Designing Multimodal Stimuli for Driving Events

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Preface

This is the master's thesis of Mattias Mannegren and it has been completed as a part of a master's programme in Industrial Design Engineering. It has been carried out at the division of Design and Human Factors at the department of Product and Production Development at Chalmers University of Technology in Gothenburg, Sweden. The master's thesis has been part of national driver interaction research project EFESOS and was initiated by Semcon who is one of the partners in this project, and that is also where the project has been conducted. The master's thesis was running from August 2011 to January 2012.

I would like to thank my tutor at Semcon, Jonas Svensson, for his deep involvement in the project and continuously giving valuable feedback to improve my work. I would also like to thank my examiner and tutor at Chalmers, Anna-Lisa Osvalder and Lars-Ola Bligård, for their support.

Further, I also want to thank the many employees of Semcon and Volvo Car Corporation who provided valuable input both before the project and during my user evaluations.

Abstract

The amount of visual information necessary for a car driver to maneuver a car safely is substantial. The rapid development of wireless communications, location-based services, safety systems and other in-car technology systems is bound to drastically increase information available to the driver within the near future. This poses a huge problem relevant to car interaction aspects as well as car safety aspects. While the driver's visual sense is usually overloaded, the auditory and tactile senses are only taken advantage of occasionally. Many studies point to the conclusion that different types of auditory and tactile stimuli would be well suited as communication channels between car systems and the driver.

This thesis project focused on investigating how to design audio-tactile stimuli for this purpose. The approach was to adjust and apply user-centered iterative product design methodology, both structured aspects such as constantly evaluating concepts against requirements, but also creative aspects, such as sketching. A case study was performed using the adjusted methodology, designing audio-tactile stimuli concepts for four different driving events. The case study identified some improvements that could be made to the initially proposed methodology, and its results suggested that there is potential in using a user-centered design methodology for audio-tactile design.

Contents

Glossary

Auditory	Experienced through hearing
Audio-tactile	Combined auditory and tactile stimuli
Infotainment	Hardware installed into cars to provide auditory and/or visual entertainment
Modality	One of the main avenues of sensation (for example vision)
Multimodal	Involving several different modalities
Tactile	Related to the sense of touch

1. Introduction

1.1 Background

The situation of a car driver is in many ways highly critical. The potential consequences in case of a mistake are unquestionably very serious, 1.2 million people die and 20-50 million people are injured worldwide each year as a result from road crashes (Peden et al, 2004). To operate the car properly, the driver must process a huge amount of information from a multitude of different sources: dashboard instrument readings, speed, direction and position of other vehicles in the direct vicinity, state of traffic lights, directions from signs, location and direction of pedestrians, etc. All these tasks are time critical and must normally be carried out at a pace and at a time that cannot be affected by the driver. The vast majority of these required tasks are mainly visual, which combined put a very heavy load on the driver's visual sense, as is supported by MacAdams (2003) and several other studies. Figure 1 displays a system model describing the flow of information received by a car driver in a traditional car.

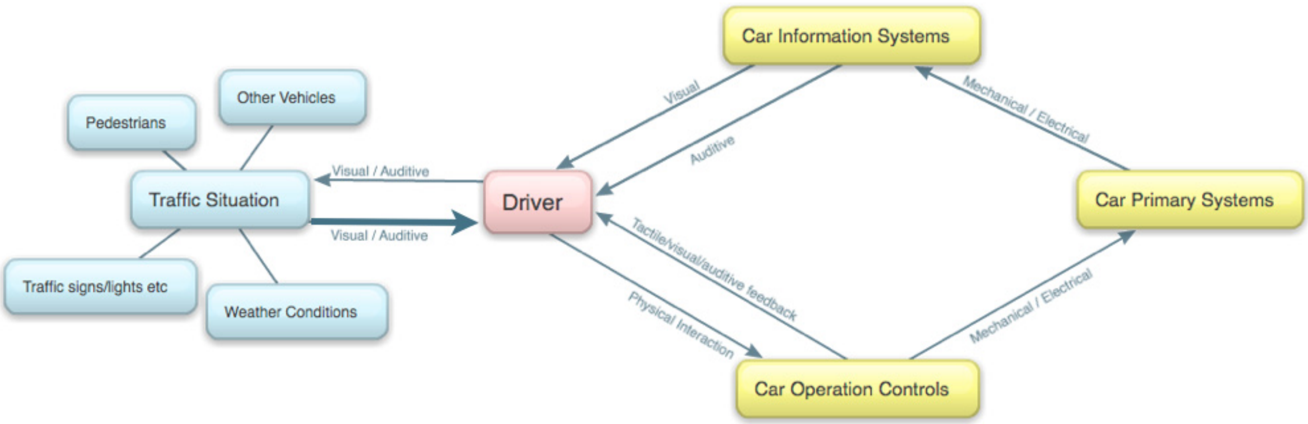

Figure 1. System model describing the flow of information within the system made up by the driver, the car and the traffic situation. The car is for clarity divided into car operation controls (steering wheel, pedals, etc), car primary systems (engine, brakes, etc) and car information systems (speedometer, information lights, displays, etc).

In addition to this, car navigation systems are well on their way to becoming standard equipment in newer cars in the western world. There is good reason to believe that they - and other forms of information technology - will within a few years be as expected in a car as a stereo is today. Today's car information systems depend heavily on the user's visual sense, which as stated above, already has a substantial workload. This increase in information technology is likely to add further to the already high visual load (see figure 2 for a system model for this scenario). Managing the infotainment system is a secondary visual task, but performing it while driving risks compromising the level of performance of the driver's primary visual task, the traffic situation. Several independent studies point out driver inattention as the major contributing factor to both crashes, (in 78% of the cases) and near crashes (in 65% of the cases) (Engström, 2011) which clearly makes this increasing amount of driver information a cause for concern.

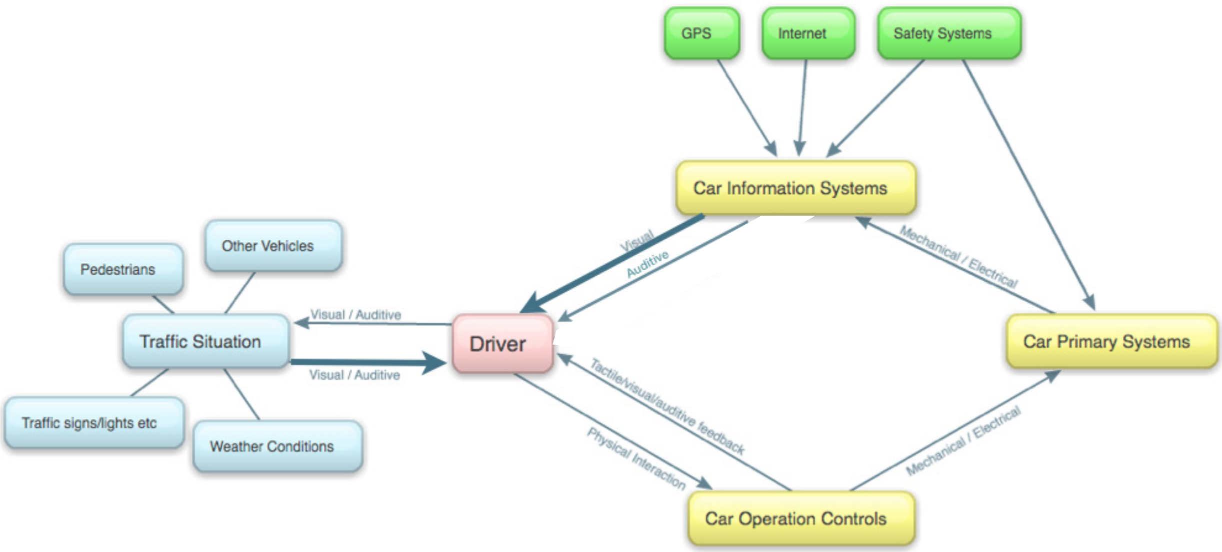

Figure 2. This is the same type of system model as figure 1, but for a modern/future car with more advanced technical functionality (represented by the green boxes on the top). The result being an increased visual load for the driver, symbolized here by a thicker arrow from the car information systems towards the driver.

The circumstances described clearly and urgently call for a way to ease the load on the driver's visual sense. According to Multiple Resource Theory (MRT) introduced by Wickens (2002), time-sharing (simultaneously performing) tasks carried out in separate modalities – for example one visual task and one auditory task – will affect performance less negatively than time-sharing two tasks carried out in the same modality. (visualized in figure 3). Thus, the driver's other senses than the visual sense has been subject to studies regarding whether or not they are suitable to use as channels of communication between the car and the driver. The two practically most promising being auditory (related to the sense of hearing) and tactile (related to the sense of touch) stimuli.

Studies have shown that modulating physical parameters of stimuli can affect the user's perception of its meaning. This is valid for audio-tactile stimuli (Chang & O'Sullivan, 2008) as well as auditory stimuli (Edworthy et al, 1995). For example the level of attention-drawing and urgency can be adjusted through modifying the envelope and pitch of stimuli, respectively. It has also been shown that tactile stimuli are easier to localize than auditory stimuli and thus suitable for communicating spatial information related to navigation or directing attention (Ho et al, 2005, Elliot et al, 2007). Another useful property of audio-tactile stimuli that has been shown is that it has significantly lower response times (to braking or accelerating in a critical situation when a car is rapidly approaching from the front or behind) compared to solely using auditory or tactile signals (Ho et al, 2007). Tactile stimuli do give a significantly lower mental effort rating when used for in-car navigation compared to visual stimuli which adds to the reasons that make it suitable. It also seems to have a low response time even under increased cognitive load (van Erp & van Veen, 2004). The possibility to direct information only to the driver is another advantage, unlike visual or auditory stimuli which usually are communicated to everyone in the car at the same time.

It is also known that stimuli in one modality can increase the perception of another, creating multimodal synergies. A simple example of this is when you are having a conversation in a very crowded, noisy room. If you look at the person speaking and can see his or her lips, you usually have no problem understanding what the person is saying, but if you cannot see the person's lips, it suddenly becomes much harder to hear what the person is saying, although the auditory stimuli is the same, the only thing that has changed is the visual stimuli.

In conclusion, there is an urgent and increasing need to decrease the visual load of car drivers. There are also several facts and findings that support audio-tactile as a suitable method to do this. Most studies however only focus on testing whether or not a certain type of stimuli or stimuli parameter is suitable for communicating certain types of information. Very little research or none at all has been done regarding *how* these audio-tactile stimuli should be designed and developed to ensure the desired functionality. A methodology or design framework for this type of work is clearly missing, and this thesis aims to provide a first step toward this.

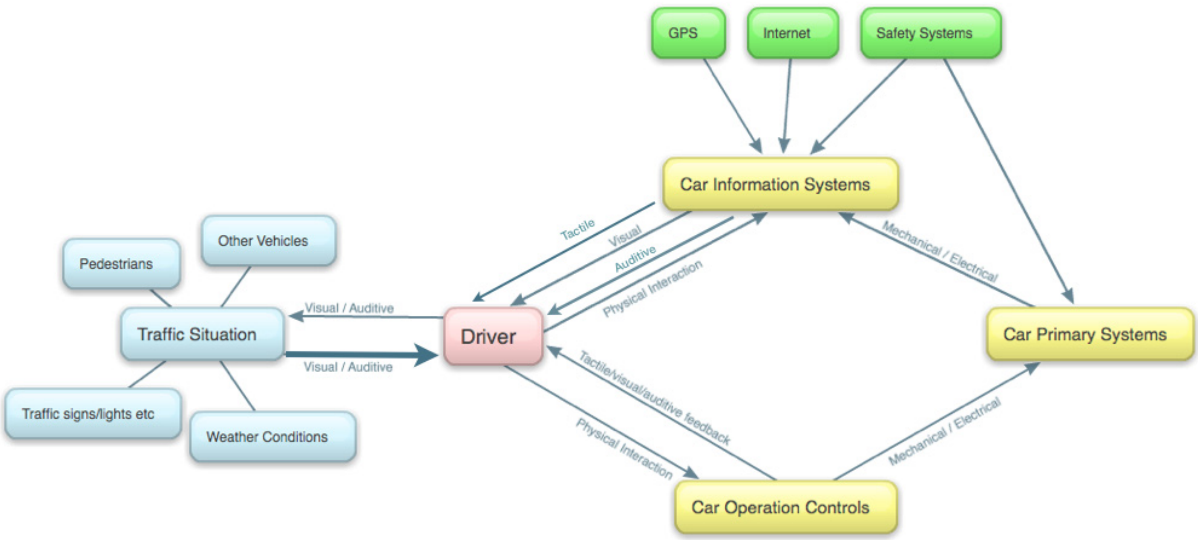

Figure 3. A system model describing how the visual load from the car information systems is lowered through the use of audio-tactile stimuli.

1.2 Purpose

The purpose of this thesis is to develop and evaluate a systematic user-focused methodology for designing audio-tactile stimuli for driving events.

1.3 Goal

The goal of this thesis is to gain an understanding for how and if product design methodology can be applied successfully to the design of audio-tactile stimuli. If this approach is deemed to have potential, it is also part of the goal to provide guidelines for how to use it in an optimal way, based on experiences from the case study.

1.4 Research Questions

To fulfill the purpose and reach the goal, the following questions need to be answered:

- How can user-centered product design methodology be applied successfully to the design of audio-tactile stimuli?
- How can audio-tactile stimuli best be used to communicate information about driving events to a car driver?

1.5 Limitations

All user evaluations in this thesis will be carried out using headphones to deliver the auditory stimuli to the participant. Any differences resulting from this compared to delivering auditory stimuli through stereo speakers in a real car will not be evaluated or considered.

Regarding the design of tactile stimuli, this thesis will only consider the types of tactile stimuli that are technically possible to communicate through the available hardware.

This thesis is focusing on a process to design audio-tactile stimuli concept for the large masses of people. Thus deaf people are not the focus here and specific needs only related to deafness are not considered.

Auditory stimuli considered in this thesis do not include any type of speaker voice signals, but are limited to non-speech signals.

2. Overall Thesis Approach

This chapter explains the overall approach used in this thesis project.

2.1 Overall Thesis Approach Outline

- Literature study
- Development of an Audio-Tactile Design Framework
- Familiarization with audio-tactile sketching
- Adaptation of product design methodology to audio-tactile design
- Case study
- Adjustments of proposed methodology based on case study

2.2 Literature Study

Initially a literature study was performed to analyze performed research in relevant areas such as interaction research regarding auditory stimuli, tactile stimuli and multimodal stimuli, especially in automotive environments. This was done to gain a fundamental understanding of the area, and to make certain that all previous relevant findings in these areas were taken advantage of. The results of the literature study can be found in the next chapter.

2.3 Development of an Audio-Tactile Design Framework

During the quick sketching in the previous phase, it became clear that there was a need for a framework clearly defining which different parameters audio-tactile stimuli consist of and how they can be manipulated. This type of framework could greatly facilitate analyzing the problem of creating audio-tactile stimuli for specific driving events and be highly useful as guidance when creating audio-tactile sketches.

A framework for audio-tactile stimuli design was created based on the results from the literature study and the experiences from audio-tactile sketching in the previous step. The parameters constituting audio-tactile stimuli were defined, starting on a basic level with the purely physical parameters, and then on two more abstract levels reflecting perceived components by user and communicables to the user. The audio-tactile design framework can be found in the chapter 4.

2.4 Familiarization with Audio-Tactile Sketching

As audio-tactile sketching is a new concept, some time was spent familiarizing with the sketching tools (Adobe Audition and the car seat capable of delivering tactile stimuli described in chapter 4) to gain an adequate level of skill in using them. This phase also included gaining an understanding of the connection between the user experience and change in the different physical parameters of both auditory and tactile stimuli, although foremost tactile stimuli. This was due to the fact that the average person's experience of tactile stimuli is usually little, perhaps only from their cell phone, compared to auditory stimuli where most people have significant experience from a multitude of different products. The nature of this familiarization with the connection between the user experience and the change in physical parameters was mainly creating sets of very quick audio-tactile sketches where one or several parameters in the stimuli were changed, and then testing them on the people involved in this thesis project to learn about their reaction. This experimentation led to several ideas regarding the use of audio-tactile stimuli that would likely not have thought of otherwise. These ideas were later entered into the morphological matrix and several of them probed to be valuable.

2.5 Adaptation of Product Design Methodology to Audio-Tactile Design

Product design methodology was used as a starting point which then was modified and adapted to suit audio-tactile stimuli design. The overall purpose of user-centered product design was attempted to keep, but some specific parts needed adjustment to be possible to apply to audio-tactile aspects instead of visual/form aspects which are often the main focus in product design methodology. For example, image boards and mood boards are frequently used product design methods to communicate a desired expression or mood to be reflected in the product design, using collages of pictures. But being highly visual in their nature, they are not very suitable for use in audio-tactile design. Thus, it was proposed that to fill this need of a source of subjective inspiration in audio-tactile design, instead of using image/mood boards, a set of reference stimuli could be collected. Normally this would likely mean mostly auditory stimuli, as the use of tactile stimuli presently is very limited. In the case of audio-tactile design for driving events, auditory signals presently used in car models from the brand could serve as reference stimuli as well as music used in tv-commercials, etc. Another example of an adaptation from visual product design to audio-tactile design was the Design Format Analysis Method (DFA) that was experimentally applied to sound elements instead of visual design elements in an attempt to analyze auditory brand identity elements in the reference stimuli.

2.6 Case Study

A case study was then performed through using the adapted design methodology to design audio-tactile stimuli concepts for four different driving events. This was done to evaluate the proposed methodology and if needed modify it. To evaluate and modify the proposed methodology as efficiently as possible, some steps were tried in different variations to see the potential differences in result. For example, the user evaluations were tried both with participants with no background at all in interaction or sound design and participants working professionally with interaction or sound design. User evaluations were also tried with giving different amounts of information to the participant about the stimuli that was about to be played.

2.7 Adjustments of Proposed Methodology Based on Case Study

For each step of the case study, documentation was done on what was done and how it went, including observations and ideas of ways that might work better. During and after the performing of the case study, this documentation was analyzed, and based on conclusions from this, it was decided upon a number of adjustments to the initially proposed methodology.

3. Theory

This chapter contains the results of the literature study performed as the starting point for this thesis. The chapter is divided into theory on sound and vibrations and theory on multimodal interaction.

3.1 Sound and Vibration Theory

This section briefly explains some basic theory on properties of sound and vibrations that are mentioned quite frequently throughout this thesis and thus important to the understanding of it. It also describes performed relevant interaction research on auditory and tactile stimuli to further support and explain the benefits of using audio-tactile stimuli for in-vehicle interaction purposes.

3.1.1 Frequency

For sound and vibration waves, frequency refers to the number of cycles per time unit. In SI-units the unit is hertz (Hz) which means the number of cycles per second.

3.1.2 Amplitude

Amplitude is technically defined as the magnitude of change with each oscillation. There are some different types of amplitude measurements. For audio purposes, the term amplitude most often refers to the root mean square (RMS) amplitude ('3' in Figure 4). The definition of the RMS amplitude is the square root of the mean over time of the vertical distance squared of the graph from the state of rest. This means that the RMS amplitude always is a little lower than the peak amplitude (1) which measures the maximum absolute value.

