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Design and evaluation of haptic feedback for in-vehicle touch screens

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Preface

This thesis is part of a five year Engineer master degree at Escola Tècnica Superior d'Enginyeria Industrial de Barcelona. It has been realized at Chalmers Tekniska Högskola, department of Product development, division of Design and Human Factors in cooperation with Volvo Cars Corporations.

There are many people I would like to thank for making this project possible. First, to Jessica Dagman, who supported me from the very beginning of this project and though these nine months and also accepted to be my supervisor despite not knowing me. To the people who are part of the division of Design and Human Factors, who shared their place, their lunch time and fika time with me since I arrived to Sweden and making me feel part of them. I would like to thank Annie Rydström and Daniel Jungegård for their commitment with the work I did and for helping me and being my connection with Volvo Car Corporation. I could not forget Volvo Car Corporation for providing me with all the material and facilities I need to fulfil this project.

There are some people who have been supporting me not only for this project but for my whole live. Those are my family, my parents both pharmacist and my sister a PhD student on pharmacy. My father, for his willingness to understand and help me, even if he had to read a book or study for that. My mom, for her kindness and moral support in every step I take in my live. And my sister, who in my bad moments has tried to cheer me up.

They are not my family, but have been with my nearly as many years as them, my friends. You are also a special part of my life and all this years with you and change me into what I am.

During this project I meet someone who has made my life happier ever since. He deserves a special mention because he is the one who know more of this project after me. I discussed everything with him, he listen to all my doubts and try to help me with anything. He has read the text as many times as me. He has been there hours and hours supporting me while I was writing. And he had tried to calm me when I was nervous due to the presentations. Ricardo, I owe you a lot, not only for what you have done to make this project possible, but for changing my life.

Gothenburg, 2011
Anna Arasa Gaspar

Abstract

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The main topic of this project is the introduction of haptic feedback for touch screens in an in-vehicle environment. Due to the numerous studies on confirmation haptic feedback, this project regards navigation haptic feedback. The importance of this project is to provide an overview of this kind of haptic feedback. Also, to prove the ability of touch screens to assist drivers in the interaction with a multifunctional device in a driving situation. For this purpose, an introduction of the background was carried out, including touch screens, technologies producing haptic feedback, the sense of touch and users in a driving situation. From this, two conclusions were taken. First, the kind of touch screen that most suits an in-vehicle environment is a multicapacitive touch screen. Also, that the best technology to produce navigation haptic feedback is the texture surface changing.

Taking these results into consideration a prototype was implemented. This prototype was tested in a usability study. The main problem found out during the usability study is the long learnability time needed by the participants due to the new way of interaction introduced to be able to navigate. From the information of the usability study the following results have been extracted. The actions that were helped by the introduction of navigation haptic feedback were navigation across items and level selectors. It has been shown that a standardized selection of haptic feedback is needed in order to reduce learnability time and introduce guessability in future touch screen devices. Some more studies, when looking upon different traffic situations must be carried out in order to understand if also theese conditions require the same amount of help introduced by navigation haptic feedback. An important result of this project is that none of the participants in the usability study turned off the optional haptic feedback, when this was included in their multifunctional in-vehicle device. This shown a trust on haptics that has to be seen as a motive to continue working on it.

Keywords: navigation, haptic, feedback, touch screens, cars, multisensory, richer experience, security, workload.

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1 Introduction

Taking a look into the latest surveys searching the main reason for accidents in the road (U.S. Department of Transportation, 2008) it is found that the top critical reason had to do with recognition errors. Recognition errors mostly happen because the driver was not paying attention to the road, was distracted or was not adequately surveying the road. In the survey hold by National Motor Vehicle Crash Causation Survey (NMVCCS) held by the National Highway Traffic Safety Administration (NHTSA) of the U.S., it can be read that up to 41 per cent of the accidents were associated with **inattention**. There is also a recurrent source of this inattention and it is **secondary task engagement** (Dingus, T. A. 2006).

Drivers should be conscious of the high level of attentive demand while driving due to the perceptual and cognitive inputs. The **limited ability** of drivers to **divide** their ***attention*** amongst all the competing sensory inputs introduces the necessity to reduce the **overload** in the different senses involved when driving. Around 90 per cent of the information received by drivers is visual (Ho, C. and Spence, C. 2008), so vision has a high risk of overload and needs some release from the other senses.

At the same time, a large amount of **new complex in-vehicle technology** is exacerbating this situation. Some examples of these devices could be satellite navigation systems, mobile phones, email, elaborated sound systems; all of them are visual demanding. Also the new usage of the known as **intelligent transport systems, like back camera,** introduce a new stream of information that can be delivered to drivers in order to reduce their unawareness of potential damage and improve their safety (Ho, C. and Spence, C. 2008). The drawback is that this, as well as with new technology systems, makes the overloaded sense situation of vision even worse.

Taking into consideration that vision is a unidirectional sense, meaning that you could only look into one direction at a time; drivers have to direct their vision to the road. However, the sense of touch can be separated into at least two different directions, hence, a driver, while holding the steering wheel with one hand can interact with other controls with the other. Some researchers have found that multimodal perception could be used to transfer some of the information given by the vision through haptics (Rydström, A. 2009). To make it a little bit more understandable, even if the information by a sensory modality as vision have already been given, a richer representation of the environment could be displayed by multimodal perception if haptic feedback is included too. This could help the driver when there is a sensory deprivation (e.g. not been able to look at what you are doing) by compensating with another sensory modality (having haptic feedback of what you are doing) (Stein, B. E. & Meredith, M. A. 1993).

The reduced space reachable by the driver while driving in combination with the already mentioned increasing number of functions and devices which need to be easy accessible for the driver, leads to the requirement of having a multifunctional centralized control. The most spread multifunctional in-vehicle's interfaces devices nowadays are rotary control and touch screens (Rydström, A. 2009). The introduction of multifunctional interfaces provides the possibility of having a large amount of functions available for the driver in the same position. Thus, functions are in a position that is comfortable for them to reach while driving and only few commands are shown at a time. However, it cancels the possibility of using haptic cues when using regular systems. It has been shown that drivers make use of them when interacting with devices in the car while driving in order to be able to focus their visual attention on the road (Rydström, A. 2009). An example of it is the usage of edges or the recognition of a button by their size or texture.

All the reasons mentioned above bring the possibility of adding haptic feedback into this type of controls to have a centralized multifunctional control with multisensory feedback for, depending on the situation, enabling non-visual interaction or assisting visual interaction.

1.2 Aim

The main aim with this project is to determine the benefits for the driver that could be provided by introducing haptic feedback for in-vehicle touch screens. There will be a clear distinction between two kinds of haptic feedback, navigation feedback and confirmation feedback. The focus will be on the navigation one as lots of other research projects have already been performed studies concerning confirmation haptic feedback.

Other purposes of this work are to grow expertise in the field of touch screen technology with the purpose of selecting the most suitable for using it in an in-vehicle environment.

Also, to develop knowledge in the area of multisensory integration in a car environment, so that it could be determined which actions in the interface require haptic feedback and if they need to be integrated with any other sense modality in a basic level.

There is another field that will be interesting to understand, this is the world of tactons. A tacton is each of the different discriminable vibration patterns. A deep comprehension of what a human being feels with the different tactons will offer the possibility to match each of them with the right action. In order to create this tactons a research in the area of haptic feedback on touch screens devices will be performed.

The overall aim of the project is summarized in the research questions. These questions will be introduced in distinct parts of the report when the information to answer them has already been discussed.

1.3 Research questions

The research questions are the basis of this project and all the procedures, research and studies have been made in order to answer them. Just below these lines, they are written in the chronological order in which they will appear in this report. As it has already been said, they will be introduced in different parts of the report as conclusions from the research work.

FIRST QUESTION: *Which touch screen technology is best for an in-vehicle multifunctional device?*

SECOND QUESTION: *Which haptic feedback technology is the best for in-vehicle touch screens?*

THIRD QUESTION: *Which actions are helped by the introduction of haptic feedback?*

FOURTH QUESTION: *Which is the best haptic experience for each interaction?*

FIFTH QUESTION: *Which benefits does haptic feedback provide to drivers?*

1.4 Goal

The core goal of this project is to investigate, develop and test a multifunctional in-vehicle interface including haptic feedback. The device in which this interface will run will be a touch screen and the type of technology used will depend on different facts such as environment of use, driver capacities and last but not least availability.

In order to achieve the main goal there are some smaller goals to be accomplished. First of all, a research on touch screen market should be carried out in order to understand the advantages and the limits of each technology. After that, some research in the field of haptic outputs on touch screens (mobile phones, pda …) should be done to discover the range of tactons available for each used technology. The next step will be to talk with specialists and make some research concerning interactions with in-vehicle touch screens so a conclusion could be reached in terms of choosing the group of interactions with haptic feedback. Once these interactions are already chosen, the suitable way to *produce* this interaction will need to be determined. Then the chosen device to simulate these outputs has to be programmed and implemented. Another version of the same device with a little variation, the lack of haptic feedback, would be implemented also. A prototype with the two multifunctional devices will be ready to make a comparative study. With the conclusions of this study, some tips on how to adapt the prototype into the user needs for its usage in next steps will be highlighted. Finally, driver benefits, as well as the interactions chosen for having haptic output and their tacton should be discussed.

1.5 Delimitations and limitations

It was considered necessary to differ from delimitations and limitations in this section. The difference between these two concepts is the willingness of the author to have these restrictions. If the author sets the boundary is call delimitation, in the other hand if it is set by something out of author´s control it is called limitation.

There is lots of limitation in this project due to the freshness of the main topic. First and foremost, the possibility to access to some technology in the market has been very difficult, not only for economical issues but also for novelty ones. There are new discovered technologies in the area of haptic feedback that are not yet released for implementation to the industry because there is no possibility of help coming from the developers because it is still under elaboration. So, this thesis will take both, economical and temporal delimitation into consideration when referring to haptic feedback technology.

There are some delimitations set on the usability study. Due to the set time for this work not long usability studies could be carried out. With long it is mean to carry a usability studies with a large number of participants. That is why further studies would be advisable with help from this written material. Also related to the lack of time there will be no test under real driving circumstances. It is necessary in more advanced steps to see how the car vibration might affect to the perception of the set haptic feedback.

The other source of delimitation is the interaction with the audible feedback. Caused by the use of a vibrational device to produce haptic feedback, there is sound coming from the device when it is vibrating. It was thought to carry the study muttering them by making the users wears some headphones to eliminate the possible effect on them. That is the reason why the prototype has not sound feedback. But as the car engine sound from the simulator is loud enough to cover the vibration sound, earplugs are not longer necessaries. The lack of audible feedback was point out by some participants in the study, and some of them suggest the advantages of both feedbacks working together. However, as this study is just a comparison and test, the one with haptic feedback and the one without do not include audible feedback the data is valuable. Audible feedback is out of this project and also the interaction between it and the haptic feedback.

Last but not least it cannot be measure improvement in feedback by tactual experiences in touch screens because in real life they will interact with other outputs in synergy. We can only make a comparison between two situations, one with haptic feedback and the other without.

1.6 Report outline

The report outline follows the chronological line followed while doing the project. Its timeline is included below this text (Figure 1.1) to help the reader understand the report outline. In the first chapter, after the introduction, the Scenario Zero is explained for a human machine interaction project. In the scenario Zero could be found the most valuable information of the research process (Prestudies). After the research process, some decision making regarding the information given is done. These decisions conditioned the implemented prototype; the decisions are the selection of touch screen and the selection of haptic feedback for the touch screen. In the same chapter, the conclusions are followed by the description and justification of the prototype. This description also includes a huge amount of discussions regarding all the little decisions taken during the implementation process. This chapter contains the section of product development of the timeline. Then, there is a little introduction into usability. This introduction to usability is made, to facilitate the understanding of the taken decision for the usability study. The introduction and discussions are followed by the presentation of the usability study that was carried out with the implemented prototype. The next chapter includes some conclusions and result discussion of the usability study. To end up with, there are the discussions, conclusions and next steps.

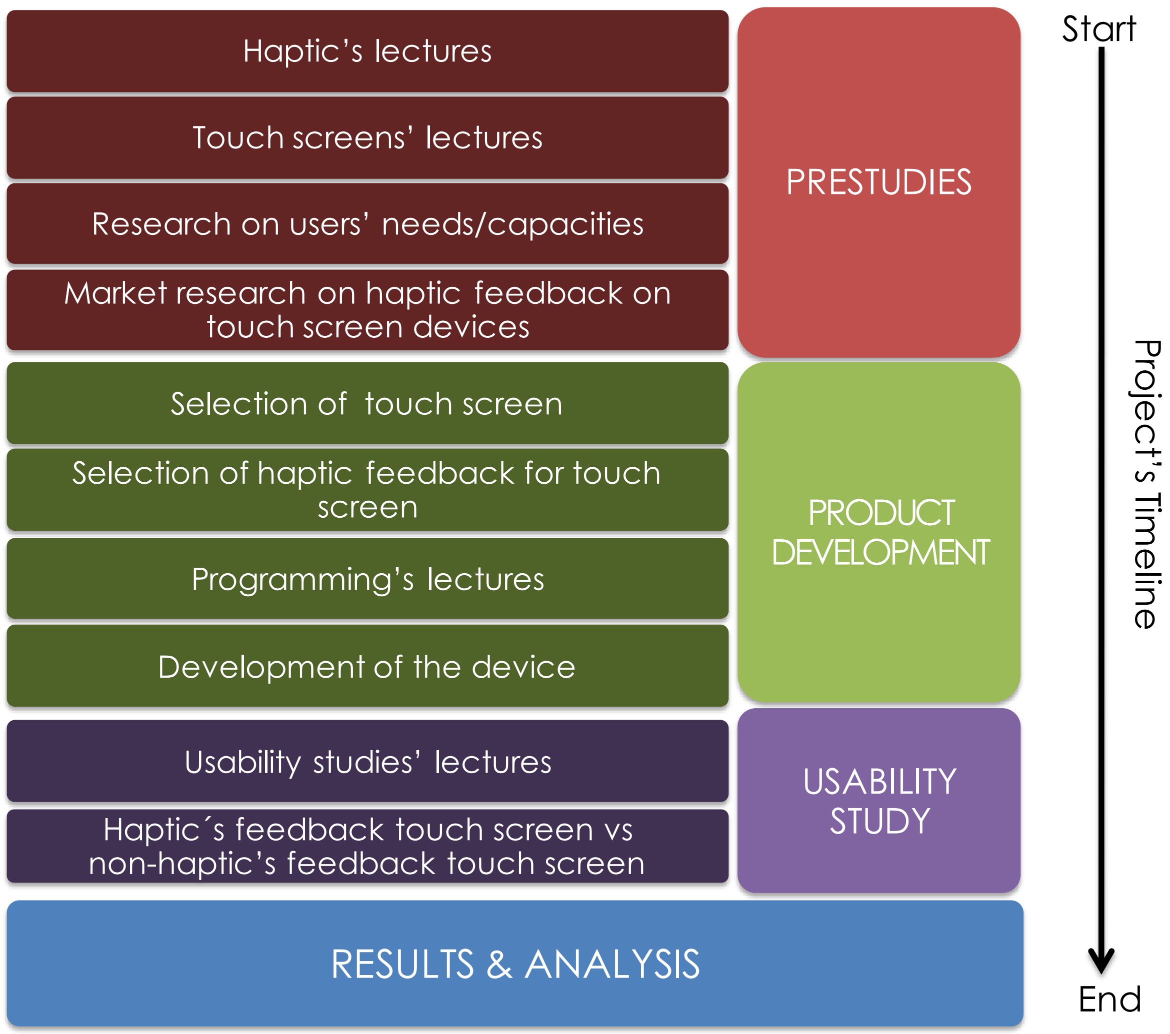

Figure 1.1 Report Timeline

2 Scenario Zero or Theoretical Framework

For the fully comprehension of the present work, a brief explanation of the Scenario Zero, found when the project was just starting, must be introduced.

This is a human-machine interaction (HMI) project, therefore this introduction will give a look into the three components of HMI, the human being system and skills, the interaction itself and the product domain and its properties (Sonneveld, M. H. and Schifferstein H. N. J. 2008). In this chapter all these matters will be introduced and some of them discussed.

Firstly, the human systems will be presented. In this case, there is a necessary introduction into the haptic's world essence, the sense of touch.

Then it is the turn for the product domain knowledge. For this project the main product domain is touch screen's technology. There will be a quick view into the technical part concerning touch screen's technology available in the market. To make them easier to compare for future conclusions, a table containing the different attributes of each technology can be found at the end of this section.

In order to understand the interaction itself, the results of a market research on haptic feedback devices are explained. The technologies that are used to produce haptic feedback found on the market research are explained. There is also in this section a comparative table regarding attributes of technologies used to produce haptic feedback. By the end of the section, a comparison between the haptic feedback actions available for each technology producing haptic feedback is included. There is also, in that section, the introduction to the analysis of users in the thesis environment. The most important fact is the user capacity of perception, so the user analysis will concern multisensory environment. Even if that could be considered as part of human’s skills in the HMI, it is placed as part of the interaction because it could change the whole meaning of it.

Before starting with the previously exposed there is an important subject to be introduced, this is product experience.

Product Experience

First of all, the reason to introduce this concept is because it is really useful to fully understand the difficulties of developing a product for the senses. Product experience refers at the people’s subjective experiences that result from interacting with products (Sonneveld, M. H. and Schifferstein H. N. J. 2008). To design for experience, one should be aware of the psychological effects elicited by the interaction with a product. That is a complex process because there are three important facts on it, the degree of senses’ stimulation, the meanings and values attached to the product and the feeling and emotions that are elicited. In order to understand the product experience designed for that project, the subjects explained above should be introduced.

2.1 Human senses and skills

Human skin is the largest organ, its surface range from 1.5 to 2 m^2 in an adult. There are two different skin types covering the human body, these are glabrous and hairy. This project is looking at touch screen, which are usually touched by fingers. The skin covering human fingers is the glabrous skin and it best suits active touch (Sonneveld, M. H. and Schifferstein H. N. J. 2008). In interaction, there is a distinction between being touch and to touch, the two different acts are call passive touch and active touch respectively (Sonneveld, M. H. 2007).

The properties that distinguish glabrous skin from hairy skin are the thickness; glabrous skin is thicker than hairy skin also tougher, and more resistant to pressure. Fingers contains fat pad that make the skin comply with the grasped object making the touch more stable. The epidermal ridges of the fingerprints permit the sensors to register lateral pressure and also increase the surface of preceptors. The density of glands in the glabrous skin is denser and reacts to force instead of reacting to temperature, as it is in the hairy skin. To end up with the differences, glabrous skin has a type of corpuscles called Meissner´s corpuscles which are responsible for the sensation of light touch and vibration (Sonneveld, M. H. and Schifferstein H. N. J. 2008).

Three layers, the epidermis, the dermis and the hypodermis compose the disposition of any kind of skin. They have different receptors, which are divided into three types: mechanoreceptors, sensitive to mechanical transformation of the skin; thermoreceptors, detecting different changes of temperatures; and nociceptors, involved in the feeling of pain. After a receptor is stimulated, neural fibres conduct the sensation to the central nervous system. Depending of the type of neural fibres of each of the receptors there are different times of adaptation to the input (Sonneveld, M. H. and Schifferstein H. N. J. 2008).

Regarding the skin sensations, there are two that must be taken into consideration, these are pressure and vibration. With pressure it is meant maintained touch and with vibration when stimulators are stimulated rhythmically, for example, touching a texturized surface or regular engine vibration. The first one is slowly adapting in contrast to the second one that is rapidly adapting (Sonneveld, M. H. and Schifferstein H. N. J. 2008). This is important in the use of haptic feedback to take into account the adaptation time of these stimulis; providing the user with a continuous vibration will be useless, as the user will not be able to feel anything after a little time. Creating different patterns or lacks of haptic feedback between haptic feedbacks might help.

2.2 Product domain and properties

Technical background

A little explanation of the different touch screens existing in the market nowadays is carried out.

There are four main spread technologies used for touch screens. Depending on the technology used, there are resistive touch screens, capacitive touch screens, surface acoustic wave and infrared touch screens. Each of them has strong features and weak features and depending on the purpose for which are used, one of the existing technologies will fit better than the other.

Resistive Touch screens

This type of touch screens base their function in the use of two flexible sheets coated with a resistive material and separated by a thin gap of air. One layer is provided with a unidirectional voltage gradient. The two resistive layers are separated until someone or something touches the screen, the soft pressure of a finger or a stylus put both parts in contact. When putting them in contact, the second layer gets a gradient of voltage that is used to know the position in the x-axis. Another operation occurs a few milliseconds later; a voltage gradient in the other direction (y-axis) is applied to know exactly where the pressure is applied (Dhir, A. 2004).

