



MALMÖ UNIVERSITY
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Navigating through haptics and sound

Exploring non-visual navigation for urban cyclists to
enhance the cycling experience

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Interaction Design
Two-year master
15 credits
Spring semester/2019
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Abstract

Bicyclist are increasingly shaping the picture of urban traffic. With regard to guided navigation through urban areas, navigation systems that are designed for this type of traffic participants do not offer a satisfying solution. Voice instructions are often perceived as annoying and far too detailed. In addition, the usage of headphones to hear these instructions reduces the hearing and localization of environmental sounds significantly. Visual information on the other hand, draws the attention too much away from the main traffic situation. This effects the ability to react to and interact with other traffic participants and the surrounding and results in a feeling of insecurity.

This thesis investigates how acoustic and vibro-tactile signals can be used to provide cyclists with necessary navigation instructions while maintaining the ability to perceive ambient sounds and keep attention to the environment. In addition, the focus is placed on the experience of guided navigation with a non-visual, multi-sensory system.

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1. Introduction

In order to orientate and move in space, vision is one of the most important senses and the sense we rely on the most. Therefore, reacting to events that are happening around us requires a high degree of visual attention to our surroundings. Besides our sense of sight, the sense of hearing plays an equally important role to react to the environment. Especially navigating in urban space requires a high degree of attention to the surrounding area and the traffic situation. No matter what kind of traffic participant, there is a continuous, mostly unconscious, interaction happening between all of them. Since everybody is in motion, ongoing change of the surroundings occurs. Each traffic participant constantly needs to be able to react to and interact with one another. The more a traffic participant gets distracted, the lower the attention to the traffic scene.

Urban spaces are characterized by dense and complex traffic. The high number of traffic participants requires fast responses in the interaction with each other to ensure a certain degree of safety. This counts especially for weaker and unprotected traffic participants like bicyclists. Cyclists move at a higher speed than pedestrians and interact more closely with cars, depending on the local cycling infrastructure. As a result they are subject to a higher accident risk (Kraftrad- und Fahrradunfälle im Straßenverkehr, 2018).

Comparable statistics on the usage of bicycles in European cities are unfortunately not existent today. Anyhow, a comparison between statistical reports from different years and countries indicates that the number of cyclists is increasing (Support study on data collection and analysis of active modes use and infrastructure in Europe, 2017). There are many reasons to switch to bicycles as a means of transport. They range from fitness training over a relaxed outdoor leisure activity to an active contribution to reduce carbon dioxide emissions. With the expansion of bicycle infrastructures and the availability of bike services, cycling is an attractive alternative compared to motorised transport. The growing supply of rental bike solutions throughout cities that are easily accessible over a smartphone is causing more and more people to use a bicycle to move from A to B. In addition, the ris-

ing number of available “pedelecs” (bicycles with an electric motor which assists the rider while pedalling) makes cycling more attractive for a variety of people. The provision of navigation solutions that are becoming ever more efficient and time-saving need to consider the growing number of cyclists and their need to pay greater attention to the surrounding traffic situation. Consequently, it is crucial to reduce the degree of distraction in navigation systems.

1.1. Research Area

Participation in traffic serves the purpose of navigation. This means moving from a starting point to a destination. In the context of traffic participation, active navigation is the most effective way to reach one’s destination. Today a variety of products and applications for navigation are existing. On the one hand, they make it easier to find the best route according to specific needs. On the other hand, most solutions increase the risk of accidents by distracting from the actual traffic situation and the environment. Navigation systems use primarily visual information to inform about one’s position, the route and provide turn-by-turn instructions. Additionally, directions can be provided acoustically through spoken voice instructions. Conventional navigation systems use the sensory channels that play the most important roles in the ability to react to our environment. In the context of this thesis, the reaction to our environment must also always be understood as the interaction between traffic participants. Especially visual information increase the risk of accidents, as the focus needs to be shifted away from the current traffic situation to perceive the navigation instruction. To reduce the accompanying distraction and to move the attention back to the traffic scene, new technology like Mixed Reality/Augmented Reality (MR/AR) is used (Narzt et al., 2004). In the automobile industry Head-Up displays are nowadays fitted as standard. These navigation solutions still focus on visual information and audio in the form of turn-by-turn instructions. Compared to shorter acoustic signals, auditive spoken information require more attention and take longer time to be understood (Fry, 1975; Klatzky, Marston, Giudice, Golledge & Loomis, 2006). That has effect on the reaction speed. The integration of shorter sounds in navigation systems are in generally not absent but are mainly used as feedback or warning signals. The involvement of other sensory channels is rather seldom present. Recently the inclusion of multi-sensory information has also been

strongly explored in automobile navigation systems (Park, Kim & Kwon, 2017). Non-visual feedback is predominantly explored for guided navigation and obstacle avoidance for vision impaired people (Dakopoulos & Bourbakis, 2010; Jacobson, 1998). In the area of pedestrian navigation, the use of non-visual interfaces has been tested in some projects. Tactile information was provided for example by a mobile phone (Komninos, Astrantzi, Plessas, Stefanis & Garofakilis, 2014; Szymzak, Rasmus-Grön, Magnusson & Hedvall, 2012) or a vibro-tactile belt (Heuten, Henze, Boll & Pielot, 2008; Pielot & Boll, 2010; van Erp, van Veen & Jansen, 2005). The usage of non-visual multi-sensory information for navigation for bicyclist though has been less researched.

1.2. Research Question

The requirements for navigation systems for bicyclists are significant different ones than for car drivers or pedestrians. While pedestrians are moving hands-free and with a lower pace and automobiles are forming a protective space around the driver, bicyclists are navigating unprotected and with a certain speed in traffic. Although there are also other “unprotected” traffic participants than bicyclists, that are moving with a higher pace than pedestrians (e.g. in-line skaters or people using motorized skateboards), this work focuses on the cyclist as target group. Not only because they increasingly make up the largest part in that group. Riding a bicycle safely is a highly physical activity that requires the involvement of the whole body and a quick reaction ability.

This thesis aims to explore how the exchange of visual navigation instructions through tactile ones and another form of conveying auditory information can be advantageous in active navigation for the cycling experience.

The research question is:

How can vibro-tactile information in combination with non-speech audio signals through open-ear headphones be used to deliver necessary navigation instructions for cyclists?

Sub question is:

How can these audio-tactile stimuli replace visual instructions and enhance the cycling experience?

For the experience of guided bicycling, route planning and customisation of the navigation system is as important as the look and feel of the whole system. Anyhow, the product design of a sleek and unobtrusive wearable will not be considered as the focus lies stronger on the exploration and effects of using a non-visual interface. The conception of an accompanying route planning and control App will also not be thematised.

1.3. Expected Contribution

As cycling is a whole-body outdoor activity, many different factors need to be respected when designing a navigation solution. Cycling is an experience that addresses all senses. Therefore, it is important to consider which sensory channels are addressed in which way. Research has been done in the field of using audio and tactile signals for navigation purpose. The main focus of these explorations focused on performance data. Data on perception and reaction time deliver good information on the effects on navigation tasks of the tested technology. The question how it feels to use a certain technology solution though, is mostly not respected. From the viewpoint of interaction design, the emotional side is also an important factor to be considered. It is expected that a non-visual navigation interface can maintain the main attention to the traffic scene more strongly compared to systems that use the visual channel. Being able to focus more on the surrounding environment can as a result lead to a feeling of more safety.

Further it is assumed that the usage of shorter, non-spoken sonic signals in combination with vibro-tactile stimuli are less distracting and perceived faster than visual information in the context of urban navigation with a certain speed. The usage of bone-conduction headphones to provide audio instructions can preserve spatial hearing. Thus, audio signals may be also perceivable in loud environments or during strong winds. Results of the exploration of an audio-tactile wearable can also be beneficial for the development of other embodied and non-visual interfaces, both, from the technological and emotional perspective.

2. Background & Theory

This chapter provides back ground information and theories to understand aspects and concepts relevant to the area this project is situated in.

2.1. Urban Space

The general term urban space or urban area cannot be clearly defined. It includes spatial and social aspects, but depended on the context and area used, they are differently addressed and interpreted. One general characteristic of urban space though is constant change. Therefore, each era, time and geographic location defines its own definition of urbanity (Siebel, 1994).

If one takes the word urban alone, a clear differentiation from rural can be made. As urban and rural are standing in contrast to each other, urban space is often equated with city. Although cities are always urban space, urban space is not always a city. An urban space that is not a city is for example the Ruhrgebiet in Germany. It is an urban area which consists of several cities and therefore does not own a city centre. According to Walter Siebel (1994), a realistic image of an urban city includes four elements: the presence of an own history, emancipation of nature, a new time regime, and quality of public space. Further characteristics that can be assigned to both, the city and the urban space are a high population and building density, large settlement units, public and private buildings as well as usable public spaces. The high building and population density goes hand in hand with a high demand for mobility and a well-developed transport infrastructure.

2.1.1. Urban Mobility

Urban mobility is a network located in public space that includes public and private transportation. That does not only imply the question of how to move from one point to the other, but also addresses the question of how to fulfil the needs of locomotion. Nowadays, participation in urban, public and social life requires people to be mobile at all times. Therefore, mobility is one of the most important factors for independent living and acting. Regarding mobility, the modern human being aims to achieve an optimum of travel factors such as time, distance, comfort or costs, depending on the purpose of travel.

In Europe over 60% of the citizens are living in urban areas, sharing the available living space and mobility infrastructure (“Urban mobility – Mobility and Transport – European Commission”, 2019). Urban areas are growing and are in constant change, which urban development must react to. Especially the complex traffic situation needs to be adapted to the change in traffic patterns. It is an ongoing challenge to provide all citizens a mobility infrastructure and an offer of transport services that fits everybody’s individual needs.

The multitude of different road users and the amount of traffic-relevant data must be considered in the development of mobility concepts, as must the ability to respond to spontaneous events and to rapidly changing traffic conditions. Intelligent traffic systems are highly developed applications in the area of information and communication technologies in the transport sector, that can be used to ensure a fast collection and evaluation of traffic data.

Thereby trends in traffic behaviour can be detected and reacted to accordingly. Besides being more efficient and cost effective, improving the safety and reducing the environmental impact are important factors for urban mobility. In terms of sustainability the question which means of transport is used to move around gets more and more into the focus of attention.

In recent decades, good progress has been made in reducing air pollution and noise levels in urban areas. However, there is still room for improvement. In the European Commission for Mobility and Transport the aim is to promote greater use of transport solutions which in themselves have a low environmental impact (“Sustainable transport - Mobility and Transport - European Commission”, 2019). Regarding climate protection, the promotion of walking and cycling is of importance. In many European cities the number of alterna-

tive means of transport to the car is increasing . Owning a car is no longer an indispensable means of transport for modern urban citizens. The multitude of alternative mobility options and services in urban areas are delivering a cheaper and more flexible solution.

The general, traffic infrastructure in most European cities is still predominantly designed for motorized transportation. A better developed public transport network and a wide range of car-sharing services will reduce the number of private cars but will not necessarily lead to a sustainable restructuring of the entire transport infrastructure. However, a change in traffic development towards a bike-friendly infrastructure can be seen. The increase in bicycle traffic, caused among other things by the availability of bike rental services and the increasing supply of pedelecs, is leading to a change in the mobility behaviour of the population. As a result, a continuous expansion and reconstruction of the bicycle traffic facilities in urban areas is taking place. Cities like Copenhagen, Amsterdam, Ghent or Ljubljana are considered the most bicycle-friendly cities in Europe. The redesign and further development of the transport infrastructure in these cities clearly focuses on environmentally friendly means of transport and serves as a model for other urban regions.

2.2. Wayfinding & Navigation

The terms Wayfinding and Navigation are often used equally, although there is a difference between them. They are closely related concepts, but wayfinding is a broader term. It describes the process of how a person or animal orients itself in an environment to navigate through it. Wayfinding includes biological factors and psychological skills. The questions of how we perceive and recognise our environment, how we build a mental model of it and how we plan a route and move through that environment are involved in that term (Montello & Sas, 2006). According to Downs and Stea (1973), four stages of wayfinding can be identified:

1. **Orientation in the environment**
2. **Route Decision**
3. **Keeping on track**
4. **Destination Recognition**

As the concept of wayfinding contains the goal of reaching a certain point of destination, the goal-directed and mental planning part is also a requirement for and part of the concept of navigation (Montello & Sac, 2006).

Navigation is generally defined as the art and science of safe and efficient manoeuvring from one point to another. The term originates from shipping and is composed of the Latin words “navis”, for boat, and “agile”, for guiding. Nowadays the term is not only used in connection with orientation and locomotion in topographical space. The word navigation refers to several subgroups and is defined differently depending on the context.

However, the main characteristics are always the questions “Where am I?” and “How do I reach my destination?”. Thus, navigation can be described as determining the position of a physical body, its speed and direction, and the course of motion in relation to a reference coordinate system to reach a point of destination. This includes determining the geographic position, calculating the optimal route as well as modifying and stabilizing the course (Bose, Bhat, Kurian, 2014).

Relating to topographic navigation, seven methods can be identified:

1. **Terrestrial Navigation** is the oldest method. It describes the determination of position by means of landmarks and nautical signs, which is why this method is mainly used in coastal navigation.
2. **Visual Navigation** describes the orientation by the use of map material. A mental transfer performance from the two-dimensional representation to the surrounding three-dimensional terrain is necessary.
3. **Astronomical Navigation** resembles terrestrial navigation. The difference is that instead of landmarks, stars are used as reference points. The position is determined by calculating the direction and height of the stars.
4. **Dead Reckoning** is the positioning by course and speed. This method is considered the base of navigation in general.
5. **Inertial Navigation** determines the geographical position by measuring acceleration and three-dimensional motion
6. **Radio Navigation** is the first electronic method and uses transmitter stations and radio signals for geo-localization.
7. **Satellite Navigation** is the latest method and determines the position using signals from 4 to 6 satellites.

A combination of several methods is called hybrid navigation or integrated navigation. The greatest possible redundancy is desired here in order to increase accuracy and to make position determination less sensitive to interferences.

2.2.1. Bicycle Navigation

There is a wide range of navigation devices, mobile apps and other navigation solutions for cyclists. Depending on the type of cyclist and their need, functions and setup are varying. Compared to navigation systems for cars, some bicycle navigation solutions offer options to plan a route considering factors like road surface, road type and elevation profile. With mobile navigation applications like Komoot, Naviki or ViewRanger routes can be created, recorded, saved and shared worldwide. Other apps like bbybike, bike citizen, I bike CPH, etc. are focussing only on one area or region. This allows to offer information in greater detail. Bikenavi, Strava and MapMyRide are examples that focus more on the training aspect of cycling and offer a selection of stored tours from other users, that can be used for workout. The connection to fitness sensors and even the integration of training and diet plans are not uncommon.

The majority of all these navigation solutions for cyclists are still focusing on delivering solely visual information and spoken turn-by-turn instructions. Navigation devices are placed on the handlebar and smartphones are ideally also attached to the handlebar by using special mountings. To perceive the spoken turn-by-turn instructions headphones are used in general.

2.2.2. Augmented Navigation

Augmented navigation is usually understood as the integration of visual augmented reality (AR) solutions into navigation systems. This means that navigation and traffic relevant data is displayed as an overlay to the real-world view. AR is also defined as the perception of the reality enriched with further computer assisted additions. A known definition by Azuma (1997,2001) defines three characteristics of augmented reality: the combination of reality and virtuality, interaction in real time and the registration and alignment of real and vir-

tual objects to each other. In principle, the computer-controlled enrichment of reality in real time not only includes vision but applies to all our senses. Hearing is often included in AR systems, but the focus lies on vision. The sense of touch is less often addressed and olfactory and gustatory displays are almost non-existent.

The most commonly used visual AR always requires a type of display. Bimler and Raskar (2006) divide these types of displays into three categories: spatial, hand-held and head-attached. In navigation systems spatial and hand-held solutions are common. The most known spatial AR displays are Head-Up displays in cars, followed by hand-held displays in form of smartphones. For bicycle navigation spatial visual displays are not possible as no projection surface is available in the direct field of view. A hand-held solution is also not an option as the smartphone or navigation device is mounted to the handlebar, facing down with the camera and both hands are needed to direct the bike. The usage of non-visual augmentation on the other hand opens up new possibilities and can be a great enrichment for navigation.

2.2.2.1. Multi-sensory Navigation

Using acoustic turn-by-turn instructions besides visual represented navigation information addresses two senses and can already be described as multi-sensory. Adding information that include the sense of touch is, at least in navigation solutions for sighted people, less available. In recent years the effects of the use of multi-sensory stimuli in the context of navigation has begun to be researched. Park (2017) tested four different modalities of presenting navigation information to car drivers. He compared the effect of using visual, visual + audio, visual + tactile and visual + audio + tactile information on reaction time, safe driving score and perceived responsiveness. The results show that the more senses are addressed, the faster the response time. The presence of tactile cues in general had a positive effect on the perceived driving experience.

2.3. Vibro-tactile directions

Using the words haptic and tactile in the context of wayfinding and navigation systems means in most cases the integration of vibro-tactile signals. Several research projects investigated how vibro-tactile signals can be used for navigation.

Integrating vibration motors in a belt gives the possibility of providing directional cues within 360 degree. With Tactile Wayfinder, a belt with six actuators evenly distributed around the waist, Heuten et al. (2008) showed that directions could be successfully identified using only tactile stimuli to navigate a route in an open field. Modulating the vibro-tactile stimuli in rhythm and pattern, additional navigation relevant information like distance (van Erp,2005), upcoming and look-ahead way-point (Pielot & Boll, 2010) or landmark information (Srikulwong & O'Neill, 2011) were tested on perception and performance time.