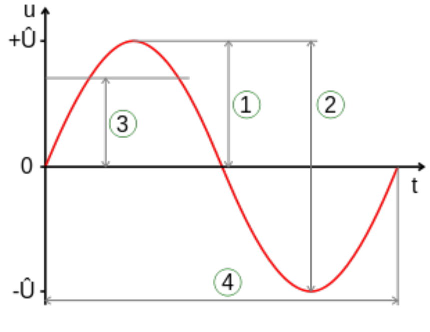

Figure 4. Waveform graph

3.1.3 ADSR Envelope

Commonly referred to as just "envelope" when speaking of sound and musical instruments, the ADSR envelope describes the amplitude over time for a certain sound. It consists of four parts (also visualized in figure 5):

- Attack time (A) – the time from zero to the amplitude peak of the sound
- Decay time (D) – the time from the attack peak level down to the sustain level
- Sustain level (S) – the level of the duration of the sound
- Release time (R) – the time from the end of the sustain level to zero

The envelope is an important component of the timbre of a sound.

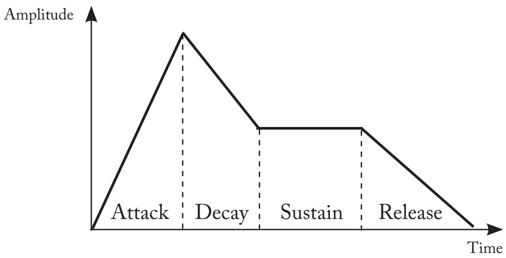

Figure 5. ADSR Envelope

3.1.4 Earcons, Auditory Icons and Speech

Earcons, Auditory Icons and speech are different types of auditory stimuli. They are distinguished both by the stimuli's physical characteristics as well as its interpretation aspects, as described by Table 1.

Table 1. Auditory stimuli

	Earcon	Auditory Icon	Speech
Sound type	Short melodic sounds	Intuitive sounds	Speech
Interpretation	Non-intuitive, needs to be learned	Intuitive, based on cultural context	Language-dependent
Example	Windows error message	Windows trash can emptying sound	Navigational messages

The earcon is the auditory equivalent of the visual icon. It can communicate quite a large amount of information during little time, just as the icon can communicate a large amount of information although using only a small amount of screen space. But it is not intuitive, and needs to be learned to be understood. The auditory icon on the other hand is intuitive by somehow making the user associate the sound with something else. An auditory icon is usually only valid within a certain cultural context, as certain sounds tend to have different associations in different cultures. Speech is self-explanatory. It is suitable to communicate complex information, but tend to be very time-consuming which risks annoying the user if using it frequently. Speech of course depends on using a language the user understands to be able to communicate information

3.1.5 Interaction Research Regarding Auditory Stimuli

Edworthy et al (1995) studied the effect of changes in four physical sound parameters; pitch, speed (interpulse interval), inharmonicity and rhythm, on 42 different adjectives. The purpose was find to potential meanings associated with simple sounds, to be able to apply these to communicate conditions during helicopter flight. Five different monitoring sounds for helicopter flight was designed based on this study.

Some results that Edworthy et al (1995) found was for example that the impression of "urgent" and "dangerous" change with the frequency of the sound. "Fast", "urgent" and "dangerous" were instead connected to the speed of the sound. In general, it is concluded that some of the sound parameters are more flexible in the way that they can convey several different meanings, which however also creates the potential risk of being ambiguous in their meaning. The inverted conclusion is also drawn, that some physical sound parameters only communicate one or a few meanings, but on the other hand they are less likely to be ambiguous or contradictory. The physical sound parameters mapping to the most adjectives was pitch (mapping to 7 adjectives), followed by speed (3), inharmonicity (2) and rhythm (1).

Sköld et al (2008) claim that the emotional response to sounds can be described in two dimensions; activation and valence (the capacity of something to affect another in a specific way). This model can categorize the urgency level of information or warning sounds of different levels. High activation and high valence result in severe warning sounds, while information sounds have low activation and low valence. Their study was performed by letting participants rate the activation and valence themselves using the SAM (Self-Assessment Mannequin, a non-verbal, graphic scale used to assess different feelings) and also by measuring physiological responses. Their results showed a significant change in both the self-assessed and the physiologically measured activation and valence.

Sköld et al (2008) also mentions that there might be the problem that a sound that correctly communicates an urgent warning, still might not elicit the correct response, as there might be a risk the user instead is paralyzed by the sound and its perceived high urgency. They further state that in a real application the differences would likely be bigger, since then the loudness and the length of sound could also be modified to communicate the level of urgency, these properties were kept constant in this study (Sköld et al, 2008). They further stress that the importance of the context the stimuli is presented in is likely very important for the emotional reaction.

Brewster (1998) found that earcons could be used to improve the usability for graphics software, for example by indicating which drawing tool was currently active. This fills a need as in graphics software, the tool palette is typically not where the user's visual focus is, forcing the user to keep switching the visual focus back and forth between the drawing and the tool palette. This significantly decreased the amount of tasks performed with the wrong tool. The different tools were distinguished by different timbres.

Auditory stimuli was also used by Brewster (1998) to create an auditory cursor to facilitate finding current mouse coordinates while drawing. This was done through playing an earcon for every pixel the participant moved the mouse cursor, so if the participant wanted to move the cursor five pixels, there was no need to take focus from the drawing to look at the ruler or coordinates, as the number of pixels moved was communicated auditory.

Brewster (1998) further found that the annoyance did not increase when using auditory stimuli, and that a majority of the participants preferred the tool palette using sound over the one without sound.

3.1.6 Interaction Research Regarding Tactile Stimuli

Although the use of tactile stimuli in interaction design is quite limited today, the idea of using tactile stimuli as a communication means is far from new. Already in 1957 Geldard performed an experiment that showed that subjects could quickly learn the alphabet based on tactile stimuli using three different intensities, three different durations and five different locations. The concept of tactons was however not introduced until 2004 by Brewster & Brown as the tactile equivalents of visual icons and auditory icons. They recognized that the visual sense has the concept of text, and its counter-part the icon, while the auditory sense has speech and the earcon. The tactile sense had Braille (tactile text used primarily by blind people) but no equivalent of the icon and earcon. The tacton is described as having the same advantages as the icon and earcon. Icons can communicate a large amount of complex information while using a only a small amount of screen space, while earcons can communicate complex information using a small amount of time. Tactons in their turn can communicate complex information in a smaller amount of space and time compared to Braille. Another important advantage of the tacton described is that tactons can operate both spatially and temporally, meaning they can complement both visual icons and earcons.

Tactons are further described by Brewster & Brown (2004) as 'structured, abstract messages' suitable to communicate information in a non-visual way. They state that tactons have potential to improve interaction, in particular in cases where the visual workload is high. Brown et al (2006) showed that tactons are easily distinguished in three parameters: rhythm, roughness and body location. They showed that using 18 different combinations of these parameters gave a recognition rate of about 80%, when used to communicate information about cell phone events. The rhythm and body location were found to be more recognizable than the roughness (Brown et al, 2006). Tactons have also been shown to be easier to localize compared to auditory stimuli, and well suitable to communicate spatial information (Ho et al, 2005).

Van Erp & Van Veen (2004) tested a tactile display made up of eight vibrating elements placed in a driver's seat by using it in a driving simulator. Visual stimuli, tactile stimuli and a combination of both were compared by having participants drive through a constructed urbanized area using navigation messages of these three different types. The response times to the messages and the mental effort were then measured. Their conclusion was that in-car navigation systems using tactile stimuli give faster reactions to navigation messages than visual stimuli and significantly lower mental effort rating than both visual and visual-tactile stimuli.

Using tactile stimuli also seemed to avoid increased response time when driver is under an increased cognitive load (Van Erp & Van Veen, 2004). They further state that using the tactile sense appears to be a valuable solution to improving interfaces within cars, potentially enhancing safety. Additionally they also drew the conclusion that there is reason to believe that the positive results shown for tactile stimuli in their simulator trials may be even bigger in a real driving setting. The reason for this was that the test participants stated that it took a while to get used to trusting the tactile messages, which could indicate that the positive effect may increase after a prolonged period of usage (van Erp & van Veen, 2004).

Tactile stimuli have been used to design a belt for navigation in military applications. The belt consisted of 8 different vibration zones where the zones closest to the correct bearing vibrated. The intensity of the vibration increased when the distance to the destination decreased. This type of tactile navigation belt proved to perform better than traditional GPS-devices communicating through visual displays. A specific gain with this was that the test participants could spot visual targets while navigating which is very difficult when using a visually based navigation device. Thus the visual workload evidently was reduced through the use of this navigation belt (Elliot et al, 2007).

Van Erp (2005[a]) found that two tactors (tactile stimulators) in close proximity sending the same signal will be interpreted as if there had been stimulation in between the tactors. They also discovered that subjects had a spatial resolution of about 3-4 cm for tactile stimuli. The exception from this was the body midline where the resolution was about 1-2 cm. Regarding the accuracy of the perceived direction, it depends on which direction. The four general directions have very little offset in perceived versus real direction, close to 0°, while directions in between them range up to 10° (Van Erp, 2005b).

3.2 Multimodal Interaction Theory

This section contains brief summaries of relevant theory on multimodal interaction that is relevant to the understanding of this thesis.

3.2.1 Multiple Resource Theory

The multiple resource theory was introduced by Wickens in 2002, and predicts multiple task performance. The theory is based on the fact that separate structures (such as the eyes and the ears) behave as if they are supported by separate limited resources. An example of the implications of this theory is that time-sharing two visual tasks will be more likely to affect performance more negatively than time-sharing one visual and one auditory task. This is referred to as having a higher time-sharing performance, and is explained by Wickens (2002) through that in this case, two different structures with two separate resources are used instead of one.

The multiple resource theory describes a set of dimensions that together form the multiple resource model (figure 6).

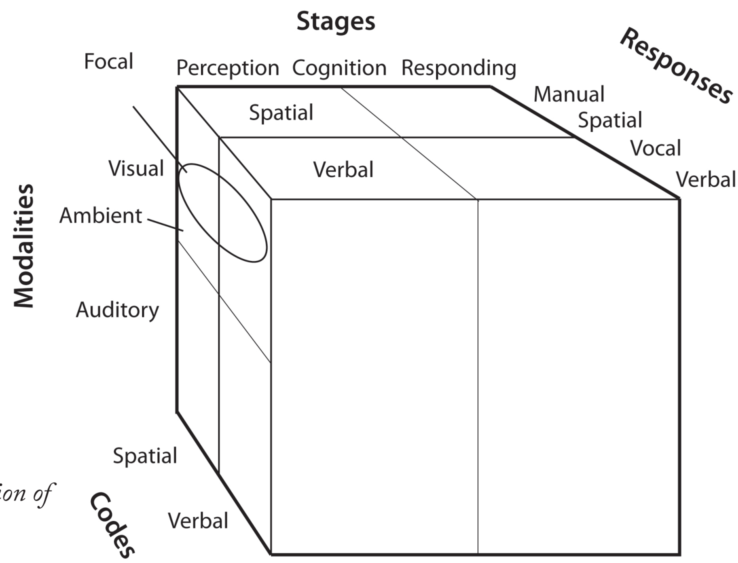

Figure 6. Graphical representation of the multiple resource model

The multiple resource model proposes four different dimensions which each has two discrete levels. The four dimensions are (see figure 6) processing *stages*, perceptual *modalities*, visual *channels* and processing *codes* (Wickens, 2002). The levels of the *stages* dimension are perception, cognition and responding. Which of course means that time-sharing performance (level of performance when performing simultaneously) of a perception-demanding task and a response-demanding task is better than that of two response-demanding tasks. The *modalities* dimension consists of the visual and the auditory levels according to Wickens. It is reasonable to argue that also the tactile level can be a modality in the same way. And the same principle applies here, Wickens (2002) describes it as 'cross-modal time-sharing is better than intra-modal time-sharing'. The visual level is further divided into two *channels*; ambient and focal. According to Wickens (2002) these two use separate brain structures and use different types of information processing. He describes how the focal vision is mainly used for fine details and pattern recognition while the ambient vision (mainly but not exclusively made up of the peripheral vision) is used to sense movement and orientation. The codes dimension is divided into two *codes*; spatial and verbal.

3.2.2 Previous Findings Regarding Audio-Tactile Stimuli

Ho et al (2007) performed a driving simulator study where they evaluated unimodal auditory, unimodal vibrotactile and audio-tactile warning signals. Participants were driving in the simulator while warning signals of the three different types alerted them of collision potential in the front or the back. The result was that the participants had a significantly faster response time to braking or accelerating when using audio-tactile signals compared to unimodal auditory and unimodal vibrotactile signals. The authors conclude that multimodal signals are a particularly effective means to capture driver attention in demanding situations.

A study made by Chang and O'Sullivan (2008) shows that an audio-tactile signal's ADSR envelope affects how much attention it draws. More specifically, the attack and decay properties affect the attention-drawing. They also find that too short tactile stimuli are not noticeable (<10 ms) and that too long signals risk being ignored in a longer perspective.

3.3 Product Design Theory

This section explains design methods and concepts normally used for visual or physical product design. The methods and concepts here have been selected on the hypothesis that they have potential to be adapted and applied to design of audio-tactile stimuli. A description of the proposed adaptation to design of audio-tactile stimuli can be seen in chapter 4, and the application of the adapted versions of the methods can be seen in the case study in chapter 5. This section however contains only descriptions of the normal applications of these methods and concepts.

3.3.1 Sketching

Sketching is a method that is frequently used within visual/physical product design. It is a fast and inexpensive way to communicate or document an idea or solution to a problem. Sketching can be used both as brainstorming, to come up with new ideas, or to "try" ideas you have thought of. For example if designing a cell phone, a sketch can give an answer that early in the design process is satisfactory accurate to questions like: do all the buttons fit in this design, what would it look like if we moved the headphone jack to that side, or what curvature will be necessary for the connecting surface if we make it this thin?

The detail level and complexity of sketches usually change throughout the product development process. In the beginning when there is usually a very wide scope and room to evaluate a large number of solutions for different problems, sketches are usually kept simple in the form of line drawings, as a quite large number of sketches are usually made. Along the development process, the number of concepts usually becomes smaller and smaller, and the detail level higher, which both gives the time needed for more detailed sketches, and a reason to create them.

3.3.2 User Profile, Personas, etc

In a user-focused product design process, there is obviously a need to define who the users of the product will be, to facilitate focusing on their needs and goals. Creating a user profile of some sort helps in order to concretize our users and their characteristics. Which characteristics a user profile contains varies depending on the type of product and which characteristics are relevant in designing for it.

A user profile in a table form is one common way of doing this. Another popular way is creating personas, which are essentially stories of fictive personalities that are likely users of the product, filled with information of these characters, such as age, family status, profession, interests, personality, favorite belongings, opinions of different things, why they use this type of product, or would want to, etc.

Regardless of which type of user profiling that is performed, it is important to make sure that it reflects the users as accurately as possible. The user profile will have significant impact on the requirement listing, which will be the basis for all evaluation of design concepts. Serious flaws in the user profile thus might have extensive consequences for the entire design process.

3.3.3 Functionality Identification

A functionality identification is a way of visually connecting the required functionality to the goals that the user of the product has. It is designed as a tree structure diagram with the very basic concrete functionality that the product needs to have at the top. We then ask ourselves why this functionality is needed, and move one step towards a more abstract functionality. We then repeat this until we arrive at the goals of the user.

An example could be for a cell phone, we need the functionality of entering data. Why do we need this? For many different reasons, so it would branch out here, with one reason being 'the user wants to enter telephone numbers'. Why does the user want to do this? 'To be able to call people'. Why does the user want to do this? Once again it would branch out, with one of the reasons being 'keeping in touch with friends and family is an important thing'.

Obviously sometimes this can be performed the other way too, starting with the user goals, asking ourselves how this can be achieved, which might be more suitable in some cases. Performing this type of analysis gives us a good overview of what functionality our product needs and why.

3.3.4 Requirement Listing

The requirement listing is a very important tool in the design process as it provides something to evaluate design concepts against. If possible, a requirement listing contains mainly measurable requirements, which are ideal as they allow for easy and objective evaluation. Measuring design-related aspects is however many times troublesome, and subjective requirements are difficult to avoid completely.

As the requirement listing is the basis for evaluation of design concepts, it is important to make sure it covers all relevant aspects of the product. The user profiling and functionality identifications (as explained previously in this chapter) are important resources to use when setting requirements as they reflect central user aspects.

3.3.5 Morphological Matrix

A morphological matrix is a way to split up functionality (often based on a requirements listing) into sub-problems listed along one axis and then list a wide range of different solutions for those sub-problems along the other axis. The morphological matrix is also often used to easily form different concepts by combining specific sets of solutions (see illustration in the example matrix below). As the matrix gives a good visual overview this is very quickly done.

	Solution ideas		
Sub-problem 1	Solution 1	Solution 2	Solution 3
Sub-problem 2	Solution 1	Solution 2	Solution 3
Sub-problem 3	Solution 1	Solution 2	Solution 3
Sub-problem 4	Solution 1	Solution 2	Solution 3
Sub-problem 5	Solution 1	Solution 2	Solution 3

■ Concept A
■ Concept B

Table 2. Illustration of how different concepts can be formed using a morphological matrix

3.3.6 Brand Identity

The brand identity is the somewhat fuzzy and subjective concept of how a brand is expressed to the consumers and users. The visual brand identity is how users perceive a brand based on the visual impressions of for example the brand's product design or marketing material. In product design, the visual brand identity is often an important factor to consider as brands today often have significant economic value, and the product design is one of the factors having the most impact on the visual brand identity.

Design Format Analysis (DFA)

The design format analysis was developed by Warell (2001), it studies the occurrence of selected design elements among a range of products. The purpose for this is often to analyze and understand what creates the visual recognition of a brand or type of product.

A DFA-analysis starts with selecting a range of products to apply the analysis to. A typical example of application could be to select the different models of a certain car brand. Certain design elements that occur in the design of several of these car models are then selected. The selection method can either be completely subjective or through more objective selection criteria. Examples of design elements can be shapes, forms, materials or colors.

Once the design elements are selected, the chosen product range is examined with regard to the presence of these design elements. A two-dimensional matrix is then constructed with the different car models along one axis and the different design elements along the other. In the intersection between a design element and a car model, a score is given based on the degree of presence of the design element in the car model. If the design element is not present at all, zero points is given, if the design element is present to a low degree, one point is given, and if it is present to a high degree, two points are given. This way, each design element accumulates a total score, describing how present it is in the selected product range. A high score represents a high possibility that the design element is a contributor to the visual recognition of the car brand.

3.3.7 Iterative Evaluations

It is common in product design to use an iterative methodology, where there is some type of creative phase, some type of evaluative phase and some type of analytic phase where the evaluation results are analyzed. Using this type of methodology, concepts are more and more refined for each iteration as the creative phase will always be based on the previous analysis of the evaluation results. It is also common that the number of concepts gradually decrease with the number of iterations increasing. With this type of methodology it is important to have a carefully made requirement listing to evaluate against, as this is what directs the refinement of the concepts.

