HEARO

MARCIAL KOCH

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Thank you all!

ABSTRACT

Every moment, the hearing system provides us with clues about the perception of our surroundings. We are able to roughly determine directions and distances of sounds in everyday life. However, to protect us from acoustic overstimulation, this ability remains relatively passive. This thesis deals with the theory of our spatial hearing system and backs it up practically with various experiments, which ultimately led to the Hearo toolkit, with which our acoustic spatial perception can be actively explored. The toolbox is portable and allows for an experimental approach at various locations. During the playful usage, the user encounters repeatedly unexpected situations. Finally, Hearo enables us to obtain spatial information that we would otherwise not be aware of.

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INTRODUCTION

Hearing is an activity that not only affects the ears, but involves our entire body. The physical phenomena of acoustics works by causing matter to vibrate and by compressing or diluting air, which spreads further through air and matter. Our body recognizes these vibrations through the skin, internal organs, bone structure and eardrums. By hearing, our nervous system is activated, which guides the signals through the body. Muscles begin to twitch and tune into the sound (Oomen, 2017). Hearing is both, an auditory and a haptic ability. The main task is thereby performed by the ears. Our two ears are capable of processing sound waves with frequencies between 20 Hz and 20'000 Hz (Rosen, 2011). Hearing with two ears is called binaural hearing. Listening differs from hearing, as it is done actively by choice. Our sense of hearing already develops at an advanced fetal stage. Aside from the sense of touch, it is one of the first developed senses of our body. Since then we hear constantly, but most of the time unconsciously. Only when we hear actively and interpret the sounds we hear, can we assume that we are listening (Barthes, 1985).

Our binaural hearing allows us to determine the direction and distance of various acoustic activities. The estimation of these activities is based on different clues. Localization is made by static and dynamic aspects. Static cues are grounded on the interaural time differentiation, the interaural level differentiation and the head related transfer function. Dynamic cues refer to the movements, especially those of the listener's head, which strengthen the localization. Static and dynamic cues also play an important role in estimating distance. In addition, environmental cues such as echo and reverb are also relevant information for the locating of a sound source (Zhang et al., 2017; Stecker & Gallun, 2012; Kolarik et al., 2015).

In spatial perception tasks, humans rely very actively on their vision and only passively on their hearing. This is also evident from the use of headphones which many people put on when they go outside. With them, they acoustically encapsulate themselves from the real world and move into a digital one. That this might not only be due to the reasons of entertainment is shown by the theory of the Walkman effect presented by Shuhei Hosokawa in 1984. While listening to a Walkman the environment gets theatricalized. If the user is able to control the acoustics, he earns more control over his environment. Through the theatralisation, the environment suddenly becomes more interesting (Hosokawa, 1984). Except for the acoustical sense, it increases the perception of all other senses.
Why does the acoustic perception have to be blocked and serve to increase the perception of all other senses? Is the acoustic reality so boring or is the real potential of our spatial hearing ability not recognized?

As an interaction designer, I am also very visually oriented. I do not want to evaluate this fact. My main concern is to discover and understand our acoustic ability of perception in a new way. I want to create experiments that encourage an interaction between people and space and create unexpected situations both for designers and broader audience.

RESEARCH FIELD

1

BACKGROUND AND CONTEXT

Binaural Hearing and its importance

To determine the importance of binaural hearing, we can imagine what it would be like to live with a monaurally or asymmetrical-binaurally functioning system. Living beings that are able to assess sound spatially, have a clear evolutionary advantage. In animals and prehistoric humans, this ability allowed acoustical scanning of the environment for predators and potential victims before they are visually perceived (Avan et al., 2015).
For today's humans, the binaural hearing has further advantages. For instance, our binaural hearing contributes to the cocktail party effect» introduced by Colin Cherry in 1953. This details the ability to localize one voice among several and thus follow the speech of individual speakers, which is an essential aspect of our social existence (Cherry, 1953). The same effect also allows for acoustic displacement to a specific spatial location (Stecker & Gallun, 2012). Thus, we are capable of concentrating our listening ability to a specific space.

While the eyes play an active role in the perception of space, the ears are rather passive. This is because our hearing covers 360 degrees of our perception while our eyes are only able to perceive 150 degrees in front of our eyes, with effective perception being limited to about 5 degrees (Moss, 1938). Passive listening protects our brain from acoustic overstimulation.

Directional differentiation

To describe acoustic events in relation to one's self, a head-related polar coordinate system is used. The centre sits in the axis between the two auditory canals. We speak about angles on the horizontal plane (azimuth) and angles on the vertical plane (elevation). The median plane is vertical and passes through the centre directly between the two eyes. Sound sources in the median plane are more difficult for humans to estimate because each point is equidistant from both ears. This is where the front-back confusion occurs, as introduced by Lord Rayleigh in 1907 (Rayleigh, 1907). In this case, it is sometimes unclear for the user to distinguish whether the sound source is located in the front or in the back. The distance is the space from the centre to the acoustic event (Blauert, 1974).

Static cues

The minimum audible angle (MAA) in azimuth and elevation depends on the type of noise and frequency and can vary from person to person. For broadband noise, which is common in reality, the MAA is approximately 1 degree in azimuth and 2-4 degrees in elevation. The brain can achieve this accuracy by using different acoustic cues (Stecker & Gallun, 2012).

Interaural level difference

The first acoustic cue is the difference in volume at which the sound reaches both ears, called interaural level difference (ILD). The decrease of volume in the ear further away from the sound source is due to the head shadow effect. The head can absorb, reflect and refract sound, depending on the relationship between the geometry of the head and the sound wavelength. In addition, the volume is further influenced by the orientation of the external ear (pinnae), with the sound reaching the facing ear on-axis and the averted ear off-axis. ILD is mainly used to distinguish between acoustic events in azimuth (Stecker & Gallun, 2012).

Interaural time difference

At lower frequencies below 200 hertz, the ILD is barely audible. Nevertheless, the localization works as well as in the upper frequencies. The reason behind this can be found in the «duplex theory» described by Lord Rayleigh in 1907 (Rayleigh, 1907). It refers to a second acoustic cue, which is related to the phase shift and time difference, called interaural time difference (ITD). It is possble that the sound hitting one eardrum causes overpressure while the other eardrum is exposed to negative pressure simultaneously. This happens because the sound travels a different distance to both ears. During this time the phase is shifted so that the sound is in a different position in each ear. The ITD depends on the speed (approximately 331m/s), the direction and frequency of sound, as well as the geometry of the head and ears. In the duplex theory, the ILD is efficient for the upper frequencies, while the ITD is used in the lower frequency range. The MAA increases mainly in the middle frequency range (between 1000 and 1500 Hz), whereas neither of the two acoustic cues is effective (Stecker & Gallun, 2012).

Head related transfer function

Already Rayleigh recognized the quality of the external ear as a possible additional cue, due to ILD and ITD being essential for the localization in azimuth, but not in elevation and median plane (Rayleigh, 1907). The head related transfer function (HRTF) refers to the filtering of an acoustic signal on its way to the eardrum. In this process the sound spectrum is modified at the head, external ear and torso. Familiar filtered spectral patterns are recognized by the brain, thus enabling directional information in the elevation or median plane. Since the HRTF is an embodied cue and not an acoustic one, it differs for each subject. This means that each individual must learn their own spectral mapping in relation to the sound source direction (Stecker & Gallun, 2012).

Dynamic cues

Through the mobility of the head and body, problems like front-back confusions disappear and the localization ability is reinforced (Zhang et al., 2017). Simply by moving the head, the relative position to the source is altered so that the ILD, ITD and HRTF can be used optimally. Finally, the auditory system combines all cues according to the existing acoustic spatial situation, so the best possible effect is achieved (Stecker & Gallun, 2012).
Distance differentiation

Humans cannot get a spatial impression of their acoustic environment from the sound direction alone. When estimating distance, a distinction is made between peripersonal space (up to about 1m from the listener) and extrapersonal space (beyond 1m). The estimation of distance to a sound source is generally less developed in humans than the directional orientation. However, several cues exist that can be used to evaluate the distance to an acoustic event. There are absolute cues that allow estimation by a single sound event, and relative cues that work by comparing several sound sources with different distances. Additionally, it depends on whether the sound source is familiar or not. If it is a sound that has already been heard somewhere from different distances and is, on average, consistent in its intensity and spectral content, source familiarity provides absolute distance information (Kolarik et al., 2015).
Volume is a relative cue that is effective in most environments and over a wide range of distances (Kolarik et al., 2015).
In many indoor environments, an absolute distance estimate can be made based on the energy ratio of reverberation (Kolarik et al., 2015).
As the sound moves through the air, its spectral shape changes. This allows relative distance estimations for sound sources in the peripersonal space and sources over 15 m from the listener (Kolarik et al., 2015).
The HRTF might also be used to determine the distance to acoustic events occurring relatively close to the listener. However, it is not clear whether this is an absolute or relative cue (Kolarik et al., 2015).
A movement of the sound source or the listener can enhance the acoustic distance perception starting from distances beyond 2 m. For sounds in the peripersonal space, motion tends to have a detrimental effect. Dynamic cues are absolute and potentially also relative (Kolarik et al., 2015).
Estimating distances to acoustic events using a single cue gives very inaccurate results. Only by combining all cues it enables the listener to make a reliable assessment of his acoustic environment (Kolarik et al., 2015). In addition, visual information can be used to calibrate acoustic distances, which get stored in the brain and can be later retrieved as known experiences.

HYPOTHESIS

In comparison to visual aspects, the acoustics are often neglected when it comes to designing space. The participation of our hearing ability in the perception of space is usually underestimated. Due to this, visual localization is generally more accurate than sound localization (King, 2008; Kolarik et al., 2015). However, there are situations in which the auditory system takes over the main task of estimating a spatial situation, for example when visibility is limited, or things are outside the visual field.

My goal is to explore ways to provoke such situations, as it enthuses me to see how much trust there is in our auditory ability in relation to the evaluation of our environment.

Rather than making a comparison between the visual and auditory senses, this project aims to playfully shift the passive role of binaural hearing in spatial perception to a more active level. This leads me to my two research questions.

HOW MIGHT TECHNOLOGY CONFUSE HUMAN AUDITORY SYSTEM AND ALLOW US TO EXPLORE OUR TRUST TO IT?

HOW MIGHT I DESIGN INTERACTIVE DEVICES AND EXPERIMENTS THAT AMPLIFY OUR ACOUSTIC SPATIAL PERCEPTION?

METHODOLOGY

Intro

The methodology used in this project is very practically oriented. The obtained knowledge from desk- and field research was subsequently implemented in experimental processes and further explored. These experiments were then examined in evaluation phases to define next steps.

Desk Research

A diverse literature on the subject, from closer and farer related fields is of central importance. For me, this also included immersing myself in the function of our body. How do we actually perceive? In recent years, partly due to the arrival of VR and AR, research in the field of binaural hearing with a focus on head related transfer function or spatial hearing impairment and treatment has increased significantly. There is a lot of discussion about this, especially in the fields of neuroscience, medicine and psychology. Architectural and technical research in the field of realistic 3D sound reproduction might also be of interest.

Experimentation

The aim was to try various things and generate many smaller prototypes to create playful situations where sound and humans meet. In most cases, these experiments were in physical form and be tested by different people. It is important for us interaction designers to look at topics from different perspectives in order to understand the complexity behind them and to define possible impacts and potentials. In addition, an experimental process helps to find a suitable media for communicating the content of findings. Observing the reactions to the individual experiments leaded to further experiments and finally to the manifestation of my statement.

Field Research

In field research, I talked to experts in the fields of binaural hearing, sound design, architecture and sound art. As a possible contact I saw Fabian Gutscher, a sound artist and designer from Zurich, who is very versatile in his work with the phenomenon of sound in art and design. I was also looking for a conversation with Beat Föllmi, a music school teacher and percussionist, who works very experimentally within the world of sound and its possibilities. In the Institute for Computer Music and Sound Technology (ICST) at the Zurich University of Arts, there are experts working in the field of ambisonic technology, which involves the three-dimensional reproduction of sound. The sound architect and teacher, Andres Bosshard is a luminary in combining the fields of architecture and sound, so I invited him for an interview. In my literature research is a doctoral thesis on adaptive sound design in architecture by Dr. Thomas Schmalfeldt. He is working currently in Zurich, so through him I got insight into the integration of sound in architecture and space in general.

In the field research phase I also entered into sound engineering and played with various physical and digital tools. In addition, I gained a deeper insight into the piezo technology, which fascinated me even before this project.

Evalutation

I first tested various prototypes on myself. For documentation and evaluation purposes I recorded my experiences on video or audio. This allowed me to determine what was worth pursuing further or which direction I did not want to follow. The last prototype I tested on the sound artist Kaspar König, whereby I also took the view of a spectator. By changing the perspective I observed the reactions of a user who saw the prototype for the first time.

MOTIVATION AND INTENDED CONTRIBUTION

With my project, I want to bring a design perspective to this rather scientifically researched area. In my understanding, a design view means making the topic more accessible and experienceable for society. The term spatial hearing is still very unknown among designers and in society, although it is an essential ability of our spatial perception. Because as long as it works, we simply take it for granted.

Furthermore, my project can contribute new perspectives and not yet considered practical realizations. I aim to create playful situations outside of the laboratory, which is different from the experimental settings existing in scientific research. Overall, my project should encourage us to perceive the acoustic environment more consciously and lead to a reinforcement of the relationship between people and their ability to listen. To achieve this, I might place the people in a scenario where they must have total trust in their listening organs, so that they regain awareness of their spatial hearing ability.