Not only the number of actuators and the used vibration patterns, but also the positioning on the body is important for how vibro-tactile stimuli are perceived. With a look on the cortical sensory homunculus, a theoretical prediction of the perception of vibro-tactile signals can be made. Nevertheless the “felt” effect can be a totally different one as the homunculus is only depicting the ability to sensory sensation of different parts of the body. With GentleGuide Bosman et al. (2003) proved that vibration on the wrist can successfully

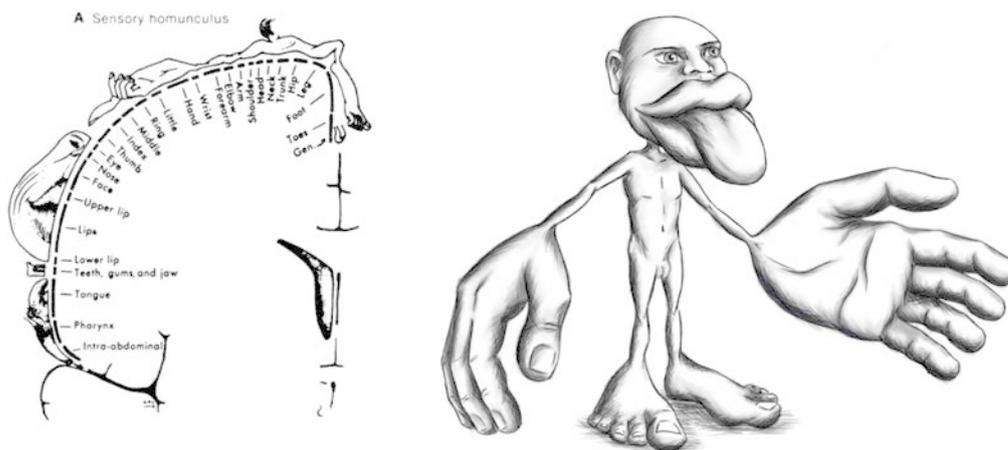


Figure 1: (left) The Cortical sensory homunculus — proportional mapped representation of the body in relative proportion to the size of areas in the somatosensory cortex (Penfield & Rasmussen, 1950). (right) Figurative representation of the sensory homunculus

provide directional instructions. They also found out that in this body region, duration and pattern of vibro-tactile signals are more effective to communicate directions than intensity. Besides communicating directions, tactile stimuli were also used to direct visual attention (Ho, Tan & Spence, 2005). Gustafson-Pearce, Billet and Cecelja (2007) not only focused on vibration but compared audio and vibro-tactile navigation information against each other. The tactile instructions were delivered through a vest with five actuators. Audio was provided over one earplug. Based on their results, simple tactile instructions lead to less errors than audio ones. They assume, that vibro-tactile input is in general perceived faster and in a more intuitive way.

2.4. Bone-conduction Hearing

To be able to hear audio signals over headphones while still perceiving the surrounding sound clearly, so called open-ear headphones are being produced since a few years. These headphones are making use of the principle of bone-conduction hearing. Bone conduction describes the transmission of sound oscillations or vibrations through the skull bone surrounding the ear by bypassing the middle ear. The mechanical vibration signals are going through the cochlea where the signal is transduced into neurobiological electrical signals by the hair cells. As outer and middle ear are bypassed, audio signals can be provided without blocking the three-dimensional ambient hearing.

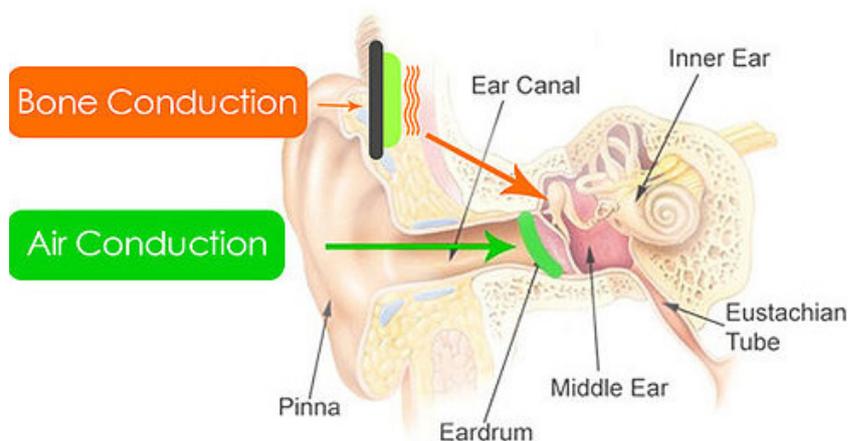


Figure 2: Mechanics of air-conduction and bone-conduction

The usage of in-ear headphones or even ones that cover the ears has a negative effect on our ability to hear directional, as the ear canal gets blocked. Especially moving in traffic, localizing the direction a sound comes from is crucial for reactions. Volume and the type of headphones are decisive for the degree of reducing the three-dimensional hearing ability. As to expect, the higher the volume, the more negative the effect on auditory perception. Comparing the usage of “normal” headphones, one ear-bud and in-ear headphones while cycling de Waard, Edlinger & Brookhuis (2011) showed that all types lower the reaction time to traffic signals. In their tests more than two of three warning signals were even missed out completely when using in-ear headphones. The influence of bone conduction headphones on three-dimensional ambient hearing and detection of possible hazards was tested with combinations of music and language (May & Walker, 2017). The results show that Bone-conduction headphones are also affecting the capability to localise sounds in the environment, but compared to conventional types of headphones the negative effect is much lower. As the type and combination of audio signals is important for perception and reaction time (Fry, 1975; Klatzky et al., 2006; Waard et al., 2011; May & Walker, 2017) further research on the effect of bone-conduction hearing on three-dimensional ambient hearing needs to be done.

3. Related Work

This chapter lists work examples and products that use vibro-tactile stimuli and/or bone conduction in the field of bicycle navigation and sports. Since cycling can be described as a sporting outdoor activity, the consideration of non-visual solutions for the outdoor sports sector is also relevant to be included.

3.1. Tacticycle

With Tacticycle, Poppinga, Pielot and Boll (2009) examined the effect of tactile cues to support tourists on bicycle tours. Vibro-tactile actuators in the handlebar were used to indicate a direction towards points of interest. As tourists are moving around in a more exploratory way, their aim was not to give precise navigation instructions. The system was tested in two set-ups, one indoor test that simulates a cycle trip virtually and one outdoor test. Additionally to the vibro-tactile hints, a visual component was added. A PDA mounted in the centre of the handlebar displayed the current position and the direction to nearby points of interest without a map. Although the inclusion may lead the attention away from the surrounding, all participants mentioned an increased awareness to the environment, using vibro-tactile directional information.

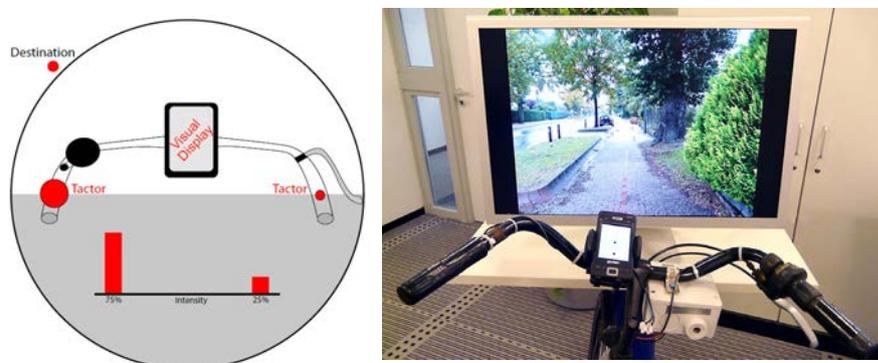


Figure 3: Test set-up of Tacticycle (Poppinga, Pielot & Boll, 2009)

3.2. Ziklo; GPS Vibe Wristband

Ziklo is a wearable navigation system for cyclists that provides navigation instruction through vibro-tactile signals on the forearm. Huxtable, Lai, Lam Choi and Zhu (2014) placed three vibration motors in a Wristlet, which are positioned from the wrist upwards along the arm. The whole system consists of two wristlets and a bluetooth connected control app on a smartphone to receive GPS information. Turn-by turn instructions are simply provided by triggering a tactile stimulus on the respective arm. To indicate the distance to the next turn, one, two or all three vibration motors are activated.

3.3. smrtGRiPS

SmrtGRiPS is a haptic, non-visual navigation solution for bicyclists. It consists of two special designed handles that are equipped with a vibration motor and a Bluetooth component. They can be fitted into the handlebar of most bikes by pushing the device into the handlebar tube and replacing the grips with the provided ones. When the handles are connected to the corresponding app via Bluetooth, instructions can be sent to the respective side in form of vibration. However, the planned delivery of the product was to take place in 2015. To date, no further progress has been made and the website is dated 2017 (April 2019).

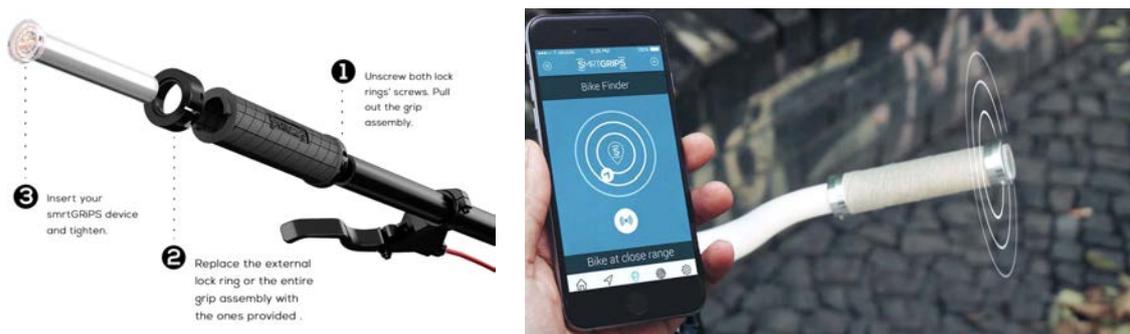


Figure 4: smrtGRiPS (source: <http://smrtgrips.com/>)

3.4. Instinct

Instinct is a concept developed by Basheer Tome, that uses haptic signals for GPS turn-by-turn instructions. Compared to other solutions using vibro-tactile signals on the handlebar, this concept uses pneumatic airbags that are integrated in the handles. Turn instructions are communicated by inflating and deflating the handles.



Figure 5: Instinct (source: <https://student.basheer.co/instinct/>)

3.5. Aftershokz's Headphones

In 2012 the company Aftershokz released the first wireless bone-conduction headphones on the consumer market. Surface transducers which are placed on the cheekbones are used to transmit vibrations to the cochlear. Today, Aftershokz are offering a product range of bone-conduction headphones that focusses on the sports sector. The headphones are marketed for ideal use in sports activities such as running, cycling and even swimming.



Figure 6: Trekz Air Headphones from Aftershokz (source: <https://aftershokz.com/products/trekz-air>)

3.6. Coros Smart Helmets

The company COROS develops athletic gear and sports wearables. They are showing that the usage of bone-conduction in a cycling context is currently in demand. In their product range they offer three different types of bicycle helmets that include bone-conduction headphones (April 2019).



Figure 7: The COROS OMNI smart cycling helmet (source: <https://www.coros.com/omni.php>)

4. Methodology

In the following section the methods used throughout the design process are briefly described. The reasons why they were selected and in which steps of the design process they were used are also broached.

4.1. Research Through Design

As a basic method used to approach the research question, the research through design (RtD) concept was chosen. The practical RtD approach describes the usage of design processes to acquire new knowledge that can contribute to design theory (Zimmerman, Stolterman & Forlizzi, 2010). Designing digital artefacts, systems or services, that are helping to answer the research question in an explorative manner have the advantage of gaining multiple perspectives on a problem by including iterative cycles (Zimmerman, Forlizzi & Evenson, 2007). The development of prototypes and implementation of experiments are performed in parallel throughout the process. This gives the opportunity to use the reflection of intermediate results to redesign process steps and design artefacts and to build on each other.

Besides using the RtD approach, the double diamond (British Design Council., 2005) is chosen as design process. That means, the whole process can be divided into four phases: Research, Synthesis, Ideation and Implementation. Depending on the stages and the desired outcome, different methods are chosen.

4.2. Videography

To discover problem areas and design opportunities in the field of urban cycling, one needs to understand all aspects of the cycling experience. As bicycling is an activity that is phys-

ical, sensory and social in nature (Spinney, 2011), cycling needs to be studied in the field, when and where it is happening. As Spinney is stating it, in such contexts, “a method of ‘being there’ without actually being there”(2011, p. 166) is required. Audio-visual recordings allow to capture situations and activities and analyse several aspects of social interactions independently of time and place. As defined by Knoblauch, Tuma & Schnettler (2014), social interactions in this context is not only to be understood as human to human interaction, but “involves any action performed by someone who is motivated by, oriented to and coordinated with others, irrespective of whether these ‘others’ are other participants, animals, artefacts, or whatever.”(p.436). The analysis of audiovisual data recorded in the field with focus on interactions in ‘natural settings’ is defined as videography by Knoblauch, Tuma & Schnettler (2014). Natural setting is to understand as situations that are typically not created by the researcher and could happen without any intervention.

In the first phase of the design process this method was used to get a deeper understanding of the previously defined user group. In the last phase videography was used for documentation and analysis in testing.

4.3. Bodystorming

Bodystorming can be summarized as methods of Brainstorming “in the wild” or as Oulasvirta, Kurvinen & Kankainen (2002) also describe it, the idea of ‘being there’ and living with data in embodied ways (p. 127). Bodystorming makes it easier and faster to understand the environment the researched interactions are taking place in. Activities like cycling are extremely complex and can not be conceived only by observation and collection of insights from the users. Active, bodily exploration on the other hand captures a more precise understanding of relationships and dependencies of actions (Schleicher, Jones & Kachur, 2010). Bodystorming methods are therefore suitable to explore complex and context dependent interactions. Besides building a felt understanding that is useful in the earlier design phases to discover and define, bodystorming methods are also effective to be used in later phases to test future scenarios.

4.4. Unstructured and semi-structured Interviews

In this thesis project, unstructured interviews were conducted in the first phase to discover problem areas and design opportunities. In the second phase unstructured interviews served to open up again for ideation with the defined design opportunity and research question in mind.

Unstructured interviews are used to gather insights on experiences from the user in a more conversational way compared to semi-structured and structured interviews (Wilson, 2014). The rather loose structure allows for more flexibility and gives the interviewee more control. The risk lies in the fact, that the conversation is moving away from the topic. At the same time, that can also be seen as a strength. Aspects can be discovered that were not considered as relevant to the topic by the interviewer beforehand. To not interrupt the conversational flow, documentation using audio recordings are useful and allow for later analysis.

Semi-structured interviews combine the strengths of unstructured and structured interviews. Predefined questions allow for gathering information to a specific topic while still leaving room for exploration (Wilson, 2014). This type of interviews were used in the implementation phase of the design process to collect data and insights in the final prototype and test stage. As semi-structured interviews were included in the test processes, a certain knowledge on the topic to answer the questions could be expected from the interviewees.

4.5. Sketching & Experience Prototyping

Sketches characterise the ideation phase and serve the role of exploring different concepts (Buxton, 2007). In this project two types of sketching were used. A small number of “conventional” sketches in form of paper drawings were created during the ideation and implementation phase. They served to visualise questions and explore possible answers simultaneously. The other type of sketching used within this project was protosketching.

As the name indicates, protosketching means sketching by low-fi prototyping. As Koskinen et al. (2009) are stating it, “Protosketching is particularly suitable for design-

ing embedded systems in which one has to simultaneously define physical prototypes and dynamic interactions in response to user behaviours” (p.1). Since this work aims to answer the question of how guided cycling experience can be improved by exchanging visual information through audio-tactile signals, it was necessary to already include technical aspects in the exploration process, before moving on to the final test stage. Koskinen et al. (2009) are also describing protosketching as sketching in experience prototyping.

Experience Prototyping is a prototyping method that focuses on how a situation is actually experienced. Since experiencing also depends on the real context, experience prototyping tries to simulate a tangible experience that allows to create and understand interactions between users and a design artefact as realistic as possible. Looking at what “experience” means in that context, Buchenau & Suri (2000) are describing experience as “a very dynamic, complex and subjective phenomenon. It depends upon the perception of multiple sensory qualities of a design, interpreted through filters relating to contextual factors.” (p. 424).

Since the research question is situated in a very specific context, it was important to go through many iterative cycles in order to be able to explore and test individual factors that are relevant to the experience of active navigation on a bicycle. Using protosketching and experience prototyping allowed to build several prototypes that focus on different aspects of a desired experience while considering previous experiences and the context that surrounds it. Many protosketches turned into experience prototypes, which were tested and again transformed into new protosketches. Thus, individual components could be quickly tested and revised.

4.6. Ethical considerations

In accordance with The General Data Protection Regulation (GDPR 2018), data that has been collected containing personal information has been handled to the best of my abilities according to the guidelines. Further, the Swedish Research Council Guidelines for ethical conduct (2017) have been consulted. All persons involved in the process were asked in advance for their consent regarding photographs, video and sound recordings and their degree of use.

In this thesis mainly gender-neutral pronouns were used. If gender-specific pronouns were used, they refer to a specific person. If the identity of a person is apparent, this person has been informed of this in addition to a previously obtained declaration of consent.

With regard to sustainability and environmental impact; during the development of sketches and prototypes; care was taken to obtain as many materials as possible from recycling and to recycle them further.

5. Design Process

The following chapter describes, how the design process was structured, what methods were used in which phases and which activities conducted in the different stages of the process.

5.1. Process structure

In order to structure the design process, the five-stages Design Thinking model in combination with the Human-Centered Design Process mindset was used as basic guideline. Like in many models, diverging and converging phases are characteristic for this design process.