3.3.8 KJ Analysis

The KJ Analysis (or Affinity Diagram as it is sometimes referred to) is named after its inventor, the anthropologist Jiro Kawakita. The original purpose of this method was to structure large data amounts from field studies. This method is however suitable for structuring most types of large data amounts that are made up of small chunks, and is thus today used in many different fields.

The methods starts with specifying what is to be achieved, for example "Find out what users think of feature A in product X" or "Structure user comments regarding usability in product Y". After this, each chunk of data is written on a sticky note. Once all data is put down on the sticky notes, the process starts to form groups of the sticky notes that belong together. If one or several particular sticky notes belong in two groups, a copy of that note can be made and one copy placed in each group. It is also common to form larger groups out of related sub-groups. Once the arranging of the sticky notes is finished, each group is given a header that is descriptive of its contents.

A typical application for a KJ Analysis in the product design process is to structure verbal data from open questions in interviews or questionnaires. The outcome of the KJ Analysis can typically be problem areas or user wishes.

3.3.9 Usability

Jordan (1998) defines the concept of usability as how easy a product is to use, i.e. how "usable" it is. A more formal definition of usability has been made by the International Standards Organization (ISO) and reads "the effectiveness, efficiency and satisfaction with which specified users can achieve specified goals in particular environments" (ISO DIS 9241-11). Effectiveness here refers to the actual results of the usage. Did the user succeed in performing the task or not? How many tasks could be performed per minute? Etc. The efficiency however relates to the effort required by the user. Number of mistakes made by the user, or the time taken to perform a task, could be indicators of this. Satisfaction is a more subjective aspect than the other two, and refers to the level of comfort experienced by the user and how acceptable the user considers a product to be as a means of achieving his or her goals.

Jordan (1998) further acknowledges the fact that usability is a dynamic aspect, that can change over time as users learn and become more familiar with a product, and the level of skill in usage of a product usually also depends on how often a product is used. As a framework to discuss these different aspects of usability related to frequency and skill of use, Jordan introduces what he calls the different components of usability; guessability, learnability and experienced user performance.

In a product design process where the user interaction is an important aspect, usability is usually of great importance. When designing for usability, the user profile is of great importance as it is a guide to which usability component(s) should be optimized.

Guessability

The guessability component of usability refers to how easy a product is to use the first time of usage. Jordan (1998) states that the easier it is to guess how to use the product, the higher the guessability. In addition to how easy it is to guess how to use it, the cost when making a mistake is also included in the guessability. For example, a ticket vending machine that forces the user to restart a time-consuming process from the beginning each time a mistake is made, would have low guessability.

A quite obvious result of the guessability definition is that this aspect is most important with products that have a high proportion of one-time users, such as a ticket vending machine, or products that the user will not have the time or possibility to learn or read instructions to, such as a fire extinguisher. Naturally, products at the other end of the spectrum, such as CAD-software packages or radar systems, having an overwhelming majority of their users being professionals, have little reason to be optimized for guessability.

Learnability

Jordan (1998) describes the learnability component of usability as referring to the cost (time, effort, etc) required to reach a competent level of performance with a task. Any specific difficulties related to performing a task for the very first time is however not included.

The learnability component is likely to be most relevant for products where the training time is short or the user needs to be self-taught with a product, but still needs to reach a certain level of performance (Jordan, 1998). This distinguishes learnability from guessability since products where guessability is important tend to not matter very much whether the user actually reaches a higher level of performance or not, as it is used only once, or a small number of times.

Like with guessability, highly complex products such as CAD-software packages are mostly operated by professionals, and have no great need for optimizing the learnability. Jordan (1998) uses the example of an aircraft pilot as an example. Normally users about to learn these types of systems receive both sufficient time to learn and extensive support in training.

Experienced User Performance (EUP)

Jordan (1998) describes EUP as 'the relatively unchanging performance of someone who has used a product many times before to perform particular tasks'. He further states that users with most products reaches a stage where further significant improvements in performance will only come over comparatively long time periods, which is in clear contrast to learnability where the increase in performance in general occurs rapidly.

This component of usability is of course most important with products where a continuous high level of performance is required. For example CAD-software packages or aircraft pilots, as mentioned earlier.

System Potential

The system potential is more of a theoretical concept than the others. This represents the theoretical highest level of performance possible. Jordan (1998) also describes it as 'an upper limit of the EUP'. Further he also states the fact that even though the EUP in theory could be equal to the system potential, this is rarely the case, on reason for this is that users might not learn the optimal way of performing tasks. An example is made of software, where keyboard shortcuts usually are plentiful, and undoubtedly faster than using the menus to perform a command, but very few even among professional users actually use more than a few of these keyboard shortcuts, and thus fall short of the system potential.

Re-Usability

The re-usability component refers to the decline in performance after a user has not used a product for a long period of time (Jordan, 1998). This decline could be the result of the user forgetting different things, such as how to perform different tasks, locations of controls or functions, etc.

It is important to note that Jordan defines not using a product for a long period of time as using a product for a specific purpose. For example, a user using a spreadsheet software program regularly, might not necessarily mean that the user regularly uses all functions regularly. Perhaps some functions are only used once every three months to compile a quarterly report. Thus, the re-usability component would be important for these specific functions, although the user might use other functions in this spreadsheet software regularly. The same principles of course applies to an automotive setting and any functions a driver might not use regularly.

4. Proposed Methodology: Quick Iterative Multimodal Sketching

This chapter is a description of the proposed methodology, motivating its different parts and explaining the different methods.

4.1 Overall Methodology Summary

This proposed process is based on the user-centered visual product design processes that are quite commonly used today. The general idea is to start with the users and their needs, and based on that create stimuli sketches which are then continuously evaluated with users and modified based on the evaluation results. Iterating this process of sketching, evaluating and modifying the sketches based on the evaluations will continuously refine the stimuli sketches.

This process is meant to be quick and iterative, using evaluations with users from the beginning of the process to avoid spending much time creating stimuli sketches that might potentially prove to be worthless later.

The overall layout of the process is as follows:

- Pre-study - Consists of collecting information about who the users are, which technological limitations need to be considered, any reference stimuli that need to be considered for the users' holistic experience, brand aspects and a literature study.
- Creating a starting-point for sketching - Using the information from the pre-study to create a list of requirements, a list of possible ways to fulfill the requirements and an analysis of brand-specific stimuli components.
- Iterative sketching and evaluation - Audio-tactile sketches are made and then evaluated. The sketches are then modified again based on the evaluation results.

4.2 Pre-Study

The pre-study is the foundation of this proposed process. The pre-study results are the input to the

4.2.1 User Profile

As part of the first step of the process it is important to gain an understanding for the users that will perceive the stimuli while driving. Although the target user group in this case is very large and thus hard to narrow down to a very specific user profile, it is still beneficial to have a profile of the users, even if it is quite loosely defined. It can serve as data to base requirements upon as well as functionality ideas. The information can also be used to decide which usability component should be optimized (see chapter 4 for more information on usability components).

An example of data to have in the user profile:

- Gender
- Age span
- Physical characteristics
- Cognitive characteristics
- Situation characteristics
    - Physical factors: noise conditions, vibrations, etc
    - Cognitive load factors: simultaneous tasks, etc

4.2.2 Technological Limitations

It is important to establish the technological limits (limitations in the hardware that will be delivering the stimuli) to be able to let the requirement listing reflect these limitations, thus ensuring that the final stimuli concepts will be adapted after the system's limitations, and also to identify which variables are available for designing.

4.2.3 Reference Stimuli

It is desirable that the user gets a coherent experience of the audio-tactile stimuli communicating different events. The reason for this is that it helps create a premium impression, but also so that they all align with the brand identity. In order to achieve this a reference stimuli is needed to compare to. Retrieving audio clips of the current auditory stimuli used in the car allows great possibilities to align the auditory parts of the audio-tactile stimuli with it and consider the holistic experience of the user when driving.

If retrieving audio clips of the auditory stimuli used in the car today is not a possibility, or if more reference material is desirable, the sound heard in tv-commercials for the brand's car models could also be used as reference in the brand identity aspect, as commercials can be expected to be well thought through and aligned with the brand identity.

4.2.4 Core values & Brand Identity Aspects

A list of the brand's core values and/or a list of attributes expressing the brand identity are very good to have as guidelines for the brand identity aspect further ahead in the process, if available. A list of attributes might not always be publicly available but core values are usually displayed for example on a car brand's website. Although this is a very subjective matter, a list of core values and/or attributes will allow for some type of evaluation of the user experience and brand identity aspect later in the process.

Especially so called premium brands often put an emphasis on the driver's user experience, through auditory signals as well as the sound emitted when closing a car door. The goal usually being to evoke specific desired feelings and associations in the driver.

4.2.5 Literature Study

Performing a literature study to find research that indicate design guidelines for audio-tactile stimuli, for example suitable physical parameters to communicate certain properties, is important to avoid doing work that someone else has done before you. It also gives the design process a solid foundation in proven science.

4.3 Creating a Starting-point for Sketching

4.3.1 Requirements Listing

The results from the pre-study are then used to create a listing of requirements for the audio-tactile stimuli. The requirement listing is to reflect all relevant information retrieved during the pre-study, which means that it should include the following types of requirements:

- User-related requirements
- Situation-related requirements
- Technological requirements
- Brand-related requirements
- Requirements derived from findings in previous relevant research
- Any event event-specific requirements

Obviously the requirements will depend on which type of event that the stimuli are to be designed for, and all of these requirement types may not always be relevant.

4.3.2 Morphological Matrix

The purpose of using a morphological matrix in this process is documentation of different solutions found in literature but also documentation of solutions from brainstorming sessions. It is suitable to perform some type of idea-generation session during this phase, for example brainstorming. Some suggestions for topics to use in brainstorming sessions are:

- Associations - Which auditory (auditory icons) and tactile stimuli are there that could make the driver intuitively associate to something desirable in this event? For example, the sound of screeching tires could perhaps make the driver intuitively think of braking.
- Core values - Which metaphors are there to the core values? For example, if a brand has Sustainability as a core value, could perhaps different sounds from nature such as wind rushing through leaves or ocean waves be metaphoric ways to communicate this?

Another purpose for using the morphological matrix is to facilitate keeping a wide focus to consider many different solutions to reaching the required functionality and avoid focusing on one or a few types of solutions (potentially missing others) before they have been evaluated. A framework for audio-tactile design was developed to facilitate in creating the morphological matrix (see section 4.3.3).

4.3.3 Audio-Tactile Design Framework

A framework for the parameters of audio-tactile stimuli for infotainment events was developed based on the literature study. This lists the different parameters of an audio-tactile stimuli for different levels of abstraction. The different levels are necessary as the relevant parameters of an audio-tactile stimuli vary regarding which aspect of it is discussed. This framework was a very useful tool for attacking the design problem in an analytical way and almost a necessity to be able to communicate different concepts in a verbal and textual form. This framework also helped in filling the morphological matrix. Figure 4 shows a visual representation of this framework.

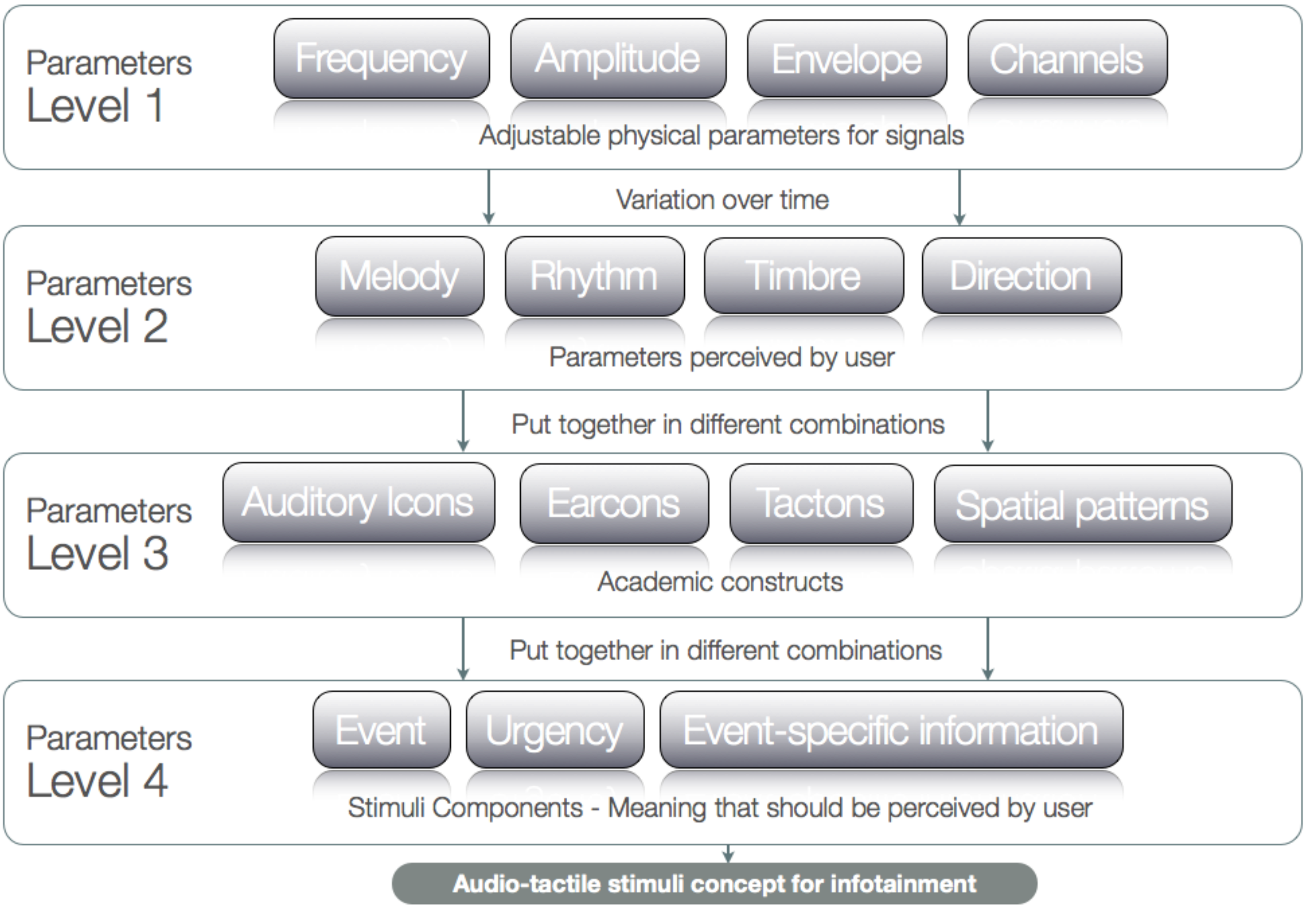

Figure 7. The audio-tactile design framework for driving event signals developed during this thesis project

4.3.4 Design Format Analysis Applied to Sound

Design Format Analysis is a method that reviews the occurrence of chosen design features among a range of products of the same brand. The method, developed by Warell (2001), is meant to be used to analyze which visual cues in products that construct visual recognition for a brand.

As part of this project is to try to modify and apply methods for visual product design to sound design, an attempt at this was made with the Design Format Analysis. This method is to be applied to the reference stimuli mentioned in section 4.2.3 to analyze them from a brand identity perspective. The goal being to analyze which auditory cues that could cause auditory recognition for a brand.

4.4 Iterative Sketching & Evaluation

4.4.1 Sketching

In visual product design, sketching is a very important tool. It is fast, inexpensive and allows for easy communication and modification of ideas or concepts. A sketch of a product can also easily be placed in an environment using photo editing software to get a feeling for how it is experienced in its natural environment, for example a sketch of a toaster can be placed in a photo of a kitchen counter.

There is obviously a need for an equivalent of visual sketching in audio-tactile design. Today's digital audio editing software provides a quite suitable way to create audio-tactile stimuli in a similar way to drawing a sketch. Using speakers or headphones, this software also provides an easy way to listen to the auditory stimuli, the equivalent of looking at a sketch. However, this type of software provides no way of "experiencing" tactile stimuli, i.e. to use the visual sketching parable, there is no equivalent to looking at the sketch. Also, when creating audio-tactile stimuli for automotive purposes, using this type of software alone does not allow for evaluating the audio-tactile sketch in its natural environment.

A way to solve the problem with not being able to experience tactile stimuli is building a device capable of delivering tactile stimuli and connect it to the audio editing software. Through using some type of mixer table it is possible to get multiple audio channels as well as multiple tactile channels. Four tactile stimulators were mounted in a car seat. One under each thigh in the seat, and two in the backrest, on the left and right side. This seat in combination with a driving simulator built from a PC with driving simulator software and a gaming equipment in the form of a steering wheel, pedals and gear lever creates an audio-tactile equivalent of looking at a sketch in its natural environment for driving event stimuli sketches (see Figure 5).

Figure 8. The driving simulator used for sketching and user evaluations during this thesis project. The seat partially seen in the foregruond of the picture is a real Volvo car seat equipped with four tactile stimulators, one under each leg in the seat, and two in the backrest, on the left and right sides.

This type of improvised driving simulator is of course not as realistic as more advanced driving simulators used by for example universities and car manufacturers for research, but it is however much cheaper, making it possible for a design team to have a driving simulator dedicated to their design work, ensuring constant access to it. This is an important part of creating an audio-tactile equivalent to visual sketching, as it is impossible to perform sketching without constantly and simultaneously looking at the sketch being made. An advanced and expensive driving simulator is likely to be frequently booked for research etc and thus not as available to a designer or design team wanting to use it for audio-tactile sketching.

The software used to create the sketches was Adobe Audition with a pack of Reaktor software synthesizers. This was in turn connected through firewire to a Tascam FW-1884 hardware control surface with eight individual mixing channels. Four of these channels were connected to a device specially designed to pump air through plastic tubes to four rubber cushions (so called "whoppee cushions") mounted in the car seat. This device consisted of four speaker elements that each was mounted in a closed volume, with the only outlets being the plastic tubes.

Figure 9. The device delivering the tactile stimuli through four independent channels. The connections for the four plastic tubes can be seen sticking out on the right. The speaker connections to be connected to the control surface can be seen sticking out on the left. The part on the right is used to close the volumes.

Figure 10. Closeup of one of the closed volumes pushing air into the plastic tubes which in their turn delivered tactile stimuli through the rubber cushions.

4.4.2 User Evaluation

Participants

As this is supposed to be a fast and iterative process, the number of test participants should be kept relatively small. In usability research there is a well-known study claiming that 5 test participants will show you 80% of the usability problems for a system (Virzi, 1992), although this is not strictly a classic usability case, it is reasonable to assume that the principle should work quite good for this purpose as well.

It is desirable to use both participants that are professionally involved in automotive interaction design or sound design and people that have no professional involvement in these areas at all. This is to obtain a large variation in the feedback and thus facilitate identifying issues of different kinds and on different levels.

