Micro and Macro: Developing New Accessible Musicking Technologies

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Abstract

During the past decades, technological inventions have widened the availability of musical instruments and applications. Different sensors, gadgets and gear open up new ways of thinking about instrument building and design. The main vision behind the development of the apps presented in this thesis is to consider accessibility of musical instruments and technologies. The thesis presents two prototype technologies for musical exploration with motion in the air, which are meant to be accessible for people with low fine motor skills. The thesis explains the relevant background concepts for accessible musical technologies and the design and implementation of the prototypes. User feedback was collected during the implementation and design of the prototypes and has been used to improve the prototypes, iteration by iteration. Qualitative observational studies showed that both people with normal and low fine motor skills were able to explore sound and music with the prototypes. Contrary to the expectation, it was found that avoiding the use of buttons and mouse did not make the apps more accessible for the people with low fine motor skills that participated in the study. It was also found that the speed of action seemed to be more important for people with low fine motor skills than the actual size of the control gesture. The developed prototypes, therefore, seem less musically interesting and probably more difficult to control than some other accessible musical instruments. However, due to being available online, the prototypes offer great potential in being more accessible to a lot of people. Web-based motion capture can allow for reaching much larger groups of people than what has previously been possible. This may ultimately also lead to both more personalized and accessible musical experiences.

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1. Introduction

1.1 Research questions

Young people with physical disabilities are more likely than others to think that their lives are less meaningful, according to the Norwegian organisation Unge funksjonshemmede (Unge funksjonshemmede, n.d.). They state that the ability to participate in sports and cultural activities is basic for equality and empowerment and for being able to build social networks. They also mention that a lot of people with disabilities and chronic illnesses today experience that there are major barriers for participation in cultural activities. This suggests that there is a need for new ways of thinking about musical instrument design. How could one overcome some of these barriers and approach more inclusive musical instrument designs? Can so-called "air instruments" be one way on the path to achieving this goal? To answer these questions, I have looked into previous work on the subject of air instruments and accessible musical instrument design. I also have designed and implemented two prototypes which have been tested by people with varying levels of fine motor skills. My main research question has been:

How is it possible to design and implement accessible musicking technologies that can be controlled with motion in the air?

I have also formulated three sub-research questions:

- *RQ1: How do the prototypes afford sound and music exploration, and how can they be taken further?*
- *RQ2: How can the prototypes contribute to making musicking technologies more accessible for people with low fine motor skills?*
- *RQ3: How do the prototypes compare with other musicking technologies that are designed to be accessible for people with low fine motor skills?*

1.2 Motivation and research contribution

My motivation for going into this matter comes from my experience from working with differently abled people and from taking courses in special education. My motivation also springs out from an activist heart with a passion for equality and inclusion. For many years I have been working assisting people with daily needs and facilitating their spare time, and I have experienced that music can be a major factor for gaining quality of life for many people. However, low fine motor skills is often a barrier for people to actually be able to play instruments themselves. For the initial idea of this thesis, I was motivated by a person I know who has a condition that causes low fine motor skills. I proposed my idea to this person, about a musical instrument web-app that only demanded gross motor skills to be handled. This was the answer I got (translated to English by me):

> This sounds incredibly exciting to me! I have dreamed about learning to play guitar and drums, but due to motor skills, this has never been possible! I know there exist similar apps, but as I know, not specifically about what you described. I want to hear more about this!

In interaction design, accessibility refers to how available an interactive product is to as many as possible, and especially people with disabilities (Sharp et. al., 2015, p. 18). The principle of accessibility will be a major goal for this thesis and for the prototypes I propose. However, due to the scope of this thesis, I have chosen to focus on a narrow category of disabilities, which is people with limited fine motor control. The reason why I chose to go on with this group of people is mainly because I saw a potential when working with motion capture equipment while taking a motion capture course at Music, Communication and Technology (University of Oslo). I saw a potential with using larger parts of the body to create sound, and I started to reflect on the idea of downscaling this technology to people's laptops and smartphones to make it more accessible to people. There are also some downsides and challenges with using sensors and cameras from people's laptops and smartphones, and those challenges will be reflected upon and discussed later in this thesis.

On the assumption that most of us have either a smartphone/tablet or a laptop with a web camera these days, I have decided to create the systems in JavaScript, so they can be run from a web browser. I have developed two different prototypes which use different types of sensors, but the concepts are still the same: the user makes hand gestures in the air to produce sound. The first prototype is called Micro and uses live motion sensor data that is retrieved from the accelerometer sensor inside the smartphone. This app requires a smartphone to be used. The second prototype is called Macro and must be used with a computer with a web camera. By using a web camera or an accelerometer sensor for motion detection, the user is able to control the system with gross motor skills (touchless), without the need of buying any extra equipment.

There are many reasons that people have low fine motor skills, and Cerebral Palsy is one of the most common conditions that causes it (CDC, 2020). As is commonly known, motor skill is also something that degenerates when we age. The population of the world is getting older and older, and what we also know is that music and music therapy can benefit health and well being for elderly people. In Norwegian special education, we talk about the term "funksjonshemning" (disability) as in terms that the environment and society is disabling the individual, not that a person is disabled (Tøssebro, 2010). Therefore I believe that there is a need and wish for reflecting around how we can combat the disabling environment differently-abled people meet when encountering musicking situations. A part of this picture is to take into account accessibility when designing new musical instruments. Hopefully, this thesis will contribute to developing novel technologies for musical exploration that are accessible for people with low fine motor skills. The evaluation of the systems will be a combination of subjective testing, user feedback and a use case experiment with people who have reduced fine motor skills.

This work related to this Master's thesis has been made during the Covid-19 pandemic. The initial ideas and research questions were formulated to be executed under the restrictions and limitations that were present during a society in a pandemic with frequent lock-downs. The pandemic has contributed to the choice of creating something that could be accessed online from people's own computers or smartphones. From the beginning, I could not rely on any plans that involved meeting people physically. Fortunately, this situation changed, and I was able to actually conduct some test sessions that involved meeting people. In the days of completing this thesis, December 2021, the society is again closing thanks to the pandemic. This is a reminder that online technologies for gathering data is something we need, at least in addition to technology we already have. Either for being able to conduct studies in times that we cannot meet physically, or by reaching out to a higher number of people. I hope that the work with this thesis can contribute to the development of online motion capture technology.

Before I started on the Music, Communication and Technology Master's programme, I knew very little about coding. I was familiar with Pure Data, and I had been playing around with HTML as a child, but that was it. During the course Audio Programming in the second semester of the Master's programme (spring 2019), I was introduced to Web Audio API and JavaScript. The prototypes developed in this thesis are based on coding skills that I have aquired on my own since I had that course, and the learning curve has been steep. Therefore, the quality of the code itself must be reviewed while keeping in mind that it was created with minimal coding knowledge and coding experience. The main focus of this Master's thesis has not been to write exceptional code, but to use coding as one of many utilities learned during this Master's programme for musicking and research.

1.3 Outline

In the second chapter, I will go through some of the main concepts and definitions that will be used in the thesis. Then I will give some attention to some other relevant work and musical instrument designs that have been done before. Chapter 3 will introduce the methods I have used to answer my research questions. In chapter 4, I will describe and explain the systems I have made and describe the design process as well as the implementation. In chapter 5, I will analyze the data that is derived from the subjective testing, user feedback during the implementation and the use cases. The last chapter will sum up the thesis, evaluate the data and try to answer the research questions. Some future work will be suggested and discussed, as well as eventual problems with the design and implementation.

2. Background

In this chapter I will go through some of the most important definitions that will be used in this thesis, but also put my work in a historical context and describe some of the similar work and research that is related to my work.

2.1 Embodied music cognition and embodied music interaction

It has been more common to acknowledge that the whole body is a part of the understanding of how music is perceived and performed (Jensenius, 2022; Leman et. al., 2017). Music is a multimodal experience that involves more than just the hearing sense. This is easily seen by studying children, who use their whole body when listening to music, typically by singing, dancing and listening at the same time. When we grow up, we learn the "appropriate" ways to engage and move our body in relation to music. To study these culturally internalized, but also unconscious and biological movements, methods of motion capture technologies have been developed to extract data and learn about people's embodied interaction with music. The prototypes developed in this thesis strive to contribute to this field by introducing some new techniques for motion capture and exploration of sound and music that are available online. Therefore I will define some of the common concepts that are used in embodied music cognition and embodied music interaction.

In embodied music cognition, it is common to separate between terms such as gesture, motion and action. In a musical context, a gesture is a movement which has a defined, self-contained meaning (Leman, 2008, p. 146, Jensenius, 2022, p. 87). The terms *motion* and *movement* are often used interchangeably, and they are difficult to separate from each other. In Oxford's Learner's Dictionary, *movement* is defined as the act of moving *something*, while *motion* is just the process of moving (Movement, n.d; Motion, n.d.). In this thesis, both concepts will be used, however, *motion* is probably the most correct and most used term in motion capture and the physics of motion.

The word motion however, does not work very well for describing something that has a beginning and an end, as motion is a continuous process. For this purpose, we instead use the word *action,* which is a gesture with a particular goal (Leman, 2008: Jensenius, 2022). Sound-producing actions happen when a performer transfers energy to a sound-producing element (Jensenius, 2022, p. 88). Both Thelle (2010) and Jensenius (2022) have created models that search to describe this separation from the human body with several stages. While some musical instruments have little separation between the action and the sound, such as the voice or a finger plucking a guitar string, other instruments have a big separation between action and sound. Digital musical instruments is an example of this, where the user action triggers a series of binary number messages that describe how electricity shall be encoded into physical sound. Internet and telematic performance opens up for an even bigger separation, as now the instruments can be played in one room and being playbacked in a completely different room. The latency due to broadcasting of music performance opens up new questions in regards to action-sound separation: how much time can we add before it is no longer considered as a sound-producing action? When is it no longer a live performance, but just an ordinary playback of music? In the next section I will define the word *musicking* which partly can answer some of these questions.

2.2 Musicking technologies

It is common to separate between *interactive music systems* and *musical instruments.* Interactive music systems were defined by Robert Rowe in 1993 as systems that are changing their behavior in response to a musical input (Rowe, 1993). Out of this definition, one could argue that an interactive music system could be everything from e.g. be a music player to a machine learning algorithm that creates new musical compositions. A musical instrument is defined in Grove Music Online as a "Vehicle for exploring and expressing musical ideas and feelings through sound" (Libin, 2018). A musical instrument is therefore closely related with the ability to express musical ideas and feelings, and will therefore exclude many musical inventions that do not have this option or have a more experimental approach and purpose.

In 1998, Chistopher Small introduced the word *musicking* as a verb for engaging with musical performance in any kind of manner. The concept included both performing, listening, composing, dancing or rehearsing (Small, 1998, p. 9). This verb resonates well with the idea that music is an embodied process, which was discussed in the previous section. A term that works better for the scope of this thesis might therefore be *musicking technologies*. This concept was coined by Alexander R. Jensenius, and is defined as technologies that cover both traditional musical instruments, but also systems for musical playback (Jensenius 2022, p. 24). This term acknowledges that music is an active process, which can involve everything from listening, performing to even building the instrument. The action-sound separation that was discussed in the previous section, which happens between the musician and the listener when a music recording is playbacked gives more sense, when talking about *musicking technologies* rather than *music instruments.*

2.3 Accessibility and accessible musical instruments

Accessibility refers to how much a product has been made available to a high number of people, regardless of their physical capacity or disabilities (Sharp et. al., 2015). Disability is defined as an impairment which affects an individual's ability to work or pull through daily life activities, which is likely to last for at least 12 months or the rest of this person's life (ibid.). Sharp et. al. highlights some of the most common conditions that should be considered when designing interactive products, such as being visually impaired, color-blindness, dyslexia and physical impairments. I have decided to narrow my focus to people with limited gross motor control. In my opinion, making something available online is also increasing the accessibility for people with low fine motor skills, as most people own a smartphone or a computer that is connected to the internet.

2.3.1 Fine motor skills and gross motor skills

Traditionally, motor skills have been categorized into two groups: Fine motor skills and gross motor skills. Fine motor skills are motor skills that involve high precision with the smallest muscle groups, like hands and fingers, e.g. threading a thread through a needle (Hauge, 2020; Sigmundsson & Pedersen, 2000, p. 19-22). Gross motor skills are related to the larger muscle groups and involve gestures like e.g. waving an arm and running (American Psychological Association, n.d; Sigmundsson & Pedersen, 2000, p. 19-22.). There is no strict distinction between fine motor skills and gross motor skills, and it can sometimes be difficult to separate between those two (Sigmundsson & Pedersen, 2000, p. 19). Most movements involve both fine motor skills and gross motor skills (ibid.). Sigmundsson and Pedersen (2000) argues that e.g. a football player uses large muscle groups, when controlling the path of a ball with her foot, but the microprecision used to pass the ball in a certain direction is a fine motor precision skill. It has been argued in the literature that gross motor and fine motor skills might be an imprecise way of categorizing motor skills.

However, traditionally motor skills have been categorized in this way, and the fine motor / gross motor skill terminology is often used when describing motor skill impairment conditions like e.g. Cerebral Palsy. Even though the fine motor / gross motor skill might be imprecise, I have chosen to use this terminology in this thesis as those are familiar terms to most people.

2.3.2 Ableism

Ableism is the discrimination of people with disabilities (Definition of ABLEISM, n.d.). Ableism is related to accessibility and is a problem I believe we should actively fight in our society, just as we fight racism, sexism, speciesism and homophobia. In Norway, only 44 % of people with physical disabilities are employed, against 74 % of the general Norwegian population (Tyldum, 2019, p. 54). According to Tyldum (2019), 85 000 people with disabilities in Norway have a wish to be employed, but are not working (ibid.). In a review by Molden et. al. (2009), 23 percent of respondents with physical disabilities reported that they had been discriminated against when applying for jobs (Molden et. al. 2009, p. 40). At the same time, only 15 percent of the general population reported that they believe that people with disabilities are being discriminated against (Tyldum, 2019, p. 55). This shows that ableism is a major problem in our society, which there is too little awareness about in the general population. Creating accessible musicking technologies might not imply any major changes to this complex societal problem, but it might be one of those famous small creeks that forms the big river.

2.3.3 Empowerment

The word empowerment is related to the transfer of power back to the powerless (Askheim, 2003, p.103). The concept was first used during the American civil rights movement in the 1970s (Rolvsjord, 2004, p. 101). Today, the word is most commonly used when talking about children, women, immigrants and people from the LGBT community (Askheim, 2003, p.103), and anti-medical movements have also embraced the word (Rolvsjord, 2004, p. 101). The empowerment term is not easily summed up in one sentence, but the main concern is about regaining people's ability to have control over their own lives (Askheim 2003, p. 105), and that people have both the ability and right to participate (Rolvsjord, 2004, p. 101).

2.3.4 Accessible instruments

In 2018, Emma Frid made a systematic analysis of 30 accessible instrument designs that have been presented in NIME, SMC and ICMC conference papers from 1975-2017 (Frid, 2018). The majority of the instruments in this survey were developed to be used by people with health conditions or disabilities specifically (Frid, 2018, p. 4). She identifies seven main categories of Digital Musical Instruments (DMIs): *tangible, non-tangible, BVMI, audio, adapted instrument, touch-screen and gaze* (ibid.). The most common category was the tangible one, that represented more than 40 % of the instruments, and the second most common was the non-tangibles (Frid, 2018, p. 5). Five of the instruments in the survey were non-tangible, which seems to be more or less the same as air instruments. The most commonly used sensors were the accelerometers, which were used seven times (ibid.). Cameras on the other hand, were only used three times.

As Frid points out herself, the dataset used in the survey is too small to draw any general conclusions (Frid, 2018, p. 5). More research is needed in the field. Despite the small dataset, it is a noteworthy notion that the tangible approach was the most common approach. One of the main findings from the survey was that half of the instruments had auditory feedback only and lacked the dimension of visual or vibrotactile feedback (Frid, 2018, p. 6).

2.3.5 Motion Composer

The Motion Composer (MC) is a device for turning movement into music that was developed by Andreas Bergsland and Robert Wechsler from 2010-2016 (Bergsland & Wechsler, 2016, p. 25). The idea that all people should be able to make music, regardless of their physical ability, is one of the main purposes behind the MC. As Bergsland & Wechsler states, those ideas resonants well with the idea of "universal design" which is a common standard within architecture and also a part of the law of discrimination (Lov om likestilling og forbud mot diskriminering (likestillings- og diskrimineringsloven), 2021).

One of the design principles of the MC is that "The MC must allow many different body parts and kinds of movements to be used" (Bergsland & Wechsler, 2016, p. 26). They argue that in this way, people with a limited motor control can take advantage of the musical potential within any kinds of body movements, and that this opens up for expressions that would normally not be available. To enable the inclusion of many different body parts to be used, they have used technology that allows extensive mapping.

The principle of including many different body parts in the system is in my view very well reasoned. However, to enable this principle, one should opt for a mapping strategy that enables motion tracking in three dimensions. To solve this, the MC is equipped with a TOF sensor together with a CCD video camera (Bergsland and Weschler, 2016, p. 31). The TOF sensor is measuring the distance between points in the room and the camera, and allows for 3D interpretation of the image[1].

2.3.6 Soundbeam

Soundbeam[2] is an accessible musicking technology that has been existing and evolving for almost 30 years (SoundbeamFilms Soundbeam, 2018). Soundbeam 6 is the latest version, which contains wireless switches, ultrasonic sensors and a touch screen device with software that include programmable libraries of instruments, sound effects and backing tracks (*What Is Soundbeam*, n.d.). To play notes and melodies, the user moves their hand in the air in front of the switches.