RELATED PROJECTS

Intro

All the following related projects are located in the field of sound. Some of them are more on a scientific level, which was important for me, because my project also combines theory and practice. Others are more on an artistic side and contain playful interactions, which served as a model for my project.

NASA Ames Research Center

Nasa has been working on the integration of spatial audio into human interfaces since the 1980s. During the research of virtual reality, they worked on the idea of 3D sound. This method simulates the acoustic cues that occur during binaural listening. Using additional head tracking, the cues are shifted in relation to the head, creating a truly digital acoustic environment in headphones (Begault et al., 2010).
In 2008, NASA developed an auditory orientation beacon display, which helps astronauts keep track of difficult spatial situations. Guidance sounds refer to different targets. The system is helpful when the targets are out of the visual field or the astronaut needs his vision for other tasks (Begault et al., 2010).
A possible application of three-dimensional auditory displays can also be found in flight tasks. As the pilot is exposed to an ever-increasing amount of information, spatial auditory cues could facilitate the visualization of this data (Begault et al., 2010).

4DSOUND

In 2012, Paul Oomen, with his Studio 4DSOUND, presented a system that allows experimentation with spatial sound. Through a grid of 16 pillars, each containing 3 speakers, sounds can be sent through the room with the program Max-

4Live. Standing inside the grid, you are exposed to a three-dimensional soundscape and are able to locate each sound exactly. With this system, Paul Oomen has already conducted numerous workshops, inviting creators, coders and performers to experiment with sound in space within an innovative context (Oomen, 2016).

Spatial Sound Institute

The Spatial Sound Institute (SSI) was founded in 2015 by the 4DSOUND founder Paul Oomen. It is a research and development centre for spatial sound technology based in Budapest, Hungary. The SSI is a collective of different people with diverse backgrounds in music, sound design, sound engineers and other disciplines. Their projects relate to Sonic Architecture, Human Space Interaction Design, Physiology and Psychology of Listening and Spatial Memetics. The following manifesto can be found on their website:

«The programme of the Spatial Sound Institute starts with the idea that the way we evolve our listening will be the way we evolve our environment. And the way the environment evolves, will be the way we evolve as human beings. This implies that we can positively influence the cycle and bring about systemic change in our environment by listening more attentively.» (SSI, 2015)

Looks Like Music - Yuri Suzuki

Back in 2013, Mudam's Publics Department invited the Japanese designer, Yuri Suzukim to create an audio-visual installation. With his project, Looks Like Music, he encourages visitors to draw black lines on the floor. Different small robots will drive on these black traces and creating sounds according to the coloured areas the visitors added. What I really like about this project is its playfulness and the way visitors are allowed to take part in the installation by performing very simple interactions everybody understands.

Blind Drive - Lo-Fi People

Blind Drive is currently in development by Lo-Fi People, a Tel Aviv based art and technology collective. It is basically a video game without video, where the player drives a car just by using his ears. The game uses 3D audio technology in order to put the player in an authentic sound environment. This project brings exactly this notion of trust the auditory system, which I want to include in my work. In addition, there is a feeling of fear, as car accidents are comprehensible and in driving experience you are used to rely on your view. Maybe this could be a hint for my project.

Shape the Future of Audio - Zimoun

Bern-based artist Zimoun exhibited «Shape the future of audio» for the first time in 2016 on a public sidewalk in Bern. It is an elevated shipping container in which you can stand in from below through a hole. All surfaces inside are covered with paper bags, which rustle due to built-in DC motors. In my opinion, the project is very immersive, as it pushes you from the sidewalk in Bern into a totally foreign sound world. It plays with the materiality of an everyday object and thus links the digital with the analogue world. I could imagine including such a connection in my project.

Echolocation - Aernoudt Jacobs

The installation Echolocation by Aernoudt Jacobs, first exhibited in Berlin in 2008, invites visitors to explore the acoustic and architectural properties of a ring-shaped water reservoir from the

inside. For this purpose, he built a device, the Echolocator, which emits optimal sounds for the echolocation technique. In total, he produced 12 such devices, each of which sounds a little different. The individual devices interact with each other and change the sound depending on where you are inside building. The interior of the building is darkened. At certain points, Aernoudt Jacobs placed additional acoustic sources and thus divided the room into acoustic zones. At the entrance, each visitor takes an echolocator, then enters the installation and is encouraged to explore the room on its own.
I see many similarities to my project. This project is also about triggering our sonic perception to understand how sound and space correlates. Aernoudt Jacobs writes that *«sound can be used as a cue for location, with sound we could be able to ‚see' acoustic and architectural shapes.»* Since echolocation is very difficult to use for beginners, he has also included visual aids to the echolocator such as a laser beam and a small display with a schematic overview of the room resulting from its acoustic feedback. In my project, I prefer to avoid visual aids. I would also like to work with sounds resulting from our own activities rather than artificial ones. I see my toolset not only in the form of a unique situation in the form of an exhibition, but also as a kind of normal everyday object.

Vespers - Alvin Lucier

Alvin Lucier's work Vespers deals with the topic of echolocation. Using a Sondol, a hand-held pulse oscillator, he invites blindfolded visitors to explore the room. The short, sharp tones with different repetition speeds are reflected from the surrounding walls, giving the visitor an acoustic overview of the room.
What is special about this work is its age. Back in 1968, Alvin Lucier was one of the first artists investigating the phenomenon of echolocation. He and his works are characterized by a very spatial view of acoustics, which makes him one of my paragons in the field of sound art.

Hearing Sirens - Cathy van Eck

Hearing Sirens is one of the projects Cathy van Eck accompanied with her PhD «Between Air and Electricity - Microphones and Loudspeakers as Musical Instruments». Between 2005 and 2011, she created a portable speaker set that plays sound from an Mp3 player into the environment on both sides through two horns strapped to the user's back. With this project she investigated the behaviour of moving sound sources and the interaction of movement and space. What surprised Cathy van Eck was the emerging interaction between the horn speakers and the environment. As you move through the room, the surrounding space is discovered in a completely different way, more than would be possible between the instrument and its surroundings.
This project shows me how important it is to think about where and how the sound source is used. The perception changes fundamentally if the speakers were attached to a different place on the body. In addition, it forces me to think not only about hand-guided movements, but also about the involvement of the whole body.

Random Access Lattice - Gerhard Eckel

In 2011, Gerhard Eckel presents his interactive Sonic Sculpture Random Access Lattice. The visitor moves a hand-held loudspeaker through an invisible grid of sound recordings, making them audible. Through the type of movement, the individual recordings and their playback speed changes. With this installation, Gerhard Eckel explores the relationship

between sound and movement. Only slow movements lead to comprehensible sound sequences, while faster movements define a new form of language.
I am convinced by the result of the interaction. Through the movement a virtual three-dimensional sound field becomes accessible and, depending on the type of movement, it additionally transforms itself. In this sense, I consider the use of human voice recordings to be exciting, since they form a unity but are nevertheless very diverse and, on the contrary, make the visitor curious to understand something.

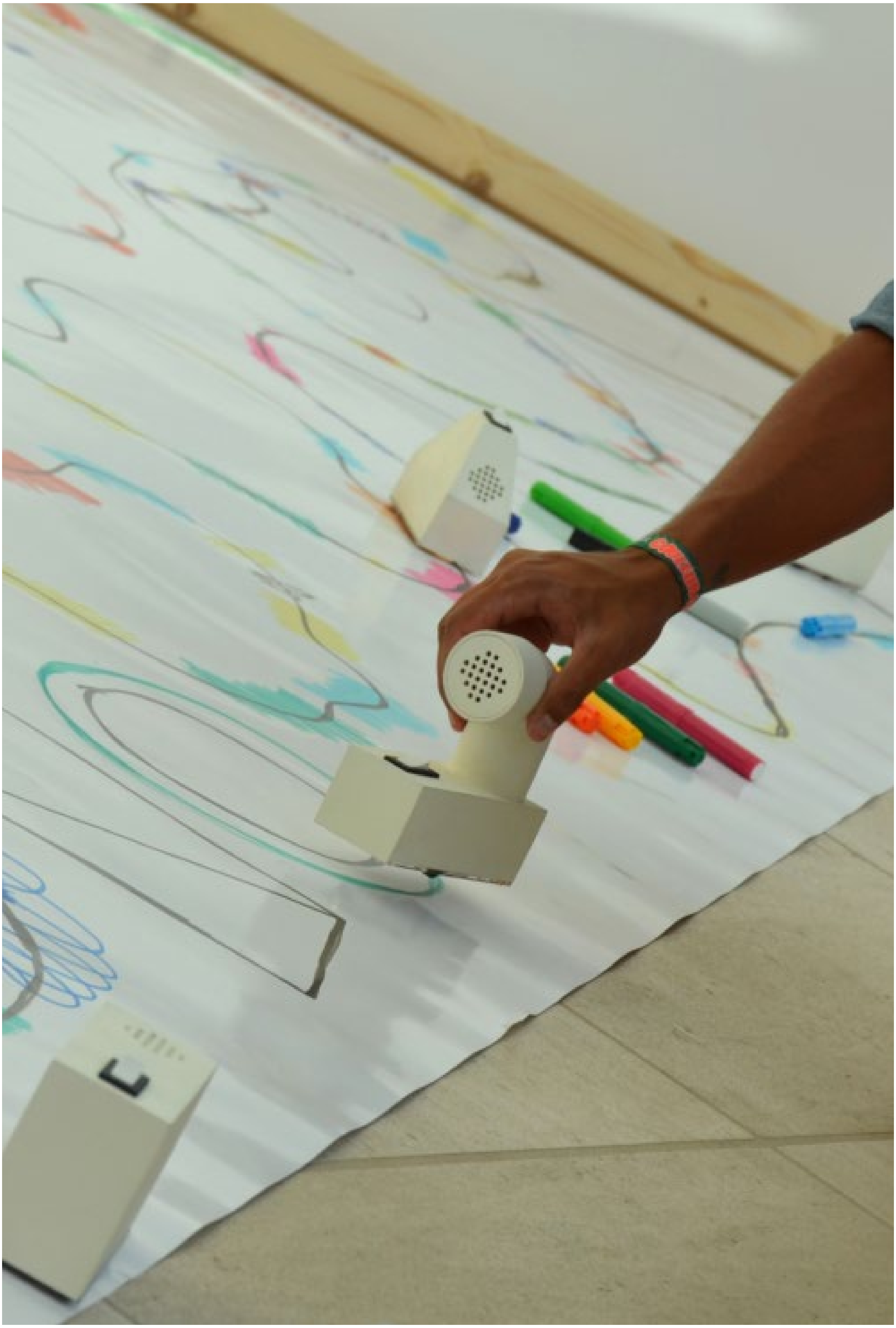


Figure 01. Yuri Suzuki. (2013). Looks Like Music. Luxembourg: Mudam.

Figure 02. Zimoun. (2016). Shape the Future of Audio. Switzerland, Bern.

Figure 03. Aernoudt Jacobs. (2008). Echolocation. Germany, Berlin.

Figure 04. Cathy van Eck. (2005-2011).
Hearing Sirens.

FIELD RESEARCH

2

ENTERING THE WORLD OF SOUND

Intro

Because my usual working process is very practically oriented, I had already placed the first experiments at the beginning of my field research. Nevertheless, the exploration of spatial acoustic perception requires an empirical process, so I thougt my strategy works this way. The main purpose of the first experiments was to get an insight into the world of sound. Questions such as: what an amplifier is, how do I operate an interface, and other basic questions should be clarified. However, it was important that I also keep a theoretical view. I tried to avoid repetition of experiments that have already been done by others through an explicit search for references in the fields I investigated.

Amplifier

An amplifier, or for short amp, is used to boost an audio signal. The power should always be more than the sound source (e.g. passive speakers) can handle. A 20 Watt speaker can easily be connected to a 100 Watt amplifier. It is important that the volume of the amplifier is not turned up to full power, otherwise 100 Watts will flow into the speaker. Most amplifiers have a stereo output and can therefore play two separate channels. With a 5.1 amplifier you have 6 separate outputs (5 speakers, 1 bass), but it needs a digital surround sound decoder to transfer the 6 channels from the computer to the aux input. Active speakers do not need an amplifier, as they already have one built in.

Audio Interface

An audio interface is basically a sound card with its own casing. It is responsible for processing audio signals. Usually it has several inputs and outputs, which are controlled separately. An audio interface is, however, not a replacement for an amplifier. The output signal is too weak to feed directly into a passive loudspeaker. In my case I use the interface because of the inputs, where I can plug in a microphone. The recordings are routed directly through the interface to my computer, where it gets live edited on a digital audio workstation and sent back to the Interface outputs.

Digital Audio Workstation «DAW»

A DAW is a computer system for processing audio. For my project I currently use 3 different DAWs. Audacity, an audio editor, is free and allows me to easily edit my own sound recordings. We encountered Reaper at the beginning of our studies and since then I have used it for several projects. It is probably the DAW I know best. Recently, I installed Ableton Live due to a classmate lending me a licence. Ableton Live is designed for creative people and therefore has a very clear user interface. It is also linked to the Max/MSP developer environment, which allows the creation of new effects. There are also people at the Institute for Computer Music and Sound Technology at the ZHdK who know how to use it.

EXISTING TECHNOLOGIES EXPERIMENTS

Intro

In the first experiments, I already refered to possible technologies that interest me and on the one hand could fit into my project. My mentors and interview partners brought to light some technologies that I did not know yet.