Type of data to retrieve in evaluation

With such a small number of participants, there is no way of gaining statistically secure quantitative data. The user evaluation is will focus on gaining qualitative data, to understand *why* the subjects perceive the sketches as they do. This type of qualitative knowledge is also easy to apply when sketching the next generation of sketches in the next iteration. Quantitative data telling you that Concept A works much better than Concept B is not as easy to implement. However if needed, complementing the unstructured interview with a short closed question or two might be suitable in some cases, and also allow for fast analysis.

How to carry out the evaluation

The test user will be informed of which type of event the sketch is designed for. How detailed this information is depends on which factor is to be evaluated. To use usability terms, is the guessability the important factor, or the learnability? If guessability is to be evaluated, the information about which type of event needs to be very limited. If learnability is more important, the participant can be informed more specifically before each scenario about which event the upcoming sketch is about.

The participants are then to drive in the driving simulator while the stimuli sketches are triggered in suitable scenarios. After this, a short and unstructured interview with the participant is performed. The interviewer mainly tries to mostly listen to what the participant has to say to not influence his/her response more than needed. But the interviewer also has a checklist containing topics to cover, and if needed will move the discussion towards these topics in a casual way.

Example of discussion topics that are suitable to cover (should be adapted to the requirement listing):

- Perceived level of urgency
- Perceived direction (if any)
- Perceived as pleasant or annoying?
- Clarity/Ambiguity of the sketch
- Any associations made by the participant?
- Was (relevant aspect) perceived through auditory or tactile stimuli?

4.4.3 Analysis of Evaluation Results

Mostly, although depending in part on the number of sketches in the evaluation, the result of an evaluation will be quite large amounts of qualitative data. As described before, qualitative data is easier to use to modify the sketches, but it is more time-consuming to analyze. For data analysis of the evaluation results a KJ analysis was chosen. One of the major benefits with the KJ analysis method is that it is a quick way to structure quite large amounts of verbal data. The results of a KJ analysis are different groups of comments from the evaluation participants, each containing comments on one specific topic

A number of conclusions are then drawn based on each group of comments. These conclusions will then form the basis for upon which modifications will be made to improve the sketches. Alternatively, if a sketch receives much negative comments and its general concept seems to have more problems than can be fixed through modifications, the decision to stop working on this concept should be considered.

5. Case Study

This chapter describes how the proposed methodology was applied to design a set of audio-tactile stimuli concepts for a number of selected infotainment events.

5.1 Selected Infotainment Events

Four different infotainment events were chosen in cooperation with Semcon:

- Turn left/right
- Welcome
- (Drive) Forward
- Infotainment success/failure

This section describes the functionality of these events and the potential for applying audio-tactile stimuli to communicate them.

5.1.1 Welcome

The welcome event occurs when the driver sits down and starts the car. The primary purpose is to welcome the driver to the car and creating a positive feeling and connecting that to the brand identity. An example of a similar function could be the Microsoft Windows starting sound on computers. This is implemented in some cars today through auditory stimuli. Audio-tactile welcome stimuli would likely have the potential to make a more memorable impression. A secondary purpose of the welcome event, could for tactile purposes be to communicate the presence and positions of the tactile zones to the driver. This might be appropriate to avoid startling the driver suddenly by unexpected tactile stimulation, which might especially be an issue for example in rental cars. It could also help notify the driver in case of malfunction in one of the tactile zones.

5.1.2 Turn Left/Right

When using turn-by-turn navigation to a certain destination, the turn event consists of informing the user of when and in which direction to turn. It could also incorporate some type of continuous communication of the distance to the turn, such as the function of the speaker voice often found in today's navigation systems declaring '500 meters to turn', ‘200 meters to turn’, etc. (However a speaker voice is only mentioned to exemplify the function here, it is not an option to be used in the auditory stimuli of this thesis project as it is outside the limitations, as stated in section 1.5). These speaker voices are very clear in their message but run the risk of becoming very annoying after the driver has heard them a number of times, to the passengers in the car they are likely even more annoying as they have no use for hearing that information. Also, speaker voice messages are not very time-efficient.

Tactile stimuli have been proven by Van Erp & Van Veen (2004) to work well for communicating spatial information related to navigational messages. They also showed that tactile stimuli used to communicate navigation messages do not cause longer response times in case of an increased cognitive load. Auditory stimuli have been shown to map adjectives such as “urgent” to physical sound parameters (see section 3.1.5). Thus it seems reasonable to assume that audio-tactile stimuli have good potential to communicate a turning event where spatial information and change in urgency are important.

5.1.3 Forward

With the development of electric cars there will likely be a need for a signal of some type communicating to the driver that all systems are ready and the car is ready to drive, as the natural auditory feedback of a combustion engine is not available in an electric car. This signal would in some way communicate motion forward to the user, which defines the forward event.

This also has, the a possible application for navigation-purposes, telling the driver to continue forward without turning in a crossing or roundabout. Like with the turn event, the facts that tactons have been shown to be suitable to convey spatial information (see section 3.1.6) and that earcons and tactons have recognition rates of about 70% (Brown et al, 2005) makes audio-tactile stimuli likely to have potential for this event.

5.1.4 Success/Failure for Infotainment Search etc

This is the event occurring when a command is executed in the infotainment system, and the system communicates to the user that this command has been executed successfully or that it has failed. The command can be of many different types, such as searching for a restaurant, requesting turn-by-turn navigation instructions to a certain destination, etc. In case of failure, it is usually also suitable to communicate whether it is a system or a user failure.

Research performed by Brewster (1998) shows that representing different tools in software with different auditory timbres showed a significant decrease in tasks performed with the wrong tool. It is thus reasonable to assume that auditory feedback has potential to help the user recognize different outcomes of a command in this case as well. Tactons have been shown to be easily distinguishable in at least three different parameters: rhythm, roughness and body location (Brown et al, 2006) and should thus also be able to communicate different outcomes of an infotainment command.

5.2 Pre-Study

5.2.1 User Profile

An analysis on which type of users these audio-tactile stimuli should be designed for was performed as a starting point for the process. With the target group being very large (all regular car drivers), the user profile could not be narrowed down enough to be of optimal use, but could still serve as some guidance when keeping the user in mind.

- Gender: Both
- Age: ~16-85
- Physical Characteristics
  - Large variations in weight, height and BMI
  - Adequate vision required to get a driver's license
  - Hearing likely ranging from impaired to fully functional (deaf people are outisde the scrope of this thesis, see Limitations)
  - Depending on geographic location, might be wearing everything from thick winter clothes to light summer clothes
- Cognitive characteristics
- Situation characteristics
  - Noise and vibrations from the engine and the road surface likely to partially mask auditory stimuli and decrease hearing efficiency, especially in the lower frequencies
  - Noise and vibrations from the engine and the road surface likely to partially mask tactile stimuli

5.2.2 Technological Limits

The available structures in the driving simulator allows for using two audio channels (left and right) and four independent tactile channels. The tactile stimulators in the Semcon driving simulator seat are made up of so called 'whoopee cushions'. These are placed one under each thigh and on both sides (left and right) of the seat backrest.

This means that all auditory stimuli need to be designed using a maximum of two channels, and that tactile stimuli need to be designed using a maximum of four channels.

5.2.3 Reference Stimuli

As reference stimuli VCC provided auditory stimuli used today in their S60 model for warning and information systems. VCC also provided a set of ten ringtones that are designed to communicate the Volvo brand identity and to be used in the in-car cell phone system

5.2.4 Core Values & Brand Identity Aspects

Volvo Cars official core values are: Quality, Design, Environment and Safety (Volvo Car Corporation website, 2011). VCC also has an outspoken aim to deliver a Scandinavian experience through color schemes as well as the materials used.

5.2.5 Literature Study

The relevant results of the literature study can be found summarized in chapter 3.

5.3 Foundation for First Generation Sketches

5.3.1 Requirement Listing

Fundamental Requirements

Every stimuli-combination should clearly communicate:

- Which driving event is happening
- The urgency level of this event

Stimuli-combinations for turning should also communicate:

- The direction of the turn

Stimuli-combinations for infotainment searches etc should also communicate:

- Success or failure
- In case of failure; whether it is a user failure or a system failure

Welcome stimuli-combinations should also communicate:

- Position of the tactile zones
- That the tactile zones can function both independently and in groups (Optional?)
- That audio can also be delivered from only the L or R channel (in case this feature are used by other stimuli-combinations)

Safety Requirements

Every stimuli-combination should:

- Be easily distinguishable from the others to avoid mixups
- Be ”loud and clear” enough/have sufficient intensity for the driver not to miss it. Redundancy through using two modalities used to achieve this if needed.
- Be as close as possible to obvious in its meaning
- Not startle the driver

User Experience Requirements

Every stimuli-combination should:

- Be experienced as being in harmony with the Volvo Brand Identity
- Be experienced as pleasant by the driver (even when exposed to it several times within a shorter period of time)
- In other ways be well-adapted to the environment of a car driver

Welcome stimuli-combinations should also:

- Communicate one or several of the Volvo Brand Identity attributes
- Evoke positive feelings

Technical Requirements

Every stimuli-combination should:

- Be designed to use a maximum of two auditory channels (L/R)
- Be designed to use a maximum of four tactile channels

5.3.2 Morphological Matrix

The morphological matrix was constructed by breaking down the required functionality in the requirement listing into subproblems. Different possible solutions for these subproblems were then identified through literature studies and brainstorming and then entered into the morphological matrix. The complete morphological matrix can be found in Appendix I.

5.3.3 Design Format Analysis

The DFA method was applied to the reference stimuli in an attempt to identify sound elements communicating the Volvo brand identity. Out of the reference stimuli, only the ring tones proved worthwhile to use in the DFA, as the other stimuli were warning signals which tend to be very short and simple, which made it difficult to analyze them.

The following sound elements were identified in the set of ring tones as possible ways to communicate the Volvo brand identity:
- One clearly dominant timbre (x points)
- High-frequency sounds (x points)
- "Cold" echo (x points)
- Piano-like timbre(s) (x points)
- Clean overall audible spectrum (x points)
- Clearly distinguishable rhythm throughout (x points)

For a more complete representation of the DFA for sound results, see Appendix II.

5.4 Iterative Sketching & Evaluation

Initially only the welcome and turn events were worked with for one iteration to be able to test the proposed iteration methodology on a smaller scale. After that all four events (also including the forward and infotainment success/failure events) were worked with for the following two iterations. This is the reason why the welcome and turn events have been worked with for one more iteration compared to the forward and infotainment success/failure events.

For the turn event concept, visual representations of the basic designs can be found in Appendix III, while KJ Analysis result summaries can be found in Appendix IV. These are provided as an example to give the reader an understanding of the workflow through seeing the designs, the modifications and the user feedback in the different iterations.

5.4.1 Turn Left/Right Event

First Iteration

Sketching

The first generation of turn event concepts were formed using the morphological matrix and were mostly very basic ideas of which stimuli component should be communicated through which stimuli parameter, and sometimes also the timing of this. For example Event Concept A consisted of the idea of having three different steps, each with increasing urgency, describing that the turn is getting closer. The two first steps being preparing the user for the turn and the third signalling the actual turn.

Rough audio-tactile sketches were made up of these five different concepts. During the sketching these concepts were continuously tested under informal circumstances. In this first iteration the main focus for the sketches was to communicate event and level of urgency. The brand identity aspect of these sketches was not yet given very much attention. Visual representations of the basic designs of the turn event concepts can be found in Appendix III.

User Evaluation

This user evaluation was performed with 6 participants who were not professionally involved in interaction or sound design related areas. The audio-tactile stimuli were played while they were driving in the simulator. The participants were told beforehand which type of stimuli would be played (for example: 'a stimuli for a turn event communicating preparation and execution of turn'), but were not told of which direction the turn would be. After a stimuli was played and the participant had acted according to how they interpreted it, a short, open interview was performed, focusing on how the participant interpreted the stimuli and why.

A recurring comment among the different concepts were that the tactile stimuli had too low intensity, resulting in that the participants barely felt it. Another general finding was that using tactile stimuli in both the left and right tactile zones in the same tacton confused the participants very much (Concept B and C). The complete KJ analysis results along with the conclusions drawn for the next iteration's sketching can be found in Appendix IV.

Second Iteration

Sketching

For the second sketching iteration, the priority was to fix the problems and enhance the positive aspects identified in the previous user evaluation. The general tactile stimuli intensity levels were increased slightly, especially in the back zones, as many participants commented that they had a hard time feeling it. Concept A received much positive feedback and was only adjusted slightly to create a more clear difference in urgency between its three steps. One of the two concepts using a tacton which consists of stimuli on both the left and right side (Concept B) was scrapped, as it received very poor results in the evaluation. The other of those two concepts (Concept C) was modified by creating a larger distance in time between the stimuli on the left and right in an attempt to decrease the confusion. Concept D seemed to be promising receiving quite positive feedback during the evaluation, however some adjustments were made to enhance it further, for example the length of the concept was decreased from about 14 seconds to 10 seconds based on comments from participants. Visual representations of the basic designs of all five concepts in this stage can be found in Appendix III.

User Evaluation

This user evaluation was performed with 4 participants who were professionally involved with automotive interaction design. The participants were beforehand only told which general area the next stimuli coming up belong to (for example: 'navigation-related'). In all other aspects this evaluation was performed in the same way as the one in the previous iteration.

Concept A still received mostly positive comments after the adjustments made. The only aspect needing more adjustments seemed to be the design of the tactile stimuli. It received comments both that it was hard to perceive and also that it was perceived as slightly unpleasant.

The modifications for Concept C only helped slightly and it was still experienced as very confusing by the participants. It was thus decided that this concept be scrapped.

Concept D once again received mostly positive comments. The concept of communicating the distance to turn in the same way as a reversing aid appealed to many participants. Like with concept A the tactile stimuli seemed to risk being perceived as slightly unpleasant and perhaps containing a lot of repetitive pulses. The second auditory signal communicating that it is time to turn seemed to confuse some participants in its meaning.

Concept E also seemed to risk being perceived as slightly unpleasant in its tactile stimuli. The turning indicator sound works very well to make participants associate it to turning, but the fact that it is so similar to a turning indicator also makes it confusing as some people interpret it as the actual turning indicator being active.

The complete KJ analysis for this evaluation can be found in Appendix IV.

Third Iteration

As there was no more time for further user evaluations, this last iteration consists of a last sketching iteration, based on the conclusions from the previous evaluation.

The envelope of the tactile stimuli in Concept A was modified to have a slower attack. This was done to be able to increase the intensity further without risking it being perceived as unpleasant. The same thing was also done in Concept D and E.

Concept D's tactile pulses were also decreased in number slightly to avoid being annoying or communicating a too high level of urgency. The second auditory signal was also adjusted slightly in intensity and time to align better with the tactile stimuli and hopefully be more clear in communicating that it is time to turn.

In Concept E the auditory sound from a turning indicator was adjusted in frequency, to still make users associate it with turning, but distinguish it from the actual turning indicator.

Visual representations of the basic designs of the concepts in this stage can be found in Appendix III.

5.4.2 Welcome Event

First Iteration

Sketching

For the welcome event, communicating the brand identity is one of the main functions. Thus the brand identity aspect was considered already in this first iteration, in contrast to the turn event sketches. The first generation of welcome event concepts was created based on the morphological matrix, the design format analysis and a sound logotype concept designed by Peter Mohlin. Reference stimuli in the form of Volvo-designed ring tones were used to perform the DFA but also as general inspiration.

Two concepts were created as very rough sketches which the author tested on himself in the driving simulator to evaluate if the concepts were possible to create as planned. A limited number of informal tests on other people involved in the project were also performed during the sketching for quick evaluations and to make some rough adjustments.

User Evaluation

After creating rough sketches for two different concepts for the welcome event a user evaluation was performed with 6 participants who were not professionally involved in interaction or sound design. They were told before experiencing the sketches that they were meant to be for the welcome event.

Concept A received comments on having too low intensity in the tactile stimuli and giving the participants more of a "horror film" feeling than a welcoming feeling. Concept B was generally experienced by participants as more calm and welcoming than Concept A, but with less premium-feeling.

See Appendix IV for the KJ analysis of the complete evaluation results for both concepts.

Second Iteration

Sketching
During the second sketching iteration the two existing concepts were adjusted based on the feedback from the user evaluation. For example the tactile stimuli intensity was increased and one of the voices in Concept A was adjusted to have more of a "warm" feeling as opposed to the "horror"-feeling experienced by some participants. Two new concepts were also created based in part on new ideas that emerged from the previous user evaluation and in part on ideas from the morphological matrix. Both these concepts were built on new ideas for spatial patterns. Concept C tried using both auditory and tactile stimuli synchronizing together in time and direction to create the impression of them revolving around the user. Concept D was similar but instead of a revolving spatial pattern it incorporated the stimuli "moving" in an x-shaped pattern.

User Evaluation
This second user evaluation was performed with 4 participants who were professionally involved with interaction and/or sound design for automotive purposes. The participants were told before experiencing them that these sketches were meant for the welcome event.

Concept A generally received very positive comments although one participant found the tactile stimuli a bit too intense. Concept B had tactile stimuli that were gradually increasing in intensity, and highest intensity was perceived as intrusive by some participants. This concept also received comments on being boring and predictable. Concept C mainly received negative comments. The auditory stimuli was perceived as dull and the idea of letting the audio alternate between the stereo channels was not liked. It also seemed as if auditory stimuli unintentionally was unequally balanced between the left and right stereo channels. Concept D received similar comments to Concept C in general, although slightly more positive regarding the tactile stimuli and more negative regarding the auditory stimuli.

Third Iteration

Sketching
The intensity of the tactile stimuli for Concept A was lowered to a level between that of the first generation and the second generation. Regarding Concept B, the highest level of intensity for the tactile stimuli was decreased, although the gradually changing intensity was kept. To avoid the concept being perceived as dull and boring, the rhythm of one of the auditory channels was adjusted to be less predictable. Instead of having tones coming at regular intervals, the last tones were played in more of an 'improvized' manner.

Concept C's problem with the unbalanced auditory stimuli was adjusted. The tactile stimuli intensity was also increased slightly based on comments regarding that in the user evaluation. The tactile spatial pattern used in Concept D which received positive comments was applied to Concept C, while the rest of Concept D was scrapped based on its poor critique in the user evaluation.

5.4.3 Forward Event

First Iteration

Sketching
One of the ideas for a forward event, was to simply use the same type of sketch as for the turn event, only change the spatial pattern and direction of audio from left/right to forward/center instead (Concept A). Another idea included tactile stimuli with gradually increasing intensity in the back zones during a few seconds, to simulate the effect of being pressed against the seat when accelerating (Concept D). There were also two concepts using modulated tactile stimuli during a few seconds to prepare the driver, followed by a short auditory signal marking the crossing or junction where to keep driving forward. One of those used a tactile stimuli modulated up and down continuously in amplitude (Concept B) while the other used a tactile stimuli gradually increasing in stimuli like in Concept D, but in the frontward zones instead of the rearward ones (Concept C).

User Evaluation
The user evaluation was conducted using 4 participants professionally involved in interaction and/or sound design for automotive purposes. They were told beforehand to imagine that the stimuli sketches related to navigation somehow, but no more detailed information than that.

