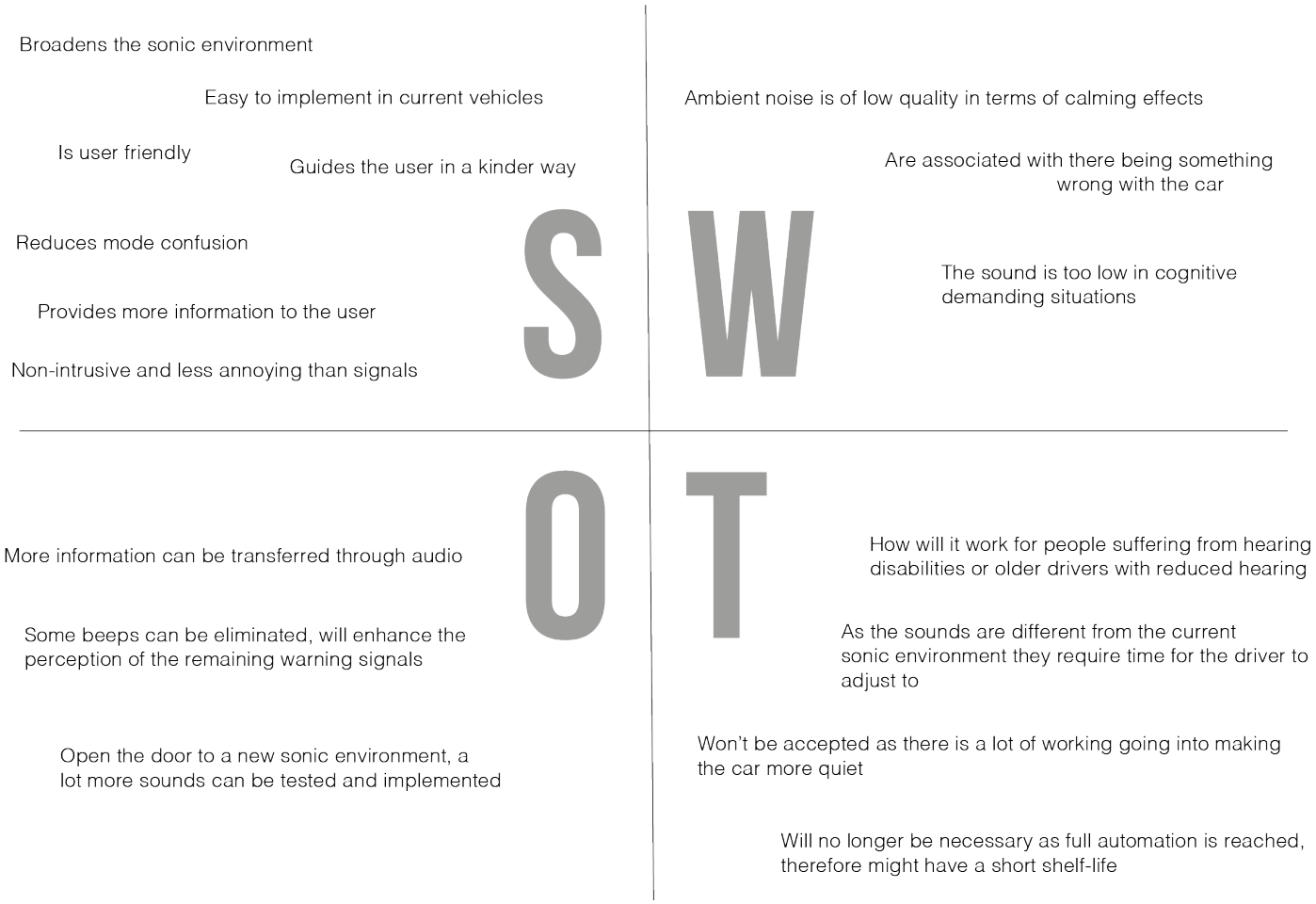


Figure 21: SWOT - analyis. Which helpees analysing the strengths, weaknesses, threats and oppertunities that "Make-no-sound"-sounds have.

As seen in the SWOT (see figur 21) there is more work to be done when it comes to the exact character of the sound to remove threats regarding how well "Make-no-sound"-sounds will be heard by all users, including people with hearing impairments. One weakness could be that the sounds will not be detected in cognitive demanding situations as they are nonintrusive sounds, as seen in Test 2. However, this was not tested during this thesis and is therefore believed to be a risk. Overall, both the strengths and weaknesses with "Make-no-sound"-sounds are that they have widened and opened doors to new ways to use sound in cars which could be a starting point to develop more and new nonintrusive sounds.

4.5 DISCUSSION OF FINDINGS

The guidelines present how by implementing non-intrusive sounds, called “Make-no-sound”-sounds, the user experience could be enhanced. Together with the visual feedback and information that the driver is provided with, these sounds creates a multi-modal interaction. Through this, the driver receives a kind nudge that informs them what mode they are currently in. By implementing “Make-no-sound”-sounds, for when the assistive function PA is activated and deactivated, as well as for when the driver needs to apply steering, the driver is supported in detecting which mode the car is in. By adding three new sounds to the function the sonic environment and auditory feedback is widened without disrupting the users’ experience of a safe and desirable drive. The three new sounds that have been proven to work during this project are a short muffled sound, a longer ambient noise or a white noise, and a lowering of the media played in the car. From the first test it was shown that non-characteristic sounds could convey a functional meaning to drivers but were dependent on the context in which they were used. Even sounds that were not usually found within a driving context could convey an on and off meaning, depending on how their characteristics were designed. In order to make the drivers associate two different sounds to the same function, they needed to share some characteristics with one another. When testing a longer ambient version of a “make-no-sound”-sound it was shown that it kindly pushed or nudged the drivers towards a certain behavior and informed them that there had been a change in the mode status. Whilst the sound tested was annoying to the user at first exposure the drivers were able to block the sound out if they choose to.

The type of feedback that is needed in an automated driving situation to enhance the driver’s user experience must be multi-modal according to NHTSA guidelines as well as results from the use test. The drivers are not fully content with the feedback that they are provided with today, which is mostly relying on visual feedback, as seen in the use study. The feedback demands explanation to be fully understood by the drivers, even though they can understand it to a certain degree. For example, when the green steering wheel in the DIM turns gray the drivers understand that the function is no longer active. However, not all users understand the stand-by mode and are confused as to whether they have to restart the function or why it is no longer active without their interference. This was expressed by users at different occasions, both through the use test, as well as during Test 3 when novice users were unsure what had happened when the function entered stand-by mode. Therefore, the drivers need feedback to ensure them which mode they are driving in, as well as feedback when the mode changes. The drivers also desire the feedback to be more subtle than warning signals, as they find it disruptive to implement more signals into the driving context.

Therefore, the way that auditory feedback could enhance the user experience is in the form of subtle, non-intrusive sounds. These sounds should still inform the driver that action needs to be taken, but not as quick or immediate as a warning signal does. As the function demands the user to actively monitor and perform certain aspects of the dynamic driving task the auditory feedback should be designed in a way that allows the drivers to be able to cognitively block them out, if they feel confident enough to rely on the visual feedback they are already provided with. The user experience is enhanced if the function allows the user to feel calm, safe and that the function is trustworthy, as seen in the EAW (see 3.2.3). By providing a kinder and subtler auditory feedback which is perceived as more supportive than a warning signal that is experienced as more negative the user is more likely to experience this sensation.

In itself the auditory feedback is not able to inform the driver of the level of automation they are experiencing. It needs the support of visual feedback to convey this message entirely. As the subtle auditory feedback is designed to be able to be blocked out, it can also be missed and therefore, there needs to be at least one more sense stimulated to translate this message to the user. The user needs to have at least one constant source of information that allows them to check the driving mode and constant auditory feedback is not suitable to convey this. There is however a great learnability when it comes to “Make -no-sound”-sounds, and when the sound has been taught, it may be possible to rely only on that.

Phase 4: Deliver

5. GUIDELINES

In this section the Guidelines retrieved from the concept development will be presented which are what the final concept is built upon.

5.1 WHAT "MAKE-NO-SOUND"-SOUNDS CAN COMMUNICATE

- "Make-no-sound" -sounds should not be used for warning signals of high importance as they can be missed.
- Are suitable for nudging the user towards a reaction multiple times without being disrupting or intrusive.
- Is noticed but not intrusive and annoying when played multiple times during a short time period
- Can communicate that the driver's attention is needed but without experience it won't be understood on its own.
- Has a high learnability
- Cannot communicate the reaction needed or the reason for the feedback in and of itself and should therefore be used as a compliment to small visual or haptic feedback

With the use of "Make-no-sound"-sounds the driver will stay informed of the mode status without having to take focus from the forwards driving condition. The sounds are designed not to be intrusive, in the way that warning signals are, and could therefore be missed if the driver do not know that they will arrive. Therefore, they should not be used for warnings such as safety warnings that require immediate action. The assistive functions demand that the user has their full focus on their driving environment and therefore the "Make-no-sound"-sounds should not create an over-trust in the system. Rather the sounds should inform the driver that the function is no longer supporting their driving without having the driver look away from the road ahead, thus creating the need to be non-intrusive.