Copper wire

Most loudspeakers consist of copper wire coils, a magnet and a membrane. This also works without a membrane, which is principally there to concentrate the sound in one direction. In an experiment I wound copper wire myself and glued it to a thin wooden plate at the back. I connected both ends of the copper wire to the outputs of an amplifier. Via the computer I let sounds run on it. To fully hear the sound, I used a magnet on the empty side of the wooden plate and moved it over the places where the copper windings are located.

Piezo

Piezo elements are multifunctional in the sense that the same element can be used as sensor, microphone or loudspeaker. A distinction is made between piezo elements and piezo films. If the technology is used as a loudspeaker, powerful amplifiers of up to 100 watts are needed to make a sound audible. In addition, they have such a poor frequency response in the lower ranges that sounds below 1.5 kHz are not really reproduced.
By chance I discovered a kind of „haptic feedback“. Out of curiosity, I connected one piezo foil to the microphone input of my amp and the other to the output. When I held both foils in my hand, the one connected to the output started to squeak. With my finger I stroked the foil and changed the pitch of the sound. By bending the foil, the frequency range changes slightly and the volume increa-

ses. When touching the foil, I felt a very slight tingling sensation, so I assumed that the current was flowing through my body, causing this feedback loop. To test this, I let a classmate touch one foil while I touched the other. Only when we shook hands the sound appeared. The effect even worked through clothing.

Hyper directional speaker

A hyper directional speaker is an extremely directed sound source that shoots the sound into the room like a laser beam. It is constructed with an area full of piezo elements that produce two ultrasonic waves that are inaudible to humans. When the waves hit something, they are slowed down, which shifts the frequency response into the audible range. When I pointed the speaker at a wall, the reflection made the sound seemed to come from the wall. On the manufacturer's website it is written that only people standing in the ultrasonic beam will hear something. That's not true, because on any surface the ultrasonic waves are converted and reflected into the whole room, so that they can be heard by everyone. When I were directly in the beam, there was a reflection over my own body, which felt like the source was right next to my ear.

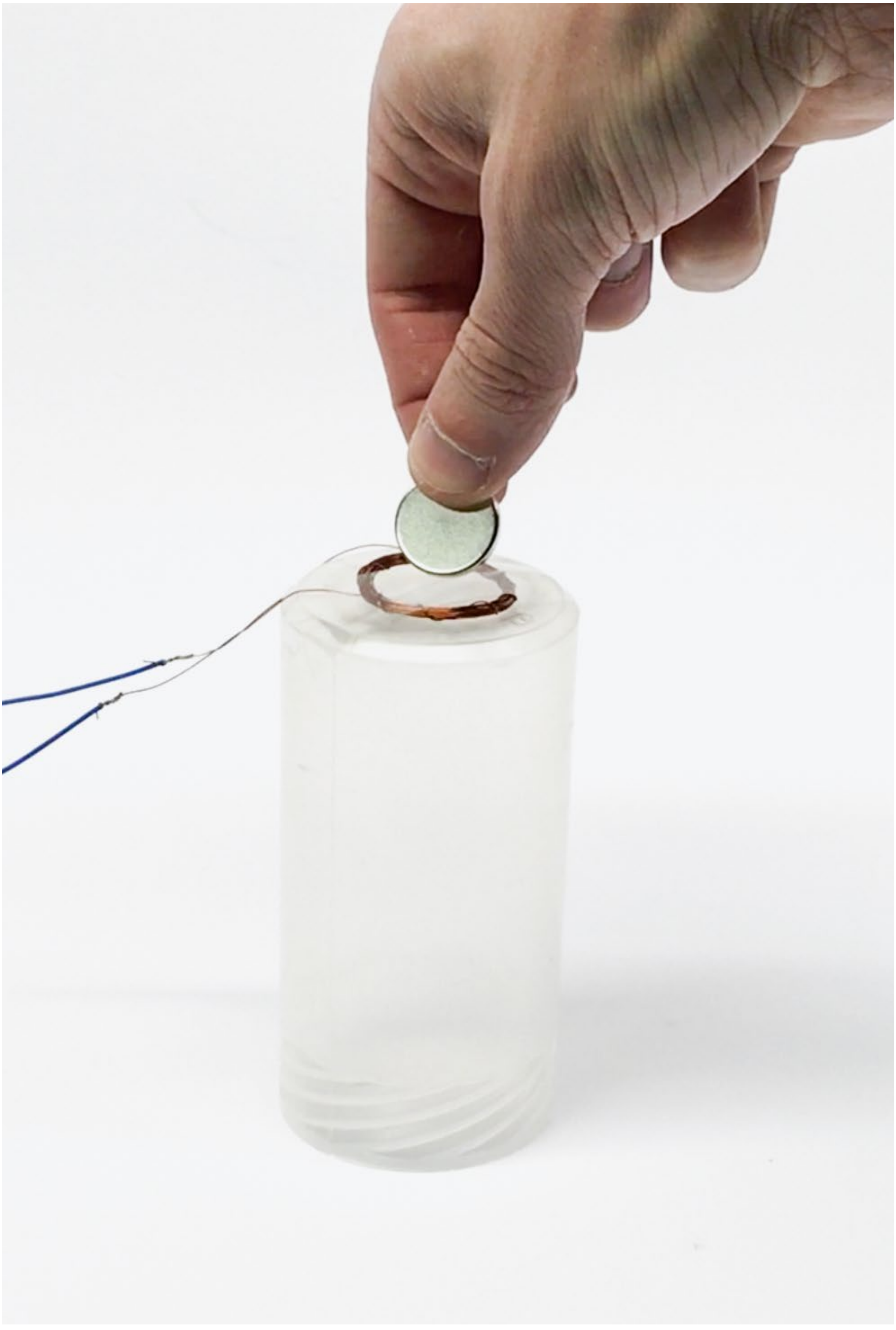


Figure 05. Copper Wire Experiment.

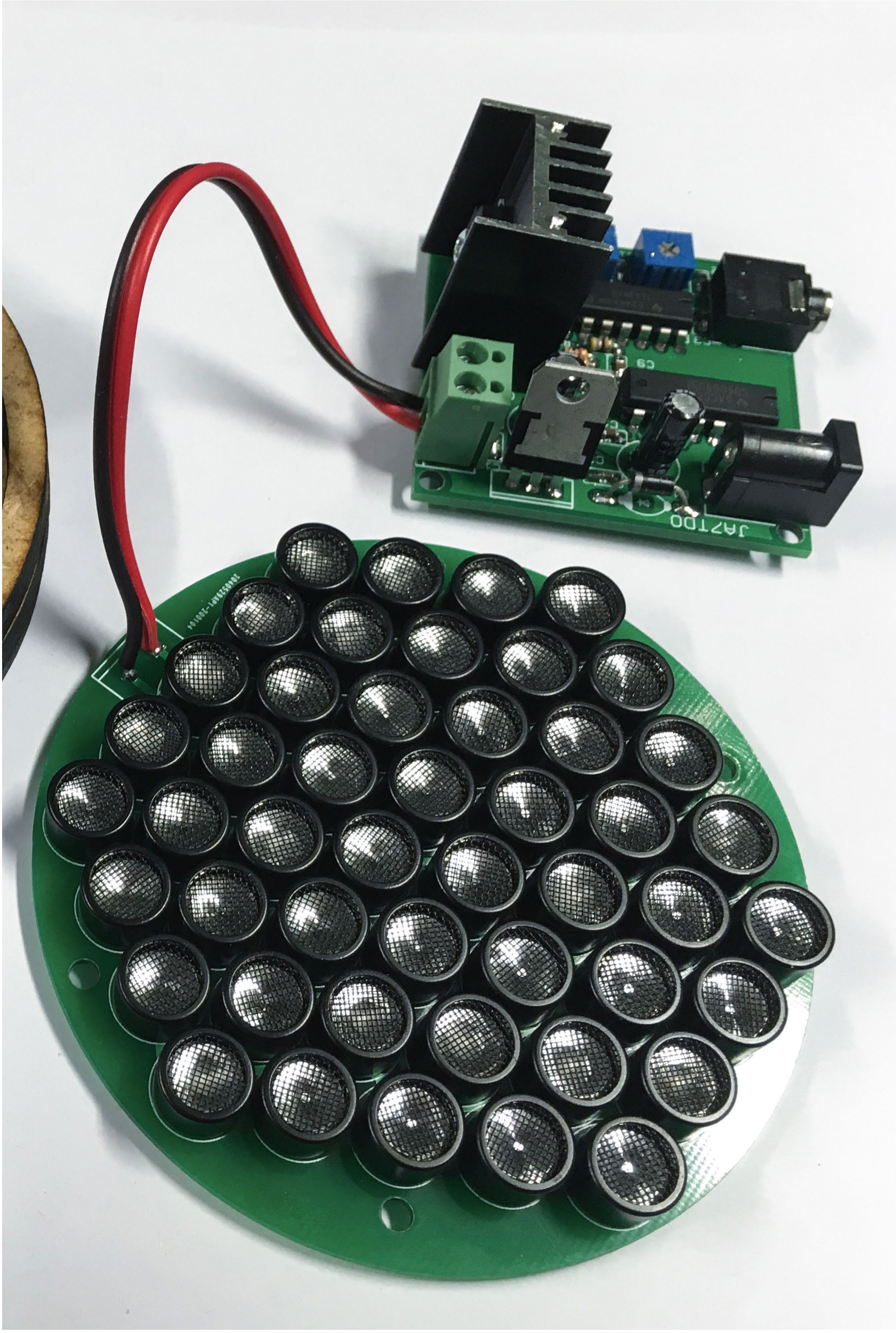


Figure 06. Hyper Directionak Speaker.

INTERVIEWS WITH EXPERTS

Kaspar König

During my field research phase I had the pleasure to talk with Kaspar König. Kaspar discovered sound as a medium after his mechanical engineering and product design studies during his master in sound art and composition. Thereafter, he has realized various sound projects. To begin with, he explained to me that he listens more with his feet than with his elbows. Everyone has their individual listening habits which they are educated with. These habits are different from day to day, from hour to hour. Sometimes we tolerate a noisy environment. A different time only a quiet surrounding. It is important to listen to yourself when realizing a sound project. For this reason, it is also rather difficult to create an acoustic confusion, because everybody hears differently. Our human intuition is to strive to be acoustically comfortable. When we design with sound, the first question is: What do I want to hear where? However, a quantification is not possible. The creation of a sound fan similar to the color fan is not an option. In return the sound is much more dynamic. It reacts much more strongly to external influences and is easy to manipulate. Nevertheless, our environment has been designed in such a fashion that we end up not wanting to listen at all. Nowadays, the aim is usually the reduction or the isolation of sounds. The focus should instead lay on the creation of an additional value, so we again start to listen to the environment.
When evaluating the acoustic environment, our perspective plays an important role. The sound of a chainsaw can be very annoying when you are close by. If you are the one operating it, it can cause a euphoric feeling. The ears generally get used to new situations faster than the eyes.

During our conversation, we came to the topic of resonance. When working with resonance, dynamism is important. It is boring just to stay on the resonance frequency all the time, only by continuously falling below and exceeding it, tension is created. One possible interaction with resonating objects is through damping them with your body. Our body merges with the other object and shifts its resonance frequency. Every part of our body has its own resonance frequency. Our vocal chords work with the principle of resonance to achieve such a volume.

After I explained the idea of audio tagging to him, he said that they are already present. There are sounds that have been imprinted on us that we consciously perceive them each time they are triggered. Kaspar says he wanted to give me an acoustic gift. Thereupon we went to the main entrance next to the Museum of Design in the Toni Areal. The first glass door on the far left produces several loud clacking noises when it swings. For Kaspar, this is an existing audio tag. Actually, I already knew that sound because I use this door twice a day. The acoustic gift lies in the fact that we both now consciously perceive this sound every time it is triggered.

Fabian Gutscher

Fabian Gutscher is an artist and producer with a focus on audio. I had already met him during the research field phase and we talked about general perception of sound and its presence in space. Some exciting facts came together, which I was not aware of. We can use numbers to define which frequencies we hear. Musicians or people with a trained ear can do this quite precisely. In terms of sight, we speak of colours, which are representative for frequencies. Fabian asked me how a room is audible. We were in the main hall of the Toni Areal. He clapped his hands once. The clapping sound reverberates in the room. The reverberation gave us an idea about the size of our surrounding space. Only through the use of an acoustic impulse the room became audible.
While we were talking, we focused our acoustic attention on the conversation. We filtered out everything else around us. This filtering process is a psychological as well as a physical strain for us. Therefore, in a room where acoustically stimuli is created a lot, you get tired very quickly, because we have to filter out a lot to protect us from over-stimulation. We are very passive listeners, because this filtering is constantly present. It is comparable with the skin. The skin is constantly exposed to stimuli. Our clothing, drafts, objects. Again, filtering is constantly happening. This in turn makes us passive sensors as well. Interestingly, the tactile and the auditory sense are the first two senses which are developed in the body already in the state of foetus.

Fabian also produces sound for movies. Audio editing works fundamentally different than video editing. The eyes are closed, the head turned, the eyes opened again. This is how video editing works simply expressed. The ears cannot be closed. The sound just keeps on going. Elements are added and removed. A moment cannot be captured like in a picture. The sound is always connected to time.
The last sound he paid attention before our conversation was the «piip» noise from the closing tram door at the top back.