As it has been mentioned before, there are good points on using each technology. Taking resistive screens into consideration, the strongest feature must be the possibility to use any kind of object to touch screens, going from capacitive materials such as stylus or bare fingers to a brush. Another outstanding property of the resistive touch screens is that they are resistant to both water and dust so there will be no problem if needed to be placed outdoors. This is the cheapest touch screen explained here. Appearing now in the market, there is a type of resistive touch screen with multitouch (Miller, P. 2009). This means a big change on touch screens, since capacitive touch screens were the only ones providing this kind of technology.

Among the weaknesses of these devices it must be highlighted the fact that the detection of the touch in this kind of touch screens is conditioned by the amount of pressure exerted by the user. The meaning of this is that there is a threshold on the amount of pressure for detection of touch, so if you do not reach it, the touch will not be considered. This fact makes the use of resistive touch screen a little bit frustrating, for example, when you have to repeat the same movement for the device to detect it. Due to the layout of the layers to achieve this technology, resistive touch screens have the worst visibility and the least amount of emitted light of the available touch screens in the market. Finishing, the last weakness of resistive touch screens introduced in this report is related to its components. The resistive layers are not hard enough, that makes the touchable layer easy to scratch, turning the touch screen's live short (Dhir, A. 2004).

Surface Acoustic Wave

With the recent investigation in the field of surface acoustic waves (SAW) a new type of touch screen appears using this technology. Acoustic waves are produced in the surface of the touch screen. When this is touched, part of the wave is absorbed. This is used to estimate where the solid interfere with the wave and set the position by the receivers (Dhir, A. 2004).

The main point of using this technology is the ability to detect information from x-axis. It also offers image clarity and resolution, as is not needed more than one layer. For SAW touch screen any solid object can be detected when touching the screen. Last but not least, even if the touch screen is damaged with scratches it will continue working properly as it does not interfere with the waves.

After the last statement it can be deduced that this type of screens has interferences when there is dust in its surface or water (if it is outdoors and rainy). As the glass is the surface in contact with the environment it is easier to be break (Dhir, A. 2004).

Capacitive Touch screens

When looking at capacitive touch screens a huge variety of possible detectors are found. The basic operation is pretty similar for all capacitive touch screens. There is an insulator, usually a glass, coated with a transparent conductor (usually Indium tin oxide ITO), which is charged with a small voltage. There are different ways and layouts that will be discussed further. This electrostatic field is distorted by the touch or the approach of an electrical conductor such as bare fingers. This distortion is measured as a change in the capacitance of the coated glass (Dhir, A. 2004).

Taking detectors into account there are two main spread technologies that need more explanation. The Figure 2.1 gives an idea the different classes of projected capacitance touch screens and the proprieties of each of them.

Surface capacitance

This technology is based mostly in the change of uniformity in electrostatic fields. To create this uniform electrostatic field a small voltage is applied to the top layer. The electrostatic field is distorted by the touch of a conductor such as fingers, which dynamically formed a capacitor. The surface touched by the conductor is the uncoated one, so the capacitance of each corner of the layer depends on the distance to the conductor (the finger), the nearer, the larger change in capacitance. This property is used to calculate the finger position on the touch screen. This property works as long as there is just one finger or conductor touching the touch screen, meaning that this technology does not allow multitouching. It is said to suffer from parasitic capacitance coupling and it needs calibration during manufacture. The strongest fact of this type of capacitive touch screen is the longevity of its lifespan due to the lack of moving parts (Tyco Electronics Corporation 2011).

Projected capacitance

The technology is also based in the creation of dynamic capacitor by touching a resistive material someway charged; the main difference is that the layer is not all coated in the back. An x-y grid of electrodes creates the conductive layer with a control in each row and column or in each intersection protected by a glass layer on top. The exact position of the conductor is measured by the change in capacitance created by a conductor touching the glass surface; there is no need of direct contact. The possibility of having many resistive layers between the grid and the touching conductor enables to have protective insulating layers and screen protectors that lengthen lifespan. Weather and vandal-proof glasses turns projected capacitance touch screen into a perfect device for outdoors conditions. There is a weakness that might be stressed, conductive smudges and similar interferences can interfere with the good performance of this touch screens. Depending on the implementation of the device, it could work with glove hands and with stylus, a really necessary fact if you need signature capture. There are two types of PCT, where the main different is based on the position of the capacitors allowing or not to have multiple-touch (Tyco Electronics Corporation 2011).

Self capacitance

Considering capacitor positioning in self-capacitance there is independence in operability between columns and rows. This means that for each row and for each column of electrodes a different current meter measures the capacity load. This disposition does not allow having multiple-touch and it suffers from “ghosting” and misplaces location sensing when more than one finger is touching it (Barrett, G. L. And Omote, R. 2010).

Mutual capacitance

In relation to the number of capacitors in a mutual capacitance touch screen in comparison to a self-capacitance touch screen there are much more in the first type. The reason why is that their disposition is in each intersection between a column and a row. That means that for a square touch screen with five columns and five rows there will be ten capacitors for a Self capacitance touch screen and twenty-five for a Mutual capacitance touch screen.

The measurement of dynamic capacitance moves from the corners to each interaction between row and column. That makes the measurement more accurate and does not suffer from ghosting as self-capacitance touch screens. It allows multi-touch operation so different fingers and stylus could be tracked at the same time.

Back to the general capacitive touch screen, in comparison to the others touch screens, it has the advantage of being able to be cleaned with fabrics with no command input. It is also more responsive than resistive touch screen, otherwise is less accurate than resistive and more costly. There are some weaknesses due to the technology in which is based the capacitive touch screen. These are the possible failure even when few amount of water is involved, the less wide range of temperature functioning and the need of at least five per cent of humidity to work. It has to be highlighted the fact that only capacitive stylus can be used in that type of touch screen and that hands covered by glove do not have a response as a general fact in the capacitive touch screen (Barrett, G. L. and Omote, R. 2010). All the characteristics given for each touch screen and its classification among capacitive touch screens can be found in the figure 2.1.

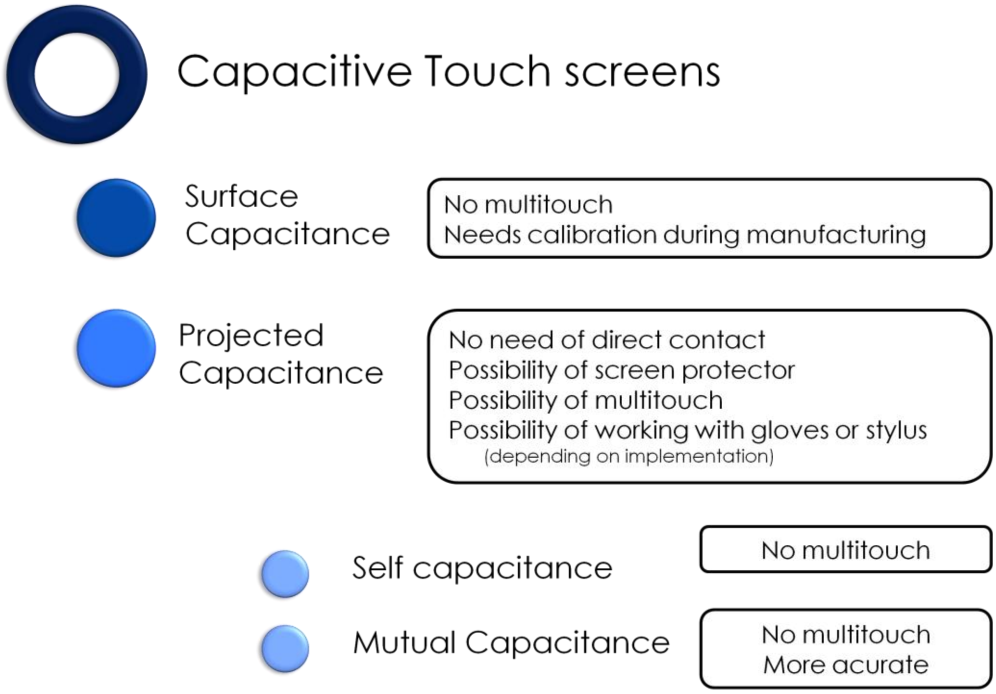

Figure 2.1 Types of capacitive touch screens.

INFRARED TOUCH SCREENS

The technology used in infrared touch screens as its name says is infrared beams. There is an X-Y array of infrared LED and photodetectors pairs around the edges of the screen. The photodetectors detect a disruption in the pattern of LED beams to pick up the exact location in which it has happened (Dhir, A. 2004). There are two types of infrared touch screens.

Optical sensitive

Optical sensitive uses infrared beams that are invisibles for human eyes. The main drawback is that strong ambient light could have a bad impact on its productivity (Mobile88.com, 2011).

Heat sensitive

This kind of technology is not often used for screens but for tactile buttons. It uses the change in heat to determine the touched point. The worst fact of this technology is that might be not useful in cold countries because it might not be sensible enough (Mobile88.com, 2011).

Taking all infrared touch screens into account it has to be stressed the fact that any kind of object could be detected but also that it is not necessary to touch the screen to activate it, even when it was not desired approach could produce activation. On the other hand, due to the fact that the beams are not in the top of the surface but a little bit above, scratches or anything happening to the surface do not affect its work extending durability. This technology does not need more than one layer on the surface of the device that is the reason why these touch screens have high visibility. The layout of the beams is really costly hence this is the most expensive touch screen.

COMPARISON BETWEEN TOUCH SCREEN TECHNOLOGIES

In order to find out which of these technologies will be better for the project a table (Table 2.1) highlighting strengths (in green colour), weaknesses (in red colour) and observations (in blue) had been made and it is included in the next page. There are observations in the table; these are marked in the characteristics with asterisks. The explanations are below and can be recognized by having the same number of asterisks.

CAPACITIVE TOUCH SCREEN

Enables multitouching*	Cleaned with clothes without command input	Posibility of protective layers (LONG LIVESPAN)	Models with pressure infor	Middle cost	Activated by capacitive stylus & globed hands**	Less accurate than resistive	Conductive smudges can interference

RESISTIVE TOUCH SCREENS

Resistant to water and dust	Cheap	Possible multitouch***	Any object detected	Pressure threshlod to detection	Worst visibility and amount of emitted light	External layer easily scratched (LIVESPAN SHORT)

SURFACE ACOUSTIC WAVE

Information from x-axis	Image clarity and reslution	No functionality affected by scratching	Any solid can be detected	Easy to break	Interfereces due to dust or water

INFRARED

High visibility	No need to touch screen to activate	Any solid can be detected	Most expensive	Not working on cold weather

Table 2.1 Comparison between touch screen technologies

*Look at the different type of capacitive touch screens, multitouch in Mutual Capacitance touch screen.

**Some information regarding globed hand in capacitive touch screens.

***Stantum's resistive touch screen.

2.3 The interaction

Market research on haptic feedback devices

When starting to talk about haptic feedback in touch screen devices as mobile phones or tablets, the vast majority of the people would think of the device vibration as the most common in nowadays electronic objects. But when going deeper into the subject and carrying some research you can notice that it is the past of haptic feedback, manufacturers are moving to a **more real experience**.

FULL BODY TACTILE DISPLAY

The first touch screen devices including haptics as feedback were implemented with vibrating motors or mechanical actuators. Those make the whole device vibrate when a feedback is needed (Poupyrev et al. 2002). Although, that solution is not the best to have haptic feedback in touch screen devices, it makes people realize that there is a need of haptic feedback for a touch screen device to be user-friendly.

Taking regular vibration into consideration there is one weak feature that must be taken into consideration. When the device vibrate you may lose your point of contact and your precision due to the movement, which makes the haptic feedback worse that the lack of it. It also makes noise when vibrating if it is placed in a rigid place, something not desirable in a large number of situations. For example if you are using haptic feedback instead of sound feedback because silence is needed. Another important fact to highlight is the lack of dimensional space feedback of the touch screen; if the whole device vibrates there is no possibility to know where you are touching or where you have to be touching instead. The consumption of energy due to the movement of the motor is relatively high and really important for those devices running with a battery. Last, as it is the whole device that vibrates there are quite few tactons that can be implemented (Poupyrev et al. 2002). Actually, even if it does not seem like an advantageous feature nowadays it is a good start for new users to get in touch with this feedback without being overload.

SCREEN TACTILE DISPLAY

Technology, regarding haptic feedback, continues its development. Designers found out the error of making the whole device vibrate not only for the disturbances that the movement might cause to the user but also for the high consumption of energy. The next step for the improvement of the haptic feedback was to focus the movement into the touch screen. Therefore, you can only get the haptic feedback if you are interacting with the touch screen; the finger touching the touch screen is the only part of your body receiving haptic feedback. As the movement was slightly less extensive people can make more precise movements while the device vibrates and do not lose their point of contact so often. Regarding noise, it is reduced due to a reduction of the surface in movement, a new design of the wave shape and more accurate mechanical design, even though it is not cancelled (Poupyrev, I. and

Maruyama, S. 2003). At that point, even if they have had focalized the feedback in the screen, the whole screen is vibrating at the same time so you still have a lack of dimensional space feedback. The technology used by this solution is relatively more advanced than the vibrating motors used by the first one. The technology is called "bending motor", its main component is an actuator constructed by piezoceramic layers with adhesive electrodes in between that shrinks or expands depending on the polarity of the electric current (Poupyrev, I. and Maruyama, S., 2003). This technology uses less energy than a vibrating motor, reducing the consumption of the battery done by the haptic feedback. The Tactons for this solution are more or less the same than the introduced by the whole device vibrating; the vibrations can be altered by changing its frequency, its amplitude and its duration, but as the technology is more advanced it might have more possibilities for tactons.

TEXTURED SURFACES

Another step forward into the integration of haptic feedback on touch screens is the introduction of static textured surfaces. It might be stressed the fact that this type of feedback have had never been included in a touch screen but in laptop's touchpads, being the main reason that texture can deform user view of the touch screen.

The development of textured surfaces started, as said by David Hill from Lenovo, by the necessity of having more compact laptops, meaning that touchpad has to be at the same level that laptop surface (Hill, D. 2010). Touchpad have to be changed otherwise users will tend to rely only in their vision while interacting with it because they cannot feel the difference between laptop's surface and the touchpad. There are three possible solutions for this problem; the first one is to have a little gap between touchpad and laptop's surface. This is not considered a good solution as all the dust will get stacked inside the gap and this might cause device's functioning troubles. The second solution is based on human's ability to distinguish between two different materials, for example, if you use rubber for the touchpad and aluminium for the laptop surface people will know which one have been touched without looking at it. This solution solved the problem with boundaries, but then laptop's developers wanted to go further and decided to introduce more feedback into its touchpad, it is then when texturized touchpad appears. David Hill from Lenovo explains in the Lenovo blog how they came up with the idea. It is based in the patterns called "the square Tenji block" invented in Japan by Seiichi Mijake in 1965 and used there since 1967 (Hill, D. 2009). This patterns indicates good and wrong directions and they are noticed by stood foots. An example of its usage nowadays can be found in the figure 2.2, the picture was taken on April 2011 from a street of the city of Gothenburg. In the picture, it can be distinguish two different patterns on the street floor just before an intersection with the road; these are used by blind people to be aware that they are arriving to it.

Figure 2.2 Majnabbegatan, Göteborg.

Based on this idea Lenovo developed a patterned touchpad in which you can feel where your finger is placed, the edges of the touchpad, the distance travelled and the speed of your movements. Compared to other touch screen's haptic feedback, there is not a wide range of possible feedbacks, and so overload is impossible. This type of haptic feedback does not provide spatial resolution; all the information given is relative to the previous position of the pattern. For example, if the pattern used is little bumping bubbles, the information of the haptic feedback is related to the feeling of two or more bubbles; the distance between them, how good their shape is felt, etc. While designing the patterns, consideration must be given to users feelings, some can find it annoying or harming. Another fact to think of while designing is friction, some people using texturized touchpad noticed texture fading by usage. By not having engine, this solution is silent, do not consume energy and there is no lose of contact point. An example of the use of this kind of texturized touchpads is showed below; figure 2.3 a touchpad from the laptop company Vaio.

Figure 2.3 Touchpad from Vaio VGN-NW21SF

"TOUCH CLICK" FEEDBACK

A relative new way to provide haptic feedback to touch screens' users is the "Touch Click" was introduced by RIM in the Black Berry Storm (Miller, P. 2008) and still included in MAC's touchpads (Ritchi, R. 2008). Figure 2.4 shows a picture of a "touch click" touchpad in a macbook. This haptic feedback is the most real one in the market because the whole screen is converted into a big button. Every time you click into any of the buttons displayed on the screen, the touch screen moves down and back up. This innovative feedback is created by a mechanism introduced below the touch screen including springs and caps. It provides a confirmation feedback, you first scroll all over the touch screen and select the desired option but to act you need to click on the touch screen. More steps are introduced for the same action meaning more time to do the same amount of things, but it is considered that with some practice you will be as fast as with regular touch screens (Miller, P. 2008). The space resolution of this solution is poor and can be blurry because the whole touch screen is moving. The lack of engine, like in the previous solution, means less noise; it can be still listened the click of the button. However, there is no battery consumption. Having just one haptic feedback –confirmation - there is no possibility of overload. Although the screen is moving there is little chance that loses of point contact occurs.

Figure 2.4 Touchpad from Macbook

LOCALIZED VIBRATION

As it has been said in the beginning, developers are trying to focalize their research more based in reality haptic feedback. For the approach to a virtualized reality devices with localized vibration have been tried to develop, which resembles the real functioning of a manual device. There have been lots of trials in this specific field of haptic feedback in touch screen, and lots of them failed. One example of this failure was using multiple actuators in the same screen, but there is what is called "vibratory crosstalk" or "tactile crosstalk" means that the waves are propagated all along the screen and focalized feedback is lost (Apple Inc 2011). This is solved by the use of cancelation waves, while one actuator creates the first wave another, with a predetermined delay, create the same amount of wave arriving to the surrounding 180 degrees out of phase (Apple Inc 2011). The same idea could be used to produce different sensation in the same touch screen by providing interferences in terms of amplitude or frequency which enables creating a wide range of Tactons (Apple Inc 2011). A possible overload of information could happen if haptic feedback is not well designed.

The most important fact of this type of haptic feedback is the introduction of dimensional space resolution, people could know if they are touching the correct spot of the touch screen by feeling or not the vibration or by feeling different patterns.

Due to the fact that actuators and engine are still working, in this type of technology for feedback in touch screens, there is also noise, possible lost of point contact and battery consumption. However, in this case, the engine has been optimized and less movement is necessary, reason why all these weaknesses have been reduced but not annulled.

ULTRASONIC AIR PRESSURE WAVE

While attended a seminar[1] on feedback on touch screen's devices a new development from a group of researchers of the University of Bristol was presented. Ultrasonic technology is used to create air pressure waves which can be sensed by human hands. This technology has been applied to mobile TV to increase its appealing. They use the phenomena of acoustic radiation pressure to deform the air surrounding the back of the TV, the use of low frequencies (40kHz) produce a sensation of air vibration in the user as the waves reflect from human skin (Alexander et al. 2011).

The main problem of using this technology for feedback on touch screens is that the feedback is given on the back of the device and placing the transducers on the front will block the visual feedback.

SURFACE TEXTURE CHANGING

In the latest days a new generation of haptic feedback for touch screens has appeared. This type of touch screen has the ability to reproduce different textures in any section of a touched device (Senseg).

The background of this technology is a biophysical phenomenon that provides feeling when a small electric field passes near human fingers. This sensation is created by the attraction force appearing between two bodies with opposite charge (Senseg). With this field running through the touch screen one could think about users' safety, but there is no point in worrying as the low usage of energy for its functioning makes this type of haptic feedback not dangerous for human beings while at the same time it has low battery consumption. Taking tactons into consideration it goes without saying that electric field brings the possibility to include

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[1] Sriram Subramanian (Guest researcher at AIT, GU/Chalmers, February 2011. Bristol Interaction and Graphics, Bristol Univ., UK. "Beyond Touch – Rich Touch and Touchless Interactions". In *Visualization research workshop*. 4th March, 2011, Gotheborg.

unlimited variations of vibrations, clicks, textures, and much more (Disney) (Bau, B et al. 2010). As they say "Possibilities are endless", TeslaTouch bring some examples in their web page, these are some that seem interesting, feeling the size of the file, draw feeling paper texture or feel grids and constraints. That is why a good design of the GUI is necessary not to overload the user.

As mentioned above, this technology enables the implementation of different textures in each section of the touch screen providing dimensional space feedback. The lack of engine makes this device to be really silent and there is no losing of point contact.

Comparison between Haptic Feedback Technologies for Touch Screen

In order to find out which of these technologies would be better for the project the table 2.2 highlighting strengths (in green colour), weaknesses (in red colour) and observations (in blue) had been made and it is included in the next page. Also a comparison between each technology to produce haptic feedback and in which actions produces haptic feedback is included in the table 2.3.