The whole process can be divided into five stages within three phases. The three phases coming from the Human-Centered Design mindset are, Inspiration, Ideation and Implementation. The five stages that derive from Design Thinking are, Empathize, Define, Ideate, Prototype and Test. The first two stages can also be seen as what Buxton (2007) describes as “getting the right design” and the last three stages as “getting the design right”.

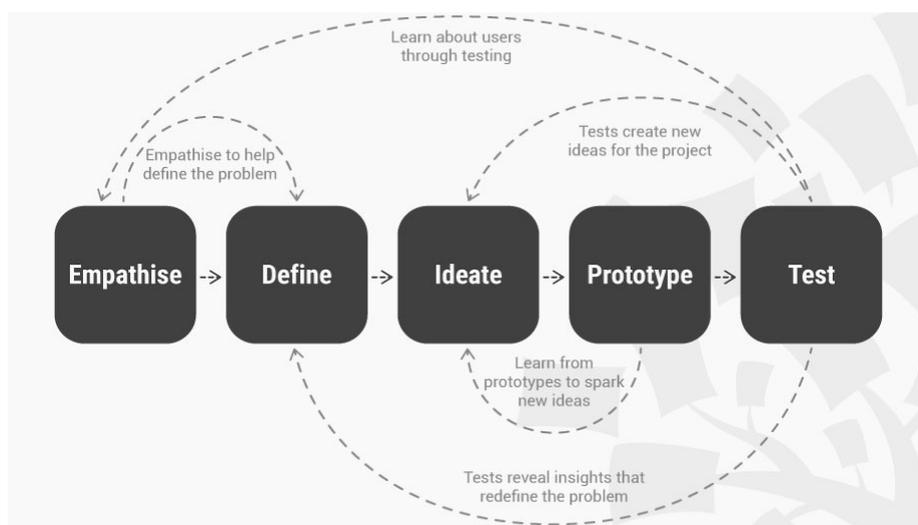


Figure 8: Design Thinking model in five steps (source: <https://www.interaction-design.org/literature/topics/design-thinking#>)

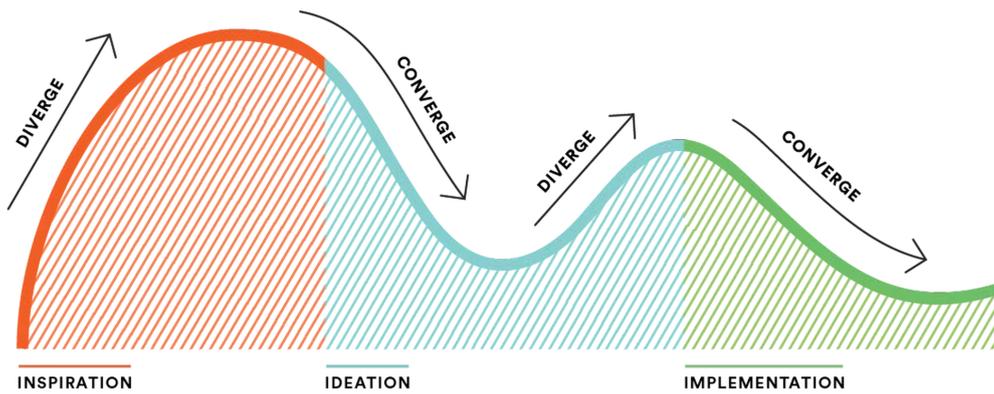


Figure 9: Design Thinking model in five steps (source: <https://www.ideo.org/approach>)

Using the design thinking model and the human-centered Design Process as guideline doesn't mean that the process for this project can be clearly divided. It is more to be understood as being used as basic orientation to structure the whole process, in which all phases and stages are merging into each other. Especially by using protosketches and experience prototyping, including several iterative cycles, the ideation and implementation phase are strongly interwoven.

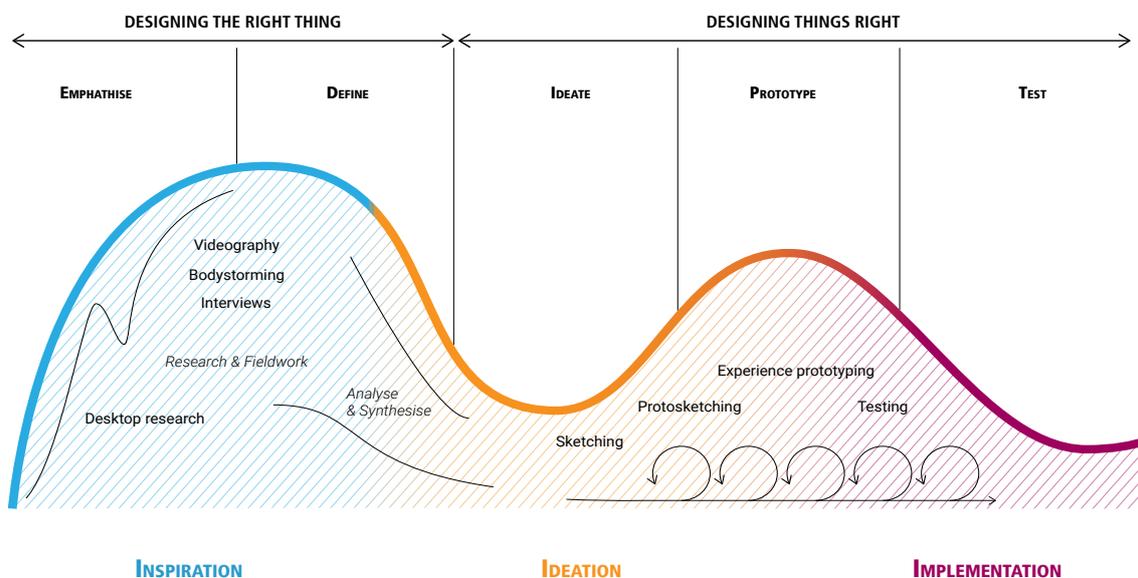


Figure 10: Depiction of the Design process

In the implementation phase research and fieldwork was taking place. This means that information about the defined design space and users were collected to discover human needs. As the name of the first stage indicates, an empathic, deeper understanding of people as well as an understanding of their experiences and motivations should be gained. All collected information was analysed and synthesised in the next step to discover problem areas and design opportunities. Going from the diverging Define stage into Ideation, the process was opened up again and a variety of ideas were created. The ideation phase was predominantly characterized by software and hardware exploration, as well as protosketching, which in the next step merged into the implementation phase with experience prototyping and testing.

5.2. Research & Fieldwork

The project started with the more general question of how navigation systems in urban areas can be augmented by addressing multiple senses while excluding additional visual information. To answer this question, existing information had to be gathered and own data collected.

5.2.1. Gain an overview

The gathering of new information in form of desktop research took place in all phases of the design process. As a first step, scientific papers and articles, projects, and existing products concerning the communication of navigation instructions through multiple sensory channels, including the sense of touch, were examined. The results showed that haptics in navigation are well researched in the context of safe wayfinding for vision impaired people. The usage of multi-sensory navigation instructions in form of audio-tactile stimuli for sighted people on the other hand, is less researched, let alone the exploration of their use in the context of urban navigation. Compared to the amount of people within different mobile groups, haptic information in the context of cycling is even more sparsely researched. As cyclists are more and more present and are increasingly shaping the transport infrastructure in urban areas, the decision was made to focus on this user group in particular.

5.2.2. Exploring urban cycling

To design for urban cyclists and discover problem areas and design opportunities, one first needs to understand the experience of cycling with all its aspects as good as possible. Methods such as desktop research and interviews alone cannot capture the complexity of this physical activity and its dependence on contextual factors for the experience. In order to investigate and answer the question how a non-visual, multi-sensory navigation system for urban cyclists might look like, some questions had to be answered beforehand. The combination of videography, bodystorming and unstructured interviews was therefore chosen to get the best possible understanding of the cycling experience and answer the following questions:

1. How do people cycle in urban areas?
2. How does it feel to cycle and what sensory perceptions are experienced?
3. What kind of digital devices are used while cycling?
4. How and for what are they used?

Over a timespan of 2,5 weeks videos were recorded with a GoPro action camera, mounted on a helmet while cycling. Recordings were done on a daily basis and performed in two cities. Some recordings were done to record the ride, while others also served to directly comment and document feedback on the felt experience while cycling in self-observation.

Besides self-observation, 8 people in 3 different cities were asked to use their bicycle as often as possible for their daily routes and pay attention to how they are cycling and what interactions with other traffic participants and the surrounding are happening. The question how they bicycle was not further specified on purpose. Additionally, they should focus on what sensations they are perceiving and how it feels in general to ride a bicycle in an urban area. It was left to them to decide if they want to actively focus on all factors during the ride and if they want to document it in any way. The results were collected in form of unstructured interviews. Two people could be interviewed in person, the other 6 were interviewed in a video or phone call. One person additionally submitted an audio file with comments on perceived impressions he experienced during one ride. The documentation of the unstructured interviews was done by taking notes directly after the interview.

5.3. Analysis & Synthesis

In the next step all collected information and data needed to be analysed and synthesized to determine problem areas and find design opportunities. Combining the collected and evaluated information from desktop research, videography, bodystorming and unstructured interviews, a good understanding and new insights could be gained and the previously asked questions be answered.

5.3.1. Findings

Although the number of people that participated is not representative, the combined and compared data indicates that the bicycle infrastructure in an urban area plays an important role in the question of how people are cycling and how it is experienced.

1. How do people cycle in urban areas?

This question cannot be answered in a general and simple way, since the characteristics that describe an urban area are too broad and not necessarily those that most influence the way of cycling. However, on the basis of the information collected, it can be concluded that cycling behaviour depends on the feeling of safety when cycling, and is more influenced by the traffic infrastructure than, for example, by the time of day or the density of traffic. Video analysis also showed that the own riding style seems to differ when cycling in other urban environments.

2. How does it feel to cycle and what sensory perceptions are experienced?

The results of bodystorming and unstructured interviews showed that people in different cities, namely Malmö, Berlin and Frankfurt, were focusing on different aspects. Being asked to talk about how they experience cycling, people in Berlin and Frankfurt were talking more about the interaction between them and other traffic participants and negative incidents that were happening in their surroundings. People who cycled in Malmö on the other hand gave comparatively more information on how their body is involved in this activity and what environmental factors like wind and surrounding sounds they perceived.

3. What kind of digital devices are used while cycling?

The audiovisual recordings that were done in Malmö and Berlin showed that headphones and smartphones are significantly often used while riding a bike. It cannot be said, if there is a difference between these cities when it comes to the frequency of usage, but the answers to the question for what they are used indicate it.

4. How and for what are they used?

Most people like to listen to music while moving through the city, no matter by which means of transport. From the video recordings no distinct conclusion can be drawn on what type of headphones are used more often and why. From the interviews anyhow, it can be said that a connection from cycling behaviour and infrastructure to how people are listening to music on a bike seems to exist. People that are cycling on a daily basis and in an urban area with a not so bicycle friendly traffic infrastructure were reporting that they stopped to listen to music while riding a bike in the city, reduced it drastically or switched from headphones to a portable bluetooth speaker box that is carried around. The reasons named were, that they don't feel safe enough when their hearing is blocked from hearing the surrounding traffic sounds and possible hazards.

From the interviews and the video analysis it can be concluded, that the usage of smartphones during riding seems to occur more often in Malmö, where a good bicycle infrastructure exists and people feel more safe in traffic. Being asked why and when people are using their smartphone while cycling, the answers varied, but the majority mentioned that they use it to check where they are and which way to go best, when having a clear destination.

5.4. Ideation & Exploration

The last two phases in the Design process cannot be clearly separated. Using the method of protosketching and experience prototyping, these last stages are circles of exploratory and defining iterations.

Based on the results from research and fieldwork, the decision was made, that for the sound in a multi-sensory navigation system, a solution should be found, that provides necessary acoustic information while still allowing it to perceive the surrounding sounds. Through the ongoing desktop research, the concept and usage of bone-conduction seemed

to be a good solution here. It was also clear that prototypes needed to be tested in the field and under various conditions to be able to answer how and whether or not audio and tactile stimuli can be used for bicycle navigation and how they are experienced.

Another decision that was made early on, was that the whole system should consist of wearable components. Providing acoustic instructions by using bone-conduction, it was plausible that some kind of speakers needed to be placed as wearable on the head. For the vibro-tactile part it was not clear from the beginning. The decision to also build the tactile part of the system in form of a wearable was made based on own experiences, self observation and some conversations with other bicyclists. The integration into the handlebars for example was no option, since not all handlebars have the same shape, the hand positions are very different while cycling and the type of road surface itself can cause strong vibrations on the handlebars.

5.4.1. Hardware and software exploration

Starting with almost no knowledge and experience in developing prototypes for embedded systems, learning about hardware and software was a big part in the last two phases of the design process.

5.4.1.1. Exploring the sensation of vibro-tactile stimuli

One first conceptual question was, where on the body the actuators for the vibro-tactile instructions should be placed. As the body position while cycling differs depending on the type of bike and not all people are wearing bicycle shoes while cycling, the option of a belt or a wearable around the ankle was discarded. Placing actuators into gloves was also rejected, as hands are to some extent already haptically stimulated while cycling and gloves are not worn by everybody and during all seasons. Thus the decision was made to place them on the wrist.

After figuring out how to control and modulate several vibration motors with an Arduino, it was necessary to test how many motors to use and where to position them around the wrist and at what distance from each other to get the best result. Best result means here to create the perception of a directional haptic sensation.

Two exploratory tests were carried out to find out how many motors should be used on each wrist and in which position. In the second test a number of vibration patterns were tested with the previously determined number of motors.

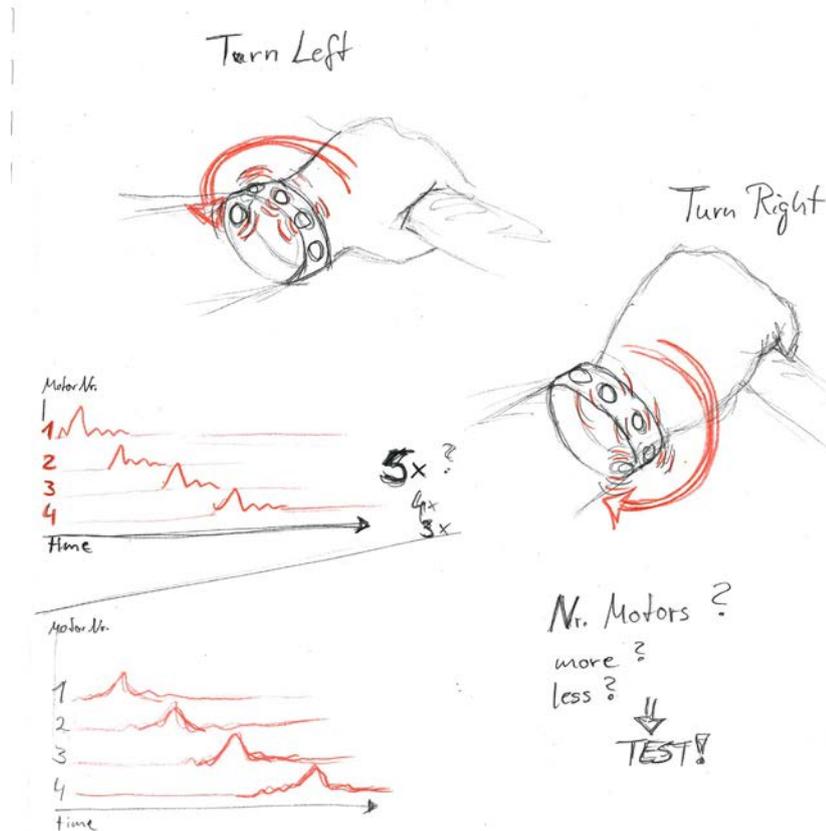


Figure 11: Sketch of possible motor positioning and vibration patterns

Test 1:

Number of testers: 4

Number of motors : 3 -5

Number of vibration patterns: 2

Simply using a piece of tape, the coin vibration motors where placed around the wrist. By that, the number and position of the motors could be changed fast and easily.

The result of this test showed that the more vibration motors are used, the less the single motors can be felt , thus a pattern perceived. An ideal position to perceive the vibration could not be determined, but the placement of a motor on the inner side of the wrist was perceived as slightly uncomfortable.

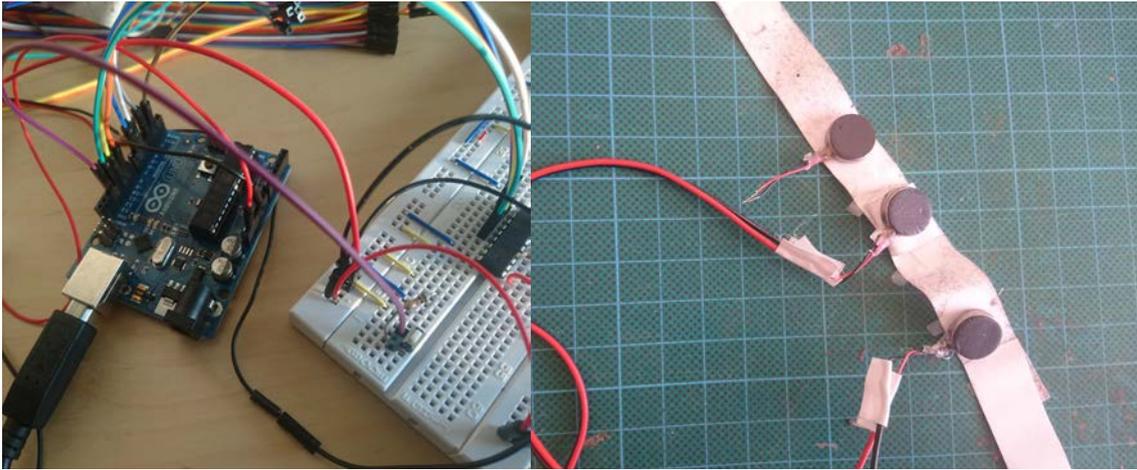


Figure 12: A protosketch to explore the perception of vibration

Test 2:

Number of testers: 7

Number of motors : 3

Number of initial vibration patterns: 4

To create a directional perception, the vibration motors were activated one after another in all tested patterns. The difference in the patterns consisted in the modulation of vibration strength, amplitude and timing. During one test round a person wanted to make changes in the code himself, to test some pattern ideas he had directly. As in this test round four more people were present, these patterns could directly be tested with several people.