The user can activate sounds and backing tracks by tapping the switches, and program soundsets and choose between library settings with the touch screen interface (SoundbeamFilms Soundbeam, 2018). There are several settings which allow for different kinds of musical interaction. According to their webpage, Soundbeam is a technology that is used especially in settings of music therapy and in special education.

2.4 Conclusions

The background studies have been giving me perspective and insight in the research that is related to the prototypes I have developed in this thesis. Terminology from the fields of embodied music cognition and embodied music interaction are related to the motion capture technologies I have developed, and will be used in this thesis. Accessibility, empowerment and (anti-)ableism are all related to the same idea of giving people the same opportunities for participation, regardless of their abilities. The Motion Composer and the Soundbeam are two examples of touch-free air instruments that have been invented as an approach to create accessible musical instruments. I will come back to these two instruments in chapter 6 to do a comparison with the prototypes I have developed.

[1] https://en.wikipedia.org/wiki/Time-of-flight_camera
[2] https://www.soundbeam.co.uk/

3. Method

In this chapter I will describe the methods I have used to answer my research questions which cover the development and comparison of new accessible technology for exploration of sound and music.

3.1 User-centered approach and iterative design

The *user-centered approach* is a common method for prototyping and developing software. Software engineering is often a part of *applied research* which is a methodology for solving practical problems, rather than aiming to acquire knowledge (Mandal, 2015, p. 61). In this section I will describe how I have used the user-centered approach method and the iterative design process to develop my ideas. In Sharp et. al. (2015), the user-centered approach is briefly summed up as a method or philosophy where the real end-users are included and also being the driving force behind the development of the product (Sharp et. al., 2015, p. 327).

Gould & Lewis described in 1985 three design principles of design: *Early Focus on Users and Tasks, Empirical Measurement* and *Iterative Design* (Gould & Lewis, 1985). *Early Focus on Users and Tasks* is about understanding and reflecting upon who the end-users of the product will be. This is achieved by studying the users' cognitive, behavioural, anthropometric and attitudinal attributes (ibid.). *Empirical Measurement* concerns that the intended users should early in the development process be involved in testing of simulations or prototypes of the product. Their performances should be analyzed, and recorded. *Iterative design* is a process of designing, testing, measuring and designing again, and should be repeated as often as necessary.

In this thesis, the main focus has been on the *iterative design* principle, but the other principles *Early Focus on Users and Tasks* and *Empirical Measurement* have also been considered. It has been clear from the beginning that the end-users will be any kind of people, but with focus on people with low fine motor skills. *Empirical Measurement* of the system was done in the observational study, where users were invited to test the prototypes while I was observing. Both people with low fine motor skills and people with normal motor skills were included in the testing sessions.

3.1.1 Usability

Usability can be considered as one of the many quality goals of a system design (Nielsen, 1993, p. 33). In the article *Iterative User-Interface Design* (Nielsen, 1993), Jakob Nielsen conceptualizes the quality goal "usability" out from five attributes:

1. How easy it is learned
2. How efficient it is (high level of productivity for an expert user)

3. How easy it is for the user to remember it to the next time
4. How error-free or error-forgiving it is, the user can make errors without it being disastrous
5. How pleasant or satisfying it is to use.

The importance of each of the five attributes will vary in different kinds of systems. The second attribute could for instance cover the ability to produce sound and music, which is being answered through the observational studies. The third attribute would be difficult to test within the one-time test and report situation which has been conducted for the scope of this thesis. The feedback forms mainly revealed answers on question 1, 4 and 5. In the observational studies, a user questionnaire was filled in after the testing, which collected answers on number 1 and 5 on a scale from 0-10. The field notes from the observational study contribute to giving answers on question 4.

3.1.2 Subjective testing

The iterative design process has been a combination of recurring feedback from MCT-students, family and friends and people of the Micro-team early in the development process, and more systematically collected anonymous feedback collected with a feedback form that followed the new releases of the prototypes. The method used to collect feedback in all stages of prototypes is called *subjective testing* (*Subjective Test – APA Dictionary of Psychology*, n.d.). The most important test person and influencer on the prototypes has been myself. After every change I made, I have been testing and evaluating the changes, based on my personal opinions. The advantage is that it is a pretty effective way of testing ideas and code, as I can test it right away when a change is done. I am also a part of the target group of the product, as the product is targeted at a general population. However, I am at a risk of encountering subjective bias, which means that I adjust the qualities of the applications to my personal taste and needs without considering others. Hence, it has been important from the beginning to include others in the testing.

3.1.3 Self-reflection method

The self-reflection method is a method for consciously reflecting upon one's own thoughts, desires and feelings, and it often involves keeping a learning diary, learning protocol or portfolio (Gläser-Zikuda, 2012). This method has traditionally been used within the fields of psychology and educational science. When developing the prototypes, I have used this method to keep track of the changes I've done and to consciously reflect upon what ideas that worked and what ideas that did not work, and at the same time note down new ideas that evolve. I have been keeping a research diary, as well as writing comments directly into the code to remember which code snippets that were important, solved a specific problem, or did not work as intended. After every change that was done in the code, I pushed the change to GitHub together with a comment on what was done.

3.2 Qualitative research and observational studies

To test the prototypes and answer the sub-research questions, methods from the tradition of qualitative research have been used. In qualitative research, the researcher often needs to be close to the research object, and the environment and context that surrounds the research object is also important to consider (Tjora, 2012). In contrast to quantitative research, qualitative research often contributes to a deeper understanding of a subject, instead of just explaining a subject of matter. Qualitative research can often be creative, but at the same time offer structure and system (Tjora, 2012, p. 19).

Personal preference plays a major role when it comes to validating an experience with a musicking technology, and qualitative study is a good approach for letting the informant be able to talk freely. However, it should be mentioned that the data generated in this study is not fitted for doing any generalization. One should also take into account that in a qualitative study like this there is a huge risk of encountering several biases. The interviewer may unconsciously influence the informant with body language or other factors, and there is a risk that the informant will answer dishonestly, e.g. due to a conscious or unconscious wish to please the interviewer.

At a later stage of prototyping, it could be interesting to do some quantitative research as well, e.g. with questionnaires, to see how a larger population would validate the prototypes. However, qualitative methods are more fitted when the aim is to study people's interaction with musicking technologies, and the method of observational studies has been conducted to study this. When a person is testing a musicking technology, factors such as physical behaviour and instant response are of interest, factors that may not be easy to self-report in a questionnaire. Generally, different methods are used to answer different kinds of questions, and ideally, both approaches could be used. Due to the scope of this thesis, and difficulties with gathering enough informants in a short time, quantitative methods have not been used at this point.

An observational study is a qualitative method. The method is also called ethnography. Traditionally this has been a method used in social anthropology, where field studies were used to study cultures in other countries (Tjora, 2012, p. 44), but it is also a common method used in embodied music interaction studies (Leman et. al., 2017). A key factor in observational studies is to be able to study the object of research in its natural context. In this thesis, this method was used to study the informants' interaction with the prototypes that were developed. In observational studies, the researcher has to choose a role that fits the research situation (Tjora, 2012, p. 52). Often, it is ideal for the observer to obtain a hidden role, as this makes it easier to study the situation in its natural environment, unaffected by the researcher. However, this is not always possible. The researcher may also be a participating observer, and try to be a part of the environment that surrounds the object of research.

Interactive observation is when the researcher has to transfer between different roles in the situation, which often is the case when the researcher has an open role (Tjora, 2012, p. 55). In most of my user test sessions, I have obtained this interactive observer role. The test sessions started typically with me just being a “fly on the wall”, observing how the informants would explore the prototypes without any help or interruption. I also expressed to the informants in advance that I would obtain this non participating role. However - to be able to see what was happening on the screen of the prototypes, I could not sit very far away from the informants. This closeness made it very natural for the informants to turn to me for a conversation during the testing. Some of the informants also needed some guidance after a while or early in the process of testing.

When it comes to giving guidance, I have been holding back as much as possible, to be able to observe how the informants would interact with the apps in a natural environment. Wrong usages and eventual reactions and strategies used when stuck, were also interesting and important to study. However, if the informants were stuck or using the apps wrongly for a long time, I chose to interrupt them, to be able to also observe how they would interact when knowing the correct way to use the apps.

To record the test sessions, field notes were taken. If the study was rolled out on a bigger scale, it might have been beneficial to do surveys and audio/video recordings, but at this small scale, I estimated that field notes were sufficient, and less of a personal intervention for the informants.

After testing the prototypes, the informants were asked to fill out an online questionnaire. This questionnaire was used to accompany the observational study with quantifiable data about their experience with the application, as well as some demographic facts such as gender, age and level of motor skills. The questionnaire also included a rubric where the informants were supposed to write freely about their experience. However, the group of informants were too few to make any statistics based on this questionnaire, and will only be used to supplement the observational study.

3.3 Reflections

The work with the prototypes started with the assumption that a touch-free approach would be a premise that increased accessibility for people with low fine motor skills. This assumption was founded on the study of other musical interfaces for accessibility that also were based on a touch-free approach, such as Motion Composer and Soundbeam. The testing afterwards showed that this assumption was not necessarily true, at least not for the three informants with low fine motor skills who participated in my study. If I had pulled through a survey before starting on the development phase, to research what kind of functionalities and design that would have been beneficial for the user group, the development phase could perhaps have been more targeted. However, due to the fact that I started the development very early in the process, I was actually able to do very specific testing with many different functional novel apps during the time of writing this thesis. I would probably not have reached this phase if I had chosen to start with surveys, as it would have been very difficult to reach out to enough people in the target group in such a short time.

Also, the group of informants included only three persons with low fine motor skills, which is too few to draw any real conclusions. Furthermore, people with low fine motor skills are a very diverse and heterogeneous group of people, and it might still be likely that the touch-free approach combined with availability online could be beneficial for other groups of people with low fine motor skills, perhaps for those who have more severe motor disabilities than the people who participated in this small study. More research and more development is therefore needed to investigate and take this project further.

Because of the Covid-19 pandemic influencing the whole world while writing this thesis, I had to plan for using methods that did not involve meeting people in real life. Luckily, the society opened up after all, and this made it possible for me to meet people to test out the prototypes, which seemed to be the best fitted method for answering my research questions. However, I have been forced to be able to adapt my research methods along the way. Which means that I would perhaps have planned things differently from the beginning if the situation was more normal. For instance, I would perhaps have been able to do observational studies earlier in the process of development, which could have charted out the course of the project in a different direction.

4. Development

In this chapter, I will describe the visual design of each of the different iterations I have created. I will also describe the technical implementation and sound design. Due to the number of different apps and iterations that have been made, it will be impossible to describe every technical detail of the implementation. I will therefore just highlight the most important parts. I have created two main systems with two different approaches, one approach for web cameras and one approach that uses accelerometer sensors. Common for all prototypes made is that I have coded them in Javascript / HTML / CSS and used Web Audio API and Tone.js for the audio engine.

4.1 Motion capture technologies

The musicking technologies I have developed in this thesis are inspired by *air instruments*. Common for air instruments is that the performer creates sound by making movements in the air. Air instruments were categorized by Jensenius (2022) into three groups: touchless air instruments, object-based air instruments and muscle-based air instruments. Muscle-based instruments are instruments equipped with sensors that sense muscle tension from the performer, e.g. instruments based on the Myo armbands[3]. Object-based air instruments are instruments that detect motion while the user is holding a controller or a device. In touchless air instruments, the performer is not touching or holding anything in their hands; like the legendary example *the Theremin*. The Macro prototypes fall into the touchless category with the web camera approach. The Micro prototypes are using mobile phone accelerometer and gyroscope sensors and are following the object-based approach.

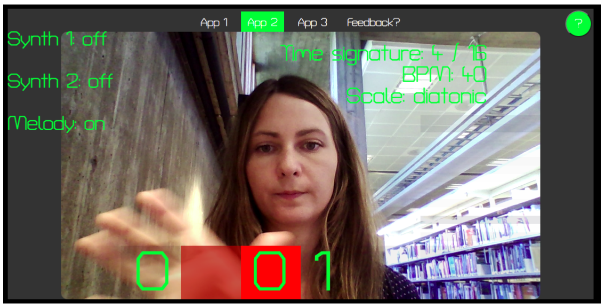
4.1.1 Macro prototypes

For motion detection of the Macro apps (see Appendix B), I chose to develop further on code from *The Diffcam Engine*[4], which is an open source core engine for motion detecting in JavaScript, created by Will Boyd. The Github page of the project[5] explains how one can reuse the code in a new project. A whole library of functions is included in the code to make the motion detection work, so I will not go into every single function, but highlight some of the most important code snippets

The Diffcam Engine captures a video stream and calculates the quantity of motion from the differences between pixels in a stream. Quantity of motion (QoM), or Momentum is the product of the mass and velocity of a particle which is moving from one point to another (Dourmashkin, 2020). To lower the latency to a minimum, the options of the variable captureIntervalTime is set to 10, which is the number of milliseconds between the capturing of images from the stream. This

[3] https://developerblog.myo.com/
[4] http://diffcam.com/
[5] https://github.com/lonekorean/diff-cam-engine

leads to lower resolution of the video, but high video resolution is not important in this case. In the original Diffcam Engine, only one extra canvas is created to visualise and capture the motion, but in this project, I have been operating with at least two canvases on top of the mirrored webcam stream to get more flexibility with regards to mapping. Each canvas is separated with it's own colour (see figure 1 and figure 2), and different parts of the screen are divided into areas mapped with different functionalities. As the instruments are supposed to be controlled with gross motor movement, the converted screen is scaled down to a very low resolution, so that it appears that there are buttons or sections in the screen. The visual feedback is an important part of obtaining an intuitive link between action and sound.



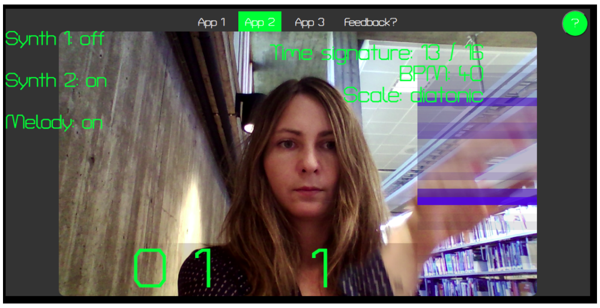


Figure 1: Visualisation of X axis

Figure 2: Visualisation of Y axis

The variable *pixelDiff* is calculated out of RGBA (red, green, blue, alpha) data from the video stream, and the variable *pixelDiffThreshold* is defined as a number beforehand. If the pixelDiff value exceeds the value of pixelDiffThreshold, the variable *score* is incremented. The *score* variable represents the quantity of the motion, ranging from 0 to the max amount of pixels. The higher the number, the higher the quantity of motion. The variable *i* represents the individual pixel that has the highest quantity of motion. In this way, one can separate the image in pixels and map different functions to single pixels. The variables coords.y and coords.x can be mapped to functions that cover the whole axis. Another interesting mapping dimension, which is not exploited in this prototype is the input of colour values.

To sum up, this system allows for several possibilities for mapping:

- var i: individual pixel activation

- var score: speed / quantity of motion
- var coords.y: Y axis value
- var coords.x: X axis value
- var rgba: colour data of pixels.

4.1.2 Micro prototypes

The motion detection technology that was used in the Micro apps (see Appendix C) are based on the detection of accelerometer and gyroscope data from the mobile phone. This is implemented with help from the handleMotion event from the JavaScript Sensors API[6]. Some of the code for accessing the accelerometer sensors were borrowed from The Web's Sixth Sense Demo[7]. Values are sourced via the acceleration events *event.accelerationIncludingGravity.z*, *event.accelerationIncludingGravity.y* and *event.accelerationIncludingGravity.z*, and used to control sound and visualization. To calculate the quantity of motion, the absolute values from all three accelerometer events are summed:

```
let totAcc = (Math.abs(event.acceleration.x) + Math.abs(event.acceleration.y) + Math.abs(event.acceleration.z));
```

The result is a value of zero when the phone is lying still. The number will increase when the phone is moved, and the more the phone is accelerated in any direction, the higher the number will be.

This system allows for the following possibilities of mapping:

- event.accelerationIncludingGravity.x = motion on the X axis
- event.accelerationIncludingGravity.y = motion on the Y axis
- event.accelerationIncludingGravity.z = motion on the Z axis
- totAcc = the overall quantity of motion

Combinations of the X and Y axis create a coordinate system that allows for additional mapping alternatives. The mobile screen is divided into areas that can be activated by tilting the phone in a certain angle. A blue dot monitors the motion coordinate, and by hovering it over a "button", the button is pushed (figure 3 and 4). To avoid that the "button" is activated several times when hovering over it, a timeout function is set. Testings showed that iPhones and Android/Windows phones output opposite accelerometer values on the Y axis, and Windows and Android phones add 0.3 on motion on the z axis. To solve this problem, a userAgent is initialized to detect the type of phone that is used, and an if statement is used to convert the values to fit the detected type of phone.

