University of Twente

Inclusive School Band: An Adapted Musical Keyboard

Thesis Bachelor Creative Technology

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In collaboration with
My Breath My Music

Under supervision of
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Abstract

This research project regards a custom adaptation for a young musician with neuromuscular disease. Through interviews, observations, and evaluations with the target user, client and experts, the musician's limitations, abilities, and goals are determined. Through literature and state of the art reviews, suitable interactions and technologies are proposed. These are evaluated and then combined into a prototype, which is assessed in context and found to increase expression, freedom, ease of playing, control, independence, and excitement for the musician. Expectedly, parts of the prototype can be implemented for people with similar disabilities, also outside of the music field, because the prototype is adaptable and involves movements that are widely accessible. Within the field of accessible musical instruments, guidelines for evaluation are lacking. For performance-based instruments, the best evaluation criterion is expressivity, which is linked to transparency, and for therapy-based instruments it is the impact on the user's life, linked to participation.

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1. Introduction

Music plays a significant role in society. In all known cultures playing music is a popular participatory experience [1]. It has cultural value, and is used for various occasions, such as celebrations, festivities, and memorials. Besides these applications, music is also used as a communication tool. Traditional musical instruments, however, are often inaccessible for people with disabilities, as they require physical control, muscular strength, and persistence in movement. Whereas study has shown musical and non-musical benefits of participation in music for families with disabled children [2]. Digital developments enhance possibilities for accessible musical instruments. Accessible movements can be mapped to sounds and actions using sensors and software. For enhanced participation in the music field, more accessible musical instruments should become available.

This research focuses on the adaptation of a musical keyboard for Ella[1], a teenager with a progressive neuromuscular disease named SMA Type II. The accompanying loss of muscle strength poses limitations when playing the keyboard. The goal is to give the teenager the possibility to play the keyboard more easily, with importance placed on expression, user experience and independence. The solution will include alternative interaction methods to take over important functionalities that the limbs can currently not fulfil. Ella's disease is progressive, which means that some solutions may not work on the long-term. An extra challenge could be to work on an adaptable solution, so it can be used at various stages of disease progression. This report describes the research, development, and evaluation regarding such a prototype, which is created in collaboration with client organization My Breath My Music[2].

1.1 Client Organization

My Breath My Music is a Dutch non-profit organization, founded by Ruud van der Wel, which focuses on the accessibility of playing music, both individually and in groups. The organization focuses on children with severe disabilities. Their activities include altering and designing musical instruments for specific clients or groups of people. Furthermore, they offer open-source software for inclusive musical interaction, lend their adapted instruments, and offer (online) music classes. My Breath My Music also founded an inclusive school band, of which Ella is a member. Throughout their work, My Breath My Music works to promote their ideas of accessibility in the music scene.

1.1.1 Client Goal

Van der Wel [3] states that My Breath My Music is an organisation that supports children in making music. The goal of My Breath My Music is making the playing of musical instruments more accessible for people, and especially children, with severe disabilities. Originally, the organization was set up for people with neuro-muscular diseases, but they widened their horizon to welcome people with any severe disability. They want to increase possibilities for these people to enter the music field and go to music schools, which are often

[1] Pseudonym name to maintain privacy
[2] https://mybreathmymusic.com/en/

not inclusive. A larger-impact goal of My Breath My Music is to increase attention for inclusion of people with disabilities. On top of that, they now advocate for the use of digital instruments in therapy. Current-day musical therapists often refrain from using anything other than acoustic instruments, while various DMIs (Digital Musical Instruments) offer more potential to enhance accessibility. Another goal of My Breath My Music is to show to disabled people that making music is also possible for them. They want to set examples for children, parents, and teachers by using role models. The goal is to make it more motivating and easier to access music. For this, Van der Wel also works together with LKCA (a Dutch organisation for cultural education and amateur art) to do research on why children with disabilities receive less musical education and what changes are necessary to provide these children with appropriate music lessons. The organisation focuses on music specifically, but their wish for impact is larger. As inclusion in one field increases, awareness grows in a broader sense.

1.1.2 The Start

In an interview with Van der Wel [3], the process and motivation with which he founded My Breath My Music become clear. Van der Wel started working with children with disabilities when he gave swimming classes at a rehabilitation centre. Later, he became a respiratory, having weekly sessions with children to practice breathing techniques and train their lungs. In 1999, he started using musical instruments to make these breathing exercises more fun and dynamic, specifically via electronic wind instruments. These are suitable because only little lung capacity is required to produce a full sound. As he worked with children with progressive illnesses, he saw how they went from walking in to being wheelchair bound to no longer being able to press the buttons of the instruments. Van der Wel never tells people something is impossible, instead he looks for solutions. Therefore, he learned new skills through online resources to create an alternative musical instrument that was more accessible, the Magic Flute. Players can play into the mouthpiece and change the tone by tilting their head. At the same time, it is the remote control for a module with which various sounds and musical scales can be selected. This makes it possible to play the Magic Flute without the use of any limbs. It is sold all over the world on a small scale and there is still a demand. His musical invention evoked happiness in the children because the children experienced something special that they did not expect to have access to. The parents of the children also experienced valuable emotions when seeing their children play music. These moments make the work of Van der Wel valuable and worthwhile. Van der Wel strongly believes that connecting with people with disabilities brings a good feeling to all parties involved.

1.1.3 Further Work

A later instrument invention by My Breath My Music is an adaptation to the guitar for children with hemiplegic cerebral palsy, meaning that symptoms occur on one vertical side of the body. These children have problems with one arm, resulting in them not being able chords on the guitar. My Breath My Music created a large mechanical handle that can play three chords when moved, with which the children can strum and play simple songs. My Breath My *Music* also developed software to make music using eye-gaze control. They made this software available for free on their website. Their latest innovation is a small computer interface, to which small switches can be connected. The switches can be adapted to the ability of the user. With these switches, the user can select a note. If the user blows in a special breath controller, the note is played. Besides inventing musical instruments, My Breath My Music set up a system where people can rent the Magic Flute and other accessible musical instruments for a low price. Through this system, there are over one hundred My Breath My Music instruments in use by severely disabled people in The Netherlands.

Next to trying to provide musical instruments, they also focus on the connection music can bring. They try to find volunteering musicians to make sure that the disabled people have someone to play music with. They also founded a school band, where their musical instruments are used in a group setting. Ella, for whom the custom adaptation of the keyboard will be made, is a member of this school band. My Breath My Music tries to use role models to show children with disabilities and their parents that it is possible to play a musical instrument for people with disabilities. Role models are also important to enhance awareness for the importance of including disabled musicians in the music sector.

1.1.4 Role in project

My Breath My Music is the client for this thesis, which focuses on adapting a musical keyboard for a member of the earlier mentioned school band. My Breath My Music provided the project concept, including the design partner to customise for. Furthermore, they provided resources such as useful contacts and interviews. They funded all the necessary materials and travel costs. Founder Ruud van der Wel has been contact person.

1.2 Design Partner

This research focuses on the adaptation of a musical keyboard for Ella, a teenager with SMA Type II. The teenager successfully plays in a school band and partakes in musical classes. She, however, experiences challenges in independently and fully participating in music.

1.2.1 Impact of ADMIs

Music is known to have multiple health benefits. Bonde [4] describes the term ‘health musicing’, a term which arose in 2002. Health musicing does not only occur during music therapy but is also present in collaborative or individual practice where music experiences are used to find meaning and coherence through hardships. Thus, health musicing means to use music to regulate and promote emotion, connection, and well-being. Participation is an important aspect of this. ADMIs can make health musicing possible for people who lack access to musical exploration. With this, ADMIs bring several benefits to the users and their families. Stensæth [2] describes musical and non-musical benefits of participation in music for families with disabled children. These benefits include communicative sharing, health improvements, meaningful experiences, nurturing of the positive, vitality, agency, and empowerment. Assistive devices, such as ADMIs, can increase the independence of people with disabilities, which can increase participation in community life when combined with interaction [5]. The independence that can come with accessibility is also important to enable interaction. In playing music, this can mean that someone can play their musical instrument without needing a helper, making it easier to play music with other people as an equal [3].

This following paragraph regarding the health impact of ADMI is taken from an assignment for the course Reflection I. Participation is a health dimension as determined by the International Classification of Functioning, Disability and Health [6]. Figure 1 shows the interrelations of participation with other health dimensions. Participation directly influences other health dimensions, such as activity and body functions & structure. Body functions & structure influence participation and activity. Activity is influenced by contextual factors and vice versa. The level of activity influences and is influenced by one's health condition. Due to such relations, increasing participation can cause a positive loop, where scores on all health dimensions increase for the individual. A study on a newly designed ADMI [7] showed that the device expanded horizons of ICF dimensions, along with other therapeutical improvements. The user research of an ADMI developed by Oliveros et. al [8] showed improvement of self-awareness, as well as physical, cognitive, communicative, emotional, behavioural, and social functioning. The TouchTone [9] was evaluated in individual and group music sessions by occupational and music therapists, findings included progress in coordination and prolonged attention and concentration. Furthermore, a successful assistive device can reduce stress and enhance quality of life [5].

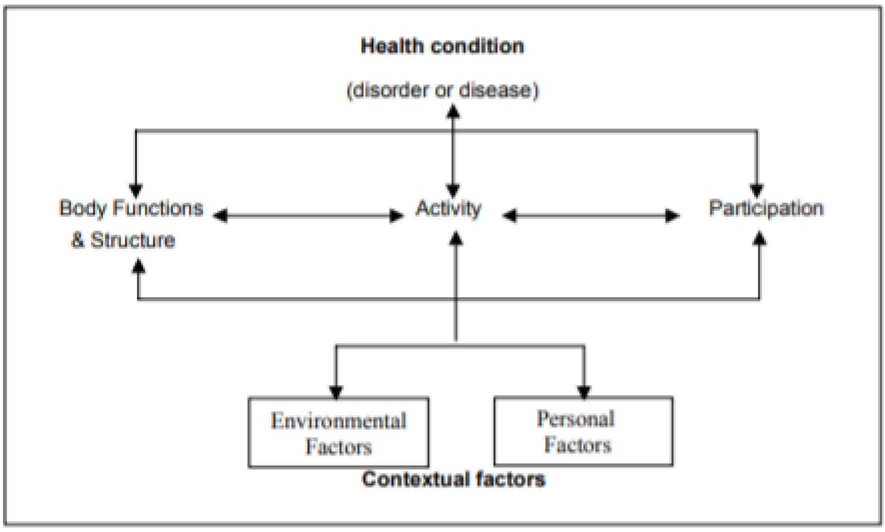

Figure 1: ICF Health Dimensions and their relations. Adapted from [6]

1.2.2 SMA Type II

Ella suffers from spinal muscular atrophy type 2 (SMA2), which is a progressive neuromuscular disorder. The National Center for Advancing Translational Sciences provides substantial information on this disorder [10], which is summarized in this section. SMA type 2 is a genetic disease that is caused by mutations in the SMN1 gene. This gene is responsible for encoding an important protein for motor neurons. The mutation leads to a reduction in the amount of this protein and subsequent death of motor neurons. The nerve cells that control voluntary muscles are affected, causing progressive muscle weakness. Symptoms usually occur between 6 and 12 months after birth. Babies can sit unsupported but are unable to stand or walk by themselves. The ability to sit is often lost around mid-teen age. Over time, problems with breathing and feeding can develop, as well as tremor of the fingers and skeletal abnormalities. As for most diseases, the symptoms vary from person to person.

The diagnosis is suspected based on physical symptoms, such as onset of muscle weakness, finger trembling, low muscle tone (flaccidity) and in most cases absence of tendon reflexes, in combination with average intellectual skills at a younger age which reaches above average by adolescence. Gene testing can confirm diagnosis by identifying SMN1 gene mutations. A treatment is the medication called Nusinersen, of which continued treatment can slow down progression and, in some cases, improve present symptoms. Other FDA-approved medications are Risdiplam and Onasemnogene Abeparvovec. To maximize independence and mobility, this medication can be complemented by physical therapy, occupational therapy, and assistive devices. In case of feeding issues, patients may need nutritional counselling and/or a feeding tube. Respiratory therapy and support may also be necessary. Sometimes surgery can be required to treat scoliosis or hip dislocation.

1.2.3 Keyboard

The musical keyboard is a digital musical instrument, based on the piano. Different tones can be played by pressing piano-like keys. The lowest notes are placed at the left of the keyboard, and the notes get higher in pitch as keys are placed more to the right. Usually, multiple types of sounds can be selected, including the piano, string instruments and synthesizers. More settings, such as volume and transposing (changing the sound of keys by semitones or octaves) can be used. Further built-in functions like metronome, sample songs and recording capabilities are often included. Better quality keyboards will enable expressive playing, by letting the volume of a tone depend on the force with which the corresponding key is pressed. Depending on the type of keyboard, the integrated functionalities can differ.

The keyboard is very well known in pop culture. It is most often used for musical support of other musical instruments, singing, and for melodic parts. In the Western world, keyboards are widely available for purchase, with many distinctive designs and in varying price ranges. Nearly all modern keyboards use MIDI (Musical Instrument Digital Interface), a common standard for communication between musical instruments and software. MIDI can be used for playing, synchronising rhythm to other components, and editing and recording of music. More information on MIDI is provided in chapter 3.1.1.

1.3 Project Goal

This project aims to help a 15-year-old keyboard player of a school band, who suffers from progressive neuromuscular disease SMA Type 2. Though she can still play the keyboard, many functionalities such as buttons, settings and sustain pedals are not accessible. The goal of this project is to develop technological alternatives to enable access to these functionalities, based on the abilities of the musician. This solution needs to be durable, mobile, financially reachable, and, most of all, accessible. It needs to fit the wishes of the player and be unobtrusive to the music experience. Several technologies will be considered, from touch buttons to mobile applications to high-speed cameras. Furthermore, multiple interaction methods will be considered, from breath play to small movements to pressing buttons. Since SMA is a progressive illness, the solution should be adaptable, so that it can be used for a long time. An additional goal is to conclude how this solution can help other people with similar limitations. This project will be conducted in close collaboration and communication with design partner Ella and client organization My Breath My Music.

1.3.1 Research Questions

The research question of this project is: How can a suitable alternative interaction of a keyboard be integrated for a teenager with SMA type 2?

To conduct the project, there are some relevant sub questions in four aspects of the design. Sub questions are worked out in the problem space, solution space, design, and evaluation.

Problem space:
- What are relevant limitations caused by SMA type 2?
- What are issues experienced by the design partner in relevant context?
- What are the physical abilities of the design partner?
- What are functionalities of importance that need adaptation?
- How do these functionalities work on the regular keyboard?

Solution space:
- What organizations focus on similar projects?
- What alternative musical interactions have been developed?
- What type of technologies are used for these alternative musical instruments?
- What type of interaction methods are used for these alternative musical instruments?

Design:
- What interaction methods would suit the abilities of the design partner?
- Which technologies are appropriate to link the suitable interaction methods to the necessary functionalities?
- Based on ideation, what are good opportunities for solutions?
- How can the best solutions be integrated into a product design?

Evaluation:
- To what extent is the design suitable for the design partner?
- How can this solution be integrated to help people with similar limitations?

1.4 Approach and Structure of the Report

These questions will be addressed in phases, which form the chapters of this report. At the start of the research, permission of the University of Twente ethics committee has been requested. Permission for the full research to be conducted is given under reference number RP 2021-08. The accompanying consent forms can be found in appendix A. The main ethical considerations of this research are described in the following chapter. A literature review was conducted regarding existing ADMI designs, which is reported in chapter three. Chapter four describes the current state, wishes, abilities and experiences of Ella, the design partner, in relevant context. In chapter five, the perspective of Ella's music teacher on the possibilities is gathered through an interview. An overview of the state of the art, thus currently existing products, is provided in chapter six. The conceptualization meeting is described in chapter seven, where conclusions on appropriate interactions and technologies are provided, as well as a list of requirements for the design. This chapter will end with a provisional design plan. Chapter eight describes the developed prototype, its interactive and technical components, and associated costs. Four evaluation activities of the prototype will be described and analysed in chapter nine. Finally, chapter ten will conclude the findings of the project, as well as describe its limitations and possibilities for future implementation and research.

2. Ethical Considerations

Before diving into the research activities, it is important to be aware of the main ethical concerns that arise. An elaborate report on ethical concerns, key moral principles, ethical analysis, and moral decisions can be found in appendix B. This report is created for the graduation course Reflection II and built upon two assignments of the Reflection I course. The findings of these courses are applied and summarized in this chapter. In this chapter, three main ethical considerations of this project are discussed, namely discriminatory effects of technology, the right to access music, and research with an underaged participant. These concepts are outlined in this chapter, but are, will be, and have been considered during every stage of the project.

2.1 Importance of Ethics

In any engineering project, ethics are important. Firstly, because ethics are relevant in all choices and aspects in life, according to Fledderman [11], thus also choices that relate to engineering activities and environments. Furthermore, Fledderman states that engineering ethics specifically relates to rules and standards regarding the conduct of professional engineers. He describes how engineering can impact public health, safety, politics, business practices and more on a large scale. Since engineering can influence many people and has such a significant impact, it is important to make well-considered decisions that are at least morally acceptable. Unethical and negligent design can lead to various safety hazards and other undesired scenarios. Since this is an engineering related project, engineering ethics are relevant to the design process. In any project, there are unique ethical concerns, which may also develop over the course of the project. Furthermore, the sensitive nature of this specific project and design partner calls for further ethical consideration.

2.2 Discriminatory Technology

The lack of accessibility of traditional musical instruments can be viewed as discriminatory. Wittkower [12, p. 15] loosely defines discriminatory technology as “a way of getting something done which produces a discriminatory effect.” This effect is caused when design is created for a norm which is based on morally irrelevant characteristics. Wittkower explains that privilege means to fall under this norm, which means one is ‘invisible’ as their characteristics are not viewed as being different from the norm. The development of traditional musical instruments has been focused on able-bodied users and assumes a level of bodily functions, including controlled movement of limbs, muscle strength and the ability to see. Able-bodied people are assumed as the norm, but there are quite a number of people who have physical and intellectual limitations. Most able-bodied people do not actively realise that musical instruments are designed for them. However, many people with disabilities come across the issue that the products are not suitable for them. Their levels of ability often go unrecognised in traditional musical instruments and attempting to play them often emphasizes that the instruments are not designed with them in mind. Without much reconsideration, musical instruments remain to be created in similar ways. These issues show the privilege of able-bodied people, who are invisible, versus the lack of privilege of people with disabilities, who are actively noticed to be different from the norm. This issue of inaccessibility is starting to gain more awareness and the speed at which alternative musical instruments are being created is increasing [3]. However, traditional musical instruments are still the common way to access music, and alternatives are not widely available. More ADMI designs, and an increased access to these, are necessary to further normalise accessible musical instruments. If there are sufficient accessible alternatives to traditional musical instruments, people with disabilities can just as easily reach musical interaction, which limits the discriminatory effect of traditional musical instruments.