The tests have shown that "Make-no-sound"-sounds have a high learnability, after a few times of exposure the driver will recognize the sounds and when informed of their meaning will understand the information they are conveying and recognize them more easily. However, the tests have shown that the "Make-no-sound"-sounds need to work alongside additional subtle feedback to be able to convey all of the information that the driver requires. Test 2 and 3 showed that repeated exposure to the "Make-no-sound"-sounds did not annoy the users or felt intrusive.

5.2 LOWERING OF VOLUME AS A "MAKE-NO-SOUND" -SOUND

- A lowering of volume as a feedback could only be used when media is played
- The minimum length for the user to notice it needs to significantly be longer than a natural pause in media being played.
- A lowering of volume is more difficult to discern in media where natural pauses is more common such as podcasts, radio or audiobooks and are therefore not suitable for these types of media.
- Due to the fact that they are difficult to discern they should not be used when the driver is involved in secondary tasks separate from the dynamic driving tasks as they risk being overlooked.
- Is not considered as disturbing or intrusive and is therefore better to use if feedback signal activated multiple times

A lowering of volume is already implemented in cars today and fits well into the mental model of communication in cars and feedback in cars. It was shown in Test 2 that when natural pauses occur in the media it was more difficult to hear and to react upon, mainly during the secondary task of making a phone call where the phone signals already have natural pauses. It was a preferred way of receiving auditory feedback as it was the opposite of adding another sound, thus feeling less intrusive. This could also come from the fact that, as mentioned before, this type of auditory feedback is already used in the current system and therefore people are more acceptant of it.

5.3 MUFFLED FEEDBACK AS “MAKE-NO-SOUND"-SOUND

- A short muffled sound has a high chance of being detected and reacted upon
- It is less annoying and intrusive than today's warning signals and is considered informative and a kind nudge in the right direction
- Can be used as an alternative to high pitch and intrusive warning sounds as a way to make feedback that occur often less annoying
- Even though it doesn’t share the same qualities as a warning signal it still matches the mental model of the driver that they need to react to the sound
- Is discernable even when played in lower volumes or with a high media played

During Test 2 the muffled sound was the only “Make-no-sound”-sounds that every user could identify. The users understood its meaning, reacted accordingly and did not feel annoyed or found it intrusive. It was noticed when played at different volumes both with additional media sound and only with the ambient sound of the road. It was the favorite “off” sound from Test 1 as the users felt it conveyed that function the best and in Test 2 the users found it to be the most informative sound out of the three. The users also felt that it was less annoying and more kind than the way a warning sound is designed today. If a warning signal can be likened to someone screaming at you to do something, this sound was considered to be someone offering their help and guidance.

5.4 AMBIENT NOISE AS “MAKE-NO-SOUND"-SOUNDS

- An ambient noise can be used to nudge and guide the user into a certain behavior or action.
- A driver will easily block an ambient noise if it matches the speed and road conditions that is driven on. When it is blocked there is no need to keep the sound activated and it could then be slowly turned off to later be activated when nudging is needed.
- An ambient noise will not be as intrusive as a “beep” sound of today and can therefore be used more frequently without being annoying
- An ambient noise is less annoying when it is not associated with something that is wrong with the car and the wind noise is perceived as the most pleasant within the car sound spectra
- Using an ambient noise for a long time and then removing it creates a heightened user experience. Even if the ambient noise goes unnoticed the silence that ensues creates a much better experience for the driver.
- The user feels a satisfaction and thrives for a behavior that is rewarded with silence.
- When the car is silent the user understands that he or she is using the car the way the car wants to be used and when used that way the user is in big need of understanding why the user should behave that way or else it will be perceived as confusing and annoying

During Test 3 it was made clear that an ambient noise of a character that is not associated with something being wrong with car was appreciated and an idea that many users enjoyed and felt had a lot of potential. It is however important that the sound matches the ambient noise that is experienced in the car so as not to associate it with something else.

The biggest issue with this sound was that many test participants felt confused when the sound was applied as an indication to whether the function was active or not. The users did not understand why they were pushed into having PA activated by the sound. It was also made clear that the ambient noise did not need to be active all the time and that a shorter version of the sound that matches the time it took for the user to block it out would be favorable when it comes to using this type of auditory feedback as this would be considered more of a nudge.

5.5 CATEGORIZING “MAKE-NO-SOUND"-SOUNDS

- Sounds that belong to the same function and demands the same response should also share the same characteristics
- The “on” sounds should have a lighter character and mediate a feeling of “keep on going” to the user
- The “off” sound should have a darker character and be short in length

It was retrieved from Test 1 that the sounds should belong together to be more understandable as well as to be less intrusive. The adjective used in the first test as well as the information retrieved from the literature review show that an “off” sound is characterized as short, chopped off, muffled, pitchy and dark. An “on” sound is characterized as happy or light and indicated that something was finished or mediating a function that “keeps on going”.

5.6 WHEN TO USE WHICH “MAKE-NO-SOUND" -SOUND

- Muffled “Make-no-sound" -sounds are more noticeable than the longer ambient noise and possesses a higher risk of being perceived as annoying if used several times during a drive.
- The reason for being nudged by an ambient noise needs to be clear for the user to not get annoyed with the sound.

A great way of using “Make-no-sound” -sounds should be to use short muffled sounds when a function activates or deactivates and use a longer ambient noise when the driver should be nudged to e.g. apply steering which is an issue when using PA. This was retrieved from the tests and was summarized and tested in the last test.

6. REFLEXIVITY AND FUTURE WORK

In this section the research questions will be answered as well as a summary of the most important findings will be presented. A suggestion on further work and a discussion regarding the design of audio as well as the future of PA and ACC could also be read in this part of the report.

6.1 REFLECTIONS ON DESIGN APPROACH

In this section a discussion regarding how it is to design sounds as visual designers as well as a discussion to where this project fits into the world of automotive and autonomous driving. This section is built upon the findings from the tests but also theories and discussions that has been held in the project group.

6.1.1 DESIGNING SOUNDS LIKE THEY WERE VISUALS

The authors of this master thesis have no previous experience when it comes to developing sounds. This was considered an obstacle in the beginning of the project especially when it came to the developing phase and the ideation phase. The general method was to consider sounds as visuals when developing and understanding that sounds can be seen as visuals in the design process. Sounds can to be kind, subtle, round, harsh and so on. It was also discovered that it is possible to discuss sounds and their shapes the same way as a shape of a product is talked about. Gestalt laws and gestalt psychology which are commonly used within product design could as with vision also be implemented in your audio interpretation. These laws are divided into different laws such as the law of closure, law of similarity and so on (Egidius, 2019). When designing an interface these laws are taken in consideration to increase usability. Functions and attributes that are similar should be close together and organized in a similar way to be more easily read and understood for example. This could also be done with sounds as the same function should have similar audio input. Where and in what situations the sound is activated should also be designed with these laws in mind and in this way the design process is very similar to when designing visual feedback and interfaces. Sounds are difficult to sketch and write so the ideation process is the one phase that differs the most. But with the same mindset the sounds used in the tests conducted during this thesis was sprung out of an inspiration source as well as with the personas in mind. With this base to work from the sounds were worked with, listened and developed further. The goal was to create sound that were kind and subtle as the sound should nudge the user in the right direction as well as be easy to understand. With this in mind the sounds were listened to and the best ones were developed further. This could be compared with when the table is filled with sketches of ways of solving a problem with the help of a new product which often is a result of a brainstorming session with some demands and problem definitions in mind. The best sketches are taken out of the pile and worked with further. As the sounds developed should not be intrusive and only nudge the user some metaphors were developed as a way of making it easier to discuss sounds as if they were visual feedback. The volume of the sound was compared with a products colour and a bright and intrusive color is not subtle and kind and easy to block out just as a sound no matter how the sound character is would be intrusive if the volume is high. The shape and material of a visual product was compared with the shape and sharpness of the sound. Even a sound with a low volume can be seen as intrusive if there is a sharp character of the sound just as something in the visual input that has a shape that is out there and does not belong in the surroundings can be intrusive even if it has a color that blends into the surroundings.

6.1.2 WORK PROCESS

In terms of work process, there are a few things that could have been avoided with more experience of working with sound design. The main issue in the first round of tests was what was going to be measured and realizing what type of findings that were relevant for the project.

During the early phases of planning Test 2 when very subtle feedback was going to be tested a lot of focus was placed on putting all of the media and the sounds implemented within the same decibel range. As inexperienced sound designers it was considered to be useful to be able to measure the impact the sounds had on the participants by getting the decibel numbers of when the sounds would be noticed and not. However, as decibel measurement is a very specific measuring tool this was a lot of work that would not result in anything definitive. With the knowledge gained from this thesis this would have been discarded early on in the process, had the test been re-done.

Overall this has been one of the biggest take-aways of the work process and the thesis as a whole. As the work has been focused on the user experience the findings found in numbers are rarely what will generate deeper knowledge of the situation. By using a quick-and-dirty approach to the tests and putting emphasis on utilizing interviews and methods like UEQ to start a discussion with the users it has been found that this is also valid results. Had the work been re-done this approach would have been adopted earlier on in the process. However, the work process that have been used have created interesting findings, a deeper knowledge and understanding of the drivers experience and overall the work process had not differed much from the approach that have been used.