Thomas Schmalfeldt

By chance I came across the ETH doctoral thesis „adaptive sound design in architecture“ by Thomas Schmalfeldt. With this work he introduces the digital baroque, which extends architecture with designable sound and thus creates

new design possibilities. The process up to the conclusion is, similar to mine, based on different experiments with different technologies. For this reason, I decided to contact him. He took time for a conversation at the Pädagogische Hochschule Zürich, where he has been teaching mathematics since 2012 and computer science since 2018.
There is no sound design in architecture. With his doctoral thesis he is, according to architects, an artist and according to artists an engineer. However, he understood neither nor, but positioned himself in between. Light design is an established component in architecture. Light can be adjusted according to individual moods and is included in the planning from the very beginning. So why should this not be possible with sound? Although we are just as sensitive to acoustics, its design in space is almost irrelevant. There is an optional module on acoustics in the architecture course at the ETH, but it is mainly concerned with fulfilling acoustic requirements. When we speak of spatial compression, the conversion of rooms becomes an issue. If the acoustics cannot be adapted accordingly, it hits the point of limitation much faster.

Thomas also showed me videos of his experiments. In one case, he equipped a table on the underside with transducers and piezo elements. When knocking on the table, the transducer changes the acoustic properties of the material. For example, he could make the table sound metallic or glass-like. This example also shows the importance of acoustics in the physical body. Although nothing changes visually, the material can be changed acoustically, so that it does sound for example cheaper or more expensive. Just like adjusting the colour temperature of light, the sound of materials could be adjusted in the future.

In another experiment, he equipped a meeting room with a hidden microphone. During sessions, he picked up the sound and played it back through the existing speakers with slightly altered reverberation values. Towards the end of the session, he switched off the system, whereupon he was asked by the session members why it suddenly sounded so unnatural. In nature, the reverberation values are constantly changing due to external influences such as wind. Slightly changed random reverberation values are constantly added to the sound that is played, creating a more natural atmosphere in the room.

Andres Bosshard

Andres Bosshard is a Zurich sound artist and has been teaching at the Zurich University of the Arts since 2005. He is a visionary sound architect and international luminary in his field. I am delighted that he has found time to talk to me. As soon as he started to speak, it was already clear to me that I would not be getting much of a chance to say anything. However, this is a good thing, because he has a huge amount off experience in exactly the area I am working on.

Our ear is fundamentally a social and not a spatial organ, because the space itself is social. It is a place where human activities take place. Through our hearing we are in contact with the space. The sound, in contrast, is opposite to the room. It wants to break out. Instead, it is reflected everywhere and returns hundreds of times. By means of an acoustic camera, the behaviour of the sound can be observed. With this camera you can see that as soon as a clapping sound is no longer audible, the sound is spread all over the room. It is no longer directed, but instead fills the entire room. Andres Bosshard thinks this is the beauty of acoustics, it invades even the smallest

matter.
The sound is comparable with light but behaves completely different. The light is too fast for us to perceive its movement. Meanwhile, in relation to sound, the present always remains blurred for our hearing system. Our hearing membrane has an inertia in which everything already happens. This means that we do not perceive the Now. The reflections play a significant role in the acoustic perception of space.

When we speak of spatial sound quality, we are referring to how well the sound produced by the opposite party is understood. We forget that also the incomprehensible sounds, the murmuring in the room, enliven the space. Through personal experience, Andres Bosshard says that sitting at the wooden tables in the ZHdK over lunchtime is like taking a bubble bath with whisky. You don‘t want to sit there for long, but afterwards you feel alive. In this sense, it is important to empower the individual person to shape the room acoustically.

Andres Bosshard recorded our entire conversation with a binaural microphone. This is a great instrument to understand the spatiality of sound, but it is not the key to it. He also gave me the tip that I should consider thinking crazy.

Veronique Larcher & Ambeo Team Sennheiser

Veronique Larcher leads the Ambeo immersive audio department at Sennheiser. She and her team took the time to answer my questions and gave me an insight into Sennheiser‘s 3D audio technology. The difference between mono/stereo and 3D sound is that 3D sound is a kind of holographic sound in space, whereas mono/stereo always sounds as if it‘s coming from the front. The 3D sound is much more dynamic, because it is already possible to render sound source motion in real time. Whether at home playing games, in front of a television, in a museum or in a theme park, 3D sound is nowadays mostly used in the entertainment industry. Sennheiser focuses on the recording of a soundscape using their developed Ambeo microphones, as well as on playback, for example through their Ambeo Soundbar or via headphones. The primary goal is not always to create a correct copy of the soundscape, but to convey it to the user in a credible way. On the question of how I can get people to listen more consciously again, one employee answered that spatial sound already requires more attention on the part of the user. A non-static sound makes the listening experience more exciting and the user automatically listens more consciously.

At the end of the conversation, I was allowed to try out the Augmented Audio Experience with the Magic Leap. Through AR glasses, I saw sound sources in the room, while I heard them through In Ear headphones developed by Sennheiser. The headphones equipped with a microphone played the real ambient sounds around me in addition to the artificial sounds. Sennheiser calls this technology „transparent listening“. This is because it is important for the AR Experience that reality overlaps with fiction. This created an increased immersive experience and made it more plausible. Now I was able to use a controller to place pre-set sounds at different places in the room or to record sounds myself. In the end, I found myself in a sound world created by myself. In my opinion the experience worked very well. When turning my head, I still knew, due to the acoustic cues, where the sound sources were situated, and I could locate them exactly every time. During the experience I also began to be more aware of my real acoustic environment. However, I could still distinguish between the real and artificial sounds. I think this is due to the type of sound. It would be exciting to find out which sounds have to be applied, so that in the end it is no longer possible to distinguish between reality and fiction.

Kurt Eggenschwiler
Empa Dübendorf

Kaspar König referred me to Kurt Eggenschwiler from the Laboratory for Acoustic/Noise Control at Empa in Dübendorf. «The activities of the Empa Laboratory for Acoustics/Noise Control are based on the fact that noise is one of the major environmental problems, and that soundscapes in buildings and in the built environment have a substantial impact on health, wellbeing and performance.» (Empa, 2020)

Kurt Eggenschwiler is also a guest lecturer at the Architecture Department of ETH Zurich and gives lectures in the field of room acoustics.
ETH Zurich does not have a research department in that field, so it is located at Empa in Dübendorf. Empa is in close contact with ETH Zurich. When I arrived there, I was introduced to various areas of acoustic research. Scenarios were set up in large halls to measure, for example, the sound transmission of a ceiling or wall construction. To do this, noise is generated on the top of a ceiling using hammermills while the noise level in the lower room is measured. The ceiling is modular so that it can be replaced. One research focus is the so-called meta-materials. These are materials that have been processed in such a way that the propagation of the sound can be controlled, for example, the sound can be resolved in the structure of the material.

Simulating and calculating the spatial behaviour of sound is only possible for simpler situations. This is also evident in the reverberation room at Empa, which I was allowed to visit. The shapes, positions and orientation of the suspended plexiglass plates were determined empirically so that they reflect the sound for as long as possible, thus creating a reverberation lasting several seconds in a comparatively small room. According to Kurt Eggenschwiler this would be practically impossible to calculate. The reverberation room becomes a similar character as a cathedral, except that the height of the room is only about 4 meters. After about 15 minutes we had to leave the room, as it became increasingly tiring to follow the reverberating conversation.

Afterwards I was confronted with the exact opposite situation of the reverberation room. The anechoic room was even more impressive. The absorbing materials on the walls make it impossible for sound to be reflected, so that it only comes from the source itself. Kurt Eggenschwiler's voice is coming from exactly his direction. It was also much more difficult to estimate the distance to the source, because sometimes it sounded as if he was right in front of me. For me it sounds quite unnatural in an anechoic chamber, because in every natural place in the world the sound is reflected somewhere, which creates a reverberating effect.

At the end of the visit we talked about the affiliation of acoustics. Kurt Eggenschwiler thinks that especially its homelessness in many areas shows that it is at home everywhere. I think that the design of our acoustic environment is a very current topic and could fundamentally change the spatial design of the future.

Figure 07. Visit Sennheiser in Zurich.

Figure 08. Visit Empa in Dübendorf.

INTERVIEWS FINDINGS

Kaspar König spoke about the adopted perspective and its influence on the perception of sound. Thus it plays a role whether the person takes on the position of a spectator or a user. Until then, I had not yet realized that the spectator is also an important component. As long as there are no headphones involved, the sound is heard by everyone within the radius of action.

The idea of Thomas Schmalfeldt with his digital baroque, which extends architecture with designable sound, had not left me alone. This led me to concern myself not only with an artificially created space, but also with real architecture. This raised the question of how to influence the built environment around us.

The idea that sound actually wants to escape, but cannot as it is reflected everywhere, impressed me.Andres Bosshard talked about how important these reflections are for the perception of space, whereupon I started to deal with this phenomenon in more detail.

At Sennheiser I was allowed to try out their augmented audio experience, where artificial and own sounds could be positioned in the room. There I noticed that my own sounds, such as a table knock or scream, had a much stronger effect than the existing sound samples. This was because I was able to create the sound myself and thus intensify the experience. By bringing in my own sounds, the experience also became much more complex. At the Empa I was shown the reverberation chamber, in which plastic elements are suspended that reflect sound for as long as possible. It was then that I became aware that the reflections can be deceptive on the one hand, but on the other hand provide information about spaces.

CONCEPT

3

CONCEPT AND APPROACH

Essentially, I find myself close to the practice of echolocation, but at the same time my project fundamentally differs from it as I am looking for the unexpected, the confusion. In addition, the ability of echolocation needs years of practice to interpret the reflected sound correctly, where my project should be useable for anybody from the onset onwards. I am not interested in creating an alternative method of echolocation, but in developing a toolset that amplifies our acoustic spatial perception. With this I would like to point out our currently rather passively used spatial hearing system and in a second step play with the trust in it, by questioning and testing it. Experiencing the acoustic properties of space is thus also present in my project.

The spatial behaviour of sound is very complex and therefore requires an empirical approach. We are constantly surrounded by noise. Better said, we are at its mercy, because we cannot close our ears and are unable to switch off our sense of feeling. Whereas in the prehistoric era close listening was part of survival instinct, modern western culture has little value to auditory spatial awareness (Blesser & Salter, 2007). In spatial design, the focus lies on acoustic containment and isolation. „Even though a space reacts to all sonic events with its own characteristic response, nobody from our modern culture imagines that an enclosed space is actually alive. (Blesser & Salter, 2007)

According to Andres Bosshard, our own sounds are what animate us and the space. In the book „spaces speak, are you listening?“ by Barry Blesser and Linda-Ruth Salter, the authors talk about the concept of aural architecture. Where light is needed to illuminate the visual architecture, sound is required to illuminate the aural architecture to make it acoustically perceptible.

«Architecture, like a giant, hollowed-out sculpture, embeds those who find themselves within it; it is to be apprehended from within. But that embedding differs between the aural and visual modalities because human activities produce sound but not light. In each case, the environment responds as if it were a partner in an auditory dialogue.» (Blesser & Salter, 2007, p. 16)

The dialogue between human and space forms the basis of our acoustic spatial perception.

Already during the Bachelor concept Seminar, I tested the trust of people in their auditory system. It could be observed that confidence in own auditory perception only emerged when the visual sense was taken into account. For these tests I used metal objects with characteristic sounds. For my next prototype I will focus more on sounds we produce, as they are always present and therefore almost no longer perceived anymore. Above all, they are the sounds that inhabit the space around us all the time. In human echolocation, humans can perceive their environment through echoes of sounds, mostly mouth clicking, that they actively produce. This ability needs years of practice to be able to use it in everyday life. Two projects, „Vespers“ by Alvin Lucier in 1968 and Echolocation by Aernoudt Jacobs in 2008, already refer to this ability. However, both projects use completely artificially generated sounds. In that sense I would like to work with a base of sounds derived from human activities, but I am not sure yet if the sounds are generated live or come from recordings.

Another point I tackled was the acoustic confusion. On one hand, the confusion together with the trust on the auditory system generates tension, and on the other hand, in a confusing situation the listener automatically gets curious. The attention increases as you want to regain control over the situation.

A reverberating space is something that architects and designers usually try to avoid in most projects. In the anechoic chamber at the Empa I had to experience first hand how unnatural a room sounds without the slightest reflection. The sound reflections in the room, which we perceive as reverberation, are the manifestation of the building voice. Through this project, I am giving this voice a platform to be perceived.

My mentors motivated me to think about my strengths and interests when it comes to my end proposal. I think my greatest interest and strength lies in the physical translation. The toolset could consist of different physical tools.

Figure 09. Bachelor Concept Seminar, Trust Experiment.

Figure 10. Bachelor Concept Seminar, Confusion Experiment.

FINDINGS AND NEXT STEPS

During all my experiments, I found that the hyper directional speaker is quite suitable for my intentions. Therefore, I packed the whole technology in a case which has the form of a flashlight. This change of shape alone shifted the affordance of this technology. I grab the „sound lamp“ and illuminate the room with sounds. If I close my eyes and swivel the lamp in different directions, I can estimate distances to surfaces through the returning sound and thus get an impression of the room. A little confusion occurs in the sense that various materials reflect differently. Glass, for example, throws the sound back very hard and directly. Absorbent materials tend to reflect soften and more quietly. When I open my eyes, there was also a slight confusion, as it takes a short time for the visual sense to take over the main task of our spatial perception. The acoustic impression of the room was different from the visual one, but somehow not inaccurate.