FULL BODY TACTILE DISPLAY

First step into haptic feedback	No overload	Lose of point of contact	Noise	Battery consumption	Lack of space resolution	Few Tactons

SCREEN TACTILE DISPLAY

No overload	Less lose of point of contact	Less noise	Less battery consumption	Wide variety of Tactons	Lack of dimensional space feedback

TEXTURED SURFACES

No overload	No battery consumption	No lose of contact point	Silent	Feeling can be annoying	Texture can fade	No spatial resolution	Just feedback speed/distanc e	Relative feedback	Might block view

"TOUCH CLICK" FEEDBACK

Real tactical feedback	No overload	No battery consumption	Little chance of point contact	Less noise	Blur space resolution	Slower use	Just Confirmation feedback

LOCALIZED SCREEN VIBRATION

Dimensional space resolution feedback	Wide range of Tactons	Less noise	Less lose of point contact	Less battery consumption	Possible overload if not well designed

ULTRASONIC AIR PRESSURE WAVE

Contactless feedback	Dimensional space resolution feedback	Silent	Wide range of Tactons	Possible overload if not well designed	Feedback localized at the back

SURFACE TEXTURE CHANGING

Unlimited Sensations	Dimensional space feedback	No lose of point contact	Very low battery consumption	Silent	Possible overload if not well designed

Table 2.2 Haptic feedback technologies and their characteristics

Comparison between haptic feedback technologies and the possibility to include haptic feedback on different actions:

	Speed	Acceleration	Execution	Scrolling	Error	Space resolution
Full body tactile display	Do not have it	Have it	Have it	Have it	Have it	Do not have it
Screen tactile display	Do not have it	Have it	Have it	Have it	Have it	Do not have it
Textured surfaces	Have it	Have it	Do not have it	Have it	Do not have it	Do not have it
“Touch Click” feedback	Do not have it	Do not have it	Have it	Do not have it	Do not have it	Do not have it
Localized screen vibration	Do not have it	Have it	Have it	Have it	Have it	Have it
Utrasonic air pressure wave	Do not have it	Have it	Have it	Have it	Have it	Have it
Surface texture	Have it	Have it	Have it	Have it	Have it	Have it

Have it   Do not have it

Table 2.3 Comparison between haptic feedback technologies and the possibility to include haptic feedback on different actions

User Analysis

Latest research on the area of multisensory integration seems to dismiss the theory that has been held from several years, the multiple resource theory (MRT). The recently developing multisensory approach claims for an information processing based on the integration of the multiple streams of sensory information coming from each of the senses to generate a coherent multisensory representation of the external world. That means that the overload of sense information can be developed in two stages of the human information processing, in the modality-specific level and/or in the crossmodal level. Moreover, the research suggests that the efficiency of the multisensory information processing could be enhanced if the information to the different senses is given from approximately the same position and the same time (Ho, C. and Spence, C. 2008).

Appling this to the actual project means that every sense stream can be overloaded and also the user can be overloaded in the multisensory integration of the different streams. The question now is, can a sense stream be released by the introduction of other streams inputs? And would it be the overall multisensory integration helped or not?

3 Results from the analysis of theoretical framework and implementation of them

After the framework research, two of the research questions can be answered. Those are *"Which touch screen technology is the best for an in-vehicle multifunctional device?"* and *"Which haptic feedback technology is the best one for in-vehicle touch screens?"*. Then, the results derived by the analysis of the framework information will be used to implement the prototype of the muntifunctional device.

3.1 FIRST QUESTION: Which touch screen technology is the best for an in-vehicle multifunctional device?

Previous chapter, scenario zero, has been done in order to conduct this decision. The first choice in this project is what kind of touch screen that fits the necessities for an in car multifunctional device. In the last section among other information it could be found a description for each technology, and the strong and weaknesses for each of them. Here it will be discussed just the good and bad features affecting the thesis purpose.

First of all, there is a highly important feature for any product included within another product, this is lifespan. It is necessary that any device included in the car has a lifespan as long as the car´s lifespan. Would it be useful to have a car with broken controls? Even though it might be replaceable, due to the fact it is integrated into the dashboard, it might be a costly reparation. For that reason the choice of the touch screen should be conditioned to the accomplishment of this requirement. In order to do so, two of the mentioned technologies would not be valid for an in-vehicle environment; those are SAW and resistive touch screen. The SAW touch screen are relatively easy to break and the resistive touch screens are easy scratched. The possibility to include any type of protective layers to the surface of the capacitive touch screens enlarge its lifespan and make this technology preferable among the others.

It is common, and much more in cold countries, to wear gloves while driving. So, it is necessary to be able to interact with a touch screen with gloved hands. All the technologies offered the possibility to have this feature, but while the others always included it, capacitive touch screens need to be designed specifically for that purpose or be used with special gloves (Purcher, J. 2011).

Also related to weather there is another restriction; the touch screen must be able to be used independently of the temperature of the environment where the user is. There is one kind of infrared touch screen, the heat sensitive touch screen, which has the drawback of not being able to detect touch if the part of the body touching it is cold. This means that if there is winter in a cold country as Sweden, and the user comes from the outside of the car, he or she will have to wait until his or her hands are hot enough to be able to interact with the car controls as, for example, heat. This is not acceptable for car controls, so that kind of technology will not be taken into consideration for car multifunctional devices.

Thinking about the future, it would be a strong feature to have the capacity to measure the pressure in the x-axis. This would enable different actions for the same button depending on the amount of pressure or selection of volumes by pressure. There are two technologies that nowadays enable this measurement; SAW and capacitive touch screens.

In the frame of the project it is imperious to make the interaction as easy as possible for the driver. Lately, a wide range of gestures have been designed for touched devices to be able to interact in an easy way. One example is the different commands in the macbook trackpad depending on the number of fingers touching it. For example it is very simple to return to the last screen by using the command to swipe (three fingers touching the screen moving from right to left). To be able to detect more than one finger touching the screen, the touch screen used needs multitouching. There are just two kind of touch screen matching this requirement, multi capacitance touch screen a specific type of capacitive touch screen and a brand of resistive touch screens, Stantum *(Stantum Unlimited Multi-Touch 2010)*.

The main requisites and which of the touch screen technologies have it or not, are showed in the figure 3.1. Also, another representation is showed using the description table used in the theoretical framework in the table 3.1. The main difference with the one used in the technology presentation is that the characteristics of each technology that are important for the project are highlighted. With important it is meant both for advantages and inconvenients.

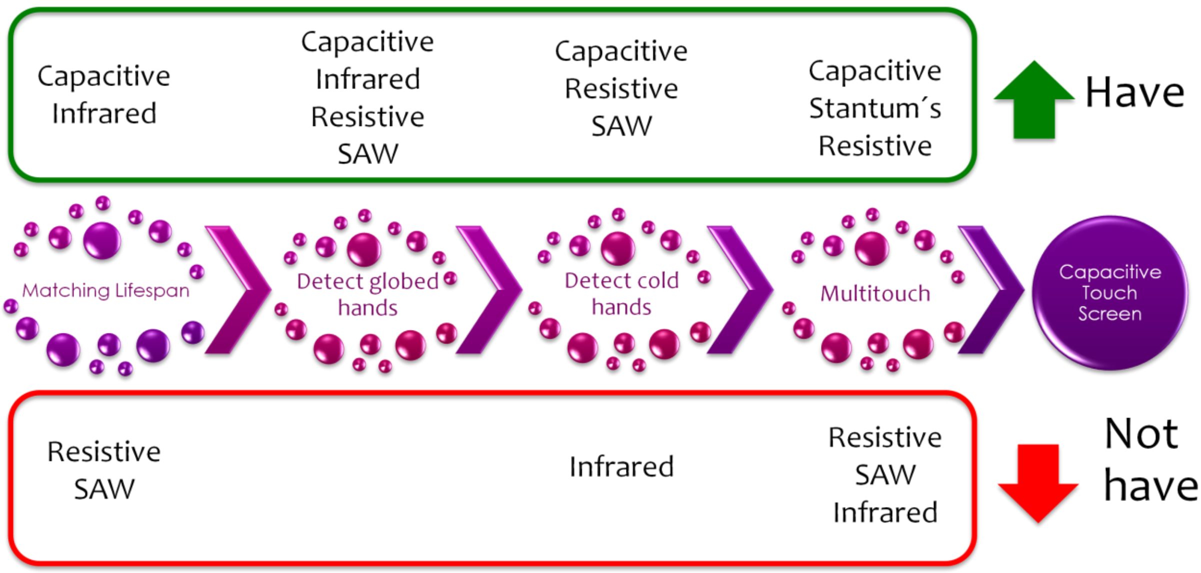


Figure 3.1 Requisites for an in-vehicle touch screen

Being able to choose among the entire technologies of touch screens, the best match with the requirements for an in-vehicle touch screen is a capacitive touch screen. From the different types of capacitive touch screen (see figure 2.1 for more information from capacitive touch screen classification) the one that suits the most for an in-vehicle environment is the **multi capacitive touch screen**.

CAPACITIVE TOUCH SCREEN	Cleaned with clothes without command input	Enables multiouch*	Models with pressure information	Posibility of protective layers (LONG LIVESPAN)	Middle cost	Activated by capacitive stylus & globed hands**	Less accurate than resistive	Conductive smudges can interference
RESISTIVE TOUCH SCREENS	Resistant to water and dust	Cheap	Possible multitouch***	Any object detected	Pressure threshlod to detection	Worst visibility and amount of emitted light	External layer easily scratched (LIVESPAN SHORT)	
SURFACE ACOUSTIC WAVE	Information from x-axis	Image clarity and reslution	No functionality affected by scratching	Any solid can be detected	Easy to break	Interfereces due to dust or water		
INFRARED	High visibility	No need to touch screen to activate	Any solid can be detected	Most expensive	Not working on cold weather			

Table 3.1 Comparison between touch screen technologies with highlighted key information

*Look at the different type of capacitive touch screens, multitouch in Mutual Capacitance touch screen.

**Some information regarding globed hand in capacitive touch screens.

***Stantum's resistive touch screen.

3.2 SECOND QUESTION:
Which haptic feedback technology is the best one for in-vehicle touch screens?

The following conclusions are extracted from the realization of the table 2.2 and 2.3. A variation of the first one could be found below, table 3.3. The key properties from each technology are highlighted in the same way it has been done before. There are some points that should be taken into consideration when choosing one of the technologies previously presented for an in-vehicle touch screen.

First of all, the location of the touch screen has to be present; it will be fixed in the dashboard of the car. Lots of efforts have been done in order to reduce car's engine vibration, and having a new device in the car making the dashboard vibrate will not help that purpose. Also it can produce noise related to the movement in a fixed place even if it is isolated. These are the main reasons why a full body tactile display is not useful for an in-vehicle touch screen. Another impediment related to fixed position of the touch screen is that you cannot hold it so the feedback must be in the front of the device. Ultrasonic air pressure wave's feedback, base its use on the fact that the user is holding the device and so the feedback on the back can be sensed. Even if the feedback could be installed in the front of the device, for example in the edges of the touch screen, the waves created to be the haptic feedback could conflict with the functioning of the selected touch screen's technology.

A fact that has been stressed all along the thesis is that the purpose of including haptic feedback is to create a richer representation of the interaction with a touch screen. That means that the interaction should be a combination of every possible stimuli, therefore the touch screen has to be able to produce audio and visual feedback too, whose are already included in touch screens. One of the technologies presented above has the inconvenient of degrading and deforming the images in the surface of the touch screen. This technology is the texture surface. It has other inconvenient, poor range of haptic feedback. However, it would be a great idea to use the principle in which is based to produce acceleration feedback in the others technologies.

Even though "touch click" haptic feedback´s technology has a poor range of haptic feedbacks, it introduce a differentiation between navigation and activation. This property is really interesting but due to its lack of complexity it is impossible to use it alone. Moreover, people will still be looking to the screen while navigating because it does not include navigation haptic feedback. Then, "touch click" could be used as a complementary haptic feedback to any of the others already mentioned.

To end this discussion, one of the main reasons to include haptic feedback in touch screen must be taken into consideration; increasing people's security while driving. As said in the last chapters, driver's vision demanding is one of the main reasons of accidents. So to increase security a way of interacting with the device without looking into it must be found. That is why dimensional space resolution is a must to in-vehicle touch screen. Having it might let the driver find something in the touch screen without taking his or her eyes off the road. The last technology left without dimensional space resolution is screen tactile feedback, and it is for that reason that is not considered as the appropriate technology.

There are only two technologies left, these are localized screen vibration and surface textured changing. Both have the properties demanded above as dimensional space resolution or large amount of haptic feedback. The fact that makes these two stand out among the other haptic feedbacks is the approach to a real experience. On the latest days companies working to produce haptic feedback in touch screen´s devices have been looking for a complete experience to reduce the sensation of virtuality created by the deprivation of the touch. In one hand localized screen vibration have the possibility to have unlimited number of tactons based in a spread technology (vibration), while in the other using surface texture changing means leading innovation.

To sum up, both, localized screen vibration and surface texture changing are really good technologies to produce haptic feedback for in-vehicle touch screens. Even though, **surface texture changing** stands out among the others as the best one for in-vehicle environment due to the lack of vibration. The technologies producing haptic feedback will be enumerated in desirable order in the table 3.2.

Order of preference	Technology
1	Surface texture changing
2	Localized screen vibration
3	Screen Tactile display
4	Full body tactile display
Used in combination with another technology	
"Touch Click" feedback	
Not able to use in this project	
Ultrasonic air pressure wave	
Textured surfaces	

Table 3.2 Technology to produce haptic feedback in order of preference

FULL BODY TACTILE DISPLAY

- First step into haptic feedback
- No overload
- Lose of point of contact
- Noise
- Battery consumption
- Lack of space resolution
- Few Tactons

SCREEN TACTILE DISPLAY

- No overload
- Less lose of point of contact
- Less noise
- Less battery consumption
- Wide variety of Tactons
- Lack of dimensional space feedback

TEXTURED SURFACES

- No overload
- No battery consumption
- No lose of contact point
- Silent
- Feeling can be annoying
- Texture can fade
- No spatial resolution
- Just feedback speed/distance
- Relative feedback
- Might block view

"TOUCH CLICK" FEEDBACK

- Real tactical feedback
- No overload
- No battery consumption
- Little chance of point contact
- Less noise
- Blur space resolution
- Slower use
- Just Confirmation feedback

LOCALIZED SCREEN VIBRATION

- Dimensional space resolution feedback
- Wide range of Tactons
- Less noise
- Less lose of point contact
- Less battery consumption
- Possible overload if not well designed

ULTRASONIC AIR PRESSURE WAVE

- Contactless feedback
- Dimensional space resolution feedback
- Silent
- Wide range of Tactons
- Possible overload if not well designed
- Feedback localized at the back

SURFACE TEXTURE CHANGING

- Unlimited Sensations
- Dimensional space feedback
- No lose of point contact
- Very low battery consumption
- Silent
- Possible overload if not well designed

Table 3.3 Comparison between technologies to create haptic feedback on touch screen with highlighted key information

3.3 First prototype

After all the research has been done and all the requirements regarding touch screens have been enumerated, the desired preferences in relation to touch screen technologies for haptic feedback has been listed in desirability order (table 3.2).

The first choice was the surface texture changing; this product was in development by two companies Senseg, a finnish company creating E-Sense (Senseg), and TeslaTouch, a division in Disney Research Headquarters in Pittsburgh (Disney). Before including this technology as first choice in the list, it was necessary to assure that this technology is available for development. No answer was received from TeslaTouch and Senseg informed that the technology is not mature enough to be able to give support to the developers. That is the reason why this technology could not be used even if it was the most suitable one for the purpose of this project.

The second choice was the localized screen vibration technology it has the same good qualities as the first choice but with one main drawback, being the addition of vibrations to the car environment, even if these are minimized compared to other vibrates technologies. But the problem was the same; there was no device in the market including the necessary features to enhance the localized feedback. There are just patents related to this technology.

Due to this unexpected fact, a backup solution must be found. It was then that it was decided to try to reproduce the same feedback that was supposed to be created in the first two choices with a less advanced technique.

The next best option among the haptic feedback technologies was the screen tactile display.

This list has been submitted to the approval of Volvo Cars when considering time and economical issues. They evaluated each of them and decided to buy a technology including android technology, the Galaxy Tab from Samsung (figure 3.2).

Figure 3.2 Picture of a Galaxy Tab

The device

The device that has been decided to buy was Galaxy Tab.
The device has the characteristics listed below:

- Microprocessor 1Ghz
- 1024 × 720
- 7 inch screen
- Multi-touch screen
- Android 2.2
- Actuators
- Actuators controllers

Functions in the multifunctional device

The selected functions for the multifunctional device are based on the ones appearing in the rotary control used nowadays for Volvo. These functions have been selected in conjunction to the actions with haptic feedback. The reason is that this thesis is not concerned about which activities that may be placed in a multifunctional in-vehicle device, rather how it can be related to haptic feedback actions.

The chosen functions must include the interactions that have been selected to produce haptic feedback. In the prototype they were:

- Maps
- Phone
- E-mail
- Radio

Actions with haptic feedback

Selecting the actions that might have haptic feedback was one of the most important decisions that should be taken during this project, for that reason it was considered necessary to have a meeting[2] with some people working with haptic feedback for vehicles. During the reunion the difference between two kinds of interactions in touch screens that might need haptic feedback was highlighted.

The first one and most spread was the confirmation feedback, this feedback is used to ratify an action without the need of actually looking at the screen. This feedback is used to answer the question "Have I done it right?". For example, when you push a button from your dashboard you can feel the pushing action and it is used as a confirmation of activation by the sense of touch. When using a touch screen you cannot differ from a pushed button or a dismiss action. Therefore, this feedback is included to suppress this lack of confirmation due to the use of touch screens.

The other kind of haptic feedback is the navigation haptic feedback. It is used to explore the different features appearing in the touch screen. It is said that drivers

[2] Annie Rydström and Daniel Jungegård (Volvo Car Coorporation), Karolina Nätterlund and Jonas Svesson (Semcon) meeting with the author on 24 May 2011.

make use of haptic cues (Rydström, A. 2009). That is easy when having regular buttons, you can navigate along your dashboard and find the button you are looking for by its shape, its texture or its disposition among the other commands, and moreover, you can know you are inside it by following its edges. But all this information is lost when your buttons are in a regular touch screen. The question that explain this haptic feedback its quite simple "Where am I?". There is a deficiency of information, studies and devices with it in the market in comparison to the large amount of data and devices from the confirmation haptic feedback. Taking a look into the use of the navigation haptic feedback in other products, there is a large integrated example of it. In every keypad from mobile phones, laptops, keyboard and any device including buttons, there are some buttons with a different texture, something that makes them stand up among the others. People use this difference to know where those buttons are and to be able to type without looking where they are pushing.

Therefore, both kinds of interaction must be represented.

ACTIONS WITH NAVIGATION HAPTIC FEEDBACK

From here, the navigation haptic feedback will be called navigation feedback and confirmation haptic feedback just confirmation feedback to make the text easier to read. The main difference of including navigation feedback is that the interaction between the user and the device could change completely. The purpose of the inclusion of this feedback is to feel each item displayed in the screen. In order to succeed in this aim, users should be able to move along the screen without activating any activity. There were two considered options to achieve this; first to activate any action on release, the other was to use the "touch-click" feedback to confirm. Due to device characteristics it was impossible to use the second one, so it was decided to implement a program with **activation on release**.

Making a program with activation on release is necessary for navigation feedback, but the confirmation feedback is being affected by this fact. If the activation of a button is done by release, the confirmation feedback is produced after release and as your finger is not longer in the screen you cannot feel it. This fact also happens with other devices with haptic feedback, which are in the market, but as these devices are designed to be hold by one hand while the other hand is interacting with it you receive the feedback in the holding hand. It is then when it must be decided if this project was concerned by navigation feedback or by confirmation feedback. Lots of studies have been carried out on confirmation feedback, but little information could be found on navigation feedback. Due to that reason it was considered more necessary to focus on navigation part, however, the confirmation feedback it is also included in the device because some of the feedback can also be felt. For example, when first touch the screen to navigate, if you were outside any button you can feel a not activated button haptic feedback, this feedback will be explained in the next section.

There will then be two ways to select one item in the screen, the regular way of interacting with a device, pressing to select and the new one, pressing, navigating and releasing in the desired item. Someone might have been asking himself or herself why should the original interaction been conserved if there is a new one. The answer is quite simple, the introduction of haptic feedback in the touch screen is meant to help and enrich the experience and it is most useful in driving situations, but the driver could also interact with the device as a primary activity and in this situation the user might desire to use the original interaction.

There are three main navigation interactions considered in the implementation of the device. These are explained below.

Navigation across Items

This haptic feedback is introduced to enable the user to feel the diverse items displayed in the screen of the device at a moment. The feedback works in comparison to lack of feedback. To be more precise, the items that can be selected in the screen have a feedback on it and the empty spaces do not. That means that when the user moves across the screen only the spaces occupied by selectable items produce haptic feedback to the user.

The main point when designing this kind of feedback is that the items in the screen should be easy to remember and also easy to remember where they are placed. This would help in the future the users to recognize those without the need to look.