6.1.3 DESIGNING FOR THE AUTOMOTIVE INDUSTRY WITH VOLVO EMPLOYEES

All the tests involving the actual PA function, the use test as well as Test 3, have been performed with Volvo employees, that did not work directly with the function, as participants. This user group proved to be quite biased towards the brand and the function, even if that was not something they worked with directly, as they had difficulty finding the negative aspects of the function and were very forgiving of its shortcomings. Their view of the function as having more to learn shows that these drivers does not fully trust the function which can be seen as problematic as it is meant to be an aid to their driving. During the tests taking place at the TT-track PA would from time to time enter stand-by mode, the participants were quick to point out that this could be because of the road condition. They did not see this as a short coming in the function rather they felt that PA had been developed to the point where it no longer needed improvement in its radar sensitivity, rather the infrastructure needed to improve to enable the function to do its job.

This was an interesting finding that becomes a problem in the ethics of reaching an autonomous driving future. As it is today, the technology that is considered to be in the forefront towards autonomous driving, such as PA, cannot be used to its full potential as the current infrastructure does not allow it to do so. However, by renouncing the responsibility to improve the technology because of this becomes problematic. With everything that technology has to offer it is very probable that technology will be able to push past these problems and therefore it is important to point out that even the most state-of-the-art solutions needs improvement. The way that the technology should be used should rather be to adapt to the conditions as they are today or in the near future rather than to adapt the conditions to the existing technology. Therefore, implementing a sound that informs the driver of the systems shortcomings both help in avoiding over-trust in the system but also highlights where improvement in the technology is needed right now. Thus, in the future the “Make-no-sound”-sounds might not be needed at all as the eventual goal of a fully autonomous car have been reached but until then it is needed both to support the driver but also give an indication to stakeholders that the function still has a way to go.

6.1.4 HOW WELL DOES "MAKE-NO-SOUND" -SOUNDS FIT INTO THE REAL WORLD

Lastly this report will consider the future in a holistic way and have a wider discussion regarding the future of transportation and where this project fits into that.

As vehicles are becoming more and more autonomous one has to question what information that the driver actually needs in order to have the desired experience. If the driving is outsourced to the car, do user really need to know what the car is doing as long as they know that the car itself knows what it is doing? In today's climate it is already apparent that users of many technical products and services are not aware of the specifics regarding how said product or service works, rather they are interested in knowing how to use it. As the market is edging closer to full automation the driver is morphing into being the passenger and the system becomes the driver. Relatable to this is that as a passenger you often trust the driver to make the driving decisions without informing you. It would probably create a greater feeling of insecurity for the passenger of the driver provide a constant update on all of their driving decisions. The passenger does not need to know that a roundabout is coming or that there is a car ahead of you, because that information is something that the driver requires, not the passenger. It is very possible that this will happen when the outsourcing the driving task to the system and if this is the case for the future the use of "Make-no-sound"-sounds needs to be re-evaluated.

An interesting aspect is how well today's drivers will handle the transition from manual drive to a fully automated driving situation, how will the users give the control to someone or something else? In order to do so the driver must have a huge deal of trust and security for the system. For the system to instill this trust in the user it needs to be rewarding to the user's action instead of only telling them when they have done something wrong. In the future it might become a situation where the users have so much trust in the autonomous cars and their functions that the only reason for choosing one car over another might be the user experience and what car makes you feel the way you want during a transportation. And what is perceived as more kind, calm, smooth and trustworthy: a screaming baby demanding attention or a kind friend who understands when you just need some peace and quiet? This thesis and the results from it are believed to be a good transit towards a car where feedback is next to none. "Make-no-sound"-sounds is a way of more quietly informing the driver what is happening because the car does not want to disturb you unless a warning is necessary where todays warning signals fit perfectly.

6.2 FURTHER WORK

The natural step for future work would be to test implementing "Make-no-sound"-sounds into a more realistic driving experience. None of the tests performed were able to mask the Wizard of Oz approach of the situation nor could the stand-by mode be properly simulated. If time would have allowed for it the concept of "Make-no-sound"-sounds could be implemented in the WoZ-cars available at Volvo Cars where in particular the stand-by mode could have been simulated. This would have allowed for a safe test of whether this type pf auditory feedback would be noticed by the user in a more subconscious way as there would no longer be any need for the user to be asked to turn it off. By doing this it would provide a more certain answer to whether these sounds have the same impact on the users as they have when actively being searched for.

Another outcome of such a test would be to see how well the auditory feedback would work alongside the visual feedback that already exists in the current cars. The tests have shown that "Make-no-sound"-sounds are unable to convey enough information in and by themselves and the users need additional feedback in order to make sense of what they are informed of. Although the tests have incorporated visual feedback as it could not be disabled, for practical and safety reasons, the "make-no-sound"-sounds have not been able to be tested in connection to it. The best attempt at this was in Test 2 where the users were reliant on the visual interface for confirmation that the cruise control was turned off. However, this was done in a simulator that lacks the feedback a driver is provided with in an actual car, the sound of the wind blowing or the physical sensation. The users were therefore more reliant on the visual interface than they might have been in a real car situation. A future test would be able to investigate whether these subtle sounds could work in combination with the quite subtle visual feedback provided for stand-by mode.

Further work would also include implementing these "Make-no-sound"-sounds into more functions as well as creating more varieties of these sounds to be able to create a greater and wider audio environment and with that enhance the user experience. The enhancement of the interior sounds which was tested in Test 3 was not appreciated by the users, some of who heard a squeaking noise in it. Some users suggested that a wind noise would be more suitable. Another approach would be to dig deeper into the users desired feelings when using PA and ACC and match a sound that would convey this. There are also more naturalistic sounds that could be explored as it was shown in the tests that when taking a sound from nature and implementing it into the car context they could still convey meaning to the users and convey a calm feeling.

While "Make-no-sound"-sounds are designed to give a kind push in the right direction for the drivers the use of this subtlety will probably not work for all drivers. Future work should also include testing the impact these sounds have on hearing impaired drivers. There is a possibility that "Make-no-sound"-sounds are too subtle to work in these cases or needs to be modified in character or volume.

As it has been shown that "Make-no-sound"-sounds has to be complemented by another sensory stimuli in order to fully inform the user future work could be aimed at creating directional sound. The subtle "Make-no-sound"-sounds could be used to direct the user's attention to where explanatory information was being displayed. As the user is not provided with much explanation for stand-by mode one possible implementation would be to use a "Make-no-sound"-sound to direct the driver's attention to the DIM where a visual message of what stand-by mode means could be displayed. Another possibility would be to look into how well "Make-no-sound"-sounds could work in other function and if any of the auditory feedback implemented in the cars today could be transferred into a "Make-no-sound"-sounds instead.

Even though the "Make-no-sound"-sounds are less intrusive than warning signals they still run the risk of annoying the user if they are repeated many times over a short period of time. As PA might deactivate many times during a ride with the limitations it currently has further work should also focus on how many times the "Make-no-sound"-sounds could be repeated until they become as intrusive as a warning signal would be.

Finally, the project and the outcome of this master thesis should work further with being implemented in cars today. There is before the implementation a need to look more deeply into the NHTSA guidelines and see the opportunity to legally applying a feedback like this in the second level of autonomous cars and if it is applicable in the futures fully autonomous driving.

7. CONCLUSION

The aim of this project was to improve the user experience of the driver of a vehicle with a second level of automation by enhancing the auditory feedback and broaden the audio environment in cars. In order to improve the user experience of the drivers the project also aimed to understand the current experience the users have of the two assistive functions PA and ACC. The sonic environment present in the current vehicles include many warning signals yet for the assistive functions in focus the auditory feedback is sparse. As these functions are in the forefront of the future desired state of autonomous driving it is important to create and maintain a safe and pleasant user experience for the drivers of these vehicles. It is also important to give the user information so to give them a feeling of trust in the system as well as a feeling of being safe in their car. Since the cars today are not fully autonomous it is of high importance to keep the mode confusion of the drivers at a minimum to ensure a pleasant and safe experience. Therefore, the project also aimed to determine how to provide feedback to the users to make them aware when the functions are supporting their driving as well as informing the driver on when they need to take control.

The aim of this project is considered to have been met. From the use tests it has been shown that multi-modal feedback enhances the driver's user experience of driving with ACC and PA. The findings from the tests performed shows that auditory feedback can enhance the user experience by informing the user of which mode they are driving in subtle way which is perceived as kinder. It has been shown that if this subtle feedback provides the experience of a quieter environment for the driver, they can be nudged to use the studied functions in the right way.

The project resulted in a set of design guidelines of how to implement non-intrusive sounds into the user experience of these two functions with a focus on PA. The sounds aim to be able to be implemented in ACC as well but in the problem definition it was clear that ACC has very little trust issues and possesses a great user experience as it is narrowing the project to focus on PA. The guidelines that was created were based on a set of use tests which had its foundation in literature and a user study with both expert and novice users of the functions. Future work should investigate how this subtle feedback would work for drivers suffering from hearing disabilities and whether they can be implemented into other assistive functions as well.

8. REFERENCES

Adielsson, A., Ekman, L., (2016). *Design Development of a Driver Display - For improved User Experience of Semi-Autonomous functions*. Gothenborg, Sweden.