During the tests I used different kinds of sounds. I played snippets of recordings of sounding things, whole soundscapes from different places, my own footsteps and my voice. During a test with classmates and also on myself, I noticed that own sounds allow more complex interactions. A spatial feedback from sounds of own activities creates a playful atmosphere and encourages people to become creative and try new things. For this reason, I decided to work with sounds of human activities.

At the moment the confusion is only weakly present. My next task is to look for implementations of how I could introduce such confusion. Could the distance, acceleration or orientation change the sound? Interaction with the directional speaker is currently limited to the hand. The question arises to which part of the body the toolset could be extended, and which forms the individual tools could take. How does it behave with several directional speakers?

So far, I have tried the experiments mostly on myself. The next step will include the involvement of other people. Since sound is perceived very subjectively, the toolset behaves differently with each person.

PROTOTYPE DEVELOP-MENT

4

EXPERIMENTS

Compared to previous experiments, which were intended to gain insight into the sound world, this section is about experiments related to my concept. While trying out different technologies I noticed that the hyper directional speaker has a strong spatial acoustic property. The sound is only audible to humans when it hits a physical surface. Due to this phenomenon I decided to build my first prototype based on this technology.

Sound Flashlight

Blesser and Salter's statement that sound itself is necessary to illuminate the room acoustically inspired me to create a first prototype. There are various tools to make visions accessible in darkness. Before the advent of electricity, torches, candles or oil lamps were used, which were then increasingly replaced by electric light. Nowadays the flashlight is probably found in every household. That is the reason why I chose the metaphor of that tool. My idea was to create a „flashlight" that illuminates the room with sound instead of light.
In order to keep the effort as simple as possible, since primarily the shape does not play a role yet, I drew a simple box on the online platform MakerCase. The sound lamp consists of a box as a basic shape, a round holder in the front for the hyper directional speaker, and a handle made of a thin steel plate. To reduce the amount of cable, I built in a Bluetooth receiver, which receives audio from the computer and leads it directly to the speaker. The prototype is not yet completely wireless, because the amplifier still needs 15 volts. Using this first prototype I made experiments with different sounds.

Steps

In the Scouts, there were situations where I walked alone in the dark on tracks in the forest. The path in front of me was illuminated by my flashlight. Only my steps and the rustling of the wind in the trees were audible. Following this memory, the idea occurred to me to project the sound of my own steps onto the surfaces of the surrounding space over the sound lamp. For this purpose, I glued two piezo transducers to the underside of my shoes, which transmit the sound via the interface to the computer. In Ableton Live I was able to modify the sound before sending it to the sound lamp. For example, I played with the reverb effect to play with the characteristics of the room and the equalizer to filter out certain frequencies to manipulate the shoe type and step behaviour.
In the beginning, the volume of the steps was too low, which I could boost with additional effects in Ableton. Unfortunately, this also increased the background noise, because the piezo elements start to noise at high volume. I noticed that the focus was more on the movement of the legs than on the feedback of the room. After a while, the sounds appeared monotonous, which resulted in a loss of interest.

Voice

The voice is interesting in the sense that everyone sounds different. Similar to a face, it creates an identity, which enables us to recognize people only by their voice. We can actively control our voice and thus form language, which we use mainly for communication. Our vocal organ is so actively controllable that I wonder why we use our voice almost „only" for communication between humans and humans. When we communicate, the room reacts to our sounds. Most of the room's reaction is filtered out by us so that we can easier follow the conversation. However, what happens if we concentrate on the reaction of the room instead?

The easiest way to bring the voice to the sound lamp was to use a smartphone application. Since every smartphone has one or more microphones integrated, it is possible to use it as an input microphone. The signal can either be sent to the computer via cable or wirelessly. For my application wireless would be more suitable. With the application PocketMicrophone, the signal is sent to the receiver program PocketControl installed on the computer. The sound quality of the signal is good. Unfortunately, there is a delay of about eight seconds from signal input to output due to the network. This delay can only be circumvented by switching to expensive lavaliere microphones or cables. With the application Microphone Live, the signal can be sent to the computer through an aux cable. This is sufficient for first experiments, but I will have to consider a wireless solution at a later time.

If my live voice occurs simultaneously with the playback on the sound lamp, the room feedback was difficult to identify. To work around this problem, I ran various delays through Ableton. In the beginning I used my voice rather hesitantly and mostly focused on speech. When I noticed that certain pitches worked better than others, I started to become playful and tried with different voice pitches. Loud tones in the higher frequencies tend to give a stronger spatial feedback. Next, I experimented with various additional effects in Ableton. With a reverb effect on my voice, the room as a whole felt larger. The feedback is most intense with tonally sustained sounds, such as „Aaaah" or „Oooh". Adding an echo effect, which is essentially a reverb perceived as a separate auditory event, enlarged the room mostly to the side where the

Figure 11. Prototype Sound Flashlight.

Figure 12. Steps Experiment.

sound lamp is aimed. The room does not get bigger as a whole but either longer, wider or higher. The echo effect is more powerful with changing voice pitch, such as „Aaaoouuh“.
Using my voice as input and output proved to be playful with many possibilities. Unlike the steps, it didn‘t get boring because the situation changed with each voice pitch. However, my mentors pointed out to me that the voice can also only be used as input, which influences the output, that represents different sounds. This advice led me to further investigations.

Snippets and Ambient Sounds

During my studies at the Zurich University of the Arts, I repeatedly recorded sounds of different events and objects. I started to create my own small sound library. Intuitively, I selected some of these recordings to play them on the sound lamp. I also distinguished between object-oriented sounds and ambient sound spaces. The ambient sounds I got from the ZHdK audio library.
Over Ableton I let the selected sound snippets run randomly with constant alternation. As I already noticed while experimenting with my voice, sounds in higher frequencies are more effective. Furthermore, I noticed that very clear sounds, such as the emptying of a water bucket or the running of a coffee machine, as these are recognisable sounds, enhance the directional effect. However, it is not enough for a confusion, because firstly my eyes were open and secondly, I was familiar with the whole setup. The ambient sound spaces were not as intense as I would have expected beforehand, which was due to the fact that ambient sounds, concentrated coming from one direction, are perceived as unnatural. However, the object-oriented sounds were credible, since in reality they are directional.

Reflection on Sound Flashlight

The feedback quality of the sound flashlight was highly dependent on the type of sound. High and clear tones favoured the evaluation of the feedback by our spatial acoustic perception. With the prototype it was possible to acoustically „illuminate“ individual facets of the room and thus gain a better understanding of the surrounding space. The fact that I could still see the room and that I was able to actively control the illumination with my hand, made the situation quite predictable. From time to time confusion arose when feedback from a different direction than expected appeared. This happens when the sound is reflected over several surfaces and is related to the handhold angle of the sound flashlight. Next, to create confusion, I explored the placement of the hyper directional speaker and its influence on perception.

Placement and Form

The placement of the speaker on the body could have a significant influence on the perception of the reflected sound. Especially the affordance of the object, how it is held or carried on the body, determines the level of influence on the user‘s side during use. Since the perception of acoustics is generally very subjective, I tested the positions on myself and on other participants and let all observations flow into the evaluation. My aim is to find out how I could bring confusion into my project by the way I wear the device.

For all following experiments I created a template with different sound samples, which I repeated at all positions. On one hand, I used sound snippets of daily objects, like a bell, coffee machine or zipper. On the other hand, I also used my own recorded voice or sound ambience.

Front-mouth

When the speaker is held in front of the mouth, it acts as a vocal amplifier similarly to a megaphone. If the face is perpendicular to a wall, the sound is reflected back frontally. The reflected sound gives the impression that there is a sound source directly in front of the face. In case the face is not directed against a surface of a wall but against a corner, the sound appears frontally as well as laterally. Due to the reflections in the corners, the sound source is perceived from a larger area.
Other test persons told me about a similar effect when the face is angled towards the wall. There are certain perspectives that lead to a frontal effect. In addition, everyone experienced the frontal effect also on walls further away, although it was stronger on closer walls.
Fundamentally, a placement in front of the mouth only changes the spatial information content that can be extracted from the voice. There is no confusion in that sense, because the direction and behaviour of the sound is actually the same as from our voice, which we have been using all our lives. Unlike the handheld version in the previous prototype, the movement is related to that of the head and is therefore more restricted. Although the movement is still controllable, the position of the ears changes as well. This means that the relation of the speaker and the ears always remains the same. Although this would promote the acoustic spatial perception, it would deter the confusion. For the design of a tool it could be an advantage that no separate microphone module is needed, since the loudspeaker as well as the microphone are placed in front of the mouth and could be combined into one module.

Figure 13. Front-mouth Position.

Front-eye

In this version, the speaker covers either one or both eyes. My considerations for the one-eyed version were that covering one eye would result in the loss of the three-dimensional vision. By the use of the loudspeaker, however, the missing three-dimensional perception is added again, not visually but acoustically. When I tried this, I realized my mistake. For the three-dimensional view both eyes are only needed in the peripersonal space. From a distance of one meter our brain fills in the remaining information, so that we also visually perceive the third dimension in space with one eye. I found the interaction with the tool very natural, since the eyes are a predominant organ in spatial perception, whose position is replaced by a loudspeaker in this case.
Other test subjects reported a stronger concentration of acoustic perception when both eyes were closed, which led to a better acoustic assessment of distances. With only one eye covered, one test person also experienced one-sided acoustic perception. For example, with the loudspeaker above the right eye, he perceived a stronger feedback on the right ear and vice versa. He also noticed clear quality differences in relation to the distance between the speaker and the face. If the loudspeaker is positioned directly in front of the eyes, the distance estimation works best. The further away the speaker is held from the eyes, the more difficult the assessment becomes.
In this variation I like the natural interaction with the device. By having both eyes closed, the acoustic estimation of distances is increased, but the lack of vision also leads to illusions. For this reason, I think these versions offer a good starting point to introduce confusion.

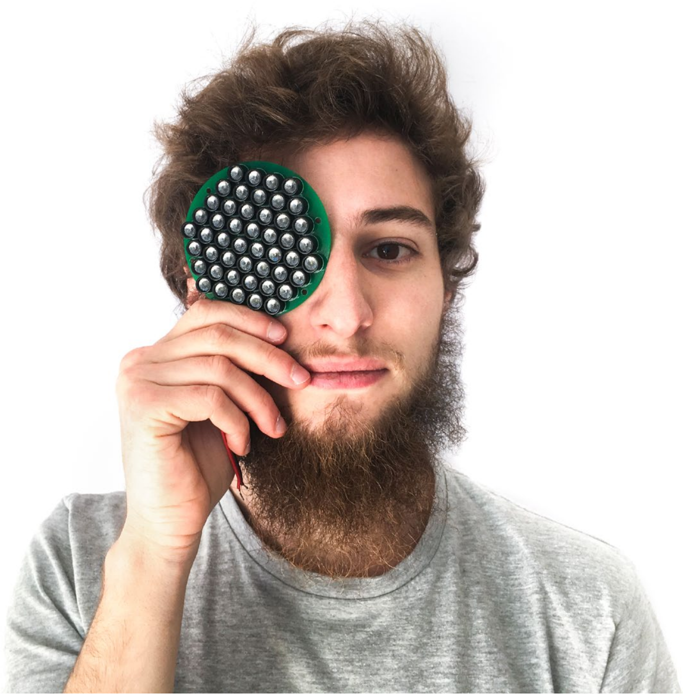


Figure 14. Front-eye Position.

Forehead

The interaction when positioning on the forehead is quite similar to that in front of the eye. What distinguishes this version from the previous one is the retention of vision, which leads to a reduced concentration of acoustic perception. When wearing the device on my forehead, I felt as if I was shooting sound laser beams into the room. This image made the device more of a superhero's ability to actively target something rather than gaining information about the room.

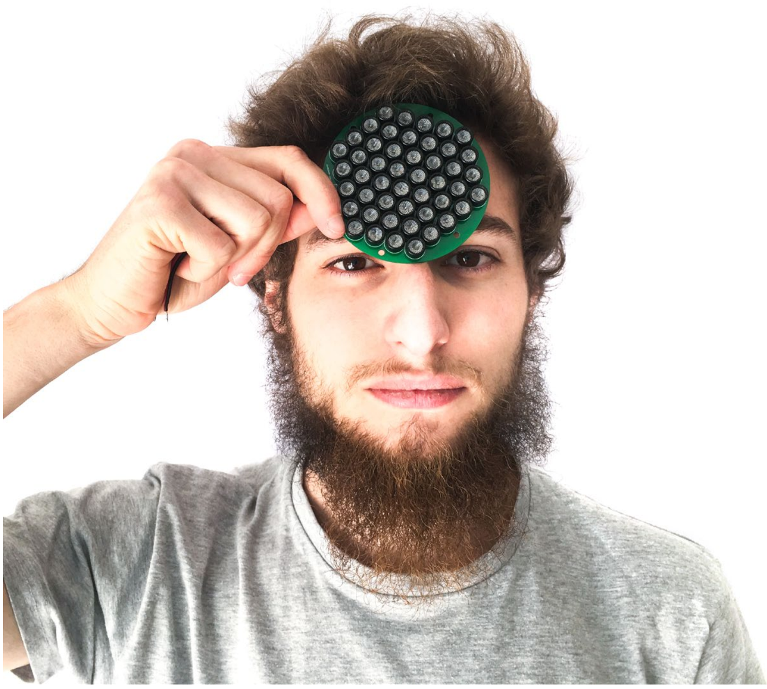


Figure 15. Forehead Position.