Concept A received mainly positive comments, with the exception of one participant who did not interpret tactile stimuli under both legs as having any direction and that one participant thought that the perceived urgency level was slightly high for a forward event. Concept B was interpreted by many as that they were supposed to break or slow down. Concept C received mixed comments, but was interpreted as 'turn right'. One participant also found it hard to perceive the tactile stimuli. Concept D could not be interpreted at all by any of the participants, and only confused them. This concept was thus scrapped.

Second Iteration

Sketching
The tactile stimuli intensity of Concept A was slightly lowered to avoid a too high perceived urgency level. The auditory stimuli also seemed to vary in intensity between the L and R channel and was adjusted to be centered. Concept B was interpreted as that the participants should break or slow down. This was based on their comments due to the fact that the tactile stimuli was active during a quite long time. The length and intensity of the tactile stimuli was thus decreased. The auditory stimuli was also adjusted to be centered like in Concept A. Concept C was interpreted by turn right by one participant. Both tactile and auditory stimuli were checked and slightly adjusted to make sure it did not give an impression of right rather than forward. The tactile stimuli were also increased in intensity a little.

5.4.4 Infotainment Success/Failure

First Iteration

Sketching
One of the main ideas was to use associations to operating systems such as Windows or Mac OSX, as they often have sounds both for success and failure. Another idea was to try to create a stimuli communicating something positive through a clear timbre and a smooth vibration, and something negative through a rough, noisy timbre and a rough

perhaps asymmetric vibration. Further, auditory stimuli with increasing frequency were tested as success sketches, while decreasing frequency were tested as failure sketches. Four different concepts were created using these ideas and others from the morphological matrix, in combination with creative audio-tactile sketching. Designing stimuli communicating an error while simultaneously designing a 'premium' experience to the driver proved to be quite difficult, as an error is a negative thing, which does not align very well with the premium association.

User Evaluation

The user evaluation was performed with 4 participants professionally involved with interaction and/or sound design for automotive purposes. They were told beforehand to imagine that the stimuli sketches related to navigation somehow, but not more than that.

About half of the concepts were perceived as intended by the majority of the evaluation participants. The other half was either perceived as difficult to interpret by several participants, or perceived as success by several participants when the sketch was intended to communicate failure, or vice versa. The rough vibrations meant to communicate failure were interpreted as metaphors for driving on rough surfaces, etc. It was clear that interpreting something as positive or negative is a highly subjective thing, which needs to be designed in an extremely clear way for people not to interpret it differently.

Second Iteration

Sketching

For the sketches that were sometimes interpreted differently than intended, the magnitude of the sketch idea was amplified. For instance, the concept using a high-frequency tone followed by a tone of a lower frequency (meant to communicate a failure) was modified to have a larger drop in frequency between the two tones. In addition to this, participant's comments were used to perform more modifications. One example of this was that several of the sketches using rough vibrations were a little longer, to allow for the participant to perceive that the vibrations were actually assymmetric and modulated in amplitude. Many users interpreted these sketches as very high urgency due to the prolonged tactile stimuli. These sketches were modified to be slightly shorter to avoid this issue.

6. Discussion

The proposed methodology of quick and iterative audio-tactile sketching used in this thesis project is powerful since it allows an understanding for the user and why they interpret an audio-tactile stimuli the way they do, which is a major strength, as opposed to only gaining quantitative knowledge such as how many percent of participants reacted to it in a desirable way. The methodology also has other strengths, such as high feasibility for application in business-driven product development as it is inexpensive, fast, and does not require a large group of people to work. Most of the tools and methods in the methodology are easy to understand even for people with no background in product design, and also allow for flexible application, i.e. to other aspects than strictly infotainment events and the option to focus on different aspects, such as functionality or brand identity aspects. This further adds to the methodology's feasibility.

However, the methodology is also based on using a quite small number of participants in the user evaluations to keep the process quick and iterative. This of course means that the results cannot be said to have much statistic significance which might be seen as a weakness, although there are studies that support that no more than five or six users are needed to uncover usability problems (Virzi, 1992). It is still to be answered though whether audio-tactile stimuli can be considered usability in the meaning, as classic usability usually refers to mainly visual stimuli. Another possible weakness in this methodology is that the type of driving simulator described does not allow for triggering stimuli automatically at certain points (such as 200 meters before a crossing, for example) but instead the evaluation leader must trigger the stimuli manually, which of course means that it will not be perfect and equal timing for all participants.

Things that could be improved in the methodology - based on the case study - is for example to not discuss abstract, complex concepts such as brand identity or urgency level with evaluation participants who are not knowing in the area of interaction or sound design. This does not work very well and discussing concrete equivalents such as for example brand identity attributes instead ('do you perceive this sketch as warm or cold') is likely to improve the evaluation results. Another adjustment that likely would improve the methodology would be to let the participants be familiar with receiving tactile stimuli from the driving seat before the actual evaluation starts. This would decrease the risk of the very first sketch played being perceived as very intense in vibrations.

Many valuable lessons were learned during this thesis project. Among them was that the selection of participants greatly affects the feedback received from evaluations, which in the long run affects the whole outcome of this thesis project. It was noted that there was a significant difference in using participants that are professionally involved in automotive interaction or sound design compared to using participants that are not. The professionals tended to be much easier to discuss more abstract concepts with, such as urgency level, as they knew its meaning from before, in contrast to the non-professionals who usually had not heard of this concept before. The professionals did however also tend to have much more pre-formed opinions on many matters, such as which type of system should use which type of signals, etc, whereas the non-professionals were more open-minded and free in their ideas and comments from not having as much former experience in the area and thus no bias towards any particular direction. The non-professionals also sometimes commented on very concrete practical issues that were sometimes overlooked by the professionals.

There was also a clear difference in responses from the participants depending on whether it had been described which type of stimuli would be played beforehand compared to if only which general area the stimuli played would belong to had been mentioned. This needs to be adapted to which type of usability component should be evaluated. If the guessability is to be evaluated, which might often be the case in automotive applications, it will likely give a more accurate result to not tell the user more than the general area of the stimuli. If the learnability is to be evaluated, it is however likely more beneficial to inform the user of which type of stimuli it is beforehand. System potential and experienced user performance are not likely to be the focus for this type of interaction design unless for race cars etc, but also for this purpose it would be more suitable to describe to the user beforehand which type of stimuli it is.

Some participants in the user evaluations seemed to perceive the first sketches as having very high levels of intensity in the tactile stimuli, although intensity levels were not higher than in later sketches. This was likely due to the participants being a bit startled by experiencing tactile stimuli from a car seat for the first time. Letting the participants try some different types of tactile stimuli, to make them comfortable and used to it before the actual evaluation starts would likely remove or decrease this skewing effect in the results.

Another interesting and valuable finding from this thesis project was that the concept of sketching to some degree can be transferred also to the audio-tactile modalities. It is however a little more complicated compared to visual sketching. For example, a visual sketch can easily be reproduced and looked at by several persons at once in presentations etc. An audio-tactile sketch requires special hardware only to be experienced, and even then it can only be 'looked at' by one person at a time. Communicating an audio-tactile sketch to someone at another location is very difficult. In part this problem has been addressed in this thesis through visual representations of audio-tactile sketches (see Appendix III) but it remains to be studied how this problem can best be solved.

An additional important thing to note regarding the user evaluations is that the way they were performed, with the participant driving in the simulator until an audio-tactile stimuli sketch was played, and then stopping for a short interview, does not fully reflect a realistic driving environment. In a real driving environment all the different concepts would be experienced in a much more holistic way, different events happening after one another, which will likely also affect the perception in different ways. For example it might be possible that many audio-tactile stimuli might be perceived as more annoying when different events happen shortly after one another. During the evaluations, all audio-tactile sketches were only experienced by participants in isolation from each other, one at a time. This should be kept in mind as it likely affects the participants' perception of them in comparison to experiencing them in a realistic driving environment. This is another reason why this proposed methodology likely is most suitable to use to create a number of concepts that can then be evaluated more thoroughly using a larger number of participants and a more realistic driving simulator, and also more realistic driving scenarios. It was considered to use more realistic driving scenarios for the evaluations, letting the participants drive around and experience a number different driving events after one another before being interviewed. However, it was judged that using this type of scenarios would have a negative impact on the participants' feedback, as they would likely forget some of their opinions if having to remember impressions of several driving events simultaneously.

It was discovered during the case study user evaluations that the participants' experience of the tactile stimuli often differed greatly. The same exact tactile stimuli could sometimes be experienced as very intrusive and unpleasant by one participant while it was barely felt at all by another. This phenomenon was expected due to participants having different seating postures, body types and types of clothes. The magnitude of the difference in experience was however far bigger than expected. This suggests that it would have been suitable to select participants for the user evaluations so that different body types were represented. Noting which type of clothes the participants are wearing might also have been useful although this is likely a minor factor indoors. The driving posture is a more difficult factor as people are not aware which type of posture they use relatively to other drivers. It is also difficult to assess, rate or compare driving postures visually.

A further potentially suitable adjustment to the evaluation procedure would be to make sure that all turn event concepts are tested in four-way crossings in the driving simulator. This would avoid the observed problem with evaluation participants basing their decision which way to take in a crossing solely on which ways are available in the crossing, rather than on interpreting the audio-tactile stimuli played.

Another thing that was not ideal regarding the user evaluations was that the thesis author both designed all the sketches and performed all the evaluations. This could in theory allow for bias influencing the evaluation results, although it of course was avoided as far as it is possible to do consciously. However if possible, it would of course be preferable to not have the same person doing both the sketches and the evaluations.

An important discovery was that just sitting down with the audio-tactile sketching tools and experiment to see what you come up with seems to be a valuable part of the methodology. When comparing to visual sketching it seems quite evident, as this is one of the main advantages and usages of the sketching method, to put the pen to the paper and actively create and randomly discover new things simultaneously. This can create ideas that are just discovered, rather than thinking of them first and then creating them.

Regarding the brand identity aspect of audio-tactile stimuli, the case study indicates that the design format analysis has potential being applied to sound also. But it does require that the reference stimuli used have an adequate length and level of complexity, which for example the warning signals did not have. The Volvo ring tones on the other hand worked well. For the method to be useful, it also requires that the driving event designed for allows for an adequately complex and long stimuli. This is often not the case with information and warning signals that occur while the car is moving, as it is desirable to keep them short and clear for safety reasons. With the welcome event however, the safety aspect is not critical as the car is standing still, thus for these types of stimuli, the DFA for sound likely has good potential.

7. Conclusion

In summary, the proposed methodology for audio-tactile design did produce a number of concepts for the selected four different driving events. The proposed methodology was based on user-centered product design methodology and used an iterative process with frequent user evaluations and an improvised driving simulator capable of delivering audio-tactile stimuli to the driver. This methodology is inexpensive, fast and the results indicate that it produces concepts that based on the performed user evaluations seem to have good potential for communicating driving events. Using an inexpensive type of driving simulator was a vital part of this methodology as this allowed continuous iterations of audio-tactile sketching and user evaluations.

These facts suggest that this methodology has high feasibility for use in business-driven product development. However, this methodology should likely primarily be seen as a way of creating candidate concepts which can then be subject to a more extensive evaluation. A larger number of participants, a more realistic driving simulator and a more controlled evaluation type is needed to draw statistically significant conclusions regarding the audio-tactile sketches.

One important finding from the case study was that the experience of tactile stimuli seemed to differ greatly - likely because of varying driving postures, body types, clothes etc. Another was that the creative experimentation with the sketching tools proved to create many new ideas and concepts suggests that this should be added as a step in the process. Just like visual sketching is performed continuously through a product design process and also sometimes performed without a defined goal in mind, audio-tactile sketching seems to work well used the same way.

The case study identified a number of suitable adjustments to the initially proposed methodology, most of which are discussed in chapter 6. A description of the complete adjusted methodology can be found in Appendix V.

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Appendix I - Morph. Matrix

Problem:	Possible Solutions:		
Communicate which driving event is happening	Tactons	Use sounds with different pitch	Sequenes of tones, melodies
	Use audio with different timbre		
Communicate direction	Use L/R stereo channels	Use tactile zones for spatial patterns. Both left zones for left, front ones for forward, etc.	Multimodally to achieve redundancy
Communicate Level of Urgency	Amplitude for both auditory and tactile stimuli	Pitch for sounds	Faster/slower sequence of tones/vibrations
	Longer/shorter tones/ bursts of vibrations	Amount of times sound/vibration is repeated	Amount of tactile zones activated
Holistic Concept of Stimuli	First simultaneous stimuli communicating specific event, then simultaneous stimuli communicating direction		Let sound communicate which driving event, simultaneously le ttactile zones show direction
	Let a short, simultaneous stimuli both in auditory and tactile modality capture driver's attentione. Then have event-specific stimuli.		Let a spatial pattern communicate specific event while a general sound communicates that 'an event' is happening.
Welcome Stimuli	Use sounds that creates associations to scandinavian nature, such as wind, ice, etc	Include vibrations in all tactile zones, to show driver where tactile zones are and how the function	
Communicate Turn	First to prepare: audio communicating turn and tactile stimuli communicating direction. When time to make turn, use same stimuli few seconds before turn, but repeated 2-3 times.		
	Subtle short audio with similar rhythm to turn indicator sound. Same rhythm in tactile stimuli in relevant zones to communicate direction.		
Communicate Lane Change	Let the two leftward/rightward tactile zones alternate giving stimuli		Use same type of stimuli as for turn, but stomehow 'less' as a lane change is kind of a small turn
	Let the two rightmost tactile zones vibrate followed shortly after by vibrating the two leftmost zones, pause then repeat. To create an impression of movement towards the right.		Spatial patterns

Problem:	Possible Solutions:		
Distinguish Events from Each Other	Pitch	Different tone sequences	Tactons
	Spatial patterns		
Communicate Distance to Turn	3, 2, 1 pulses to signify 300m, 200	Give tactile stimuli at certain interval, with increasing amplitude	Give auditive stimuli at certain intervals with increasing pitch
	Audiotactile at first notification, then only tactile the rest of the distance notifications		'Logarithmic' intervals, similar to a reversing aid
Communicate 'Forward'	Tactile stimuli in two forward zones. Simultaneously or alternating	Tactile stimuli in the rear zones followed by stimuli in frontward zones. Then pause, then repeat. To create a feeling of movement towards front.	
	Both front tactile zones give stimuli simultaneously in turning indicator-rhythm		Use the same tacton as for turn left/right, only change to front zones. Would maintain consistency.
Communicate 'Success' or 'Error'	Sound with the same feeling as 'tada', 'pling' etc in Windows	A lower tone followed by a higher communicating a positive result, and inversed communicating negative	
	'Clean' or 'noisy' timbre	Short tactile pulse for success or several pulses when error	Sound associated with alarms etc for negative
	Metallic 'clonk'-sound or similar 'dirty' sound to represent error	A spatial pattern that is noisy, irregular, etc might communicate something negative?	
Tactile equivalents of auditory icons	Driving on bumpy roads	Knock on the shoulder	Acceleration pressing driver against seat
	Engine vibrations		
Communicate Brand Identity	Cold/ice/snow-sounds: scandinavian	Piano, strings: associations to classic luxury, premium	See DFA

Appendix II - DFA

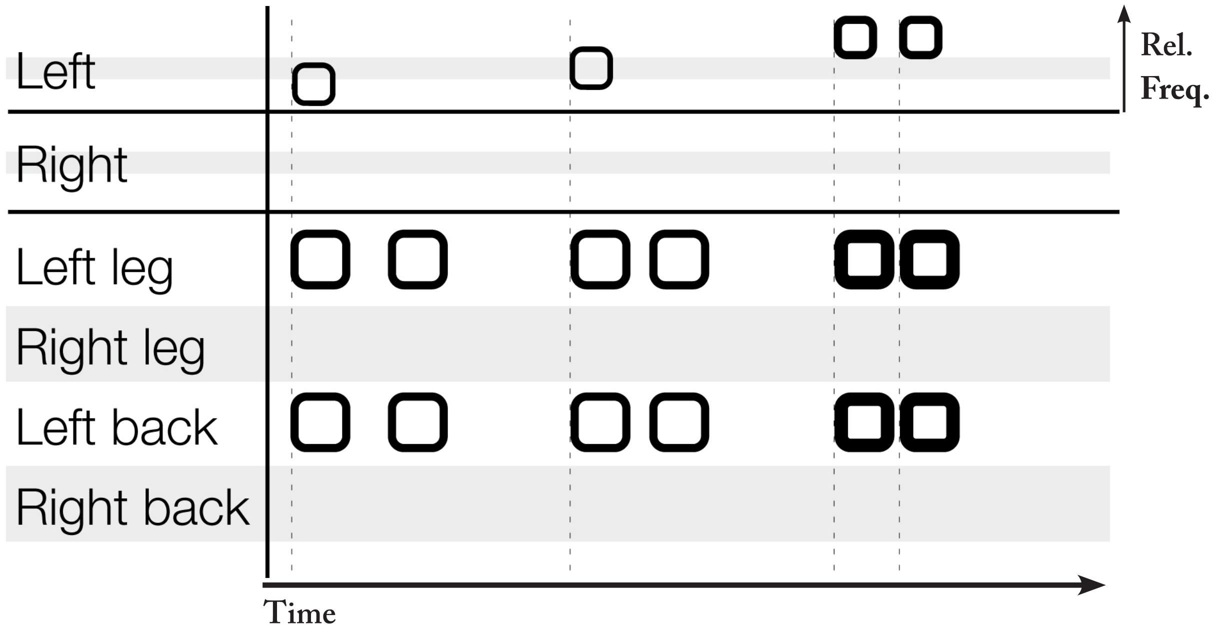
RT1-RT10 on the X-axis top represent the 10 different ring tones from the Volvo S60 model. On the Y-axis on the far left are different sound characteristics. If a sound characteristic is present in a ring tone to a high degree, it is givene the score 2, if it is present to a small degree, the score 1. If not present at all, the score is zero. The accumulated score for each sound characterstic is summed up on the far right and also for each ring tone on the bottom. For clarity in the table, only the sound characterstics that received scores of 10 or higher are presented in the table. Lower score than 10 was judged as not contributing to the brand identity.

	RT1	**RT2**	**RT3**	**RT4**	**RT5**	**RT6**	**RT7**	**RT8**	**RT9**	**RT10**	
Clearly dominating timbre	2	2	2	2	2	2	1		1	1	**15**
High-frequency sounds		2	2	2	1	1	1	2	2	1	**14**
"Cold" echo	2		2	2		1			2	1	**10**
Piano/xylophone sounds		2	2		2	2	2		1	2	**13**
Clean/Light overall sound	2	2		2	2	1	1	1			**11**
Clear rhythm		1	1	1	2	1	2	1	1	2	**12**
	6	**9**	**9**	**9**	**9**	**8**	**7**	**4**	**7**	**7**	

Appendix III - Turn Event Sketches

This appendix contains visual representations of the audio-tactile sketches of different generations. The two auditory and four tactile channels are represented by one row each. A timeline runs along the x-axis of the table.Stimuli are represented by squares on the rows, their position on the x-axis representing when in time they appear. The thickness of the squares' borders represent the amplitude of the stimulus, the thicker the border, the higher the amplitude. The roundness of the corner's square represent the attack of the stimulus. Rounder corners means slower attack while sharper corners means faster attack. The auditory stimuli's relative frequencies are represented by their position in the y-direction.