[6] https://developer.mozilla.org/en-US/docs/Web/API/Window/devicemotion_event
[7] https://sensor-js.xyz/demo.html

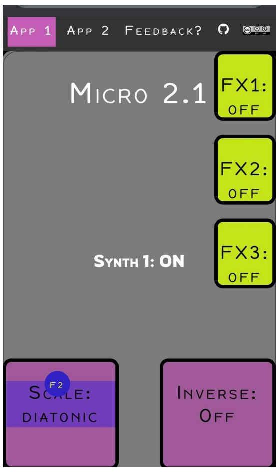


Figure 3: Hovering "Scale" button

Figure 4: Hovering "FX2" button

4.2 Sound and music design

4.2.1 Web Audio API and Tone.js

Web Audio API is a system in JavaScript that is designed for creating and designing audio features for the Web (Web Audio API, n.d.). Such features can be anything that is related to audio, such as effects, visualizations, oscillators, playback of audio etc. Different features are connected together in a chain as nodes. An audio chain starts with the creation of an audio context which is created with one or more audio sources. Further, it is connected together with nodes which usually are effects, and and then finally connected to the output which is called "Destination" (figure 5):

Figure 5. Audio context. Image source: https://developer.mozilla.org/en-US/docs/Web/API/Web_Audio_API/audio-context_.png

Tone.js is a JavaScript framework that builds upon Web Audio API (Tone.Js, n.d.). Tone.js features many effects and pre-designed synths, and is easy and intuitive to code, and this is why I chose to go for the Tone.js library.

4.2.2 Mapping strategies

The importance of complex mapping when designing digital instruments, has been emphasised by Hunt et al. (2017). They exemplified this principle with the "Two Sliders and Two Sound Parameters" instrument; an instrument consisting of two sliders - the first slider controlled the pitch and the other slider controlled the volume. In an experiment, their students instantly understood how the instrument worked and got tired after a couple of minutes playing with it. In the other experiment, they tested out a different instrument which had the same input and output parameters, but the mapping was more complex. The students struggled a lot more, but at the same time, they also reported more enjoyment while playing with the instrument (ibid.).

Many traditional acoustic musical instruments use several input parameters to control the one output parameter, and also one input parameter can control several output parameters (Kvifte, 1989). One example can be the trumpet, where the musician controls pitch both with pressing down the three valves in different combinations, but also with shaping their lips, as well as adjusting the air pressure. As well, the air pressure produced by the trumpet player does not only control the pitch, but also the volume of the sound. This is called "many-to-many mapping". While many traditional instruments "naturally" come with complex mappings, we have to consciously consider it when we are designing new digital instruments because of the separation between action and sound. Hunt et al.'s overall conclusion in their research was that the layer of mapping is very important and should be considered when developing new digital instruments (Hunt et al. 2017, p. 40). When working with the prototypes, it has been a goal to follow this ideal of many-to-many mapping. However, when pursuing a touch-free interface for gross motor motion in the second and third iterations, without buttons, the number of possible mappings have been limited.

Figure 6 and Figure 7 illustrate how the different inputs of Micro 2.1 app 1 and Micro 2.1 app 2 are mapped to the musical parameters:

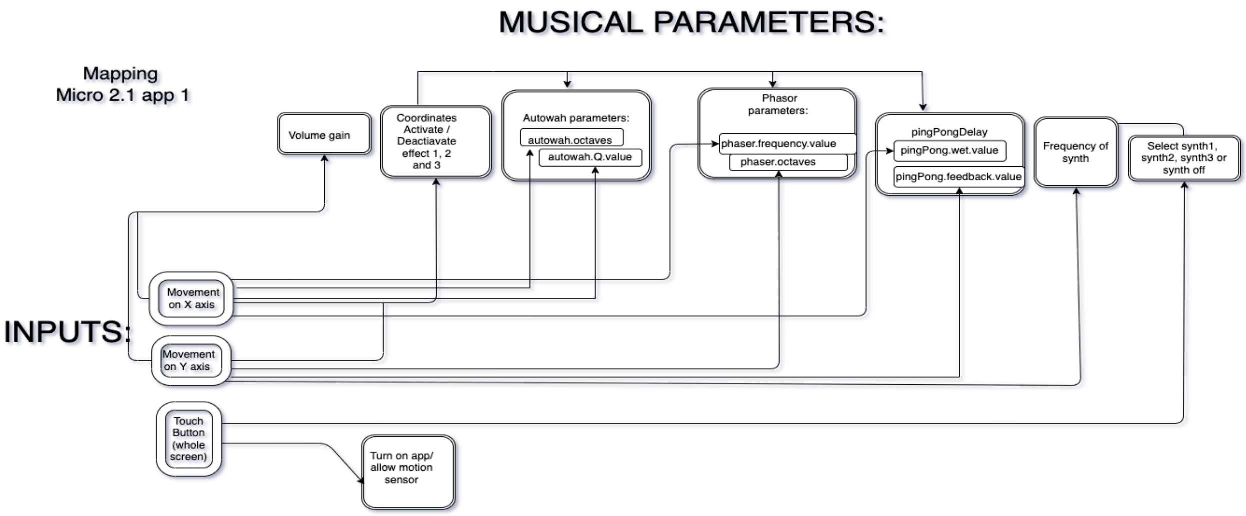


Figure 6. Mapping of Micro 2.1 app 1

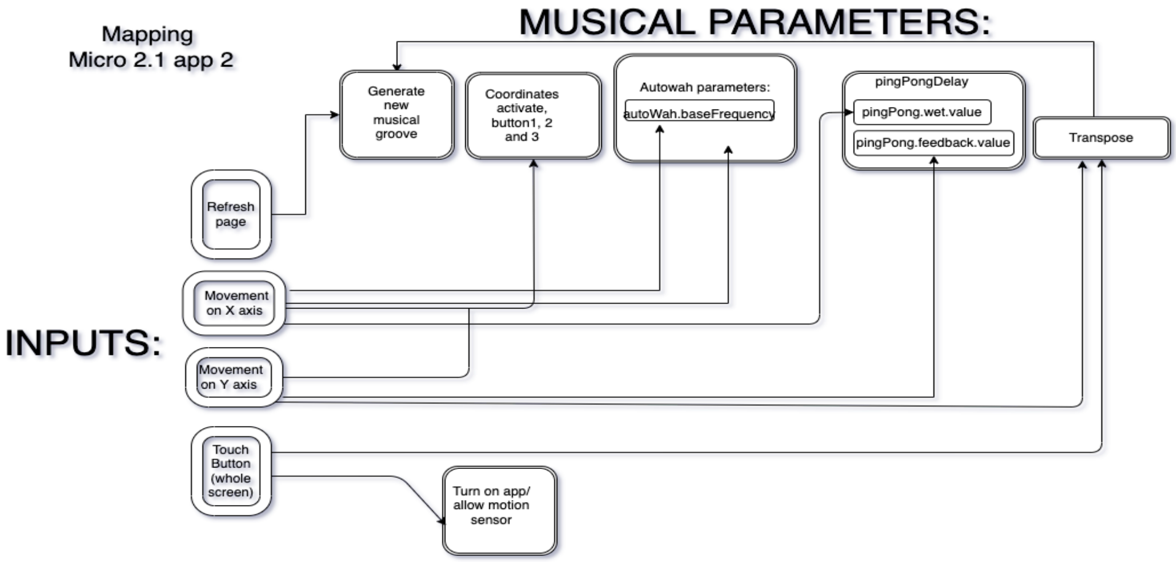


Figure 7. Mapping of Micro 2.1 app 2.

4.2.3 Macro 2.1 app 1 and Micro 2.1 app 1

The overall sound design system behind these two apps are the same, while the interaction and motion capture technologies are different. Both apps include several synth engines, samples, effects and solutions for manipulating the timbre and sound with effects.

The latest Micro iteration includes three synth instruments from the Tone.js library:

- A Tone.DuoSynth, where the first voice includes a fmsawtooth oscillator and the second voice is a pulse oscillator.
- Two Tone.Synths, where the first includes a sine oscillator and the second includes a square oscillator.

Each synth can be manipulated and designed with many variables, such as envelopes, filters and volume. One of the instruments used in Macro 2.1 app 1 look like this:

```
const synth1 = new Tone.MonoSynth({
    oscillator: {
        type: "sine9"
    },
    envelope: {
        attack: 0.9,
        decay: 0.3,
        sustain: 0.5,
        release: 0.3
    }
}).connect(gainSynth1);
```

In the first iterations, there was an option for selecting between different scales. Therefore, a system for selecting notes in a scale has been proposed. The variable *scaleSelect* is by default assigned as an array with notes from a C major scale. By using if and else, the synth plays the note that is assigned to the number in the array:

```
if (i == 248)
  synth.triggerAttackRelease(scaleSelect[0], "2n"),
  document.getElementById("synthNote").innerHTML = "Note: " + scaleSelect[0];
```

By changing the scaleSelect array, one can easily select between different kinds of scales.

4.2.4 Macro 2.1 app 2 and Micro 2.1 app 2

A system for randomized musical groove is proposed. Every time the page is loaded, the function createRandomness(); is executed, and different musical parameters like instrument, timbre, rhythm, scale, bpm and time signature are decided. When the page is loaded, a number of Math.random(); functions are run. Four instruments are generated every time the page is loaded:

- Drum machine
- Bass
- Chord instrument
- Melody instrument

When the page is loaded, the drum machine will start to play without any option of interaction from the user. The only way to interact with this instrument is to refresh the page to generate a new groove. The drum machine in Macro 2.1 app 2 consists of two Tone.Sampler instruments, which contain hi hat, bass drum and snare sounds. The samples used to create the instruments were created in Logic Pro X, with soft synths from the Logic Pro library. In Micro 2.1 app 2, Tone.MembraneSynth was used for bass drum and tam tam sounds and Tone.MetalSynth was used for hi hat sound.

The rhythm pattern is built up of tiny sections of rhythm patterns that in a for loop are randomly pushed from if and else statements. The for loop is run upon loading of the page, and the if and else statements are decided by the randomly generated numbers. The hi hat pattern is built up of ♫ and ♩ patterns. While the bass and snare array is built up of ♫ , ♩and ³♪♪♪ patterns. The same principle goes for the generation of the melody.

A combination of sampler instruments and synth instruments from Tone.js have been used to build the remaining instruments. The synth instruments have been built up of elements from the Tone.js library, such as AMsynth sine9 oscillator, DuoSynth with a fmsawtooth type oscillator, an envelope and a filter and some other synths. The sampled sounds are a combination of drone sounds I have recorded and edited before and other recordings done with soft synths in Logic Pro X. The instruments in the groove will also be randomly selected.

Each time the page is loaded, a scale will be selected, which will decide from what array of notes the random melodies and harmonics of all instruments shall be made up of. The current available scales are two different arrays of diatonic scales, two different arrays of pentatonic scales, two different arrays of whole note scales and one array of harmonic scale notes. Each of the arrays are divided into three separate arrays to spread the notes in different instruments, like this:

```
const pentaNotes3 = [3, 6, 8, 11, 13, 15];
const pentaNotes2 = [-8, -6 , -4, -1,  1, 3, 6];
const pentaNotes = [-20, -18, -16, -13 ,-11, -8, -6, -4 ,-1];
```

The bass instruments will only select notes from the lower register and the melody instruments will only select notes from the higher register. The tempo is randomly selected out of five different values: 40, 50, 60, 90 and 120. The time signature will be a randomly selected number between 2 and 16.

The user can interact with the musical groove by turning on and off the three instruments *Synth 1, Synth 2* and *Melody,* as well as changing the attack and release of two of the synth instruments. The user is also able to change Q value and octaves of the autoWah effect and feedback value of a pingPong effect. As it is now, the user has to refresh the page to create a new randomized groove, but in the future, the user should be able to interact with the groove in real time by manipulating the different musical parts.

The algorithm to create a random tone generator was borrowed from a StackExchange thread[8], and then developed further by me. First the frequencies are converted from a integer to a frequency with this algorithm:

```
const freq = note => 2 ** (note / 12) * 440;
```

Then the random array of notes are created with this algorithm:

```
const randomNote = () => scaleNotes[Math.random() * scaleNotes.length | 0];
let random = freq(randomNote());
randomArray.push(random);
```

[8] https://codereview.stackexchange.com/questions/203209/random-tone-generator-using-web-audio-api

Before this, the array scaleNotes has been assigned from a selection of notes,

```
function getRandomInt(max) {
  return Math.floor(Math.random() * max);
}
const randomScale = getRandomInt(14);

if ((randomScale == 0) || ( randomScale == 13 ))
   scaleNotes = pentaNotes,
   scaleNotes2 = pentaNotes2,
   scaleNotes3 = pentaNotes3,
```

The melody is built up of small sections of rhythm and notes, based on several if and else statements.

```
let random4 = getRandomInt(10);
  if (random4 == 4)
        randomMelodyArray.push(random6);
  if (random4 == 5)
        randomMelodyArray.push((random6 + " " + random6).split(" "));
  if (random4 == 6)
        randomMelodyArray.push((random + " " + random2).split(" "));
  else
        randomMelodyArray.push((random + " " + random2 + " " + random6).split(" "));
```

A random number between 0 and 10 is drawed (random4), and another random number (random6) will be pushed to *randomMelodyArray.* Shown above is a simplified version, but this system can be expanded upon to make more complicated melody lines.

4.3 Macro prototypes design description

4.3.1 Design of first iteration: Macro 1.0

There are three different versions of the app, and all of them can be reached from a top menu bar. The
apps have mainly been tested on Mac OS in Google Chrome. In all of the apps, there is a question mark button in the upper right corner which expands a menu with simple directions of usage when pushed. All of the Macro apps have a mirrored live video stream from the user's web camera that monitors the user's motion.

App 1

The first Macro 1.0 app is a simple synth instrument with three different canvases that controls different elements. Two of the canvases include only a line each on the X axis, coloured respectively red and yellow and one canvas has an Y axis control surface to the left which is coloured blue. Each of the X axis control surfaces are mapped to one synth each. The synth type can be changed or turned off by tapping the two pink buttons left to the respective control surface. The vertical, blue control surface to the right controls the effects. Effects can be turned on and off with four separate pink buttons on the right side. In the bottom of the screen, there is a volume control as well as a mute button.

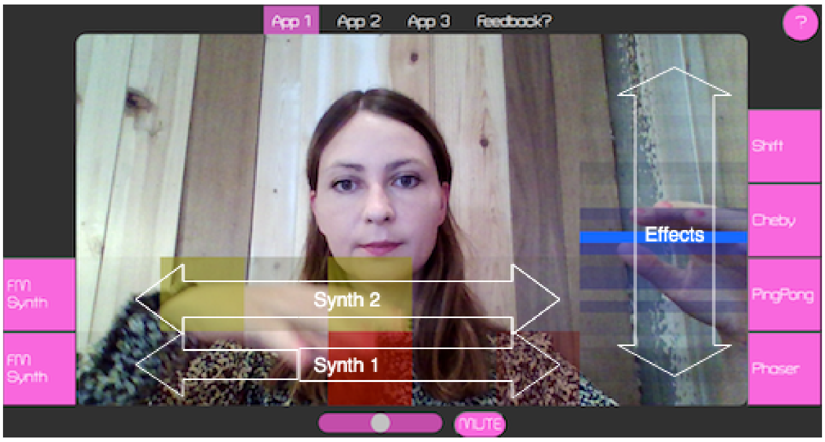


Figure 8: Macro 1.0 App 1

App 2

The second Macro 1.0 app has only one X axis control surface (coloured red) and one Y axis control surface (coloured blue). When the page is loaded, three random arrays of note values are generated. Three different synths will loop these notes. By using gestures on the X axis, the users can mute and unmute the different synths. The three synths are connected to two effect nodes: a pingPong delay and a phaser. With upgoing gestures on the Y axis (blue), the phaser frequency value is increased.

To initialize the app, the button "PRESS to start" has to be pressed. This is because Tone.start(); and Tone.transport.start(); have to be activated from a user gesture. There is also a mute button in the interface.

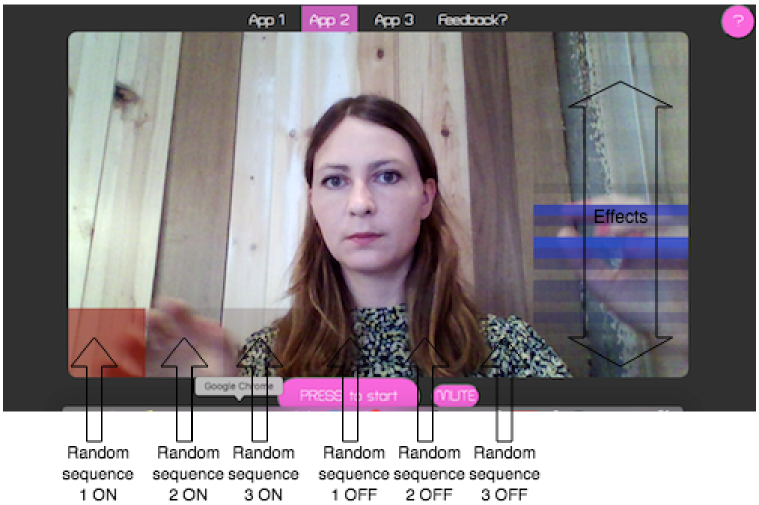


Figure 9: Macro 1.0 App 2

App 3

Instead of using synths, in this version, pre-recorded loops are used. A 3 x 2 square yellow coloured control surface enables the activation and deactivation of different instruments of the loop. The lower row of yellow squares activate the instruments in this order: Drums, bass, piano (see figure 10). The upper row deactivates the instruments. Also in this app the vertical control surface on the right side is mapped to effects, but in this version, this bar is also mapped to a synth with notes on the pentatonic scale. The higher the gesture, the higher the pitch.