The screens and items including this kind of haptic feedback are three. The first and easiest to interact with is the main screen and the items are its four activities options. The next one is the radio and the items are the five set radio stations. This buttons are a bit smaller and closer to each other. The last items with navigation feedback are the keypad from the telephone. These are 16 buttons from numbers to actions and they are pretty close together.

As it can be seen from the description above, they go from really easy to distinguish to more difficult in three levels. Doing it that way enables to measure up to which level the users are able to distinguish the different buttons.

Level Selectors

There are many level selectors in the infotainment commands of a car, for example the volume, the dial selector, temperature and many others. It is interesting up to a point to have a way to measure how much the user has increased those selectors.

A fact that requires a special mention is the design of the selector. Nowadays the selectors that are found in cars are rounds as rotary selectors, this is because for the user is it easier to move a round physical selector that a linear one that has end edges. In this case the selector is not physical but digital and it is easier to follow a line that a round without slipping out of the edges. Furthermore, producing a line give to the user a feedback on the direction of the selection. If it is moved to the right means higher and to the left down. These two main reasons are why there was just one line selector in the prototype; this selector is the volume of the radio.

Scrolling through Data

Some large amount of data as e-mails or contact is displayed in list. To be able to read this information from the distance where the driver is sitting the letter should be big enough. This makes impossible to fit all the information in one screen and therefore, a scrolling list is necessary. When the user is interacting with a scrolling list in a touch screen, there is no haptic feedback to know if they are actually moving the list and moreover how fast are they moving it. To cover this deficiency the scrolling trough data haptic feedback was created. There are two scrolling list in the prototype and it was chosen to have one with haptic feedback and the other without haptic feedback.

Actions with confirmation haptic feedback

In the other hand there is the confirmation feedback. It should be stressed the possibility to include wrong-activation confirmation feedback or lack of haptic feedback for the same purpose. Due to the localization of the touch screen, onto the dashboard in a car, with the possibility of having vibration from the motor that can be confused with a confirmation feedback, it was decided to better include an error haptic feedback when the interaction was not well performed ond the action was not activated. The actions included in the first prototype to have a confirmation haptic feedback are listed below.

Activated Action

When a button is clicked in any way, this was explained before in this text (pp. 39), an activation haptic feedback is transferred to the user. The buttons that have activation feedback are the main menu buttons, the radio buttons, the e-mails, the contacts list in the telephone and the keypad buttons from the telephone. Another variation of the activated action feedback included in the telephone buttons is more suitable from the author point of view. But there is one drawback, elongation of learnability. That is the reason not to use this variation, but it will be presented by the discussion

Not-Activated Action

The not-activated haptic feedback is produced when an activity or button was not well selected, e.g. when you click in an empty space or when you ask for an unavailable command. You receive this feedback in the device when you click in an empty space of the screen, when you push a telephone contact without deselecting the last contact or while calling, video calling or messaging another telephone button is pushed without ending the last action.

Type of haptic feedback

After selecting both the activities and the interactions that would include haptic feedback, the next decision to take is the haptic feedback for each one. For this purpose there were three possibilities that match the device acquired. All three are connected and are part of the Universal Haptic Layer (UHL) from Immersion (Immersion Corporation 1).

In one hand there is the android effect library from Immersion, this library contains a wide variety of predefined tactons that can be implemented at any time by the device (Appendix I). In the Immersion page it can be found advices on the use of it as tips of what they might mean for the users (Immersion Corporation 2). Another way to produce the haptic feedback is to use the standard vibration method from Immersion. This method enables a vibration with one input, the frequency in milliseconds. The last one is to use Motive Studio, a tool from Immersion to design a completely new tacton (Immersion Corporation 3).

The novelty of the use of haptic feedback for in-vehicle touch screens requires the usage of simple tactons and a very narrow range of them. The reason is that the user needs to recognise them quickly, to be able to do that few tactons might be learned and they have to be easy identifiable. That is why it was preferable the use of the first two ways of tacton, the library and the vibration method. Now, the tactons used for each haptic feedback would be explained.

There are some facts that have been taken into consideration when choosing the haptic feedback. First, regarding the library of predesigned tactons of Immersion, the different haptic feedbacks available in the library (Immersion 4) can be defined by four main characteristics. These characteristics are the kind of effect, width of the pulse, percentage of power and number of times that the effect is played. For any tacton chosen from that library each of its characteristics will be discussed. Although, there is one that will be the same for all of them; the percentage of available power. The power will always be 100% due to the low power of haptic feedback of the device. Taking into consideration how an effect will be selected, here you can find a little explanation. It has been said that the use of haptic feedback is looking for a real experience, this could be due to the recently introduction of haptic feedback to touchable devices. To be more precise, when a new perception of a product is created one important property is to be as guessable as possible for the new user. The easiest way of producing a good guessability in product is that some domain knowledge of haptic feedback could be used. There is no background for the user on the main subject of haptic feedback in touch screens because there is no haptic feedback standardized for them. So it might be considered any haptic feedback, not only touch screen haptic feedback. This means that the haptic feedback for a virtual action will be developed from the real haptic feedback with the physical object.

CONFIRMATION FEEDBACK

For the two confirmation feedback the selection were made upon what could be found in the library of predesigned tactons.

Activated Action

For the activated action confirmation feedback, as in this case it is mostly used for activated button, the most suitable kind of effect will be a click effect. As explained in the introduction to this section, in the case of a button, the haptic feedback of a real button might have been taken into consideration for the design of a haptic feedback of a virtual button in a touch screen in order to be as guessable as possible. Even thought navigation across the screen suggests the fact that the buttons are pressed when you released for activation. The fact is that in a real button situation you get two haptic feedback from it; the force against the finger when you press and release it. This can be regarded as two feedbacks, which is why the confirmation haptic feedback will be composed by two effects. Regarding the wideness of the pulse, to be able to choose between the different options the real click of a button must be analyzed. It is quite a long feedback when you touch a button because you have to realize the whole course of the button to activate it. That is why a long pulse was chosen.

The specific feedback is number 15 in the list of haptic feedback from the library of Immersion (Appendix I). The summary of haptic feedback number 15 is shown in the table 3.4.

Number of effects	Type of effect	Wideness of pulse	Power percentage
Two effects	Click Effect	Wide pulse	100% power

Table 3.4 Summary of the haptic feedback number 15

Not-Activated Action

The approach to the not-activated action confirmation feedback must be really different to the activated one. The reason is that in this case, the physical button does not produce any haptic feedback; there is just lack of it. But it was chosen to have a haptic feedback in this case for the virtual button for the reasons that were explained before in this text. First, to have a link between the two confirmation haptic feedbacks a click effect was chosen. As it is impossible to look for the physical haptic feedback, it would be nice to look for other kinds of feedback regarding the same situation. When looking at auditory feedback for not-activated action a buzz is often used, a repeated and short feedback. Translating these into the library characteristics it means that the feedback must be a narrow pulse and it has to be repeated at three times that it is the highest number of repetitions.

The specific feedback is number 21 in the list of haptic feedback from the library of Immersion (Appendix I). The summary of haptic feedback number 21 is shown in the table 3.5.

Number of effects	Type of effect	Wideness of pulse	Power percentage
Three effects	Click Effect	Narrow pulse	100% power

Table 3.5 Summary of the haptic feedback number 21

NAVIGATION FEEDBACK

In comparison to the confirmation feedbacks, navigation feedbacks have to be simpler. The reason is that they are repeated over time when the user is making any change on the position of the finger in the screen. That is why the vast majority of the navigation feedbacks are composed by one effect.

Navigation across Items

The navigation across items feedback must be not really sharp. The reason is that feedback repeated a lot of times at sharp vibration could be annoying after a while. Also, it might be taken into consideration the fact that vibrator fibre nerves are quick adapting and patterns must not be followed to be able to notice the haptic feedback for the necessary time. A single bounce effect combined with the fact that haptic feedback just appears when finger position is changed seems to match all the requisites. There is no possibility to regard the physical haptic feedback to create the virtual. That is related to the design of virtual objects in comparison to physical button. To be able to navigate easily between items, they must be placed within a relative wide separation one from the other. Also they must be quite big to be easy to click. These two design patterns provide a big space inside the items. With regular items as buttons there is no haptic feedback on top of the button but the kinetic of its volume or maybe the shape of it. But including just the edges of the button, which is the haptic feedback of regular buttons, is not enough. Thus, the virtual haptic feedback is included both in the edges and inside the item when moving across.

The specific feedback is number 9 in the list of haptic feedback from the library of Immersion (Appendix I). The summary of haptic feedback number 9 is shown in the table 3.6.

Number of effects	Type of effect	Wideness of pulse	Power percentage
One effects	Bounce Effect	Long tapered pulse	100% power

Table 3.6 Summary of the haptic feedback number 9

Level Selector

Often, when a physical level selector is designed, it is introduced some opposition force to its move in steps. This is felt by the user as some force against the move of the level selector and depending on the number of resistances solved the user know how much has moved the level selector. An intuitive way of producing this haptic feedback for level selectors is to include a feedback that increases frequency or intensity or both when increasing the value of the selector. For this purpose it was chosen to increase the frequency of haptic feedback because the maximum intensity for the device used was too low and that fact makes it extremely difficult for the user to feel the lowest level. This was seen as a source of confusion for the user, who due to the lack of perception of the feedback might think that the action was not performed.

Here, the function that has been used to create this difference can be seen. The frequency of the haptic feedback is an exponential on the selected volume.

$$frequency = 10^{volume}[ms]$$

The function was implemented by the android method vibration (Google Inc. 1).

Scrolling through Data

The scrolling through data feedback, even if it is a navigation feedback, is also in a way a confirmation haptic feedback because it ensures that the moving action is performed. For that reason the same confirmation feedback for activated items is used.

The specific feedback is number 15 in the list of haptic feedback from the library of Immersion (Appendix I). The summary of haptic feedback number 15 is shown in the table 3.7.

Number of effects	Type of effect	Wideness of pulse	Power percentage
Two effects	Click Effect	Wide pulse	100% power

Table 3.7 Summary of the haptic feedback number 15

The prototype

The prototype (figure 3.3) was implemented in Java (android 2.2) and xml. The program used to create the code and compile the code is Eclipse Java EE IDE for web Developers with the Java Development Kit (JDK) 6u21, Android Software Development Kit (SDK) r12 and Android Development Tools Plugin (ADT). With the installation of the Android SDK an Android SDK and AVD Manager is also included to download essentials SDK (Google Inc. 2).

The use of "no" in the next explanations has to be explained. Due to the possibility of misunderstandings, in this section when "no" means lack of, the whole word is written in capital letters (NO). In the other hand if "no" refers to the confirmation haptic feedback of no-activated item haptic feedback, the word is written in the without capital letters or with the first letter in capital letters, if necessary and is linked to activated or navigation with a line (No-activated, no-activated, No-navigation and no-navigation).

MAIN MENU

The main menu (figure 3.3) has four buttons which, when selected, redirect the user to the chosen function. The black screen has NO navigation feedback in contrast to the items. The items have activated action feedback and the black screen has the no-activated feedback.

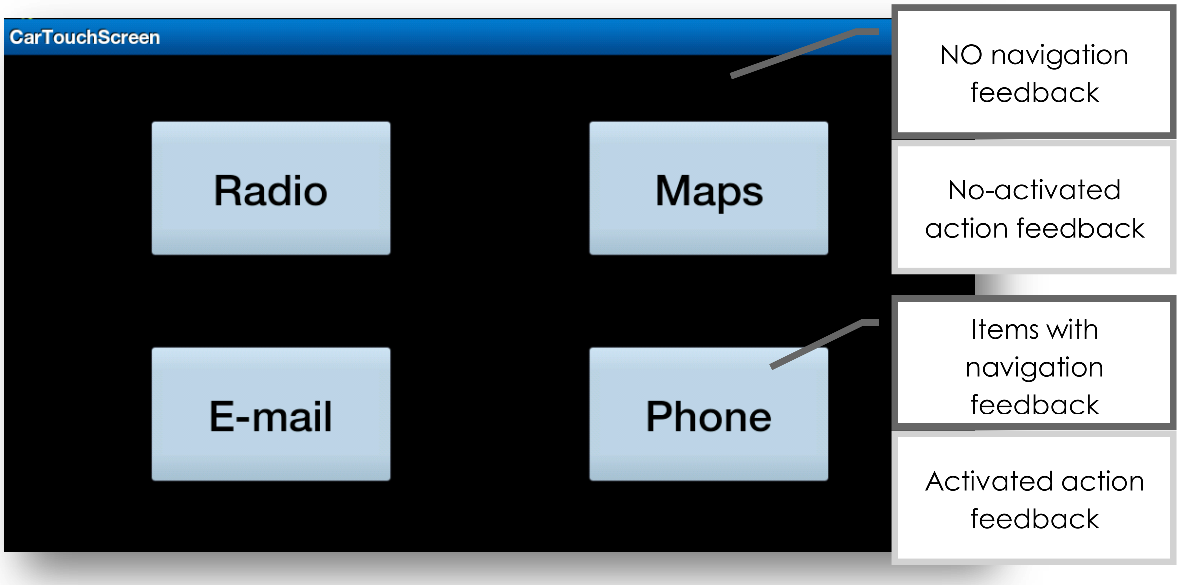


Figure 3.3 Screenshot of the main menu

The Radio

The radio has five buttons to select one of the set dials, a level selector to change the volume and three labels with the dial name, number and set volume (figure 3.4). For the set dial buttons there is navigation feedback in contrast with the lack of navigation feedback in the black screen. There is activated action confirmation feedback in the buttons and no-activated action feedback in the black screen. Here, it can be found the only level selector in the prototype and has level selector haptic feedback.

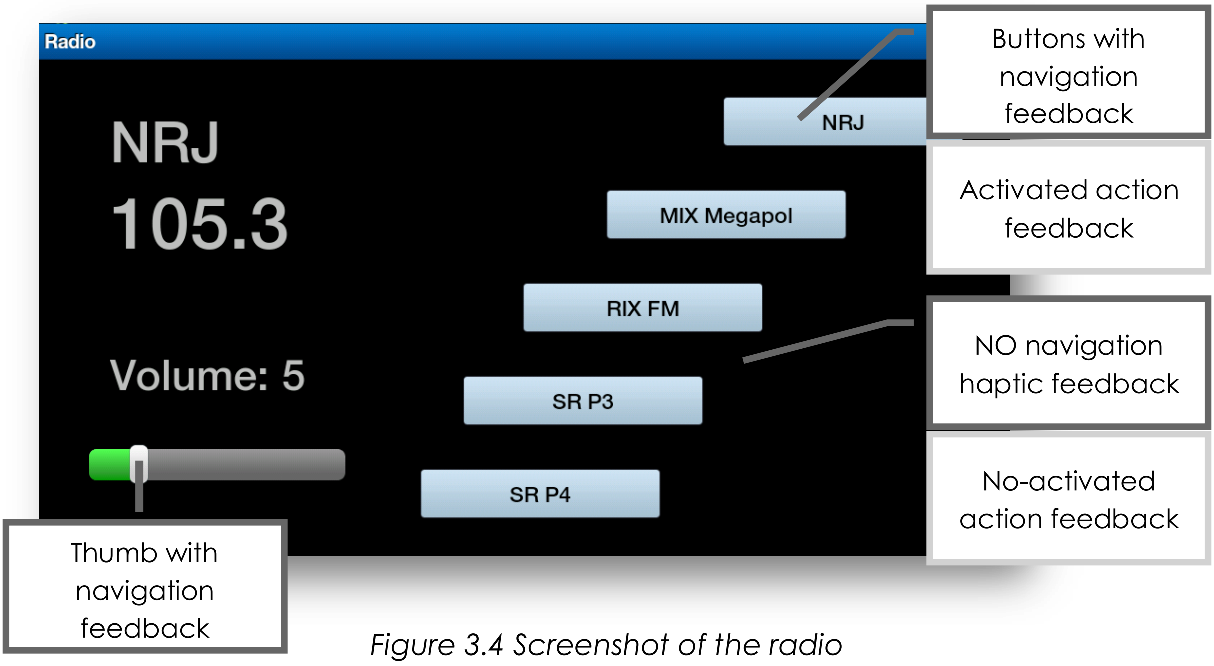


Figure 3.4 Screenshot of the radio

Maps

In the maps screen there is no more than an image (figure 3.5). The reason is that the usage of GPS is considered to take place in a not driving situation. When a driver want to go to a certain point GPS should be set in the very beginning to get the best directions. If the driver decides to set the GPS while driving, there will be a huge visual demand and there is little that can be done by including haptic feedback. The only haptic feedback, of the ones that have been selected for the prototype, which can be suitable in this situation, is the scrolling through data haptic feedback. But there will be visual demand because there is no possible way, with the technology available now, to searching a place. Audible commands that can be activated by the driver will be advisable.

Figure 3.5 Screenshot of the maps

E-MAIL

The e-mail is a scrolling list with 18 numbered items (figure 3.6). When the user selects one item the main body of the e-mail appears on the screen as a dialog. The scroll list has navigation feedback and the items have activated action feedback.
The audio was not implemented in this prototype, but the combination of it with the haptic feedback could be useful. For example, it will be really visual demanding to read the e-mail while driving. Thus, the dialog could be read out load by the device when selecting an item on the list.

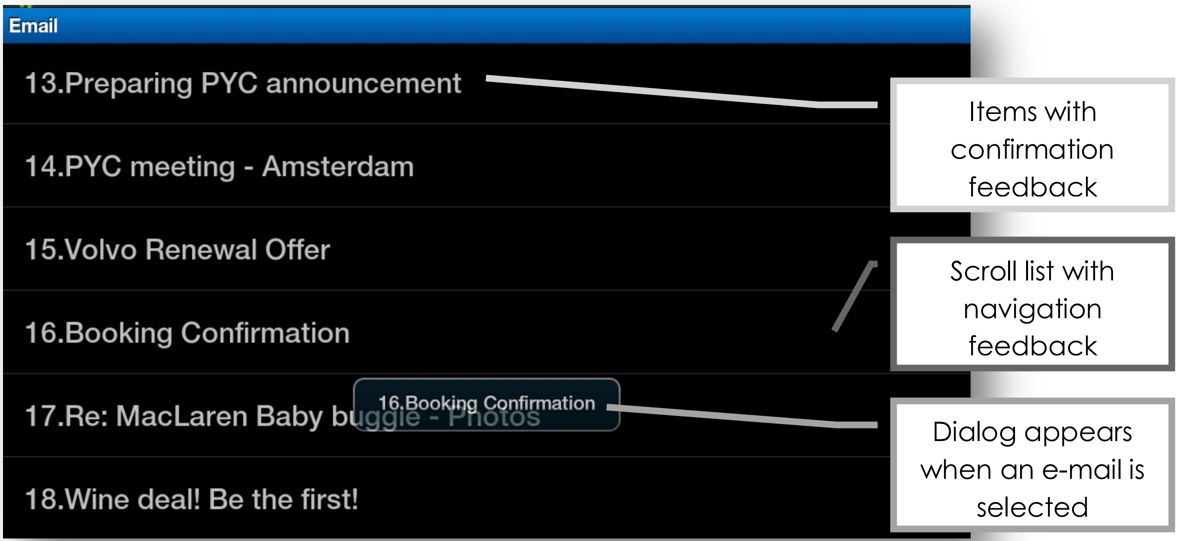


Figure 3.6 Screenshot of the e-mail

TELEPHONE

The telephone is the most complex screen from the ones designed for the prototype (figure 3.7). There is a scrolling list in the left with the contacts, for each contact there is a check box. Only one check box can be checked at a time. On the right there is the 16 phone buttons and the label where it is show the performed activity. The Scroll has NO navigation feedback. The Check box has confirmation feedback. There are two situations, when a contact is selected and no other is selected before, then, there is activated action feedback. But, when a check box is checked and the user checks another one, there is a no-activated action feedback. The label has NO navigation feedback and no-activated action feedback. The buttons have navigation feedback. For the confirmation feedback is a little bit more complex. There are two types of buttons: the non-performing buttons, numbers, symbols and delete; and the performing buttons video call, message and call. When any of the performing buttons is selected and the user does not deselect them and touch any other button a no-activated action feedback is performed even if the action is performed. This feedback is provided to show that something has been finished in order to perform the new button action. Otherwise, an activated action feedback is given to the user.