An example can be seen below:

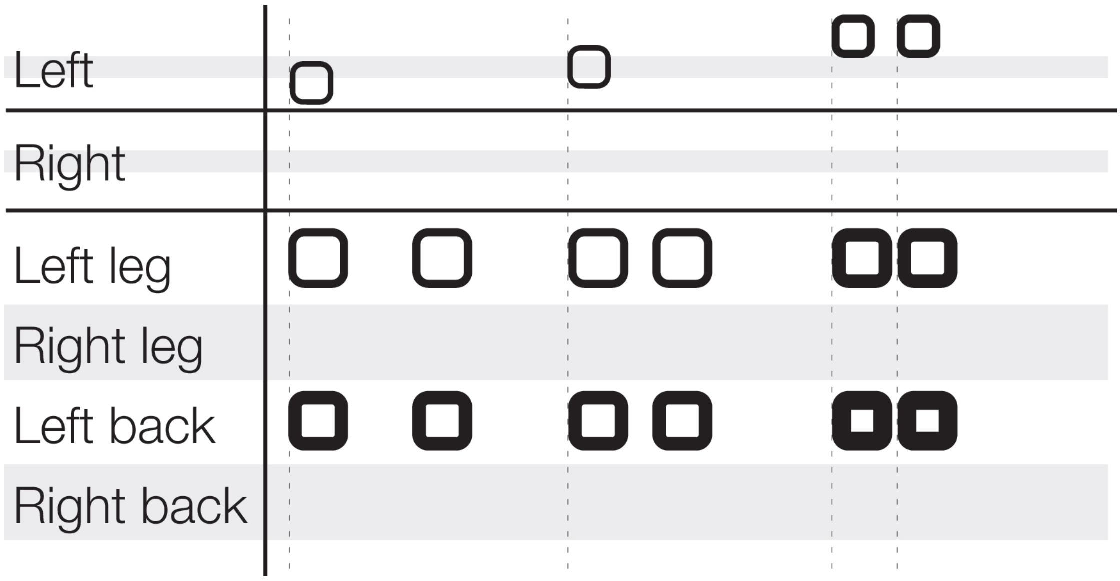


See the following pages for representations of the audio-tactile concept sketches, all generations of one concept are presented on the same page to allow for easily seeing the changes between iterations.

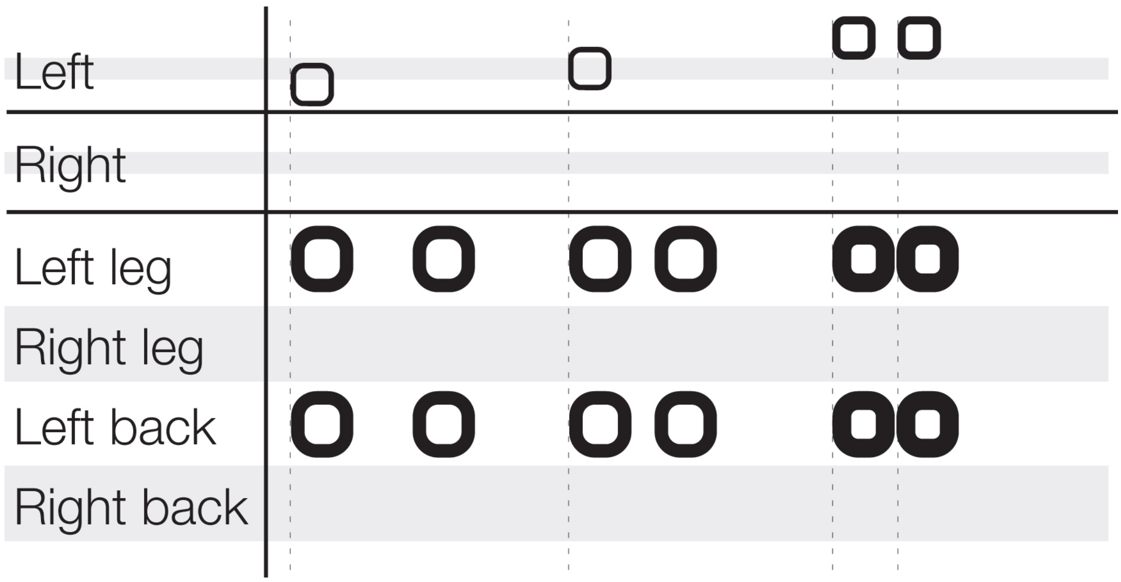
Turn Event - Concept A (left turn)

Generation 1

Generation 2

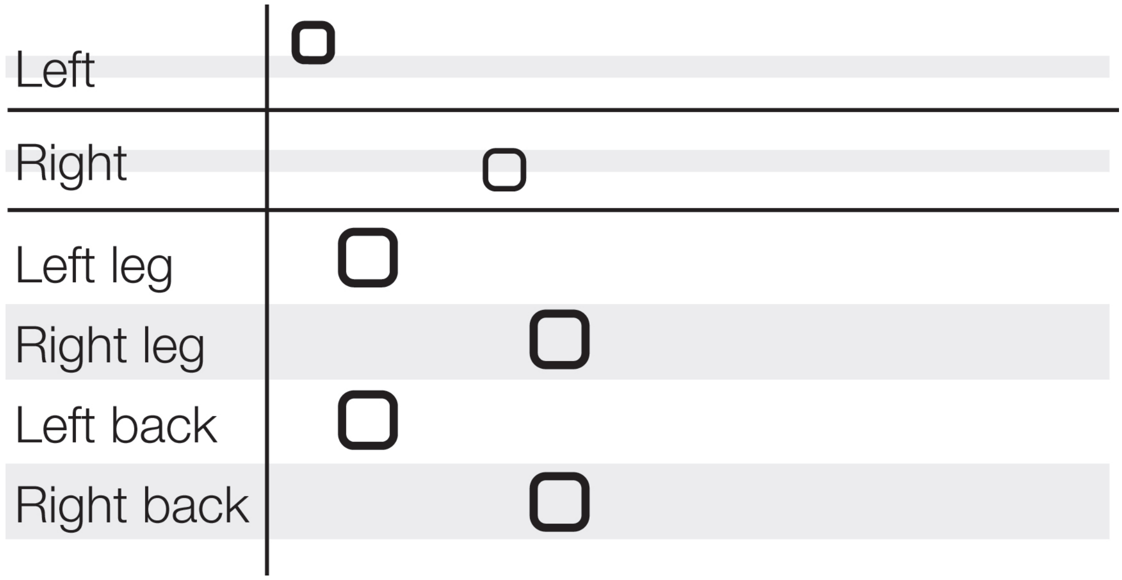


Generation 3

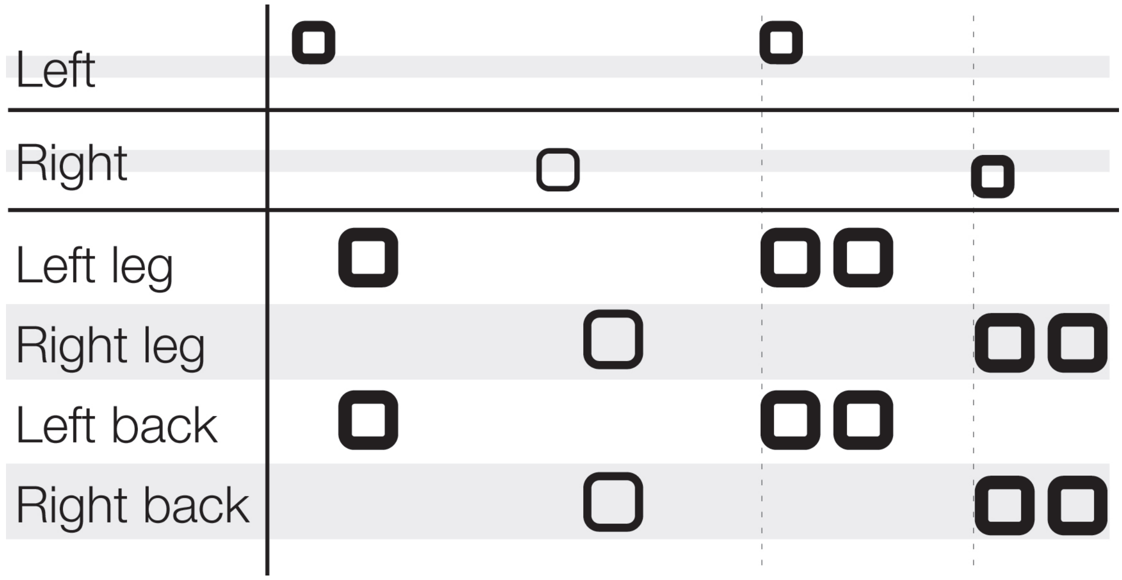


Turn Event - Concept B (two turns, left/right)

Generation 1

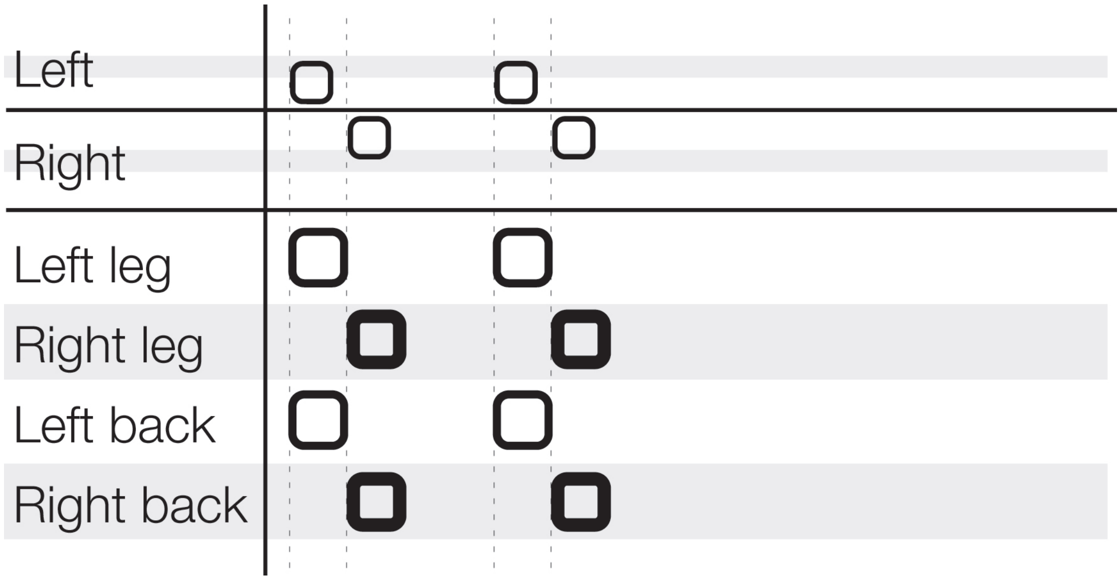


Generation 2



Turn Event - Concept C (right turn)

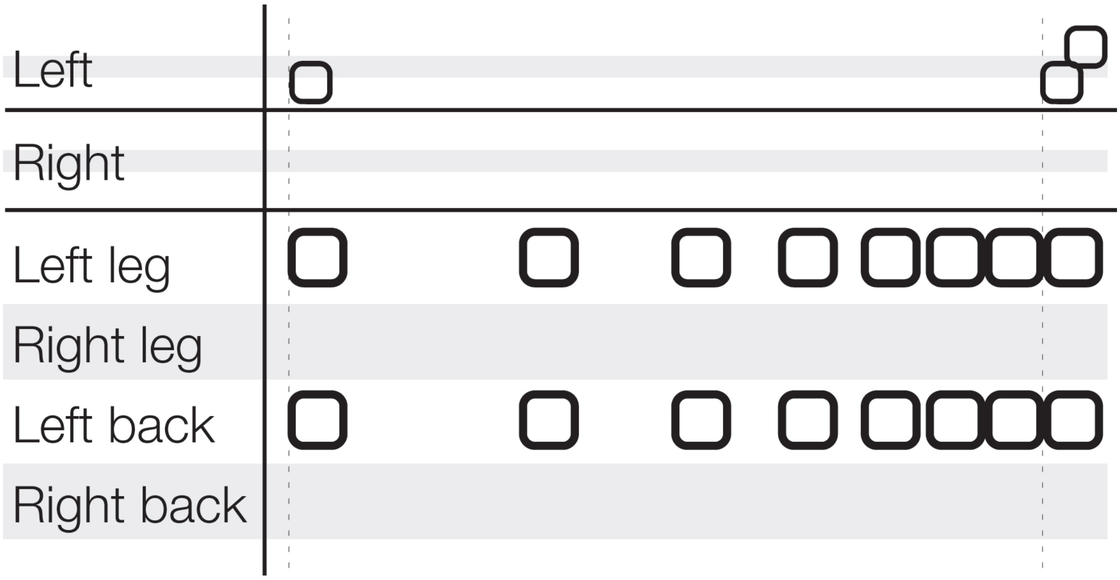
Generation 1



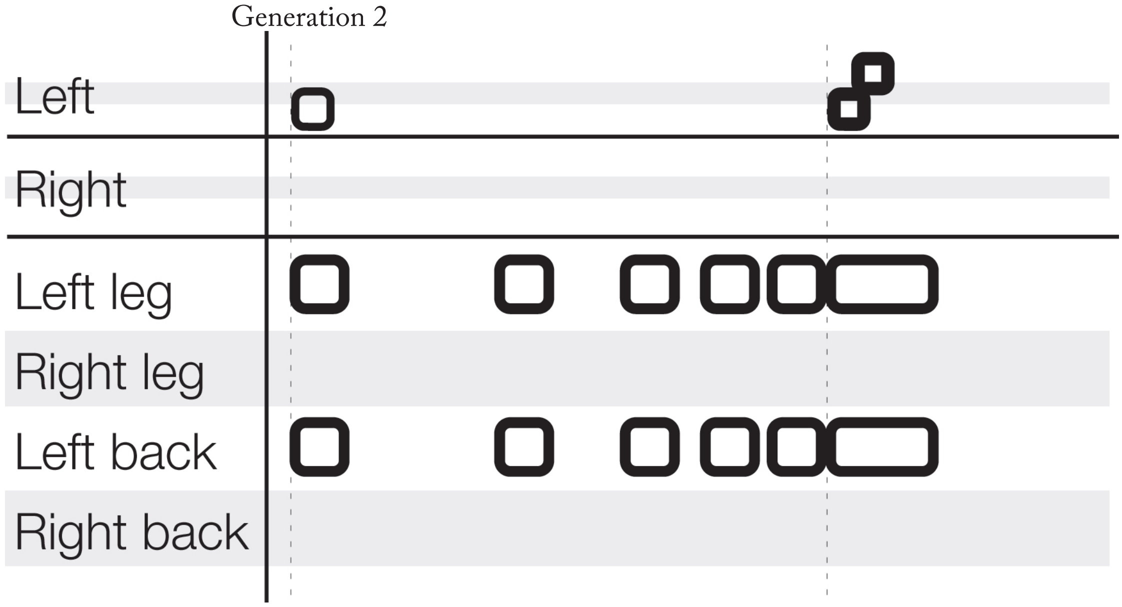
Concept scrapped

Turn Event - Concept D (left turn)

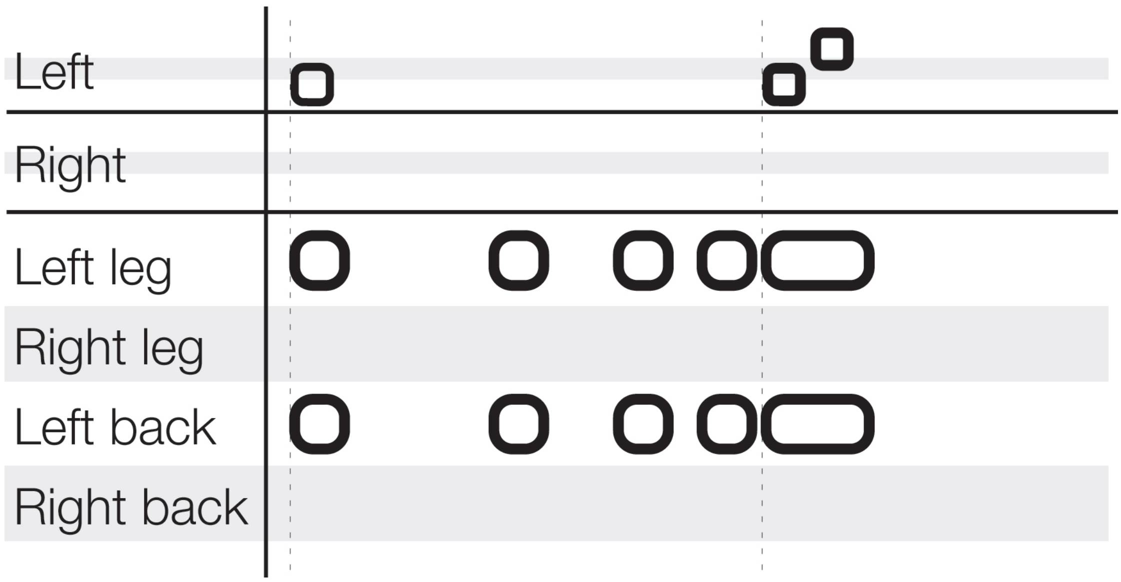
Generation 1



Generation 2

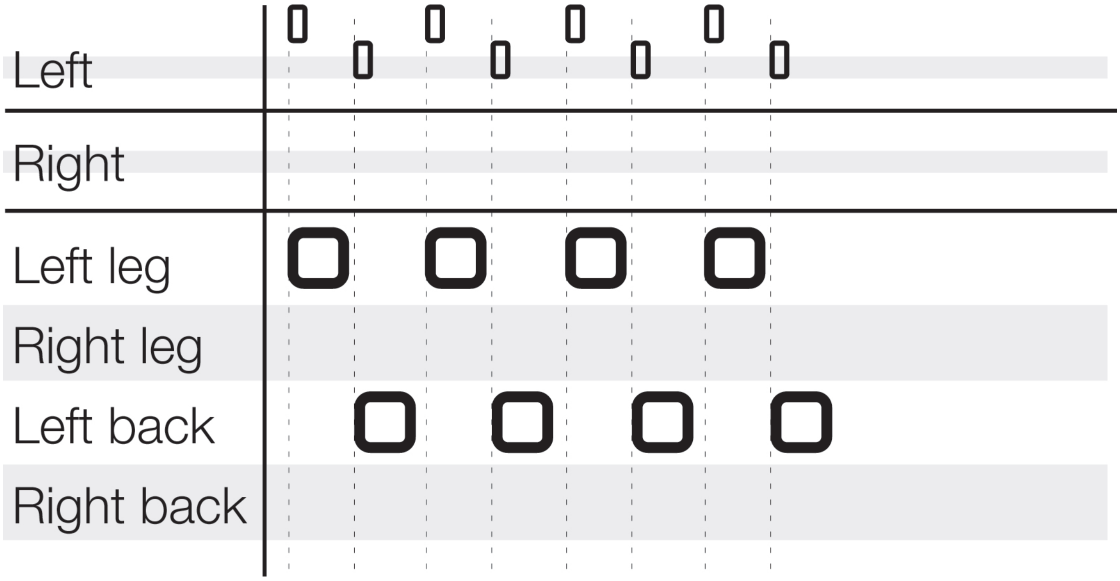


Generation 3

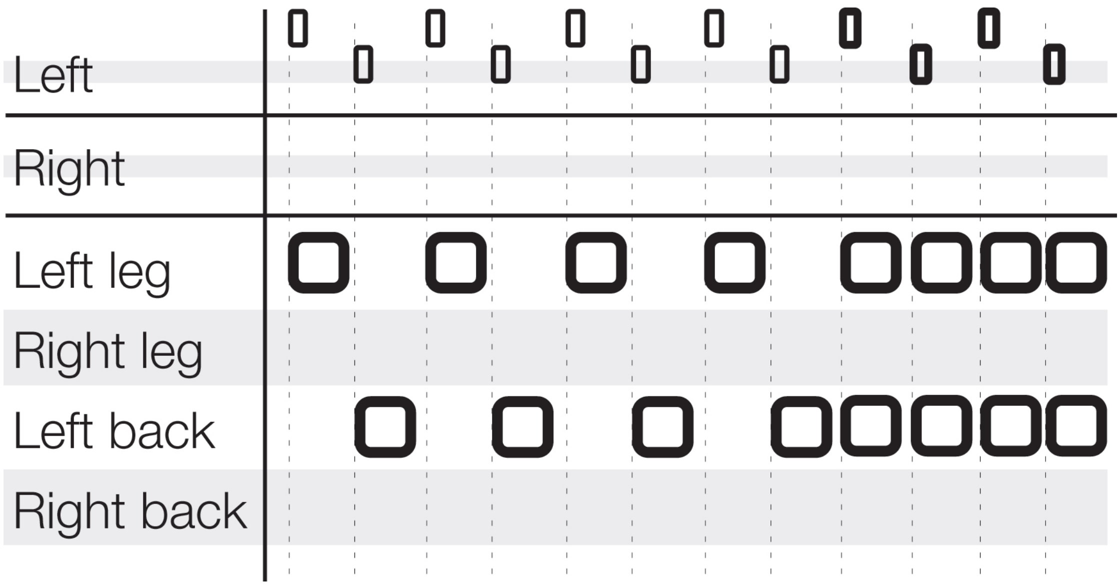


Turn Event - Concept E (left turn)