However, ideally, these alternatives should not be designed solely to address the difficulties of those affected. Wittkower [12] describes how manufacturing accommodating artifacts to solve the difficulties faced does not avoid the discriminatory effect of the technology. For example, creating left-handed scissors to avoid the discriminatory effect of most scissors being created for right-handed use. He also claims that one cannot design technologies that are accessible for everyone, yet should attempt to design for most people to avoid a negative discriminatory effect. Therefore, especially adaptable musical instruments could lower the discriminatory level of musical instruments, as these can accommodate people of different abilities. Examples of this are M2M [7] and musical improvisation interface [8] (see chapter 3.2), which are improvisation interfaces that use web-cameras and can easily be set to track any voluntary movement, ranging from that of limbs to eyebrows. Both the type and size of the movement can be altered. The Octotonic [13] (see chapter 3.2) is another non-contact device that can be adapted to different ranges of mobility, though it requires some movement of the extremities or limbs. An older example, from 1996, is Composability [14], which is a custom composing software that can be used with many controllers, including mouse, console keyboard, and one or multiple switches. Composability can also be made appropriate for users with visual impairments by changing some settings. This way, the same product can be used by a large variation of people and is thus suitable for most people. In this graduation project, the potential to change common practices can be increased by not creating just a customisation for one specific end user, but by creating an accessible and adaptable system that can fit people of different abilities, including that of the design partner. In such a way, the product can be designed to be accessible for many people, which is, according to Wittkower [12], the best way to avoid discriminatory design. Furthermore, though the focus of this project is the design partner, the ideal situation would be to create something that can help more people. During a meeting on the 7th of May 2021 (see chapter 7), this was discussed with the design partner and client, who both agreed that a product that could also be used and implemented for others would be desirable. Additionally, the client stated that the product will be made available online on an open-source basis if it functions well, meaning people worldwide can build and implement the product. This can be done by or for people with various levels of ability. Though it is not necessary for many people, when finished it will work for most. This way, the project may help increase accessibility of musical instruments on the long term with a limited discriminatory effect.

This project, however, is still a custom adaptation for a specific person with a disability, which requires discrimination during the process. On the one hand, increasing accessibility will lower discrimination, as more people can partake in the same activities at the same locations as able-bodied people. On the other hand, to increase accessibility, (positive) discrimination is often necessary. The IEEE Code of Conduct [15] is a widely accepted document describing the ethical standards in the field of engineering. The code states “We will not discriminate against any person because of characteristics protected by law” [15, p. 1]. These characteristics include disability. A similar unpaid graduation project would less likely be conducted for an able-bodied musician who would like some alternative interaction for ease. The design partner of this project is technically able to play the keyboard without the product that will be created during this project. She is also already member of a school band and therefore, already reaching a decent level of participation. With the adaptation she could play more easily and independently, but she can already play to some extent. Thus, the project adapts a product to one person's need, while the same is not done for many other people who may benefit from it in some way. There are still many arguments to make the keyboard more accessible for this specific user, as there is a difference between the accessibility for her and the accessibility for an able-bodied person with specific preferences. However, it is good to be mindful of that this could be considered (positive) discrimination, as customization emphasises that there is a disability. There is therefore a dilemma because current discrimination in the design process is used to decrease future discrimination. This decreased discrimination is through an increase in access. However, the product resulting from this project may also emphasize disability, as the customization emphasizes that there is a need for customization. This may well be worth it, as accessibility of a musical instrument increases, but it does not solve, and may even add to, a larger scale problem.

2.3 Right to Access and Participation

The rights to access and participation are covered in numerous declarations by the United Nations. The declaration of Human Rights [16] states "All human beings are born free and equal in dignity and rights. They are endowed with reason and conscience and should act towards one another in a spirit of brotherhood. Everyone is entitled to all the rights and freedoms set forth in this Declaration." Thus, the rights stated in the declaration apply to all human beings. Article 27.1 of the declaration covers the right to participation, stating: "Everyone has the right to freely participate in the cultural life of the community, to enjoy the arts and to share in scientific advancement and its benefits." Furthermore, people with disabilities are specifically covered in the UN Convention on the Rights of Persons with Disabilities [17], which is signed by 164 countries and regional integration organizations [18]. Article 3 of its general principles includes principles c: "Full and effective participation and inclusion in society", e: "Equality of opportunity", f: "Accessibility" and h: "Respect for the evolving capacities of children with disabilities and respect for the right of children with disabilities to preserve their identities." From these articles, it can be reasoned that people with disabilities have a right to equal access to the arts, which includes music. Not only access is required, but also effective participation, inclusion, and equal opportunity. Though Ella already reaches participation by being in a school band, she does not have equal access or opportunity due to the inaccessibility of her musical instrument, as well as most other musical instruments. Furthermore, article 3h is interesting, and especially becomes interesting when considering SMA Type 2 is progressive. Ella chose to play the keyboard and to play in the school band, a hobby and role that she has made part of her identity. If her disease progresses and this disables her from playing music in the school band, this will not help with the preservation of her identity. When designing a prototype, it would be valuable to create interactions using movements she will be able to make for a long time and/or to incorporate an element of adaptability, which can assure she can use the prototype long-term.

The UN Convention of Children's Rights [19] also addresses the right to access the arts, in three different articles. The convention addresses recreation and participation in art in article 31, stating

> 1. States Parties recognize the right of the child to rest and leisure, to engage in play and recreational activities appropriate to the age of the child and to participate freely in cultural life and the arts.
>
> 2. States Parties shall respect and promote the right of the child to participate fully in cultural and artistic life and shall encourage the provision of appropriate and equal opportunities for cultural, artistic, recreational and leisure activity [19, p. 9].

When it comes to rights for children with disability specifically, article 23 on participation is relevant:

> 1. States Parties recognize that a mentally or physically disabled child should enjoy a full and decent life, in conditions which ensure dignity, promote self-reliance and facilitate the child's active participation in the community [19, p. 7].

Furthermore, the convention states the right to freedom of expression, including art if so desired, in article 13:

> 1. The child shall have the right to freedom of expression; this right shall include freedom to seek, receive and impart information and ideas of all kinds, regardless of frontiers, either orally, in writing or in print, in the form of art, or through any other media of the child's choice [19, p. 4].

Articles 31 and 23 regard States Parties specifically, which is in line with the nature of the convention, of which much is aimed at responsibilities that governments have in ensuring the well-being of children. Even so, the rights mentioning State Parties regard aspects that are important for children’s well-being. With the articles mentioned in this section, the United Nations clearly lays out the importance of participation in the arts, which includes music. The right to participation is approached from four different viewpoints, namely those of cultural life, recreational activity, participation, and inclusion (specifically for people with disabilities), and freedom of expression. These are four main reasons why people with disabilities, including Ella, should receive equal access to music and musical instruments. This project aims at helping Ella reach this access and can be used to help other children and adults gain more equal opportunities as well. By increasing access to music for at least one child, this project helps reach children’s rights. Besides the equal participation in art being a right, this participation can have other benefits, including health benefits described in chapter 1.2.1. Therefore, reaching these rights of inclusion and participation can also help reach other rights and goals, such as those that are health related.

Additionally, this graduation project can help enable a role model. As stated in an interview with the client [3] (see chapter 1.1), role models are necessary to increase inclusion. There is currently a lack of disabled role models in the Dutch music sector. Role models can show children with disabilities and their parents that disabled people can play music too. Furthermore, it can help normalise people with disabilities in the music sector. This can lead to an increase of awareness in able-bodied counterparts, which helps in reaching inclusion. The client of this graduation project expects that the target user of this graduation project has potential to become a role model for many. Therefore, this project can help increase participation and inclusion on a larger scale.

2.4 Vulnerable Design Partner

The Convention of Children's Rights [19] is created because of the vulnerable nature of children and specific children needs, which are different from general human needs [20]. Simply put, children should be considered differently and more carefully than adults. Article 12 in this convention regards the right to be heard as follows:

> States Parties shall assure to the child who is capable of forming his or her own views the right to express those views freely in all matters affecting the child, the views of the child being given due weight in accordance with the age and maturity of the child [19, p. 4].

Poretti [20] explains that children should be involved, and even participate as actively as possible, in research that affects them. Poretti states three reasons for this, namely this children's rights article, the efficiency of the research, and the empowerment children experience due to participation. In case of this project, the results directly affect the design partner, thus she should be given appropriate chances to express her views. The design partner is 15 years old and intellectually relatively mature, therefore, her input should be weighted as such. Ella should not make the design choices, as future users can not always know and express what they need. Most users are not trained to make designer decisions, may not know the possibilities that well, and often did not do in-depth research. However, Ella's perspective is important in this research, as it can help ensure accessibility and useability. She should be viewed as an expert on her abilities, needs and preferences. Thus, this project uses active user involvement in which the design partner is accommodated more carefully than averagely due to her vulnerability.

In week six of University of Geneva's course on Children's Human Rights [27], Morrow describes ten main topics to consider to ethically prepare research with children. The first of these is the purpose of the research. In this case, to increase the accessibility of the keyboard for Ella. The second topic to consider is assessment of the harms and benefits for the children and any other people involved in the research. The most obvious benefit for Ella is the custom adaptation, but the benefits also include the empowerment of contributing to something that concerns her and learning more about her possibilities in music making. The risks are limited as much as possible in the preparation and throughout the process through safe prototypes, open communication of expectations, and discussions with the project supervisor before every research activity. Furthermore, most activities are conducted remotely to limit the risks of spreading COVID-19. The risks of fatigue or disappointment remain, which is communicated openly with the design partner and her legal guardian. The third topic Morrow describes regards respecting privacy and confidentiality. In this graduation project, all standards for handling sensitive data are applied, including safe storage and anonymisation. Furthermore, the target user and her parents can request deletion of data. Additionally, the client is informed on the implications of sharing information about the project, as this could identify Ella. The fourth topic Morrow describes regards selection and participation, which includes communication and representativeness. In this project, the target user has been suggested by the client, who is expectedly capable of ethical selection, as he is experienced in the field. The fifth topic regards economic matters, including whether funding is taken from an ethical source and whether children are compensated for their effort and time. The funder of this project is My Breath My Music, an ethical and relevant sponsor. Ella's participation is rewarded with a more suitable keyboard adaptation. If she refuses to participate in some of the research, she will still receive an adaptation, but it may be less suitable as a result. The sixth topic Morrow mentions regards the review of aims and methods, including review by an Ethics Committee and influence of the participants. As described in chapter 1.4, the University of Twente Ethics Committee has approved the full research. Furthermore, for some research activities, Ella is asked to review a preparation. Though the researcher determines the activities, there is flexibility to adapt to Ella's needs and preferences. The seventh topic that Morrow regards the provided information, which should be relevant and accessible. This also relates to the eighth topic of informed consent. Ella has been provided with an elaborate leaflet and consent form, to be read and signed by her and a legal caregiver, at the beginning of the research (see appendix A1). Furthermore, throughout the process, she is provided with information on expected research activities. Additionally, relevant rights are repeated at the beginning of each activity. Morrow's ninth topic regards the way research findings are used and presented, which should be representative and fair. In this report, a lot of effort and thought is put into representative and respectful reporting of results. Furthermore, Ella was given the opportunity to review the chapters that regard her, though she chose not to. The final topic is the impact of the research on children in general. This project may lead to an invention that helps at least one child with a disability gain access to musical instruments. Perhaps (parts of) the design can also help others. Furthermore, the client expects the project can further promote and normalize music making for children with a disability [3]. There is thus reason to believe that the research will have a positive influence on some children. There is no reason to believe there is a significant negative influence.

As stated in the beginning of this chapter, these ethical concerns are considered in every aspect of this research. They have influenced the research activities, such as interviews, as well as the language used in this report. The next chapter contains a literature review on earlier development of ADMIs. The two following chapters describe research activities with target user and an expert, subsequently. Chapter six will describe various existing ADMIs. In chapter seven, a conceptualization meeting with the client and design partner leads to requirements and a provisional design plan. This meeting partially consisted of an evaluation of the design ideas, described in chapter 9.1. Chapter eight describes the prototype as it is designed. This prototype is evaluated in chapter 9.3 and 9.4, leading to the conclusion provided in the concluding chapter.

3. ADMIs: A Literature Review

This chapter provides an introduction and deeper insight into Accessible Digital Musical Instruments (ADMIs). The chapter consists of two main parts, namely an introduction to (A)DMIs and a literature review on ADMI design. The first part, which is the introduction to (A)DMIs, is useful to get a grasp of the position and potential value of this project in the field of music and accessibility. The second part, which is the literature review on ADMIs, provides insight into important aspects of ADMI design and evaluation.

3.1 Introduction to ADMIs

ADMI stands for Accessible Digital Musical Instrument. These are digital musical instruments (DMIs) that are appropriate for people with physical and intellectual disabilities. A DMI is a musical instrument or interface that uses electrical circuitry to produce sound. Some examples designed by My Breath My Music were given in chapter 1.1.3, including Eyewi and the Magic Flute. The next section will begin by describing the rise of DMIs and ADMIs in the music sector. Then, the current field of ADMI development is outlined. After this, the impact of this field will be discussed. The section will end with emphasizing the importance of mapping and giving some information on types and techniques of mapping.

3.1.1 History of (A)DMIs

Technological developments provide space for an increasingly rapid development of (A)DMIs. The earliest documentation of mechanical musical instruments found is the Book of Ingenious Devices, stemming from 850 AD [21]. In this publication, one hundred mechanical devices are described, of which two were automated. The authors are three Iranian brothers who invented an automatic flute player [21]. This was potentially the first programmable computer or machine [22]. Steam was used to produce sounds, and there were settings which could be modified to change sounds and patterns [22]. In the late 19th and early 20th century mechanical music machines were on the rise, with among others the player piano [22]. This is any acoustic instrument that plays pre-programmed music operated by mechanisms of pneumatic (using air pressure) or electro-mechanical nature [22]. The pre-programmed music was in the shape of a piano roll, a roll of paper with perforations which triggered notes [21]. Another mechanical music machine of this time was the orchestrion. This mechanical pneumatic machine was used to attract visitors to events between 1850 and 1930 [21]. These machines contain multiple acoustic instruments and sound like full orchestras. Orchestrions are still in use and created currently, though have become significantly less popular.

The MIDI association provides information on the history of electronic musical instrument [21], summarized in the following two paragraphs. Since the late 19th century, electronic musical instruments have been developed. Early instruments were Ondes-Martenot (1928) and Theremin (1927). According to S. Crab, as cited in [21], the Theremin uses a heterodyning vacuum tube oscillator, which was commonly used in electronic musical instruments design. This changed in 1960s, when transistors became available. In the 1950s, the RCA Synthesizer I and II were created. They were exceptionally large at first, but quickly sized down to reasonable sizes. The synthesizers were taken out of the university laboratory and used in the field by musicians due to Robert Moog. The synthesizers used control voltages but were inconsistent in how these were implemented. The inconsistency caused a lack of compatibility, meaning there was only limited possibility to connect synthesizers.

D. Smith of Sequential Circuits and I. Kakehashi of Roland Corporation worried that lack of compatibility could negatively impact the use of synthesizer and lower sales. In 1981 the first discussions on a need for universality began to circulate. This triggered the development of MIDI, which stands for Musical Instrument Digital Interface. With MIDI, a variety of information can be sent using simple commands. MIDI was first announced and implemented in 1982. In 1983, the first devices of different companies were successfully linked during a presentation. Around this time, the MIDI Specification, the list of all available commands, only included extremely basic instructions, such as notes and output volume. By now, MIDI messages offer a lot more control over various recording gear, computers, and even stage lighting. The method of MIDI has not changed since development, but the protocol has grown elaborately, implementing song files, new connection mechanisms and various MIDI products. Thirty years after the development of MIDI, Smith and Kakehashi received a Technical Grammy Award. The first MIDI user group to form was the International MIDI Association (IMA). MMA, Musical MIDI Accompaniment, arose in 1984, with the first goal to create a complete, updated documentation of the MIDI Specification. IMA ceased to exist, and The MIDI Association (TMA) was established in 2016 as a replacement. More practical information on midi can be found in chapter 5.3.

In 1966, Varèse [23] wrote about the "liberation of sound" and his "right to make music with any and all sounds". He described the endless possibility digital musical creation could offer, and even spoke of an "entirely new magic of sound". He mentioned how music could be created from thought and that new musical notations would be necessary to fully illustrate the ideas of musicians. He addresses the fear of digital music and describes digital music making as additive to traditional musical instruments, not replacement. Varèse [23, p. 18] further addresses the criticism stating: "anything new in music has always been called noise".

Though digital musical instruments are now widely used and accepted, there are some concerns. Schloss [24] speaks of the cause-and-effect that has disappeared with new musical creation. He is especially concerned with the influence this has on live performance and the relationship between audience and performer. According to Schloss, the visual aspect and visible effort of performance are important for the live experience. This relationship between gesture and sound is called transparency and is directly linked to the expressivity of a performance [25]. Furthermore, Schloss [24] describes how musical creations are now not always finished at the time they are performed, but instead created and altered on stage, leading to a different live experience. The changing of musical instruments does not only change the sound and number of possibilities, but also has a cultural impact.

This thesis focuses on ADMIs, digital musical instruments used to increase the accessibility of music. The first documented time DMIs were used to enhance accessibility was with the development of the Rhodes piano [26]. When tasked with providing therapy for the wounded during World War II, piano teacher and builder Rhodes used the military's scrap materials to build toy pianos that could be played while lying down. Due to the success of this invention thousands of copies were made [27]. He was awarded a Medal of Honour for the therapeutic achievements and his method is described in the army archives [27]. The development of the Rhodes piano inspired numerous attempts towards making music more accessible for people with handicaps, often through technology [26].