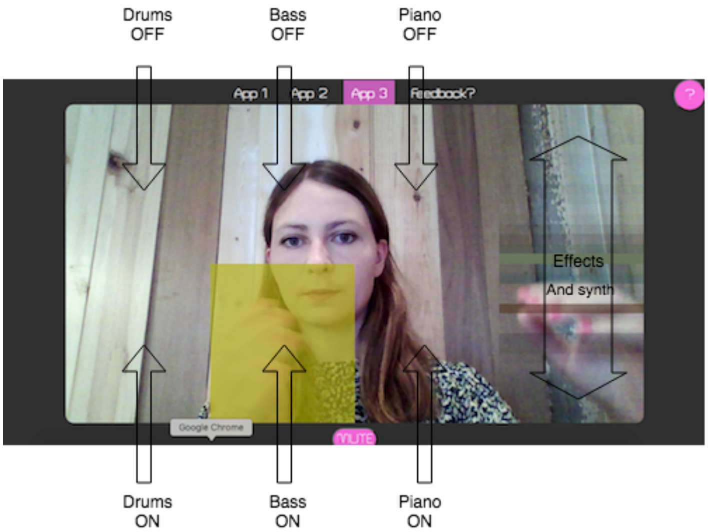


Figure 10: Macro 1.0 App 3

4.3.2 Design of second iteration: Macro 2.0

Based on the feedback that was received from the feedback form, a main goal for this iteration was to create a better visual design, with better visual indication of how the motion was related to the sound. Another goal was to improve how it sounded. A third goal was to remove buttons to make it entirely based on air motion and gross motor gestures. However, the initialization of Tone.transport.start and Tone.start had to be activated from a user action. To reduce the amount of buttons in the interface, I have integrated this inside the same function that initializes the web camera, in the function initSuccess(requestedStream). The only buttons the user has to click is the "approve web camera access" button when the page is loaded and the help button if the user needs to see the instructions again. Common for the two apps in this version, is that the instructions appear upon opening the page and gradually fade away. By doing this, the user does not have to click any button to see the instructions.

App 1

A challenge was to create buttons that could be activated with motion in the air that was picked up by the web camera. The solution was to create a series of if and else if statements that activated and deactivated several functions based on the individual pixel activation value (i). In this iteration one can only play with one synth at a time, and the pitch is mapped to the blue vertical canvas to the right. The notes played are displayed in front of the canvas (see figure 11). Two additional canvases in the front appear as buttons for turning on and off and switching between effects, scales and instruments. Coloured opaque boxes display the three different categories of the "buttons". When an effect is turned on, the message "on" is displayed in the control area. When it is turned off, the message "off" is displayed. The same principle is used with the instruments and scales. Only three of the four effects were included in this version, to not overload the screen with buttons.

Figure 11. Macro 2.0 app 1

App 2

App 2 and 3 from Macro 1.0 were combined into one app. In this second app, a system for generation of random music is proposed. Inspiration was taken from one of the patches used in

RITMO's Self-playing guitars[9], as well as the web-app Synaesthesia[10] for the concept of creating something that randomly generates music, but also offers user interaction. When the page is refreshed, a random loop of music is generated, with parameters as time signature, BPM, scale and instruments. In this iteration, the user can activate and deactivate instruments in the loop by holding the hand in front of certain areas of the screen. "1" means on and "0" means off. With the blue control area on the right, the user can control effects, which in this version was Wah Wah, Ping Pong delay and envelope attack and release of two of the synths.

Figure 12. Macro 2.0 app 2

4.3.3 Design of third iteration: Macro 2.1

Much of the design choices in this iteration are the same as in Macro 2.0. In both App 1 and App 2, the same instructions as in the start screen will appear when the "?"-buttons are pushed. Also, the start screen instructions are shown for a longer time before they disappear, and they are easier to read due to bigger contrast.

App 1

The main focus of this iteration was to improve the visual design, the interaction with the user and to improve how it sounded. The feedback from the 2.0 version showed that the users unintentionally activated the "buttons", and one of them suggested having more free space in the screen that was not used for interaction. The visuals of the font were improved so that it was easier to read. The amount of interaction was reduced down to a more limited and simpler version with fewer and bigger buttons, and one of the button rows was removed. In this version, it is only

[9] https://www.uio.no/ritmo/english/projects/self-playing-guitars/
[10] https://wheelibin.github.io/synaesthesia/

possible to switch between two instruments and two effects, and there is no option of turning off the effects or the instruments. The option of choosing between different scales is removed. Also, based on user feedback, the pitch control area on the right side was scaled down to fewer notes and bigger "keys".

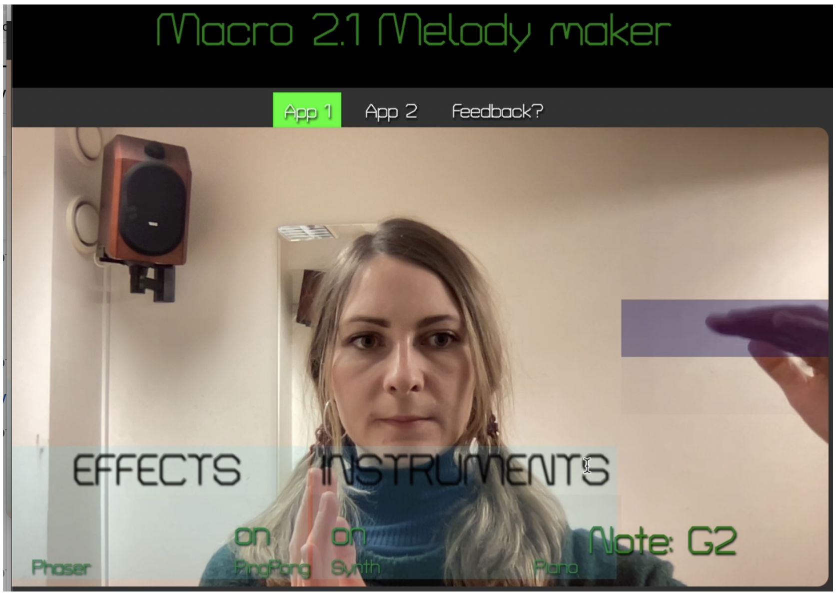


Figure 13: Macro 2.1 app 1

App 2

This iteration includes a section for each of the instrument in the loop visible on the screen ("Synth 1", "Synth 2" an "Melody"), to indicate where to apply the motion. Instead of "0" and "1", the message "on" and "off" indicate if the instrument is activated or not. The random music generator engine was also improved in this version, with more options of instruments, timbre and scales.

Figure 14: Macro 2.1 app 2

4.4 Micro prototypes

The Micro apps were developed as a part of the MICRO project at RITMO Centre for Interdisciplinary Studies in Rhythm, Time and Motion at the University of Oslo, and were supposed to explore further on the ideas and concepts about micromotion and inverted mapping that Alexander Refsum Jensenius had developed. The Sverm project was a central source of inspiration while working with the Micro apps (Jensenius & Bjerkestrand, 2012). In the Sverm instrument, motion tracking technology was used to measure tiny changes in motion of the participants - micromotion. The sound would decrease when the participants accelerated their movements. However, in this project the apps were developed further with more focus on the musical and motion tracking part, rather than the micromotion and inverted mapping concepts. In this section I will go through the design of each of the apps that were included in the three different iterations of the Micro prototypes.

4.4.1 Design of first iteration: Micro 1.0

The first Micro prototypes that were launched for testing, included three individual apps that could be reached from a top bar menu. Common for the design of all of the apps is a help button in the upper right corner, which expands a box with a few simple directions for each of the three apps. All of the three apps share the same basic visual appearance with a pink container on a black background. Inside the pink container there is an image of a microwave oven which contains a pink dot that monitors the motion of the user. All apps have an Inverse on/off for the option of switching between the two mapping modes (inverted/not inverted).

App 1

App 1 is a basic melody instrument where the user is able to select between a square and a sine synth. The user plays notes by tilting the phone, and may choose between three different musical scales: a major scale, a pentatonic scale and a whole note scale - by clicking a button. It is possible to turn the different effects on and off with buttons on the side. The pitch is mapped to the Y axis, and different parameters of the effects are mapped to the X axis and Y axis.

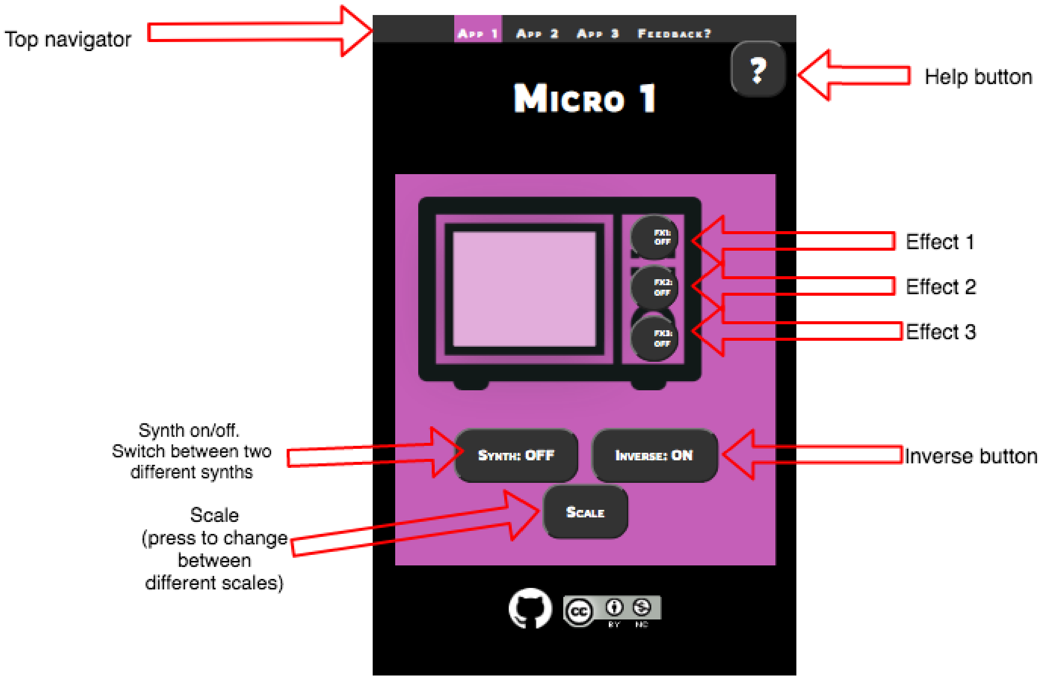


Figure 15: Micro 1.0 app 1

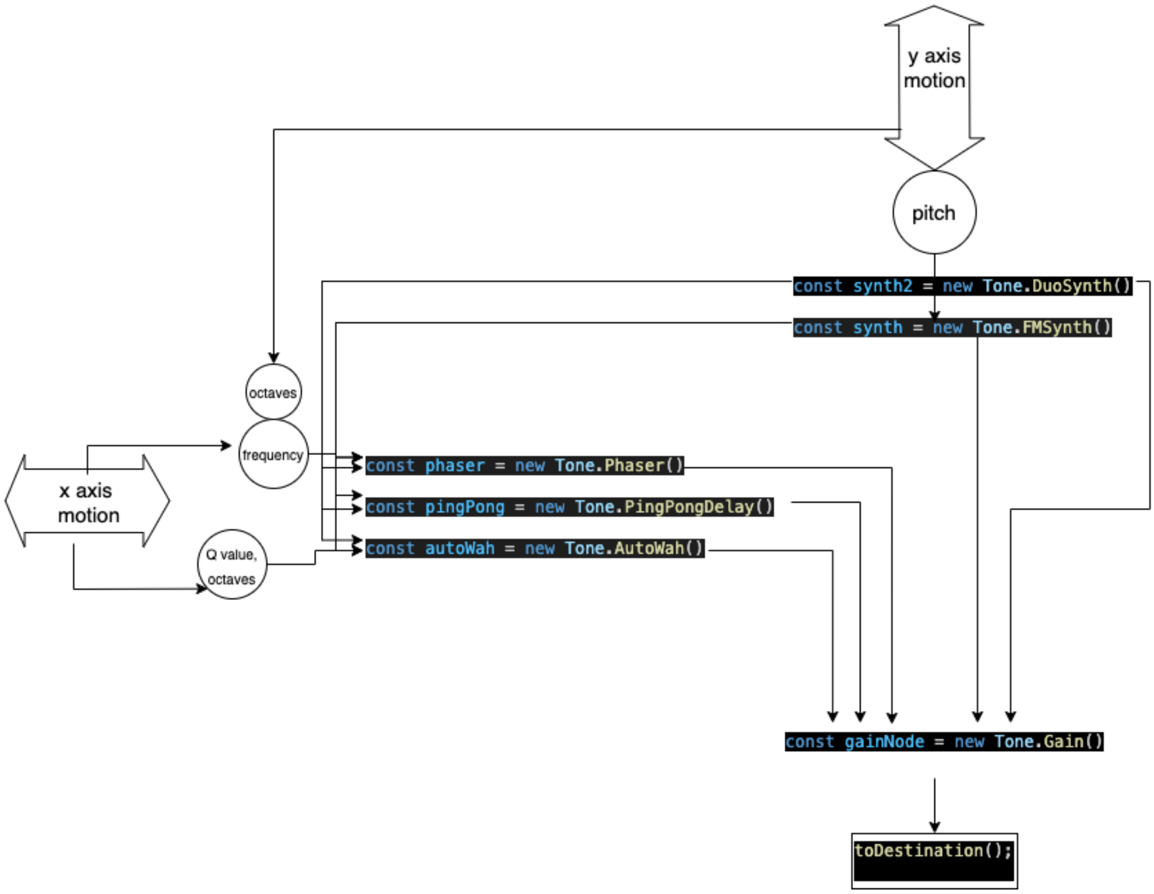


Figure 16: Signal flow of Micro 1.0 app 1

App 2

In this version, three different random loops of notes are produced when the page is loaded. The loops are activated and deactivated when the user tilts the phone in different angles. Also with this app there are effects with parameters mapped to both X and Y axis, but no ability to turn on or off the effects. The quantity of motion is mapped to the tempo of the loop instead of volume. When the phone is accelerated, the BPM of the loop will decrease. The button called "inverse", gives the opposite effect when activated.

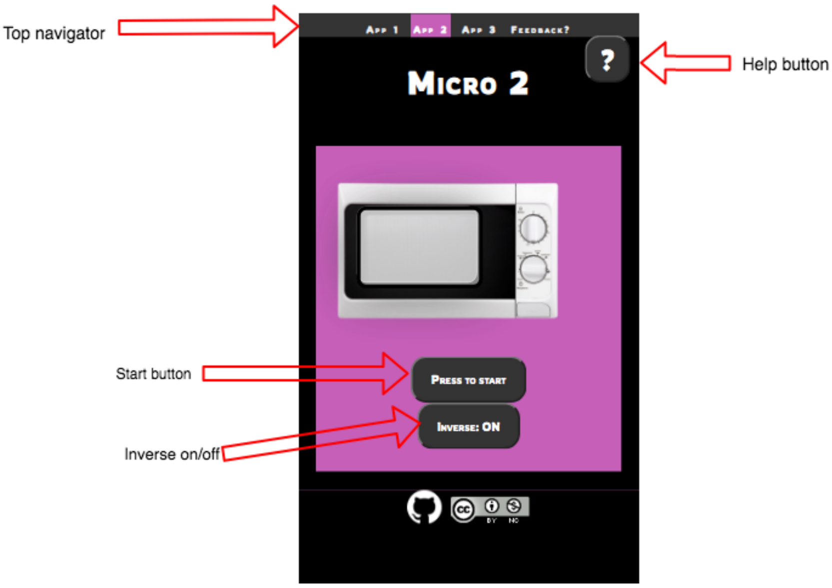


Figure 17: Micro 1.0 app 2

App 3

Three different pre-recorded loops with separate instrument tracks are integrated in the app. To load and switch between different loops, the button *PRESS to start* is tapped. By tilting the phone on the Y axis, different instruments are muted/unmuted. On the X axis, different parts of the loop are activated/deactivated. Grids show the separation between the different areas. E.g. If the pink dot is on the top left side of the screen, the drums are alone playing loop version one (figure 18).

Figure 18: Micro 1.0 app 3

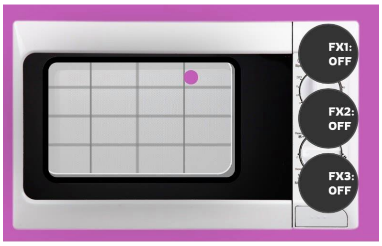


Figure 19: Micro 1.0 app 3

Figure 20: Micro 1.0 app 3

If you move the dot to the right part of the screen, but still keep it in the upper grid, the drums will play loop version two (figure 19). If you move the dot one grid down (figure 20), the drums will remain playing, but together with the bass. And for each new grid you move on the Y axis, you will include another instrument in the loop. In that way, you can add and remove instruments in the loop and switch between two parts of the loop.

Effects are switched on and off with buttons on the right side. Different parameters attached to the effects are controlled by tilting the phone on the Y and X axis. Volume gain is mapped to acceleration of the phone (in any direction). By default, an inverted mapping is approached, so that the volume will decrease the faster you move the phone. This inversion can be turned on and off via an inverse button.