Bizley, J. & Cohen, Y., (2013) *The what, where and how of auditory-object perception* Nature Review Neuroscience, Nature Publishing Group, London, UK.

Blauert, J., Jekosch, U., (1997). *Sound-quality evaluation a multi-layered problem.* Acta acustica united acustica 83 (5), 747 - 753. Ruhr-University Bochum, Germany.

Blauert, J., Jekosch, U., (2003). *Concepts behind sound quality: some basic considerations.* In: INCE Conference Proceedings. Vol. 206, No. 1, Pp. 72 - 79. Ruhr-University Bochum, Germany.

Bligård, L.-O. & Osvalder A.-L., (2010). Chapter 5-9 in: *Methodology for prediction and identification of mismatches in the interaction between user and artefact*. Chalmers University, Gothenburg, Sweden.

Bredereke J. & Lankenau A. (2002). *A Rigorous View of Mode Confusion.* Universität Bremen, Bremen, Germany.

Bussolon, S., (2016). T*he X Factor: Defining the Concept of Experience.* In Design, User Experience and Usability. Toronto, Canada.

Campbell, J. L., Brown, J. L., Graving, J. S., Richard, C. M., Lichty, M. G., Bacon, L. P., … & Sanquist, T., (2018, August). *Human factors design guidance for level 2 and level 3 automated driving concepts* (Report No. DOT HS 812 555). Washington, DC: National Highway Traffic Safety Administration.

Chi, C., Sari Dewi, R., Huang, M., (2016). *Psychophysical evaluation of auditory signals in passenger vehicles.* Taipei, Taiwan.

Constantino, F., Chait, M., Kashino, M, Paranamana, S. & Pinggera, L. (2012). Detection of Appearing and Disappearing Objects in Complex Acoustic Scenes, PLOS, San Francisco, US.

Design Council., (2019). *The Design Process: What is the Double Diamond?*. Retrieved 2019-01-22 from: www.designcouncil.org.uk/news-opinion/design-process-what-double-diamond

Duffy, V.G., Ng, P.P., Ramakrishnan, A., (2004). *Impact of a simulated accident in virtual training on decision-making performance.* Int. J. Ind. Ergon. 34 (4), 335 - 348. Purdu University, Indiana, US.

Edworthy, J., (1994). *The design and implementation of non-verbal auditory warnings*. Appl. Ergon. 25 (4), 202 - 210. University of Plymouth, UK.

Egidius, H., (2019). *Psykologilexikon.* Natur och Kultur. Stockholm. Retrieved 2019-04-05 from: https://www.psykologiguiden.se/psykologilexikon?Lookup=gestaltlagar.

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

Gantt., (2019). What is a Gantt Chart? Retrived 2019-01-23 from: www.gantt.com/

Gould, R., (2016). *Auditory Icons,* retrieved 2019-02-25 from http://designingsound.org/2016/11/24/auditory-icons/

Green, P., (2018, 27 December). *Want sleep? Add sound.* New York Times. New York, US.

Hagman, W., (2018). *When are nudges acceptable?: Influences of beneficiaries, techniques, alternatives and choice architects.* Lindköping University, Lindköping, Sweden.

Hagman, W. (2019). *Interviewed by Marcus Berggren and Hanna Hellquist for Morgonpasset I P3, 3 April.* Sveriges Radio. Stockholm, Sweden. Available at: https://sverigesradio.se/morgonpassetip3gasten?date=2019-04-03

Hassenzahl, M., (2005). *The Thing and I: Understanding the Relationship Between User and Product. In Funology: From Usability to Enjoyment.* eds. M. A. Blythe, A. F. Monk, K.Overbeeke and P. C. Wright. Kluwer Academic Publishers. Alphen aan den Rijn, Netherlands.

Hellier E., Naweed A., Walker G., Husband P., Edworthy J., (2011). *The influence of auditory feedback on speed choice, violations and comfort in a driving simulation game.* Plymouth, UK.

Horswill, M. S., & Plooy, A. M., (2008). *Auditory feedback influences perceived driving speeds*. Perception, 37, 1037–1043. University of Queensland. St Lucia, Brisbane, Australia.

Hornsby, P., (2010). *Hierarchical Task Analysis. Innovating UX Practice - Inspirations from software engineering.* UX matters. Berkshire, UK. Retrieved 2019-04-10 from: https://www.uxmatters.com/mt/archives/2010/02/hierarchical-task-analysis.php

Howard, B. (2013). *What is adaptive cruise control, and how does it work?*. ExtremeTech. Retrieved 2019-01-23 from http://www.extremetech.com/extreme/157172-what-is-adaptive-cruise-control-and-how-does-it-work

Ihlström, J., Stave, C., Strand, N., (2018). *A case-study on drivers' mental model of partial driving automation.* ResearchGate. 25th ITS World Congress. Copenhagen, Denmark.

ISO, International Organization for Standardization (2010). *Ergonomics of human-system interaction - Part 210: Human-centred design for interactive systems.* ISO 9241-210. ISO. Geneva, Switzerland. Retrieved 2019-04-05 from: https://www.iso.org/standard/52075.html 2019-02-13

ISO, International Organization for Standardization, (2003). *Ergonomics. Danger Signals for Public and Work Areas* (Standard No. ISO 7731:2003). ISO. Geneva, Switzerland.

Johnson-Laird, P.N., (1983). *Mental models: Towards a cognitive science of language, inference, and consciousness.* Cambridge University Press. Cambridge, UK.

Kang, M-W., Momtaz, S U., (2017). *Assessment of driver compliance on roadside safety signs with auditory warning sounds generated from pavement surface a driving simulator study.* Florida, US.

Kim M, Lee, Y, Son, J. (2010). *Age-Related Physical and Emotional Characteristics to Safety Warning Sounds: Design Guidelines for Intelligent Vehicles.* IEEE, pp. 592-598. New Jersey, US.

Krippendorff, K. (2005). *The semantic turn: A new foundation for design* Chapter 4.3, Taylor & Francis, 2005. Abingdon, UK.

Kuwano, S., Fastl, H., Namba, S., Nakamura, S., Uchida, H., (2002). *Subjective evaluation of car door sound.* Proc. Sound-Quality Sym., Dearborn MI. Osaka University. Osaka, Japan.

Larsson, P., Bazilinskyy, P., de Winter, J. (June, 2017). *Continuous auditory feedback for displaying automation status, lane deviation, and headway in a heavy truck.* Delft University of Technology. Delft, Netherlands.

Lemaitre, G., Susini, P., Winsberg, S., McAdams, S., Letinturier, B. (2009). *The sound quality of car horns: designing new representative sounds.* Acta acustica united Acustica 95 (2), 356 - 372. Paris, France.

Mind Tools., (2019). *SWOT-Analysis - Discover New Opportunities, Manage and Eliminate Threats.* London, UK. Retrieved 2019-05-06 from: https://www.mindtools.com/pages/article/newTMC_05.htm

Meng, F., Li, S., Cao, L., Peng, Q., Li, M., Wang, C., Zhang, W., (2016). *Designing fatigue warning systems: the perspective of professional drivers.* Appl. Ergon. 53, 122 - 130. Tsinghua University. Beijing, China.

Norman, D.A., (1987). *Some observations on mental models, in Gentner, Mental models*. pp. 7-17. San Francisco, US.

Norman, D.A., (1988). *The design of everyday things*. Basic Books. New York City, US.

North, A.C., Hargreaves, D.J., (1995). *Subjective complexity, familiarity, and liking for popular music.* Psychomusicology A J. Res. Music Cognition 14 (1 - 2), 77. University of Leicester. Leicester, UK.

Patterson, R.D., (1982). *Guidelines for Auditory Warning Systems on Civil Aircraft.* Civil Aviation Authority. London, UK.

Kim M, Lee, Y, Son, J. (2010). *Age-Related Physical and Emotional Characteristics to Safety Warning Sounds: Design Guidelines for Intelligent Vehicles.* IEEE, pp. 592-598. New Jersey, US.

Krippendorff, K. (2005). *The semantic turn: A new foundation for design,* Chapter 4.3, Taylor & Francis, 2005. Abingdon, UK.

Kuwano, S., Fastl, H., Namba, S., Nakamura, S., Uchida, H., (2002). *Subjective evaluation of car door sound*. Proc. Sound-Quality Sym., Dearborn MI. Osaka University. Osaka, Japan.

Larsson, P., Bazilinskyy, P., de Winter, J. (June, 2017). *Continuous auditory feedback for displaying automation status, lane deviation, and headway in a heavy truck.* Delft University of Technology. Delft, Netherlands.

Lemaitre, G., Susini, P., Winsberg, S., McAdams, S., Letinturier, B. (2009). *The sound quality of car horns: designing new representative sounds*. Acta acustica united Acustica 95 (2), 356 - 372. Paris, France.

SAE international. (2014). *Automated driving levels of driving automation are defined in new SAE international standard J3016.* Warrendale. Pennsylvania.

Sarter, N.B., Woods, D.D., Billings, C.E. (1997). *Automation Surprises Handbook of Human Factors & Ergonomics.* McGraw-Hill, New York, US.