3.1.2 Current Field of ADMIs

Currently, there are multiple organizations that focus on making music more accessible. My Breath My Music, client of this research project, is a Dutch foundation that works with children with severe disabilities in numerous ways. Drake Music Charity[3], based in the United Kingdom, advocates and works for accessibility of music for a wide variety of people and disabilities. The OHMI (One Hand Musical Instrument) Trust[4], also based in the United Kingdom, works on making musical instruments accessible to play with one hand. These are some of the most famous organizations that focus on making music more accessible through inventions, education, lending of musical instruments, and more. There are also some smaller scale Non-Governmental Organisations, such as Dutch charity Muziekotheek[5], which takes requests for financial aid to have musical instruments adapted and lends adapted musical instruments for free.

There are some quite well-known ADMI designs, such as the Soundbeam and the AUMI project, which receive increasing attention. However, people usually come across such interventions only as they start researching the field of music accessibility. The ADMIs are not known to the wide public. In general, there has not been a lot of focus on disability in the music field in the past. In recent years, the field of ADMI development has been starting to receive more attention, as there is a growing focus on both invention and increasing inclusion [3]. Despite increasing attention, the field of ADMI design is still small. Most people working in the field know each other to some extent [3].

3.1.3 ADMI Mapping

Mapping describes how gestures are connected to sounds in a digital musical instrument. It is everything that happens between the user interface and sound generator, located in the software of the product. In an acoustic musical instrument, the control mechanism and sound generator are inseparable [28]. In digital musical instruments, the controller and generator must be connected, the relationship between them must be defined [28]. This is what mapping does. Altering the mapping can entirely change the character and playing experience of a musical instrument [28]. Hunt [28], for example, describes a modern Theremin prototype at a final university project that required continuous hand movement for the volume to work. Thus, you could only hear any sound if there was a change of position. This phenomenon occurred due to a wiring mistake by a student. However, the instrument became much more exciting to play, as one's own energy directly created sound. The sound got more texture, and the instrument was very engaging. While the instrument was unexpectedly exciting and unusual, the mistake was later corrected to the traditional Theremin. This version of the Theremin gives insight into the value of a mapping method that uses the energy of the player, as well as the difference that mapping can make.

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[3] https://www.drakemusic.org/
[4] https://www.ohmi.org.uk/
[5] https://www.muziekotheek.nl/

In an experiment, Hunt [28] compared a simple to understand one-to-one mapping to a more complex one-to-multiple and multiple-to-one mapping, respectively. In a one-to-one mapping each sensor controls one parameter. In a one-to-multiple mapping, one sensor controls multiple parameters at the same time. In a multiple-to-one mapping, multiple sensors simultaneously control the same parameter. Hunt developed mappings with which music could be controlled with two simple sliders. In his experiments, he found a one-to-one mapping with a controller in which only one parameter could be controlled at once was viewed as extremely limited. While a one-to-one mapping with a controller in which multiple parameters can be controlled simultaneously led to frustration. Contrarily, the same controller where multiple parameters could be controlled with a multiparametric mapping, was received well after getting used to. This mapping was counter-intuitive at first, but the complexity of gestures was later experienced as expressive and like a musical instrument. The more complex mapping required constant movement from the user to create sound, increasing engagement. The interest in the more complex mapping was also noticeably higher, even though the same interaction method was used in the simple one-to-one mapping.

Another experiment by Hunt which compared three similar interfaces showed the lack of stimulation in one-to-one mapping, which was accompanied by quick learning but lack of improvement or expressivity. Contrarily, a one-to-one mapping requiring constant movement, thus the user’s energy as input, led to a more engaging and natural instrument [28]. This interface was more difficult to control, but there was more improvement in skill over time. The third interface required the same constant movement but used many-to-many mapping. The instrument posed a challenge, which was also its appeal, as it had a learning curve like that of a traditional musical instrument. In acoustic musical instruments, control variables are also cross-coupled due to the physics of the materials and shapes. People using more complex mappings scored higher on complex tasks than simple tasks. This is due to simultaneous control of many parameters, which makes it easier to complete complex tasks and harder to isolate parameters to complete simple tasks. The people who used simple mappings scored higher on simple tasks than complex tasks. In general, beginners tend to prefer simple mappings, whereas more experienced musicians prefer complex many-to-many mappings.

An important aspect to consider when creating a mapping is transparency. Vamvakousis and Ramirez [25] state that transparency is the level to which performer and audience can understand the relationship between gesture and sound. For this, the observer’s view of the mapping of physical interaction to audio is important to consider, as the cause-effect relation is crucial to performance, as stated by Schloss [24]. He also describes that some magic is good, but too much magic is detrimental. This is important to keep in mind when working on many-to-many mappings. Generally, more complex mappings are less intuitive to understand. If the mappings are too complex, a performance is not appreciated as much. Schloss [24] gives an example of this with the Flying Karamovoz Brothers, a juggling act. Over time, they started combining music and juggling, where rhythms would be created with one-to-one mapping from juggling moves. As they advanced, they created complex mappings, using ultra-sonic sensors and elaborate MIDI hardware. However, the audience would be confused and lost, as they did not know what was being done physically and what was done by the computer. Some even thought they were juggling to a tape. Thus, not only should energy, engagement and complexity of mapping be considered, but also the transparency of the mapping. Both the user and audience perspective are important in the success of mapping.

3.2 Literature Review on the Design and Evaluation of ADMIs

This section covers the literature review on scientifically developed and evaluated ADMIs. It is adapted from an assignment for the course Academic Writing, improved and edited to fit this thesis. This literature review aims to provide an insight into developed Accessible Digital Musical Instruments (ADMIs), specifically ones designed or appropriate for muscular disease related disability. This is useful to get a grasp of the technological and interaction possibilities, as well as common benefits and limitations that occur. This review will start with giving an idea on the types of ADMIs that are designed. Secondly, three ways to enhance accessibility are discussed. Simultaneously, the types of disabilities focused on and the interaction method used to accommodate for these will be outlined. In the third section, various ADMI evaluation criteria and methods are compared. This will give insight into what is important for successful design, as well as appropriate evaluation. Finally, methodologies of the various design processes will be compared to gain insight into useful design approaches. The knowledge gained in this literature review will help work towards an appropriate keyboard adaptation for Ella, a teenager with SMA type II.

3.2.1 Performance or Therapy-Based ADMIs

In ADMI design there are two common types, namely performance-based designs, which are comparable to traditional musical instruments and are most fit for the stage; and therapy-based designs, which focus on improvisation and communal playing. Examples of performance-based ADMIs are the adapted sanshin [29] and adapted bass guitar [30], examples of therapy-based ADMIs are a musical drum interface [8] and the Octotonic [13]. Some ADMIs are entirely new, including the Octotonic [13] and TouchTone [9]. Other ADMIs are adaptations of existing musical instruments, such as the sanshin [29] and bass guitar [30] adaptations mentioned earlier. In particular, many adaptations mainly consist of custom software that can be linked to existing interaction systems, among which Composability [14], movement-to-music computer technology [7] and the Eyeharp [25]. In conclusion, there are ADMI designs for performance and therapeutic purposes, existing of entirely new instruments and instrument adaptations, the latter often through custom software.

3.2.2 Methods to Increase Accessibility

There are three main design methods to increase the accessibility of musical instruments. The first method is to build custom controllers, often used for people who do not have full motion but can exert a level of control over at least one of their extremities. One problem with traditional musical instruments is that they usually require controlled use of two hands. The adapted sanshin [29], adapted bass guitar [30] and Touchtone [9] instead assume controlled movement of only one hand. Further interactions are implemented using a custom controller for thumb movement of the affected hand [29], off-the-shelf pad-controller for one or two feet [30] and touch-sensitive pads for the affected hand [9]. These designs are created for users with muscular dystrophies [29], one arm amputation [30] and hemiplegic cerebral palsy [9]. Interestingly, for the disabilities that affect the body more widely, namely muscular dystrophy and hemiplegic cerebral palsy, an appropriate off-the-shelf controller was not available. This given further underlines the inaccessibility of many traditional and modern musical instruments and the need to create accessible custom controllers.

The second method is to use widely accessible movements, which are typically used to accommodate people with little to no movement of the extremities. An example of this is eye gaze interaction, as used in the EyeHarp [25] and EyeGuitar [31], which are appropriate for people with severe physical disabilities. Their aim is to be accessible for many different disabilities, among which the disease ALS. The adapted sanshin [29], in contrast, is specifically designed for people with ALS, while assuming some control of the hands. ALS is a progressive disease and while the EyeHarp and EyeGuitar could be used during most stages of the disease, the adapted sanshin is only useful for earlier stages. This is because controlled eye movement is usually preserved until the latest stages of ALS and other progressive disabilities. Therefore, the eye gaze controlled EyeHarp [25] and EyeGuitar [31] are accessible for a larger number of people, including people with more severe disability. In contrast to these examples, some devices that are used as ADMIs are not originally designed to be an ADMI. This includes a brain interface which experiments with using brain waves to make music [32], though this does not yet allow for very controlled music making. Interestingly, the research paper does not mention anything about potential use by people with disabilities, which further underlines the lack of focus on the accessibility of musical instruments. Assumably, the interaction type would be very accessible in case of severe physical disabilities, as it is an interaction that does not require any voluntary physical movement. Designs that use widely accessible movements usually cater to a wide range of disabilities, whether intentional or not, as the interaction is accessible for most levels of ability.

The third method enables accessibility for various levels of physical ability with the same device, through implementing adaptability. For instance, the improvisation interfaces musical drum interface [8] and movement-to-music software [7] track non-contact movements with a web camera, which can be calibrated to movements of nearly any body parts, including limbs, head and eyebrows. Likewise, the Octotonic [13] uses infrared sensors for gesture-based interaction of larger non-contact movements and can also be adapted to respond to different levels of mobility. Alternatively, Composability [14] can easily be used with many different controllers, including mouse, console keyboard, and one or multiple switches. Additionally, the software includes settings to give supplementary audio feedback for people with visual impairments [14]. In a like manner, for the adapted sanshin [29] necessary adaptations only need to be made on the controller, while the rest of the device remains unaltered. The device was designed for two design partners, with a custom controller for each. During the research, one design partner lowered ability due to disease progression. To cater to him, some adaptations were made on the custom controller. Adaptable designs are appropriate for people with a broad range of physical disabilities, as well as at various stages of progressive disability, by being easily adaptable to function with many different movements. This can also enable people with progressive diseases to keep using versions of the same musical instrument. In summary, accessibility can be increased through custom controllers for people with some voluntary movement of the extremities, widely accessible interactions for people with severe disabilities of the extremities, and adaptability for a wide range of disabilities.

3.2.3 Evaluation of the Success of ADMIs

The design success of ADMIs can be evaluated in diverse ways with varying criteria. The literature discussed in this review use three notable standards for evaluating the success of ADMIs. The first of these standards is similarity of ADMIs to traditional musical instruments. The score on this standard depends more on the possibilities and amount of control the instrument offers than the type of interaction used. The EyeGuitar is claimed to not be like playing a musical instrument by the case study subject, but more like playing with your eyes [31]. In contrast, the adapted bass guitar [30] and EyeHarp [25] are specifically considered very much like a traditional musical instrument in interaction and learning curve. Since one of these is also controlled by eye gaze, the type of interaction is not the reason something is or is not experienced like an actual musical instrument. Instead, the adapted bass guitar [30] and the EyeHarp [25] provide control over a broad range of musical aspects, such as pitch, timing, dynamics, chords, arpeggios, hammer-ons and quick successive notes, more so than the other designs covered in this review. In contrast, the EyeGuitar [31] takes out the rhythm aspect to make the interaction more accessible and intuitive. That the EyeGuitar offers a lack of music playing experience shows that rhythm is very crucial to the feeling of playing a musical instrument. As mentioned, the difference between the adapted bass guitar [30] and EyeHarp [25], which were regarded as similar to musical instruments, and the other designs covered in this review is the amount of options that is available. Thus, ADMIs with a lot of control and possibilities are considered most like traditional musical instruments, and specifically the rhythm is an indispensable aspect of a music playing experience.

The second standard is the level of expressivity a musical instrument offers. When considering the level of expressivity of a performance, transparency is important. Vamvakousis and Ramirez [25] state that transparency is the level to which performer and audience can understand the relationship between gesture and sound (see chapter 3.1.4). Though expressivity is linked to transparency for both performer and audience, the audience perspective was only considered in the EyeHarp [25] out of all designs discussed in this review. Admittedly, the adapted sanshins [29] were evaluated during, as well as used for, performances. However, the audience perspective is not analysed. Research into the audience perspective is also not part of the suggested future research for any of the ADMIs covered in this literature review. Transparency is thus evaluated to a limited extent, while it is an important aspect in the level of expressivity of a musical instrument.

The third standard used to measure the success of an ADMI is its impact. Scherer and Glueckauf [5] state that the value of assistive technology is ultimately determined by its impact on daily activities and participation in community life, for which both independence and interaction are important. As a result, they describe, a good assistive technology can reduce stress and enhance the quality of life. However, only the TouchTone [9], movement-to-music technology [7] and EyeHarp [25] assess therapeutical benefits of the design. Some designs were even evaluated mostly (EyeHarp [25] and EyeGuitar [31]) or only (adapted bass guitar [30] and Brain-Computer Music Interface [32]) with able-bodied participants. Since the influence on participation is rarely evaluated, it is hard to determine and compare the value of ADMIs, as well as their interaction methods and technology types. In conclusion, design success is evaluated on various aspects including similarity to regular musical instruments, expressivity, and influence on life, of which the latter is suggested as the best evaluation aspect. However, since ADMIs are evaluated in varying ways in practice, it is hard to compare design success.

3.2.4 User and Expert Involvement in the Design Process of ADMIs

In the literature of this review, there are two main types of stakeholders involved in the research. A commonality in methodology is also found. Some of the ADMI designs covered in this literature review were designed with continuous input of the target users. For a maximally effective and thus impactful use of assistive technologies the device and its features should relate to the users' goals, preferences, and environmental resources [5]. This implies that user involvement is important in ADMI design. The adapted sanshin was designed by Yamashiro et al. [29] for two former sanshin players with muscular dystrophies who stopped playing the sanshin due to the progression of their disease. Both design partners received a custom-made controller to use with the affected hand, but they use the same actuator unit. Additionally, Oliver et al. [8] designed a musical improvisation interface for use within occupational therapy settings, as some children were unable to partake in drum lessons. To ensure a good fit for all disability levels, a few of the most severely disabled children participated in the design process through observations, testing, and feedback. Both designs were sufficiently accessible for the target users. Thus, user involvement can enhance accessibility and impact of an ADMI.

Additionally, some of the ADMI design processes used expert involvement. The musical improvisation interface designed by Oliver et al. [8], Octotonic designed by Challis [13], and Touchtone designed by Bhat [9] use continuous input from relevant experts who will be using the design, including musical therapists, occupational therapists and special needs educators. In the research for these ADMI designs, problems of experts were analysed and the experts' wishes were gathered. Additionally, in the improvisation interface by Oliver et al. [8] these experts were also involved in gathering observations during evaluation, which not only gave an enhanced insight into the user experience, but also into the instrument's potential therapeutical benefits in terms of psychosocial skills and body function. Furthermore, the Touchtone's first evaluation included gathering initial reactions from therapists to ensure a good adoption, and its second evaluation consisted of evaluating the ADMI within individual and group music sessions led by therapists [9]. In both these evaluations therapeutic benefits were found. Thus, expert involvement can increase focus on therapeutic benefits in ADMI design.

Moreover, some design processes included observations before ideation. In the adapted sanshins [29] daily life thumb movement of the target users was observed to design accessible controllers. Similarly, an alternative interaction for rhythm-based games designed by Vickers et al., the EyeGuitar [31], used gameplay task analysis of able-bodied participants. The data gathering was specifically focused on collecting eye gaze data of regular play, which could then be used to design an intuitive eye gaze interaction. For Challis' design of the Octotonic [13], existing assistive devices for music making were analysed in their respective special needs' education settings. In case of the adapted sanshins [29] and Octotonic [13], observations of people with relevant disabilities led to accessible and free-standing designs, which provide ownership and control and are also fit for performances. In the EyeGuitar [31], observations of able-bodied gamers led to a very quick and efficient interaction, which allowed for higher accuracy and speed than the original interaction. Hence, observations can help ensure accessibility, control, and efficiency in ADMIs. To summarize, user involvement can help reach accessibility and increased impact, expert involvement can increase therapeutic benefits, and observations can lead to accessible and efficient ADMIs that offer a considerable amount of control.

3.3 Conclusion

This literature review aimed to provide insight into existing Accessible Digital Musical Instruments (ADMIs), which is useful to determine possibilities in technology and interaction, suitable design methods, and common benefits and limitations that occur in ADMIs. This knowledge will be applied in the development of a custom keyboard adaptation for a teenager with the progressive neuromuscular disease SMA type II.

The common types of ADMI are performance-based, best evaluated by its expressivity, and therapy-based, best evaluated by its therapeutical impact. Most ADMIs are designed for a broad range of disabilities by creating accessible or adaptable interaction. Additionally, to increase accessibility, custom controllers are often necessary. To create an ADMI that is experienced like a traditional musical instrument, the amount of control and possibilities of the ADMI are more important than its type of interaction. Rhythm is a crucial aspect that should not be removed. To enhance the expressivity of an ADMI, the transparency of the mapping from both audience and user perspective is important. However, the actual value of an ADMI is best measured by its impact on the daily life of the user. In terms of design methods, active expert involvement can lead to insights into therapeutic benefits. Additionally, active user involvement can ensure sufficient accessibility. Furthermore, observations during the design process can lead to an increase in accessibility, control, and efficiency.

The custom keyboard adaptation of the current design project is performance-based and should be experienced similarly to a traditional musical instrument. Therefore, good transparency and large amount of control are important. Since the basic interaction of the keyboard is useable and some functions should be replaced, a custom controller could be a suitable solution. Since SMA type 2 is a progressive disease, accessible and adaptable interactions should be implemented to ensure usability over a longer period. Furthermore, active stakeholder involvement and relevant observations can lead to a more suitable design. Therefore, these methodologies are implemented in the research.

3.4 Discussion

There are limitations in the literature covered in this review, and limitations in this review itself. Both will be outlined in the coming section. Afterwards, suggestions for further research in the field of ADMI and this project, respectively, are given. The suggestions for further research in the field of ADMI fall out of the scope of this project. The future research suggestions relating to this project will be considered throughout this thesis.