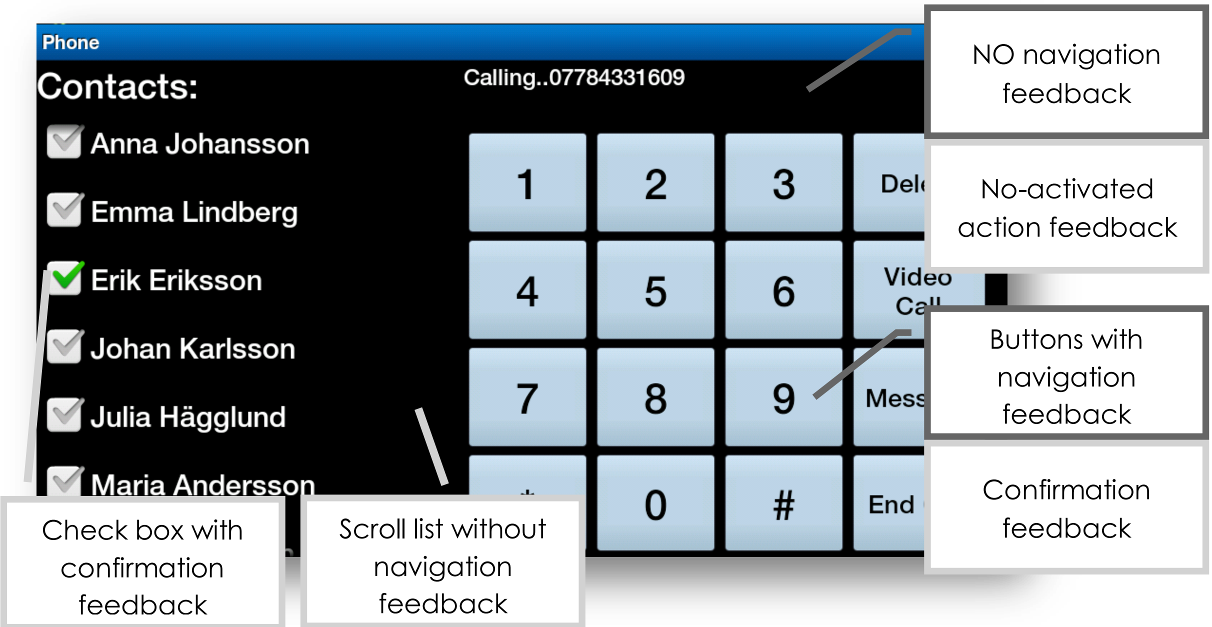


Figure 3.7 Screenshot of the telephone

4 The Usability Study

The study carried out during this thesis is a usability studies. The first thing anyone could ask themselves is what a usability study is. Answering that question is the object of the brief introduction on this field that can be found just below. After that there is a presentation of the simulator used for the study. The reason to introduce it so early is that the technologies available could determine which methods for measuring could be implemented. Then, depending on the effects of user characteristics in the data recorded, the participants in the study will be defined. To continue delimiting the type of usability study, the methodology used is presented. Data acquisition and the apparatus used to measure them are explained in the next point. Finally the conclusions of the study are presented in the last point.

4.1 Usability

Usability is introduced in the design process because there is a lack in recognition of the limitation of people who might need the products. It is a property of the interaction between a product, a user and the task or set of tasks. The definition of usability that can be found in the ISO DIS 9241-11 is *"The effectiveness, efficiency and satisfaction with which specified users can achieve specific goals in particular environments."* (Jordan, P. W. 1998).

Effectiveness

It is the level of goal or task achievement. For some uses it can be only success or failure but for others it can be the extent to which a goal is achieved. The more likely a product succeeds in its goal the more effective it is (Jordan, P. W. 1998).

Efficiency

The efficiency is the amount of effort that is required to accomplish a task or a goal. The less effort needed to finish the task the more efficient it is (Jordan, P. W. 1998).

Satisfaction

This is the most subjective part of the definition of usability and therefore the most difficult to measure. It is defined as the level of comfort that the users feel when using a product and how acceptable the product is to users as a mean of achieving their goals. So it goes without saying that more comfortable and more acceptable means more satisfaction. This is the most important aspect of usability when we have a product whose use is voluntary (Jordan, P. W. 1998).

4.2 The Simulator

The simulator used for the usability analysis is located at Volvo Torslanda in the HMI lab. A picture with some references to the layout and the available technology in the laboratory can be found at the end of this section (Figure 4.1). There are two main parts in the simulator, the driving simulator and the cockpit.

The cockpit simulator has been made from a front part cockpit of a S80 including passenger and driver. Some modifications have been made on the cockpit to be able to simulate a regular driving situation. First the rear mirrors have been replaced for three 12-inch TFT screens, which reproduce the supposed rear vision of the scene. Then, there has been placed a low frequency speaker under the driver sit to simulate the road vibration. The infotainment panel between the driver and passenger sit is easy changeable to be able to check different dispositions. A screen on front of the driver dashboard indicates the driver speed at each moment.

The driving simulator is provided with a 5.1 sound system to simulate the surround sound road, wind and engine among others. A 180 degree round screen provide the space to create the driving scene, that is created by five projectors providing a 1900x1080 resolution.

The simulator is connected with a six computers to be able to control the scene created and also to collect and share information with the different devices that are disposed in the car. Lots of performance information can be storage as speed or base line deviation. There are also some cameras and eye trackers to analyse glances.

All the information given here is extracted from a Volvo Car Corporation internal report written by Ingrid Pettersson.

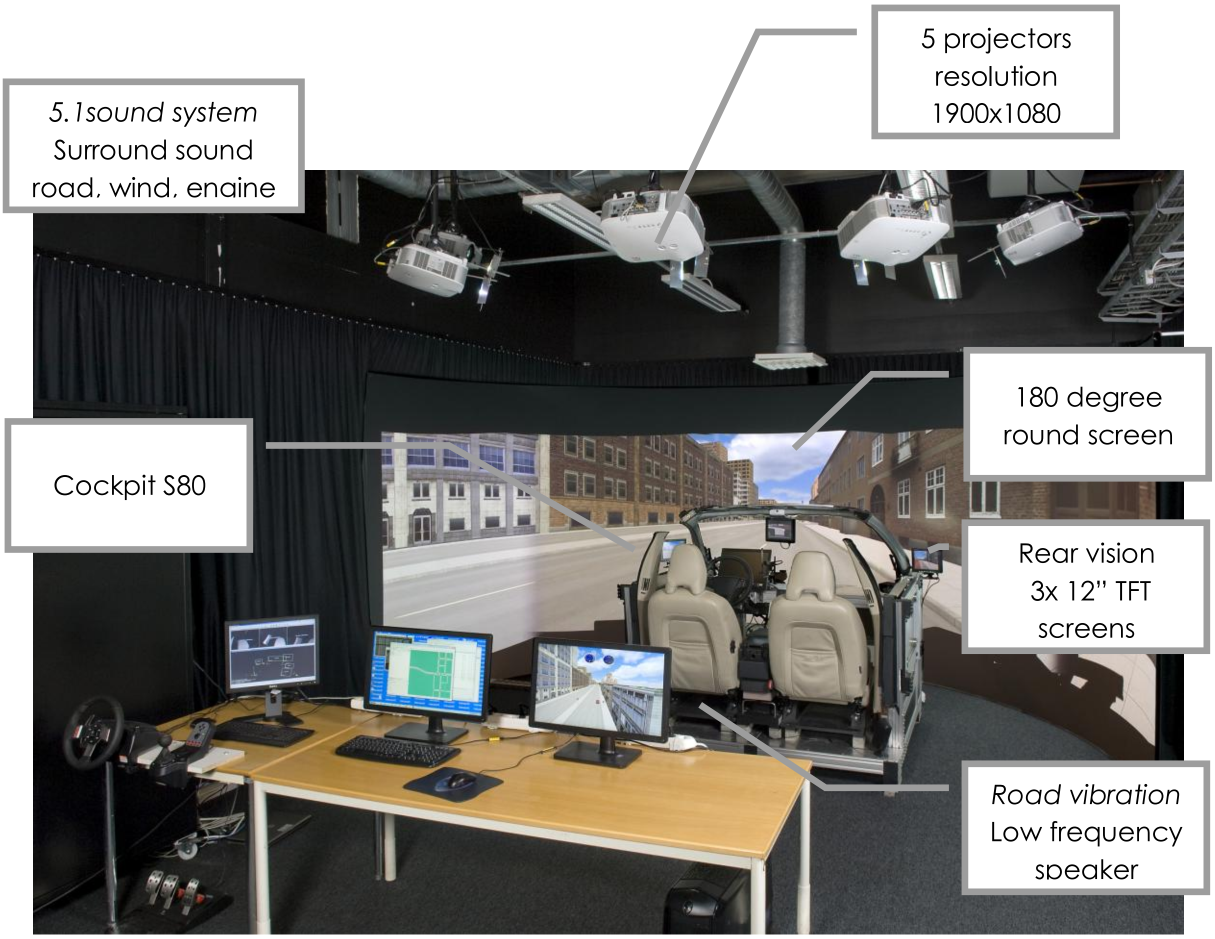


Figure 4.1 Simulator at Volvo HMI laboratory

4.3 The Participants

The users' characteristics could cause some effects on usability. Just below there is a list of the features that are more probable to affect usability, these are defined in order to understand and determine participants' requested characteristics. Participants in the study must meet them so that the data recorded is not conditioned by external variables to the study. There are five user characteristics that may have some effect on usability, these are experience, domain knowledge, cultural background, disability and age and gender (Jordan, P. W. 1998). Here will be only discussed three of them, as two do not cause any relevant effect in that study. These three are experience, domain knowledge and age and gender. Also there will be a requirement related to the simulator and the measurement tools used.

Experience

The experience one has doing a specific task, might affect the ease or difficulty of its completion. Lots of designers use consistency for their product, which means that from a previous experience a user is able to generalise to be able to do a new task. That confronts a lot of times radical improvements needed by some products in the market because the inherent usability benefits of compatibility with other products may be lost (Jordan, P. W. 1998).

FOUR YEARS IN POSSESSION OF A DRIVER'S LICENSE

The primary activity accomplished by the participants of that study is driving, but the main interest of the study is the secondary task, navigating through an in-vehicle touch screen. Therefore, no attention must be paid to the driving task. To avoid any interference between both activities, the participants have to be used to drive a car without paying too much attention to the mechanical movements needed to drive it; otherwise the recorded data could be incorrect. For example, the eye tracking could record a new driver looking into the touch screen when what he or she is actually doing is to look to the change of gears to make sure the change he o she is doing is the right one. Also there is a spread thought that new drivers rely much more in vision than any other driver, and this could condition data.

Domain knowledge

Having knowledge of a task that it is independent of the product that is being used to complete the task could affect on the performance of the user (Jordan, P. W. 1998).

NO OWNERSHIP OF THE SAME MODEL AS THE ONE AT THE VOLVO

Including domain knowledge in your design is often seen as a good fact but in this case it could be prejudicial for the interest of this project. If one of the participants in the study already have had the same car in which is based the simulator, he or she will be familiar with the disposition of the tools. So, when asked to make something the participant would automatically try to do as usual, looking for the regular controls. This kind of actions will affect the data recorded from the study. That is why participants on the study must not have ownership of the same model of the used Volvo.

Age and gender

Taking into consideration age and gender, it is really important to be able to find the target market in which this technology will fit. Age can be a factor, because every younger generation is more used to interaction with technology with which they grown up. Young people are more likely to accept high technology devices whilst elderly people might not (Jordan, P. W. 1998).

TOP AGE OF 40

The study might be compromised by the reluctance of participant to use technology or the unfamiliarity to use those kinds of devices. Because of that, the range of people attending this study must not go above 40 years old. It is considered that people to 40 year might have used tablets at least once in life so it will be easier for them to get used to use it. Moreover, this will equilibrate for the young people who are not attending the study, 22 year old and younger, due to the experience on the primary activity. These people are more likely to accept the technology and to found easier the interaction with it.

Requirements related to the simulator and measurers

There is another requirement that is related with the simulator itself. As it will be said later in this report an eye tracking will be used to get some data. Do to the operation of that measurer there is the next requirement.

NO WEAR EYEGLASSES

To ensure good quality eye tracking data the participants in the study could not wear eyeglasses[3].

The global participant´s requirements

All the participant´s requirements mentioned above are summarized in the table below (Table 4.1). For a participant to be able to take part of the study must fulfil all the minimum requirements.

REQUIREMENT	VALUE
Ages of driving car license	> 4 years
Ownership of the used model Volvo	No
Age	< 40 years
Eyeglasses	No*

Table 4.1 Participant´s requirements for the usability study

*Due to some technical problems during the study eye tracker was no longer user and this requirement was no longer needed.

4.4 Methodology

The methodology followed in a usability study depends highly on the type of product being tested. It is an indubitable statement the fact that performance with a product is likely to improve significantly in relation to the number of times a task with it is repeated. So usability improves over time if the product is used. This fact was stressed by Jordan at al. (1991) who have presented a model of usability with three components depending on the number of times the product is used. Later (1994) this model has been enlarged by two more components. In the following section a brief view into that model is carried out.

[3] Annie Rydström (Volvo Car Corporation).

Components of usability

Here it will be presented the five-component model. If we take into consideration the levels of improvement we will have guessability, lernability, experienced user performance (EUP) and system potential. Out from that scale there is a special but not less important component re-usability.

GUESSABILITY

"Guessability is the effectiveness, efficiency and satisfaction with which specified users can complete detailed tasks with a particular product for the first time". (Jordan, P. W. 1998).

Products

Products that need good guessability are those whose users are one-off, meaning that it will be used just for one time when necessary. An example of this type of products are emergency tools, when an accident is occurring you will have to use it for the first time and you have to guess easily how to use it because it is a matter of time to get it worse. Taking commercial implications into consideration, the lack of guessability may put off products that might have been comparatively easy to use in the long-term. Because when buying the user consider is really difficult to figure out how to use the product. (Jordan, P. W. 1998).

LEARNABILITY

"Learnability is the effectiveness, efficiency and satisfaction with which specified users can achieve a competent level of performance on specified task with a product, having already completed those tasks once previously." (Jordan, P. W. 1998).

Products

The range of products that need a short time of learnability is wide, it includes the self-taught products and products with short training time. A useful example of that are tools which functioning is learned in a course, and you have a set time to learn how to use it (Jordan, P. W. 1998).

EXPERIENCE USER PERFORMANCE (EUP)

"*The effectiveness, efficiency and satisfaction with which specified experienced users can achieve specified tasks with a particular product.*"

It is the time in which your performance has not significant changes after have been using the product several times to perform a particular task (Jordan, P. W. 1998).

Products

Products with little pressure to learn quickly but with a need of high performance once the product operation has been learned are suitable as EUP. For example users of software packages use a lot of time to become good in a program but once learned they are quite quick managing it (Jordan, P. W. 1998).

SYSTEM POTENTIAL

"*System potential is the optimum level of effectiveness, efficiency and satisfaction with which it would be possible to complete specified tasks with a product.*"

It is the maximum level of performance that would be theoretically possible for a product. That means that system potential is the upper limit of the EUP, so normally EUP is shorter than System potential.

There is an important subject introduced by Norman, Draper and Bannor (1986), the shells of competency. These shells are the different steps of EUP in which the user is stuck until he or she found the way to improve. The shells are each time closer to the system potential (Jordan, P. W. 1998).

Products

The products that need to take into consideration System potential are those whose EUP is limited by System potential. This means that even if the user improves its performance there is no possibility to make it better because of product limitations (Jordan, P. W. 1998).

RE-USABILITY

"The effectiveness, efficiency and satisfaction with which specified users can achieve specified tasks with a particular product after a comparatively long period away from these tasks."

There is no doubt that after a while not using a product to make a specified task there is a possible decrement in performance. This could be caused because the user has forgot how to perform the task, the functioning of a control or where a control is located.

Re-usability can be for a whole product or just for a single task that is not do it usually and it depends on the amount of time since last time used (Jordan, P. W. 1998).

Products

Re-usability is important for products that are used intermittently, to be able to remember how to perform a task without taking too long (Jordan, P. W. 1998).

A graphic of the notional learning curve is displayed below with each component of usability (Figure 4.2).

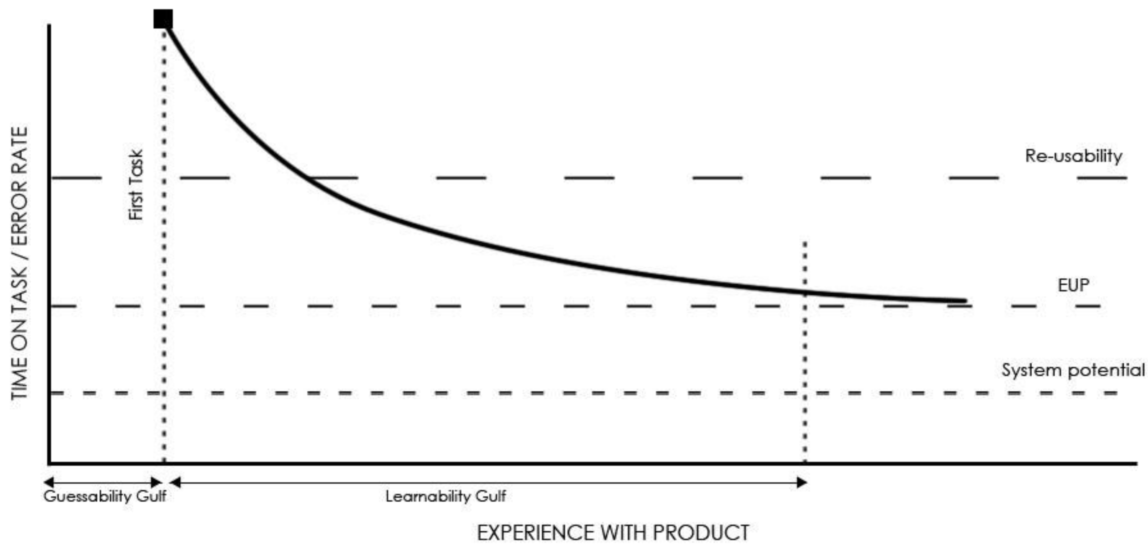


Figure 4.2 Notional learning curve, adapted from Jordan (1998)

Components for the study

Regarding the actual project, there is a wide range of users; everyday users who use the car to commute, weekend user who use the car to go outside the city the non-working days and finally, sporadic user who use the car once in a while. Another thing that has to be taken into consideration is the usage of the different functions of the touch screen. Even if a user takes the car every day, he or she might not use the touch screen, so it makes him or her a sporadic user for the touch screen. Moreover, if the user uses the touch screen but there is a function that is used from time to time, this user is a sporadic user for this specific function.

All this means that there are a lot of different users for this device so every component of usability should be considered. Due to time and resource limitations this project will just take two into consideration, even though the reasons why the others are not involved in this study will be discussed.

Guessability

Guessability is an interesting component to take into consideration from the point of view that a user could turn off the haptic feedback if the received information from this stream is not enough guessable.

To follow usability guides it is important to have the possibility to adapt a product to the user desires (Jordan, P. W. 1998), in this case it means to make possible for the user to turn off the haptic feedback or just to be able to have a stronger or a lighter feedback. This fact must be seen as strength of the product as a touch screen but for the purpose of the project, looking to the benefits haptic feedback could give to a driver using in-vehicle touch screen, it is a threat. What if the user turns off haptic feedback at the beginning because he or she does not feel comfortable with it and miss the possible benefits it might bring to him or her in the future?

To be able to know if this will happen or the product has enough guessability to the user wait longer, an interview will be carried out after the first use.

Learnability

A fact stressed by nearly all the people making studies with touch screens is the importance of familiarity with the device and with the haptic feedback introduced into the device to fully realize if the haptic feedback has any benefit for the user. So that is why learnability is the most important component of usability for this study.

Regarding a regular use for this device, a car driver would get some tips from the seller of how to use the device but mostly of the functioning would be self taught and it should be easy to learn in order to be useful to the driver.

The study should then be done after some training with the device with and without haptic feedback. And the interview after the test will regard learnability concepts.

Experience user performance (EUP)

This component of usability will not be tested in this project because large amount of time and resources will be necessary in order to set EUP. Nonetheless it will be interesting in further works to test it.

A remarkable fact about EUP is that drivers use the same car for several years so even if the time to arrive to EUP is long they are highly probable to reach it. And after reaching that EUP if a norm to design haptic feedback is followed in future works, products will benefit from experience as an advantageous effect of user characteristics.

System potential

System potential cannot be evaluated in a short period of time because the importance of it is in relation of EUP. So as with EUP it will be interesting to test it in future work to see if system potential is limiting EUP.

Re-usability

For all the spontaneous users it will be necessary to test re-usability but also it is because a matter of lack of time that this is not treated in this study

Design of the usability study

Here there is a resume of the steps followed in a usability study.

First Questionnaire

When a participant comes to the laboratory to join the study, it will be asked to fill in a participant characteristic form. This questionnaire could be found in the appendix II. The characteristics asked are the following:

- Sex
- Age
- Since when he or she got driving license?
- How often does he or she drives a car?

- If he or she has a car?
- Which brand is her or his car?
- Which model is her or his car?

First trial with the simulator without the touch screen

The participant was asked to sit in the simulator and adjust the seat. After everything is set, the participant will have the opportunity to drive the car without interacting with the touch screen. The reason to do this first trial with the simulator is for the participant to feel comfortable with the simulator. The participant will be asked to drive until she or he feels comfortable with it. No data will be taken of this first trial.

Baseline Set

After the first trial, the baseline of road deviation will be set. To be able to set it the participant will drive until reach a stable speed (speed limit is set at 90km/h). Then, the baseline track will be measured for 30 seconds. The data of the baseline is:

- Speed
- Standard deviation.