Schofield, L., (2019). *What Is the Function of an Instrument Cluster in a Car* Retrieved Apr 29, 2019 from: https://itstillruns.com/function-instrument-cluster-car-7350828.html

Schrepp, P., (2019). *User Experience Questionnaire Handbook.* SAP Research. Waldorf, Baden-Württemberg, Germany.

Sincero Mae, S., (Aug 1, 2013). *Top-Down VS Bottom-Up Processing.* Retrieved Apr 29, 2019 from: https://explorable.com/top-down-vs-bottom-up-processing

Sodnik, J., Dicke, C., Tomazic, S., Billinghurst, M., (2008). *A user study of auditory versus visual interfaces for use while driving.* Int. J. Human-Computer Stud. 66(5), 318 - 332. London, UK.

Staunstrup, P. (2017). *Hur du skapar användbara personas (infograf).* Retrieved 2019-04-05 from: http://staunstrup.se/blog/malgruppsanalys/hur-du-skapar-anvandbara-personas-infograf/

Thaler, R. H. and Sunstein, C. R. (2009). *Nudge: Improving Decisions About Help, Wealth and Happiness.* London: Penguin Books. London, UK.

Volvo Cars, (2019). *Pilot Assist.* Retrieved 2019-02-12 from http://volvo.custhelp.com/app/answers/detail/a_id/9731/~/pilot-assist-ii

Volvo Cars, (2019). *Pilot Assist and Lane assistance*. Retrieved 2019-02-12 from https://www.volvocars.com/uk/support/article/3395a91b40bddd9ac0a801511916dab3

Volvo Cars (2019). *Head-up display.* Retrieved 2019-04-29 from: http://volvo.custhelp.com/app/answers/detail/a_id/9540/~/head-up-display-%28hud%29

Winsten, J., (2016). *Curbing distracted driving with "situational awareness".* Boston, US.

Wikberg-Nilsson, Å., Törlind, P., & Ericsson, Å. (2015). *Design - process och metod.* Lund: Studentlitteratur. Lund, Sweden.

Wogalter, M.S., Kalsher, M.J., Racicot, B.M., (1993). *Behavioral compliance with warnings: effects of voice, context, and location***.** Saf. Sci. 16 (5), 637 – 654. Rensselaer Polytechnic Institute, Troy, US.

Yost, W.A., (2009). *Pitch perception. Atten. Percept.* Psychophys. 71 (8), 1701 - 1715. Arizona State University, Tempe, US.

Pictures used without reference in the picture are taken from Volvo Cars Content Store.

APPENDIX

1. Benchmark questionnaire
2. PUGH
3. Interview questions from use test
4. Empty UEQ
5. Results from UEQ use test
6. HTA ACC and HTA PA
7. ECW and PUEA
8. Full script test 2
9. KJ analysis from test 2
10. Full script test 3

APPENDIX 1 - BENCHMARK QUESTIONNAIRE

How well did the car follow the guidelines?	Not at all 1	2	3	4	Very well 5
A display indicating which automation mode is currently active	○	○	○	○	○
A simple display to communicate basic information about the mode or status of the automation to the driver	○	○	○	○	○
The current system status is provided at all times.	○	○	○	○	○
The automation system reacts to the driver request instantly.	○	○	○	○	○
If the transfer between driver to system was successful an update the displayed status of the automation.	○	○	○	○	○
Distinctive messages are used for successful and unsuccessful transfer of control events.	○	○	○	○	○
The driver is provided with information on when they need to take control.	○	○	○	○	○
The driver is provided with information on how to take control if a specific control input is required.	○	○	○	○	○
Notifications and messages related to a “take control” message are multimodal.	○	○	○	○	○
Provide information about the system at a level of detail that can be understood.	○	○	○	○	○
Employing strategies that engage the driver’s attention when deemed necessary.	○	○	○	○	○
Encourage drivers to attend to forward roadway conditions.	○	○	○	○	○
Make it very easy for the driver to override the automation.	○	○	○	○	○
Avoid enabling interaction features just because they are possible.	○	○	○	○	○
When appropriate, explain what is being done and why.	○	○	○	○	○
Do not provide unnecessary information.	○	○	○	○	○
Use multiple modalities to communicate.	○	○	○	○	○

In google forms there was also an opportunity to comment on why it got the grade that it got. This questionnaire was done for both Volvo and Tesla.

APPENDIX 2 - PUGH

SCORE		NHTSA GUIDELINES	SCORE	
ACC	PA		ACC	PA
4	5	A display indicating which automation mode is currently active	4	3
3	4	A simple display to communicate basic information about the mode or status of the automation to the driver	4	4
4	4	The current system status is provided at all times.	4	4
5	2	The automation system reacts to the driver request instantly.	4	5
3	5	If the transfer between driver to system was successful an update the displayed status of the automation.	3	3
3	4	Distinctive messages are used for successful and unsuccessful transfer of control events.	3	2
3	4	The driver is provided with information on when they need to take control.	3	4
3	2	The driver is provided with information on how to take control if a specific control input is required.	3	4
3	4	Notifications and messages related to a “take control” message are multimodal.	3	4
2	4	Provide information about the system at a level of detail that can be understood.	3	2
3	4	Employing strategies that engage the driver’s attention when deemed necessary.	3	3
2	3	Encourage drivers to attend to forward roadway conditions.	4	3
3	5	Make it very easy for the driver to override the automation.	4	5
2	2	Avoid enabling interaction features just because they are possible.	3	4
2	2	When appropriate, explain what is being done and why.	2	2
5	4	Do not provide unnecessary information.	5	4
1	4	Use multiple modalities to communicate.	1	3
51	59	TOTAL SCORE	56	62

APPENDIX 3 - INTERVIEW QUESTIONS FROM USE TEST

Show them how to turn on the ACC and the PA.

Turn on the
ACC:

1. How do you feel when you start the ACC?
    a. How does the car communicate and give you information?
        i. Is it enough?
2. How often do you use ACC?
3. Do you feel that you know what it is doing when it is active?
4. Do you perceive it as being intelligent?
5. Do you feel safe using it?
6. How does the car communicate and give you information?
    a. Is it enough?
7. Do you find it to be easily accessible?
8. How do you feel when you turn it off?
    a. How does the car communicate and give you information?
        i. Is it enough?
9. In which situations do you enjoy using ACC?
10. How would you want to feel when using ACC?

Turn on the
PA:

1. How do you feel when you start the PA?
    b. How does the car communicate and give you information?
        i. Is it enough?
2. How often do you use PA?
3. Do you feel that you know what it is doing when it is active?
4. Do you perceive it as being intelligent?
5. Do you feel safe using it?
6. How does the car communicate and give you information?
    a. Is it enough?
7. Do you find it to be easily accessible?