3.4.1 Limitations

The literature covered in this review mostly used qualitative evaluations using a small number of participants. The small number is partially because qualitative evaluations are very costly in terms of time and resources. Additionally, it may be hard to recruit and accommodate participants with relevant disabilities. Therefore, many evaluation methods included able-bodied participants. This can only evaluate the success of the design to a limited extent, especially since the design success is best determined by the influence on the user's daily life and participation. The focus of the evaluations of literature used for this review differed a lot. Only some literature evaluated the therapeutical benefits, while the value of assistive technology can best be determined by these benefits. Furthermore, only one of the designs was evaluated on audience perspective. The differences in focus of user evaluation make it hard to compare design successes of ADMIs, as well as interaction methods, technologies, and other design aspects. The conclusions that are given in this literature review may, therefore, not be entirely accurate, as they are based on literature and ADMIs that are difficult to compare. More research would be necessary to fully grasp the value of design aspects on the success of design.

3.4.2 Further Research

To determine the value of design aspects, there should be a clear guidance for how design value can be assessed. This could consist of an elaborate literature review leading to guidelines which are complete, accurate, evaluated, accepted, measurable and achievable in terms of resources. The field of ADMI is still relatively small, which could mean it is doable to widely implement a standard for evaluation. The guidelines for evaluation methodology should include the effects on participation and daily life of relevant participants. Additionally, an aspect that is useful to consider, especially for performance-based ADMIs, is transparency, which is also linked to the expressivity of a musical instrument. For the transparency aspect, both audience and musician perspective should play a role. Preferably, the impact of ADMIs should also be evaluated on the longer term since it is valuable to grasp whether and which ADMIs are motivational and beneficial upon adaptation as well as for longer use.

The benefit of evaluation guidelines is that ADMIs can then be compared, leading to a better grasp of what works well and what does not. If evaluation approaches are similar, over time this can lead to knowledge that helps set guidelines for design aspects specific to ADMIs. An additional method to gain insight on the influence of specific design aspects would be to evaluate different versions of an otherwise similar design. Evaluating the success of similar iterations which include different combinations of design aspects - such as interactions, technologies, and mapping - can provide insight into the value of the separate design elements. Additionally, these different combinations of design aspects can be compared to grasp how certain design elements influence each other, as well as how the value of these aspects can best be utilized in context. When evaluating design elements, it is also valuable to evaluate the iterations of ADMIs in different contexts, as some elements may be more appropriate depending on the goal of the ADMI. A better grasp on how specific design elements contribute to the character and acceptation of ADMI can inspire more effective designs. This might even lead to guidelines on or a widely accepted approach to ADMI design, where there is little guidance yet.

This literature review was conducted as part of the research activities that will lead to the adaptation of a musical keyboard for a teenager with SMA type 2. This literature review provided insight into important aspects of ADMI and their influence on user experience. However, there are non-scientific ADMIs - as well as digital musical instruments (DMIs) which may be accessible - which are relevant as well. Existing ADMIs include the Magic Flute, Eyewi and Magic Metallophone, as developed by My Breath My Music[2]. Relevant DMIs include electric wind instruments, as used by Van der Wel [3], breath controllers, as mentioned by Ella’s music teacher (see chapter 5), and MIDI Voice Controllers [22]. These products and additional relevant designs should be investigated with the intention of gaining inspiration for ideation, as well as a broader grasp of interaction and technology possibilities. This will benefit the ideation phase of this ADMI design project, by enabling both broader input for the brainstorming and knowledge for more specified ideas. The following two chapters will describe activities and results regarding stakeholder involvement of the target user and an expert, subsequently. Chapter six will outline more existing ADMIs. In chapter seven, a conceptualization meeting with the client and design partner leads to requirements and a provisional design plan. This meeting partially consisted of an evaluation of the design ideas, described in chapter 9.1. Chapter eight describes the prototype as it is designed. This prototype is evaluated in chapter 9.3 and 9.4, leading to the conclusion provided in chapter ten.

4. Design Partner

To be able to make an accessible product that works for a specific end user, it is necessary to have knowledge on who the design is for. To gather this knowledge, a semi-structured interview and remote observations have been conducted. As mentioned in chapter 1.4, both the ethics committee of University of Twente has approved research activities. This chapter describes the approach and results of these research activities. It hereby provides insight into the limitations, needs, abilities and preferences of Ella, a teenager with SMA type 2 who plays the keyboard in her school band.

4.1 Goal

It is necessary to get more in-depth knowledge on Ella to ensure the prototype is appropriate for her. The perspective of Ella is important to determine what kind of functionalities should be adapted and which alternative interactions could best be used to take over these functionalities. Furthermore, her preferences in the prototype's design characteristics should be considered. These characteristics may include ease of use, level of expressivity, number of options, ease of transportation and aesthetics. This knowledge can lead to a more adequate customization.

4.2 Approach

To fully grasp Ella's perspective, two research activities have been conducted. The first activity was a semi-structured interview, consisting of three sections. The first section of the interview regarded Ella's abilities, limitations and needs in interacting with a keyboard. This section focused on how Ella currently interacts with her keyboard and which major problems she faces during practice. Some questions also required Ella to rate the value of gaining access to certain technical functionalities of the keyboard - such as transposing, sustain and sampling - as well as the importance of certain design characteristics. The second section of the interview covered Ella's physical abilities per body part, in terms of movement range and strength, how voluntary and controlled these movements are and what level of fatigue occurs in prolonged use. The third section explored Ella's familiarity in interacting with technology as a user. This included technology use in daily life and experience with alternative interaction methods, such as eye-gaze.

This semi-structured interview lasted 45 minutes in total. Since Ella is underaged and therefore vulnerable, regular breaks were offered and the approach was relatively flexible. Before the interview Ella was reminded of her rights to refuse to answer questions or to stop the interview entirely. At the beginning of each interview section the purpose of the questions was explained. The interview preparation, which describes the questions asked, can be found in appendix C1. After concluding the three sections of this first research activity, a transcript of the interview was made.

The interview did not lead to a sufficiently detailed insight into Ella's interaction with the keyboard. Therefore, the second research activity was planned and conducted. This consisted of remote observations, through videos of Ella practicing at home. Ella was asked to film herself during practice, and make sure at least her hands, keyboard and upper body were clearly visible. These videos were then analysed with focus on movements in the interaction with the keyboard.

4.3 Results

The results of the interview and observations have been analysed and combined. In this subchapter, these results are categorized in three subsections. Firstly, the physical abilities of Ella will be described. Secondly, her current interaction with the keyboard and her wishes for customization are outlined. Thirdly, Ella's familiarity with technological devices is described.

4.3.1 Physical Abilities

There are numerous aspects of ability that can be considered. Firstly, those related to movement, among which size, speed, ease, and amount of control. Secondly, the level of force that can be applied. With both aspects, there is a possibility of fatigue, which can occur to different extents after different lengths of time. All these aspects are described in this subsection.

Ella can move her legs and feet in small ranges. The movements are controlled and slow. She cannot move her legs for a long time due to fatigue, whereas she can move her feet a bit longer. She can barely apply force with her legs, hips, and feet. She can bend her torso forwards and backwards in a limited range, whereas she cannot turn her torso. The torso movements are controlled, and limited fatigue occurs during prolonged use. It is expected she can also apply some force in these movements, though this has not been tested.

When it comes to her arms, a lot more movement is possible. She can make controlled movements at a medium speed in a limited range. Moving her arms causes fatigue, but she can do so for a considerable amount of time. She is also able to apply some force and can lift half a kilogram with her arms. Her arm movement when applying force is slow but controlled. She can only use her arm strength for a brief time due to fatigue. Ella cannot put her arms up above her shoulders. She cannot open her arms far or move her arms sideways by a lot. She can also not turn her hands upwards entirely, but only up to 90 degrees inwards. Ella can move her wrists quickly and controlled to a considerable extent. She can move most of her fingers quite a lot, with exception of some fingers on her left hand, which she can move to a noticeably lesser extent. Her finger movements are quick and controlled. She can do these movements for quite an extended period. Ella can apply a bit of controlled force with her fingers, which she can apply quickly with her thumb and index finger, though slower towards her little finger. She gets fatigued when using strength in her fingers, but can do so for a prolonged period, which she also does when playing the keyboard.

Ella can move her head and neck quite a lot, with the exception that she is unable to turn her head far to the right. Her head and neck movements are quick and controlled. During these movements, Ella experiences little fatigue which enables her to execute them for 15 minutes at a time. It is not known whether she is able to apply force with her head movements, as she has never consciously attempted this. Her eyes are not limited in movement. She can move her eyes quickly and controlled for a long time with little to no fatigue occurring. The same applies to her mouth. Additionally, she has a lot of control over her breath, but is not able to take deep breaths. She can do controlled and quick short breaths over an extended period with little to no fatigue occurring.

4.3.2 Keyboard

Ella uses a Yamaha PSR-EW410 keyboard and will keep using this keyboard for the foreseeable future. Ella views ease of learning, ease of use and ease of setting up the installation as the most important design characteristics. She also places importance on the precision and expressivity of movements. Her keyboard already has an element of expressivity as the volume of a note is set by the force with which a key is pressed. This built-in expressivity is sufficient for an expressive playing experience, but it is important that the level of expressivity is not lowered by the prototype. In an ideal situation, the expressivity of the keyboard is even enhanced by the adaptation. Furthermore, Ella would appreciate being able to use a lot of the options and functionalities that are built into her keyboard, but this is not of immense importance. Additionally, she would see value in being able to connect the prototype to other musical instruments and products but does not prioritise this. She does not care about the compactness or aesthetics of the solution. When it comes to compactness and weight, it is enough if she can transport the prototype. For this, the prototype should remain under fifteen kilograms.

Three functionalities are of extremely high priority, namely the sustain, turning on the keyboard, and transposing. Firstly, Ella experiences fatigue during keyboard playing when attempting to keep keys pressed for a prolonged period. Having access to the sustain function of the keyboard would help, because notes ring longer while the sustain function is triggered. Therefore, having an accessible alternative to the sustain pedal would directly increase her ease of playing. Secondly, Ella is currently unable to turn on her keyboard by herself. This means she cannot practice the keyboard if her mother is not at home. Once the keyboard is turned on, Ella can practice without additional help. Being able to turn her keyboard on by herself would increase Ella's independence. Thirdly, Ella can only reach a limited range on the keyboard. She plays in the middle of the keyboard in a range that covers about half of her keyboard. The transpose function can set the keys to sound an octave higher or lower. This would give Ella access to the notes she cannot reach without changing her physical range.

The buttons for most of the functionalities are inaccessible to Ella. The problem with this is the distance of the buttons. If the same buttons would be within a smaller distance from her, she would not have difficulties using them. To access setting buttons that are too far to reach she currently uses a stick. She, for example, uses this stick for turning the keyboard off after she is done playing. This is a regular stick with a rubber end, which stops it from slipping off the buttons. This is a provisional solution as it is inconvenient. Therefore, the functionalities of the keyboard should be replaced in a more accessible way. Some functionalities, such as the sustain, need to be accessed while playing, while others, such as volume, only need to be accessed in between songs. Some functionalities would be pleasant - though not crucial - to access during playing, such as sampling.

Ella struggles to play with her left hand, which is harder and less successful than playing with her right hand. She does not use all the fingers of her left hand while playing the keyboard. The difficulty may partially lower with a lot of practice but is expected to remain. While practicing, Ella practices her right hand, with which she plays the more melodic parts of the repertoire, more than her left hand, with which she plays the more supportive parts of the repertoire. With both hands, Ella visibly makes movements from her wrists and lower arms to press the keys of her keyboard. Her elbows, upper arms and shoulders are not moved when playing the keyboard. Her upper arms also remain in place when she moves her arms to reach sideways. This means she turns her arms sideways, making a curved motion to the side. When changing a setting she can barely reach, she reaches the buttons by moving most of her upper body forwards and subtly leaning sideways. In between songs, she regularly bends forward a bit to reach her sheet music or necessary settings. While playing, she subtly rocks her body back and forth in an expressive manner. Additionally, she moves her head sideways and up and down to read sheet music and view her hands on the keyboard. She makes comparable movements with her eyes, which are mostly aimed downwards during practice, and are therefore a bit closed.

4.3.3 Technological Familiarity

In daily life Ella frequently uses a HP ENVY x360 13-ay0xxx laptop for school and gaming. She also uses a Galaxy XCover 4s phone and Apple MD528NF/A iPad Mini for games and communication. Furthermore, she regularly watches television. She spends multiple hours per day on such technologies. This comes easy to her and there are no major frustrations. Ella does not need much assistance to use her technological devices. She uses her hands to interact with the devices, by placing her fingers on the buttons as intended.

Ella plays music games, such as rhythm games, on a regular basis. Additionally, she owns computer software to record and compose music, which she does not use often. In this software she needs to insert her songs note by note, which gets boring and tedious after a while. This tedious work demotivates her to the point that she would rather not go through the effort of using the composing software. She would prefer to record her compositions by just playing them on her keyboard. Afterwards, she would like to be able to change the recordings, but the options for this do not need to be extensive. Her keyboard, composing software and music games are the only music related technologies she currently uses. However, Ella used to play the electric saxophone, which is controlled using the breath and the fingers of one hand. She liked playing with her breath but stopped playing the electric wind instrument because she prefers the keyboard. She is drawn by the variety of options the keyboard offers, as each hand can play something entirely different. In contrast, she was only able to play simple melodies on the electric saxophone.

4.4 Conclusion

Ella uses a modern keyboard which can use MIDI with a USB to host connection. The adaptation should work for this keyboard. For the adaptation, focus should be on the ease of learning, use and setting up the installation. Ideally, some expressive elements are also incorporated. At the very least, the expressivity of the keyboard should not be lowered by the prototype. In terms of functionalities, especially the sustain, transposing and turning on of the keyboard should be made accessible. Ideally, Ella can also use the prototype to independently change sounds and effects. The sustain should be easily useable during songs, the changing of effects would preferably be useable during songs, and the other functions would be sufficiently incorporated if they are only accessible in between songs. The product should be no heavier than fifteen kilograms. The distance of buttons or other interactions from her body should be minimal.

Since Ella tends to move her upper body, head and eyes while playing the keyboard, using these movements for interaction during a song is unintuitive. Larger movements are not yet used, but these are obtrusive and difficult if used for a prolonged period. However, large and/or specific upper body, head, and eye movements that are not yet used can be used in between songs. Furthermore, her arms and fingers can easily be used for interaction in between songs if the interaction requires little to no force. These movements should be near her body and remain below the shoulder. However, her fingers, hands, wrists, and lower arms are already used while playing the keyboard, so should only be used in between songs.

For functionalities that need to be accessed during songs, unobtrusive movements should be used. These are movements that do not limit the current playing experience, because they require unused body parts in a way that does not impact posture. An unobtrusive moment is easy to do in combination with the usual interaction. Furthermore, an unobtrusive movement does not lead to accidental triggering of functionalities. In case of playing the keyboard, unobtrusive movements include movement using the legs, feet, breath, and mouth. Ella cannot move her legs for a prolonged period, so this interaction should not be used a lot. If leg movements are used, they would only be suitable for changes that occur occasionally. Furthermore, the interaction should require no force from the legs. Her feet would be more suitable, as she can move them for a longer period. Still, the interaction should require little to no force or speed. The feet are commonly used as interaction method in musical instruments, including the keyboard, because foot movements are unobtrusive and intuitive, as described by Larsen et. al [33]. However, for Ella, this solution might not be as useable in the future due to the progression of her disorder. Often, the leg and feet muscles deteriorate more quickly in SMA type 2 [10]. Additionally, Ella experiences fatigue when moving her feet, so this movement is already not suitable for frequently used functionalities. Mouth movement would be more easily accessible, as Ella experiences no substantial limitations in mouth movements. The same goes for breath interaction, which she already has positive experiences with. If only short breaths are required, this would be well accessible for Ella.

Ella is sufficiently able to use ordinary technological devices and software. Furthermore, she does not experience intellectual limitations, so non-customised software and product design are sufficiently understandable for her. Therefore, existing controllers and software can be incorporated if these are physically accessible for Ella.

4.5 Future Research

There are multiple movements that have not been discussed, including movement of the shoulder. For example, moving the shoulder up and down or forwards and backwards. Ella does not use movement from her shoulder during practice. Logically, shoulder movements influence the position of the lower arm, and may therefore be obtrusive, especially with larger movements. Another movement that is not considered in the interview is that of the eyebrows. Ella does not move her eyebrows while playing, so there might be possibilities for an unobtrusive interaction. However, the head movements she naturally makes while playing could make it harder to decently capture her eyebrow movements. To account for this, a sensor may need to be mounted on her head. If this installation becomes heavy and/or blocks movement or viewing range, it becomes obtrusive. Alternatively, good facial tracking technology may be suitable, especially since the head movements are slow, small, and gradual. If shoulder and/or eyebrow movement are potentially suitable for the adaptation, the possible interactions should be discussed and evaluated with Ella. First, her music teacher is interviewed, which will be covered in the next chapter. After this, an overview of the state of the art is provided in chapter six. Chapter seven outlines a conceptualization meeting, leading to requirements and a provisional design plan. This meeting partially consisted of an evaluation of the design ideas, described in chapter 9.1. Chapter eight describes the prototype as it is designed. This prototype is evaluated in chapter 9.3 and 9.4, leading to the conclusion provided in the concluding chapter.

5. Music Teacher Perspective

Ella receives music lessons from a teacher, who has relevant expertise in her abilities and what a keyboardist needs. The teacher is approached for a discussion on potential solutions.

5.1 Goal

Ella's music teacher is an expert in both keyboard performance and Ella's relevant abilities. Firstly, the music teacher is aware of what a keyboardist needs on stage, including the current practice in the field. This awareness is valuable since it is important that Ella can independently control the most important functionalities on stage. Discussing these necessities can therefore lead to relevant requirements. Furthermore, knowledge on the current practice can help grasp existing products and accompanying possibilities, leading to a more complete state of the art overview. On top of this, the music teacher knows Ella's level of playing, including abilities and difficulties. This enables the music teacher to judge the relevant capabilities of Ella when it comes to understanding and learning an additional interaction. The goal of this research activity is to get a grasp on what the music teacher thinks is necessary and feasible when it comes to adaptations. Additionally, it will lead to a better insight into current practice and possibilities in the field. Furthermore, insights gained from this activity can be used to decide on suitable requirements.