Training with the touch screen with and without haptic feedback

During the pilot study after the usability study, it was found that the guessability is null. Thus, the guessability study was not longer included in the usability study, even though, the question regarding turning off the haptic feedback on the device was formulated during the learnability questionnaire. The main reason of this lack of guessability is the introduction of the new interaction with the touch screen. The reasons and some solutions will be discussed latter in this thesis.

So due to the lack of guessability an introduction to the new way of interacting is explained to the participant. After this introduction, the participant follows a trainee base on the study structure. The participants are allowed to perform as many trials as wanted. Some data was collected and storage in case it is necessary to be analysed. The data sheet is attached in the appendix II.

Test with and without haptic feedback

Two blocks of five exercises compose the main test. One block is with enabled haptic feedback and the other without. There were four participants in the study; half started with the haptic feedback enabled and the other two without. This is decided in a random way. The five exercises are the same for each participant with some variations decided in a random way. The exercises were:

- Go from the main menu to one of the functions of the device.
- Go to the radio and turn the volume to any volume in a certain range.
- Go to the radio and change the dial to a certain one.
- Go to the e-mail and select any item between a certain interval.
- Go to the phone and call or video call a certain contact.

The data acquisition during the test is related to the performance (appendix II):

- Speed
- Deviation of the standard path

- Time on task

INTERVIEW ON LEARNABILITY

The learnability interview is divided into three parts. These are the two tests right after each learnability block and the shared questionnaire. The two tests are composed by an adaption of the DALI test and the SAM.

This adaption of DALI is a subjective workload test specially for haptic devices (Chin, E. et al. 2008; Pauzié, A. 2008). This method allows to compare the workload (including fatigue as an origin of the workload experienced by the driver) induces by several situations for an individual (approach of "human factors design", to define which condition is less costly for the user), and not to evaluate the capacity of an individual according to the mean of a population (approach "tests in psychology")[4].

In this framework, at least 2 conditions must be set up(one reference and one to be tested) and to apply the DALI at the end of each of them, then to compare the results of the two contexts for the same person, with a turn over between participants (not always the same situation applied first) [4].

SAM is a pleasureness test (Desmet, 2002). With SAM three factors can be tested: happiness of using the product, stimulation by using the product and control over the product. These and the shared questionnaire can be consulted in the appendix II.

4.5 Data acquisition

Data acquisition was planned to measure the usability of the introduction of haptic feedback for in car touch screens. To be able to measure usability we should measure its three components:

EFFECTIVENESS:

There is no need to look at effectiveness; all the participants were able to perform the actions and the quality was the desired.

EFFICIENCY:

Different performance measures would be taken in order to determine different facts. Also a subjective measurement on workload just after the each block of the test will be performed by the participant to reassure the performance measures.

Secondary activity performance measures

Time on task

Affects drivers' visual behaviour?

Eye tracking

ISO metrics number of glances and glance duration

Driving performance is affected?

Deviation of a normative path

[4] Annie Pauzié (Research Director, IFSTTAR/LESCOT).

Speed

Affects cognitive workload?

DALI (Driving Activity Load Index)

SATISFACTION:

To determine the satisfaction with the prototype two sorts of information will be used.

SAM

Questionnaire:

After learning how it is used, will you say it is easy to know what is happening in the device without looking at them when the haptic feedback is turn on?

Will you say that haptic feedback had helped you in this in the usage?

In which task do you think haptic feedback has helped you most?

Will you prefer in any task the option without haptic feedback? In which one? Why?

If this touch screen had been installed in your car and you are able to turn off the haptic feedback will you do it?

4.6 Results

First of all, it must be stressed, that due to the lack of time no more than four participants could be part of the usability study. Thus, the collected data is really little and no information on performance could be found. Nonetheless, the collected data and the results will be shown here.

The participants in the study were one woman and three men, ranging from 32 to 35 years old. They get their driving license between 13 and 15 years ago. Two of them drive daily, another twice a month and the last one once a month. The two people who drive daily own a car, which brands are Toyota and Volvo. For the two that do not have their own car, there is one who is a member of a car pool.

There is some information that must be taken into consideration when looking at the data. Participant two, must be looked in a different way that any other in the study. It was highlighted during the product the little guessability that the device have in relation with the new way of interacting. But, this case go further more into that, the participants were teach in the new way of interacting with the device. Even though, the necessity of navigating was highlighted several times during the study the participant could not help himself clicking. The automatic way of interacting of the participant was difficult to change in a short period of time. That was stressed by the participant in the learnability questionnaire “I could not feel any haptic feedback”. For him, both blocks were the same.

Efficiency measurements

PERFORMANCE MEASURES

Here, the performance measures are detailed. They are presented in tables for every task and separated from participant and the kind of feedback received. For visual-haptic feedback (VH) and visual feedback (V).

Differences in Time must not be taken into consideration due to the effect provoked by the curves and cars coming in the other direction. When any of these facts occur, the driver waits to make the task.

Task 1: Go to one item in the main menu

Task 1	Participant 1		Participant 2		Participant 3		Participant 4	
	VH	V	VH	V	VH	V	VH	V
Time	12.37	2.50	1.58	4.40	3.97	3.65	2.62	4.39
Speed	68.83	76.94	81.91	81.25	74.28	83.24	85.86	91.15
Deviation of normative path	0.047	0.078	0.250	0.149	0.070	0.172	0.033	0.139

Table 4.2 Performance measures for task 1

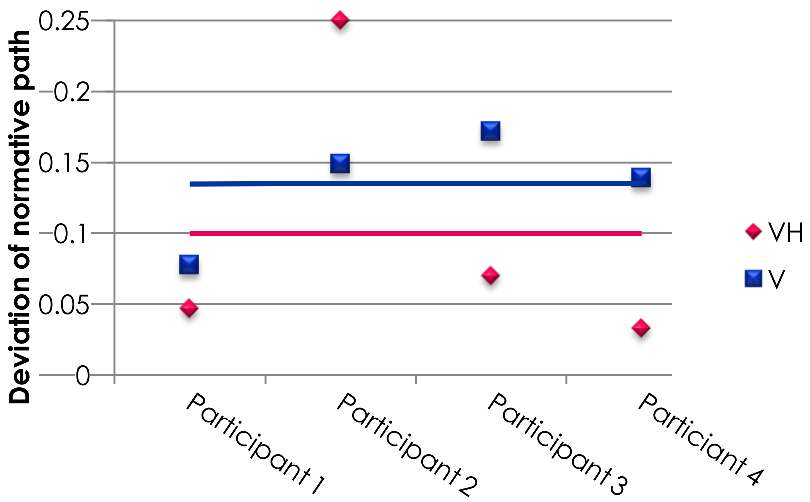


Figure 4.3 Deviation of normative path and media for task 1

For task one, the media of deviation of normative path for the visual-haptic feedback is lower than the ones for visual feedback. For the participant two the deviation of the normative path for visual-haptic feedback is higher than the one for visual feedback (figure 4.3).

Task 2: Go to the radio and turn the volume to a certain range

Task 2	Participant 1		Participant 2		Participant 3		Participant 4	
	VH	V	VH	V	VH	V	VH	V
Time	7.62	6.42	5.19	4.90	27.56	15.46	8.05	5.74
Speed	75.63	78.94	100.17	84.99	81.11	73.30	74.86	73.98
Deviation of normative path	0.067	0.217	0.404	0.084	0.375	0.211	0.148	0.284

Table 4.3 Performance measures for task 2

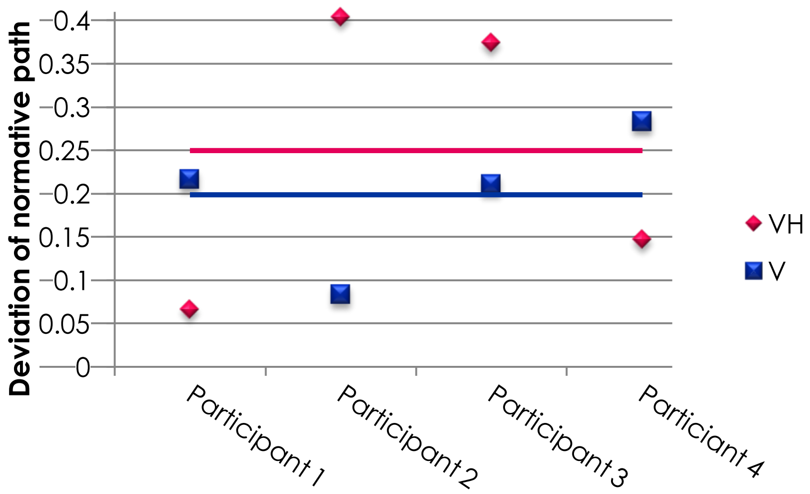


Figure 4.4 Deviation of the normative path and media for task 2

For task two, the media of the deviation of the normative path for the visual-haptic feedback is higher than the ones for visual feedback. From both, participant one and participant four, the deviation of the normative path is lower in the case with visual-haptic feedback (figure 4.4).

Task 3: Go to the radio and change the dial to a certain one

Task 3	Participant 1		Participant 2		Participant 3		Participant 4	
	VH	V	VH	V	VH	V	VH	V
Time	11.49	4.89	8.37	2.97	9.69	9.92	16.64	3.17
Speed	71.99	86.91	100.92	81.49	80.94	83.93	75.85	74.52
Deviation of normative path	0.301	0.150	0.344	0.308	0.245	0.350	0.232	0.191

Table 4.4 Performance measurements for task 3

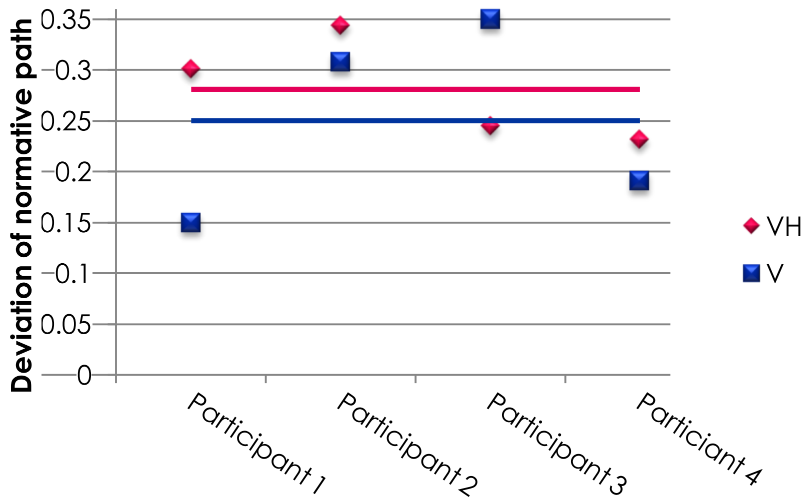


Figure 4.5 Deviation of the normative path and media for task 3

For task three, the media of the deviation of the normative path for the visual-haptic feedback is higher than the ones for visual feedback. From participant three, the deviation of the normative path is lower in the case with visual-haptic feedback (figure 4.5).

Task 4: Go to the e-mail and select one from a certain range

Task 4	Participant 1		Participant 2		Participant 3		Participant 4	
	VH	V	VH	V	VH	V	VH	V
Time	6.35	7.32	3.68	4.42	4.49	8.99	4.30	4.04
Speed	73.04	93.71	83.92	69.68	79.42	78.42	79.45	76.42
Deviation of normative path	0.336	0.376	0.441	0.195	0.101	0.168	0.063	0.170

Table 4.5 Performance measurement for task 4

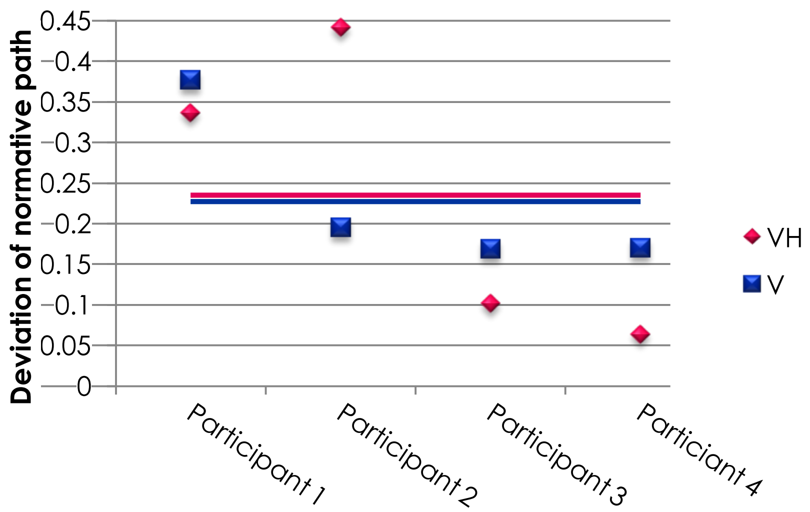


Figure 4.6 Deviation of the normative path and media for task 3

For task four, the media of the deviation of the normative path is nearly the same for the case with visual-haptic feedback and the one with visual feedback. But from participant one, three and four, the deviation of the normative path is lower in the case with visual-haptic feedback (figure 4.6).

Task 5: Go to the phone and call/video call a contact in the list

Task 5	Participant 1		Participant 2		Participant 3		Participant 4	
	VH	V	VH	V	VH	V	VH	V
Time	7.97	12.29	6.62	7.97	10.25	9.09	*	5.37
Speed	72.70	79.65	77.14	62.12	80.51	77.22	*	77.62
Deviation of normative path	0.077	0.150	0.474	0.333	0.201	0.114	*	0.126

Table 4.6 Performance measurements for task 5

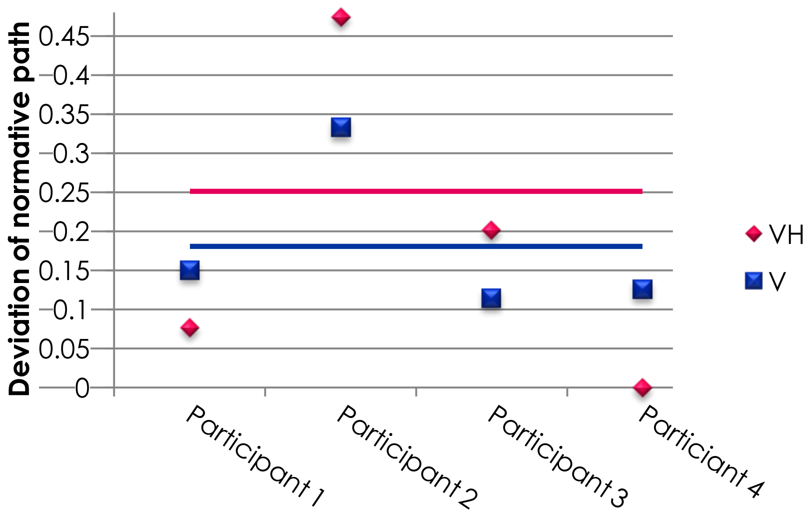


Figure 4.7 Deviation of the normative path and media for task 5

For task five, the media of the deviation of the normative path for the visual-haptic feedback is higher than the ones for visual feedback. From participant one, the deviation of the normative path is lower in the case with visual-haptic feedback (figure 4.4). Participant four is has not report deviation of normative path due to bad recollected data (table 4.6).

DALI

Results of DALI are displayed below (Table 4.7). The results are on percentage of workload, in first place for every aspect and finally the total.

Participant & type of test (VH/V)	Participant 1		Participant 2		Participant 3		Participant 4	
	VH	V	VH	V	VH	V	VH	V
Effort of Attention	5	4	16	11	5	4	5	4
Visual demand	20	17	16	14	21	21	14	20
Auditory demand	0	0	2	1	0	0	0	0
Tactile demand	8	1	2	5	4	3	3	0
Temporal demand	1	4	0	2	1	1	3	7
Interference	19	20	11	10	20	20	17	15
Situation stress	1	1	24	19	4	4	4	0
Percentage of workload	**54**	**47**	**71**	**62**	**55**	**53**	**46**	**46**

Table 4.7 Pondered data from DALI

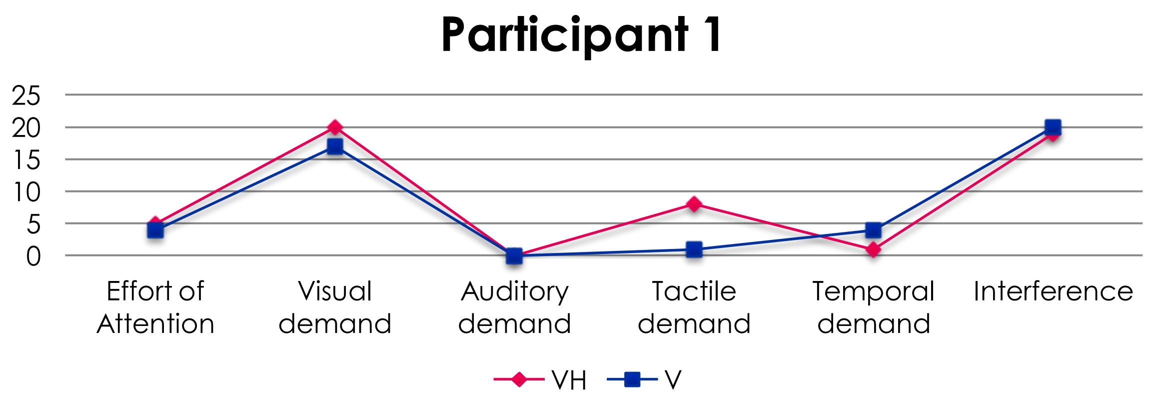


Figure 4.8 DALI pondered data of participant 1

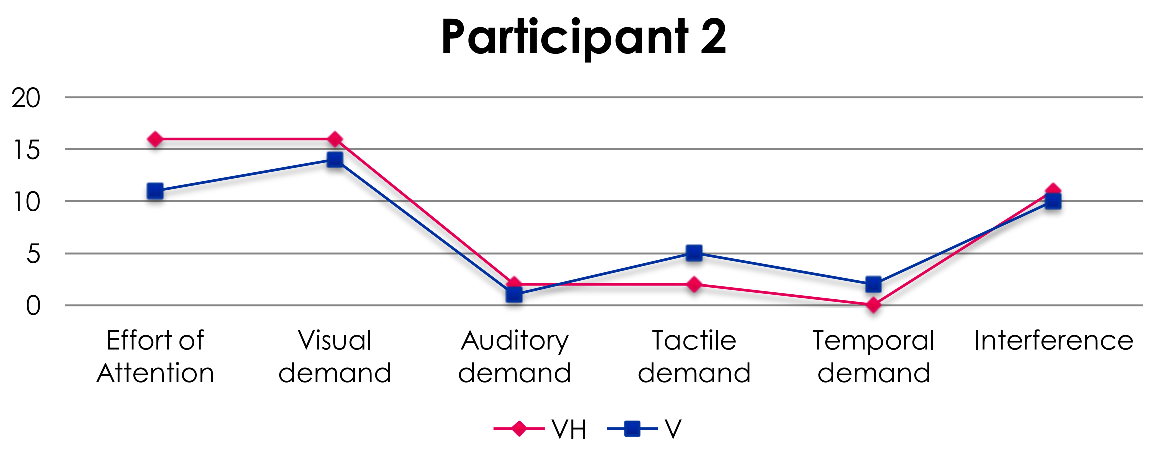


Figure 4.9 DALI pondered data of participant 2

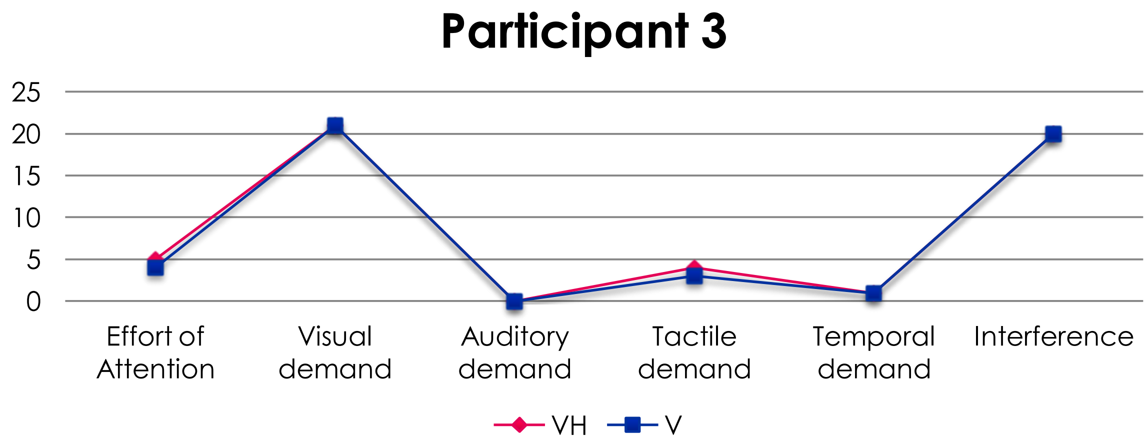


Figure 4.10 DALI pondered data of participant 3

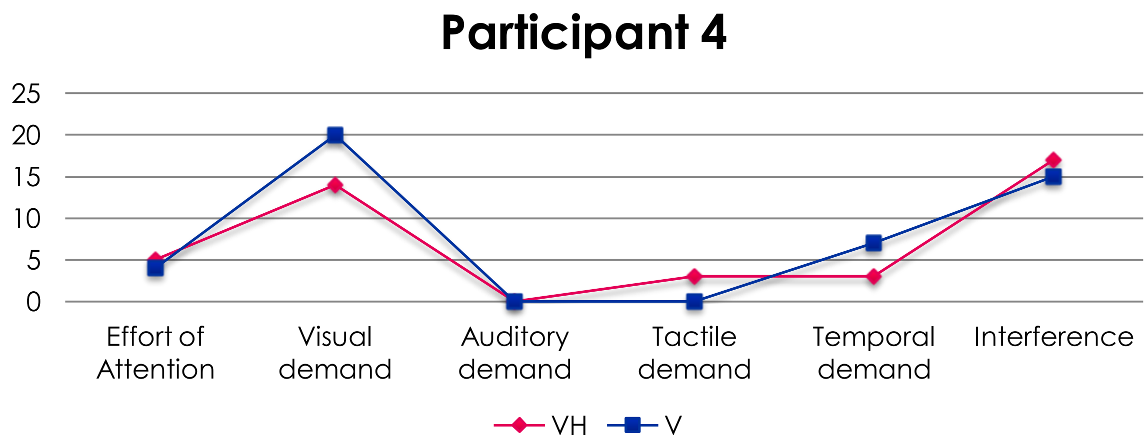


Figure 4.11 DALI pondered data of participant 4

It seems obvious that, in the case with visual-haptic feedback, the percentage of workload for tactile demand will be higher than in the case with visual feedback. But there is an exception for participant two. This can be due to what have been explained at the beginning of this section, for the second participant, both blocks were the same. The participant could not change the usual way of interacting with touch screens to the new way; navigation. Due to this fact DALI data for participant two will not be considered for further evaluations.