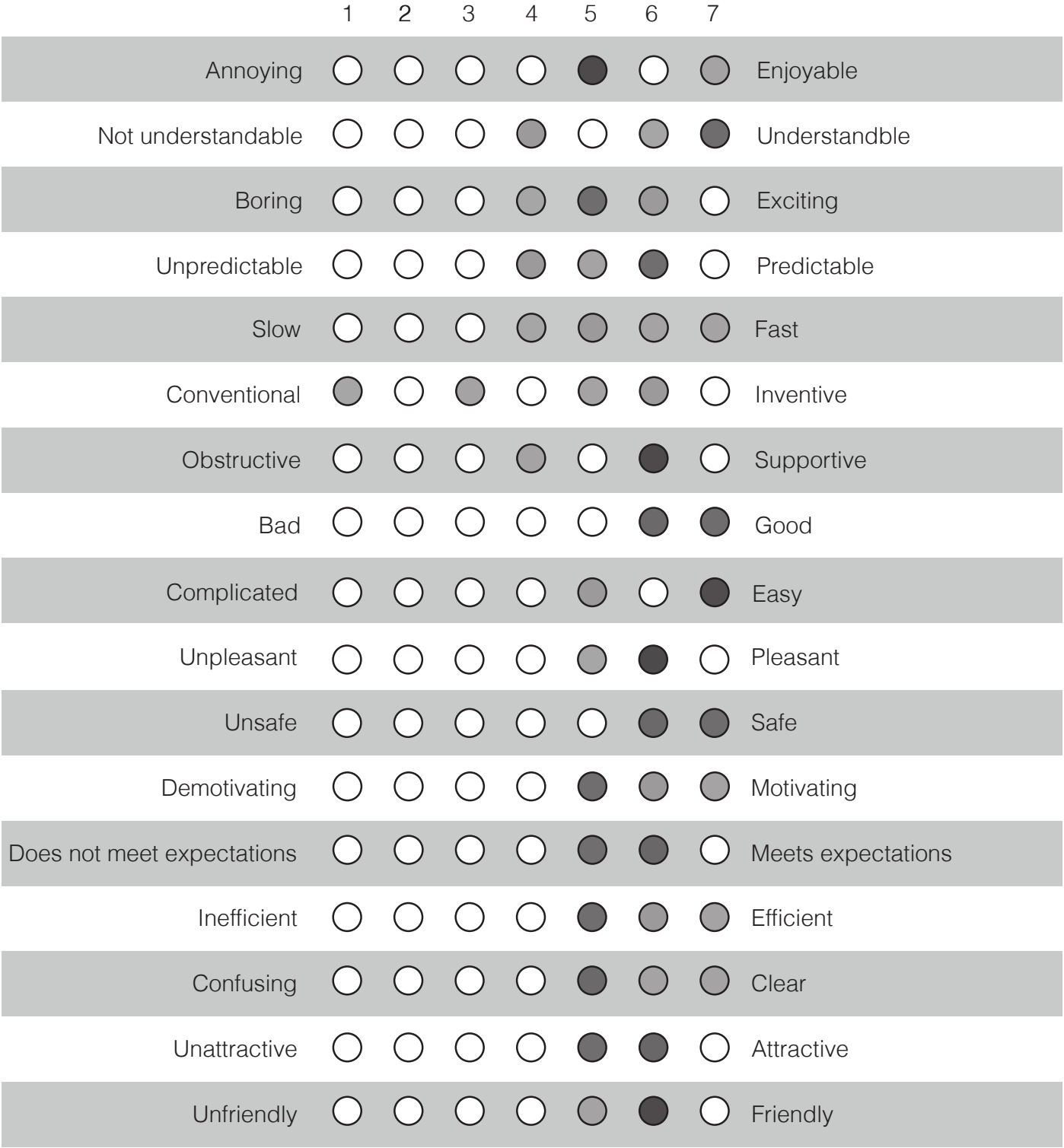
APPENDIX 4 - EMPTY UEQ

	1	2	3	4	5	6	7	
Annoying	○	○	○	○	○	○	○	Enjoyable
Not understandable	○	○	○	○	○	○	○	Understandble
Boring	○	○	○	○	○	○	○	Exciting
Unpredictable	○	○	○	○	○	○	○	Predictable
Slow	○	○	○	○	○	○	○	Fast
Conventional	○	○	○	○	○	○	○	Inventive
Obstructive	○	○	○	○	○	○	○	Supportive
Bad	○	○	○	○	○	○	○	Good
Complicated	○	○	○	○	○	○	○	Easy
Unpleasant	○	○	○	○	○	○	○	Pleasant
Unsafe	○	○	○	○	○	○	○	Safe
Demotivating	○	○	○	○	○	○	○	Motivating
Does not meet expectations	○	○	○	○	○	○	○	Meets expectations
Inefficient	○	○	○	○	○	○	○	Efficient
Confusing	○	○	○	○	○	○	○	Clear
Unattractive	○	○	○	○	○	○	○	Attractive
Unfriendly	○	○	○	○	○	○	○	Friendly

User Experience Questionnair (UEQ)

APPENDIX 5 - RESULTS FROM UEQ USE TEST

ACC



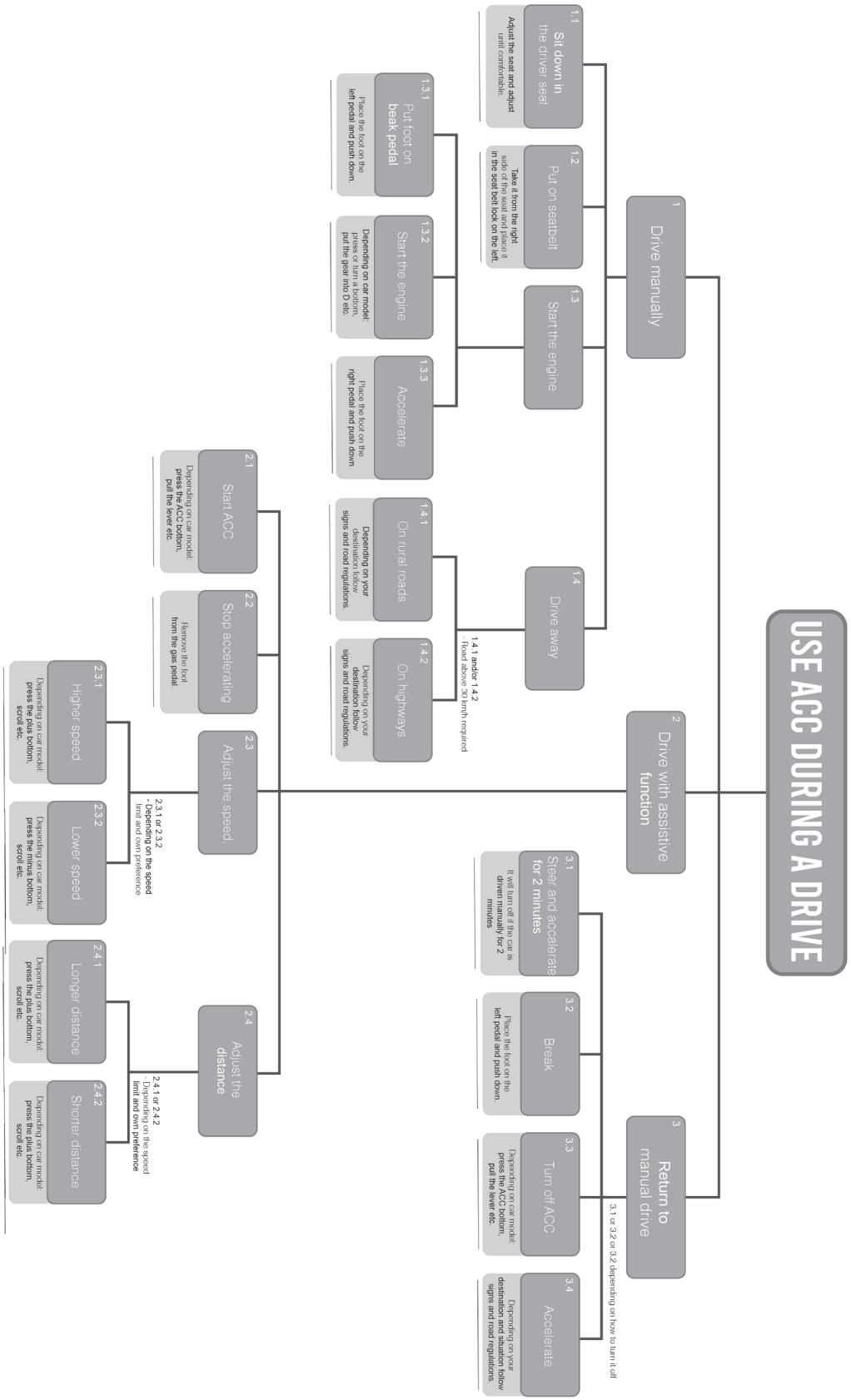
User Experience Questionnair (UEQ)