5.2 Approach

The client of this project, Ruud van der Wel from My Breath My Music, provided contact information of Ella's music teacher. The teacher was contacted with the request for an online meeting to discuss perspectives and ideas he already has. The appointment was set for the 4th of March 2021 and took place over Skype. The call lasted for 40 minutes without a break. In a conversational brainstorm session, rough ideas and findings were discussed. Furthermore, information on technical aspects such as MIDI connections and sustain pedals were discussed, as well as additional functionalities, such as transposing and changing of sounds. Furthermore, the teacher provided information on existing products and practices. Additionally, there was a discussion on suitable unobtrusive interaction methods. Thus, information gathering and a start of the ideation phase were combined in this activity. The conversation was unstructured, and the subjects were interactively discussed in an organic order. In the following section, the results are presented in an order that best structures the knowledge gained. They build upon knowledge gained in earlier stages, such as the design partner interview and ADMI literature review.

5.3 Results

For most keyboards, as well as products and applications that are used in combination with keyboards, the universal software language MIDI (see chapter 3.1.1) is used. Using MIDI, devices can be connected at a plug-and-play basis. This means that once the right connection is set up, the devices can already communicate. This is thus only a matter of using the right cables. The music teacher uses a keyboard with a USB to host output, which he connects to his Apple devices using an iPhone camera connection kit. Keyboards that have original MIDI outputs require an extra MIDI to USB interface from the keyboard to the connection kit. The necessary cables and interfaces can be cheap, starting at 10 euros on certain web shops. Alternatively, they can often be found in thrift stores. Devices that are compatible with MIDI send and/or receive MIDI messages of multiple types, including note information, control changes and channel numbers. The messages exist of an array of numbers that is sent and interpreted. There are universal MIDI messages, such as CC64 for sustain (of which 'on' and 'off' messages can be sent), and messages specific to the device. To use MIDI successfully, the most important aspect is to find the commandos which are used for different functionalities. There is documentation available for this, which can expectedly be found on the last pages of the instruction manual of the specific MIDI device; on the website of the company that developed the MIDI device; or on another online source, though this might not include the device-specific messages. If, however, the documentation cannot be found, it is technically possible to figure out commandos using trial and error, though this is cumbersome.

The sustain is an important functionality of the keyboard, which is controlled using a sustain pedal. A sustain pedal is a simple switch with enclosure, which is connected to the keyboard sustain input. When the pedal is pressed, the electric circuit is closed, which means a current can go through. When the pedal is unpressed, the electric circuit is open, and the current is blocked. The keyboard manages the switch input internally. It should be easy to develop a suitable switch to control the sustain with any movement. The most crucial step of creating this adaptation is deciding on an accessible and appropriate interaction to control the sustain function with. Ella has already purchased and tried a regular sustain pedal, but it is too heavy for her to use. If using interaction with the feet for the sustain or other functions, an exceptionally light or even non-force pedal should be used. There are already some existing foot pedals which require little to no force using different technologies. The music teacher, for example, owns an optical expression pedal which can be moved forwards and backwards. This pedal contains a light and a light sensor, as well as a piece of plastic that blocks and unblocks the light as the pedal is touched. If the light is blocked, the resistance is so great that the current is negligible. This pedal requires no force, just moving the foot up and down is enough. Though this example concerns an expression pedal, the same pedal and technology can also be linked to the sustain or another similar function. Another type of pedal which requires no force consists of a reflecting material attached to the foot in combination with a highspeed camera, which is further described when discussing the Aerodrums in chapter 6.5. The music teacher expects that the optical expression pedal is simpler.

The interaction for the sustain function needs to be an unobtrusive movement, because the sustain is used during songs. Finding unobtrusive movements for playing the keyboard is tricky. The foot is intuitive and easy to use rhythmically over an extended period, according to Larsen et al. [33]. Ella's feet do not have a lot of strength, but some movement is possible. It does cause exhaustion and is therefore not suitable for longer or frequent interactions. Moving the legs sideways would be another unobtrusive movement, though expectedly not more accessible for Ella because foot movements are less exhausting for her than other leg movements (see chapter 4.3.1). If the legs and feet are inaccessible another movement needs to be considered. According to Larsen et. al [33], the head is the best alternative for movements in rhythmic patterns, though it is not optimal due to chance of fatigue or injury, as the neck muscles are unsuitable for this purpose. Furthermore, Ella already makes some head movements during play (see chapter 4.3.2). This means small head movements are obtrusive due to accidental triggering, and large head movements are also obtrusive due to the inconvenience of the movement itself. The interaction should also not require movement of the arms, as this would impact how the hands are positioned on the keyboard. Eye movements would also not be suitable, as Ella needs to look at the conductor, her sheet music, and her hands during a performance.

A suitable interaction method for the sustain can be the breath. There are existing breath controllers which work using MIDI. These transfer breath changes into MIDI information. It should be possible to reprogram the final MIDI messages such a controller sends. The internal software routing can be changed using Logic Pro[6], which will change the mapping of the controller. The music teacher thinks a simple blow controller could work to control the necessary functionalities. Another interaction to consider would be that of biting. This is a more simplistic solution. For this, Ella would need a thin cable with a part that can be bitten to close the electrical circuit. This would technologically be easier than breath interaction. However, with a bite switch, there should be extra attention for the safety of the product.

Keyboardists often use applications to manage their settings on stage. These can run on a laptop, advanced synthesizer, or iPad. There are numerous applications that work with MIDI and can manage the settings of different songs. In many such apps a setlist for the live performance can be created, in which all necessary settings are incorporated. When the song is selected, the application will send MIDI programme changes to the keyboard to change the settings to the determined preset. This allows the musicians to quickly switch to all the necessary settings, without having to manually insert them on their keyboard. Instead, the musician can press a single button that goes to the next song and sets all the corresponding settings. Some existing apps that can be used to create such setlists are iMIDIPatchbay, Mainstage (Apple), Camelot (Pro), SetlistMaker, Mobile Sheets Pro (Android), Bandhelper, Onsong and Forescore. The music teacher himself is not familiar with these apps or their costs.

Instead of interacting with the software directly, some musicians prefer separate controls to skip through the setlist. A switch can select the next song in the playlist. To allow for quick correction when accidentally skipping too far, or more flexibility in the song order during the performance, an extra switch can be incorporated to go back in the playlist. It is likely that one or multiple existing applications have enough options and sufficiently effective software to control the desired functionalities. Furthermore, such applications normally use MIDI and should therefore be compatible with Ella’s keyboard. It is likely that custom software is not necessary. If it is, the software would be similar to the existing applications with some customisation to attend to Ella’s needs. An off-the-shelf switch that is suitable might not be available. Most keyboardists use a pedal or regular switch. Since the settings only need to be changed in between songs, obtrusive accessible movements can be used, such as pressing a button by hand. This is an intuitive and easy solution. For Ella, a light-weight switch or touch-sensitive pad should be used. It should be placed in proximity of her body. Alternatively, the switches could be mounted on a head piece and triggered by touching them with the head. Another possible place for the buttons is the elbows. The switches can then be triggered by either touching the elbow with the other hand or gently bumping the elbow

[6] Software that doubles as digital audio workstation (DAW) and MIDI sequencer

against the wheelchair or another object. As stated in chapter 4.5, the level of shoulder movement Ella is not yet known. Though the switches usually do not need to be used during play, it is important to keep in mind that they should also not accidentally be triggered during play, since this would still make the interaction obtrusive. This should be kept in mind when placing the switches. The music teacher expects buttons for the hands or elbows would not quickly get in the way.

The transposing function is built into MIDI keyboards by default. The settings can therefore be controlled with simple MIDI programme changes. On a keyboard, the transposing can usually be managed with two buttons, namely an octave up and an octave down button. Even though the current buttons are inaccessible for Ella, the functionalities can be made available through external buttons if these are mapped to send the necessary programme changes. Alternatively, it might be possible to add the transposing settings to the setlists in an application. Especially if the adaptation also uses such an application to change the types of sounds, this would be the easiest solution. The music teacher also suggested to take apart a cheap MIDI keyboard and use the hardware of its buttons. These could be installed in closer proximity to Ella. However, this is not the best solution available and might be a waste of keyboard. Another possibility would be to custom make a controller using MIDI and Arduino. There are keyboardists who have made DIY Ableton controllers in such methods. The music teacher is not sufficiently knowledgeable on Arduino to know if this is the route to take.

There are quite some possibilities when it comes to finding solutions. A good method for prototyping would be to try things at home with a MIDI keyboard, if possible. The music teacher also mentions the Jostiband, which is an orchestra consisting of children with handicaps. They make remarkably simple solutions for limitations that occur and have been doing so for 20-30 years long. They have likely come across similar situations, where musicians could not control an entire instrument, but were still able to play it decently. The music teacher thinks it can be valuable to consider how they would manage such a case. It might be useful to gather information on their existing solutions and even contact them for guidance. This could be very educational due to their amount of experience.

It is best to make an adaptation that is simple. There are always complications right before a performance. Especially in orchestras and bands that use a lot of technology, technological difficulties will occur. This is especially the case if every member has their own set-up with assistive devices. When such difficulties occur, it is convenient and reassuring if your own set-up is simple and trustworthy. This limits your own stress and the totality of issues that occur. If issues arise regardless, a set-up that is simple can easily be fixed by yourself and/or people that are already present. Thus, an important message of Ella's music teacher is "keep it simple, as easy as possible is usually best!"

Ella learns quickly and easily and has high cognition. The music she plays in the school band is already quite easy for her, even though she has not played for a long time. She plays songs ten times more complex than what she began with and already plays at a level that did not seem possible at first. During classes, some improvisation is necessary to find out what is possible and what cannot be improved, especially in the beginning. The classes are online, so the teacher cannot see Ella's hands most of the time. A lot of the dynamics are figured out with questions and trial and error. Ella can communicate her opinions and experiences well.

After the interview, a new consideration came up. For most musicians, the transposing only needs to be changed in between songs. Ella, however, can only play a limited range of her keyboard (see chapter 4.3.2). Therefore, she might benefit from transposing within songs, without disturbing her playing. This may be even more relevant when she wants to play more difficult songs in the future The transposing needs to be accessed less than the sustain, so the sustain function needs to be connected to the easiest movement. Upon discussion with Ella, it is confirmed that transposing during a song would be valuable. Furthermore, she agrees that it should be possible to trigger the sustain and transposing simultaneously. Therefore, the transposing should be connected to a different unobtrusive interaction than the sustain. Breath or jaw movement is thus not ideal. Movement of the tongue might be suitable if this can be captured accurately without causing discomfort. Alternatively, an entirely different unobtrusive movement can be considered. For example, simple eyebrow movement. Since Ella expects the transposing needs to be accessed less often than the sustain, the sustain function should be connected to the most accessible movement.

5.4 Conclusion

When it comes to creating the sustain adaptation, the most accessible unobtrusive interactions are breath and biting. Ella has full control over her breath and does not experience fatigue (see chapter 4.3.1). She can only control short puffs and breaths. Ella already has experience with breath interaction to play music and experienced this positively (see chapter 4.3.3). There are existing breath controllers, and it is possible to change the mapping of these. Breath sensor information can thus be mapped to the sustain. It may be possible to control multiple functionalities using the breath. The second interaction method that seems appropriate is biting. This is an accessible movement that can be done rhythmically, like how a foot pedal can be used. Though it would take some time to get used to, it would not be a complicated interaction. Furthermore, the design partner has full control over mouth movements and does not experience fatigue due to these movements (see chapter 4.3.1). It would be an unobtrusive, simple-to-understand interaction that can be done during keyboard playing and requires little demand. A simple switch should be created, one that is sufficiently small and uses appropriate material. There should also be extra consideration for the safety of this switch. There is an input on the keyboard for sustain pedals, to which such a switch can be connected.

When it comes to changing the settings of the keyboard, there is existing software that is already used in the field. An application that has the necessary functions and is not unnecessarily complicated should be used. The application can be connected to buttons or pedals to switch through pre-determined settings easily. For this, light-weight switches near Ella's body are appropriate. These buttons can be pressed with the hands in between songs, as the settings usually do not need to be changed during a song. Alternatively, the buttons can be connected to the elbows and pressed by bumping the elbow against an object. This may enable Ella to keep her hands on the keyboard which lowers the amount of required arm movement. When it comes to the transpose function, it would be ideal if this can be triggered while playing, instead of only in between songs. Since it is also best if this can be triggered during the sustain, a separate interaction would be ideal. This interaction does not have to be as easy as that of the sustain, as it is used a lot less frequently. Ella values a solution that is easy to learn and use (see chapter 4.3.2). She learns quickly and easily, so the solution does not need to be extremely intuitive, as long as it is not complex. Her desire for a simple solution matches well with the music teacher's advice.

5.5 Further Research

There are four areas of further research, namely state of the art, design partner related, client perspective, and technological. State of the art is an investigation of relevant existing products. This meeting and chapters 1.1.3 and 3.2 have outlined some existing products, but only some of the available interaction methods and technologies are considered. Through investigation of more ADMIs, inspiration for further ideas can be gained. Interaction methods should be considered, but also the sensors that can best be used to measure such movements. The hardware is important to consider for useability and user experience. Furthermore, the types of software that are used for certain products is valuable knowledge, as this can help determine suitable (existing) software for the adaptation. Chapter six will outline the current state of the art, ending with an overview of potential interaction methods and technological aspects such as sensors, hardware, and software.

The second area of further research regards the design partner, Ella. After this brainstorm session, three main aspects of investigation were determined. The first of these regards the way the transposing function is ideally integrated, whether she should access this during songs or only in between, and whether it should be possible to trigger it as the same time of the sustain. The second aspect is to gain further insight into Ella's physical abilities. Certain movements, such as that of the shoulders, have not been discussed. Furthermore, interactions require a specific movement, while only broad knowledge on Ella's abilities has been gathered so far. Once there is an idea for appropriate interactions, their accessibility should be discussed with Ella. If they seem suitable, they should be evaluated in the context of playing the keyboard. For this, it is important that Ella can do the interaction often over a period of at least the length of a performance. Furthermore, it is important that she can control the movement rhythmically. Not only is the accessibility important, but also the intuitiveness and Ella's preferences, so the evaluation should include an interview. Ideally, the evaluation is done with a mock-up or low fidelity prototype to avoid unnecessary work. The last research aspect is to grasp the expected progression of Ella's disease. The first interview was only concerned with current physical abilities. If there is any educated estimate of how her disability will progress, it is valuable to make choices that have an increased chance of being accessible for a longer time.

The third research area is the client perspective. The client is personally involved with the school band. He works on the repertoire and will therefore have an idea on the importance of certain functionalities for their performance. On top of that, the client is an expert in the field and knows what is important to consider in projects like this. Furthermore, the client is the sponsor and provider of this project, so it is important to gather a better view of his expectations to ensure client satisfaction. It is also important to get a better insight into practical concerns, such as available budget. All this can help determine requirements for the product. The client, Ruud van der Wel, has been contacted with the wish for a meeting. He suggests a meeting with Ella's presence to discuss the current state of the project. This meeting is described in chapter seven.

The fourth area regards technological research. When it comes to technological research, it is important to investigate the feasibility of the discussed ideas. For this, the existing applications and their possibilities should be investigated. Practical concerns, such as device compatibility and possibilities of connecting a variety of switches should be part of this investigation. If an application expectedly suffices, it should be tested in practice with a MIDI keyboard and simple switches. This way, the functionality and suitability can be evaluated. If no application seems suitable, possibilities for custom software should be researched. For this, the MIDI documentation is important and should be carefully studied. Furthermore, a suitable programming language should be determined. In chapter 5.3, Arduino is already introduced as a potential language. Of course, there are more languages that may be more suitable, and even a combination of different programming languages should be considered. Besides research into software options, the technological feasibility of a safe, comfortable bite switch should be investigated.

The next chapter will cover the suggested state of the art research. This will lead to a better understanding of preferred interaction types and technologies. After this, chapter seven will cover the conceptualization meeting. This chapter will bring new knowledge on requirements, based on a meeting with the client and design partner. In this meeting, disease progression, accessibility of interaction types, and practical concerns are also discussed. To further decide on the suitability of interaction methods, an evaluation session with Ella needs to be conducted, which will be described in chapter 9.2. By the end of chapter seven, the appropriate interaction methods and technologies will be synthesized into a provisional design plan. Chapter eight will describe the actual prototype that is designed, which differs from the design plan based on technological research and possibilities. This prototype needs to be evaluated, of which the methods, results and conclusions can be found in chapter nine. This is followed by chapter ten, which offers a conclusion on the entire project.

6. State of the Art

This chapter describes a broad range of existing (A)DMIs that can inspire future design. A large segment of the relevant products is divided into the well-known charitable organisations they are associated with, as introduced in chapter 3.1.2. A quick overview of interactions and technologies of these products will be provided at the end of the chapter.

6.1 My Breath My Music

Introduced as the client of this project, My Breath My Music focuses on making it possible for children with severe disabilities to play music. This is enabled through novel designs, lending of musical instrument, and increasing awareness.

Yamaha WX5 & WX11

These off-the-shelf electronic air instruments[7,8] are played using light breath and one or two hands. The instruments are mostly made of plastic and require a sound generator. They are arranged similarly to a 16-key saxophone, using switches to set the desired notes and thumbwheels to play bends (a note that changes pitch)[9]. In addition, breath and lip pressure are measured and converted into MIDI messages of volume and additional parameters. The mapping of these parameters can be changed, which is done by My Breath My Music to adapt the WX5 for single-handed playing, as shown in Figure 2, and to make the instrument even lighter to play. The WX11 has an ergonomic design that allows for the instrument to be held close to the body. Light breath makes for a widely accessible interaction. The products are not designed specifically for people with disabilities and do therefore not emphasize the disability of the user (see chapter 2.2). Overall, these are expressive and accessible controllers that play similarly to an actual wind instrument.