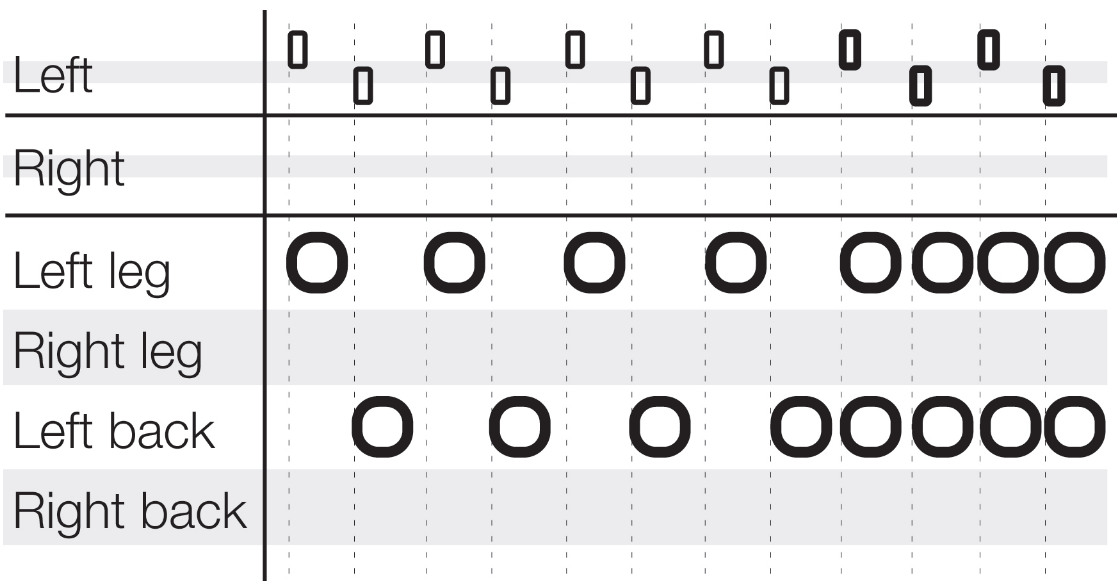
Generation 1



Generation 2



Generation 3



Appendix IV - KJ Analysis Results

(Transcripts from interviews are in Swedish)

Turn Concept A KJ Analysis - Evaluation 1

Tactile stimuli
- Vibrationen i benet var klockren.
- Vibrationerna hade en bra nivå.
- Didn't feel the vibrations at all. (After I increased intensity to about 5 markers on the amplifiers he felt the leg but the back only a little bit.)
- Vibrationen kittlas lite (men han är ganska kittlig). Lite lägre frekvens skulle nog vara behagligare, med högre nivå då istället. Inte helt lyckad placering av taktila zonerna under benen.
- Gillar taktila stimulin. Men själva signalen och placeringen just nu är lite irriterande.
- Vibrationerna uppfattas sämre i ryggen än under låren.
- Vibrationerna kändes tydligare i låren.

Summary of relevant aspects for next iteration
- Increase vibration intensity in back zones

Cognitive Aspects
- De tre stegen var bra för att man blev lite förvarnad.
- När det blev två toner fattar man snabbt att det är då man ska svänga även om det inte är helt intuitivt.
- Kände av att intensiteten ökade med urgencyn så att säga.
- Uppfattade att det var två ljudsignaler när det skulle svänga.
- Gillar det informationsmässiga ljudet, kopplar det till typ announcments på flygplatser och i flygplan. Gav en tydlig hint om att nu kommer det nåt man ska uppmärksamma.
- Lagom nivå av urgency, tydligt att det var information och inte någon panik eller varning av något slag.

Summary of relevant aspects for next iteration
- The concept of an early notification of upcoming turn is good
- Keep a clear difference between "upcoming turn"-notifications and "turn now"-signal
- Earcon/timbre relating to information announcments at airports etc might be good to keep as it makes user expect information to come
- Keep the perceived urgency at this level, signals information, and not "panic/warning".

Direction
- Uppfattade riktningen främst genom vibrationer under låret. Uppfattade även att ljudet låg på högersidan.

- Uppfattade att svängen skulle ske åt höger. Kände att han missade kurvan (jag laddade fel scenario så att det var en vänstersväng) eftersom det inte gick att svänga åt höger där.

- Riktningen var tydlig både i ljuden och vibrationerna.

- Hörde signalen och vibrationer på högersidan.

- Mycket tydligt vilken riktning det var.

- Fattade att det var sväng åt höger som gällde även om det inte var helt klart. Mestadels pga vibrationerna som jag förstod det.

Summary of relevant aspects for next iteration
- Keep the concept of communicating direction through both audio and vibrations

Auditive stimuli:
- Lagom ljudvolym.

- Lagom intensitet på både ljud och vibrationer.

- Ljudsignalen var lite låg nivå.

Summary of relevant aspects for next iteration
- Perhaps increase volume of auditive stimuli slightly to accommodate both the ones liking the volyme now, and the ones thinking the volume was slightly too low

User experience
- Kändes ganska bekvämt och passande för situationen.

Change Log:
- Increased vibration intensity slightly in the back zones

- Increased the difference in time between the two vibration pulses, relatively between the three different parts

- To make the difference between the three parts more clear and thus communicate the change in urgency more clearly (also in line with the general conclusions from the KJ analysis, to make a clear distinction between preparation and turn-now)

Turn Concept A KJ Analysis - Evaluation 2

Auditive Stimuli
- Ljudvolymen var också bra, hördes, men störde inte

Tactile Stimuli
- Kände bara höger sida i ryggen, inget under benet
- Vibrationerna kändes lite svagt, men inte obehagligt
- Vibrationerna kändes rät t bra
- Kände vibrationerna mest i ryggen tror jag
- Vibrationerna kändes helt ok, inte obehagliga
- Kändes lite som en elektrisk stöt, typ ett elstängsel. Kanske p g a att vibrationen kändes väldigt högfrekvent. Jag tyckte det kändes lite obehagligt.

Direction
-Jag fick en känsla av att det var åt höger jag skulle
- Kände att både vibrationer och ljud kom på höger sida
- Riktningen kände jag via vibrationerna främst, fast jag hörde också att ljudet endast kom från höger
- Interpretation of Possible Communicated Event
- Kanske lagom för mindre akuta grejer
- När man vet att det är ett navigationsstimuli skulle jag tolka det som 'sväng höger'
- Den passar ju inte till ifall något skulle hoppa framför bilen, den är för klen för det
- Typ LDW skulle den nog passa för
- När du säger navigation skulle det kunna vara att jag närmar mig ett mål, det vore ju positivt

Interpretation of Parameters
- Högre ton i tre steg tolkar jag som att det blir mer och mer uppmärksamhetskrävande
- Tolkar de tre stegen som något belönande, det går mot mer positivt, stigande toner, dur-ackord
- Jag fick en känsla av att det blev mer och mer "nu är det dags", via tonhöjden
- Den andra tonen känns som att det är högre urgency relativt först
- Inte helt intuitivt vad stimulit ska säga

tConclusions
- The concept seems to work well overall
- The area which could be improved is the tactile stimuli. The following issues should be improved:
- Make vibrations better perceived in the legs
- Increase intensity slightly - performed
- Consider tactile zones placement
- Design the vibration pulses to be perceived as more pleasant
- Slower attack for vibration pulses - performed

- Lower frequency?

Based on this, the concept seems to be the most promising concept together with Turnprep. This concept should be developed further regarding the tactile stimuli for the next generation, to hopefully

Turn Concept B KJ Analysis - Evaluation 1

Tactile stimuli
- Här kändes vibrationerna också ganska bra i ryggen.
- Samma grej här med att det kittlas under benen.
- Vibrationspulserna i ryggen känns väldigt dåligt.
- Efter spelning av stimuli flera gånger uppfattas vibrationer både höger och vänster.
- Vibrationerna här var lägre styrka jämfört med förra gången. Den högra sidan var ok men den vänstra var väldigt svag.

Summary of relevant aspects for next iteration
- Slight increase in vibration intensity for back zones

Cognitive Aspects
- Fattade att det gällde vänstersväng först och sen högersväng.
- Bra som förberedande för att det kommer två snabba svängar.
- Lite förvirrande att båda vibrationerna kommer innan svängen. Hade varit enklare ifall den andra vibrationspulsen kommit efter att man gjort första svängen.
- Det blev förvirrande, innan jag svängt vänster så skulle jag svänga höger.
- Om man vet om det så funkar det jättebra, annars kan det vara svårt att tolka det som en vänstersväng följt av en högersväng.
- Tolkar det som att köra vänster och sen höger. Men vibrationerna kom för snabbt efter varandra så att det kändes som ett varningsljud eller liknande mer än en svängsignal.
- Skulle nog vilja ha detta innan jag kör in i korsningen, men sen vilja ha de individuella svängarna precis innan de kommer. Skulle kunna vara en variant.

Summary of relevant aspects for next iteration
- Slightly bigger pause between stimuli for the two turns to make it less confusing and emphasize that it is two separate turns
- Consider to have this before as a heads up, and then give more intense signals when it is time to turn
- Find better scenario in simulator to evaluate

Direction
- Eftersom det spelades i de öronen så fattade han riktningen, kände även vibrationerna.
- Uppfattar att man ska svänga vänster. Uppfattade inte högersidan först.

Auditive stimuli:

- Tyckte att även denna hade fina och tydliga ljudsignaler som förra. Kanske att den går upp på slutet som gör det

- Hörde inget ljud i vänster öra (har hörselskada).

- Lagom intensitet i både vibrationer och ljud.

Summary of relevant aspects for next iteration
- Keep multimodality in communication of direction

User experience
- Skulle nog inte reta sig på varken stråkar eller pianoljud. Så länge det inte är ”tokiga” ljud så retar man sig inte på dom så mycket.

- Både ljud och vibrationer kändes bekväma. Kändes skönt att ljudet kom lite innan och vibrationen efteråt.

Change log:
- Increased time span between stimuli for each turn

- To make it more clear in communicating that it is two separate turns

- To avoid confusion by letting driver receive stimuli for both left and right almost simultaneously

- Increased relative difference in amplitude between first and second turn - both for tactile and auditive stimuli

- To more clearly communicate a higher urgency(distance) for the first turn than the second

- Modified the concept to consist of two parts

- To include the former stimuli sketch as a heads-up, and then two separate stimuli communicating when to turn

- Heads-up part consists of one tone and one vibration stimuli, in sequence, turn-now part consists of one tone and two vibration pulses, with the first one being simultaneous with the tone

-To create a difference between heads-up and turn-now in urgency

Turn Concept C KJ Analysis - Evaluation 1

Tactile stimuli

- Vibrationerna känns ju väldigt tydligt. Känns något tydligare i benen än på ryggen.
- Känner i ryggen sämre än under låren.
- Känner vänster rygg och höger lår, men ingen annanstans. Känner allt utom vänster lår efterföljande gånger.
- Skulle vilja ha kraftigare respons i vibrationerna. Ljudet däremot vill man ju inte ha för kraftigt för då kan man tro att det är en varning.
- Fick en svag vänster och sen till höger.
- Vibrationerna var lite svaga på denna.
- Vibrationerna kom lite för snabbt efter varandra.

Summary of relevant aspects for next iteration

- Increase vibration intensity in back zones?

Cognitive Aspects

- Efter förklaring så skulle man lätt lära sig den. Den är väldigt tydlig och säkert lätt att lära sig.
- Dock kändes det bättre ju fler gånger jag provade den. När jag fick veta vad det var, så kändes det faktiskt ganska bra.
- När man tänker efter så känns det ju logiskt.
- Ska man tolka det taktila så skulle det nog vara att man ska svänga vänster i så fall..(fel)
- Gällande vector så uppfattade han vibrationerna vänster/höger solklart, men missade meningen.
- Det blir förvirrande med pulser både till vänster och höger.
- Man uppfattar surrningen mer än ljudet.
- Förvirrande att det är vibrationer både på vänster och högersidan.
- Eftersom det vibrerade i båda axlarna uppfattade jag det som att jag skulle stanna. (Har lite svårt att manövrera i körsimulatorn)
- Blir lite svårt när man inte vet vad man ska vänta sig.
- Gillar den kanske mer som filbyte än som sväng.

Summary of relevant aspects for next iteration

- In general this concept seems to confuse people very much, at least initially. It did not work at all as a concept for turning, it seems. A possibility could be to try it as a change lane-stimuli instead.
- I believe there is a risk that the tacton being repeated twice, is perceived as once long tacton, due to a quite short distance in time between the repetitions.
- A bigger difference in amplitude between the vibrations on the left and right side might make it less confusing for the user to receive vibrations on both sides

Direction

- Hörde bara plinget i det högra örat, svängde därför höger.

- Tolkade det som en vänstersväng och sen högersväng (fel)

- Första gångerna fick jag inte känslan av att det pekade åt höger, utan blev förvirrad att det vibrerade på båda sidor. Dock kanske det skulle vara större skillnad i amplitud mellan höger och vänster.

Summary of relevant aspects for next iteration
- This is the big problem with this concept, the communication of direction is unclear

Auditive stimuli:
- Fint ljud även om jag inte riktigt förstod vad jag skulle göra.

- Klart och tydligt informationsljud, gillar mycket. Visar att det kommer information.

- Kändes som att det var ljud i båda öronen först och sen bara till höger.

Summary of relevant aspects for next iteration
- The earcon/timbre in itself seems to be quite liked by users

User experience
- Koherent mellan ljud och vibration, kändes som bra kvalitet och passande för situationen.

Change log:
Decided to scrap concept

Turn Concept D KJ Analysis -Evaluation 1

Tactile stimuli
- Vibrationerna kändes på denna.
- Vibrationerna kändes lika tydligt i benen som i ryggen.
- Vibrationsstyrkan i skiss 1 kändes starkare. Skiss 1 kändes på något sätt tydligare.
- Vill ha mer intensitet i vibrationerna. Särskilt när man kör bil med vibrationer från motor och väg så behövs det nog högre intensitet. Men även nu har han svårt att uppfatta dem.
- Pulserna skulle behöva ha snabbare attack så att de märks mer.
- Kände inte vibrationerna bra alls, de borde vara högre intensitet på dem.

Summary of relevant aspects for next iteration
- Higher intensity in vibrations

Cognitive Aspects
- Den gillade jag! Gött att vibrationerna ligger kvar hela tiden så att man vet att man inte missade. Och sen ett nu är du framme, här ska du svänga, ljud.
- Absolut bättre att inte blanda in båda sidor, här är bara ljud och vibrationer på ena sidan. (Refererar till skiss 3)
- Förvarnade att jag skulle svänga vänster.
- Den var fin men jag tror att jag tycker att den kommer för tidigt första gången. Man kanske kan korta ner den lite. Gillade ändå att det var en auditiv signal som indikerade i början och sen kom tillbaka auditivt när svängen kom, och däremellan bara vibrationer.
- Sketch 1 upplevdes som tydligare än denna.
- Uppfattade det första som att han skulle svänga och att sen att han var framme (första gången råkade jag trigga för tidigt och även glömma att förklara grundidén med stimulit).

Summary of relevant aspects for next iteration
- Continuously updating user of distance to turn seems promising
- Make the entire length of the concept a bit shorter.

Distance
- Bättre att kommunicera avståndet på det här sättet jämfört med ”raka” avstånd. Smart. Det kan vi klappa oss på axeln för att vi kommit på.
- Väldigt intuitivt att mäta avstånd på det sättet.
- Det funkar med att kommunicera avstånd såhär, det är ok.
- Förstod att vibrationernas mellanrum som minskar motsvarar minskat avstånd till svängen.
- Uppfattade att snabbare pulser menade närmare till svängen, det funkade bra.

Summary of relevant aspects for next iteration
- This way of communicating distance seems intuitive and promising and should be further developed.

Direction
- Tydligt dock att man ska svänga vänster.

Auditive stimuli
- Både ljud och vibrationer kändes tydliga.
- Ljudnivån kändes möjligtvis lite låg kanske. Att kunna justera ljudet själv vore en bra funktion, typ som man justerar sätet efter person

Summary of relevant aspects for next iteration
- Perhaps slightly higher volume for audio signals

User experience
- Annars tyckte jag igen att det var fina signaler, koherent, bra. Kändes passande för situationen..

Change log:

Decreased the total length of the stimuli from about 14 seconds to about 10 seconds

Based on feedback from user test 1 and also to try to make the distance-information to "flow more smoothly" and continuous

Change the "turn now"-part of the stimuli to a longer vibration pulse (75 ms compared to the other pulses at 25 ms) instead of three short 25 ms pulses.