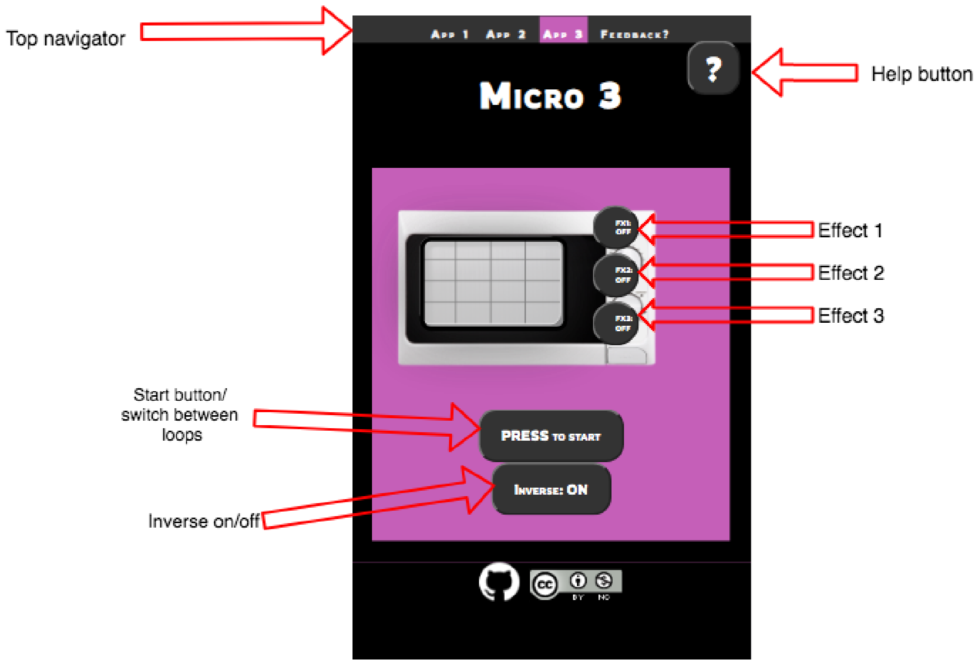


Figure 21. Micro 1.0 app 3

4.4.2 Design of second iteration: Micro 2.0

In the second iteration of the Micro Apps, I decided to develop further on the concepts from app 1 and combine the ideas behind Micro app 2 and Micro app 3 into a new app. Secondly, I decided to remove buttons as far as possible, and make the visual feedback larger and clearer. Common for both apps are clearer instructions which appear and gradually fade out when the page is loaded, this to increase accessibility. The opacity of the blue dot was removed to avoid confusion.

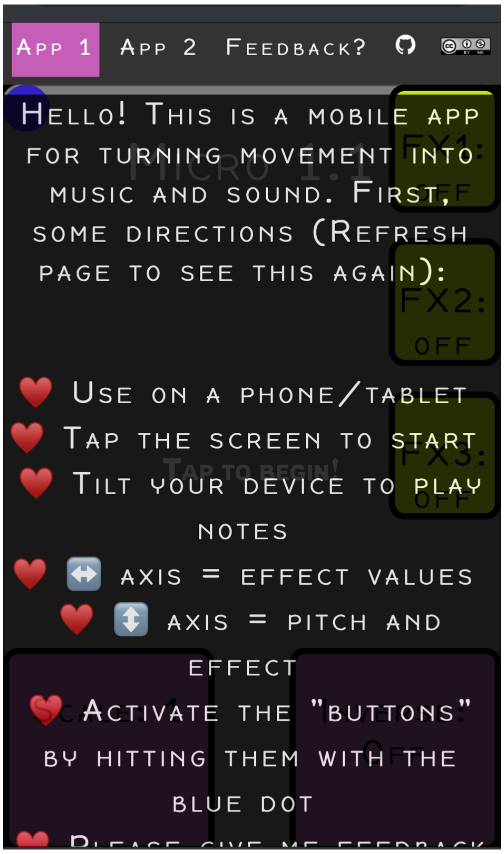


Figure 22. Micro 2.0 app 1: Instructions

App 1

The biggest change is the size of the control area and the replacement of buttons. The blue dot that indicates motion, is now moving around in the whole screen area. Buttons are replaced with areas that can be "touched" with the blue button by tilting the phone. However, buttons could not be entirely avoided, as the accelerometer sensor needed to be activated from a button. This button covers the whole screen to be as accessible as possible. Since the button is already there, it also serves as a button for switching between several synth instruments. We have two air motion activated "buttons" in the lower part of the window, one to change scale, and one to change between inverted and non-inverted modes. There are three "buttons" in the right area of the window, one for each of the three effects. The main functions are the same as in the first iteration, and the sound design is also more or less the same.

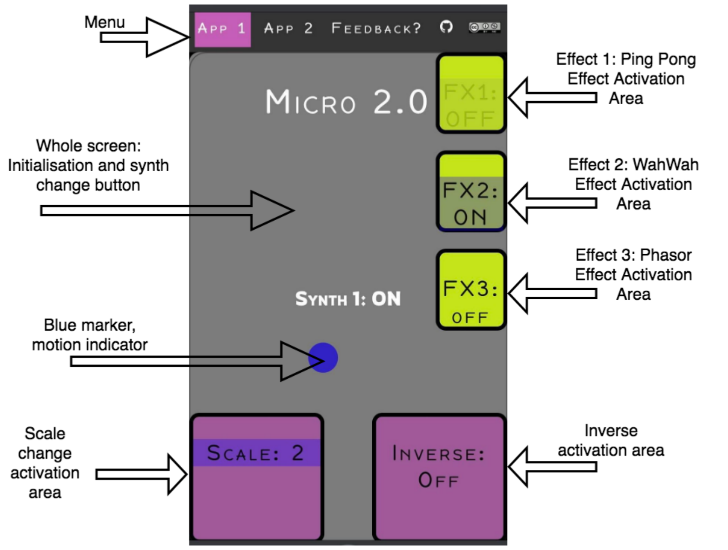


Figure 23. Micro 2.0 app 1

App 2

Just as in App 1, instructions will appear when the page loads and are visible for about 15 seconds before they disappear. Three yellow activation areas appear as buttons and are located on the right side. They are activated by being hit by the blue marker. When the page is loaded, a random musical groove is generated with parameters such as time signature, tempo, scale and rhythm pattern. The randomly generated parameters are visible in the left lower corner of the screen. The drum groove will be activated upon opening of the app and always play, with no option of turning on and off. The user can activate and deactivate the different instruments in the loop by hitting the three different activation areas with the blue marker. There is also an option of pressing any area of the screen which will give a pitch change effect that lasts for about two seconds.

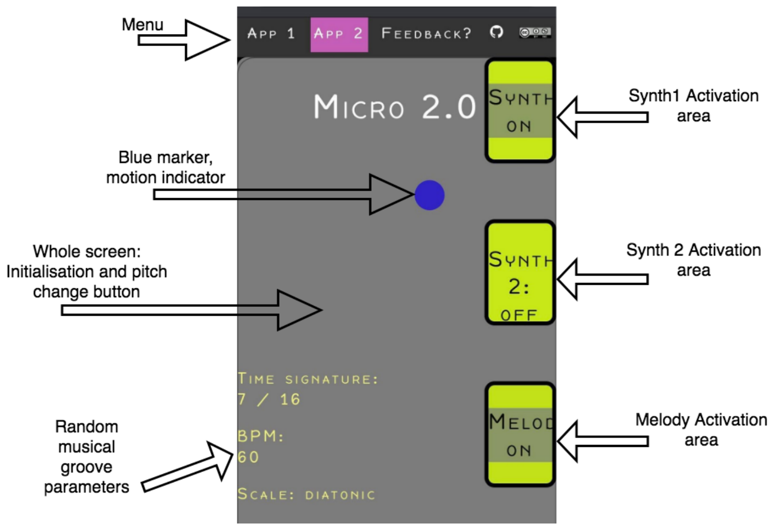


Figure 24: Micro 2.0 app 2

4.4.3 Design of third iteration: Micro 2.1

The overall design of the third iteration is not very different from Micro 2.0. Most changes are based on feedback from users and involve some change in the back-end of the systems. I tried to find a solution to make the apps stick in portrait mode, but without success, so I included a note about this in the instructions.

App 1

The only visual change in App 1 is that the name of the scale ("pentatonic", "whole tone") is showing instead of "scale 1", "scale 2". The biggest change is that the application now adapts to the operating system. Testings showed that iPhones have an inverted gyroscope data stream values compared to Android and other types of smartphones, which made the apps work differently on different kinds of phones. Now, the applications detect the operating system upon the initialization of the apps, and convert the data values there after.

App 2

Most features in this app are the same as in Micro 2.0 App 2. The biggest visual change is that the transpose value is displayed when the user moves around with the app. Upwards movements increase the value, downward values decrease the values. When the screen is tapped, the tonality of the loop is permanently transposed. In this version, effects are made more prominent, and there is a wider variety of instruments that can be selected upon the random loop initialization.

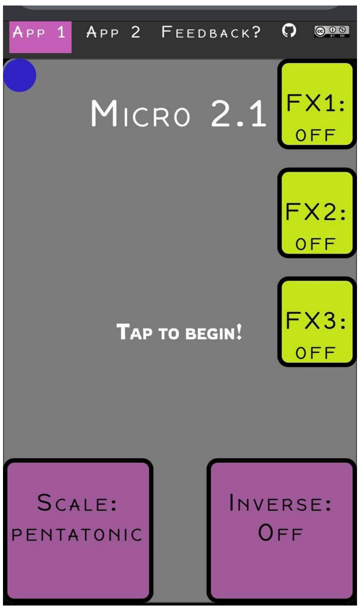


Figure 25. Micro 2.1 app 1

Figure 26. Micro 2.1 app 2

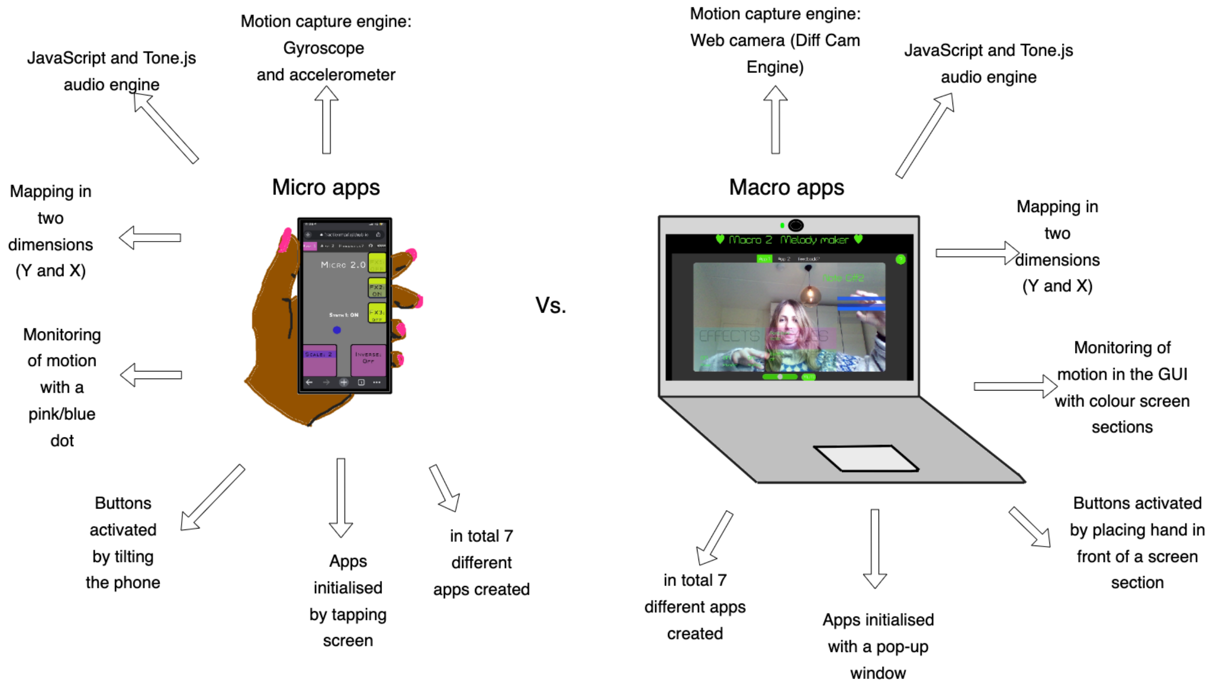


Figure 27: Comparison of the Micro and the Macro apps

	Version	Mocap technology	Coding language	Musicking approach	GUI monitoring of motion	Normal motor skills: average enjoyment rating (1-10)	Low motor skills: average enjoyment rating (1-10)	Normal motor skills: average challenge rating (1-10)	Low motor skills: average challenge rating (1-10)	Normal motor skills: average learnability rating (1-10)	Low motor skills: average learnability rating (1-10)
Macro 2.1 	App 1	Web cam + Diff Cam engine	Javascript / HTML / CSS	Melody Synth with effects	• 8x1 pixel blue vertical right side canvas • 6x1 pixel red horizontal canvas	6	3.3	4.3	6.6	8	2.3
	App 2	Web cam + Diff Cam engine	Javascript / HTML / CSS	Random music generator	• 32x1 pixel blue vertical right side canvas • 6x1 pixel red horizontal canvas	5.6	1	4.3	7.6	7.6	2.3
Micro 2.1 	App 1	Accelerometer and gyroscope	Javascript / HTML / CSS	Melody Synth with effects	• Blue dot with position corresponding to X/Y position	6	2.3	3	5.3	8	4
	App 2	Accelerometer and gyroscope	Javascript / HTML / CSS	Random music generator	• Blue dot with position corresponding to X/Y position • Transpose value	7	3.3	2.3	7.6	7.6	2.3

Figure 28: Comparison of the Micro 2.1 and Macro 2.1 apps with data from the observational studies

5. User testing

This chapter will describe the user testing and observational studies that were rolled out as a part of the development and evaluation of the prototypes.

5.1 Feedback forms - Macro prototypes

5.1.1 Macro 1.0

Seven user replies were received on the feedback form that followed the Macro 1.0 release (see Appendix D). In general, the response seemed to be mostly about technical issues that made people unable to initialize the app. One of the respondents gave this comment:

> "This is cool! It would be nice to have a better visual indication of how the movements relates to the sounds made, as not it is a bit hard to understand what is going on."

This comment was important for the development of the next iteration, which included an improved system for visual feedback.

Four out of seven users reported that one or more of the apps were not working or that they did not get any sound. One of these said that it was because they did not get their web camera working. It is difficult to spot the reason why the apps did not work just from the feedback form (except from the one user who mentioned that the reason was the web camera). It can be unsupported browsers, operating systems, drivers or web cameras. The code might also be very demanding in regards to GPU and CPU usage, which can cause lagging, crackling sound and other problems. The feedback form was perhaps too little precise to spot out the right reason for certain bugs, so for the form that followed later iterations, follow-up questions about operating system and browser were included.

5.1.2 Macro 2.0

A total of 13 answers were received on the feedback form for Macro 2.0 (see Appendix E). Four of the respondents reported that it was too easy to activate the buttons unintentionaly on App 1. One person commented that there was no control area on the left side, and also suggested that the "keys" should have been bigger. In general, many people commented that it was difficult to control the app, difficult to know if anything was turned on or off, and the contrast made it difficult to read the font. One person also suggested that the same instructions could come back when the "?"-button was pressed.

For the second app, some people experienced glitches in audio. People also suggested some solutions on how to show the user where to toggle the buttons. Many people liked this second app better than the first app and said it was more creative, but several people were rather negative.

5.2 Feedback forms - Micro

5.2.1 Micro 1.0

The first Micro iteration included three different apps with three different approaches/ideas. The feedback form of the first iteration received in total ten replies (see Appendix F). Much of the feedback was about unclear instructions, not getting any sound from App 2 or other sound issues. One respondent seemed confused by the fact that the opacity of the dot was mapped to the acceleration of the phone and replied that "the dot was disappearing sometimes". Two respondents also called for better instructions.

Micro 1.0 App 2 demanded that the phone was tilted in a certain position in order to activate the sound. One respondent commented on this and suggested that the random loop of app 2 could respond to the position of the phone upon initialization, so that there was sound from the beginning. The principle of "Instant music, subtlety later" has also been described by Perry Cook as one of the principles for designing computer music controllers (Cook, 2017, p. 1). Other informants also complained about app 2 not working. One of the ten informants that tested out the Micro app stated that it was difficult to handle the app because of the buttons.

5.2.2 Micro 2.0

There were a total of 18 replies on the feedback form on the second release of the Micro prototypes (see Appendix G). Overall, the feedback was more positive than in the first iteration. Out of 18 respondents, two respondents reported that there was no sound: the first one used iPhone 8 with Safari, the other one used iPhone 12 mini with Facebook internet. It is difficult to speculate on the reason why it did not work, as it has been reported working on other iPhone 12 mini phones (including my own phone, tested to work with Facebook internet), and another user reported it working on an older iPhone model as well (iPhone 7). Six respondents reported satisfaction with this iteration, and one of them reported that this version was better than the previous one.

Several respondents complained about it being difficult to reach the upper part of the screen with the blue dot, as the phone had to be tilted upside down. This problem was specifically reported by users not using an iPhone. This was due to the fact that the value stream of the gyroscope is different in iPhones than in Android and other phones, and the direction is flipped. As I had mainly used an iPhone for testing when developing the apps, this cross-platform related bug had not been discovered until now.

Some of the respondents reported problems with turning on and off the synths and effects. Two people pointed out that the application works badly when the phone is not locked in portrait mode. One of the respondents said they were a music therapist, and said there was potential within the concept and that it reminded them about Soundbeam. This person also commented that it was difficult to produce any actual music out of the apps, and that it was more of a “sound-mess”.