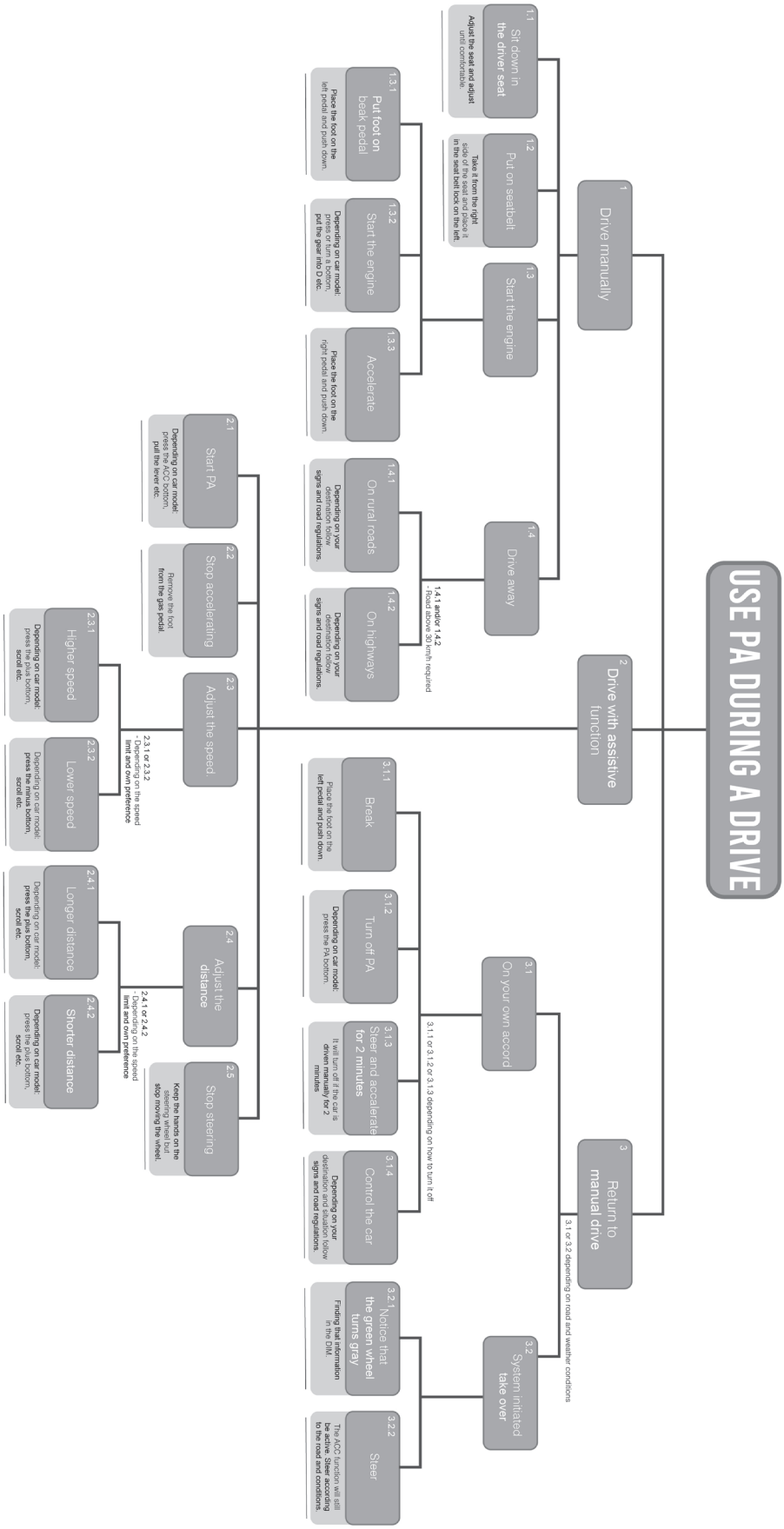
PA

	1	2	3	4	5	6	7	
Annoying	○	○	○	◐	●	○	○	Enjoyable
Not understandable	○	○	○	○	●	◐	○	Understandble
Boring	○	○	○	◐	○	●	○	Exciting
Unpredictable	○	○	○	◐	◐	○	○	Predictable
Slow	○	○	○	◐	◐	◐	○	Fast
Conventional	○	○	○	○	○	●	○	Inventive
Obstructive	○	○	○	○	◐	◐	◐	Supportive
Bad	○	○	○	○	●	◐	○	Good
Complicated	○	○	○	◐	◐	◐	○	Easy
Unpleasant	○	○	○	○	●	◐	○	Pleasant
Unsafe	○	○	○	◐	◐	○	◐	Safe
Demotivating	○	○	○	◐	◐	◐	○	Motivating
Does not meet expectations	○	○	○	◐	●	○	○	Meets expectations
Inefficient	○	○	○	◐	●	○	○	Efficient
Confusing	○	○	○	○	●	◐	○	Clear
Unattractive	○	○	○	○	◐	●	○	Attractive
Unfriendly	○	○	○	○	◐	◐	○	Friendly

User Experience Questionnair (UEQ)

APPENDIX 6 - HTA ACC AND HTA PA




USE PA DURING A DRIVE
1 Drive manually
1.1 Sit down in the driver seat
Adjust the seat and adjust until comfortable.
1.2 Put on seatbelt
Take it from the right side of the seat and place it in the seat belt lock on the left.
1.3 Start the engine
1.3.1 Put foot on beak pedal
Place the foot on the left pedal and push down.
1.3.2 Start the engine
Depending on car model: press or turn a bottom, put the gear into D etc.
1.3.3 Accelerate
Place the foot on the right pedal and push down.
1.4 Drive away
1.4.1 On rural roads
Depending on your destination follow signs and road regulations.
1.4.2 On highways
Depending on your destination follow signs and road regulations.
1.4.1 and/or 1.4.2
Read above as much required
2 Drive with assistive function
2.1 Start PA
Depending on car model: press the ACC bottom, pull the lever etc.
2.2 Stop accelerating
Remove the foot from the gas pedal.
2.3 Adjust the speed
2.3.1 or 2.3.2
Depending on the speed limit and own preference
2.3.1 Higher speed
Depending on car model: press the plus bottom, scroll etc.
2.3.2 Lower speed
Depending on car model: press the minus bottom, scroll etc.
2.4 Adjust the distance
2.4.1 or 2.4.2
Depending on the speed limit and own preference
2.4.1 Longer distance
Depending on car model: press the plus bottom, scroll etc.
2.4.2 Shorter distance
Depending on car model: press the minus bottom, scroll etc.
2.5 Stop steering
Keep the hands on the steering wheel but stop moving the wheel.
3.1 Break
Place the foot on the left pedal and push down.
3.1.2 Turn off PA
Depending on car model: press the PA bottom.
3.1.3 Steer and accelerate for 2 minutes
It will turn off if the car is driven manually for 2 minutes
3.1.4 Control the car
Depending on your destination and situation follow signs and road regulations.
3.1 On your own accord
3.1 or 3.1.2 or 3.1.3 depending on how to turn it off
3.2 System initiated take over
3.2.1 Notice that the green wheel turns gray
Finding that information in the DIM.
3.2.2 Steer
The ACC function will still be active. Steer according to the road and conditions.
3.1 or 3.2 depending on road and weather conditions
3 Return to manual drive

APPENDIX 7 - ECW AND PUEA

Use Case: Pa goes into stand-by mode

Problem: The user doesn't drive in, what they perceive, to be a safe and desirable way

ECW	Answer	Problem seriousness	Potential Usability Problem	Problem type
Will the user know that they are responsible for steering?	Yes and no, very little feedback is provided	2 (=small chances of success)	Small visual and haptic feedback. No auditory feedback provided.	Hidden Text & Icon
Will the user interface give clues that show that they need to steer?	Yes	2 (=small chances of success)	The interface gives easily missed clues that forces the user to look away from surrounding traffic	Hidden Text & Icon
Will the user associate the right clue with the desired function?	Yes and no	2 (=small chances of success)	If they notice the clue they will probably know that they need to steer. Otherwise they won't	Text and icon
Will the user get sufficient feedback to understand that they have control of the vehicle? (symbol goes from green to gray)	No	2 (=small chances of success)	Only receives feedback from one sense, visual	Feedback Text and icon
Will the user get sufficient feedback to understand that they have control of the vehicle? (they are now steering)	No	2 (=small chances of success)	Might feel it haptically but only if they are turning.	Feedback

Explanations

Problem seriousness

5. Yes - A very good chance of success

4. Yes, probably - Probably successful

3. Do not know - Impossible to decide if success or not

2. No, uncertain - Small chance of success

1. No - A very small chance of success

Problem types

User (U) - The problem is due to the user's experience and knowledge, possibly because the user is accustomed to different equipment

Hidden (H) - The interface gives no indications that the function is available or how it should be used

Text and icon (T) - Placement, appearance and content can easily be misinterpreted or not understood

Sequence (S) - Functions and operations have to be performed in an unnatural sequence

Feedback (F) - The interface gives unclear indications of what the user is doing or has done

Use Error	**Error Type**	**Error Cause**	**Primary Consequence**	**Secondary Consequence**
Don't notice that it goes into stand-by	R1 – Information not obtained T3 – Message transmission incomplete	Rule-based mistake	Driving in an unsafe and undesirable way (3)	Over-trust in system which might lead to crash (1)
Don't understand what stand-by means	T1 - Message not transmitted	Knowledge-based mistake	Feel unsafe and uncertain whether the function is active or not (4)	You turn the function off (5)
Error Detection	**Error Recovery**	**Consequence Protection**	**Error Prevention**	
2 – Remote	Yes, switch back to manual	Learn more about the function	Clearer as well as multi modal feedback	
3 – Occasional	Yes, drive manually	Learn more about the function	More information	

Explanations

Error type

Error Type		Explanation
Plan	P1	Plan preconditions ignored
	P2	Incorrect plan executed
	P3	Correct but inappropriate plan executed
	P4	Correct plan executed but too soon/too late
	P5	Correct plan executed in wrong order
Action	A1	Action too long/short
	A2	Action mistimed
	A3	Action in wrong direction
	A4	Action too little/too much
	A5	Misalign
	A6	Right action on wrong object
	A7	Wrong action on right object
	A8	Action omitted
	A9	Action incomplete
	A10	Wrong action on wrong abject
	A11	Unnecessary action
Checking	C1	Checking omitted
	C2	Check incomplete
	C3	Right check on wrong object
	C4	Wrong check on right object
	C5	Check mistimed
	C6	Wrong check on wrong object
Retrieval	R1	Information not obtained
	R2	Wrong information obtained
	R3	Information retrieval incomplete
Communication	T1	Message not transmitted
	T2	Wrong message transmitted
	T3	Message transmission incomplete
Selection	S1	Selection omitted
	S2	Wrong selection made

Error cause

(L) Lapse - A memory lapse, forgetting the intention. Why am I doing this? 'Forget plan or execution'.

(S) Slip - Failure of attention during execution. A correctly planned action is not correctly executed. 'Good plan, bad execution'.

(R) Rule-based mistake - Occurs during problem-solving of familiar situations. Misapplication of good rules, i.e. well-known rules are used incorrectly to make a decision. 'Bad plan, good execution'.

(K) Knowledge-based mistake - Occurs during full attention to problem-solving activities, or problems never encountered before. Wrong decision based on own conclusions drawn from prior knowledge and known rules. 'Wrong conclusions, correct execution'

(V) Violations - Intended act or omission of act that violates present regulation and/or instruction, e.g. braking rules. Error action can be cutting corners to save time, omitting safety checks etc.