The result was, that using three motors, the middle one was always perceived as weaker when the maximum strength was the same for all motors. Another finding was that a more irregular rhythm created a stronger feeling of being “pulled” into one direction.

After the tests, more vibration patterns were created to cover more navigation instructions than the turn signal. Thus vibration patterns were explored that could work as turn indicator, warning or stop signal and “destination reached” feedback. Turn indicator means a signal that is send a certain distance before the next cross road to inform the cyclist in advance in which direction they will need to turn next. At the end, a total of 12 vibration patterns were selected for further testing; 4 for the turn signal, 3 for the turn indicator, another 3 for warning/stop and 2 for the destination signal.

5.4.1.2. Exploration of acoustic signals

Out of interviews it could be concluded that navigation voice instructions are often perceived as too long and disturbing. In the desktop research additionally papers about studies were found that prove that shorter non-spoken sounds are perceived faster and easier than spoken language.

Based on that, acoustic signals for the navigation system should consist of simple sounds and leave out any form of language. It was plausible that sounds for a navigation system that is used outside, needs to be clearly distinguishable from the surrounding sounds, especially when using an open-ear solution. In this case, clearly distinguishable means that it should not be too close to any kind of traffic and nature sounds. Besides that, other requirements were, that the sound should not be too shrill, annoying or distracting.

Together with a befriended conductor, different instruments were tested to find a suitable sound. The decision was made to use a steel drum, because the sound is unambiguously distinct from urban traffic and nature sounds. Another reason was the deep resonance and the rich sound which comes from the fact that harmonics of overtones and undertones resonate in a struck tone. Due to time constraints the recordings were only done quickly over a smartphone. A big part of the resonance and the long reverberation got lost, but the richness of the sound could still be persisted. The sounds were only minimally edited and not altered.

Sound examples

On the hardware and software side a lot of time had to be spent to figure out how to run the sounds on an Arduino with an Mp3 player module using the trial- and-error method. Different actuators were also tested. First a simple piezo was used, then two types of small speakers and finally a surface transducer to find out which one is best suited for this type of sound to create a type of bone conduction wearable. Various problems arose with the sound, which could not be solved quickly or partly not at all. One problem that could not be solved was, that even if the volume was set to the maximum in the software, the sound was extremely quiet, no matter which actuator was used. Despite of a slight noise, one type of the small speakers the sound was anyhow perceivable quite and clear when holding them

directly onto the ear. The surface transducer seemed to create less noise, but was even more quiet. Thus further explorations and tests were done with the speaker.

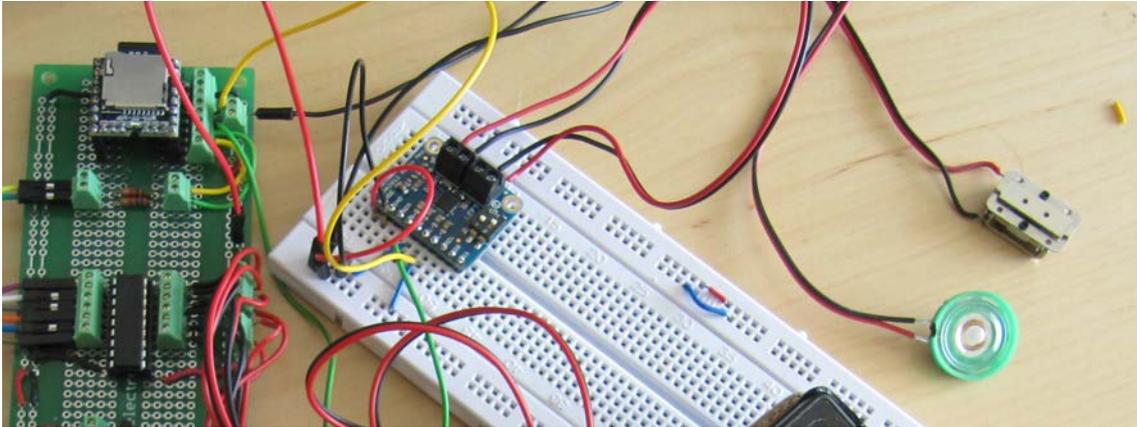


Figure 13: Setup to test different types of acoustic actuators

5.4.1.3. Combining haptic and acoustic

After both the haptic and the acoustic part had been brought to work individually, the next step was to combine and synchronise them. At that stage everything was set up on a breadboard and controlled with buttons over an Arduino Uno. As not enough pins were available to connect 6 motors, two speakers and several buttons, only one “wristband” and one speaker were used at first to combine, synchronise and compare the combinations. A series of combinations was tried out from the 12 selected vibration patterns and 21 sound files. A total of 7 combinations were selected, which were tested with a small group of people. For turn signal, turn indicator and warning signal each, 2 versions remained. For the destination sound only one version was selected to be used for further testing.

For the tests, that were done individually, two low-fi wristbands were created in which the vibration motors were sewed in. With Velcro tape the wristbands were fixed around the arms of the participant. To perceive the acoustic signals, the participants needed to hold the speakers in their hands and press them directly to their ears. Even with the small number of 6 testers, some preferences for signal versions could be identified. Nevertheless, no versions was sorted out, but based on the feedback, small adjustments in rhythm and modulation of the vibration patterns were made.

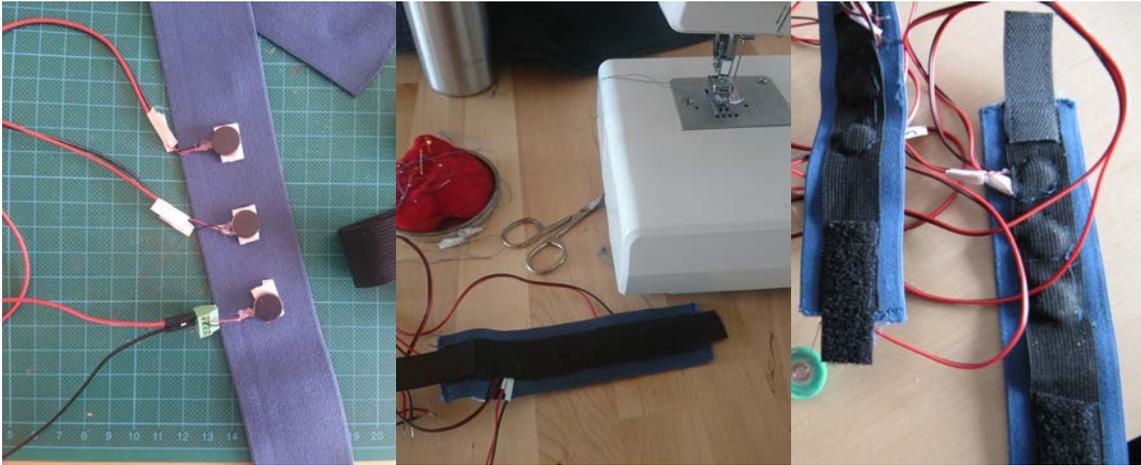


Figure 14: Creation of a wristband prototype

5.4.1.4. Hardware & software optimisation

The first protosketches and experience prototypes were build using an Arduino with a Breadboard to connect and control the actuators. After vibration and sound were brought together the breadboard was replaced by a breadboard PCB (printed circuit board). To minimize the risk of mayor mistakes, the assembly was transferred to the PCB almost one-to-one. By that the whole setup got a bit clearer, the amount of free cables was reduced and it was faster to build up and dismantle.

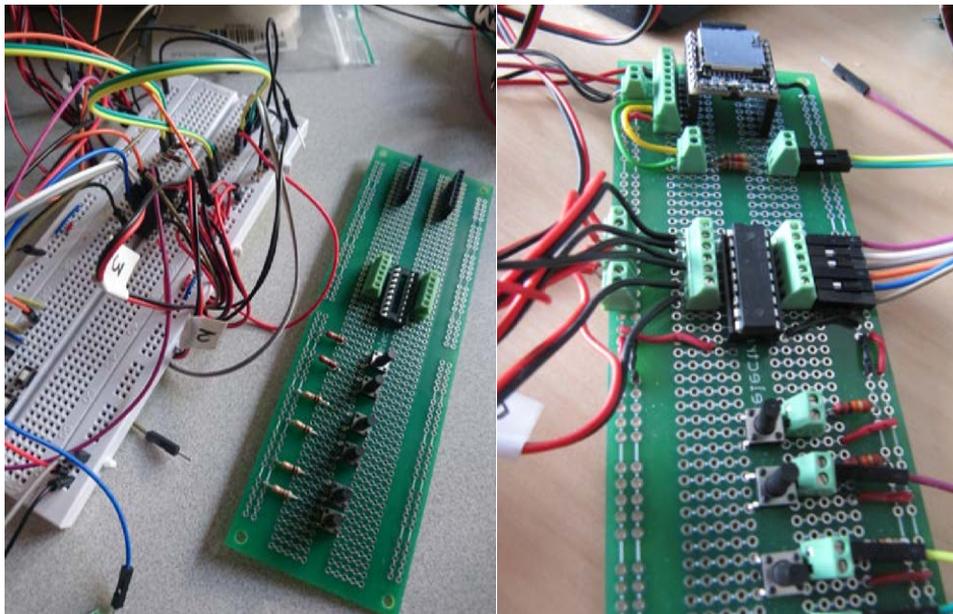


Figure 15: Transfer from a breadboard to a PCB breadboard

Since prototypes for this project have to be tested in the field, i.e. while people are moving through urban space on their bicycles, the system had to be able to be controlled wireless. The first step in that direction was to switch to a bluetooth enabled microcontroller that can easily be powered by battery. In the next step a bluetooth connection between the microcontroller and a smartphone needed to be build up. A solution also needed to be found to not only be able to communicate between the smartphone and the microcontroller, but to also make it fast and easy to send commands. Using the NRF Connect Application at first, commands needed to be typed in and manually send over from the smartphone to the microcontroller. To make the controlling faster and easier, the NRF Toolbox offered a simple and comparatively quick to set up solution that offered only the most necessary functions and was also customizable. Via a minimalistic interface, digital buttons could be assigned commands which were sent to the microcontroller with one tap.

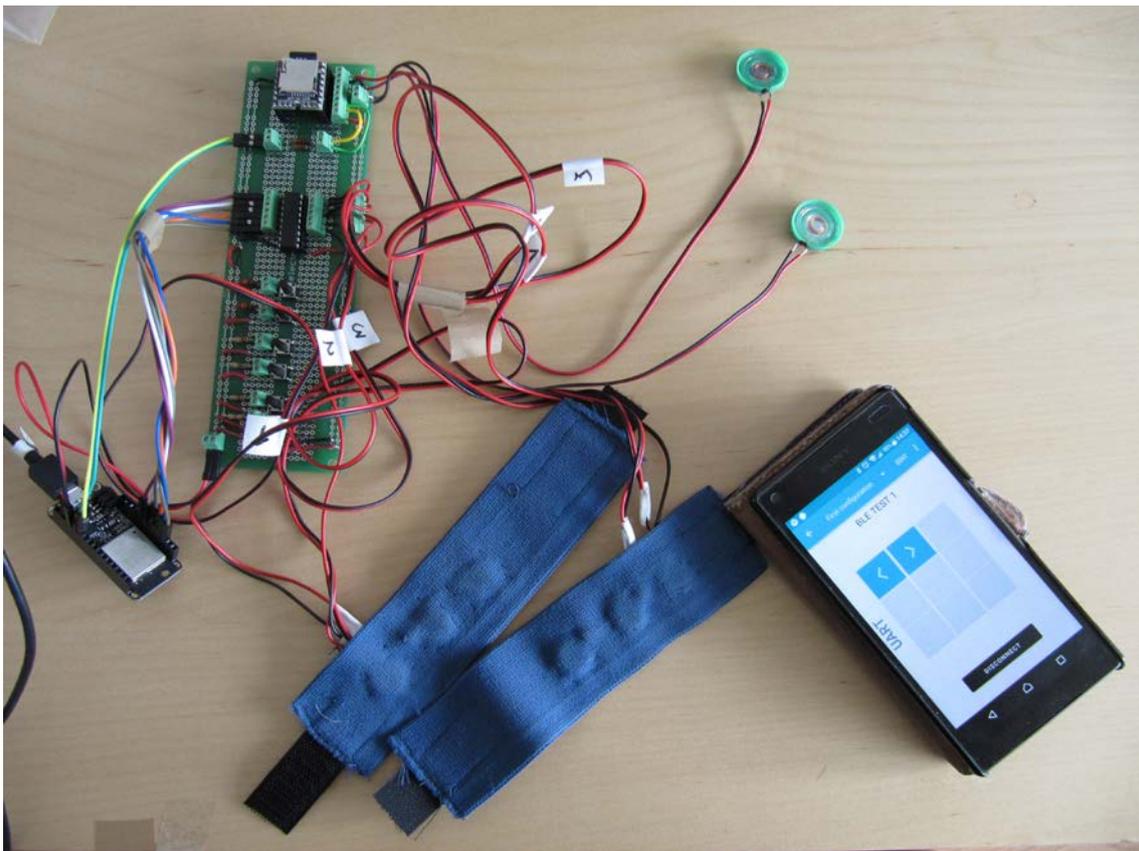


Figure 16: An experience prototype version that is controllable over bluetooth, using the NRF Toolbox App

Since the microcontroller could be addressed wireless now, physical buttons were not needed anymore. In order not to interfere with the cycling of the participant, the entire control unit for the actuators had to be as small as possible, so that it allows to be easily attached to the body and would not be too disturbing or distracting. To realise that, all components of the control unit were transferred again and soldered or plugged onto a smaller circuit board. Going smaller in size, adding a new component and making it powered by batteries, the whole circuit was redesigned.

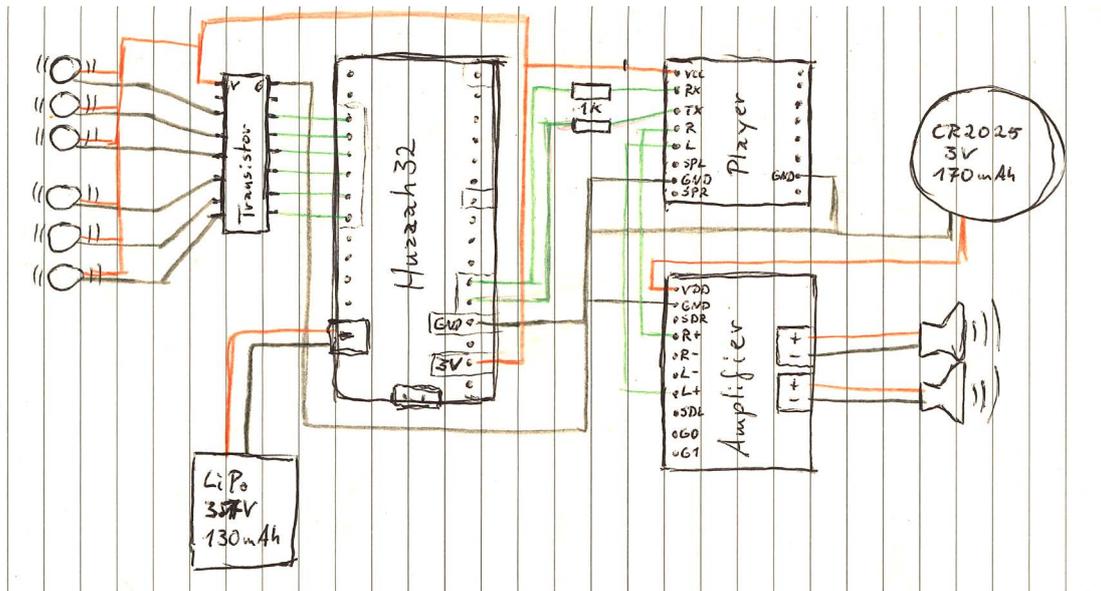


Figure 17: Sketch of the minimised and optimised circuit

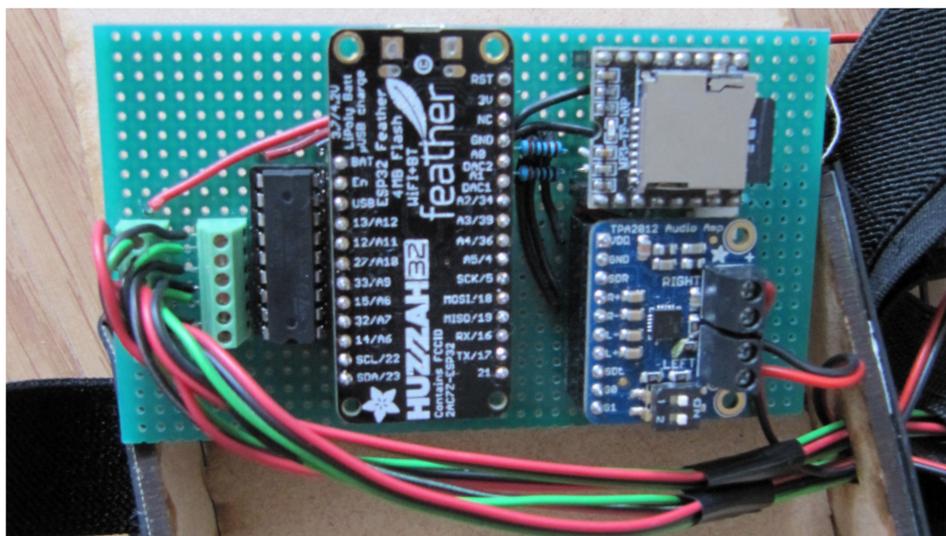


Figure 18: Final circuit soldered and stacked on a smaller PCB

Software sided even more versions and iterations were done. With each actuator and each component that was added or changed, a variety of code versions were created. Ongoing changes were made to make the code smaller, faster, easier to read and edit. It was particularly important to be able to edit the code quickly and easily, so that feedback could directly be reacted to during testing and changes made “on the go” together with the testers.