5.3 Observational studies

The third prototype iterations; Micro 2.1 and Macro 2.1, were tested with observational study test sessions followed by a questionnaire (see Appendix H). Three individuals with low fine motor skills as well as three individuals with normal motor abilities were invited to participate in the study. The users were using the same devices for testing, a Lenovo Y50 for testing of the web camera-based solution (Macro 2.1) and an iPhone 12 mini for the smartphone based solution (Micro 2.1). For consistency, the computer was ideally placed in front of a steady white background before the testing started. The participants were asked to read a consent form and gave their oral consent before starting (see Appendix I).

5.3.1 Testing on informants with normal motor control

The test persons were two women and one man, aged from 26-65, two of them had no musical training, the last one had much musical training. With the Macro app, the “melodies” produced were mostly scales up and down. The informants tested out many different kinds of hand gestures, such as waiving gestures, using one or both hands, and fast and slower actions. All of the informants encountered problems with the “buttons” switching on and off unintentionally when navigating their body in front of the screen. It also seemed difficult to link the connection between the video stream and the motion that produced the output, e.g. one user made hand gestures very close to the screen - in front of the “buttons”, but outside of the area that was being picked up by the web camera.

On the Micro app 1, one user commented that it is problematic that there is a continuous stream of notes and that there should be a way to stop the sound. For all of the three users with normal motor control, it seemed pretty easy to activate buttons by tilting the phone. To sum up the test sessions from the informants with normal motor skills, they reported in general that they enjoyed the smartphone apps better than the computer based solutions, and the average enjoyment with the apps was slightly above neutral. They reported that the apps were generally easy to learn how to use, and not very challenging. They were able to use the different functionalities in the apps, either on their own, or with guidance from me. However, those answers are only based on the opinion of three people, and should not be generalized. It should also be taken into account that the answers might be more positive due to the fact that the informants knew me personally, and were testing the apps and answering the questionnaire in front of me.

5.3.2 Testing with informants with reduced fine motor control - test person 1

The first informant with reduced fine motor control was a man aged 26-35 who reported that he had very much musical training, but he played no instruments or used any music apps. This man was very interested in music and seemed to be a musical person. He sat in a wheelchair and had most function in his left hand.

We started with Macro 2.1 app 1. We encountered some problems in the beginning of the session because there was a bookshelf in the background which seemed to be interpreted as motion by the web camera. After we made the background more neutral, we were able to continue. He did not use his right hand, so all motion was done with his left hand. It was difficult to use the right side melody bar with his left hand, so he used his head instead. He kept saying that the app was too sensitive and he seemed very frustrated with the app. I got the impression that he had melodies in his head that he wanted to play, but it was very difficult for him to use the app to play actual melodies. It was mostly sound and notes, not real melodies - which was not "enough" for this person.

The overall feedback on Macro 2.1 app 2 was much the same, he pointed out that it was too sensitive. It also seemed that he did not like the idea behind the app - to just turn on and off parts of a loop was too unchallenging. He argued that this app was not giving him any feeling of achievement. Overall, the webcam based apps seemed very frustrating for him to use. He used 18 minutes on Macro 2.1 app 1 and 16 minutes on Macro 2.1 app 2.

He also tested out the first iteration of the Macro app, Macro 1.0 app 1. In this version the melody bar was more piano-like, on a horizontal control area. He reported that this approach was better than the vertical approach.

When testing out Micro 2.1 app 1, the feedback was much more positive. He was holding the phone in his hand, turned it on and used it as intended. He pointed out that this app also was too sensitive. He held the phone very steadily and used several minutes to change between two notes. After nine minutes of playing with the app he stopped and said again that he liked the app, but that he thought it should be less sensitive.

Micro 2.1 app 2 seemed a little more difficult for him to handle, as he had to turn his hand in positions that looked uncomfortable. He also reported that he was unsatisfied with this version, as in the computer app, he did not like the concept of turning on and off instruments in a loop. He did not like the fact that it was not possible to produce the ideas and melodies he had in his head.

I asked what he thought about the concept of tilting the phone to activate buttons instead of clicking buttons, and he answered that he liked this concept very much. He reported that for him, it was easier to tilt the phone than to push buttons. For him, this technology could be used instead of keyboard and mouse.

5.3.3 Testing with informants with reduced fine motor control - Test person 2
This informant was in a wheelchair, aged between 26 and 35 and had reduced fine motor control. He told me before we started, that for a long time he had wanted to play the guitar, but because of reduced motor control, this had been very difficult or impossible. He told me that he was very positive about my project, and he had a lot of expectations.

We started with Macro 2.1 app 1. I told him that the app had to be controlled with hand gestures in the air. He started by using his hands very close to the screen, and asked very quickly about how precise one had to be. I answered that he could try to explore this on his own. Then, he suddenly seemed to understand the concept and started to create a melody, but his hand was still very close to the computer screen, so he activated many notes at the same time. We discovered that it was problematic that the melody bar was on the right side, as he was left handed.

Then, he navigated his hand with a slow upwards movement along the melody bar. He pointed out that it was difficult to distinguish what notes were being played and suggested that it should look more like a piano. He quickly understood the concept with the "buttons", and he was able to activate them with motion in the air. But when trying to create a melody with the new setting, it was very difficult not to activate the buttons unintentionally.

He suggested that there should have been a setting that had made the settings more stable, to avoid unintended output of the movements. He also pointed out that there should have been a way to see what notes are possible to produce, before they are produced, for example with grids. He mentioned more ideas, for instance to connect with a tablet with touch, or to use the voice, or a combination of this.

With Macro 2.1 app 2 I noticed that the layout on the start screen with instructions was too long, which forced him to scroll down on the page, which was inconvenient and unnecessary. In the beginning he navigated his finger very close to the screen, without letting the finger be picked up by the web camera. After a short time he moved his hand back again, so the motion was being picked up. It looked like he was able to use the different functionalities of the app, but it looked less engaging for him compared to the first app. He asked shortly after about what the app was for, and also suggested that there should be a button to have some control of the tempo. He also suggested that there should be a way to plan the content of the app before it was started, e.g. checkboxes with different settings.

During the test session, we had a conversation about design and accessibility, and he told me about his experience with accessibility in video game design. He mentioned that many games demanded that the user had very fast fine motor control. Guitar Hero was for instance a game he never had been able to play. This was the main difficulty when playing video games, to be fast enough. He addressed an important issue: how to optimize the video games that already exist? We talked about this issue and how it was related to musicking technologies. He also talked about some video games that with success had implemented several accessibility settings. One of these games was *The Last of Us I* and *II*, which have 60 configurable options that can be customized to a person's needs[11].

When testing the first Macro iteration, Macro 1.0 app 1 his immediate reaction was that the horizontal melodic control area worked better than the vertical melodic control area. This version also had normal buttons, to be controlled with a mouse or with a touchpad, instead of air motion buttons. I asked him how it was for him to click buttons with a mouse. He said that for him, using a mouse was not a problem, and this was what he was used to.

When testing the mobile based apps, he held the phone with both hands. It looked challenging to tilt the phone, and it seemed difficult to turn the phone all the way to reach the buttons. He said that touch is much better for him, so having the option of using his finger to control the blue dot would have been more ideal for him. He seemed to like that there is a blue dot that monitors the motion, and said that this dot makes it easier to touch the buttons.

The experience with Micro 2.1. App 2, was more or less the same as with app 1, and he suggested that the app should have touch buttons in addition to the tilting solution. I asked him if he had tried any musical apps that used touch, but he answered that he did not know they existed. I invited him to test out Bebot[12], a musical smartphone app that uses touch, and he agreed to test out this app. On this app he played a melody with one finger, and he said that this app was much better for him. He did not use much time on this app though, but he mentioned that he was interested in trying this out more later.

5.3.4 Testing with informants with reduced fine motor control - Test person 3

This was a man aged 26-35 who was in a wheelchair and had reduced fine motor control. He was a highly musical person with a genuine interest in music. He could sing and play the piano and had

[11] https://www.playstation.com/en-us/games/the-last-of-us-part-ii/accessibility/

[12] https://apps.apple.com/us/app/bebot-robot-synth/id300309944

also composed a song which he showed me. When starting to test the applications, it appeared that he had problems with understanding the English instructions, so I translated the instructions for him on all of the apps. He did not use very much time on any of the apps he tested, so not all functions were explored.

With Macro 2.1 app 1, he started by using finger movements with both hands in front of the screen, as if he was playing the piano. Very soon he asked me if the movements done with his left hand were not doing anything, and then I explained that the horizontal part of the screen was for switching between instruments, and effects, and the horizontal blue bar on the right was for creating notes. He used an open hand very close to the screen, and seemed to be finished after six minutes. With Macro 2.1 app 2, he was also moving his hand very close to the screen, and after two minutes he asked “It isn’t me playing?”. It seemed a little uncertain to me if he understood the relation between his movements and what was happening on the screen, as it did not look like he tried to use the functionalities like turning on and off the “buttons”.

With Micro 2.1. App 1, he was able to tilt the phone to change notes, and he was holding the phone very steady and was tilting it in different directions. He used his thumb to click on the screen, and the instrument changed. But it looked like his intention was to “click” the buttons. I explained to him the concept with the buttons, that one had to tilt the phone to activate the buttons. He said he wished the buttons could be clicked and that it is too hard to tilt the phone. The reaction was pretty much the same with Micro 2.1 app 2, and the informant used only a couple of minutes on this app, and seemed perhaps a little uninterested.

The user also agreed to test the Bebot app. With this app he was able to interact much more. At first, he played one note with his thumb. He played notes up and down and created musical melodies. He also used more fingers and created harmonies with up to four fingers. He seemed to have more control over this app, and used words like “cool” and “intuitive”.

After the testing I asked him what he thought about playing this app compared to playing the piano. He answered that he thought this app was more difficult to learn how to play than piano. He expressed that he was satisfied with the instruments he already knew how to play, but he believed the apps I had showed him would be great for people with more severe motor control problems than he had. He prefered to sing and let other people accompany him. However, he had always had a dream about learning to play piano on a professional level, but he did not have fast enough motor control to be able to play like that. He also had a wish to play drums, but for the same reason, this was not feasible. He had accepted that this never would be possible and had decided to focus on his vocal skills.

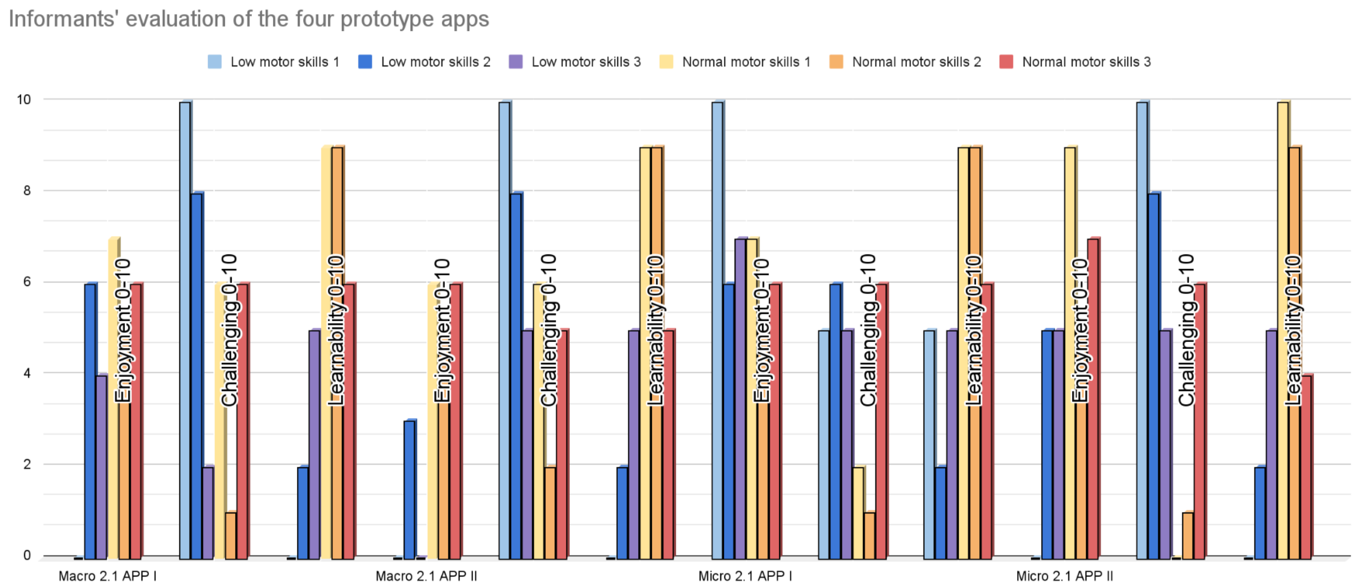


Figure 29: Results from the questionnaire that followed the observational user studies.

5.3.5 Observational studies: Conclusions and reflections

The purpose of the observational studies was to explore how the prototypes afford sound and music exploration and accessibility. The test sessions showed that Macro 2.1 app 1 and app 2 are almost as accessible for the informants who had low fine motor skills as the informants who had normal fine motor skills. The observation showed that the test persons from both groups were able to achieve almost the same control over the application in about the same short amount of time. All of the informants faced the problem of unintended output, as the software interpreted all kinds of motion as input. However, the informants with low fine motor skills self-reported that all of the apps were more challenging to use, more difficult to learn and less engaging than the informants with normal motor skills, but the number of informants are too few to generalize.

All four apps included a minimal number of buttons and were mostly based on in-the-air motion. For one of the users with low fine motor skills, this was reported as positive in regards to accessibility, but for the two other informants with low fine motor skills, this approach made the apps *less* accessible. They reported that mouse and touch interfaces were something that they were used to and comfortable with using, and would prefer to use such technology to increase their control with the apps. These findings are however not enough to say that the air motion approach was a failure, as the number of informants with low fine motor skills were very few, and all of them had some finger motoric function. A combination of touch, mouse and air motion technologies, and a way to personalize the functionalities, should probably be an approach to adapt the instrument to each individual user. Two of the informants also suggested using voice as a possible input in the apps.

When it comes to allowing for sound and music exploration, the apps are still on a primitive level. The users with low fine motor skills prefered the versions where one was able to control the pitch of a note. The apps that generated random loops of music were generally not enjoyed by this group of informants. All of them questioned or criticized the fact that they were not able to manipulate the app with their own musical ideas. In Macro 2.1 app 1, the informants asked for a more piano-like control area to produce notes in, instead of the vertical bar on the right side of the screen. They were invited to try the Macro 1.0 version, which included a horizontal control area, an prefered this approach to produce notes with.

Micro 2.1 app 1 was the approach that was enjoyed the most by the users who had reduced fine motor skills, and one of the users seemed to have a great musical experience using it. At this stage, the app does not produce any musical intervals larger than a second, and the only way to produce any silence is to hold the phone still for a while, which is very limiting musically speaking. The tilting of the phone seemed to work pretty good for most of the users, however, for some of them it looked difficult to tilt the phones 180 degrees to reach the buttons when tilting.

Two of the three users with low fine motor skills said they were comfortable using touch technology, and would prefer that the mobile apps came with touch buttons in addition to what already was there. Due to this, they were invited to try the Bebot app which is a synth app that allows the user to use touch to create sounds and music. The informants reported enjoying this approach in many ways. To include simple touch interactivity in the apps in combination with the air motion technology, will therefore be a good idea, and probably not excluding most people with low fine motor skills. This will also give more options of mapping and can solve the problem several users pointed out with Micro 2.1 app 1, that one cannot create intervals larger than a second. An approach that might work is to implement note attack with touch and note release when the finger is lifted from the screen.

Conversations with the informants and questionnaires showed that two of the three users with low fine motor skills had been hindered from being able to play musical instruments because of low fine motor skills. The third informant had high enough motor skills to play the piano, but was not able to achieve the level he had dreamed of. However, he was able to sing on a relatively high level and highlighted the importance of interaction with other musicians. It was interesting to see that he accepted his limitations and took advantage of his strengths. The informants pointed out speed as a main motor ability challenge when playing musical instruments and using game controllers. This suggests that the main motor skill obstacle when playing musical instruments perhaps is not the physical *size* of the gestures, but the *speed* of action. An important design factor when working on the prototypes in the future, will therefore be to find out how one can improve the level of interaction without demanding rapid actions.

Low fine motor skills come in many different versions, and each individual has their own difficulties which demands that the technology can adapt to each individual. Digital musical interfaces can possibly allow for this kind of adaptation of mappings and functionalities, and making it available online, would make it even more available for people with the equipment they already have.

6. Conclusion, Discussion and Reflections

6.1 Summary and answer to main Research Question

The focus for this Master's thesis has been to design and implement new musicking technologies that can be controlled with motion in the air. Embodied music cognition and accessibility have been the fields of research that founded the theoretical background for this thesis. To design and implement the musicking technologies, the method of user-centered design was used, where user feedback was a part of the iterative design process. The last iteration of the apps were tested by people with normal motor skills and people with low fine motor skills with an observational study. The fourth chapter of this thesis describes how the proposed prototypes were designed and implemented. The final design involves two different main approaches, one approach that uses web camera motion detection and another solution that uses accelerometer and gyroscope sensors.