Next to the Ear

I positioned the speakers just below the ears, facing to the sides. Due to the proximity to the ears, I could hear the sound directly from the speaker, which drowned out the feedback from the room and thus destroyed the spatial acoustic effect. Although I had already rejected this version, I let the test subjects try this position. Surprisingly, one of them had not held the speaker like me but faced forward under the ear. This position changed the situation dramatically. Instead of hearing the speaker directly, the feedback was again in the foreground. This time, however, the feedback was heard like someone was holding a loudspeaker right frontal the ears. This position is not suited for estimating distances, but it would be suitable for detailed hearing similarly to a magnifying glass. As an example, different surface textures could be heard.

Figure 16. Next to the Ear Position.

Shoulder-mounted

Since the side position below the ears was placed too close to the auditory canal, I decided to use the shoulders as the next position. The goal would be to wear a loudspeaker on both shoulders. At that moment, I only had one hyper directional speaker, so I could not really try this position. For this reason, it was a very one-sided experience for me and also for others, which made it more difficult to evaluate the room. What was different from the previous positions, however, was that the sound direction did not match the natural forward direction of the mouth. Instead, the sound was always emitted to the side, even though the mouth was directed forward. This experience was initially confusing for all test subjects, and everyone always looked in the direction of the sound. When the head was moved, the position of the ears shifted in relation to the speakers on the trunk. This helped in the estimation of sound direction. In order to explore the room by using sound, a movement of the whole body is required for this type of attachment. I like the fact that the whole body is involved, because hearing is not only limited to the ears, but also occurs through the skin, bones and even the organs. When the carrier walks upright, he illuminates the horizontal plane. Only by leaning to the side he directs his shoulders up or down, and thus includes the elevation plane. Although this is a less natural movement, it increases the involvement of the whole body. After all, who says that acoustic spatial exploration must be based on the same movements as visual exploration? I think that especially since we hear with the whole body, acoustic spatial perception also demands whole-body movements.

Figure 17. Shoulder-mounted.

Overhead

To test this version properly, I needed the help of a second person. While I was standing, the other person held the speaker over my head. Not knowing the direction of the source caused some confusion as the sound was sometimes reflected over several walls. This was the first time I experienced the front-back confusion myself. Only when I turned my head slightly, I could determine with certainty whether the speaker was pointing forward or backward. Every time before the speaker takes a new position, it rotated away from the original angle. During this rotation I got feedback from the different directions, which enabled me to place myself in the room. Because the speaker is above your head, the rest of your body will not be in the way if it gets rotated. This allows a 360-degree view in the horizontal plane. The circumspection in the vertical plane (elevation) is added, better than in the shoulder position, by tilting the head. I see a lot of potential in this version, as it contains a confusing component and requires physical movements for a spatial circumspection.

Figure 18. Overhead Position.

Backhanded

As with the shoulder version, the idea here is to mount a speaker on each of the two backhand surfaces. However, the difference to the shoulder position would be that the hands could take any angle independently of each other, which would probably have led to a much more complex situation, since the shoulders are always in the same relation to each other. The backhand position is very similar to the previous prototype of the sound flashlight, with the difference that the sound direction is less predictably controlled. The test persons took the most bizarre hand positions by partially dislocating their arms. Very few of them found it necessary to move anything other than their arms and hands, as they could cover everything with them. For example, instead of turning the whole body, the backhand is simply directed behind the back. The test persons concentrated mainly on the exercise of the conscious movements and partly ignored the sound feedback to be interpreted.

Figure 19. Backhand Position.

On fingers

I removed the four emitters from two broken ultrasonic distance sensors. I connected them with cables and glued them to my fingers. While I was running sound over them, I realized why my main loudspeaker has 48 of these emitters. With only four of these emitters the output was very quiet and the feedback therefore not noticeable. Another problem was the arrangement. Since they don‘t form a field like the main speaker, but can be moved individually, the emitters are separated which generates four different feedbacks. It is possible to hold the fingers and the emitters together, but even so the direction is difficult to control as the angles to each other are still not voiced. I found the finger interaction very refreshing and amusing. However, since this version was not audible, I decided not to test it with other persons.

Figure 20. Finger Position.

Conclusion on Positioning

Most positions involve the head since our main auditory organ, the ears, are attached to it. The interaction with the movement of the head, the ears and the loudspeaker create confusing and exciting situations. Already at the beginning of the experiments, it became clear that with closed eyes the acoustic concentration and thus the acoustic spatial perception increased, in addition to leading to confusing situations. Acoustic perception was not as subjective as I first thought, since there was a basic agreement of most test persons in nearly every experiment. Nevertheless, there were small differences in which certain participants were able to assess a situation better or worse than others. In the end, I noticed that all experiments were based on the facts in my background research at the beginning of my thesis. All positions involved either more the sound direction or the distance. Both provide information about the relation of the carrier to the surrounding room and provide him with information about the space itself. If the loudspeaker is always in the same relation to the ears as it was with the position in front of the eyes, this promotes the estimation of distance. However, if the loudspeaker constantly changes its reference to the ears, it is possible to play more with the estimation of direction. After these experiments, I saw potential in the front-eye position on the one hand, since the removal of the view caused confusion. On the other hand, I found the shoulder position, as well as the position above the head, through the included movement of the body during exploration, as a suitable starting point. Finally, I decided to use the front-eye position as my distance tool and the position above the head as my directional tool, since the shoulder position would firstly require a second speaker and the confusion was more pronounced with the other two positions.

What would others do?

During the experiments with different people I was asked repeatedly about the purpose of this tool set. Basically, my aim is to bring the topic of acoustic spatial perception more into conversation, so that in a chain reaction, people in the field of spatial design would attach more importance to it. My toolset should arouse curiosity and encourage others to try it out for themselves. After a tip from a lecturer I realized that I could also turn the question around. Instead of people asking me questions, I could ask them for what they would use this tool set for. I sent the following description of the tool set to people with different backgrounds;

In my bachelor thesis I design a set of tools which can be attached to the body or held in the hand in any way and which enables us to acoustically perceive the space and its composition. For what would you use these tools?

«I would use it as a flashlight. Which means, that I would like to illuminate objects acoustically and for orientation.» (Silas Trachsel, spatial planner)

«I already got an incredibly sophisticated tool for this. It's my ear. However, as an electronic musician, I would find it extremely interesting to model the acoustic properties of the room using a technical tool.» (Fabian Gutscher, sound artist)

«To find out how much space is disturbed by electronic sequences. How pure the space really is? I think a lot of people would be interested in what kind of electro-polluted environment they live in.» (Nadja Moser, architect)

«For me it would be exciting to hear distances and sizes. To get an acoustic feedback of how big a room or how wide a place is. Similar to a bat to get an inner picture of the surroundings.»
(David Bomatter, spatial planner)

«I'd love to hear colours. I was inspired by the artist Neil Harbisson, who implanted an antenna into his head, which emits a different vibration frequency into the head for each colour. The difference would be that in my idea the colours start to speak, and the sound seems to come from the coloured surfaces.»
(Patricia Achermann, landscape architect)

These were the responses to my question about the use of this toolset. I was surprised that there were so many different ideas and that the interest to try it out was really there. At this point, I decided to create a box in which these tools are supplied. I could then send this toolbox to people who would like to experiment with it and implement their own ideas. The box could then be passed on from one person to the next, so that it moves from contact to contact and builds up its own network. In this way, a social component could also flow into my project. The two initial tools, the distance and direction tool, were developed by me through my experiments. However, I built the components in a way that they can be put together in a modular way, so that other people could also design their own tools. How exactly this could look like, I will explain in the prototype section.

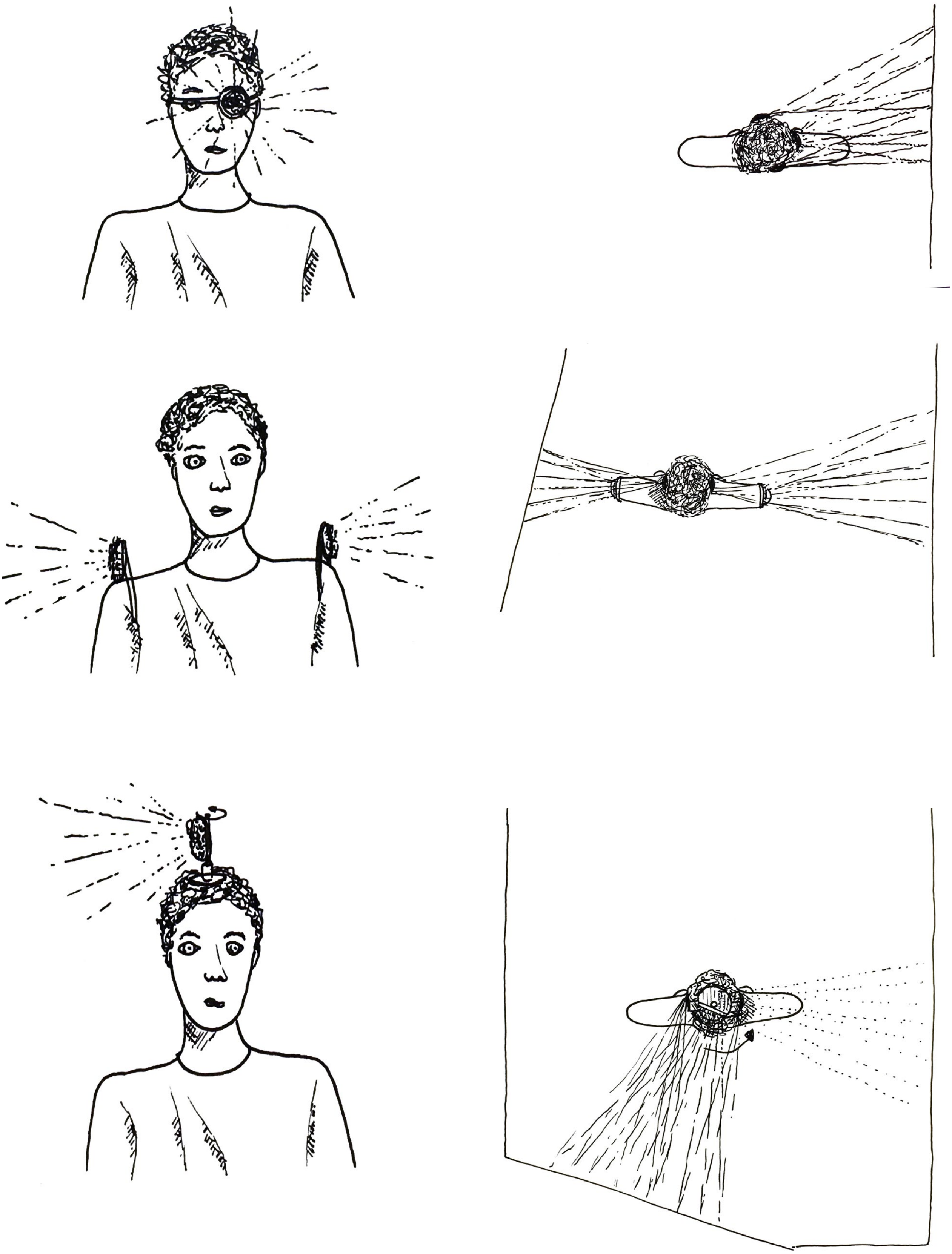


Figure 21. Sketches on Positioning.

HEARO:
FINAL PROTOTYPE

Hearo is a set of tools with which our acoustic perception of space can be actively explored. The toolbox is portable and allows an experimental approach at various locations. During the playful usage, the user encounters repeatedly unexpected situations.

Toolbox Composition

The toolbox contains different parts that fulfil specific tasks. The central element is the amp, which serves as the power supply and signal receiver. The two directional and distance tools I developed are connected to the amp module with an aux cable. The speaker itself is not fixed to the two tools, but is meant to be an independent element, which is clicked to one of the two tools with magnets. This brings the introduction of a modularity that later allows the design of other tools that only need to have a connection counterpart for the speaker. For my experiments I mainly used my voice. For this reason, the box contains an input module which is able to pick up the voice and maybe also other sounds from human activities. The last component consists of a manual that explains all modules and the intention of the box.

Industrial Design Moodboard

For the optical design I was looking for an aesthetic that I like and that fits the project, but on the other hand is also possible to realize with my CAD knowledge. Consequently, I remembered 70's devices of the big electronic companies like Sony, Telefunken, Panasonic or Braun. Especially the devices from Braun, influenced by the German industrial designer Dieter Rams, are very understandable and mostly composed of simple geometries. I found it somehow a fitting analogy to orientate myself on the aesthetics of these electronic devices, which were made suitable for mass

production by the design at that time. Like these devices, my project is only at the beginning and should be as easy as possible to use. Best would be plug & play. Furthermore, the simplicity should support the development of further tools by others. In addition, the introduction of plastic has generated forms that do not always indicate the intended use of the devices. I encountered designs where I am not sure yet what the device is doing behind them. My tools deal with something intangible in that sense and create confusing situations, so I think that such a design fits.
Their retro futuristic nature certainly made people feel modern back then. I think that's a nice thought if people today would see acoustic spatial perception as modern trend, as something that should be given more attention.