5.5. Prototyping

Final tests were going to be made outside in the “natural setting”. Thus, it was important to build a prototype that was as unobtrusive as possible and didn’t make the testers feel like an “alien” or a science fiction character. If one moves in public space, a factor that should not be neglected is how we are perceived by the outside world. A feeling of unease would with some probability have an impact on the cycling experience and the test results.

To protect the control unit, a small box was build. Making it as small as possible while still leaving room to fit some batteries in, a low-fi prototype was build out of cardboard first. This made it possible to adjust the previously calculated dimensions and determine the correct size and position for an output for the cables. In order to protect the control unit sufficiently, the final box was assembled from single parts made of MDF using a laser cutter. To make the box water-resistant to some degree, it was covered with parts of an old bicycle tyre and inner tube.

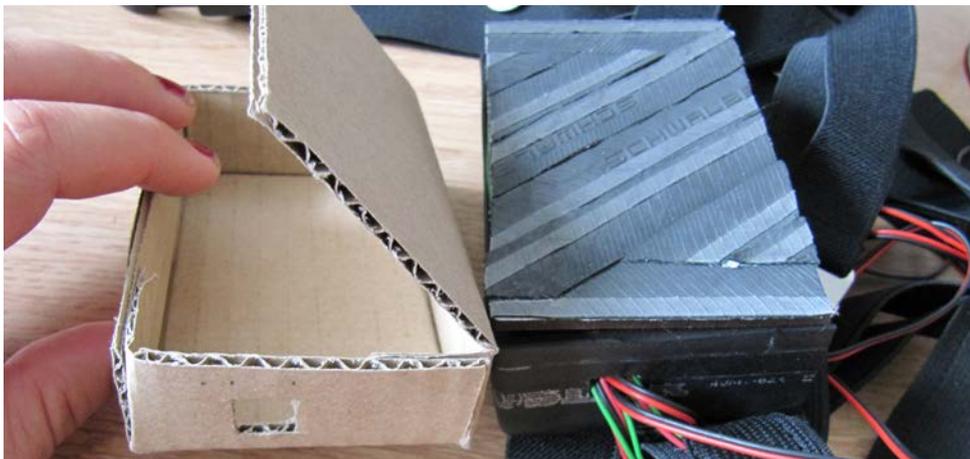


Figure 19: paper prototype and final box to function as housing for the control unit

For the acoustic part, the question arose how to attach the acoustic actuators to the head and which type to use to get the best listening experience. Through experimentation, it became clear that the use of surface transducers to apply the principle of bone conduction sound is only possible if they can be attached firmly and with some pressure to the head in the ear region. Since this could not be implemented to 100% and the speakers were clearly more perceptible in comparison to the surface transducer at looser contact, it was decided to use these for further prototypes. In the next step it was explored in which kind of wearable the loudspeakers can be integrated. The speakers also had to be encased and should be as comfortable to wear as possible.

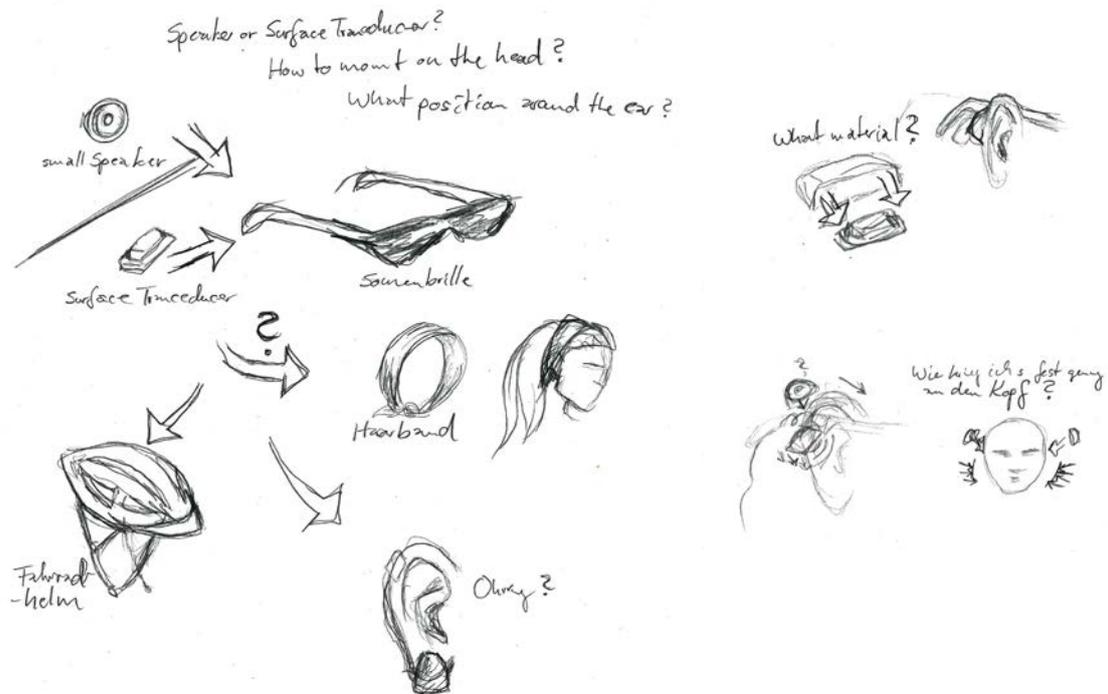


Figure 20: Sketches to explore where and how to mount acoustic actuators

Attaching the speakers to sunglasses seemed like a very good solution. Another promising solution was to design headphones that were bent around the ear-cup and placed the speaker in front of the ear. Since the sunglasses may not fit comfortably on the heads of all participants and one would not like to use sunglasses in cloudy weather or darkness, the “bend around the ear” headphone version was chosen for a prototype that can be used outdoors while cycling.



Figure 21: Protosketches exploring cover materials and position of speakers when mounted on sunglasses

The speakers were covered from the back by building a construction that created a small resonance enclosure. It was build out of wire and hot glue and covered with synthetic leather fabric that was left from another project. For a comfortable feeling of wear, small cushions were made of the foam of a rinsing sponge which were also clothed with parts of the synthetic leather . The other part of the headphones that should keep the speaker in place, was build out of wire and the foam of a rinsing sponge in which the cables were hidden. This construction was also covered with synthetic leather. The headphones were bendable so they could be easily fit on different ears.

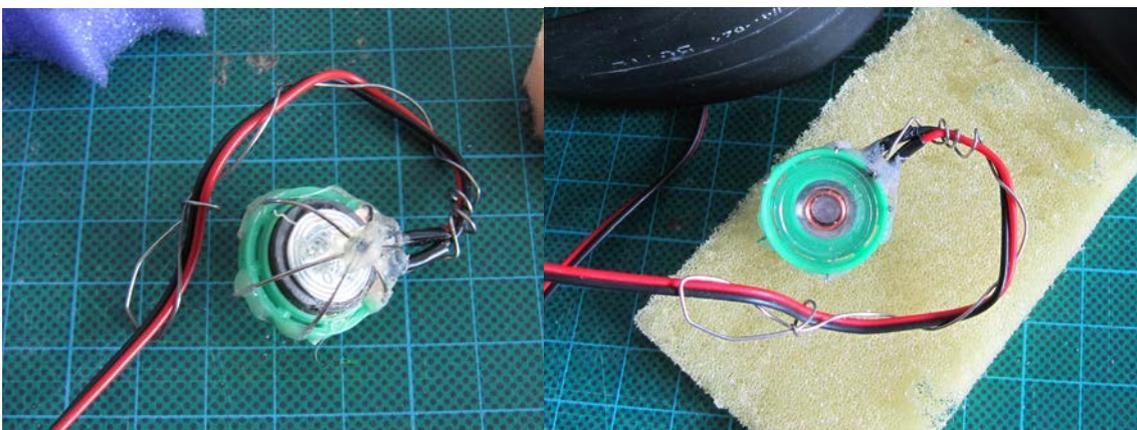


Figure 22: Building of an open-ear prototype



Figure 23: Different stages of building the final open-ear headphones

A next big step was to figure out how to attach the whole prototype system to the body and how to hide the cables. As it was summer, using a big hoody in which all electronic parts could be hidden was no option. The requirements for the prototype were to be lightweight, not to warm, adjustable to different body heights and shapes, be comfortable to wear and not to create a feeling of unease.



Figure 24: Sketches to explore where on the body to mount the control unit

For inspiration and to find possible solutions second-hand shops were visited. A pair of suspenders that were found offered a good solution for securing the box to the body. Making the whole prototype fix on different body heights and shapes, different elastic band were used to cover the cables, build new wristbands and a belt for attachment. Some parts as a piece of elastic band and a buckle were re-used from an old backpack. The cables leading to the wrists were not only sewn into elastic fabric, but also provided with a function by sewing on reflective bands. The same applied to the wristbands. Here, reflective elements were added, which at the same time indicated on which arm the respective wristband was to be placed. For flexible attachment, the wristbands were equipped with a metal eyelet and a one-sided self-adhesive Velcro tape. This made it possible to change the size of the circumference of the wristband to a much greater extent than by using conventional Velcro tape. In order to fix the “cable channels” to the arms, loops were created from elastic bands and Velcro tape, which were attached to the upper and lower arm respectively.



Figure 25: (top) Creation step of the reflective wristbands; (bottom) Attachment of the wristband and cable channel on the arm

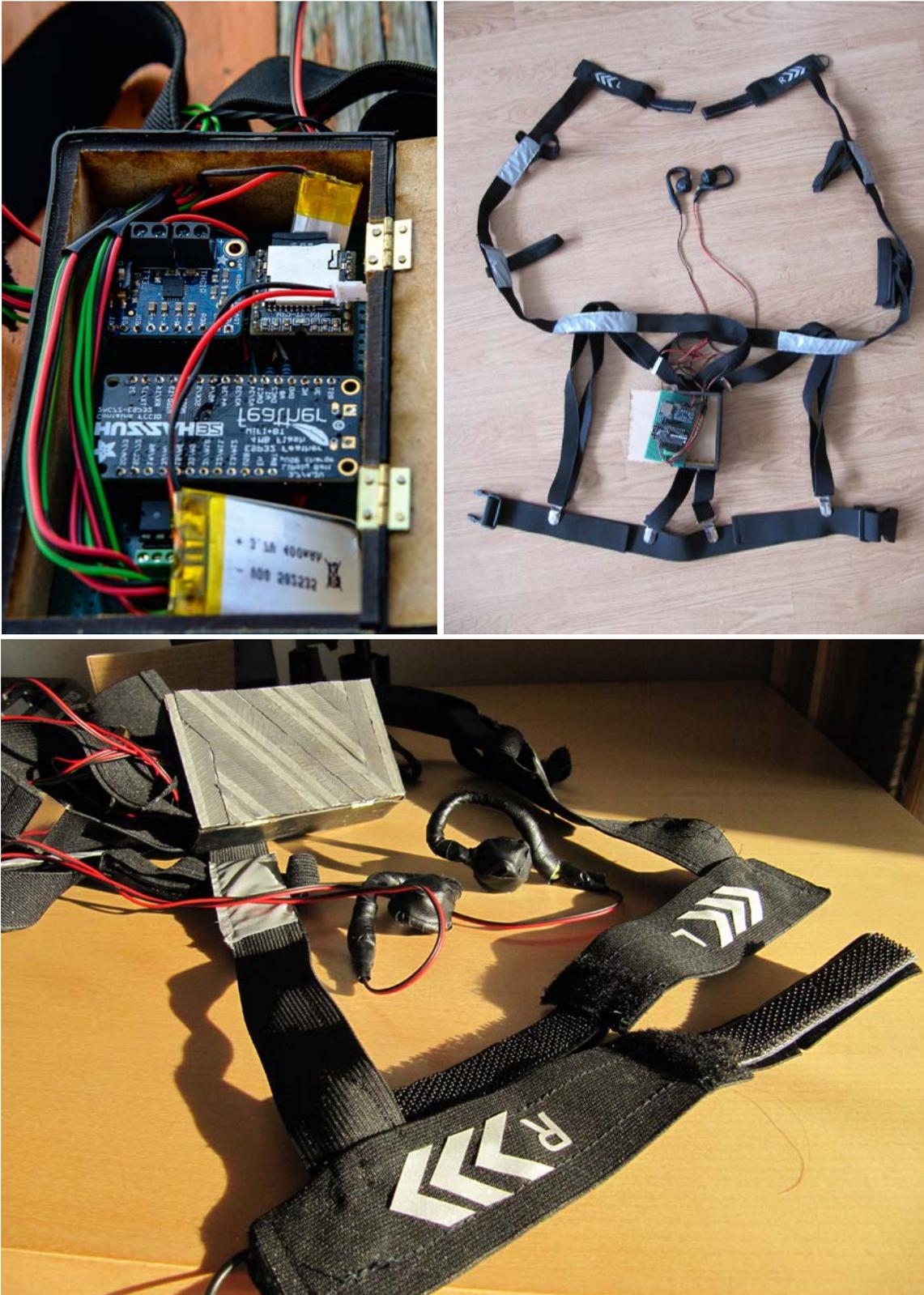


Figure 26: Hardware parts and assembly of the final prototype

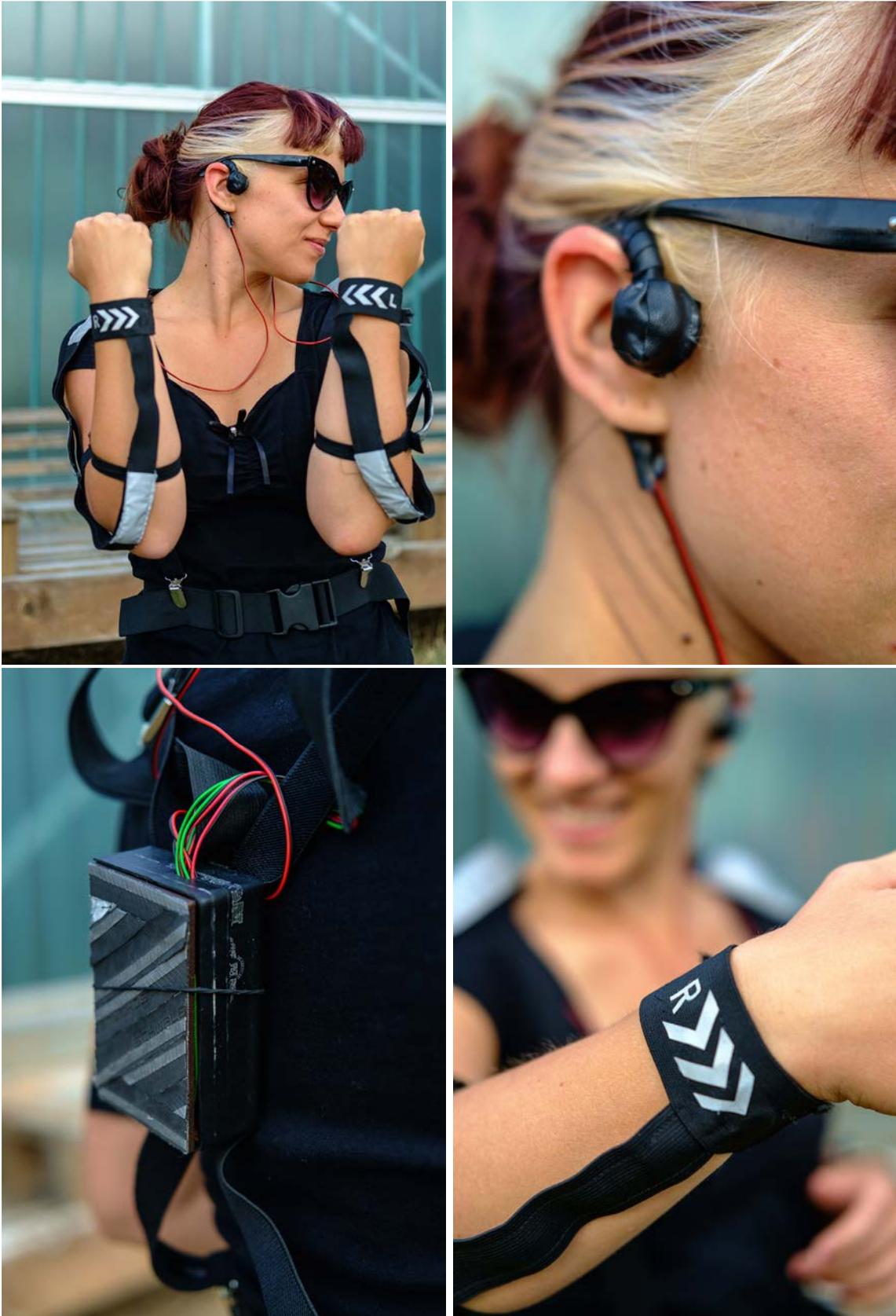


Figure 27: Prototype worn by a persona with detail views

5.6. Testing

Before moving into the final testing phase, a test round with only 4 people were done to select which sound and vibration combination should be used for the tests with the final prototype. Some minor changes in the code were also done to be able to address the senses separately, i.e. for each navigation instruction the acoustic signal, the haptic signal or a combination of both could be activated.