My hypothesis is that this will create an even clearer distinction between the preparing pulses and the turn-now pulses. Also, this uses the reversing sensor analogy even more as these often use a continuous sound when indicating "time to stop reversing". (This is also in line with the general conclusions from the KJ analysis, that the preparing stimuli should be clearly distinguishable from the turn-now stimuli)

Slightly increased intensity in vibrations

To make stimuli more clear to user and avoid risk of it not being perceived by user

Slightly increased amplitude in audio signals

To make stimuli more clear to user and avoid risk of it not being perceived by user

Turn Concept D KJ Analysis - Evaluation 2

Auditive Stimuli
- Förstod inte riktigt plinget i slutet där
- Ett dubbelt pling känns mer uppmärksamhetskrävande än ett enkelt
- Det första plinget kändes lugnt, det andra blev jag lite förvirrad av, kändes som att jag missat nåt

Tactile Stimuli
- Avståndsbedömning i vibrationerna var bra
- Tydlig auditiv signal, och vibrationerna förstärkte detta lite
- Jag uppfattade inte att vibrationerna blev snabbare och snabbare
- Vibrationerna förmedlar en hög urgency, failure eller fara. Amplituden är så hög.
- Nu kände jag [vibrationerna] i benen
- Kopplar fortfarande vibrationerna mycket mer till varning än till navigation

Direction
- Kände av riktningen både genom ljud och vibrationer
- Tydligt att det var vänster. Den kontinuerliga avståndsbedömningen på vänster sida matar på nåt sätt liksom in riktningen
- Den här [skissen] var tydligare både med ljud och vibrationer i riktningen
- Inga tveksamheter alls gällande riktningen

User Experience
- Förberedandet var så tydligt att själva svängen blev lite sekundär
- Tolkar den här betydligt mer som en sväng jämfört mot den förra. Betydligt mer navigationssyftande
- Jag tyckte den var bra
- Den var schysst, mer intuitiva signaler
- Jag kände att det närmade sig någonting
- Kändes lite som att någon var irriterad på en och trummade med fingrarna, eftersom det var vibrationer hela tiden

Conclusions

As this concept uses a quite large number of vibration pulses, it seems there is a risk that the user perceives this as a high urgency event or as somewhat annoying. Possible solutions to this:

Use vibration pulses with a slower attack - Performed

Decrease the number of vibration pulses (would probably make the distance information through the tactile stimuli less obvious) - Performed (one vibration pulse less)

Lower amplitude in vibrations (would however potentially increase the risk of some people not feeling the tactile stimuli)

It seems there is a risk that people do not understand the second auditive signal and are confused by its meaning. However the first signal seems to be understood. Possible solutions to this:

Decrease the volume of the second auditive signal to a level closer to the first, to decrease risk of second auditive signal being perceived as some type of high-urgency warning. - Performed (level now only slightly higher than first signal)

Adjust timing of second auditive signal to suit better in a more natural way with the last tactile stimuli (the one longer than the others) to emphasize their connection better (which is the case for the first auditive signal) - Performed

This concept seems, together with Increasing Intensity, to work the best. Also here the tactile part of the stimuli should be adjusted to be perceived as more pleasant and low-urgency for the next generation.

Turn Concept E KJ Analysis - Evaluation 1

Tactile stimuli
- Missade att det var vibrationer första gången.
- Mer tryck i vibrationerna vore bra.
- Uppfattade att det skulle vara vänstersväng men uppfattade ej vibrationerna.
- När jag väl kände vibrationerna så kändes de tydliga.
- Vibrationen kändes inte så mjukt och fint som det var innan. Kanske att man skulle kunna ta en kontinuerlig ljudkurva och modulera upp och ner istället?

Summary of relevant aspects for next iteration
- Higher intensity in vibrations
- Perhaps make smoother vibrations, or one continuous vibration modulated up and down
- Perhaps make the tactile stimuli vary in frequency instead of in spatiality

Cognitive Aspects
- Kopplar till blinkersljud. Fattade direkt.
- Denna kanske kan vara bättre i tajta situationer där det är svängar frekvent till höger och vänster.
- Finns tillfällen då den är att föredra kanske över den förra, även om jag gillar den förra bättre.
- Tydligt att det var åt vänster och att det var ett reläljud.
- Tydligt, toppen, som en blinkers.
- Förstod inte kopplingen till blinkersljud utan kopplade det mer till ”en gammal moraklocka”.
- Den här kändes bättre än de andra. Man är ju van vid blinkers när man svänger, så hjärnan uppfattar direkt att det är en sväng på gång.

Summary of relevant aspects for next iteration
- Using a commonly known sound that everyone connects to turning seems to be promising and should be examined further

Distance
- Här får man ingen uppfattning hur långt det är kvar till svängen.

Summary of relevant aspects for next iteration
- Concept should perhaps be extended with some type of distance communication

Direction
- Ljudet ur vänster öra var det som mest gjorde att man uppfattade riktningen.
- Vibrationerna förstärker dessutom intrycket av åt vilket håll det är.

Auditive stimuli:
- Hjärnan kopplar direkt med det här ljudet, stor skillnad mot de andra ljudsignalerna.

- Upplevde ljudet mer än känslan.
- Det var ett bra ljud.
- Det var ett ljud som jag hörde bra.
- Riktigt tydligt faktiskt. Kände både ljud och vibrationer.
- Riktigt bra nivå både på ljud och vibrationer, tydligt.
- Det var bättre nu, och blinkersljudet är jättetydligt (efter att först glömt ta på sig lurarna)
- Ljudet tycker jag inte värst vidare om.
- Det tickande ljudet var så överraskande att jag inte kände vibrationerna.

Summary of relevant aspects for next iteration
- The auditive part of this stimuli seems very promising indeed

User experience
- Det kändes inte riktigt som att de hängde ihop.

Change log:
Changed the concept to have two parts. First part has lower amplitude in audio and alternates between left/right tactile zones. Second part has higher amplitude in audio and pulses in both tactile zones at every audio-”tick”.

This to communicate a change in urgency and make it clearer when it is time to turn.

As it seemed the tactile stimuli in this concept were not perceived by more users than for the other sketches, the frequency was changed to 50 Hz (like the other sketches use) instead of 75 Hz that this sketch was now using

Turn Concept E KJ Analysis - Evaluation 1

Auditive Stimuli

- Ljudet var helt ok, men inte “wow”. Det var som att det påkallade uppmärksamhet.
- Typiskt blinkersljud åt vänster.
- Jag kände mig lite förvirrad (av ljudet) eftersom jag kände “jag borde blinka nu” och “det här ljudet ska jag själv initiera”.
- “Är blinkersen igång nu?” tänker man. Dock är det ju väldigt tydligt kopplat till svängande.
- Jag kopplar inte ljudet till något annat, ingen särskild association (jfr tidigare koppling till varuhus)
- Meningen var klockren, men det blev förvirrande eftersom man kunde tro att man råkat stöta till blinkersspaken.
- Blinkersen gör det väldigt intuitivt att svänga vänster.

Tactile Stimuli

- Frekvensen i vibrationerna känns lite hög.
- Vibrationerna känns väldigt obehagliga.
- Skulle kanske kännas bättre att vibrationernas intensitet minskade istället, eftersom vibrationerna i bilen ökar/minskar med hastigheten.

Cognitive

- Kände riktningen både genom ljud och vibrationer
- Mismatch. Känns som “varning” taktilt och “sväng vänster” auditivt.
- Tolkar det som att urgencyn ökar vibrationsmässigt i den andra delen av stimulit.

User Experience

- Lite snällare den här (jfr turnprep).

Conclusions

Like the other concepts, the vibration pulses seem to need to be adjusted to be perceived as “softer” and not as urgent warning signals. Possible solution:

Slower attack - Performed

Using the blinkers sound seems to work well for making people associate to a turning event. The blinkers sound however does confuse people since they are confused whether or not the turn indicator is actually activated or not.

Modifying the auditive stimuli slightly, for example in frequency, might distinguish the signal enough from the turn indicator to avoid confusion, but still make people associate it with turning. - Performed (auditive signal is now continuously modulated in frequency from low to high which will distinguish it from a turning indicator signal as well as communicate a continuously increasing urgency)

Appendix V

Proposed Methodology: Quick Iterative Multimodal Sketching - Adjusted

Overall Methodology Summary

This proposed process is based on the user-centered visual product design processes that are quite commonly used today. The general idea is to start with the users and their needs, and based on that create stimuli sketches which are then continuously evaluated with users and modified based on the evaluation results. Iterating this process of sketching, evaluating and modifying the sketches based on the evaluations will continuously refine the stimuli sketches.

This process is meant to be quick and iterative, using evaluations with users from the beginning of the process to avoid spending much time creating stimuli sketches that might potentially prove to be worthless later.

The overall layout of the process is as follows:

- Pre-study - Consists of collecting information about who the users are, which technological limitations need to be considered, any reference stimuli that need to be considered for the users' holistic experience, brand aspects and a literature study.
- Creating a starting-point for sketching - Using the information from the pre-study to create a list of requirements, a list of possible ways to fulfill the requirements and an analysis of brand-specific stimuli components.
- Iterative sketching and evaluation - Audio-tactile sketches are made and then evaluated. The sketches are then modified again based on the evaluation results.

Pre-Study

The pre-study is the foundation of this proposed process. The pre-study results are the input to the

User Profile

As part of the first step of the process it is important to gain an understanding for the users that will perceive the stimuli while driving. Although the target user group in this case is very large and thus hard to narrow down to a very specific user profile, it is still beneficial to have a profile of the users, even if it is quite loosely defined. It can serve as data to base requirements upon as well as functionality ideas. The information can also be used to decide which usability component should be optimized (see chapter 5 for more information on usability components).

An example of data to have in the user profile:

- Gender
- Age span
- Physical characteristics
- Cognitive characteristics
- Situation characteristics
    - Physical factors: noise conditions, vibrations, etc
    - Cognitive load factors: simultaneous tasks, etc

Technological Limitations

It is important to establish the technological limits (limitations in the hardware that will be delivering the stimuli) to be able to let the requirement listing reflect these limitations, thus ensuring that the final stimuli concepts will be adapted after the system's limitations.

Reference Stimuli

It is desirable that the user gets a coherent experience of the audio-tactile stimuli communicating different events. The reason for this is that it helps create a premium impression, but also so that they all align with the brand identity. In order to achieve this a reference stimuli is needed to compare to. Retrieving audio clips of the current auditory stimuli used in the car allows great possibilities to align the auditory parts of the audio-tactile stimuli with it and consider the holistic experience of the user when driving.

If retrieving audio clips of the auditory stimuli used in the car today is not a possibility, or if more reference material is desirable, the sound heard in tv-commercials for the brand's car models could also be used as reference in the brand identity aspect, as commercials can be expected to be well thought through and aligned with the brand identity.

Core values & Brand Identity Aspects

A list of the brand's core values and/or a list of attributes expressing the brand identity are very good to have as guidelines for the brand identity aspect further ahead in the process, if available. A list of attributes might not always be publicly available but core values are usually displayed for example on a car brand's website. Although this is a very subjective matter, a list of core values and/or attributes will allow for some type of evaluation of the user experience and brand identity aspect later in the process.

Especially so called premium brands often put an emphasis on the driver's user experience, through auditory signals as well as the sound emitted when closing a car door. The goal usually being to evoke specific desired feelings and associations in the driver.

Literature Study

Performing a literature study to find research that indicate design guidelines for audio-tactile stimuli, for example suitable physical parameters to communicate certain properties, is important to avoid doing work that someone else has done before you. It also gives the design process a solid foundation in proven science.

Creating a Starting-point for Sketching

Requirements Listing

The results from the pre-study are then used to create a listing of requirements for the audio-tactile stimuli. The requirement listing is to reflect all relevant information retrieved during the pre-study, which means that it should include the following types of requirements:

- User-related requirements
- Situation-related requirements
- Technological requirements
- Brand-related requirements
- Requirements derived from findings in previous relevant research
- Any event event-specific requirements

Obviously the requirements will depend on which type of event that the stimuli are to be designed for, and all of these requirement types may not always be relevant.

Morphological Matrix

The purpose of using a morphological matrix in this process is documentation of different solutions found in literature but also documentation of solutions from brainstorming sessions. It is suitable to perform some type of idea-generation session during this phase, for example brainstorming. Some suggestions for topics to use in brainstorming sessions are:

- Associations - Which auditory (auditory icons) and tactile stimuli are there that could make the driver intuitively associate to something desirable in this event? For example, the sound of screeching tires could perhaps make the driver intuitively think of braking.
- Core values - Which metaphors are there to the core values? For example, if a brand has Sustainability as a core value, could perhaps different sounds from nature such as wind rushing through leaves or ocean waves be metaphoric ways to communicate this?

Just sitting down and experimenting with the sketching tools is also likely a very good way of coming up with ideas for the morphological matrix. It is strongly suggested that some time is spent for free and creative audio-tactile sketching with this purpose.

Another purpose for using the morphological matrix is to facilitate keeping a wide focus to consider many different solutions to reaching the required functionality and avoid focusing on one or a few types of solutions (potentially missing others) before they have been evaluated.

Design Format Analysis Applied to Sound

Design Format Analysis is a method that reviews the occurrence of chosen design features among a range of products of the same brand. The method, developed by Warell (2001), is meant to be used to analyze which visual cues in products that construct visual recognition for a brand.

As part of this project is to try to modify and apply methods for visual product design to sound design, an attempt at this was made with the Design Format Analysis. This method is to be applied to the reference stimuli to analyze them from a brand identity perspective. The goal being to analyze which auditory cues that could cause auditory recognition for a brand.

The DFA applied to sound only creates useful output if the reference sounds used have adequate complexity. Examples of sound that do not work very well could be standard warning sounds, such as the reminder sound to put on the seat belt. However, more complex polyphonic sounds work better. Also, it should be evaluated whether the event designing for is suitable for a more complex sound. If not, it might be difficult to incorporate any sound elements identified through the DFA in a stimuli meant for that event. In general, very low-urgency events are the ones benefitting most from using the DFA for sound, for example the welcome event.

Iterative Sketching & Evaluation

Sketching

In visual product design, sketching is a very important tool. It is fast, inexpensive and allows for easy communication and modification of ideas or concepts. A sketch of a product can also easily be placed in an environment using photo editing software to get a feeling for how it is experienced in its natural environment, for example a sketch of a toaster can be placed in a photo of a kitchen counter.

There is obviously a need for an equivalent of visual sketching in audio-tactile design. Today's digital audio editing software provides a quite suitable way to create audio-tactile stimuli in a similar way to drawing a sketch. Using speakers or headphones, this software also provides an easy way to listen to the auditory stimuli, the equivalent of looking at a sketch. However, this type of software provides no way of "experiencing" tactile stimuli, i.e. to use the visual sketching parable, there is no equivalent to looking at the sketch. Also, when creating audio-tactile stimuli for automotive purposes, using this type of software alone does not allow for evaluating the audio-tactile sketch in its natural environment.

A way to solve the problem with not being able to experience tactile stimuli is building a device capable of delivering tactile stimuli and connect it to the audio editing software. Through using some type of mixer table it is possible to get multiple audio channels as well as multiple tactile channels. This in combination with a driving simulator built from a PC with driving simulator software and a gaming equipment in the form of a steering wheel, pedals and gear lever creates an audio-tactile equivalent of looking at a sketch in its natural environment for automotive-related stimuli sketches.

This type of improvised driving simulator is of course not as realistic as more advanced driving simulators used by for example universities and car manufacturers for research, but it is however much cheaper, making it possible for a design team to have permanent access to it. This is an important part of creating an audio-tactile equivalent to visual sketching, as it is impossible to perform sketching without constantly and simultaneously looking at the sketch being made. An advanced and expensive driving simulator is likely to be frequently booked for research etc and thus not as available to a designer or design team wanting to use it for audio-tactile sketching.

User Evaluation

Participants

As this is supposed to be a fast and iterative process, the number of test participants should be kept relatively small. In usability research there is a well-known study showing that 5 test participants will show you 80% of the usability problems for a system (source here), although this is not strictly a classic usability case, it is reasonable to assume that the principle should work quite well for this purpose as well.

It is also important to have participants both that are and are not professional in the area of interaction or sound design. Further it is also desirable to have different body types represented among the users as both seating position and body mass are likely to affect the perception of the tactile stimuli.

Type of data to retrieve in evaluation

With such a small number of participants, there is no way of gaining statistically secure quantitative data. The user evaluation is will focus on gaining qualitative data, to understand *why* the subjects perceive the sketches as they do. This type of qualitative knowledge is also easy to apply when sketching the next generation of sketches in the next iteration. Quantitative data telling you that Concept A works much better than Concept B is not as easy to implement. However if needed, complementing the unstructured interview with a short closed question or two might be suitable in some cases, and also allow for fast analysis. It is also important to note along with the answers of each participant whether he or she is a professional within the area, and approximate body type, to be able to draw conclusions based on this in the analysis later.

How to carry out the evaluation

The test user will be informed of which type of event the sketch is designed for. How detailed this information is depends on which factor is to be evaluated. To use usability terms, is the guessability the important factor, or the learnability? If guessability is to be evaluated, the information about which type of event needs to be very limited. If learnability is more important, the participant can be informed more specifically before each scenario about which event the upcoming sketch is about. It is important to let the participants try some basic tactile stimuli before the actual evaluation starts, to avoid that the participant is startled by the sudden and unexpected tactile stimuli he or she is likely not used to.

The participants are then to drive in the driving simulator while the stimuli sketches are triggered in suitable scenarios. If a turn event sketch is to be evaluated, it is important to use a four-way crossing to avoid that the participants choose which way to turn based on visual impression rather than the audio-tactile stimuli. After this, a short and unstructured interview with the participant is performed. The interviewer mainly tries to mostly listen to what the participant has to say to not influence his/her response more than needed. But the interviewer also has a checklist containing topics to cover, and if needed will move the discussion towards these topics in a casual way.

Example of discussion topics that are suitable to cover (should be adapted to the requirement listing):

- Perceived level of urgency
- Perceived direction (if any)
- Perceived as pleasant or annoying?
- Clarity/Ambiguity of the sketch
- Any associations made by the participant?
- Was (relevant aspect) perceived through auditory or tactile stimuli?

Analysis of Evaluation Results

Mostly, although depending in part on the number of sketches in the evaluation, the result of an evaluation will be quite large amounts of qualitative data. As described before, qualitative data is easier to use to modify the sketches, but it is more time-consuming to analyze. For data analysis of the evaluation results a KJ analysis was chosen. One of the major benefits with the KJ analysis method is that it is a quick way to structure quite large amounts of verbal data. The results of a KJ analysis are different groups of comments from the evaluation participants, each containing comments on one specific topic

A number of conclusions are then drawn based on each group of comments. These groups of comments should also be cross-referenced to see if any conclusions can be made based on the participants' knowledge in the area and body type. These conclusions will then form the basis upon which modifications will be made to improve the sketches. Alternatively, if a sketch receives much negative comments and its general concept seems to have more problems than can be fixed through modifications, the decision to stop working on this concept should be considered.