The main research question in this thesis was: *How is it possible to design and implement accessible musicking technologies that can be controlled with motion in the air?* The work with this thesis shows that it is possible to develop several novel approaches to web-based musicking technology that are based on motion in the air. The web camera based solution allows for simple exploration of sounds and music, but can be developed further by using image recognition to increase the accuracy and precision and to include more complex mappings. The accelerometer sensor approach introduced tilting as an alternative to buttons, which seemed beneficial to one of the informants with low fine motor skills, but as a disadvantage for the remaining two. The observational studies pointed towards a need for musicking technology that can adapt to the individual and can change betweens different settings of mappings. The speed of actions should be considered as important in addition to the size of the gestures. The studies showed that the prototypes could benefit from including touch technology to increase the accessibility for people with low fine motor skills.

6.2 Answer to RQ1:

How do the prototypes afford sound and music exploration, and how can they be taken further?

The initial idea when I started to develop the prototypes was to create musical instruments. However, due to the premise of making the apps entirely based on motion in the air, the possibilities for mapping and musical expression have been compromised after each iteration, which means that it has been difficult to create something that allows for *musical expression* on a high level. Hence, the goal has rather been to create something that affords *sound and music exploration.* The observational studies of the last iterations showed that the informants were able to explore timbres, sounds and melodies, but on a very basic level. The easier it was to learn how to use and interact with the prototypes, the more enjoyment the informants reported. At this point, the goal with the prototypes was to explore sound and music with motion in the air, which was a success. All of the informants were able to produce sound and to interact with the prototypes. However, the informants reported a wish for being able to express themselves musically on a higher level, and to e.g. play a melody. They reported that the applications were too sensitive, which made it difficult to interact. The next step will hence be to include mouse and touch interactivity to improve the interactivity and mapping possibilities. The apps, especially the Micro prototypes, can easily be made more interesting musically speaking by implementing touch in addition to the tilting.

Most musical instruments demand hours of practice upon achievement of mastery. Hence, it is expected that the users would struggle with expressing themselves musically with the prototypes after only a few minutes of interaction. As the creator of the instruments, I have been able to practice playing the prototypes for a longer stretch, and after one hour of practice, I could play a simple melody on Macro 2.1 App 1: Twinkle Twinkle Little Star (see Video 1 attached in Appendix A). Melody is only one dimension of musical expression though, and there is still a long way to go to increase the options for musical expression. The first step for this particular app could be to apply machine learning with image recognition to avoid that all motion is interpreted as input.

6.3 Answer to RQ2:

How can the prototypes contribute to making musicking technologies more accessible for people with low fine motor skills?

The second and third iteration of the prototypes were designed to be used entirely with motion in the air, with as few buttons as possible. The observational studies showed that this premise was making the apps less accessible for two of three informants with low fine motor skills, who prefered and were used to using mouse and touch technology. For the third informant, the tilting approach was offering higher accessibility than touch, which indicates that implementing this approach in musicking technology can improve accessibility for some people. The main obstacle for the informants with reduced fine motor skills was not primarily the physical size of the gestures, but rather the speed of motion. This suggests that buttons should not necessarily be avoided, but instead be implemented in a way that does not depend on quick actions. I suggest that the air motion approach should be implemented in addition to touch and mouse technology, not replace them. Ideally, there should be a neat way to optimize the setting to each individual prior to using the apps.

The prototypes that were based on web cameras (Macro 2.1 app 1 and 2) were difficult to control, regardless of the informants' motor abilities. The fact that the camera was picking up any kind of motion, made it difficult to avoid unintended output. In general it looked a bit more difficult to handle the apps for the people with low motor control than for the people with normal motor control. However, the difference between the group with reduced motor skills and the group with normal motor skills was not very big, which may suggest that there might be a potential in working on this further. Also, both Motion Composer and Soundbeam are based on motion in the air, which indicates that others have successfully researched this as a beneficial approach. I suggest that e.g. machine learning with image recognition can be implemented to teach the system to recognize what movements that should be interpreted as input. By using machine learning methods, the instruments could possibly adapt to the individual, and the accessibility of the instruments could increase drastically. When the system is more fine tuned in regards to input/output, the number of available mappings will increase, and this will also benefit the possibilities for musical expression. The use of eye tracking can also be implemented to include people with more severe motor impairments.

The most important factor that speaks in favour of accessibility is the focus on making the apps available online. The empowering factor by using technology that already exists in people's phones and computers is something that can contribute to making the technologies accessible to people with low fine motor skills, as most people use this technology already today. Skipping the steps of buying physical equipment can lower the threshold for testing out new technology, and can also be beneficial as this group of people easily can be included in online testing and further development.

6.4 Answer to RQ3:

How do the prototypes compare with other musicking technologies that are designed to be accessible for people with low fine motor skills?

The main difference between the prototypes developed in this thesis and technologies that already exist is that my prototypes are designed to be accessed from a browser. Both Soundbeam and Motion Composer, which are described in the background chapter, are based on hardware solutions that are well developed and evaluated, but difficult and expensive to possess if you do not already have access to it. At the time of writing this thesis, the price for a Soundbeam 6 full set is 121.275 NOK[13]. This price excludes most people from being able to play it, and therefore the accessibility is also lowered, in my opinion. However, both Soundbeam and Motion Composer use sensors that offer more complex and precise mapping than the Micro and the Macro apps, which allows for more interesting musical interaction. While Soundbeam uses ultrasound for motion

[13] https://www.amajo.no/products/soundbeam-6-big-band-kit

detection, Motion Composer uses a CCD video camera and ToF sensor, which opens up for motion detection in three dimensions and mapping that involves many different body parts. The motion capture technology developed for the Macro and Micro prototypes are only exploiting two dimensional motion, which limits the repertoire of movements. However, at the time of writing, ToF technology is starting to be integrated within mobile phones[14], and several smartphones already are equipped with one. Smartphone cameras and web cameras are also getting better and better. This is one of the reasons I early in the process decided to stick with the technology that already exists in regular smartphones and computers. The work done in this Master's thesis is meant to be a starting point that can continue to evolve when the computer-, smartphone- and tablet technology is evolving and e.g. ToF sensors are common in computers and smartphones.

6.5 Reflections and future work

6.5.1 Universal design for musical instruments?

While doing the observational studies, I have met people who have never been able to play the musical instruments they wanted because of limited motor skills. I have met people who can play instruments, but never will be able to play on the same level as a musician who has normal motor abilities. But having accepted their limitations and gained virtuosity based on their own potential. This has forced me to reflect on why I am doing this. Who am I to come and say that everyone should be able to play any instruments? I am not really suggesting that everyone should be able to play any kind of instrument. Most of us will actually never be a musician, even though we could if we tried. What I am trying here is to bring in some of the same thinking that exists in architecture and in interaction design: the *person* is not disabled, but the *environment* is disabling them. This means that if a person in a wheelchair can not enter a building because of stairs, the building is the disabling factor. This is why there are laws and rules for universal design in architecture, which empowers disabled people to not be disabled and let people take part in the society regardless of their abilities. I suggest in this thesis that we introduce some of the same thinking when designing new digital musical instruments and musicking technologies.

While considering accessibility might be a good design principle in musical instrument design, one should also not forget that the process of creating an instrument can also be considered to be a part of the art. Jensenius (2022) argues that the luthier also should be considered as an artist, and the luthier and performer often can be the same. In our days, the luthier often is forgotten about, due to mass production of instruments. If the luthier hand work should be considered as an art form, in my opinion, we should not try to put strict boundaries and limitations on the principles of the design. It could possibly be damaging to the creativity and freedom that is crucial for an art form to

[14] https://root-nation.com/en/articles-en/tech-en/en-what-is-a-tof-camera/

thrive and exist.

My intention with this thesis is not to talk down approaches to instrument making that do not come from an inclusive or universal way of thinking. I do not try to advocate for a universal design principle in regards to musical instrument design, in the same manner as e.g. architectures should consider it. This is just one of many ways of thinking about the luthier craftsmanship, and hopefully, try to highlight this way of thinking as one of many manners one can consider when designing new instruments.

6.5.2 Haptic feedback and modalities

Traditional musical instruments are made of solid material that needs to be touched to create sound. This will give the user haptic feedback. The Macro prototypes are touch-less and lack this sensory dimension. How can this be a problem? The lack of haptic feedback has been discussed by Marc Leman as one of the four key problems regarding interactive music systems, and in particular electronic musical instruments (Leman 2008, p. 162). The lack of multimodal feedback was also addressed by Emma Frid in her survey of accessible instruments that were presented in NIME, SMC and ICMC during the period 1975-2017 (Frid, 2018). In Leman's research with acoustic musical instruments, one of the findings was that haptic feedback is crucial for fine gestural control of the instruments and for musical expressiveness (Leman 2008, p. 163). A touch-less instrument will by definition lack haptic feedback, so it might be a good reason to assume that this can be a gap to fill. This opens up for creativity. Could other groups of senses be involved, or could there be mapped haptic feedback in other ways?

The visual feedback and the audio mappings might be even more important for a touchless instrument that lacks the sensory dimension of haptics. The feedback that was received after the first iteration of both the Micro and Macro apps supports this claim. Several respondents reported a wish for better visual representation of the sound and problems with understanding the link between their action and the sound. Another reason that it might be a good idea to involve haptic feedback as a third modality in the instruments, is that people with low fine motor skills, such as people with Cerebral Palsy, often can have other physical disabilities as well, such as problems with vision or hearing (CDC, 2020). I suggest therefore that future similar projects should consider involving other modalities or sensory dimensions. When that is said, it would also be interesting to find out more about the effects of limiting the sensory dimensions in a musical instrument. What is it really doing with the musical experience when only one or two modalities are in use? Dark dining is already a thing, where people eat in restaurants in the darkness. What about creating an air instrument which is designed to be played in darkness, where the only senses used are the motor sense and the hearing?

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Appendix A

Blog post and web page

- A blog post related to the Master's thesis will be published on this address: https://mct-master.github.io/masters-thesis/2021/12/14/fractionMari-micro-and-macro.html
- A web page with documentation, link to github and demonstration videos for the prototypes will be published on this address: https://fractionmari.github.io/microandmacro/

Appendix B

Macro prototypes

The Macro prototypes are web apps that must be opened on a computer with web camera (not Safari) from these links:

- Iteration 3: Macro 2.1 app 1 and app 2: https://fractionmari.github.io/macro3/
- Iteration 2: Macro 2.0 app 1 and app 2: https://fractionmari.github.io/macro2/
- Iteration 1: Macro 1.0 app 1, app 2 and app 3: https://fractionmari.github.io/macro

The instructions of usage are included in the apps. Demonstration videos of the prototypes are attached in the zip file Supplementary_files.zip (uploaded on DUO). The person in the videos is the same person as the author of this thesis.

- Video 1: Macro_2.1_App_1_Demo.mp4
- Video 2: Macro_2.1_App_2_Demo.mp4
- Video 3: Macro_1.0_App_1_App_2_App_3_Demo.mp4

Repository of Iteration 3: Macro 2.1 app 1 and app 2 is attached in the zip file Supplementary_files.zip:

- macro3 (folder)

Appendix C

Micro prototypes

The Micro prototypes are web apps that must be opened on a smartphone from these links:

- Iteration 3: Micro 2.1 app 1 and app 2: https://fractionmari.github.io/micro3/
- Iteration 2: Micro 2.0 app 1 and app 2: https://fractionmari.github.io/micro2/
- Iteration 1: Micro 1.0 app 1, app 2 and app 3: https://fractionmari.github.io/micro

The instructions of usage are included in the apps. Demonstration videos of the prototypes are attached in the zip file Supplementary_files.zip. The person in the videos is the same person as the author of this thesis.

- Micro_2.1_App_1_Demo.mp4
- Micro_1.0_App_1_App_2_App_3_Demo.mp4

Repository of Iteration 3: Micro 2.1 app 1 and app 2 is attached in the zip file Supplementary_files.zip:

- micro3 (folder)

Appendix D

Report from ‘Macro app v. 1.0: Feedback?’

Collected results per. 6. December 2021 13:51

- Delivered replies: **7**
- Commenced replies: **0**
- Number of sent invitations: **0**

This prototype is currently under development. If you have any feedback, negative or positive, or any comments, please send me an anonymous message in the field below: *

- Hello! This is cool! It would be nice to have a better visual indication of how the movements relates to the sounds made, as not it is a bit hard to understand what is going on.
- Unfortunately I was not able to get my camera working because my browser (edge) had used a camera that was no longer available (split cam driver) as the camera and despite trying and changing the camera this site had access to to the Webcam, I was unable to help the site switch.
- I could not make app 1 and 2 function. I got no sound. App 3 did I get sound, but could not change from one to the other sound.
- Cool apps. A bit hard to understand how to best interact with them in a concise way. It is difficult to trigger the same pattern repeatedly without doing many other unindented actions
- Great work! App1 Generally it is easy to use and has nice sounds and gives at the same time space to explore To the effects: The effects are cool, not too dominating, giving a good twist, PingPong - effect for itself quite subtle but in combination with the synths on the left evolves better! Fm synth left: Not clear why there are two bottons with the same lable in the first instance, then later I realized I could use them together - nice effect! It was also a surprise that they change they function ones pressed again after trying out. App2 Nothing happened when activating the button. App3 Super track, one didn't wanted to interrupt at the same time it was nice to interact with it, but one does not understand what is happening when applying gestures - perhaps there could be a little legend next to it indicating how one influences the sample? Good luck with it, looking forward to learn more about the project!
- I really enjoyed playing around with the three apps, learning how to use them as instruments and explore the sonic space they offer. The first one was highly configurable and I felt that position the webcam against a static space (tilting the webcam up) I could control the sounds it would make reliably. Also getting closer to the webcam with my hand was able to have more dramatic effects on the sound. The second app had less control options but the sounds were much more dynamic and atmospheric which I enjoyed. The final app was interesting as motion was able to dynamically shift the outcomes of the prearranged tracks in someway. This felt like I was a musician in a larger ensemble rather than a solo performer.
- Hi. the app1 doesnt seem to work for me, app2 and app3 works. app 3 is super loud in comparison to the app2. but they both seem to work. What I think would have been helpful was if there was a wiki or a guide to exactly know what I am supposed to do and how it works. Right now I was just waving my hand trying to do something and make some noise, without understanding how my actions are generating or altring the sound. But the project is so cool and would definitely try it again once there are more updates. -Abhi

Appendix E

Report from 'Macro app v. 2.0: Feedback?'

Collected results per. 6. December 2021 13:53

- Delivered replies: **13**
- Commenced replies: **0**
- Number of sent invitations: **0**

With text answers

This prototype is currently under development. If you have any feedback, negative or positive, or any comments, please send me an anonymous message! :)

This form will be open until the 20th of october.

Comments on App 1:

- Very cool idea! I had some trouble with turning on and of effects as they tended to switch back to the first position. I for some reason also had some trouble producing sounds with this app. The information given in the beginning could maybe be included in the information given when you press the ? button so that all the information could be acquired at any time.
- SYKT KULTTTTTTT - men ble ikke helt musikk hehe.
- Vanskelig å styre, vanskelig å få effekter osv. til å forbli på. Fort gjort at man skifter effekt fordi man kommer borti dem.
- A nice idea, nice to have many changeable parameters. However, it was hard to control visually. When trying to 'push' a button, the hand generally passes by other buttons and also activates them, without meaning to. I wondered why there's no controllable elements in the left upper section of the screen? The piano keyboard on the right side is quite nice, but if we have leftover screen where I can move, would it make sense to allow the keyboard bigger keys by bending it around, for instance?
- The first application worked well and had a good UI, the constrast made the text quite hard to read.
- Application does load, error message "Something went wrong" was displayed
- works well on the laptop as you can move yourself to turn different parts of the app on, the mobile device is harder as you have to move it more dramatically to turn different functions on which is harder if you have to rotate the device around
- The scales on the right side of the screen worked on this application. Controls were quite hard to use. The app was interesting an unique, gave me a very new experience. The gui was a little bit in the way and I felt that trying to turn something on would turn multiple other things on too since they were so close together.
- Interesting concept, but very hard to control in any meaningful way. For instance I found it very hard to know when anything was turned on or off. It could be that the test conditions were not ideal, since the background was far from monochrome.
- For both the apps I got a message saying something went wrong and couldn't use them. I denied permission to use webcam when first opening because I wasn't expecting it to be needed for the app and couldn't find a way to trigger the option again to change my answer. I tried reopening the page in firefox and chrome and in private browsing.
- Maybe worth giving the user an area where the camera doesnt respond to movement to provide some control to the user as its easy to hit alot of the bottom buttons
- Fun tool, but very hard to control. I give up quite fast, and it feels like a theremin in a way, almost impossible to master. Maybe if I knew more about what it does, and how to achieve it (ie what does light vs dark areas in the cam-view do, or what about colors?)

Comments on App 2:

- i liked both apps, but possibly prefer the second one some minor glitches in the audio, otherwise a fun project
- This app was easier to understand and use, but I had some trouble with turning on and off the synths and melody with this app as well. Good look with this project! :)
- Samme som på App 1
- The randomised - or rather, pre-determined but outside of the knowledge and control of the player - elements here worked better for the practical implications of playing an app this way. At the same time the brain automatically tries to understand what and how I am controlling with my movements, and as a player it would make me more engaged and enthusiastic if I could find out more about that, and try to control those elements I can according to my wishes. I imagine a more creative approach like this app (versus app1) would work better for this kind of usage, but the form of how this is done, can be further developed to create a more engaging player experience, I imagine. Great work!
- The second app's UI was a little more difficult to use, the green circles that appear at the bottom of the screen could show as blank circles to show the user where to toggle them.
- felt it was easier to navigate this on a laptop and a phone and the sound of it was nicer to listen to, I think this one allows the user to experiment with it more
- The scales on the right side of the screen did not work for me, maybe it was a browser problem but they did not give any audio output. Once again the controls were hard to use, however the gui was a not in your face. Reading the text over the camera was quite difficult. Once again the app was interesting and created a unique experience I had not had before
- Enjoyed this one more, probably because the fixed loop gave me som structure and it wasn't that important that I had full control of what I did. Still difficult to interact with the buttons - I never found a way to turn on Synth 1. I think it would be good to find another way to interact with the settings.
- Same problem
- Similar to the other app in responce
- Not so fun, as I can't make it sound nice. I guess it's possible to change tempo and time signature, but with this starting point it get's too annoying to explore for me, so I'd rather get back to the first app.