5.6.1. Participants & test environment

Based on the analysis results in the Define stage, it was clear that the prototype needed to be tested in different urban environments. Since videography and bodystorming took place in different cities, the final tests were also carried out in Malmö, Frankfurt and Berlin. In total 25 people were testing the prototype. From these 25 tests 19 were carried out in the field, i.e. while people were moving outside on their bicycles. The other 6 were “dry tests”, which means that the participants did not use any means of transportation, with which they achieve a faster speed than a pedestrian but remain just as unprotected. These “dry tests” have been performed both indoors and outdoors, while sitting, standing or walking. As the extended target group would not only include different types of cyclists, one test-person was moving on in-line skates and another one on a skateboard. 11 tests were conducted in Malmö, 8 in Frankfurt and 6 in Berlin. From the people who took part in bodystorming and interviews and those who were part of the exploratory test phases during the process, the majority was also participating in the final tests.

In addition to performing tests in cities with a different bicycle infrastructure, factors such as type of road and pavement, type of bicycle, weather condition, noise level, time of day, etc. tried to be included where possible. The street types that could be included in the test were separated bike lanes, bike lanes on streets, side streets and main roads. The types of pavement that was tested on were asphalt, pavers, cobblestone and gravel. Since the type of bike influences the riding style and the vibrations that occur during the ride on the bike itself, it should be mentioned that 3 participants used a racing bike, one a fat bike and another a recumbent bike.



Figure 28 : four examples of different test environments

5.6.2. Test procedure

The first step was to put the prototype on the participant. For a test in the field, a smartphone was mounted on the handlebar of the bike from the researcher. The researcher was riding behind the participant and sent commands via the smartphone to the control unit to trigger an acoustic navigation instruction, a haptic one or a combination of both. The order in which instructions were given only via vibration, only via sound or vibration with sound in combination was randomly chosen. The participants were asked to react according to their interpretation of the information they received. Except for the first 3 tests, the participants were informed in advance which navigation instructions are available. The tests were not following any selected route. It was decided spontaneously and depending on the surrounding situation which way to take and which instructions to send accordingly

The first 5 tests were carried out in a safer environment, i.e. only cycle paths and off-road paths were used. This served to test whether the sensory stimuli can be perceived while cycling and be interpreted as navigation instructions. In all other tests carried out in the field, it was tried to include as many different types of roads and pavements as possible.



Figure 29: Outdoor test setup. Researcher riding behind the test person, sending navigation commands from a smartphone that is mounted on the handlebar.

Using the Think-Loud method, participants were asked to verbalize their thoughts directly during the test. Based on the communicated thoughts, some questions were asked from time to time and/or short conversations were held if the traffic situation allowed it. If the participant has given their consent in advance, the entire test was recorded with a GoPro camera. After completion of the test semi-structured interviews were conducted, which were audio recorded with the smartphone. The video and audio recordings were subsequently transcribed into notes. Basic and comparable information were then transferred into a spreadsheet (see [Appendix](#)).

6. Results

This chapter summarises the general results of the tests. With a few exceptions, there will be no detailed discussion on individual feedback.

6.1. Wearing the prototype

By the use of suspenders, elastic materials and adjustment possibilities, it was possible to attach the prototype to participants of various body types. Testers mentioned that it didn't feel much different than carrying a small backpack and that they very quickly stopped thinking about wearing a whole construct. The general feedback on the open-ear headphones was that they are much more comfortable to wear than they look. Depending on the ear shape the speakers were partially covering the tragus. Nevertheless, the ear canal was not blocked and the surrounding sound could be perceived clearly. Some testers had the problem that the headphones were sitting too loose, even after bending. This resulted that wearing the headphones, especially in stronger winds, was perceived as stressful. For the wristbands it was pointed out that having reflector elements on the wristbands that name the direction is especially beneficial for people with left-right weakness. The worry that participants could feel uneasy was fortunately not confirmed. On the contrary there were statements like "it feels like a super hero costume" or "somehow I feel cool, wearing that thing".



Figure 30: Test participants wearing the prototype

6.2. Perception of audio-tactile instructions

Although, many different factors as well as individual preferences and the perceptive ability of singular senses are influencing the experience of cycling, comprehensive results could be determined.

6.2.1. Acoustic instructions

From the first three tests, it became clear that acoustic signals and their meaning had to be learned in advance. Without having heard the different sounds and melodies beforehand and having their meaning explained, it was not possible for the participants to interpret the signals. If they had previously perceived the combination of sound and vibration however, no further explanation on the meaning of the sounds was necessary. Still, the sounds were perceived as quite ambiguous.

None of the participants had used open-ear headphones before. Most testers were surprised about how clear they could hear the sound instructions while still being able to perceive the ambient sound. The sound of the steel-drum was perceived as clearly distinguishable from the surrounding, even in loud environment. Five tests were for example carried out in an area which is located in the approach lane to a major airport. During two tests an ambulance passed by. Even under these conditions the sound instructions were heard. In general, the sound was perceived as soft, comfortable and calming.

Most people who understood the warning or stop signal as such, would prefer a more aggressive and high pitched tone if this instruction should really make you stop. To just make you slow down and pay more attention, the sound is evaluated as sufficient enough, especially in combination with the vibration. Participants who in general were paying more attention to the sound and could distinguish the melodies right away as well as interpret their meaning correctly, turned out to be people that deal with music a lot or are musicians themselves.

6.2.2. Haptic instructions

The directional instructions in form of vibro-tactile stimuli was perceived and understood by every participant. Participants that were sceptical that the vibration could be disturbing and distracting, were positively surprised how comfortable and natural it felt to them. The vibro-tactile instructions were most often described as intuitive, immediate and precise. Most testers would trust on haptic signals only if they would need to choose between vibration and sound. Surprisingly, even two participants that were stronger reacting to the acoustic signals said that they would rank vibration higher. Participants mentioned that vibration does not need to be learned to interpret is and understand the instructions. Merely the warning/stop signal was not always clear, dependent on the context.

People who were part of the experimental tests in previous steps of the design process, mentioned that in earlier tests they felt a stronger sense of being pulled in one direction. Also the intensity and the clear distinction of the individual vibration patterns was perceived more clearly. This cannot be explained by the fact that earlier tests took place in a closed environment while the final prototype was mainly tested in the field, since three of these participants “dry-tested” the final prototype also in an closed environment. Comparing the usage of haptic and acoustic stimuli only, the preference lies clearly in the haptics.

6.2.3. Multi-sensory instructions

The combination of acoustic and haptic instructions was judged to be the best variant. It was perceivable even in situation with a high noise level, when cycling on cobblestone and even when both occurred at the same time. All signals were interpreted and reacted to with almost no difficulties. Although the combination of sound and vibration was evaluated as best solution, testers said that they could forgo the sound instructions.

6.3. Comparison to conventional navigation systems

Almost all testers stated that they use navigation systems, both in cars and on bicycles. The most named system was Google maps, followed by komoot. While the use of visual information and voice instructions in car navigation varies from person to person, the majority said, that on the bike they only use visual information. In general, active navigation is used less on the bicycle in comparison to the car. Especially voice instructions are rarely used. Reasons that were named were for example, that in the car one needs to pay visual attention to the traffic but outside sounds are not so relevant. On the bicycle on the other hand it is more important to hear which sound is coming from which direction. Voice instructions are also not used while cycling, as it is preferred to use headphones to listen to music. Spoken instructions are additionally perceived as too long, including unnecessary information. The impression of getting too much information also counts for navigation systems that are specially designed for bicycling.

On the question of how participants would evaluate the usage of audio-tactile stimuli for active navigation in comparison to conventional navigation systems, all participants agreed that a non-visual solution is a better alternative.

Eleven out of 19 participants that were tested in the field mentioned that they are feeling much safer. For a few participants it was because they perceived the system as more reliable and immediate, for others it was that they had the feeling that they could concentrate more on the situation, for even others it was the fact that they didn't need to use their phone to re-examine route and position. Most participants did not miss visual information, but a few would like to have a map for route planning and the possibility to look at it, if needed.

Comparing the delivered sounds to voice instructions, the non spoken directions were evaluated as better solution. Only two participants mentioned that it could be beneficial to have voice instructions in ambiguous situations.

6.4. Differences determined by external factors

Apart from individual preferences and experiences, some differences in how the stimuli were perceived and understood could be observed.

The not clearly defined warning or stop signal was in average differently interpreted in the different cities. While in Malmö the signal was mostly perceived as a sign to slow down or stop, participants in Berlin and Frankfurt were interpreting it in more ways. Three participants in Berlin presumed, that they went the wrong way and should turn around. In Frankfurt 4 people deduced that it was a signal to continue straight, especially when sound only was used. These differences depend also on the context and the situational condition at that moment, and it can not be established with certainty if the urban infrastructure, the noise level or other factors were leading to that result.

Two of three participants that were riding a racing bike and are cycling frequently rated the experience as very positive and helpful, but didn't liked the fact that the system is an additional wearable. If it would be an existing product, they would prefer to have the components integrated in already existing parts that they are wearing when cycling, like helmet or gloves. They argued that everything one needs to put on in addition, is one thing to much. The sound instructions were evaluated as highly positive and almost indispensable by these participants. This may be due to the fact that on a racing bike the pavement and every unevenness is felt much more intensively than on any other type of modern bike, influencing the ability to perceive the vibration patterns.

As to assume, and briefly touched upon in part 6.2.1, the noise level in a certain area had a noticeable impact on the perception of the navigation directives, in particular the sound instructions. In almost all tests that were carried out in louder environment, the results on fast perception of the navigation instructions were poorer. This applies not only to the acoustic but also to the haptic stimuli.

Despite this observations, it should be pointed out that the number of participants is not representative and that a causal connection between the factors that are listed in this part and the perception of the system cannot be established

6.5. Further feedback and findings

Right at the beginning of the final testing phase it got clear, that in terms of navigation a signal that is informing about having reached a destination is valuable but not necessary. In the context of testing without setting a route with a defined destination at the beginning, this signal makes little sense though. Hence the signal for destination reached was not extensively tested. In most cases the destination signal was send as a kind of function check before the participant started to ride. That actually allowed the participant to get a first impression on the sensory stimuli that could be send over the system. In case the test was ended at the same point as it started, the destination signal was also send at the end when reaching the “start and finish” spot. Out of the context the signal was then also understood as destination reached or alternatively as “test finished”.

At the beginning of the tests, when the participants have not yet experienced all the instructions several times, the signals could mostly just be interpreted based on the context. In particular the distinction between turn indicator and turn signals was most context-dependent. A few testers mentioned that in obvious situations it would not play any role if different directional signals exist, as long as it is perceivable from which side of the body it is coming and at which point in time you receive it. If the next crossroad is still in distance, it is clear that the perceived signal must be the turn indicator. If one perceives a sensory stimulus from the system on one side of the body directly before an intersection, it is obvious that it must be the actual turn signal. This could also explain why participants who were performing the “dry test” needed to hear and/or feel the different instructions more often than testers in the field, to be able to identify them clearly.

Basically, it can be said that the system was quick and easy to understand and learn. The majority was familiar with the different instructions after experiencing them only two to three times. In order to be able to say at any time and context-independently which signal it is and to recognize the differences exactly, some testers stated that it requires a kind of tutorial or manual or one has to use the navigation system a few times more.

Despite reporting to have a stronger attention to the traffic situation, two participants mentioned that the turn indicator had briefly turned their attention to the corresponding side, but not so strongly that they were distracted or the whole attention would be drawn away from the main scene. One participant compared it to the situation when somebody is

sneaking up to you, tipping you on the shoulder but showing up on the other side. In this context, it was also mentioned as positive to be able to spot new things in the environment that would not have been seen without the brief shift of attention.

The minimalistic approach was something most participants highlighted in particular. The system does not provide many instructions, but for bicycle navigation through urban areas it was perceived as just the right amount. Especially with regard to safety, the low number of different signals and the corresponding lower distraction was considered positive. Since some participants were used to receive more detailed navigation information and on a more frequent basis, they became unsure whether the prototype still worked if there had been no instructions for a longer period of time. After learning that the system provides only the most necessary instructions, these testers considered the minimalism as positive and in the context of cycling the better approach. Nevertheless, to trust the system one would need to re-learn the way navigation instructions are communicated.

Throughout all tests, it was mentioned that the provided directions may not always be enough, for example when approaching a roundabout or an intersection with more than four junctions. However, it was considered the better solution, to stay with as few navigation instructions as possible. As one tester stated: “the worst that could happen is that one would need to turn around or go a longer route”. For a few participants the sound could also be more minimalistic. One tone that varies only in number of notes and rhythm or even just a “beep” could be enough.

One interesting observation was, that when the participants talked about the sensory stimuli they perceived, many of them moved their hands rhythmically and made noises to it, regardless of whether they talked about vibration, sound or the combination. This could be observed in the interviews and during testing, even when the combination of vibration and sound was not tested before yet.



Figure 31: Participant giving feedback on the perceived stimuli by moving the hand according to the melody and rhythm of the vibration pattern

7. Discussion

The final outcome of this thesis project is a fully functioning prototype which serves as a concept for a non-visual, multi-sensory bicycle navigation system. To safely navigate in urban area, it is important to stay aware of the surrounding and everything that is happening around to be able to react and interact in time. By using audio-tactile instructions, this work aims to deliver a system that can provide the necessary information to stay on track while allowing the bicyclist to keep their main attention to the traffic situation. As the first interviews at the beginning of the process showed, the effective use of conventional audio-visual navigation solutions for active navigation when cycling is usually perceived as disturbing. One could argue, that by providing additional information only over one sensory channel, the experience could already be improved. However, the problem lies elsewhere. If used at all, spoken voice instructions are perceived as too long and detailed and visual information are taking away too much attention. Therefore it was clear from the beginning, that the visual channel will not be addressed. For the acoustic part, a different form of audio had to be found. In addition to acoustic signals haptic signals were included. As shown by Park, Kim and Kwon(2017), addressing multiple sensory channels in navigation systems improves the riding experience and leads to faster reaction time. Especially the inclusion of vibro-tactile stimuli is assumed to be perceived faster and more intuitive (Gustafson-Pearce, Billet & Cecelja, 2007). The results of the final tests are confirming that the perception of navigation instruction over multiple channels is experienced as the overall better solution. The combination of sound and vibration can be perceived in almost all situations. Dependent on which sense was affected by external factors, the information communicated over the other sensory channel was considered as indispensable.

As the experience of cycling in urban space is highly influenced by context, former experiences and a variety of external factors, it is necessary to take all of them into account when designing for bicyclists. The results of the analysis in the early phase of the design process and the results of the final tests clearly show that factors such as road infrastruc-

ture, traffic density, composition of road users, noise levels, type of road, pavement and bicycle, to name but a few, affect not only the general cycling experience but also the sense of safety in bicycle navigation. All these different factors and the necessity to be able to constantly interact with other traffic participants and the surrounding, was one reason to choose a minimalistic approach. Another reason for a minimalistic system was, that in fact not much information is required when using active navigation as a cyclist. Mainly due to the exploratory tests during the ideation and early implementation phase, the assumption occurred that only a small number of navigation instructions is required. This assumption could be confirmed with the tests in the field. Participants reported that it was just enough information having a turn indicator and a turn signal to navigate and to stay on track. In active navigation it is important to get the right information at the right time. Testers said that it is most important to know what to do in the next moment, if they need to turn left or right and being prepared for it.

In navigation systems a warning or stop signal may not be necessary, but in terms of examining whether and how audio-tactile instructions are understood, the integration of this signal was an important part. The limitation of navigation instructions was also making the participants feel more connected to their surrounding and less distracted, as they were not constantly “disturbed” by unnecessary information. Information in visual form was only mentioned to be needed when planning a route beforehand or for review in unclear situations. Visual information in form of a static map has the advantage that it is not time and position depended. The information that can be gathered is ideal for planning and to look several steps ahead.

The feedback on the sound instructions in comparison to spoken voice instructions confirms that acoustic signals are perceived as faster and easier to understand (Fry, 1975; Klatzky, Marston, Giudice, Golledge & Loomis, 2006). It should be emphasised here that this is a matter of pure perception. If one compares the actual duration of shorter spoken navigation instructions with the duration of the audio files used, the audio files are mostly much longer. As Klatzky, Marston, Giudice, Golledge and Loomis (2006) conclude, this leads to the assumption that the cognitive load to understand sound is lower than the one to understand language. In this respect however, the concept of how the designed system functions may also play a bigger role. Since the directional information were only provided on the respective side of the body, not only cognitive load but also body perception could play a role in perception speed.

Due to technical problems the development and inclusion of bone-conduction headphones could not be realised. Therefore, it could not be demonstrated that the use of bone-conducting headphones, compared to conventional ones, is advantageous in localizing sounds in the environment while simultaneously perceiving additional acoustic signals (May & Walker, 2017). Nevertheless, it was possible to show that a type of open-ear headphones enables the hearing and localisation of sound even when additional acoustic stimuli are transmitted. It also became apparent that the audio signals were distinct and clearly perceivable even under very loud ambient sounds and strong winds.

8. Conclusion

The aim of this thesis project was to explore how audio-tactile stimuli can be used to deliver directional information in active bicycle navigation and enhance the cycling experience without the usage of visual information.

It could be demonstrated that a system with a minimal number of audio-tactile instructions is perceived as safer and more direct than conventional navigation systems. This has a clearly positive impact on the experience in guided bicycle navigation. Nevertheless, the result can not be generalised, as the cycling experience in general is highly context dependent and influenced by a variety of different factors. More research needs to be done to confirm the positive effect of audio-tactile information on the navigation experience.

Through fieldwork and a row of iterative cycles of prototyping and testing it could be demonstrated that multi-sensory stimuli in form of audio-tactile signals can provide enough information to replace visual information in specific contexts. Furthermore, it was shown that it is crucial what kind of acoustic signals are used and how they are transmitted. These results can be useful for further research and development of non-visual embodied interfaces.