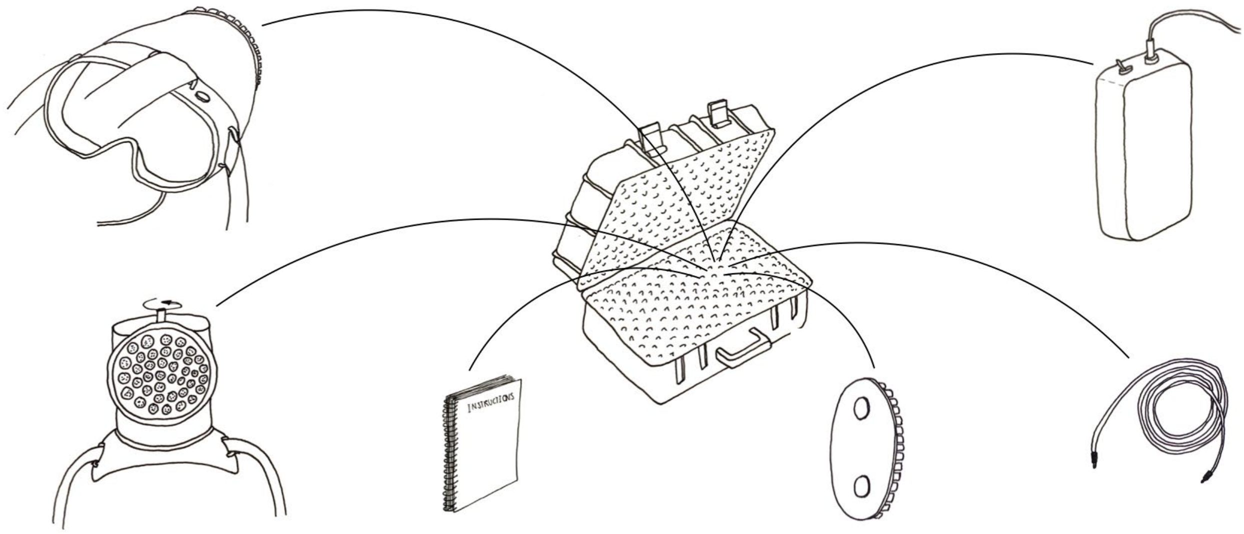
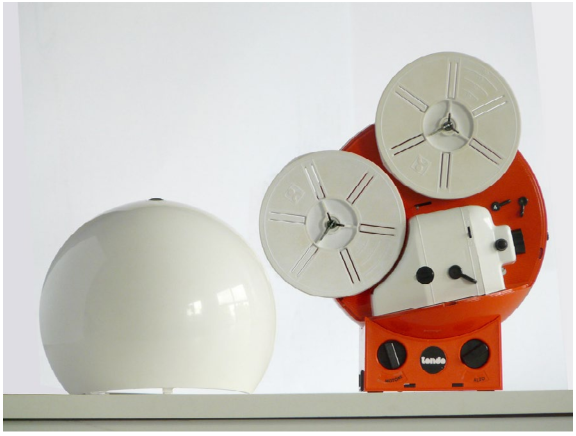


Figure 22. Toolbox Composition.

Figure 23. Industrial Design Moodboard.



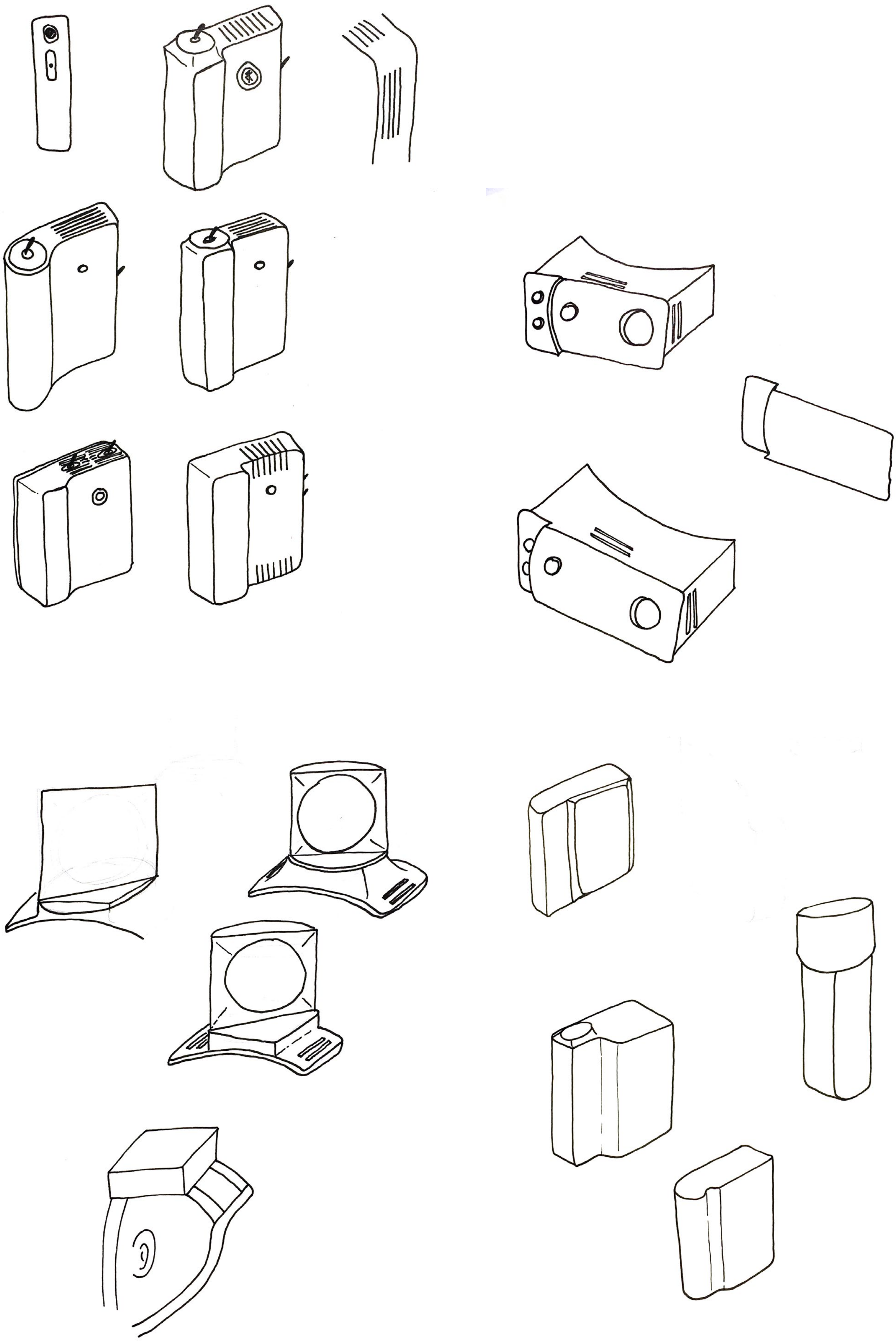
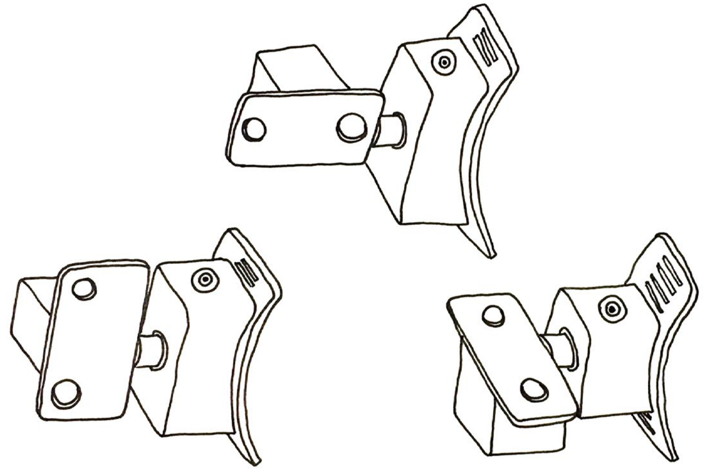
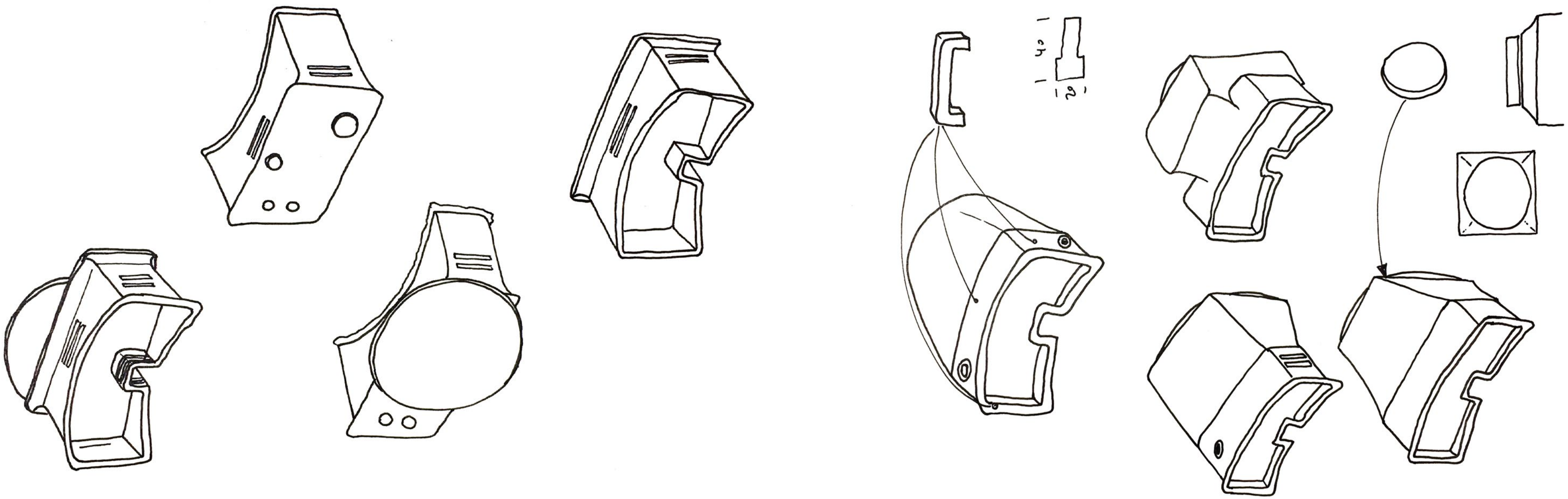


Figure 24. Design Sketches.





Fabrication Process

I created all parts in Onshape, a free to use online CAD. The general wall thickness is 2.5 millimetres, but the parts were designed as hollow as possible to save material. I, then, had the parts 3D printed in the manufacturing department of Roche Diagnostics in Rotkreuz using selective laser sintering method (SLS). Polyamide is a break-proof yet flexible material that is ideal for this type of mould.
I sanded the printed parts with an 800-grit paper before applying the first layer of pure white paint. Then I sprayed the parts twice with a two-component clear varnish. To further smooth the surface, I sanded everything again with the same sandpaper. All surfaces that remain white are taped. Now the orange color was applied. Finally, all parts are covered once more with the clear varnish.

In the finished parts I installed all prepared electronic components. Before everything was screwed together, I tested the individual functions.

Figure 25. Printed SLS Parts.

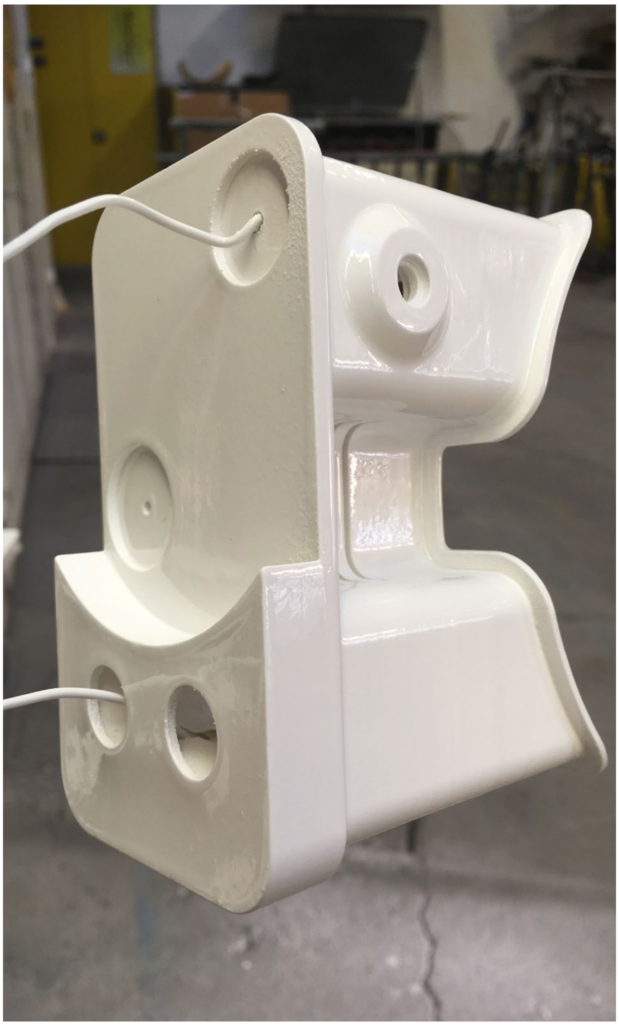


Figure 26. First coat of paint and varnish.

Figure 27. Choosing the Color.

Tools

Amplifier

The amp module is equipped with a 1.8 ampere li-po battery with 14.8 volts output voltage, a suitable amplifier for the hyper directional speaker, a Bluetooth receiver, as well as a voltage converter to generate additional 5 volts out of the battery voltage for the Bluetooth receiver and other devices. All these components are stored in a small box, which is carried by a belt clip. The aux cable port and the main switch for battery operation are facing upwards. On the side, the box offers another connection to plug in a power cable for battery recharging. An additional switch distinguishes between battery charging or power operation from the cable, so that the amp module can be used for further experimentation even when the battery is empty.