What kind of device did you use when testing?

E.g. Mac, PC, tablet, smart phone? Laptop or desktop computer?

- macbook
- Mac
- Mac
- mac
- Mac
- Laptop Win 11
- PC Windows 10
- laptop and iphone
- Laptop
- Windows laptop
- Mac laptop
- Mac
- Macbook

Which browser are you using?

E.g. Google Chrome, Firefox, Safari, Edge, DuckDuckGo, etc.

- firefox
- Google Chrome
- Chrome
- google chrome
- Chrome
- Chrome
- Google Chrome and Edge
- google chrome and safari
- Google
- Chrome
- Tried firefox and chrome
- Chrome
- Google Chrome

Appendix F

06/12/2021, 13:53 Micro app v. 1.0: Feedback? – Report - Nettskjema

Report from 'Micro app v. 1.0: Feedback?'

Collected results per. 6. December 2021 13:53

- Delivered replies: **10**
- Commenced replies: **0**
- Number of sent invitations: **0**

This prototype is currently under development. If you have any feedback, negative or positive, or any comments, please send me an anonymous message in the field below: *

- Hei! Her var det mye skraping på lyden på alle appene.
- Kul idé!! Tok meg litt tid før jeg skjønte at den brukte "bak" kameraet på mobilen, og ikke "foran/selfie"-kameraet :') ellers funket alle tre appene. Skjønte ikke hva invert-knappen skulle gjøre. Bruker en samsung-mobil. Tvi tvi!
- I thought app 2 wasn't working perhaps because the instructions could be clearer. Maybe you could have it so that there is one random loop in the middle corresponding to the position of the phone before people move their ohones. I liked app 1. App 3 was also cool.
- Tried accessing using Safari on older model iPad but was unable to hear sound (app seemed to visually indicate it was receiving motion data, just couldnt hear results). Will see if different software, or device, or less rigorous blocking protocols let sound through
- Virker som et morsomt leketøy, men jeg er nok en dårlig testperson fordi jeg ikke er spesielt opptatt av musikk. Er ikke helt sikker på om jeg forstod poenget😉
- Vi prøvde Micro 1, og oppdaget at hurtig bevegelse av mobilen ga størst uttelling og raskest melodiføring. Prikken på skjermen forsvant innimellom, - hadde vært gøy å se et visuelt mønster ihht musikken, er det mulig å utvikle? Noe som pirrer nysgjerrigheten og åpner nye muligheter for brukeren?
- Morsom app og annerledes app. Det kunne gjerne stå helt i starten hva slags app dette er, så man lettere skjønte hvordan man skulle bruke den. Feks dette er en app som lager musikk ved hjelp av bevegelse på telefonen. Jeg syntes den første funket best. Den andre fikk jeg ikke til å få lyd utav. Den tredje hakket ganske mye.
- Couldnt get app 2 to make sound. Would be cool to cobtrol the amount og dampening when moving / not moving the phone. Is it possible to select / import soundtrack?
- App 1 and 3 functioned well, app 2 did not. These apps which worked, the sound decreased and increased when moving the phone along the x-axis. Also when switching the phone, the sound changed intensity and tact. Thats good.
- God og klar lyd, men vanskelig å få til med knappene.

Appendix G

Report from 'Micro app v. 2.0: Feedback?'

Collected results per. 6. December 2021 13:54

- Delivered replies: **18**
- Commenced replies: **0**
- Number of sent invitations: **0**

<u>With text answers</u>

This prototype is currently under development. If you have any feedback, negative or positive, or any comments, please send me an anonymous message! :)

This form will be open until the 20th of october.

Comments on App 1:

- Ikke lyd
- Norsk ok? Likte responstiden på toneskiftene. Lydvolumet sank når jeg holdt tlf. i ro. Skulle gjerne hatt fast volum og styrt andre parametere som f.eks q-filter med en av xy-z retningene. (Eller amdre bevegelser?) Det gikk vra å skru av og på synth 1. Det gikk ikke bra å bytte mellom effektene. (Bruker VoiceOver på iphone 12 mini, os 15.0.2)
- A bit to sensitive for my taste, would be easier to control if it responds a bit slower and not so "fine grained"
- Ny måte å få frem lyd på for meg. Forstod ikke hvordan jeg kunne forandre pitch på en kontrollert måte.
- I have previously tested your first apps and I think this app worked much better. The different synth channels were distinct. When moving my phone, the sound amended perfectly. Good work.
- It sounds a vintage music of movie and yeah it's was nice experience it is good just the pitch a slight high and thick
- Neat idea, the tilting works perfectly. However, I'm not sure what the buttons do and I don't think they work. The instructions don't clarify either.
- The scale seems slightly unresponsive when trying to flick through the options.
- For begge appene: Spennende konsept, og som musikkterapeut tror jeg appen kan brukes aktivt med klienter med ulike funksjonshindre. Minte litt om Soundbeam som er en del brukt i musikkterapien. Når det er sagt syntes jeg det var vanskelig å få til ordentlig musikk ut av den, det var stort sett bare et «lyd-rot» imens jeg tiltet frem og tilbake. Håper å følge appen i utvikling, lykke til! :-)
- Cool and fun to make sounds with, a few bugs with having multiple fxs turned on as well as the blue maker. It's also pretty much impossible to use with auto screen rotate on. Aslo invert seems to do nothing not sure the purpose of it
- When phone rotated to landscape mode it seemed that the tilting function stopped working
- Ingen lyd
- The functionality in app 1 works fine.
- Enjoyable and easy to play with. Due to ergonomics the upper screen is less natural to use, which is a bit limiting. For the same reason the upper button is harder to reach. Fx3 stopped working after a while with silence as result. It would have been nice if I could control it without looking. E.g. by having some other control for the buttons. Maybe some quick jerks or something?
- First application is statifying on an Interactive level. Moving the blue dot to toggle buttons is interesting. I would like to have seen some visual responce to the audio it it just could of the dot changing in responce.
- Not always clear where the sound interactions tookplace on the page. Also difficult not to accidentally press the buttons and the blue dot has a lot of small scale erratic movements
- Hard to move ball on the top part of the screen, had to tilt phone almost upside down to get there. Moving left to right was easy to do.
- Really nice performance! I enjoyed it.

Comments on App 2:

- Ikke lyd
- Same issue with control as App 1, it works but it would be nice to have a random button that changes the tempo, time signature and scale while playing with it
- Ny måte å få frem lyd på for meg. Forstod ikke hvordan jeg kunne forandre takt og trommelyder på en kontrollert måte.
- I think app 2 was exciting, because of the change of music, when moving my phone.
- Same as App 1. I don't hear anything.
- Not enough time to ready all of the instructions before the application starts. I would prefer to click an option to start the app instead.
- It was very enjoyable to experiment with the application and hear the different sounds it can produce
- Ingen lyd
- The beats give users some direction to begin with the musicking. It's fun. I could barely reach the top-right button although I tilted my phone 200 degree.
- Unfortunately I got no sound here
- Similar to the first app on responce.
- I wasn't sure whether moving the dot around was doing anything other than turning the buttons on and off. Don't know what you meant by pink ponging or what I was supposed to do.
- Same issues as the first.
- When I try to trigger the melody box, the app stucks.

What kind of device did you use when testing?

Tablet or smartphone? Which model?

- iPhone 8
- Iphone 12 mini
- iPhone SE2, iOS 14.?
- Samsun Galaxy S10 plus
- Smartphone, IPhone 7
- I phone 11
- Android smartphone
- iPhone 12
- iPhone x
- Phone, huawei p20 lite review
- iPhone 11
- iPhone 12 mini
- Nokia 8.3 is a smartphone.
- OnePlus Nord mobile
- Samsung smart phone

- smartphone android 8.1.0 OnePlus 6
- Smartphone. Samsung galaxy s20
- Galaxy S9

Which browser are you using?

E.g. Google Chrome, Firefox, Safari, Edge, DuckDuckGo, etc.

- Safari
- Google Chrome
- Samsung Internet
- Google
- Safari
- Samsung internet
- Safari
- Safari
- Google Chrome
- Google chrome
- Facebook
- Google Chrome.
- Chrome
- Chrome
- Firefox
- Google chrome
- Google Chrome

Appendix H

Report from 'User Case Study- spørreundersøkelse etterpå'

Collected results per. 6. December 2021 13:54

- Delivered replies: **6**
- Commenced replies: **0**
- Number of sent invitations: **0**

With text answers

Dette er en spørreundersøkelse for å kartlegge hvorvidt musikkinstrumenter er tilgjengelige for folk med nedsatt finmotorikk. Undersøkelsen er en del av en masteroppgave ved UiO hvor nye musikkinstrumenter utvikles, med fokus på folk som har nedsatt finmotorikk.

Spørreundersøkelsen er anonym, og ved å svare samtykker du til at svarene dine blir brukt i masteroppgaven min.

Ansvarlig for denne undersøkelsen er Mari Lesteberg, og min veileder er Alexander Refsum Jensenius.

Tusen takk for at du deltar!

Hva er din alder?

Answer	Number of	Percentage	
Yngre enn 16 år	0	**0%**	
16-25 år	1	**16.7%**	
26-35 år	4	**66.7%**	
36-45 år	0	**0%**	
36-45 år	1	**16.7%**	
46-55 år	0	**0%**	
56-65 år	0	**0%**	
eldre enn 65 år	0	**0%**	
Vil ikke oppgi alder	0	**0%**	

Hva er ditt kjønn?

Answer	Number of	Percentage	
Kvinne	2	**33.3%**	
Mann	4	**66.7%**	
Ikke-binær	0	**0%**	
Annet	0	**0%**	
Vil ikke svare	0	**0%**	

Har du noen form for finmotoriske vansker?

For eksempel vansker med å holde bestikk, tre en tråd i en nål, skrive med blyant, trykke en liten knapp,etc.

Answer	Number of	Percentage	
Ja	3	**50%**	
Nei	3	**50%**	
Vet ikke	0	**0%**	

Hvor mye musikalsk trening har du?

0 = Svært lite musikalsk trening

5 = Middels mye musikalsk trening

10 = Svært mye musikalsk trening

- 1
- 2
- 9
- 10
- 4
- 10

Spiller du noen musikkinstrumenter eller bruker du noen former for digitale musikkverktøy i dag?

F.eks. sang, piano, gitar, trommer, blåseinstrumenter, strykeinstrumenter, digitale musikkinstrumenter, DAWs (digital audio workstations), loopstations, musikkoding (som MAX eller PD), etc.

Answer	Number of	Percentage	
Ja	2	40%	
Nei	3	60%	

Hvis du svarte JA på forrige spørsmål: hvilke(t) instrument(er)?

- tverrfløyte, litt piano og sang
- Keyboard, synger, cubase 4

Hvis du svarte NEI på forrige spørsmål: har du noe ønske om å spille et instrument?

Og med å spille et instrument mener vi alt fra å synge til å spille tradisjonelle instrumenter, til digitale musikkinstrumenter, DAWs (digital audio workstations), loopstations, musikkoding (som MAX MSP eller Supercollider), og så videre.

- Piano
- Piano
- Alltid hatt lyst til å spille gitar og piano

Har du blitt forhindret i å spille de musikkinstrumentene har hatt lyst å spille pga nedsatt motorikk?

- ja har det
- Ja, pga fingermotorikken er det utfordrende å spille gitar. Er utfordrende å gjøre ulike grep. Samme gjelder piano og å holde nede ulike tangenter samtidig.
- Nei, har ikke hatt lyst å spille andre enn de jeg spiller Kanskje hatt lyst å spiller, men slått det fra meg. ikke nødvendigvis pga motorikk. Eller for sakte motorikk

Bruker du i dag noen apper eller web-apper for musikk, og isåfall hvilke?

- Nei
- youtube, iTunes
- Spotify
- Nei
- Nei
- nei

Nå kommer det noen spørsmål som handler om opplevelsen av appene du nettopp har testet.
På spørsmålene blir du bedt om å svare et nummer mellom 0 og 10.
Et tips kan være å svare fort på svarene uten å tenke seg om så mye; det første som faller deg inn er ofte riktig på slike spørsmål.

Først ute er appen for PC som heter Macro 2.1 og består av to apper.

Hvor mye glede hadde du av å bruke Macro 2.1 App 1?

0 = Ingen ting, det kjedet meg

5 = Nøytral

10 = Kjempegøy, moret meg masse

- 7
- 5
- 6
- 0
- 6
- 4

Hvor utfordrende var Macro 2.1 App 1?

0 = Ikke utfordrende i det hele tatt

5 = Nøytral

10 = Svært utfordrende

- 6
- 1
- 6
- 10
- 8
- 2

Hvor enkelt var det å lære seg å bruke Macro 2.1 App 1?

0 = Svært vanskelig

5 = Nøytral

10 = Svært lett

- 9
- 9
- 6
- 0
- 2
- 5

Hvor mye glede hadde du av å bruke Macro 2.1 App 2?

0 = Ingen ting, det kjedet meg

5 = Nøytral

10 = Kjempegøy, moret meg masse

- 6
- 5
- 6
- 0
- 3
- 0

Hvor enkelt var det å lære seg å bruke Macro 2.1 App 2?

0 = Svært vanskelig

5 = Nøytral

10 = Svært lett

- 9
- 9
- 5
- 0
- 2
- 5

Hvor utfordrende var Macro 2.1 App 2?

0 = Ikke utfordrende i det hele tatt

5 = Nøytral

10 = Svært utfordrende

- 6
- 2
- 5
- 10
- 8
- 5

Nå kommer det spørsmål om appen som er for smarttelefon, nemlig appene som heter Micro 2.1.

Hvor mye glede hadde du av å bruke Micro 2.1 App 1?

0 = Ingen ting, det kjedet meg

5 = Nøytral

10 = Kjempegøy, moret meg masse

- 7
- 5
- 6
- 10
- 6
- 7

Hvor utfordrende var Micro 2.1 App 1?

0 = Ikke utfordrende i det hele tatt

5 = Nøytral

10 = Svært utfordrende

- 2
- 1
- 6
- 5
- 6
- 5

Hvor enkelt var det å lære seg å bruke Micro 2.1 App 1?

0 = Svært vanskelig

5 = Nøytral

10 = Svært lett

- 9
- 9
- 6
- 5
- 2
- 5

Hvor mye glede hadde du av å bruke Micro 2.1 App 2?

0 = Ingen ting, det kjedet meg

5 = Nøytral

10 = Kjempegøy, moret meg masse

- 9
- 5
- 7
- 0
- 5
- 5

Hvor utfordrende var Micro 2.1 App 2?

0 = Ikke utfordrende i det hele tatt

5 = Nøytral

10 = Svært utfordrende

- 0
- 1
- 6
- 10
- 8
- 5

Hvor enkelt var det å lære seg å bruke Micro 2.1 App 2?

0 = Svært vanskelig

5 = Nøytral

10 = Svært lett

- 10
- 9
- 4
- 0
- 2
- 5

Har du noen andre kommentarer?

- Kult prosjekt! På Macro 2.1 hadde det vært morro med effekter som hvit skjorte på hvit bakgrunn og svarte hansker! Da ville det kanskje være lettere å bruke pianoet mer presist!
- Litt vanskelig på makro-appene å ikke få genseren osv til å treffe knappene mens man spiller. Lettest å spille med en hånd. Fint med piano. Skulle gjerne sett en sammenslåing av app 1 og 2 på pc :D! Appene på mobil var enklere å sette seg inn i og mer morsomme syntes jeg! Men sett gjerne opp sensitiviteten litt slik at man ikke må tippe mobilen så langt frem for å treffe de nederste knappene. Man kan enkelt lage kule beats.
- Du er godt på vei og inne på noe viktig. :)
- Veldig interessant vitenskapelig prosjekt. Flott at noen tar tak i dette!

Tusen takk for tiden din!

Appendix I

Samtykkeskjema for testing av prototyper til masteroppgave

Dette prosjektet er en del av en masteroppgave i Music, Communication and Technology ved Universitetet i Oslo, der det utvikles nye web-baserte musikkinstrumenter med et fokus på tilgjengelighet for mennesker med nedsatt finmotorikk. Du har blitt invitert til å teste ut appene jeg har laget, og ved å delta på denne testingen samtykker du samtidig til at din tilbakemelding blir brukt i min masteroppgave. Ingen sensitive data blir lagret, og du kan når som helst trekke deg og dine svar ved å kontakte meg, Mari Lesteberg, som er ansvarlig for dette prosjektet.

Det vil ikke bli utført filming eller lydopptak, men jeg vil ta notater underveis mens du tester ut appene som vil være helt anonymisert. Etter du er ferdig med testingen vil jeg spørre deg om du har lyst til å fylle ut et spørreskjema. Dette er også helt frivillig, og du kan når som helst trekke deg.

Ansvarlig for dette prosjektet er Mari Lesteberg, og Alexander Refsum Jensenius er min veileder.

Tusen takk for at du deltar!