Consequence seriousness

1. Death - Loss of function or permanent impairment or damage to body structure.

2. Major - Permanent impairment or damage to body structure.

3. Moderate - More severe injury requiring medical treatment.

4. Minor - Minor reversible injury.

5. Negligible - Inconvenience or possibly minor reversible injury.

Error detection

1. Improbable - Extremely difficult to detect

2. Remote - Difficult to detect

3. Occasional - May be detected

4. Reasonable - Likely to be detected

5. Frequent - Most often or always detected

APPENDIX 8 - FULL SCRIPT TEST 2

You are driving to work; the ride will take about 20 minutes and during this time you will listen to the radio, a few podcasts and some music. During this ride you will use cruise control to start this you press B and you change the speed by pressing the up and down arrows and you want to lay between 70 and 80. You have a missed call from your colleague, and you want to call her back sometime during the ride. You do so by telling the car to: "ring kollegan". A few times during the ride the car will communicate with you through three different types of feedback. When you hear or feel this feedback you have to confirm that you are still actively driving by "wiggling" the steering wheel or the assistive function cruise control will be turned off.

Questions:

In between the sound tracks and during the test:

- IF THEY WIGGLE: Why did you wiggle?

IF THEY DIDN'T: Were you ever close to wiggling?

- How did you interpret the sound?

After the simulator ride:

- What 3 types of feedback did you hear

- What type of feedback did you appreciate the most? Why?

- What type of feedback did you dislike the most? Why?

- In which context would you prefer each sound?

- Was it at any of the situations when you felt disturbed? Is it during the songs, the podcast or the radio?

-In the form you stated that you usually listen to XX, would you be okay this notification when listening to XX?

- Was it difficult?

APPENDIX 9 - KJ ANALYSIS FROM TEST 2

KJ - ANALYSIS

TEST 2

11 - 13 MARS 2019

The test participants were put in a simulator and listened to different media and sound feedback that was incorporated in them.

HEAR AND UNDERSTAND THE FEEDBACK

- The "boom" was something I reacted strongly to
- Strong "boom" sound
- Hear a "boom" sound
- The "Boom sound was clear
- Strong "bonk" sound
- The beat of the drum is clear
- It sounded like a beat on a drum and it was clear
- This off sound was clear
- I reacted to something that sounded like a ball bouncing
- It was clear rustle sound
- Heard a lowering
- It felt like it did not belong to anything else so I reacted upon it (white noise in pod)
- It was clear that the volume changed
- Heard a white noise very clearly (in song)
- The rustle sound was clear to me and clear that it was something that I should react upon
- It sounded like leafs that rustle and did not sound like the surroundings and it was clear that something needed my attention
- I heard a radio noise that I felt I should react upon
- I heard a sound that made me feel like I did s omething wrong (off sound in podcast)

SOUNDS THAT ARE NOT APPRECIATED

- The rustle sound was least enjoyable because it did not feel natural in a car situation
- I heard absolutely nothing, why did the CC turn off?
- The white noise I liked the least as it did not feel natural
- During the silent bit the "boom" was too low
- The rustle sound is weird
- The boom sound is easy to detect as a warning sound compared to the other sounds.
- That rustle sound was hard to understand because there is other stuff that sounds like that. A soda or water that boils. It appears more in nature.
- Personally I would like to have something that is more distinct
- Now it disappeared, I do not like that as a warning sound (volume change)

SOUNDS THAT ARE APPRECIATED

- Enjoyed the "boom" (bonket) the most as it was easy to detect among the surrounding media sound.
- Lowering of the volume worked best. The downside to that is that you obviously need to listen to something. Would work in music and in podcasts and radio just as well.
- Because it is very important to know when the car is no longer on auto pilot I would accept the white noise but I enjoy the lower of the volume a lot more.
- I prefer the "boom" sound as you understood what happened and it sounded like a warning sound. It was easily understood.
- I appreciate the "boom":s the most!
- The white noise can be annoying but it is necessary so that is why I accept it as a feedback.
- The drum sound was more annoying and irritating than when the volume was lowered. When the volume was lowered you were like: "okay, something has happened what do you want me to do".
- The "boom" was my favorite feedback sound, I associate it with driving, it was kind. Like a nice push and I heard it every time and feel confident that I would in the future which is positive.
- It can be good with something discrete like these sounds for drivers that drive long distances because for them the beeps can become annoying
- The rustle sound I think I reacted best upon. It was easy to detect against the surroundings.
- The boom sound is easy to detect as a warning sound compared to the other sounds.
- The rustle sound would not bother me it was interpret as part of the media.

LEARNABILITY

- The "boom" sound is easy now, heard it several times
- Thought I heard the boom again b ut this time it was lower
- There's that off sound again
- The drum beat is very clear and easy for me now
- Now I recognize the sounds that does not belong
- Now that the sound went down this time I reacted on it
- The second time the volume changed I felt like I should act upon it
- Will absolutely react upon the lower volume from now on
- I interpret the lowering of the volume as a sign that the radio had bad reception
- I assumed it was a sound as I heard it before and the CC was turned off
- At first I did not think about the rustle sound as a feedback but now I understand that it is
- After the last time when the CC disappeard I was like: "aha! That was the sound"
- I recognize the white noise now
- I though I heard that before so I reacted on it now that it came again (White noise)

SOUNDS THAT ASSOCIATED WITH OTHER THINGS AND DISAPPEARS

- The hum sound was a bit disturbing. You thought that the car might be broken or the radio has bad reception
- Because I know the last song it is easier to recognize the "swisch" and the "bonk" because I know they do not belong there.
- The rustle sound can be mistaken for something that is wrong with the reception of the radio
- Was unsure if the sound might be a sound of a car honking, maybe it was from the road

HEAR BUT DO NOT REACT UPON THE FEEDBACK

- Heard a "boom" sound but it was to low for me to react
- What was that sound!? (off sound in radio)
- Was that something? (off sound)
- The "swisch" sound I thought was something else, like a car so I did not react upon it
- I think I heard a sound but was to unsure to react to it
- When the volume went down was not at all annoying but I did not understand that I was supposed to react upon it
- It went quite in the pod cast but I did not react upon it, should I have?
- "Schhhhh" it was a sound like that, was that the feedback?
- It sounded like a "boom" but I did not think that was one of the sounds

ACTIVE DRIVING TASKS TAKES THE DRIVERS ATTENTION

- The sound came when I was doing a lane change and I think I missed it because of that
- I was busy driving so I did not hear anything
- No idea why it turned of (during a call to the colleague)
- I did not hear any sound and did not listen really when I was calling
- It was difficult to hear because I was focusing on the driving

THE PERCEPTION DEPENDS ON WHAT IS LISTENED TO

- The radio has many sounds as it is making it hard do define the sounds that are not supposed to be there
- When listening to talking the "boom" sound was very clear but the "swisching" sound did not work at all. The "swishing" sound would blend into much with the talking
- Their talking was lowered so that is why I thought something was happening
- In the middle of a nice guitar solo it would be annoying if the music is turned down
- The sound (referring to the white noise) during the music was clear that it did not belong there
- The white noise might disappear more in the music than in the podcast
- In podcast it could be difficult to perceive when the volume is lowered as talking itself have pauses
- It was clear that the "boom" sound was not part of the music
- I am thinking that in podcast there is pauses anyway so I might miss the lowering of the volume
- The white noise is very clear during the music. It is registered and absolutely noticed during the music
- The "drum" sound is the easiest to recognize during radio which is what I listen to the most
- The white noise fits better and is less annoying when listening to music compared to a podcast
- I think it is annoying when I listen to music that the volume is lowered
- In music the volume change would probably work best. Because then you react and think: "Wait what happened now?"

THOUGH IT WAS PART OF THE PLAYED MEDIA

- I reacted to some radio jingle even when it was not a feedback
- It was a moment where it might be part of the music but maybe it was not I was not sure
- Thought the feedback was part of the podcast
- I interpret the lowering of the volume as a sign that the radio had bad reception
- Thought the radio was turned off when the volume was lowered
- I thought I heard a "pschhh" sound but made the conclusion that it was part of the podcast that is why I missed it
- Misinterpret the background noise as a feedback, heard a clicking sound
- I do not recognize the song and then I did not understand the feedback as the song itself had so many sounds that I did not recognize
- It felt like there was a part that did not belong to the music but I m not sure
- I almost thought it had something to do with the podcast (referring to the white noise)
- The muffled sound could be confused with the music. That it is part of a drumbeat and then you might miss it

APPENDIX 10 - FULL SCRIPT TEST 3

SCRIPT

Test sound with visual feedback	In the curve on lap 1: Did you hear a change in the surrounding sound? • Did you think it was enough for you to notice? • Did you find it disturbing?	1. Drive one length with PA, ask them to turn it off in the curve (start playing sound) 2. Second length of first lap tell them to turn it on and off 3. Drive one lap where you tell them to turn it on but NOT off 4. Drive one lap where you don't tell them anything
Test sound 1 with additional media with visual feedback	Did you hear a change in the surrounding sound? • Did you think it was enough for you to notice? • Did you find it disturbing?	1. Drive two laps where you don't tell them anything
Interview and UEQ	Do the UEQ out loud. How does it feel when you start PA? How does it feel when it turns off? Did you find the addition of sound to be annoying or helpful? Do you think it would be easy to block out the noise? Did the silence enhance your experience? What would you say are the pros of this type of sounds instead of a warning signal? • What do you think would be the cons? Was it easy to understand? Was it easy to learn? Did you feel like it disturbed you music/pod?	