9. Acknowledgements

I would like to thank all my friends and volunteers who participated in the tests and interviews for giving me very useful insights and feedback. I would like to thank Nils Helge Jensen for exploration and test sessions to find suitable sounds. I would like to thank Nadja Borchert for mental support and always having a sympathetic ear for me. Further, I would like to thank David Cuartielles for helping me with programming when I got stuck.

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Appendix

Test feedback spreadsheet

Test factors		Street types				Pavement			Environmental factors	Other	Usage of navigation systems	Cycling behavior
Testperson	City	"Protecte d" ways and Bike lanes	Bike lanes on street	Side streets	Main roads	asphalt	sand	cobbleston e				
Person 1	Malmö	x				x	x			sound and vibration patter not 100% aligned	uses google maps from time to time. especially when riding in an area that is not so good known yet. only the map is used, no active navigation. to get the information on the route and current position the phone is taken out of a pocket while driving, but sometimes the testperson also stops	cyles almost on a daily basis
Person 2	Malmö	x				x	x			slight volume differences between the different sound, racer bike		cycles on a daily basis and rides responsible. was living in different cities with different bicycle infrastructures. Is familiarwith cycling rules in sweden, denmark, and the netherlands and cycling culture .used different types of bikes in the last few years
Person 3	Malmö	x		x		x	x		windy			
Person 4	Malmö	x		x		x			every now and then heavy gusts	with Skateboard	- Has used different navigation systems/ apps before. Sound instructions were only enabled for the really important information, no additional information like in x meters left or right were enabled. If the system didn't allow for a more detailed selection, customisation of what type of information should be provided in which form, sound is not used at all	does not cycle often, goes around mostly on the skateboard, thus the test was also done on the skateboard
Person 5	Malmö	x				x	x				Uses navigation a lot, especially when somewhere new or going new ways More visual person, no sound on for navigation, also, because phone in pocket. Taken out while driving to have a look on the map	bikes a lot more since living in malmö. almost on a daily basis since about one year thinks its important to hear surrounding, especially in car or on bike when in a big city without so good and bike lanes
Person 6	Malmö	x				x	x		Windy	doesn't own a smartphone	naviation system " in the car sound instructions are good as you need to focus on the traffic - never used navigation on the bike as no smartphone owned	cycles regularly, ibut also dependent on the season. in the summer on a daily basis in winter more seldom

Test factors			Feedback / Results								
Testperson	City	Test procedure/ order	Vibration only				Sound only				Vibration and Sound
			Turn indicator	Turn signal	Stop / be aware	Destination	Turn indicator	Turn signal	Stop / be aware	Destination	Turn indicator
Person 1	Malmö	No information on what type of signals are included in the system were given. Only information was, that the prototype in a navigation system that uses sound and vibration same start end end point order of signal types: vibration only, sound only, combination,	first two to three times the difference between indicator and turn signal could not be clearly distinguished, after having "learned" the difference no problems or confusion occurred anymore	same as turn indicator	signal was clearly interpreted as stop	confusing, test person thinks at first something went wrong, maybe went the wrong way After having perceived the combination of sound and vibration the signal was interpreted as end of test or destination reached (same as sound only)	the meaning of the sound was not understood at all at first. As the sound was only played on the according side (left or right) it was clear that it should be a directional instruction after having perceived it in combination with the vibration it got clearer what it means	same as turn indicator	receiving sound on both sides, it was deduced that it should be the stop signal, based on having received the vibration signal before	Sound signal was interpreted as either "end of test" or destination reached	Having perceived vibration and sound instructions separately before, the combination of both and its meaning was understood right away, it felt a bit confusing and strange though as the sound and the vibration pattern were not synched to 100%. the sound was starting about half a second later than the vibration
Person 2	Malmö	basic information was given, that there are 4 different signals. it was not mentioned that the navigation instructions are given either as sound only, vibration only and the combination of both order of signal types: vibration only, combination, sound only, random	send signals: turn indicator right ... turn right , reaction: "I think the next I need to go right Oh, now I definitely need to go right"			not tested	was interpreted in the right way, because the signals were experienced before in form of vibration. The timing was the important factor		first time not really understood, although the sound was played on both ears problem was that the volume on the speakers was different.	not tested	perceived as the best variation. comments: the combination is most clear and understandable
Person 3	Malmö	no information was given before the test same start end end point order of signal types send: sound only, combination, vibration, random	was sometimes confused with the turn signal the first several times it was perceived, after having experienced the vibration pattern several times, the difference to the direct turn signal was clearly distinguishable	was always understood	was understood as stop without any confusion	not tested	first time signal was send: not understood, but as the sound was only played on one side, it was assumed that one could turn now	first time signal was send: big confusion because a difference from the sound/melody was recognised but as the meaning was not known and the sound was also only played on one side like the turn indicator	sound was interpreted as stop. comment: there is sound on both ears, so I probably need to stop if I don't need to turn	not tested	turn indicator, turn signal without any problem. also experienced as sound a
Person 4	Malmö	information on possible signals were given before the test same start end end point order of signal types: vibration only, then vibro + sound, sound only	difference between the two turn signals directly recognised, second one felt more strong and constant → showed that by making sound and gesture		Was understood as a stop	meaning was not clear as not destination was set before	Sound good, and distinguishable and understandable once heard before in combination with vibration, but could be a bit more different	same as turn indicator	was understood as slow down. To be a stop /warning signal it should be much different from the turning signals in sound, e.g. higher pitched, more aggressive	not tested	meaning totally clear un each other
Person 5	Malmö	information on possible signals were given before the test order of signals send: First two turns combination, then sound only a few turns + stop, then vibro only, then combination again with all possible instructions	interpreted in the right way, also because experienced the signals already before in combination with sound			not tested	interpreted in the right way, also because experienced the signals already before in combination with sound			not tested	signals understood and
Person 6	Malmö	information on possible signals were given before the test order of signal types: combined, then vibration, then sound, then combination again	the difference between indicator and turn signal was basically clear because before already perceived in combination with sound. nevertheless there was an insecurity which signal is really is. only based on the context (distance to cross road) is was clear			not tested	because experienced and understood in combination before, also understood when sound only - sound is felt as really soft and comfortable and really good to perceive - also the headphones are comfy → probably more stable when a real product, then perfect			not tested	first time the signals were 100% clear what is the actual turn signal. especially small side path

Testperson	City				preference	More comments
		Turn signal	Stop / be aware	Destination		
Person 1	Malmö	"..."	"..."	"..."	no preference	
Person 2	Malmö	understood directly	"..."	"..."	combination if the headphones are fitting better	- super easy to learn - with these kind of headphones i would consider using audio instructions - feels safely guided
Person 3	Malmö	all and stop signal were understood as such so because all signals have been heard and vibration stimuli individually		was interpreted correctly as destination reached	vibration only as person likes to listen to own music while cycling	as the test person was familiar with the area the test was conducted and the final "destination" was known, the last two instructions were not respected/were ignored. When asking the testperson if they received a signal, they said yes, but they thought as we are almost "home" the test will end now maybe anyway Testperson was not giving hand signs when turning although they normally do it. said that it's maybe because they are aware of that this is a test and I am in some way responsible and "protecting" them Vibration instructions are clear enough but testperson would prefer to listen to her own music instead of getting navigation hints in audio form
Person 4	Malmö	difficult to distinguish from	it would be nice to have the current stop signal as a "slow down" and another more aggressive one for stop	the combined signal with vibration and sound was interpreted right but was still not 100% clear. It would probably be understood when one had set a destination before	vibration only	- Easy and fast to get and learn - The vibration and the noise did their job properly, they felt nice and smooth as a way to navigate through the streets - it feels definitely safer and more reliable! - "the headphones did their job splendidly and im guessing with further minor improvements, like having a better grip, and waterproofing, the prototype will be perfect" - "i recon if i train with it abit more i'll master all the notifications that i receive from the device faster" - gave rhythmic handsignals before and while turning -> when receiving instructions
Person 5	Malmö	perceived as logical		testperson had no clue what it could mean	vibration only as testperson doesn't like to wear headphones while cycling. But would consider trying it again with open ear headphones, as the combination was in general felt best	- Thinks especially when running, where you listen to music for sure, the vibration navigation would be great (e.g. when following a new trainings route) - would like to have such a system as it feels ways more safe to use than google maps
Person 6	Malmö	rather send it was not an indicator and what the vibration especially as there was a	understood as slow down	not tested	likes the combination of sound and vibration best	- feels really good informed about where to go - feels safe to use - sees it to become a real product - likes that there is not too much information. if one is riding for example during rush hour you need to concentrate on so many more things already

Test factors												
Testperson	City	Street types				Pavement			Environmental factors	Other	Usage of navigation systems	Cycling behavior
		*Protecte d' ways and Bike lanes	Bike lanes on street	Side streets	Main roads	asphalt	sand	cobbleston e				
Person 7	Malmö	x	x	x		x	x		every now and then heavy gusts		- uses navigation systems a lot. in the car, on the bike and also when walking - tries to remember as much as possible from the map when planning a route as they doesn't like to take out the phone all the time to look at it -> looks on map while riding - doesn't use audio instructions at all - having the phone on the handlebar is even worse then holding in hand, feeling that it's not really safe and you look down even more often	is since about a year cycling on a daily basis - does not like to use headphones when moving/cycling outside
Person 8	Malmö		x	x	x	x		x	every now and then heavy gusts		uses google maps often cycling and walking. doesn't know malmö too good yet	does not cycle too often as he has no bike, but it get's more and more. Uses rental bikes
Person 9	Malmö	x	x	x	x	x	x	x	every now and then heavy gusts	wears glasses	- uses navigation systems just if necessary and finds them annoying - in the car google maps is used, visual and sound instructions - on the bike maps is used less. quick looks, only taking out of pocket while driving, when feeling lost or going the wrong way then stopping to look more close on the map - tested the halo for bike navigation and liked that the system is not giving too much unnecessary information and that you are able to explore your surrounding more	cycles almost daily
Person 10	Malmö	x	x	x	x	x			every now and then heavy gusts	on Rollerskates, wears glasses - one headphone was not sitting good at the beginning of the test	- uses google maps regularly - when skating testperson stops to have a look at the phone and the map. when cycling testperson doesn't stop but only slows down - uses voice instructions only in the car	cycles a lot, but prefers to move around with inliners if he doesn't have to carry too much with him
Person 11	Frankfurt		x	x	x	x		x	Windy , Ambulance passing -> extremely loud	fatbike	- uses google maps, komoot and OSMand - uses navigation only visually, looks before on the map and stops if unsecure - uses voice instructions only when in car	cycles everywhere. public transport is only used when being ill - listens to music while cycling most of the time by using a bluetooth box
Person 12	Frankfurt		x	x	x	x		x	passing a street fest -> ambient noise from people and music		- use google maps and komoot - on motorbike navigation voice instructions are used over headset and from time to time looking on the map -> smartphone mounted - when using navigation on bike. First looking on map and stopping in case the feeling one goes wrong way or is not sure where to go	- cycles almost daily. if not cycling using a motor bike - listens to music while driving the bike over bluetooth box, used headphones before, but didn't felt safe with it - feels more secure when listening music over a box as one can still hear what happens around

Test factors			Feedback / Results								
Testperson	City	Test procedure/ order	Vibration only				Sound only			Vibration and Sound	
			Turn indicator	Turn signal	Stop / be aware	Destination	Turn indicator	Turn signal	Stop / be aware	Destination	Turn indicator
Person 7	Malmö	information on possible signals were given before the test same start end end point order of signal types: combination, then sound, then vibration, then random	difference between the vibration pattern is recognised and also interpreted in the right way but vibration in general feels a bit weird. maybe just because it's something so different and new		testperson just slowed down a little bit	not tested	the difference between the sounds is not to 100% clear the first few times, although perceived in combination at the vibration before and there interpreted in the right way sound is perceived as nice, especially because of the bass		not understood at all	not tested	indicator first understood as "proper" turn signal
Person 8	Malmö	information on possible signals were given before the test order of signal types: vibration only, combination, sound only, random	first time the signals are send, no clear differentiation could be made. after perceiving the turn idicator and turn signal e few times, the difference in the pattern is realised. testperson shows what they perceive by making rhythmic signs with one hand and making sounds to it although no sound was played		made a fast stop	not tested	can't differentiate between the sounds thruout the whole test		difference more or less just realised as sound was played on both speakers compared to the directional instructinsignals	"funny sound"	no problem to understand
Person 9	Malmö	information on possible signals were given before the test order of signal types: vibration only, sound only, combination, random	perceiving the two different directional instructions for the first time, the difference was felt but the meaning only clear out of the context		first time perceived this signal it was interpreted as stop, but it was also confusing	not tested	- better to have sound than voice instructions. In car though it is good to have information like turn in x meters. anyway, what is e.g. 100 meters?		from the sound hard to interpret as stop or warning, should be more aggressive	not tested	no problem to understand
Person 10	Malmö	information on possible signals were given before the test order of signal types:vibration only, random	first time signals are perceived, the difference was not clear. turn indicator was interpreted as turn signal, especially as the situation allowed to turn and the "real" turn signals was not experienced yet. after having perceived both signals several times and a combination in between, there were no problems to recognise which signal was send		slight confusion, slowed down	not tested	sound only is hard to distinguish. especially turn indicator and turn signal are ambiguous			not tested	
Person 11	Frankfurt	information on possible signals were given before the test same start end end point riding through two big squares and one park order of signal types: vibration only, combination, sound only, random	no problem to guess the meaning from the start		is understood as continue straight	not tested	- sound cues compared to voice instructions when perceived as way more pleasing , comfortable and direct - even when an ambulance passed, it was perceivable that sound was played but not which one		meaning not clear	not tested	no problems to understand when giving feedback, the sound was perceived
Person 12	Frankfurt	information on possible signals were given before the test same start end end point order of signal types: combination, sound only, vibration only, random			- stop and or warning should be more extreme on both wrists. Suggestion two times short and then a long continuous vibration	not tested	sounds could be interpreted because the combination was perceived before, but could be way more minimalistic - different single tones or different number of "beep" tones could be enough			not tested	- signals were easy and understandable

Testperson	City				preference	More comments
		Turn signal	Stop / be aware	Destination		
Person 7	Malmö	Turn signal clear, especially from the vibration	was ignored although interpreted as either "be aware" and/or slow down	understood as destination reached or test finished	combination of vibration and sound	<ul style="list-style-type: none"> - modification, customisation for each user, how early in which distance you want to receive the indicator before the actual turn signal, maybe also type of sound, sound, vibration or combination to activate - stronger focus on vibration - sound needs to be learned, vibration was faster learned and distinguished automatically
Person 8	Malmö	no problem to understand	as testperson doesn't pay much attention to the sound, the stop signal and the destination signal are at first perceived as almost the same ("I just felt, that there is vibration on both arms. I haven't paid attention what sound was played")		combination, although the sound couldn't be differentiated the combination of vibration and sound felt most reliable and precise	<ul style="list-style-type: none"> - even with the strong winds the sound was clear and loud enough to perceive - on one side the sound was more quiet, but most likely because the headphone was not sitting perfect
Person 9	Malmö	"..."	"..."	not understood, was interpreted as test ended and thank you	likes especially the vibration but the combination with sound is great and all in all the best version	<ul style="list-style-type: none"> - worries that people would not use headphone that are only for that use, they would use it for music - you need to get used to not have the visual information and knowing your position on the map exactly - system is in general perceived as a great alternative that is for sure safer than using navigation apps
Person 10	Malmö			understood as destination reached or test finished	combination is best, but if it would be a product, testperson would buy only the vibration part	<ul style="list-style-type: none"> - always repeats that the vibration is really nice and feels more safe - more information needed to maybe know which exit to take in a roundabout or similar unclear situations - gives you more freedom and feels safe to use
Person 11	Frankfurt	and signals talking more about that	- a more aggressive sound would maybe be good for stop, even an annoying one, maybe also stronger vibration	perceived as something like "level finished" (like when playing a game)	paid more attention to the sound, likes the vibration most but would use a combination for navigation	<ul style="list-style-type: none"> - headphones were sitting a bit too loose - no information missed - would prefer this type of navigation instructions compared to former used ones - better than other because: in general feels pleasing, clear and nice softer sound, no need to look on the smartphone -> no need to stop (at least not when there is no totally unclear street situation), one can concentrate more on the street and what's happening around - does not go with music but a bluetooth box to still hear surrounding
Person 12	Frankfurt	fast, directly to	- interpreted the stop or warning signal as continue straight although all possible instructions were communicated beforehand		doesn't really matter, no real preference	<ul style="list-style-type: none"> - in general a good idea, would use it if new to a city or an area or to follow a faster route or for training purposes, - maybe even for motorbike, but needs to be tested if that really works of course - would like to have it in combination with the teesy → in the way that a more shrill tone comes up when more information and important details are available - doesn't like the provided sound - it does not necessarily need a straight ahead but maybe still good in a roundabout or if the main street makes a curve and there is a side street going straight → on the other hand a go straight command would be annoying to have all the time then