Contrary to what was initially believed the percentage of workload due to temporal demand decrease in the case with visual-haptic feedback. For two out of three participants workload visual demand increase for the case with visual-haptic feedback while for one decrease.

Further studies will be needed in order to extract significant information from that data.

Satisfaction measurements

SAM

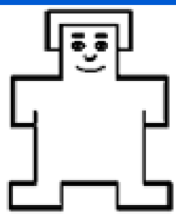
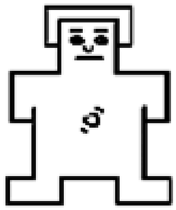
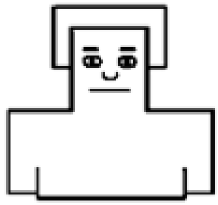
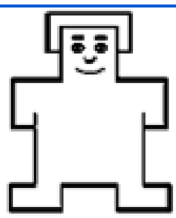
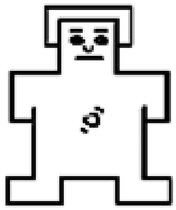
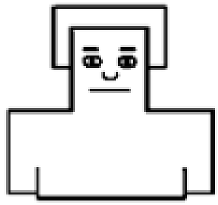
Participant 1	Happiness	Stimulation	Control
HV			
V			

Table 4.8 Selected manikins for HV and V feedback by participant 1

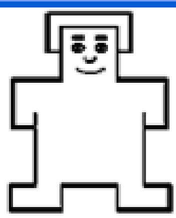
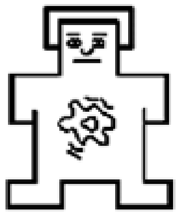
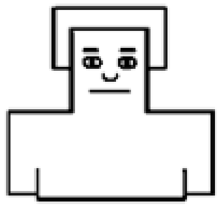
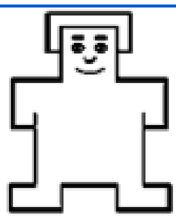
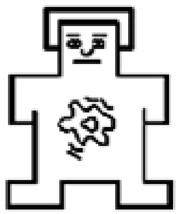
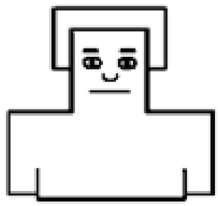
Participant 2	Happiness	Stimulation	Control
HV			
V			

Table 4.9 Selected manikins for HV and V feedback by participant 2

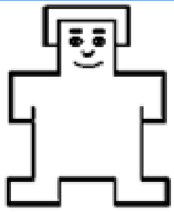
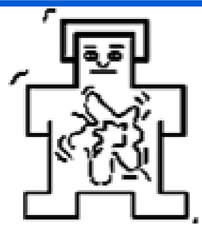
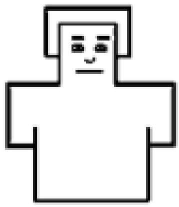
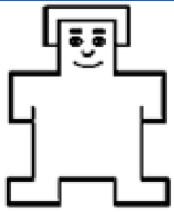
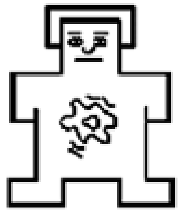
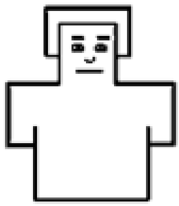
Participant 3	Happiness	Stimulation	Control
HV			
V			

Table 4.10 Selected manikins for HV and V feedback by participant 3

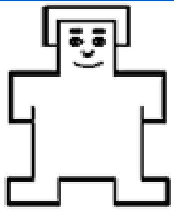
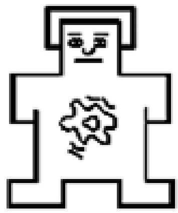
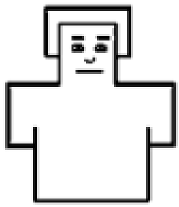
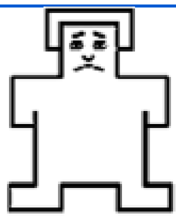
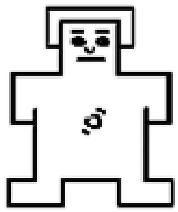
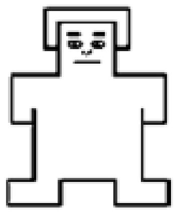
Participant 4	Happiness	Stimulation	Control
HV			
V			

Table 4.11 Selected manikins for HV and V feedback by participant 4

There is no major change between the two different feedback´s situation, but for the participant number four, table 4.11. The participant seems to have better feelings for the haptic-visual disposition than the visual.

QUESTIONNAIRE

The questionnaire designed is an open questionnaire. The reason is that, navigation haptic feedback is a new topic, and there is quite few information. It could be interesting to see a new point of view of the participants in the study that will bring new fresh information that could help into the introduction of new research branches. Due to this fact, there is no way of introduce the answers in an organized way. Hence, a question will be first introduced and the different answers, and so on.

After learning how it is used, will you say it is easy to know what is happening in the device without looking at them when the haptic feedback is turn on?

Two of the participants point out, they feel they need to know more the systems to be able to interact without looking at the screen. Also two regards the home screen is the easiest one to work without looking due to the little number of items. One of the participants says it is not easy to know what it is happening without looking. This participant is the one that did not manage to navigate along the screen, so the participant did not get any navigation feedback. That is why this participant point of view is not regarding navigation feedback and will not be considered as a test of it. But it will be considered regarding personal opinions.

Will you say that haptic feedback had helped you in this in the usage?

Taking into consideration that this question is regarding navigation haptic feedback, participant two answer will not be considered.

One participant out of three say it helped and another one say that it do not. The last one, points out that he feels quicker when he is not using the navigation in the screen. So, he thinks he is not helped.

In which task do you think haptic feedback has helped you most?

The three participants that use navigation feedback said that the home screen is the one where haptic feedback helped them the most. The one that did not navigate said is the volume selector level. The reason may be that even if the participant does not navigate the volume selector level navigation feedback can be felt.

Will you prefer in any task the option without haptic feedback? In which one? Why?

Half of the participants do not prefer any task without haptic feedback. The other half rather scroll without haptic feedback.

If this touch screen had been installed in your car and you are able to turn off the haptic feedback will you do it?

None of them say they will do it.

Other comments:

There are two participants who note that there were conditions where the navigation feedback is not useful due to the tightness of the items. Also, the same participants observe that there is a lack on other sense feedback. One of them mentioned that the use of a wider range on haptic feedback might be useful. Another one, that the haptic feedback is so low that ask so many attention from him. One special remark was that the radio dials shape is difficult to follow. Last, that some of them have problems using the volume bar. That might be caused by the small design of it.

5 Analysis of usability study

With the usability results and analysis some information may be extracted to answer the rest of the project questions. But, for some of them further studies or larger, in terms of participants, must be carried out to take some conclusions. Below, for each of the project questions an explanation is given.

5.1 Third Question: Which actions are helped by the introduction of haptic feedback?

To answer this question, the focus must be on navigation haptic feedback because is on that situation where haptic feedback must be perceived. There are three navigation haptic feedbacks, navigation through items, level selectors and scroll through list.

Navigation through items has been highlighted as the most useful haptic feedback in the device for the vast majority of the participants. Moreover, in the question "In which task do you think haptic feedback has helped you most?" of the questionnaire, three out of four have answered the main menu. Also, this can be reassured by the performance data. If the deviation of normative path is regarded, in the main menu, all the participant who navigate have lower deviation record when haptic feedback was turn on (figure 4.3). Menus with easy distinguishable items with navigation through items haptic feedback have been selected as the most helpful situation.

During the study, the participants interact with three levels of difficulty on feeling the different items. Meaning that, every new activity on navigation across items was more difficult to perceive. Items were closer and smaller. The third level was claimed to be really difficult, because the closeness between objects blur the comparative effect between lack of haptic feedback and haptic feedback. Some tips were given by the participants on that. There are two possible solutions, to be able to navigate throw close objects. The first one is to use different haptic feedback on navigation to be able to differentiate between items. This method is used on QWERTY keyboards. All the physicals keys have the same haptic feedback, but there are two that have an additional haptic cue, the F and the J. The cue is a little banner on the key and helps the user to distinguish the diverse letters. The other solution is to combine haptic feedback with another feedback, for example audible feedback. The user will know if he or she is inside of a button with the haptic feedback and audible feedback could say in which item he or she is.

The only **level selector** in the prototype was the volume selector. The participant who did not chose navigation the main menu as the most helpful task with haptic feedback, has regarded the volume as it. It was said that one of the reason why the participant two select this one is because there is no need to navigate to feel this haptic feedback. However, there are other navigation feedback that can be felt without changing the way to interact with the touch screen as scrolling list. Other participants point out in the questionnaire that is difficult to know if the volume selector is being moved. That is why the navigation feedback for the level selector is a interesting. Although, the performance data of the deviation from the normative path does not reassured this information. The reason for this result might be the design of the level selector that was small and some of them decide to have a look at the screen after some trials without succeed. It is really easy to glance at the screen to see where the selector is located but after that the automatic reaction is to move it while looking at the road. The haptic feedback is useful to know if the user actually moving the selector.

The only drawback in haptic feedback on the prototype was scrolling lists. Some of the participants did not find this haptic feedback useful. Two out of four participants preferred it without haptic feedback. This could be for two reasons; the action is not helped by the introduction of haptic or the haptic feedback is not suitable for the action. Further studies must be carried out in order to say which is the reason.

5.2 Fourth Question: Which is the best haptic experience for each interaction?

It is really necessary to give a look into that part. Maybe, with others haptic feedback the interaction will be more intuitive and the learnability time will decrease. Maybe, different haptic feedbacks have different reactions on the workload of the user. But all these are just conjectures, and need some data to be tested.

During the usability test it has been stress the lack of guessability and also the long learnability time of this kind of technology, the vast majority of it is due to the new way of interacting with the multifunctional device. This drawback cannot be solved, although once one individual learn how to interact it would be the same with all the devices, with some variations in the confirmation way. The next possible reason why learnability is so long is the use of haptic feedback. There are lots of standardized visual or audible feedbacks but there is no standardized haptic feedback. Some of the companies how create haptic feedback or how create the devices to create haptic feedback gives some tips on when to use them. The point is that none of them seem to take into consideration navigation haptic feedback if it is not for scrolling. This lack of standardization provoke that, even if a user remember what means a haptic feedback for a specific technology or device, he or she might not be able to use this knowledge for any other device, because no one is following any kind of rules to integrate haptic feedback in their devices

This means that, every time a user receive haptic feedback from a device, he or she has to be aware of which device is using and remember each haptic feedback on it. This seems pretty complicate when a user could be using several devices at the same time. Would not be easier to have the same haptic feedback for any devices or the same haptic feedback for the same kind of devices or at least the same haptic feedback for the same brand? But know it seems nobody is taking this into advice and for the same brand different models have different haptic feedback. The reason for that might be the quick ground in technology in the branch of haptic feedback in touch screen and also the huge competency to be the leader in innovation.

Regarding the fact that the introduction of haptic feedback for in-vehicle touch screen is done in order to make them more secure, some consideration must be taken on making standardized haptic feedback for in-car environment. Therefore, the appearance of new technologies must be regarded as some way of making this interaction more real but always following the standardized haptic feedback.

The short time to make the project combined to the amount of background recompilation work turns impossible to answer this question do to the poorness of the studies. More studies with different kinds of haptic feedback should be carried out in order to be able to give a strong answer for that.

5.3 Fifth Question: Which benefits does haptic feedback give to the driver?

Although this thesis main aim was to answer this question it will be impossible to do that due to the little quantity of data of the study. However a huge quantity of questions on that area could be formulated.

First, the simulation used in the usability study, takes place in a countryside road with light traffic. Some of the participants have regarded this as a non-dangerous situation, where you can look at the screen without causing any problem. But, what about a real traffic situation where your attention must be directed to the road?

Further studies might be placed in different traffic situations and see it the use of the navigation have some relation to this.

- Does haptic feedback for in-vehicle touch screens help on traffic situations?

Looking to the DALI results, two out of four participants did not improve their visual demand when there is haptic feedback in the device. Moreover, the global workload increase when the device have both haptic and visual feedback. Some of the participants note that the reason for this is the lack of knowledge of the device and the disposition of the items for each screen. So, there are some new questions.

- Do users make use of haptic feedback for in-vehicle touch screens after the learning time?
- Does haptic feedback for in-vehicle touch screens release visual workload?
- Does haptic feedback for in-vehicle touch screens release workload?

All these questions and the advices on every answered project question must be taken into consideration in next steps in this area.

6 Discussion

The discussion will be carried out in four sections depending on what it is discussed. These sections are research questions, the results, the method and future work.

Research questions

Regarding the project questions, it must be remarked that they were too comprehensive for this project. Especially with consideration to that the actual prototype were delayed and it also had to be programmed from scratch.

The method

As described in the introduction, the use of haptic cues by the drivers when interacting with physical controls was introduced by Annie Rydstöm in her PhD (Rydström, A. 2009). It was assumed that people will do the same when interacting with a touch screen device. But people are not used to make use of haptic cues when interacting with touch screen devices. That is perhaps one of the main reasons why time for learnability is longer than expected. The automatic reaction when interacting with a touchable device in an in-vehicle environment is to click on the screen. This is shown in a participant proceed; even if he had been asked to navigate, the automatic gesture was to click. Another participant pointed out the lack of haptic feedback in the trainee when the haptic feedback was enabled. The reason was that navigation was not performed. After the planned trainee, every participant is asked to use both programs, the one with haptic feedback and the one without, as much as they needed. It is then, when he asked for another trainee, to be able to perceive the haptic feedback on navigation. From the study, it was also obvious that the learning sessions could have been longer, because a longer time to learn the items and their layout in the screen is needed. Thus, some questions could be answered, for example, after a while will a user interact with the touch screen navigating or clicking? Or there will be some situations where the use of navigation interaction will be more suitable and others where click interaction will suit best?

The lack of audible feedback was remarked by the participants. It must be included in order to fulfil the thought of having a richer representation of the perception. It was not possible due to noise from the vibration, and therefore the use of headphones would become advisable.

The usability study was carried out in a relaxed environment with few cars and a country road. Some participants note that they were able to look at the device without putting themselves in a real danger. In another situation more attentive demanding they will not be able to take away the eyes from the road. Further studies might be placed in different traffic situations and see if the use of the navigation has some relation to this.

The results

One of the main relevant facts why it is important that the device has navigation feedback is to release visual overload. There is no sufficient data from the DALI questionnaire to accept or deny that the introduction of haptic feedback will release vision.

There were two design shapes to follow when the user navigates in the screen. Some of them are disposed in lines, like the volume of the e-mail, and some of them are in curves, like the radio stations. It was stressed by one of the participants the difficulty of following the curve make by the radio stations in comparison to the line of the volume. That was a fact that has been discussed before in this thesis, but no relevance was given to it. There is no way to confirm the fact that lines are easier to follow when navigating than any other curve since just one curve disposition was tried. A special usability study trying different dispositions will be necessary to make some statements.

Despite the long learnability and the novelty of the interaction, none of the participants will turn off the haptic feedback in their in-car device if the prototype was installed in their own car. This shown a trust on haptics that has to be seen as a motive to continue working on it.

Future work

Looking at the prototype there are some interacting issues to improve. During the introduction to the implemented prototype, a variety in the haptic feedback for the confirmation action in the case of keyboards keys has been mentioned. The confirmation feedback for keys was impossible to feel due to the usage of confirmation on release. When the user needs the confirmation his or her finger has already released the screen. Nonetheless, nowadays there is a new way to type in Samsung keyboards, this is called SWYPE. Writing with SWYPE enables a confirmation on release of the key button not the whole touch screen. So the confirmation feedback can be feet by the user. But a lot of more questions appear. When is necessary to produce the haptic feedback, for a word or for every letter? SWYPE compare the movements to the most probable word in the dictionary. Hence, for every movement the selected keys might differ. So, if the feedback is for every key would it be played in the correct order? It will be use in driving situations or just in a not driving situation?

7 Conclusion

Conclusions of this project are based on the project questionnaires. That is why the questions will be introduced again and answered.

First of all, the questions answered after the documentation and research will be answered. After, the ones answered with information from the usability study.

For question number one, *Which touch screen technology is best for an in-vehicle multifunctional device?,* the answer has been **multi capacitive touch screen**.

Regarding second question, *Which haptic feedback technology is the best one for in-vehicle touch screen?* The answer, without any doubt is **surface texture changing**, even though, it will take some time to have it in a car dashboard.

Starting with the questions answered after doing the usability study, there is the thirds question of the project. *Which actions are helped by the introduction of haptic feedback?* There were three tested actions, but just two of them seemed to help participants, those are **navigation through items** and **level selectors**.

The fourth question, *Which is the best haptic feedback experience for each interaction?* The truth is that due to the fact, that just one usability study was carried out, there is no answer for this question. But there is one fact that needs special mention, **standardized tactons for each actions** is needed.

Last, the big question, Which benefits does haptic feedback give to the driver? Another time, there is no answer for this question, just a lot of more questions. Does haptic feedback for in-vehicle touch screens help on traffic situations? Does haptic feedback for in-vehicle touch screens release visual workload? Does haptic feedback for in-vehicle touch screens release workload? Do users make use of haptic feedback for in-vehicle touch screens after the learning time?

The main conclusion of this project is that a lot must be done in this field, beginning by carrying studies to answer all the questions that have appeared during this project.