[7] https://mybreathmymusic.com/en/yamaha-wx5
[8] https://mybreathmymusic.com/en/yamaha-wx11
[9] https://www.soundonsound.com/reviews/yamaha-wx5


Figure 2: The Yamaha WX5. Adapted from [8]

Magic Flute

The Magic Flute[10], seen in Figure 3, is a stand-alone electronic wind instrument which uses head movement and light breath as interaction methods. Notes are triggered by blowing into the instrument. The pitch can be altered by tilting one's head forward and backward, changing the angle of the Magic Flute. The pitch is higher if the head is tilted backward, and lower if tilted forward. The same interactions are used to control the actuator unit, which contains sound generating software and a small display showing the current note. The instrument also functions with MIDI, enabling a broader range of sound packs. The flute can be mounted on a tripod or held by the musician. With the magic flute, people can play and control a musical instrument independently without use of any limbs. Due to the light play, the instrument is also suitable for people who can generate little air pressure. Furthermore, the intuitive interaction is appropriate for people with a lower level of cognition. This is an example of a musical instrument that is accessible through using widely accessible interaction methods (see chapter 3.2.2). The Magic Flute is fit for both improvisation and written music. There is a growing collection of sheet music available on the My Breath My Music website.

[10] https://mybreathmymusic.com/en/magic-flute

Figure 3: The Magic Flute. Adapted from [11]

Eyewi

The Eyewi[12] is another electronic wind instrument, still at prototype stage, which uses the breath as one input, and head or eye tracking as second input. Its custom software and documentation on the set-up, existing of off-the-shelf products, are available on the My Breath My Music website for free. Eye Play MIDI windows software is used to set the desired notes by selecting fields on the screen using eye or head tracking (see Figure 4). With an USB breath controller, the notes are triggered with expression. The instrument can be used to follow lessons, play prewritten music, and do improvisation sessions. A widely accessible interaction is used, as only voluntary eye or head movements and control over light breath are needed.

[11] https://www.muziekotheek.nl/uitlenen-instrumenten/magic-flute/
[12] https://mybreathmymusic.com/eyewi

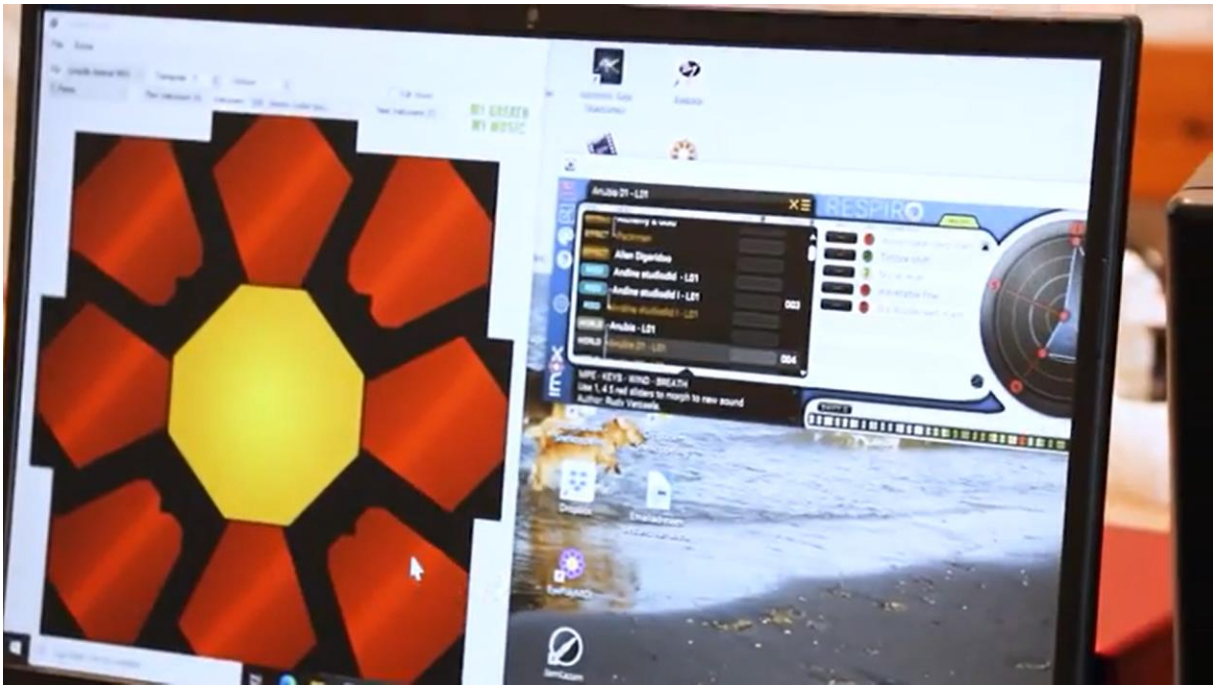

Figure 4: Eyewi. Screenshot from [13]

The Quintet

The Quintet[14] (see Figure 5) is a stand-alone, robust musical device designed for every-day use in the field of occupational therapy. It can be used by up to five players using attachable switches. Each switch corresponds to a role with sound samples in pre-programmed songs. Making music with switches is convenient and easy, suitable for people with low cognition, and useable for people with varying motor abilities. The switches are light-weight and large and can, for example, be mounted on a headrest. The Quintet has a built-in speaker, uses a battery, and is easy to set up, making the device portable. Its simplicity and accessibility make the product useful in therapy settings. It can be used to introduce a child to using switches or playing music, to train collaboration and for Forced Hand Use training.

[13] https://www.youtube.com/watch?v=JwDRZKnvB2g&t=9s
[14] https://mybreathmymusic.com/en/quintet

Figure 5: The Quintet. Adapted from[14]. Cropped

Magic metallophone

The magic metallophone[15] is a custom-made accessible version of a xylophone, published on the My Breath My Music website on an open-source basis [34], so that people can build the instruments themselves. The product consists of three subsystems, namely electrical, base and mallet, as seen in Figure 6. The electrical subsystem contains relays, button switches, rotary switches, a potentiometer, and an input for switches. An Arduino Mega receives inputs of the switches and triggers the corresponding software functions in the control box, which contains the electrical components. The control box is housed in the base subsystem, which also contains the metallophone and an add-on wooden and 3D-printed construction with LEDs and solenoids. The solenoids cause the mallets to move to trigger a note. The mallets with yarn heads are positioned on a bar in the mallet subsystem. To change the volume, the height of the bar can be altered using a pin joint. The metallophone contains four switches. Switches one and two play the next ascending and descending note of the scale, respectively. The third switch plays the same note again. The fourth switch skips a note, playing the second ascending note. This way, the full metallophone can be played melodically. There is an aspect of adaptability, as the switches can easily be changed to require different movements and levels of force.

[15] https://mybreathmymusic.com/metallophone

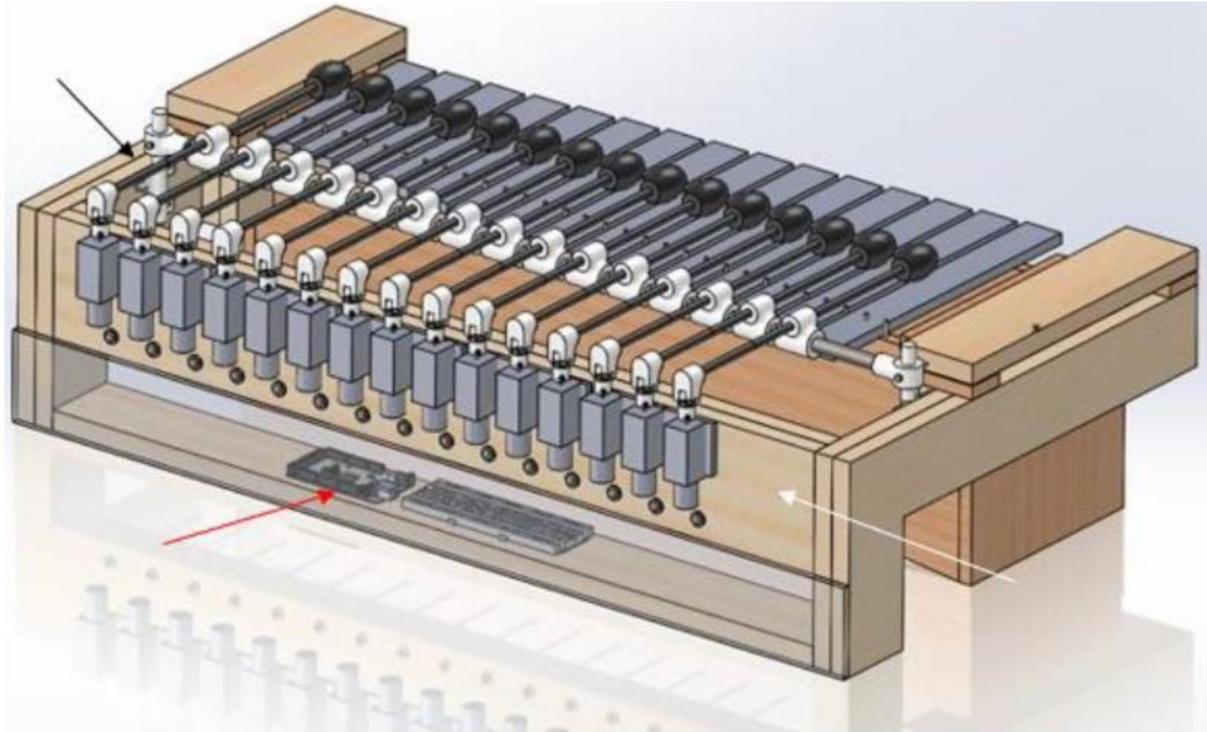

Figure 6: Design of the metallophone (red arrow: electrical subsystem, white arrow: base subsystem, black arrow: mallet subsystem). Adapted from [34]. Cropped

6.2 OHMI Trust

OHMI stands for One Handed Musical Instruments. The organisation[4] works on making musical instruments accessible for one handed playing. One of their activities is adapting, promoting, and designing suitable musical instruments.

Synthobone

The Synthobone[16] (see Figure 7), designed by Petter Ericson and Thomas Hardin, is a prototype based on the trombone, requiring only breath and one hand. The instrument consists of a software synthesizer using Teensy[17]. The interaction consists of a slider which can be operated by thumb, and four buttons for the other fingers which can be used to play overtones. The prototype adapts traditional trombone positions and is therefore easy to understand and teach for experienced trombone players. This is an example of accessibility through a custom controller (see chapter 3.2.2).

[16] https://www.ohmi.org.uk/electronic.html

[17] USB based microcontroller development system, similar to Arduino

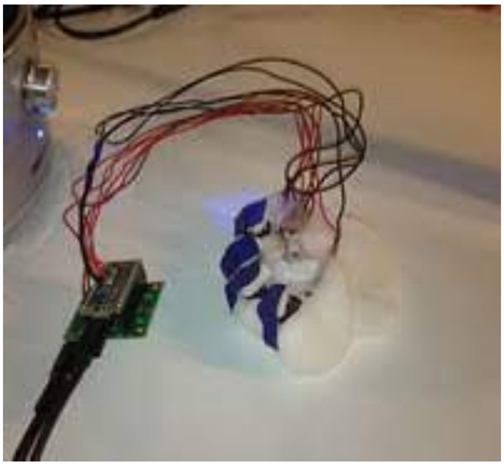

Figure 7: The Synthobone prototype. Adapted from [18]

Jamboxx

This electronic MIDI wind controller[16,19] (see Figure 8) is styled after the well-known mouth harmonica and requires only slight breath and small head motions. By puffing and sipping, notes are triggered. The pitch is changed by moving the mouthpiece left to right on the instrument, which is mounted on a tripod. The types of sound, as well as scales, can be changed. The mapping can be adapted for various levels of breath capacity and head motion. The instrument is not designed specifically for users with disability and does therefore not emphasize the disability of the user (see chapter 2.2).

Figure 8: The Jamboxx. Adapted from [20]. Cropped

[18] https://www.hackathon.io/synthobone
[19] https://www.jamboxx.com/
[20] https://www.rehabmart.com/product/jamboxx-musical-instrument-41694.html

The Linnstrument

This MIDI controller (see Figure 9), designed by Roger Linn[21], uses notepads that can measure three dimensions of finger movement; finger pressure for volume, also allowing for vibrato; left-right swipes for continuous pitch changes, also allowing for expressive bends; up-down finger movement for changing the timbre of the sounds. Furthermore, strike and release velocity are sensed. The notes are arranged in a grid similarly to a traditional stringed instrument. Visual feedback shows where the white keys on a keyboard would be. All parameters and settings can be accessed and changed with touchpads on the edge of the controller. There are several modes, such as drum sets, strum mode or control fades, and many different tunings for the rows. The instrument can also be used in combination with a sustain pedal. The power efficient USB powered controller sends MIDI messages to which any sound pack can be connected. The controller is a very full and expressive musical instrument that offers a lot of possibilities. When it comes to accessibility, the instrument requires controlled use of at least one hand (or foot) but does not require force. Therefore, it is less heavy to play than a regular guitar. Furthermore, a full sound can be reached with only one hand, especially when it comes to melodies. The product is sold commercially, and a version adapted by Shukla is used by OHMI[16]. In this version, the complex set-up process is reduced to solely turning the device on. The musician can then play elaborately with one hand without the need to re-program settings to find accessible modes. The device itself is not designed for people with disabilities and does therefore not emphasize disability (see chapter 2.2).

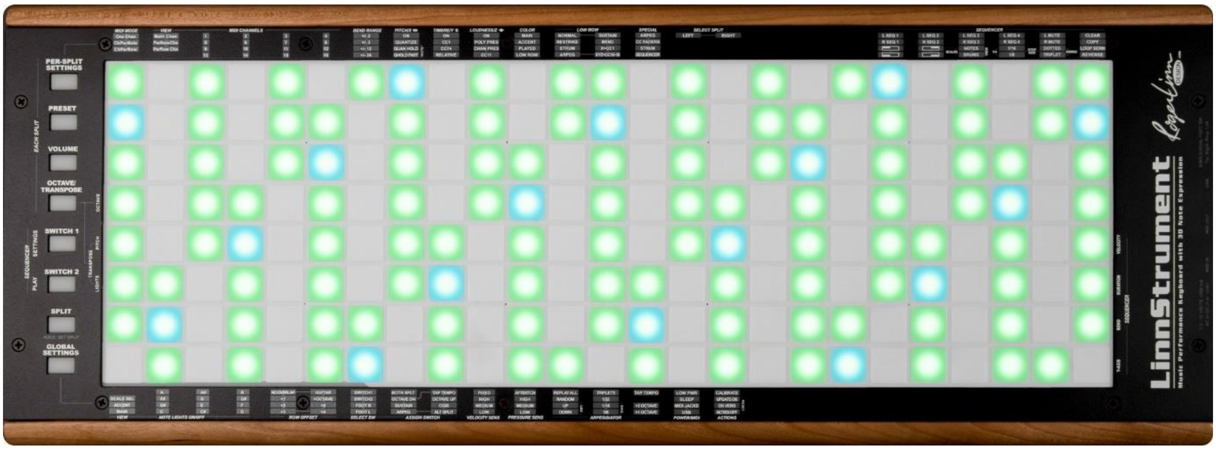

Figure 9: The Linnstrument. Adapted from [22]

P-bROCK Digital Bagpipe Chanter

This digital bagpipe[16], designed by Duncan Menzies, is useful to teach and learn to play the Great Highland Bagpipe. Finger movements and breath are measured using infra-red reflectance sensors and an air pressure sensor. These sensors are built into an acoustic chanter, making the playing experience the same as that reached with a traditional chanter **(**see Figure

[21] https://www.youtube.com/watch?v=px0Id-fVD9M
[22] https://www.rogerlinndesign.com/linnstrument

10). Through a custom software algorithm, the chanter can be used to play the bagpipe with one hand without emphasizing disability (see chapter 2.2).

Figure 10: The P-bROCK Digital Bagpipe Chanter. Adapted from [16]. Cropped

6.3 Drake Music

The Drake Music foundation[3] works in the field of technology, disability, and music. The organisation advocates for an increased accessibility of the music field. To enable this, they create and provide accessible musical instruments.

Kellycaster

The Kellycaster[23] is a guitar adaptation designed by Matthews and Kelly. It consists of a custom body with short neck of which the strings can be strummed using the right hand. With the left hand, chords are selected on a keyboard. A pickup transmits the signals to a Bela board[24], which connects the chords to the string movements. The interface uses Max for Live and Ableton Live, doubling as a compositional tool. The feel and expressivity of the guitar are maintained with the full range of chords available for the musician. The instrument has successfully been used for performances and composing (see Figure 11).

[23] https://www.drakemusic.org/technology/instruments-projects/the-kellycaster/

[24] an ultra-low latency audio platform

Figure 11: The Kellycaster being played. Adapted from [25]. Cropped

AirHarp

The AirHarp[26] is a custom-made stand-alone musical instrument that fits on the wheelchair of the target user (see Figure 12). Motion sensors measure sweeping non-contact hand motions, which are transformed into melodies. Large, colourful buttons are used to enhance visibility. The interaction attempts to maximise the expressive control achievable for the user.


Figure 12: The Airharp being tested. Adapted from [26]

[25] https://cdm.link/2017/09/take-a-look-at-the-kellycaster-a-unique-and-accessible-instrument-built-by-dmlabs/
[26] https://www.drakemusic.org/technology/instruments-projects/airharp/

Tone Ruler

This stand-alone musical instrument, designed by Mo[27] using Arduino, is portable, as it is small, operates by battery and has built-in speakers. It is played with non-contact movements measured by ultrasonic sensors. The distance from the device is mapped onto changes of pitch, using Frequency modulation synthesis (FM synthesis) to create rich sounds with little resources. The Tone Ruler is similar to the popular Soundbeam (described in chapter 6.4), but much cheaper and smaller, as can be seen in Figure 13.