Figure 28. Amplifier.

Distance Perception Tool

The Distance Tool is a type of glasses that takes the sight and in return provides a better acoustic distance perception. The glasses are worn over an elastic band that goes around the head. Located on the front are two magnetic connectors to attach the speaker module to it. The audio signal is then transferred to the speaker through the magnets. For this reason, it is important to make sure that the ground and power poles come together correctly. The contacts are asymmetrical in size so that there is no risk of confusion when connecting them and causing a short circuit. There are two additional holes in the front. Behind them is a lidar sensor which can measure the distance to the next obstacle by means of a laser. It is therefore possible to map the effectively measured distance to a sound effect. In my experiments, for example, I mapped the distance to the intensity of the reverberation, which caused confusion, as closer walls contained more reverb feedback than farther away walls. The lidar is controlled by an Arduino MKR 1000, which sends the data wirelessly to the computer via Shiftr.io. These electronic components inside are hidden under a screwed plate. The plate can be removed at any time. On the bottom of the glasses is a port for an aux cable which can be connected to the amp. The cable carries the audio signal for the speaker and an additional 5 volts to power the Arduino and the lidar sensor.

Figure 29. Distance Perception Tool.

Direction Perception Tool

The directional tool is carried on the head via an elastic mount, similar to a bicycle helmet. A distinction is made between a fixed and a moving part. The lower part is padded and rests directly on the head. On the side of the fixed part is the aux connector for the speaker signal which comes from the amp module. Above the fixed part, separated by a ball bearing and shaft, lies the moving part of the tool. At the front of the moving part are the same two asymmetrical magnetic connections for the speaker as on the distance tool. The weight of the moving part is unilateral, so that a slight inclination of the head is enough to start its rotation. A slip ring is installed to prevent the cable from winding up due to the rotation.

Input Tool

Since I often used my own voice in my experiments, I also included an input module. The module contains a bluetooth headset with a built-in microphone, which is connected to the computer. On the bottom side is an aux connector, which is linked via cable to the corresponding mating connector on the amp module. The cable supplies 5V Volt power to maintain operation. On the side is a button for power on/off and pairing mode. To prevent the sound from blowing over due to breathing or wind, an additional thin windscreen is attached.

For the technical conception of the input tool, I needed longer than for all other elements. Like with the amp, I wanted to pass the signal via Bluetooth. Unfortunately, this proved to be more difficult

Figure 30. Direction Perception Tool.

for transmission than for reception. My first thought was to connect a microphone to a Bluetooth transmitter, which then sends the signal to the computer. These transmitters are actually designed to transmit the signal from a TV to a wireless headphone and use a suitable protocol for this purpose. The computer could be paired with the transmitter but did not recognize the signal as input. So, I got myself a cheap Bluetooth mono headset with a built-in microphone. This was recognized immediately, and I was able to make recordings in the Audacity. Since this type of headset is intended for phone calls, it uses a protocol that only allows very weak sound quality of 8 kHz sample rate. My previous DAW Ableton Live does not allow such low sample rates as input. To work around this problem, I installed the application Loopback, which routes the received audio signal to Ableton. This loopback converts the signal to the standard sample rate of 44.1 kHz.

The Input tool includes above mentioned mono headset for audio pickup and wireless transmission to the computer. On top is a simple windscreen that filters out the air blasts from the mouth. On the bottom is the Aux connector to connect the input module to the amp that supplies power to the headset.

Figure 31. Input Tool.

EVALUATION

When I tested the Hearo prototype on myself for the first time I was surprised how much I enjoyed using my own voice not only for communication between people. It was like playing with an echo, which I could modulate on the computer. When using the distance tool there were moments when I didn‘t know exactly where I was standing in the room, until I suddenly got a strong feedback so that an approximate localization was possible again. The directional tool is less influenceable there. By turning my head I could move it, but it could not really be controlled. This resulted in exciting moments, for example when I heard several feedbacks from different directions.

The second user was the actor I hired for the project video. The three of us, including the cameraman, were in an old factory building. The surfaces were hard on one side with large windows and soft on the other side with fabric curtains. Several large vertical steel beams ran through the room. Because the steel beams gave a more powerful feedback, the actor was able to move around them without any problems using the distance tool. However, what provided clarity in the distance tool was confusing with the directional tool. As the speaker rotated, it kept sliding over the steel beams, but the actor‘s reaction came too late, so the speaker was already at another point. Several stronger reflections had an effect on the actor, which created this confusing situation for him.

The highlight was when I took the toolkit to Kaspar König‘s studio in Emmental , where he as an expert in sound art, played around with it. On the one hand, it was the first time that Hearo had travelled and tried it out in a completely foreign place. On the other hand, I saw the joy in Kaspar‘s eyes when, with the rotating loudspeaker on his head, he howled various sounds into the input device, while turning his head to explore the feedbacks. We both think that Hearo has two sides of experience. As a user, as well as a spectator. The experience is not less immersive in the role of a spectator, because the sounds are bounced around the room while you stand in the middle also hearing the reflections, but from totally different angles than the user. I think that if a presentation or performance of this project will happen, the audience would have to change sides and actively participate. So, they must take both the role of a user as well as that of a spectator.

Figure 32.

Figure 33.

Figure 34.

Figure 35.

REFLECTION

After the last presentation the actual reason for a toolbox became clear to me. It was never just about all tools being nicely packed together and passed on from person to person. Instead it was mainly about the fact that this acoustic experience is very location dependent. I used the tools mainly in two rooms at home and therefore I have not yet exploited the potential of this tool set. During filming of the project in a hall at the disused paper factory in Cham, I faced an unexpected impression of the acoustic feedback from the tools totally different from those at home. These feedbacks were influenced by the size of the room, the different surfaces and the architecture in general, which were unlike to those at my home. The idea of this case makes it possible to play with the acoustics of different places. By adjusting the modulation of the audio on the digital audio workstation on the computer, local conditions can be taken into account. Therefore, it would be essential for my process if I could take the tools to different places and try them out on site.

I have also realized that the experiments have always come from me and that open experimentation with other people would be extremely important as this is one of the cores of my project. For this reason, I asked Kaspar König again as a first contact point, who immediately agreed to play around with the tool set. I will visit him once in the next weeks in his atelier in Emmental where we will go to different places inside and outside. And who knows maybe I will even leave the case with him so that he can pass it on to the next interested person as soon as he is finished.
At this point the question arose on how to document this process of other people' experimentation. Kaspar suggested to me that a tablet could be built into the lid of the suitcase, where after opening it an instructional video could be shown and

then the experience could be recorded by the tablet camera from the perspective of the suitcase. Actually, a good idea, but I think it should be recorded from the user‘s point of view, where the sound is picked up by a binaural microphone in the ears. A further question was about to collect these experiences.

Figure 36.

Figure 37.

CONCLUSI-
ON

5

CONTRIBUTION

The name Hearo comes from the term hero, as the portable devices amplify the ability of acoustic perception, similarly to a superhero who has an enhanced ability.

The acoustic perception of space is present in every healthy person. Nevertheless, many people are not aware of how powerful this ability really is. Hearo creates unexpected situations and thus puts our acoustic perception of space on a more active level. The user begins to rediscover his hearing system, although it has actually always been present. The toolkit serves as a basis for further research by interested people in this field. The main target groups are designers, architects and room planners, but also everyone else who is interested in this topic. From my own experience, I know that many architects plan geometries and select materials without considering the consequences for the acoustics. I imagine an architect wearing Hearo to illuminate the room he has planned himself and to find out what it means for the room's acoustics to have so many hard surfaces. Or a musician who starts shaping the room musically with the tools.

During my investigations, I repeatedly came across research papers that try to prove a thesis with rather strict experiments. One example among many others is found in Oechslin, Neukom and Bennett's work on the Doppler effect, where they wanted to prove that the «Doppler effect, which shifts the frequency of the direct sound and its reflections, is sufficient to identify correctly whether a moving sound source approaches or recedes (Oechslin et al., 2008)».
To verify this, they created a precisely defined setting and tested the exact same situations with twelve participants. I am aware that this is necessary to prove an assumption on a scientific basis and that my project has a different intention.

Hearo, therefore, creates a more playful experimental approach to the research area of spatial acoustic perception.
The technology of hyper directional speakers comes from a military context. Such modules under the name «LRAD» are used by the US military for communication and for controlling masses during protests. (xx) The project Hearo shows a new application of the hyper directional loudspeaker technology by addressing the resulting reflections in space. When using Hearo, confusing moments can arise, and the technology manifests itself as the opposite of control. The user loses control and unexpected situations arise.

When I ran a shower sample, Kaspar mentioned that as a user he had goose flesh. For him it was like feeling the water already on his skin. I, myself, was amazed by this suddenly occurring psychoacoustic component, which I hadn‘t even thought of before. The field of psychoacoustics deals, among other things, with emotions linked to sounds. Because Hearo involves the user‘s environment, the experience becomes more immersive. Thus, my project could also have an impact in the field of psychoacoustics.

By acoustically illuminating the surroundings, the acoustic properties of places are revealed. The effects that arise are different at each location. The user begins to read and understand these properties. In the context of spatial design, this could lead to a sensitization with regard to materials and geometries and their effect on the acoustics. We constantly illuminate the room with our language, but we pay little attention to the reflections, as we find them rather disturbing. Hearo focuses on these reflections and thus gives places their acoustic value back, which we have always ignored until now.

Generally, I am very satisfied with my process and the resulting outcome. Later, I would have preferred to experiment even more intensively with the last prototype. The free experimental phase at the very beginning helped me a lot to find a suitable way. At the same time, during this phase I got a lot of ideas for further projects, for example with the discovered analogue feedback of the piezo film or the copper wire loudspeaker.
I had noticed that over time I became almost immune to the sensation of the hyper directional loudspeaker and was therefore happy for every test person, as they gave me personal feedback from their experience.

When I look back, I can almost see some irony behind the fact that the circular movement of the head when using the directional tool resembles the movements of the people in the video from the Bachelor Thesis Seminar at the very beginning. Additionally, I became aware that my officially first project in the field of interaction design called «Echolon» 4 years ago also deals with spatial acoustics and I find it pleasant to see that my studies end on a similar theme.

Lessons learned

General Learnings

Since the individual design phases in this project took much longer than in any other project during the studies, the learning factor was correspondingly greater. In the beginning I had much longer experimentation phases like 3 to 4 days and through that forgot a lot in my evaluation afterwards. I shortened these phases to half or 1 day, so the evaluation was more precise and through that I could define a new direction much faster.

During this time, it was difficult to do user tests, as I worked from home and somehow tested the same persons. Especially during my project, I thought that the users has to be physically present. However, I realized that people generate helpful thoughts if they are simply asked and no visual clues are provided. At one point in my process, I thought up a few questions and scattered them over mail and messenger, and I got many helpful answers back.

Personal Learnings

Due to all my experiments, I got an understanding of the field I was investigating. I learned new digital audio workstations like Ableton Live and deepened my knowledge in Reaper. I also got an insight into the 3D based CAD Onshape, which I know quite well by now. Through experiments with the piezo foil, the piezo element and the piezo transducers, I discovered the various applications and properties of this technology.

This bachelor thesis contains a theoretical component with the thesis and a practical component with the project itself. I had done desk, field and other researches on previous projects, but on this one it was much more detailed over a longer period of time. The theory always accompanied the practice and so I constantly reflected on what I had already done and was able to determine what I will do. I learned that a practical work can benefit a lot from a parallel theoretical work in the same field.

FUTURE STEPS

At an earlier stage I had rejected the idea of an instructional video and planned an explanatory sequence of images instead. I had already taken the pictures for it, but there was not enough time to wrap it up properly. As soon as this is done, I will continue to test the toolkit with different people and eliminate any errors that still occur. The Bluetooth connection especially worried me, because the coupling with the computer does not always work at first attempt.

What kind of composition would enhance the spatial effect of Hearo?

My main goal is to pass Hearo on to interested people, so that they can experiment with it without me still being present. However, when I was working with Kaspar König in his atelier, running various sounds through the tools, I realized that I would like to devote some time to the project myself. Kaspar thought that it would be necessary to create a kind of composition that would work very well on Hearo by creating strong reflections in the room. This composition could be delivered as default with the toolkit and gives a first impression of what would be possible.

How to communicate the project to interested people?

One possibility would be to hand over the toolkit to a person who already expressed interest during my process. This could be Kaspar König, Fabian Gutscher or Joëlle Bitton. These first users would then, as soon as they are finished, ask people they know and hand over Hearo to them. The clue is that I probably don‘t know these people, so this way the project will also have a social aspect.
Another possibility would be to call them up via social media and the project website of the ZHdK. Although the first does not exclude the other, I am currently

more focused on the idea of the „wandering“ Hearo.

How could a Hearo community work?

Another question is, how I and the Hearo community learn about the different processes of the users. Should the experiments be recorded uniformly, for example with a binaural microphone, or is it up to each user to decide for himself? For the sake of simplicity, I think it is better if everyone decides how the process is documented. But it is obvious that these documents should be collected somewhere, so that the whole community can see them. One idea would be a collaborative blog, where documents can be posted in different formats by individual participants. On a larger scale, it would be ideal to create a project website. The website might contain not only the documentation, but also a basic project description and instructions, as well as the compositions of individual people to download, so that the Hearo community can try out the work from each other.

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