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Appendix I

UHL Effect Library List

ID	Name	Description
0	Sharp Single Click - High Power	Click Effect, Narrow Pulse, 100% Power
1	Sharp Single Click - Mid Power	Click Effect, Narrow Pulse, 66% Power
2	Sharp Single Click - Low Power	Click Effect, Narrow Pulse, 33% Power
3	Strong Single Click - High Power	Click Effect, Wide Pulse, 100% Power
4	Strong Single Click - Mid Power	Click Effect, Wide Pulse, 66% Power
5	Strong Single Click - Low Power	Click Effect, Wide Pulse, 33% Power
6	Bump Click - High Power	Bump Effect, Wide Rounded Pulse, 100% Power
7	Bump Click - Mid Power	Bump Effect, Wide Rounded Pulse, 66% Power
8	Bump Click - Low Power	Bump Effect, Wide Rounded Pulse, 33% Power
9	Bounce - High Power	Bounce Effect, Long Tapered Pulse, 100% Power
10	Bounce - Mid Power	Bounce Effect, Long Tapered Pulse, 66% Power
11	Bounce - Low Power	Bounce Effect, Long Tapered Pulse, 33% Power
12	Sharp Double Click - High Power	2 * Click Effect, Narrow Pulse, 100% Power
13	Sharp Double Click - Mid Power	2 * Click Effect, Narrow Pulse, 66% Power
14	Sharp Double Click - Low Power	2 * Click Effect, Narrow Pulse, 33% Power
15	Strong Double Click - High Power	2 * Click Effect, Wide Pulse, 100% Power
16	Strong Double Click - Mid Power	2 * Click Effect, Wide Pulse, 66% Power
17	Strong Double Click - Low Power	2 * Click Effect, Wide Pulse, 33% Power
18	Double Bump - High Power	2 * Bump Effect, Wide Rounded Pulse, 100% Power
19	Double Bump - Mid Power	2 * Bump Effect, Wide Rounded Pulse, 66% Power
20	Double Bump - Low Power	2 * Bump Effect, Wide Rounded Pulse, 33%

		Power
21	Triple Click - High Power	3 * Click Effect, Narrow Pulse, 100% Power
22	Triple Click - Mid Power	3 * Click Effect, Narrow Pulse, 66% Power
23	Triple Click - Low Power	3 * Click Effect, Narrow Pulse, 33% Power
24	Tick - High Power	Tick Effect, Short Single Pulse, 100% Power
25	Tick - Mid Power	Tick Effect, Short Single Pulse, 66% Power
26	Tick - Low Power	Tick Effect, Short Single Pulse, 33% Power
27	Long Buzz - High Power	Long 1000ms Buzz Effect, 100% Power
28	Long Buzz - Mid Power	Long 1000ms Effect, 66% Power
29	Long Buzz - Low Power	Long 1000ms Effect, 33% Power
30	Short Buzz - High Power	Short 250ms Buzz Effect, 100% Power
31	Short Buzz - Mid Power	Short 250ms Buzz Effect, 66% Power
32	Short Buzz - Low Power	Short 250ms Buzz Effect, 33% Power
33	Long Ramp Up - High Power	Long Transition Ramp Up Effect, 100% Power
43	Long Ramp Up - Mid Power	Long Transition Ramp Up Effect, 66% Power
35	Long Ramp Up - Low Power	Long Transition Ramp Up Effect, 33% Power
36	Short Ramp Up - High Power	Short Transition Ramp Up Effect, 100% Power
37	Short Ramp Up - Mid Power	Short Transition Ramp Up Effect, 66% Power
38	Short Ramp Up - High Power	Short Transition Ramp Up Effect, 33% Power
39	Long Ramp Down - High Power	Long Transition Ramp Down Effect, 100% Power
40	Long Ramp Down - Mid Power	Long Transition Ramp Down Effect, 66% Power
41	Long Ramp Down - Low Power	Long Transition Ramp Down Effect, 33% Power
42	Short Ramp Down - Low Power	Short Transition Ramp Down Effect, 100% Power
43	Short Ramp Down - Mid Power	Short Transition Ramp Down Effect, 66% Power
44	Short Ramp Down - High Power	Short Transition Ramp Down Effect, 33% Power
45	Fast Pulse - High Power	Single 200ms Ramp Up/Down Pulse, 100% Power
46	Fast Pulse - Mid Power	Single 200ms Ramp Up/Down Pulse, 66% Power

47	Fast Pulse - Low Power	Single 200ms Ramp Up/Down Pulse, 33% Power
48	Fast Pulsing - High Power	5 * 200ms Ramp Up/Down Pulse, 100% Power
49	Fast Pulsing - Mid Power	5 * 200ms Ramp Up/Down Pulse, 66% Power
50	Fast Pulsing - Low Power	5 * 200ms Ramp Up/Down Pulse, 33% Power
51	Slow Pulse - High Power	Single 500ms Ramp Up/Down Pulse, 100% Power
52	Slow Pulse - Mid Power	Single 500ms Ramp Up/Down Pulse, 66% Power
53	Slow Pulse - Low Power	Single 500ms Ramp Up/Down Pulse, 33% Power
54	Slow Pulsing - High Power	3 * 500ms Ramp Up/Down Pulse, 100% Power
55	Slow Pulsing - Mid Power	3 * 500ms Ramp Up/Down Pulse, 66% Power
56	Slow Pulsing - Low Power	3 * 500ms Ramp Up/Down Pulse, 33% Power
57	Buzz with Bump - High Power	Buzz Transition Effect with Bump Click Ending Effect, 100% Power
58	Buzz with Bump - Mid Power	Buzz Transition Effect with Bump Click Ending Effect, 66% Power
59	Buzz with Bump - Low Power	Buzz Transition Effect with Bump Click Ending Effect, 33% Power
60	Buzz with Bounce - High Power	Buzz Transition Effect with Bounce Ending Effect, 100% Power
61	Buzz with Bounce - Mid Power	Buzz Transition Effect with Bounce Ending Effect, 66% Power
62	Buzz with Bounce - Low Power	Buzz Transition Effect with Bounce Ending Effect, 33% Power
63	Alert 1 - High Power	Alert Pattern 1, Repeated Short Buzz
64	Alert 2 - High Power	Alert Pattern 2, Repeated Fast and Slow Pulses
65	Alert 3 - High Power	Alert Pattern 3, Repeated Bumps and Ramp Up Effects
66	Alert 4 - High Power	Alert Pattern 4, Repeated Long Ramp Up and Down Effects
67	Alert 5 - High Power	Alert Pattern 5, Repeated Strong Click Effects
68	Alert 6 - High Power	Alert Pattern 6, Repeated Click, Bump and Bounce Effects
69	Alert 7 – Low, Mid and High Power	Alert Pattern 7, Repeated Short Buzz at Low, Mid and High Power Settings
70	Alert 8 - High Power	Alert Pattern 8, Repeated Short and Long Ramp Up Effects

71	Alert 9 - High Power	Alert Pattern 9, Repeated Click and Bump Effects
72	Alert 10 - High Power	Alert Pattern 10, Repeated Long Ramp Up with Sharp Click Effects
73	Explosion 1 - High power	Game Explosion Effect, 600ms, Mid Duration
74	Explosion 2 - High power	Game Explosion Effect, 300ms, Short Duration
75	Explosion 3 - High power	Game Explosion Effect, 600ms, Mid Duration
76	Explosion 4 - High power	Game Explosion Effect, 1200ms, Long Duration
77	Explosion 5 - Mid power	Game Explosion Effect, 240ms, Short Duration
78	Explosion 6 - Mid power	Game Explosion Effect, 220ms, Short Duration
79	Explosion 7 - High power	Game Explosion Effect, 1250ms, Long Duration
80	Explosion 8 - Mid power	Game Explosion Effect, 440ms, Mid Duration
81	Explosion 9 - High power	Game Explosion Effect, 915ms, Long Duration
82	Explosion 10 - Mid power	Game Explosion Effect, 450ms, Mid Duration
83	Weapon 1 - High Power	Infinite Repeating Strong Click – Machine Gun
84	Weapon 2 - High Power	Infinite Repeating Bounce Effect – Machine Gun
85	Weapon 3 - High Power	Infinite Repeating Strong Bounce Effect – Machine Gun
86	Weapon 4 - High Power	Single Short Buzz Effect – Single Shot Weapon
87	Weapon 5 - High Power	Single Short Bounce Effect – Single Shot Weapon
88	Weapon 6 - High Power	Single Wide Pulse Effect – Single Shot Weapon
89	Weapon 7 - High Power	Repeated Pulse Effect with Long Ramp Down – Charging Weapon with Strong Single Shot
90	Weapon 8 - High Power	Repeated Pulse Effects with Bumps and Strong Buzz – Charging Weapon with Strong Single Shot
91	Weapon 9 - High Power	Long Ramp Pulse Effect with Strong Buzz and Long Ramp Down – Charging Weapon with Strong Single Shot
92	Weapon 10 - High Power	Increasing Short Pulse Effects with Strong Buzz and Long Ramp Down – Charging Weapon with Strong Single Shot
93	Impact Wood – High Power	Low Frequency Pulse Effect, 100% Power

94	Impact Wood – Mid Power	Low Frequency Pulse Effect, 66% Power
95	Impact Wood – Low Power	Low Frequency Pulse Effect, 33% Power
96	Impact Metal – High Power	Low Frequency Pulse Effect, 100% Power
97	Impact Metal – Mid Power	High Frequency Pulse Effect, 66% Power
98	Impact Metal – Low Power	High Frequency Pulse Effect, 33% Power
99	Impact Rubber – High Power	Low Frequency, Ramping Down Pulse Effect, 100% Power
100	Impact Rubber – Mid Power	Low Frequency, Ramping Down Pulse Effect, 66% Power
101	Impact Rubber – Low Power	Low Frequency, Ramping Down Pulse Effect, 33% Power
102	Texture 1 – Low Power	Infinite Repeating 67Hz, 33% Power
103	Texture 2 – Low Power	Infinite Repeating 83Hz, 33% Power
104	Texture 3 – Low Power	Infinite Repeating 100Hz, 33% Power
105	Texture 4 – Low Power	Infinite Repeating 111Hz, 33% Power
106	Texture 5 – Low Power	Infinite Repeating 125Hz, 33% Power
107	Texture 6 – Low Power	Infinite Repeating 143Hz, 33% Power
108	Texture 7 – Low Power	Infinite Repeating 166Hz, 33% Power
109	Texture 8 – Low Power	Infinite Repeating 200Hz, 33% Power
110	Texture 9 – Low Power	Infinite Repeating 250Hz, 33% Power
111	Texture 10 – Low Power	Infinite Repeating 333Hz, 33% Power
112	Engine 1 – High Power	Infinite Repeating, 250Hz, 100% Power
113	Engine 1 – Mid Power	Infinite Repeating, 250Hz, 66% Power
114	Engine 1 – Low Power	Infinite Repeating, 250Hz, 33% Power
115	Engine 2 – High Power	Infinite Repeating, 200Hz, 100% Power
116	Engine 2 – Mid Power	Infinite Repeating, 200Hz, 66% Power
117	Engine 2 – Low Power	Infinite Repeating, 200Hz, 33% Power
118	Engine 3 – High Power	Infinite Repeating, 143Hz, 100% Power
119	Engine 3 – Mid Power	Infinite Repeating, 143Hz, 66% Power
120	Engine 3 – Low Power	Infinite Repeating, 143Hz, 33% Power
121	Engine 4 – High Power	Infinite Repeating, 100Hz, 100% Power

122	Engine 4 – Mid Power	Infinite Repeating, 100Hz, 66% Power
123	Engine 4 – Low Power	Infinite Repeating, 100Hz, 33% Power

Anex II

Participant Characteristic's Form

Name: ....

Sex: Man ☐ Female ☐

Age: ....

How much time do you have of driving license?

....

How often do you drive a car?

....

Do you own a car? Yes ☐ No ☐

If you have answer yes in the last question:

Which brand is your car?

....

Which model is your car?

....

Trainee Data Sheet

First trainee: with haptic feedback ☐ without haptic feedback ☐

ACTIVITIES:

1. Go to .... Speed..
   Time to succeed........................... Deviation...
2. Turn the volume .... Speed..
   Time to succeed........................... Deviation...
3. Change to dial .... Speed..
   Time to succeed........................... Deviation...
4. Go to the............................. of the email
   Speed........................... Deviation...
   Time to succeed...........................
5. .... to ....
   Speed........................... Deviation...
   Time to succeed...........................

Second trainee: with haptic feedback ☐ without haptic feedback ☐

ACTIVITIES:

1. Go to .... Speed..
   Time to succeed........................... Deviation...
2. Turn the volume .... Speed..
   Time to succeed........................... Deviation...
3. Change to dial .... Speed..
   Time to succeed........................... Deviation...
4. Go to the............................. of the email
   Speed........................... Deviation...
   Time to succeed...........................
5. .... to ....
   Speed........................... Deviation...
   Time to succeed...........................

Interview on Learnability

First test: with haptic feedback ☐ without haptic feedback ☐

ACTIVITIES:

1. Go to ....
   Efficiency:
   - Time on task ....
   - Isometrics number of glances.............................
   - Glances duration..
   - Deviation of a normative path............................
   - Speed...
2. Turn the volume ....
   Efficiency:
   - Time on task ....
   - Isometrics number of glances.............................
   - Glances duration..
   - Deviation of a normative path............................
   - Speed...
3. Change to dial ....
   Efficiency:
   - Time on task ....
   - Isometrics number of glances.............................
   - Glances duration..
   - Deviation of a normative path............................
   - Speed...
4. Go to the............................ of the email
   Efficiency:
   - Time on task ....
   - Isometrics number of glances.............................
   - Glances duration..
   - Deviation of a normative path............................
   - Speed...

5. ……………………. to ………………………………

Efficiency:

- Time on task ……………………………………………...
- Isometrics number of glances………………………..
- Glances duration……………………………………...
- Deviation of a normative path……………………….
- Speed................................……………………………

GLOBAL

Efficiency:

- DALI

Satisfaction:

- SAM

Second test: with haptic feedback ☐ without haptic feedback ☐

1. Go to …………………………………

Efficiency:

- Time on task ……………………………………………...
- Isometrics number of glances………………………..
- Glances duration……………………………………...
- Deviation of a normative path……………………….
- Speed................................……………………………

2. Turn the volume …………………….

Efficiency:

- Time on task ……………………………………………...
- Isometrics number of glances………………………..
- Glances duration……………………………………...
- Deviation of a normative path……………………….
- Speed................................……………………………

3. Change to dial ………………………

Efficiency:

- Time on task ……………………………………………...
- Isometrics number of glances………………………….
- Glances duration………………………………………..
- Deviation of a normative path……………………….
- Speed..................................…………………………

4. Go to the……………………….. of the email

   Efficiency:

   - Time on task ……………………………………………...
   - Isometrics number of glances………………………….
   - Glances duration………………………………………..
   - Deviation of a normative path……………………….
   - Speed..................................…………………………

5. …………………….. to ……………………………….

   Efficiency:

   - Time on task ……………………………………………...
   - Isometrics number of glances………………………….
   - Glances duration………………………………………..
   - Deviation of a normative path……………………….
   - Speed..................................…………………………

GLOBAL

Efficiency:

- DALI

Satisfaction:

- SAM

Questions:

After learning how it is used, will you say it is easy to know what is happening in the device without looking at them when the haptic feedback is turn on?

Will you say, haptic feedback had helped you in this in the usage?

In which task do you think haptic feedback has helped you most?

Will you prefer in any task the option without haptic feedback? In which one? Why?

If this touch screen had been installed in your car and you are able to turn off the haptic feedback will you do it?

Other comments:

DALI Questionnaire

Instructions:

Throughout this experiment the rating scales are used to assess your experiences in the different task conditions. Scales of this sort are extremely useful, but their utility suffers from the tendency people have to interpret them in individual ways. For example, some people feel that mental or temporal demands are the essential aspects of workload regardless of the effort they expended on a given task or the level of performance they achieved. Others feel that if they performed well the workload must have been low and if they performed badly it must have been high. Yet others feel that effort or feelings of frustration are the most important factors in workload; and so on. The results of previous studies have already found every conceivable pattern of values. In addition, the factors that create levels of workload differ depending on the task. For example, some tasks might be difficult because they must be completed very quickly. Others may seem easy or hard because of the intensity of mental or physical effort required. Yet others feel difficult because they cannot be performed well, no matter how much effort is expended.

The evaluation you are about to perform is adapted by a technique that has been developed by NASA to assess the relative importance of six factors in determining how much workload you experienced. The procedure is simple: You will be presented with a series of pairs of rating scale titles (for example, Effort vs. Mental Demands) and asked to choose which of the items was more important to your experience of workload in the task(s) that you just performed. Each pair of scale titles will appear on a separate card.

Circle the Scale Title that represents the more important contributor to workload for the specific task(s) you performed in this experiment.

After you have finished the entire series we will be able to use the pattern of your choices to create a weighted combination of the ratings from that task into a summary workload score. Please consider your choices carefully and make them consistent with how you used the rating scales during the particular task you were asked to evaluate. Don't think that there is any correct pattern: we are only interested in your opinions.

If you have any questions, please ask them now. Otherwise, start whenever you are ready. Thank you for your participation.

Rating scale definition:

Title	Endpoints	Description
Effort of Attention	Low/high	To evaluate the attention required by the activity –to think about, to decide, to choose, to look for…
Visual demand	Low/high	To evaluate the visual demand necessary for the activity
Auditory demand	Low/high	To evaluate the auditory demand necessary for the activity
Tactile demand	Low/high	To evaluate the specific constrain due to the tactile stimulation during the driving activity
Temporal demand	Low/high	To evaluate the specific constrain due to timing demand during the driving activity
Interference	Low/high	To evaluate the possible disturbance between the driving activity and any other supplementary task such as phoning, using systems or radio.
Situation stress	Low/high	To evaluate the level of constrains/stress during the driving activity such as fatigue, insecure feeling, irritation, discouragement…

Effort of attention
or
Visual demand

Effort of attention
or
Audio demand

Effort of attention
or
Tactile demand

Effort of attention
or
Temporal

Effort of attention
or
Interference

Effort of attention
or
Situation stress

Visual demand
or
Auditory demand

Visual demand
or
Tactile demand

Visual demand

or

Temporal

Visual demand

or

Interference

Visual demand

or

Situation stress

Auditory demand

or

Tactile demand

Auditory demand

or

Temporal

Auditory demand

or

Interference

Auditory demand

or

Situation stress

Tactile demand

or

Temporal

Tactile demand

or

Interference

Tactile demand

or

Situation stress

Temporal demand

or

Interference

Temporal demand

or

Situation stress

Interference

or

Situation stress

Rating sheet:

EFFORT OF ATTENTION

LOW HIGH

VISUAL DEMAND

LOW HIGH

AUDITORY DEMAND

LOW HIGH

TACTILE DEMAND

LOW HIGH

TEMPORAL DEMAND

LOW HIGH

INTERFERENCE

LOW HIGH

SITUATION STRESS

LOW HIGH

Weighted rating:

Study: ....   Trial #: ....

Study Date: ....   Participant #: ....

Haptic feedback enabled: Yes ☐   No ☐

Source of workload tally and weighted rating worksheet				
Scale	**Tally**	**Weight**	**Raw Rating**	**Adjusted Rating (Weight x Raw)**
Effort of attention				
Visual demand				
Auditory demand				
Tactile demand				
Temporal demand				
Interference				
Situation stress				

Sum "Adjusted Rating" column =

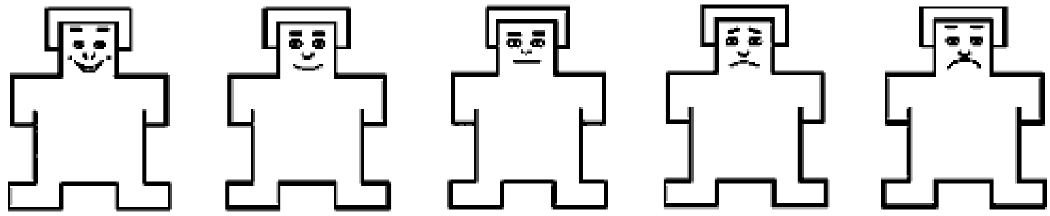
WEIGHTED RATING =

SAM Questionnaire

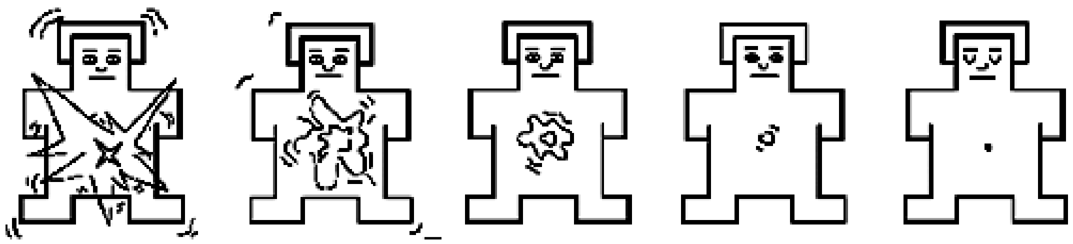
SAM Instructions

This is SAM. It represents your emotions towards the experience you had. Here are some instructions about using SAM:

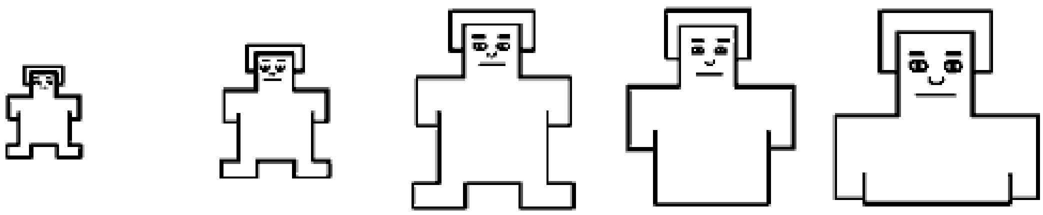
1. Do not rate the item/experience. Rate your **emotions**.
2. SAM has three rows of pictures.



This row ranges from a **very big smile** to a **very big frown**. It represents emotions ranging from **completely happy** to **completely sad.**



This row represents emotions ranging from **very stimulated** to **very bored and dull.**



This row represents how much **in control** you feel starting from **being controlled or cared for** on the left to **being in control or dominant** on the right. This row does not represent positive or negative feelings but only how much in control you feel.

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