Test factors												
Testperson	City	Street types				Pavement			Environmental factors	Other	Usage of navigation systems	Cycling behavior
		"Protecte d" ways and Bike lanes	Bike lanes on street lanes	Side streets	Main roads	asphalt	sand	cobbleston e				
Person 13	Offenbach			x		x		x	air corridor → partially extremely loud		- uses google maps in form of voice instructions over headphones on one side - stops to look on the map, but feels that that is sometimes also really dangerouse, depending on where you stop, are able to stop - always looks for easy solutions friends are partly using, to mount the smartphone on the handlebar, but is actually not really willing to buy one. Also the price and the mounting are important and still sceptic if the phone really is fixed safe there	cycles regularly, weekly but not in the winter - likes to listen to music but only over one headphone (in-ear)
Person 14	Offenbach			x		x		x	air corridor → partially extremely loud		- uses komoot and google maps for navigation on the bike - mostly using the map, but sometimes also voice - voice instructions are used less, as it is disturbing - if audio used, headphone used one- sided - mounts his smartphone on the handlebar to use the navigation, to look on the phone - in the city he feels it is actually a no - go to look on a map while riding, thus tries to memorise as much as possible to not have the need to look	- usese the bicycle almost daily int the summer, not so much in the winter - listens to music while going on the bike rather seldom, mostly on longer ways, tours - in the city almost never , even on longer distance, because of the constant need of quickly attention - thinks it's important, especially in the city to hear what's going on around you and from which direction sounds are coming
Person 15	Offenbach			x		x			air corridor → partially extremely loud	wears glasses, racer bike	- likes best to use the navigation system in his head :) - uses a web route planner to plan routes for longer tours or to look up a way for going by bike, tries to remember the way - in case of feelling lost or on the wrong way in the city (seldom on the countryside) google maps is used -> having phone in the pocket and pulling it out while riding to have a look ont he map - when not in the city, nothing is used to check if one is still on the right, planned rout. but it's also ok and nice explorative when going alone.	- bicycle used for almost all ways, no matter which season - doesn't listen to music and uses no headphones on the bike as apretiates the additional possibility and ability to register with hearing
Person 16	Offenbach	x	x	x		x		x	air corridor → partially extremely loud	wears glasses problems while tetsting. in between sound was not reacting, one time vibration was not reacting, box felt apart because of backpack and test needed to be stopped	- only visual, first view and planning with map and on the way checking the map, phone mounted on the handlebar - was never thinking that it is taking away attention from what is happening around	uses the bike for all shorter ways (under 5 km)

Test factors			Feedback / Results								
Testperson	City	Test procedure/ order	Vibration only				Sound only			Vibration and Sound	
			Turn indicator	Turn signal	Stop / be aware	Destination	Turn indicator	Turn signal	Stop / be aware	Destination	Turn indicator
Person 13	Offenbach	information on possible signals werer given before the test same start end end point order of signal types: vibration only, combination, sound only, random	- vibration most intuitive and directly felt - different patterns recognised after the second or third time, then super clear - vibration patterns werer harder to distinguish on bad pavement	either continue straight or turn around		not tested	- sound was not clear → resulting in no reaction - just after experienced the sound a few time s already alone and in combination, the instructions were recognised - finds it hard to hear differences in sound especially when in higher traffic as the attention is directed to many other things that are happening aroun			not tested	signals in combination fr are easy and fast to unc testsituations - vibration more intuitive sound although it would on havier pavement (co
Person 14	Offenbach	information on possible signals werer given before the test same start end end point order of signal types: combination. vibration only, sound only, random	super easy and intuitive to understand	- stopping/ be aware signal was interpreted as it ("I think I need to slow down or even stop")		not tested	- sound can also be more minimalistic - one type "pling"of tone but maybe only shorter or longer tone or types the tone is played in a row - the used type of sound was nice and comfortable , soothing and also different enough from the surrounding sounds, but reminds of other things			not tested	no problem to perceive,
Person 15	Offenbach	information on possible signals werer given before the test same start end end point order of signal types: vibration only, sound only, combination, random	- difference between the type turn instructions were clear and good to differentiate	signal was totally unclear, didn't make sense intuitively like the turn signals		not tested	- sound not clear at all, would have liked for that to test and "learn" it before using it outside on the bike - sound was good to hear but of course it's the question what does it mean, but can probably be learned easily. learning the meaning of a specific sound or melody is easier as learning a new leanguage.	was ignored, as the meaning was not clear and first idea was that it means to just continue straight ahead		not tested	
Person 16	Offenbach	information on possible signals werer given before the test order of signal types: combination, sound only, vibration only, random	- vibration instruction differences between the turn signal types were felt and understood directly, not only because of the context and time aspect			not tested	the difference between indicator and turn signal is not clear	interpreted as continue straight		not tested	- having vibration and sr vibration makes one fee connected to your surro

Testperson	City				preference	More comments
		Turn signal	Stop / be aware	Destination		
Person 13	Offenbach	<p>vibration and sound understand in all different , could live without the be needed when riding (blestone)</p>	- stop signal was clear	understood as destination reached or test finished	vibration only as type of sound if reminding of church somehow	<p>- would like to have more information in spoken form , e.g. how many kilometers are still left until next .. and to destination, time to destination maybe average speed every now and then, ...</p> <p>- the type of headphones was a really nice solution to still hear whats going on around you</p> <p>- it total it feels way more safe → not having the need to look on the phone is great and still get the basic information</p> <p>- would prefer to still only use headphone on one ear, first used to it, second where you here the music or for such case sounds or voice instructions, no wind can disturb sound with in-ear headphones. With the open ear headphones the wind was to hear quite strong when coming from the front</p>
Person 14	Offenbach	understand and react right away		not 100% clear but still guessed that it could mean that you reached your destination	- vibration is perceived as the best alternative to maps - the combination with sound is in general the most understandable, but in case one doesn't want to wear headphones from time to time or the sound could feel disturbing when interrupting the music one would like to listen to	<p>- Thinks it's great idea, especially when it would , as he assumes, work without the "construct"</p> <p>- likes the sound instead of voice more, but also questions if it is good to distinguish from the surrounding in every situation, although he didn't had any problem</p> <p>- fears that something like an phantom- effect can occur from the vibration or similar like with your smartphone sometimes, that you think it's vibrating only when you hear some kind of sound that reminds of the vibration sound</p> <p>- the intensity of the signals was good balanced</p> <p>- likes the minimalism</p>
Person 15	Offenbach		to work as a stop it needs to be more stronger in vibration and more urgent sound. to slow down the current version works	not understood	likes the combination of sound and vibration most, then comes vibration. sound only is no option if not in the combination	<p>- everything that you attach to your body, especially the head is an additional loading that is not wanted</p> <p>- when it comes to the sound, test person fears, that one can get to the point that you rely and trust too much on the instructions</p> <p>- receiving sound instructions or voice doesn't matter if it come at the right time at the right point</p> <p>- system feels more reliable and precise</p> <p>- active navigation created a lot more stress, if one uses only a map to look at when you what you are more free and not awaiting any information. doesn't matter how the system works</p> <p>- the less one wears the better</p> <p>- integrated in clothes that one wears on the bike anyway it would be best. maybe in the bike pants, the waist</p>
Person 16	Offenbach	sound or even only ling of being more unding	- did not directly react to the stop/ aware signal, but after being asked what she thinks it could be, first intention was to turn around, or maybe be slow down	feels/sounds like a success	vibration only as she would like to listen to music	<p>such a system would be super great to use on the e-scooters especially when travelling and exploring new cities</p> <p>- thinks it is totally ok to have a look on your phone while riding a bike, but on such an e-scooter it is super dangerous</p> <p>- for some people it might still be best to have voice instructions</p> <p>- says she is the most visual type and would not like to not have any map. maybe vibration additionally to the map</p> <p>- the first sound (before sitting on the bike) -> functional test command) was perceived as loud (not too loud) and room filling -> test person thought everyone around her has heard the sound too, but I could not hear anything standing directly beside her</p>

Test factors												
Testperson	City	Street types				Pavement			Environmental factors	Other	Usage of navigation systems	Cycling behavior
		"Protecte d" ways and Bike lanes	Bike lanes on street lanes	Side streets	Main roads	asphalt	sand	cobbleston e				
Person 17	Offenbach		x	x		x		x	air corridor → partially extremely loud	wears glasses, hears less on one ear	- uses komott, google maps and osmand, now mostly komoot - stops to have a look on the map, if having the need to check the route and if still on the right course - realised at one point the it is more and more dangerous to check a map while driving, also because it seems that one needs to also think for the other traffic participants more and more	- started to use the bike for almost all ways about a year ago - does not listen to music while going with the bike - feels unsafe to go with music over headphones and as he could not find an alternative solution fast, he got used to not listen to music while biking
Person 18	Berlin	x				x			strong wind	wears glasses	- normally doesn't use digital navigation systems only paper maps	uses the bike for most ways all the year round
Person 19	Berlin			x	x	x		x	partly louder traffic noise	sun glasses + helmet, racer bike	- uses navigation systems, not so much on the bike but in the car - experienced navigation systems used in cars often as not precise enough, not fast enough	loves to cycle but needs to use the car more often in the last years. if there are ways that can be done with the bike, it is preferred. otherwise on free weekends bigger tours are done (unfortunately doesn't happen often)
Person 20	(Malmö)								outdoors, standing	Dry test		cycled regularly but not currently (since about half a year)
Person 21	Berlin								extremely loud, indoors, sitting	Dry test, has no smartphone	doesn't use navigation systems	doesn't cycle often, maybe once a month
Person 22	Berlin								extremely loud, indoors, sitting	Dry test	- uses google maps for active navigation in the car and on the bike - pulls out phone while riding to look on the map - no voice instructions used as they are annoying and too much and often	bicycle is used almost daily and during the whole year
Person 23	Berlin								extremely loud, indoors, sitting	Dry test		uses bicycle in the summer, maybe once or twice a week

Test factors		Feedback / Results									
Testperson	City	Test procedure/ order	Vibration only				Sound only				Vibration and Sound
			Turn indicator	Turn signal	Stop / be aware	Destination	Turn indicator	Turn signal	Stop / be aware	Destination	Turn indicator
Person 17	Offenbach	information on possible signals were given before the test order of signal types: vibration only, combination, sound only, random	depending on the situation partly understood as the turn signal	turn signal always clear and intuitiv	either continue straight or turn around	not tested	sounds actually good to hear and understand, but as not hearing so good on one ear, it doesn't feel so balanced - no problem to distinguish between the indicator and the turn signal		not clear what it means	not tested	different signals are eas understand in the combi
Person 18	Berlin	information on possible signals were given before the test order of signal types: combination, random	perceives a difference to the actual turn signal but reacts with turning to the regarding side if possible	no problem to understand and reacts right away	stops but thinks it's more a turn around	not tested	testperson does not react to sound throughout the test but gives feedback to perceive it right away			not tested	
Person 19	Berlin	information on possible signals were given before the test same start end end point order of signal types: vibration only, combination, sound only, random	- difference in vibration pattern between indicator and turn signal not perceived - because of situation, surrounding vibration only even worked without feeling a difference in the pattern - test person experienced a stronger feeling of movement in the vibration, pulling to a side in the really first vibration test compared to the test with the final prototype		was it stop or turn around?	not tested	clearly and fast perceived and interpreted in the right way all the time no confusion with the turn signal	clearly and fast perceived and interpreted in the right way all the time	- as experienced before in combination the meaning was clear and a fast reaction - to use the current sound as stop it should be adjusted to sound more urgent	not tested	- perceived, understand confusion
Person 20	(Malmö)	information on possible signals were given before the test order of signal types: combination, vibration only, sound only, combination	- pattern differences clearly perceived - gives feedback how the pattern is perceived by moving the specific hand and making sounds to it		without sound, only vibration the signal is esier to interpret as a slow down and/or stop	not tested	having heard the two different melodies 2, 3 times, alone or in combination there is no problem to differentiate and understand it in the right way		sound to soft for stopping but even only for increasing attention	not tested	- first time signals are perceived - concluded that the first is the indicator, the next is the destination - difference is clear and understood
Person 21	Berlin	information on possible signals were given before the test order of signal types: vibration only, combination, sound only, random	- "both are feeling nice and pulling to the side" - feels a different rhythm and strenght and concludes that the stronger one must be the turn signal, forgot what other directional instruction there is		no clue what it could mean, short shock moment	not tested	nice and comfy sound but no idea what it means, only that it has to do with a direction is clear when it comes from only one side				
Person 22	Berlin	information on possible signals were given before the test order of signal types: vibration only, sound only, combination	signals send quite quick after each other, thus interpreted as indicator and turn signal, as one felt stronger and longer		interpreted as a signal to pay attention in what form ever	not tested	melody difference between indicator and actual turn signal needs to be learned, not intuitive		concluded that sound is played on both sides it needs to be the "pay attention" or the mentioned destination reached signal	not tested	- all signals are way esier to understand - feels more instant
Person 23	Berlin	information on possible signals were given before the test order of signal types: vibration only, combination, sound only, random	felt a pulling but could not distinguish the two different signals			not tested	- likes the "feeling of the sound, but not that it sounds to "esoteric" - hard to clearly hear in between when not covering the headphones and ears (->loud environment, sitting inside in a pub)			not tested	

Testperson	City				preference	More comments
		Turn signal	Stop / be aware	Destination		
Person 17	Offenbach	y to distinguish and ination	contues to think it means continue straight but mazbe also because is expecting to receive anz kind of information on each intersection	not toally clear	the combination is best	<ul style="list-style-type: none"> - would definitively buy a system like that if it would be a product - sound coming from one side also leads the attention in that direcionm but not too strong - minimalistic, basic information while drivng super nice, more information and settings, customisation can then be in the route planning and maps that could be checked - a permanent reminder, signal may not be bad to know that the sytem is still active - a type of be aware or stop is not necessary - could totally dispense any visual navigation information with this system - if you know in whch distance to the next turn you need to take the first indication pattern is coming, then it is soo clear and intuitive-> it can get almost an automated reaction -> you could also set it by yourself in with distance
Person 18	Berlin		- stop, be aware is at first interpreted as continue streight	not tested	no preference. it's all such a new experience that it could be useful no matter in which way	<ul style="list-style-type: none"> - doesn'T react to any signals but gives feedback what was perceived and actually interprets turn signals and stop signal the right way - feels that receiving signals only on onw side, the balance also automatically goes into that direction - if such a system proofs as reliable -> a few times using it and easy and safe reaching the destination, it's a great system
Person 19	Berlin	and reacted to with no problem or		interpreted as such, creates a "good feeling"	- in general the combination is the best solution to get all the information reliable in all situations, - an option to switch modes between haven either sound, vibration or the combineateion would be best	<ul style="list-style-type: none"> - always awaiting an instruction not because of test situation, test person is always awaiting if any instructions are coming when approaching a crossroad when using active navigation - says that especially on the bike a system like that would be very useful - on cobblestone the sound signals are absolutely necessary - reacts stronger to sound and has no problems to distinguish the different signals acustically - sound perceived as much more comfortable as speech, speech in navigation systems is also often quite unpersonal computer-voice - likes the minimalism, one doesn't need more information on the bike and the density of information is also good to be less - another signal for turn around could be useful - doesn't like to wear additional gear when cycling, an integration of the headphones into the helmet or glasses would be nice, wristbands no problem - perceived as more precise, reliable and safe. only reflecting wristbands are in itself increasing safety
Person 20	(Malmö)	erceived it is logically played one needs to be he actual turn signal signals are easy to	works as creating awareness but whould probably not make him stop	concluded as destination sound as it was the only signal that was mentioned and not sent so far	combination	
Person 21	Berlin			has no idea what it could be but seems like a confirmation or achievement	no preference everything a nice new experience	- likes the experience, but in the context of cycling he can't give much feedback or even imagine how it really works
Person 22	Berlin	er to understand in combination		- concluded the signal to be the destination signal - reminds of sounds in regional trains when you are entering the next station	combination works best, but would be fine to use vibration only	would have liked to test is on the bike outside on the street
Person 23	Berlin			"funny"	vibration only	would have liked to test it in an different environment

Test factors												
Testperson	City	Street types				Pavement			Environmental factors	Other	Usage of navigation systems	Cycling behavior
		"Protected" ways and Bike lanes	Bike lanes on street	Side streets	Main roads	asphalt	sand	cobblestone				
Person 24	Berlin								extremely loud, indoors, open space, walking	Dry test		cycles almost daily all year round
Person 25	Frankfurt								outdoors, walking	Dry test	uses google maps, in the car with voice instructions on the bike not	used several types of bikes on a daily basis for many years, but moves around by car now more often - when cycling does like to listen to music by using a bluetooth box

Test factors													
Testperson	City	Test procedure/ order			Feedback / Results		Sound only			Vibration and Sound			
					Turn indicator	Turn signal	Stop / be aware	Destination	Turn indicator	Turn signal	Stop / be aware	Destination	Turn indicator
Person 24	Berlin	information on possible signals were given before the test order of signal types: combination, vibration only, sound only, random			the difference between the vibration patterns is in general perceived, but needs to feel it a few more times to differentiate them intuitively		understood correctly	not clear what it is, but if there is an app to it, it can maybe mean that there is more information available now or something like that	- interpreted and reacted to correctly, because perceived in combination with vibration before - otherwise the melodies and their meaning will need to be learned			not tested	the first time the signals indicator is interpreted as soon as the turn signal i replies: "no, now I really directly while communic
Person 25	Frankfurt	information on possible signals were given before the test order of signal types: vibration only, combination, sound only, random			signals were send shortly after each other - the context of distance to an intersaction was missing - were understood as indicator and turn signal (information of possible signals werer just given before)		interpreted as "pay attention"	not tested	after having perceived in combination, no problem to interpret the signal as turn indicator - in comparison to turn signal the sound could be more simple		not 100% clear should maybe be a simple high "beep"	not tested	signals in combination c more clear to understand

Testperson	City	Turn signal	Stop / be aware	Destination	preference	More comments
Person 24	Berlin	are played, the turn is turn signal, but as s sent, the testperson need to turn" -> reacting it	understands is to stop	interprets the signal as "finished"	combination works best	- would like to test is outside on the bike - imagines that it works good even outside when riding the bike
Person 25	Frankfurt	if vibration and sound and to differentiate		concluded that it needs to be the signal for destination and thinks it could work	no preference	not much feedback only short time for the test and testperson was not really motivated and in a bad mood that day