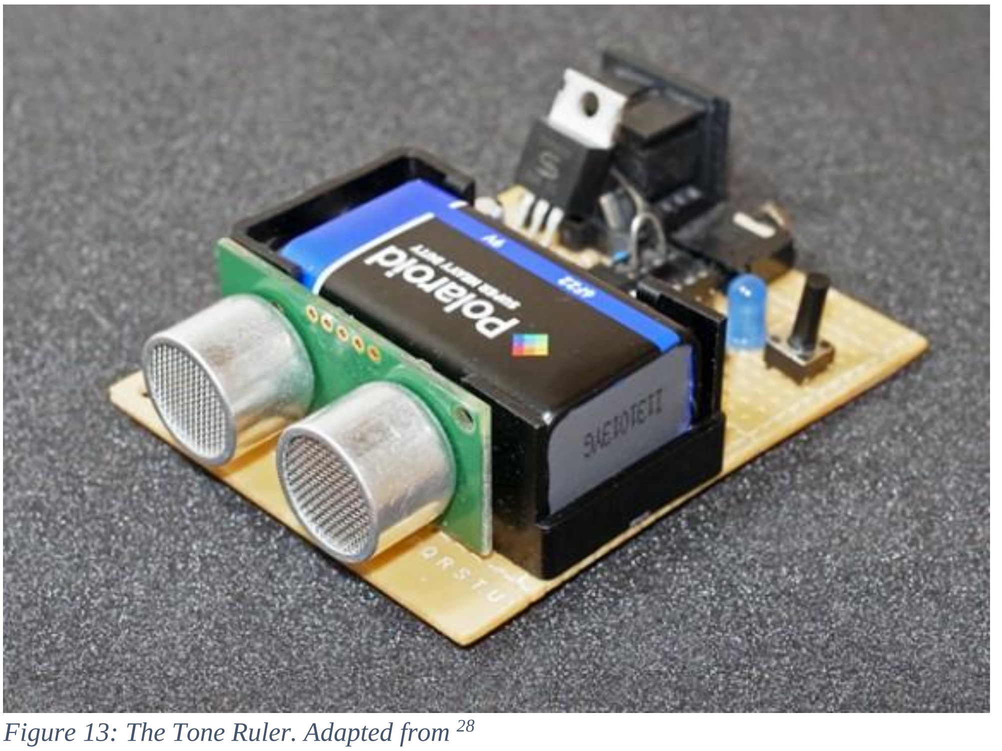

Figure 13: The Tone Ruler. Adapted from [28]

Music Blower

The Music Blower[29] is a stand-alone, battery powered breath operated synthesizer, also designed by Mo using Arduino. By blowing into a tube, built-in sounds, scales, tunes, and arpeggios are triggered. The notes are selected using a random function, allowing for minimal control. The user still controls rhythm, speed, and length. The interaction is very accessible, and the instrument is easy to learn and play. The music blower can be used with MIDI as well.

Mi.Mu Gloves

The Mi.Mu gloves[30] are wearables that measure hand movements to create music (see Figure 14). They are designed by Imogen Heap to enable expressive live creation, composition, and recording. This allows artists to avoid actively using computers during

[27] https://www.youtube.com/watch?v=j57c0UHVgZs
[28] https://www.drakemusic.org/technology/instruments-projects/tone-ruler/
[29] https://www.drakemusic.org/technology/instruments-projects/music-blower/
[30] https://mimugloves.com/

performance, enabling a more transparent way of making music. In her TED talk[31], Heap shows how the product can be used for improvisation, effects on existing sounds, looping, and even building up a full song. The Mi.Mu gloves can measure the positions of all fingers and three types of wrist angles and hand directions, including the acceleration of these movements[32]. It also contains a button, which doubles as visual feedback. Customizable haptic feedback is also included. In its software programme named Glover (see Figure 15), movements can be mapped to effects with up to nine customizable finger postures at the same time. A new posture can be created and trained quickly, after which it is recognized. Furthermore, effects and sounds can be connected to hand and wrist movements, also allowing for different movement combinations, such as affecting pitch by moving the left hand up and down only if the hand is in fist posture during these movements. The movements are mapped to MIDI messages, which can be sent to any software. The Mi.Mu gloves are available for purchase for a broad audience. Kris Halpin is the first person to use the Mi.Mu gloves as an accessible musical instrument, in collaboration with Drake Music. The instrument is accessible because it allows for a lot of customization and requires no force. The performer oversees the level of transparency and expressivity. The musical instrument is complex and is hard to master. In contrast, the solution for Ella should be easy to learn and use (see chapter 4 and 5). Additionally, designing something this complex falls outside of the scope of this project.

Figure 14: The Mi.Mu gloves. Adapted from [33]

[31] https://www.youtube.com/watch?v=7oeEQhOmGpg
[32] https://www.youtube.com/watch?v=2jR2yi5XPqY
[33] https://dublin.sciencegallery.com/sound-check-exhibits/mimu-gloves

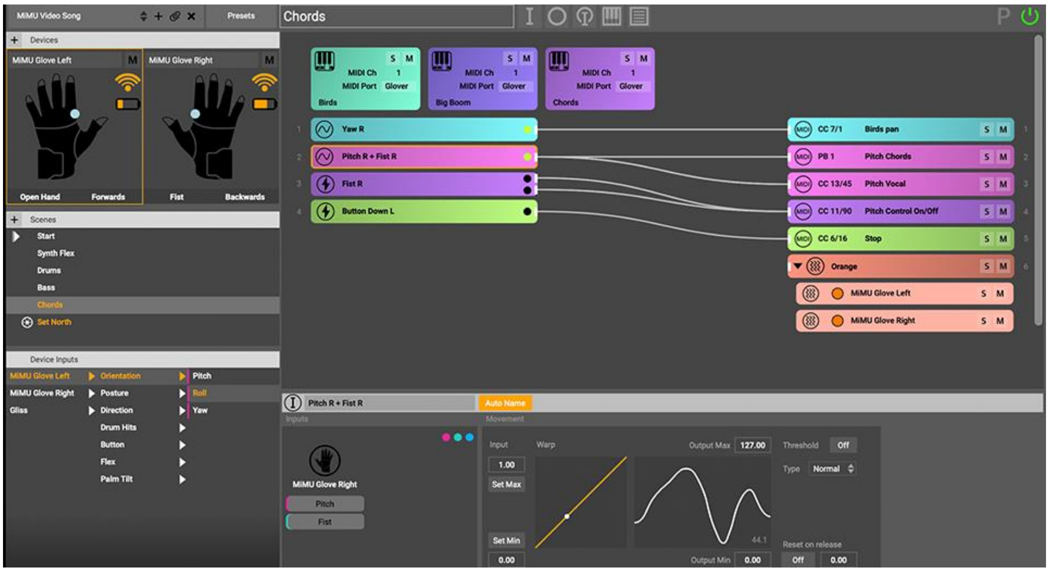

Figure 15: Glover, the dedicated software for the Mi.Mu Gloves. Adapted from [34]. Cropped

6.4 Additional ADMIs

Adaptive Use Musical Instrument (AUMI)

This freely available app[35] (iOS, Mac, and Windows) uses camera tracking that already exists on most modern digital devices to measure non-contact gestures (see Figure 16). The user is visible on the screen and can place a cursor on the body part which should be tracked. The cursor can then be controlled by moving this body part. There are three main interaction modes, namely zone tracker, radial tracker, and relative movement. The sizes and amounts of zones can be altered, changing the required amount of movement and control, so that even eye movements can be used. Different sounds, scales and notes can be attached, and even custom audio samples can be uploaded and used. A predetermined sequence can be set, meaning the order of the notes is already determined, and the movement triggers the next note in sequence, leaving only rhythm aspects to the user. The musical instrument is intuitive and easy to get some sound of, though hard to reach a lot of control over. It is mostly fit for improvisation and exploration and can be played solo or in groups. If it were to be used in a performance, lighting might pose an issue, as this can impact the ease of tracking movements. The AUMI has been evaluated in educational settings [35], used in recreational and structured music playing sessions, and evaluated in community music therapy to assess the effectiveness in achieving specific music therapy goals. This was done in a setting where only acoustic instruments and vocalization had previously been used. Improvements were found in areas like socialization, communication, engagement, and relaxed physical movement. The AUMI software is regularly updated and presented at conferences, symposia, and festivals.

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[34] https://mimugloves.com/glover/
[35] http://aumiapp.com/index.php

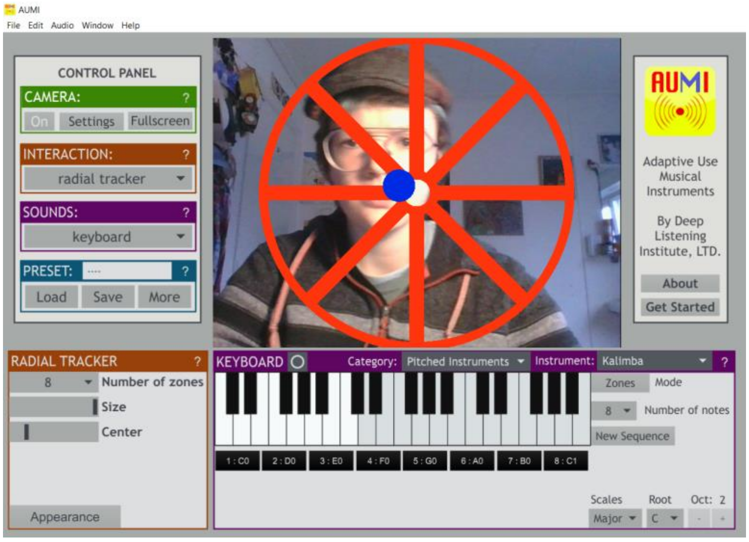

Figure 16: Setting up AUMI

Soundbeam

The Soundbeam[36] (see Figure 17) is a well-known non-contact musical instrument with internal sound generation. Up to four ultrasonic sensors are used to detect a wide range of movements. Through its implemented and customizable soundsets, it allows for exploration of different genres, improvisational soundscapes, sampling, and other playing types. A lot of control and independence are enabled, as well as expression and communication using music. The Soundbeam is mostly used in therapeutic settings, for problems including learning difficulties, autism, dementia, Down's Syndrome, depression, Cerebral Palsy, and challenging behaviours.

Figure 17: The Soundbeam. Adapted from [37]. Cropped

[36] https://www.soundbeam.co.uk/#
[37] https://www.flaghouse.com/Sensory-Solutions/Auditory/Technology/Soundbeam-6.axd

MIDI Creator & MIDI Gesture

The MIDI Creator[38] is a highly adaptable and versatile MIDI controller to which up to fourteen inputs of choice can be connected. The device converts voltage messages of all inputs into MIDI data, using eight presets. There are plans to enable customization of these sets. MIDI Gesture is an input that measures non-touch gestures, in a range set to 1, 2 or 3 meters, using ultrasonic sensors. A voltage is generated based on the degree and distance of the movement to the sensors. The inputs are proportional, making it hard to trigger a particular note, but allowing for expressivity. Both devices, which can be seen in Figure 18, were designed with Special Needs children in mind.

Figure 18: The MIDI Creator & MIDI Gesture. Adapted from [38]

6.5 Relevant DMIs

Voice Controlled Interface for Digital Musical Instrument (VCI4DMI)

The Voice Controlled Interface[39] (see Figure 19) uses a physical input that is often still unused by digital musicians, namely the voice. The interface can be used to influence continuous instrument parameters with minimal latency through generative and adaptive dual-layer mapping. It can also be used as handsfree synthesizer input, though offering limited control. Unsupervised machine learning algorithms and dimensionality reduction techniques are used to create maps between heterogeneous spaces for musical control [36] to maximize the amount of exploration with the voice characteristics of the user. Due to these AI techniques, the amount of expressivity is maximized and the need for user intervention in the system setup is minimized. Control signals are created by the timbre of the voice because this can be measured with minimal response latency. Vocal gestures, which have varying timbres, and vocal postures, which have constant timbres, can be connected to instrument parameters. Pitch and energy from the voice can be connected to key, velocity, and duration parameters.

[38] http://www.muzines.co.uk/articles/midi-gesture-and-midi-creator/7735
[39] https://www.youtube.com/watch?v=dPBszUkNEys

The musician can customize these mappings. The software uses Max/MSP and MATLAB for the programming and uses MIDI to communicate [36]. Max for Live is used to connect the interface with Ableton Live, which is used to select instruments and effects. The user can switch between presets quickly with visual feedback. The goal of the interface is to offer digital musicians an additional type of interaction, though the product should be useable as ADMI, as voice control is a widely accessible type of interaction. However, the product is complicated to use, so is not suitable for people with limited cognition.

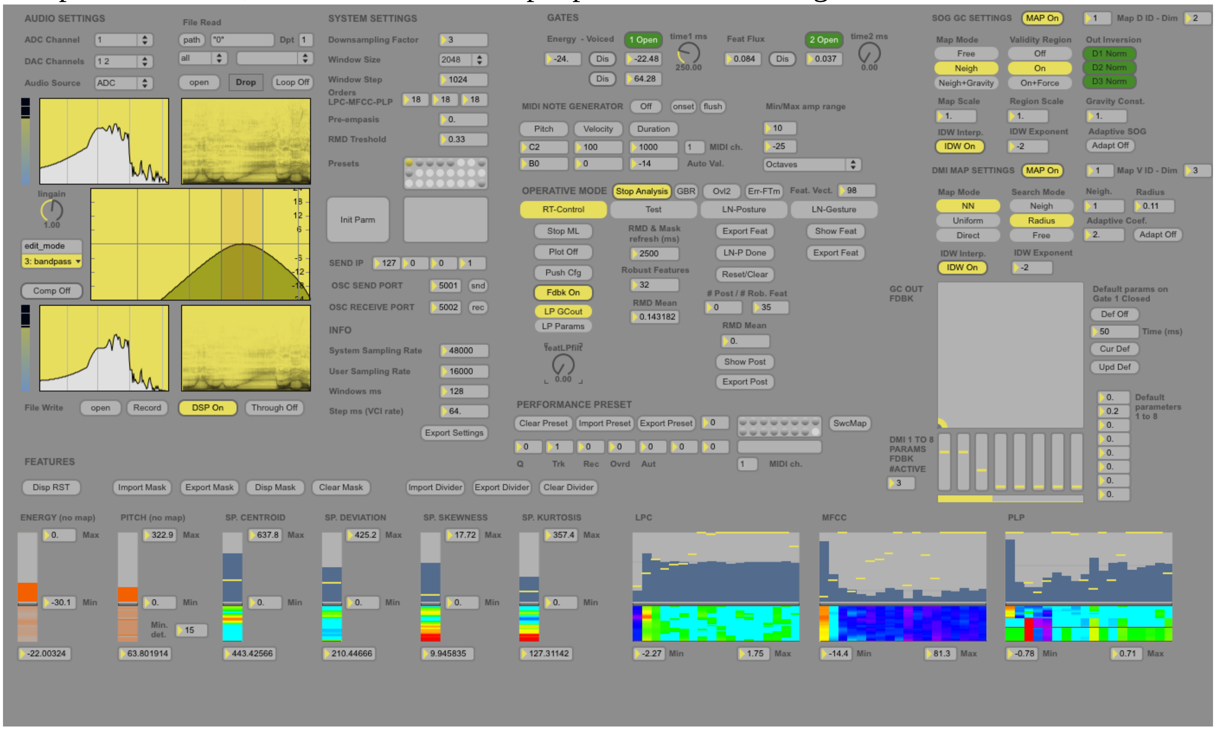

Figure 19: The Voice Controlled Interface for Digital Musical Instrument. Adapted from [40]

Aerodrums

With the Aerodrums[41] (see Figure 20) people can learn, play, and record drums in the air, with absence of an actual drum set. It contains two drumsticks with weighted reflective ends, two reflective foot pieces, a light with special lens and a high-speed camera. A compatible PC is required. The Aerodrums are created to solve space and transport related limitations, not physical limitations. However, the high-speed camera in combination with reflective foot pieces does not require force and can therefore be more accessible than traditional pedals.

[40] https://stefanofasciani.com/2015/05/21/voice-controlled-interface-for-digital-musical-instruments/
[41] https://aerodrums.com/home/

Figure 20: The Aerodrums. Adapted from [42]. Cropped

Theremin

The Theremin[43] (see Figure 21) is a non-touch musical instrument, which uses one antenna for pitch control and one antenna for volume control. It works like a capacitor. Capacitors have two conducting plates with a dielectric in between. Negative charge builds up on one side but cannot cross the dielectric. This causes a change in direction, leading to a circuit with an alternating current. The Theremin contains only one plate of a capacitor, and the musician's hand functions as the second plate. The air in between functions as dielectric. As the musician moves their hand closer to the antenna more charge builds up. The resulting current is mixed with a current produced inside the Theremin, which transfers the frequencies to the range of a piano. The Theremin has an expressive, transparent, and intuitive interaction which offers control over multiple parameters. Subtle changes in movement can be heard, meaning good control over the arms is necessary. However, no force needs to be applied and the amount of control that can be reached is not lesser with physical deformities. Therefore, in some cases, the Theremin or products based on it could be used as an accessible digital musical instrument.

[42] https://www.slagwerkonderdelen.nl/Aerodrums-The-Quiet-and-Portable-Alternative
[43] https://www.youtube.com/watch?v=KDG15-iTJLw

Figure 21: A Theremin. Adapted from [44]. Cropped

MIDI Breath Controller

MIDI Breath Controllers[45] (see Figure 22) use air pressure sensors to turn breath into MIDI messages. For this, a novel signal processing algorithm is used. It is not a stand-alone musical instrument, but enhances expressivity of synthesizers by giving control over volume, expression, velocity cross-fades and more. Minimum and maximum input and output ranges can be set, as well as a sensitivity curve. This means the controller can be customized to fit the user's strength of breath. Its bendable headset can also be adjusted as desired. The controller offers a hands-free way to control MIDI parameters and could therefore be used to increase accessibility of musical instruments.

[44] https://www.bax-shop.nl/blog/muziekinstrumenten/de-theremin-wat-kun-je-ermee/

[45] https://www.tecontrol.se/products/usb-midi-breath-controller

Figure 22: A MIDI breath controller. Adapted from [45]

6.6 Final Overview

This section will provide a brief overview of the findings regarding interactions and technologies in this chapter. Conclusions on which interactions and technologies are fit for design partner Ella will be given in chapter 7.3.

6.6.1 Interactions

There are several interactions covered in this chapter, of which five main interaction methods will be outlined in this chapter. The first interaction method is breath, as used in the Magic Flute, Synthobone, Music Blower and more. Of the devices covered in this chapter, the Music Blower is the only musical instrument that uses solely the breath as interaction. Breath interaction is widely accessible and therefor fit for ADMIs. Furthermore, in some of these instruments the sensitivity is high, meaning less force is necessary. A second interaction that is used a lot is non-contact gestures, as used in the Soundbeam, AirHarp, AUMI and more. These range from controlled arm movements to voluntary movements as small as that of an eye. Some of these devices are very adaptable in the type of movement they track, and therefore very accessible. None of these devices require force, which also enhances accessibility in some cases. The third interaction is head movement, as used in the Magic Flute, Jamboxx, some of the non-contact devices and, when necessary, the Quintet. Head movement is a widely accessible interaction method and therefore accessible. The fourth interaction is finger and hand movement, as used in the Kellycaster, Mi.Mu Gloves, Linnstrument, Synthobone and more. The Mi.Mu Gloves and Linnstrument can be used in many ways and are customizable. They are not designed to enhance accessibility but can be used for this. The Kellycaster and Synthobone are custom controllers that ensure accessibility for the designated users. The last interaction method covered is that of the voice, where timbre changes the sounds. This is a novel interaction method, used in Voice Controller Interface for digital musical instruments (VCI4DMI). The voice is a very widely accessible interaction, and can therefore be suitable for ADMIs.

6.6.2 Technologies

A variety of technologies are used in the described products. The types of sensors that are used depend on the type of interaction. For non-contact gestures, these are ultrasonic sensors measuring distance; infrared sensors measuring reflectance; built-in web cameras; high-speed cameras; and capacitor systems in older devices. For breath interaction, air pressure sensors are used. On top of this, simple switches are commonly used, some of which require little force. For analog input, sliders can be used. Some devices allow for many different sensors to be connected.

The sensors are housed in hardware. For this, various materials and techniques, such as 3D printed parts and woodwork, are used. Sometimes traditional instruments are used, such as a MIDI keyboard or the chanter of a bagpipe. Contrarily, for some ADMIs, the only hardware is a mobile device with built-in web camera. Tripods are commonly used to ensure hands-free interactions. Weight and material of hardware can be important, for example to better measure reflectivity, get a higher quality sound, ensure durability, or enhance ease of transportation. Some devices have their own sound generator, while others require MIDI connection to generate sound. Some ADMIs can work by itself as well as with MIDI. ADMIs and custom controllers are commonly created with Arduino, a popular easily programmable hardware controller. Arduino can be used to gather input from switches and slides, as well as control outputs such as LEDs, motors, and currents. These currents can, for example, trigger solenoids. Teeny is a possible substitute for Arduino.

Sensors allow for the interaction with hardware to be sent to the software of the product, which is responsible for the mapping. Often, quality existing software is used where possible. In some (A)DMIs, custom software is combined with facial tracking software that already exists on most modern devices. Furthermore, Ableton, a popular music software, is commonly used in (A)DMIs. To connect custom software to Ableton Live, Max for Live, which uses Max MSP programming, is often used. Some of the described devices use elaborate renewing software in combination with Ableton Live to enhance possibilities for control. Artificial intelligence, such as unsupervised Machine Based Learning techniques, can optimize possibilities without requiring the musician to manually change settings. In other (A)DMIs, the musician or caregiver can customize settings to increase accessibility.

The decision on the appropriate interactions and technologies for Ella will be made after an evaluation of the design ideas, described in chapter 9.1. This evaluation is part of a meeting for conceptualization, of which other aspects are described in chapter seven. This meeting also leads to the requirements and provisional design plan of the prototype. The final design is described in chapter eight. Chapter nine describes multiple evaluation activities, including the evaluation of this prototype. This helps to reach a conclusion on the research project, which is described in chapter ten.

7. Conceptualization Meeting

This chapter sets the transition from the research phase to the design phase. For this, all findings are discussed in a meeting, which lead to a final overview of feasible interaction methods and technologies. Furthermore, requirements and evaluation criteria are set. Finally, a provisional design plan is created.

7.1 Goal

To combine the previous findings into a product, it is important to get a good grasp on the ideas and expectations of design partner Ella and client Ruud van der Wel. The accessibility of the considered interaction methods needs to be checked. Furthermore, the feasibility of technologies should be discussed. When determining what is most suitable, it is important to know the expectations, preferences and needs of client and design partner, as well as practical resources, such as budget. By combining these findings, a preliminary design plan can be made. Thus, the goal of this activity is to gain means to transition from theoretical to practical approach, and from research to design phase.

7.2 Approach

On the 7th of May 2021, a meeting between designer, client, and design partner took place. This meeting started with an update on the project process and a discussion regarding the planning of the coming weeks. First the minimum and maximum expectations of the design partner and client were discussed. Subsequently, the current ideas for prototypes, based on the music teacher interview and ideation, were communicated. Ella was asked about the expected accessibility of these plans. Furthermore, the client was asked about the feasibility and suitability of the plans. After this, some practical considerations, such as budget and corona regulations, were discussed. The meeting ended with a spoken summary of the results, which was confirmed by all parties involved. This activity, at the same time, had an element of evaluation, which is more clearly described in chapter 9.1.

7.3 Results

The results are combined with all earlier findings, leading to a summary of anticipated interaction methods and technologies that were confirmed during the meeting. This is followed by a list of requirements, which combines client wishes, design partner needs, technological aspects, and more, gathered from all research activities.

7.3.1 Appropriate Interaction Methods

For the sustain and transpose functionalities, two different accessible and unobtrusive interactions are required. These include biting, breath interaction, eyebrow movement and potentially foot movements. The biting switch that is researched before the meeting requires the strength of biting through a small carrot. This is manageable for Ella, and the size of the switch also poses no problems. Whether the sustain should be controlled with single long presses or two short presses depends on the accessibility of both movements. Long presses would be more intuitive and allow for more expressive control. Short presses, however, might be less demanding for Ella. She prefers the long presses and expects this to be manageable. Whether these biting movements are accessible will be evaluated, which is documented in chapter 9.2.

Breath interaction is also a possibility if only short breaths are required. Furthermore, eyebrow movement is accessible, as Ella expects she can make measurable eyebrow motions for an extended period without fatigue. It is not intuitive, but not complex to understand. Ella expects it can work and even showed enthusiasm for the idea. Additionally, small foot movements that require no force may be possible and are preferred by Ella. She also explains she is on medication that limits the progression of the disease, which is now negligible, voiding the concern of future accessibility. To ensure the accessibility of foot movements, it is decided that an evaluation activity will take place. More on this choice can be found in chapter 9.1. The evaluation on interaction methods can be found in chapter 9.2.

Ella expects she will use the sustain more than the transpose functionalities. She expects not being able to use the sustain is more limiting than not having access to transpose functionalities. Thus, the sustain should be linked to the most suitable movement. For the sustain, only one movement is necessary. For the transpose function, two movements are required. Some actions, such as turning on the keyboard and changing settings, are only needed at moments Ella is not actively playing the keyboard. The required movements should still be accessible, but do not need to be unobtrusive. For such actions, her hands are an intuitive and manageable interaction. However, the necessary movement should be within a small range. This can either be near Ella's body or near the keys she is already interacting with. The latter is preferable, as it requires smaller arm movements.

7.3.2 Appropriate Technologies

Ella owns a Samsung Galaxy XCover 4s, HP laptop ENVY x360 13-ay0xxx and Apple MD528NF/A iPad Mini. The latter uses operating system iOS 9.3.5 and cannot be updated further. Ella tried to use her keyboard with her iPad before with apps Beathawk, Garageband, Sampletank CS, Syntronik CS, KORG Module, Groovebox and Aparillo, but was unable to use most of them. She was unable to install them on the iPad, expectedly due to the outdated operating system. Still, it is expected that at least one application that can send MIDI messages to change the necessary settings can be found. These software applications are more qualitative, efficient, and steady than the software that can be created within the scope of this project. Therefore, if an existing application is accessible and contains the necessary functionalities, this is preferred over custom software. To control the software, two buttons that require little force should be connected. These exist and are already used by My Breath My Music.

Bite switches already exist and can be purchased[46] (see Figure 23). The switch is FDA approved, so, from a safety standpoint, more suitable than a switch that can be created in the scope of this project. As described in chapter 7.3.1 this switch meets the requirements of small and light enough. If foot movement is used, two light to no pressure pedals are required. Possibly, there are suitable products available off-the-shelf. If not, it is feasible to create them. Movement can be measured in different methods, requiring different technologies. There are two feasible options for this project, namely ultrasonic sensors or active infrared (IR) sensors.

[46] https://store.airturn.com/products/airturn-bite-switch

An ultrasonic sensor sends out a sound above the frequency range humans can hear. This sound is reflected by any object or body part that nears the sensor. The time it takes for the reflected sound to be received is turned into a value that relates to the distance of the object to the sensor. This is also represented in Figure 24. In IR sensors, the phenomenon is the same, but infrared light is used instead of sound. Sensors that include light are more prone to error on stage, as there can be many lights and movements. Thus, the ultrasound sensor is a better option. If, however, the IR sensor is used, a quality housing is required to avoid noise.

Figure 23: AirTurn bite switch. Taken from [46]

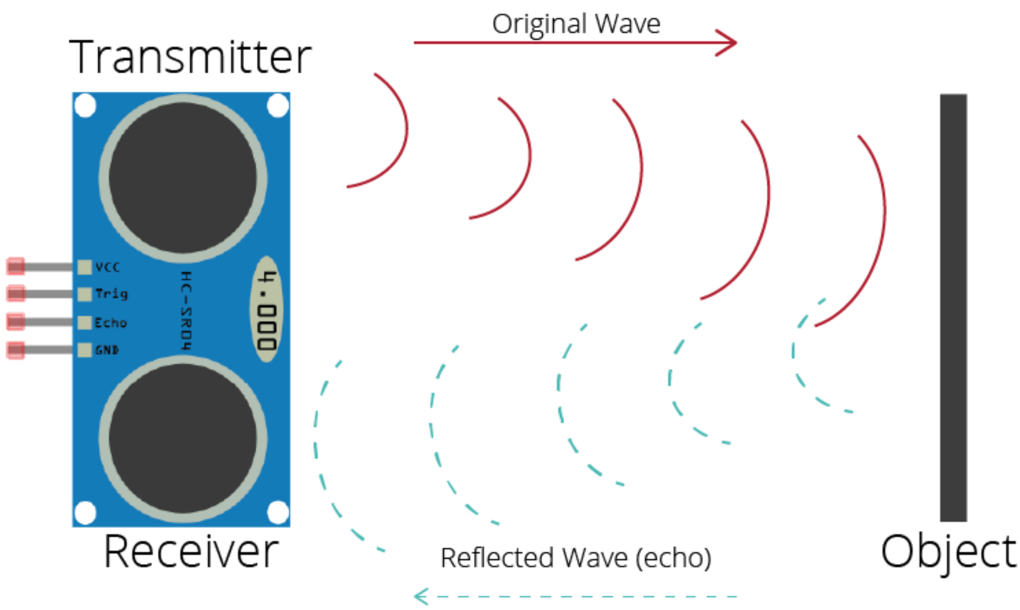

Figure 24: Schematic of an ultrasonic sensor. Taken from [47]

[47] https://randomnerdtutorials.com/complete-guide-for-ultrasonic-sensor-hc-sr04/

The minimal distance of the sensors should be considered when researching and purchasing, as sensors with three millimetres or three meters minimal distance require different hardware and amounts of space. It is best to have a small minimal distance, so that the set-up is compact and there is a lower chance of error due to movements of band members or decor. With both sensors, the sensitivity is important, as this decides the minimal amount of movement necessary. The exact size of the required movement depends on the values chosen in custom software. The sensors can be connected to an Arduino with simple software. This software should receive two analog inputs and transfer them into two MIDI messages depending on their values. Both the Arduino and tablet should be connected to the MIDI in/output of the keyboard. For this connection, a break-out cable or MIDI interface box is necessary.

In many cases, a smart plug can be used to turn devices on. To evaluate if this is possible on Ella's keyboard, the keyboard button should be held down while power is applied [37]. If the keyboard turns on in this case, a smart plug is effective. The keyboard should be plugged into a smart plug, after which the power to the keyboard can be turned on and off with the corresponding software [37]. The keyboard on/off button should then be kept in the on state. If necessary, the button dan be pressed down with a marble and piece of tape. Depending on the type of keyboard, the keyboard can also be set to always turn on when receiving power with a menu setting [37]. If the keyboard does not turn on in this case, it may be better to use a different keyboard. The client stated that if a modification is not doable with Ella's current keyboard, the best solution may be to use a different keyboard. In this case, the keyboard would have to be a light playing one, at least as light as the one Ella currently uses. Additionally, this new keyboard needs to work with MIDI, which is the case for most modern keyboards. Preferably, it also turns on in the situation described before. Alternatively, there are MIDI keyboards that use less electricity and can be powered through MIDI. Such a keyboard can be connected to a device, which will power the keyboard when it is turned on [38]. Computer settings can usually be adjusted to turn USB outlets off when the computer shuts down. This should be done if the keyboard does not automatically shut down when the computer is turned off. In conclusion, for turning the keyboard on a smart plug, new keyboard and/or MIDI connection device are necessary.

7.4 Requirements

It is important to set up a list of requirements for a successful product. Requirements are conditions that the product should meet to be a suitable solution. These requirements can guide the design process, as well as provide standards for the evaluation stage. They reflect wishes from Ella, her music teacher, and the client, as well as practical, technical, and ethical possibilities and limitations. The requirements for this prototype are determined based on this meeting, and described in Table 1.

Table 1: Requirements of the prototype

Requirement	Explanation	How to evaluate
The prototype is sufficiently accessible for Ella.	Ella can use the prototype once it is set up. She can independently control every function the prototype is aimed to replace and can manage to do so for 2 hours on end (duration of performances,	Ella can effectively control every functionality the prototype is meant to control. She does not get too fatigued to continue during

	rehearsals, and private practices). Independence is an important goal of the project, as it can increase participation and confidence, therefore adding to Ella’s quality of life.	her regular practice session, which lasts 2 hours.
The prototype works with a light-playing keyboard.	Due to loss of muscle strength, Ella can only reasonably play on light-playing keyboards. The solution should work on her current keyboard, which is preferred, or one that plays at least as lightly.	The prototype functions with her current keyboard or a new keyboard that does not require more force.
The prototype functions well.	Though some error is allowed and may not be noticeable by an audience, a lot of errors would make the solution obtrusive. Whether an error is acceptable depends on the type and severity of the error, although even minimal errors may be problematic if they occur often. Furthermore, to function well, the prototype should have minimal latency, one that is not noticeable. Overall, the prototype should be useable in relevant contexts, and Ella should have confidence in its ability to function sufficiently.	All functions of the prototype can be used during performances, rehearsals, and practices without new frustrations. Ella does not notice a latency while playing.
The prototype is durable.	The value of the solution is higher if it keeps functioning well for a long time. This is also better from an economic and ecological standpoint. Durability can be increased by making separate elements replaceable. If a single sensor breaks, it would be best if the sensor can be replaced without damage to other parts.	A scientific evaluation is outside of the scope of this project, as the project is short term. However, there should be no damage to the prototype during the practice sessions that take place during the project. Furthermore, products that are expected to be durable should be used. Fragile parts and parts that are used a lot, such as sensors and connectors, should be replaceable without damage to other parts.
The final material costs are under 900 euros.	Economic considerations are not a limiting aspect of this project, as, since adaptations are often expensive, sufficient budget is available. Furthermore, the value of this product for Ella and others who	The final costs are 400 euros. If this is exceeded, this is explicitly discussed with the client with as much information as available. The exceeding of this

	implement it is higher than reasonable monetary costs. However, the solution should aim at a few hundred euros of monetary costs, and higher costs should correspond to a significantly better solution. Purchases of large sums should be discussed with the client.	budget should lead to a significant improvement in another requirement, such as durability, accessibility, or independent control over functionalities.
Ella can turn on her keyboard independently at home.	If Ella can turn her keyboard on independently at home, she will be able to practice when her mother is not home. This adds to her freedom and independence, and thus quality of life.	Once set up, Ella can turn on the keyboard without help.
The prototype replaces the sustain.	The sustain is important on any piano or keyboard, as it can add to its expressivity. For Ella, the sustain is even more important, as it would enable her to keep keys pressed for a shorter moment, which would make the keyboard less demanding to play.	Ella can successfully sustain notes when desired for as long as desired.
The prototype allows Ella to change common settings.	Being able to use common functions on a keyboard adds to the possibilities in playing. Especially as Ella progresses and becomes better at playing, it can transform her performance to be able to change the settings to what is most appropriate for the song. This can also enable more styles and variation. Furthermore, being able to use common functionalities can add to confidence and participation of Ella as she can do something most people can do.	After set up, Ella can use the prototype to change settings such as volume, type of sound and effects independently.
The prototype enables Ella to transpose octaves without pausing.	The transpose function (octave up and octave down) is linked to nonobtrusive movements that can easily be triggered while playing the keyboard. The latency should be minimal or at least steady so that the latency can be accounted for by Ella while she is playing. The audience should not notice the latency.	Ella can use the transpose function when desired with a latency that is not noticeable for an audience.
The transpose and sustain functionalities can be used at the same time.	To switch between octaves in a way that allows more freedom in playing, the transition should be smooth and thus not limit another	Ella can trigger the transpose while the sustain is already triggered.

	function that should be used during songs. Thus, the interaction methods for the transpose and sustain should be so that they can be triggered at the same time.	
The solution is easy to learn and use.	Ella is already learning how to play a musical instrument. Though using a new interaction can take some time to get used to, it should not be overcomplicated, as this would negatively impact Ella's learning and playing experience.	Ella makes noticeable progress within three regular practice sessions.
The documentation on the prototype is clear enough for the prototype to be recreated.	The documentation needs to be sufficiently clear to avoid errors in recreation. Especially unsafe situations should be avoided. The documentation should be understandable for at least someone in Ella's environment, so that they can set the prototype up for her and fix common issues when technical difficulties occur. For this, Ruud van der Wel would be suitable, as he is present for performances. He might also be in contact with someone that can benefit from similar set-ups.	The client understands the main workings of the product and understands the details when inspecting the relevant documentation. He should feel confident that he could recreate the product for someone else using the documentation as main source.
The set-up is simple and can be created and fixed by amateur digital musicians and engineers.	After this project, the prototype will be placed online on an open-source basis. The prototype can create value for more people worldwide if it is manageable to recreate for people who only have some experience with wiring and programming. It is acceptable if people must investigate the topic a bit and spend some time on understanding the concept. However, it should be possible to recreate for someone who is above averagely experienced in engineering concepts. This way, most people will know someone who can recreate the prototype.	If the documentation is shown to someone in the first year of Creative Technology, they are confident they can recreate the set-up within a week.

7.5 Provisional Design Plan

The requirements and research conclude in the following preliminary design plan. For turning on the keyboard, suitable smart plugs will be researched and ordered, if effective with Ella's keyboard. The software of these plugs should work with an operating system Ella uses.

For the sustain, a bite switch will be connected to the sustain input of the keyboard. Depending on the results of the interaction method evaluation (see chapter 9.2), the switch signals may need to be reprogrammed using Arduino. This would turn the sustain on with a single press and off with a second press. Alternatively, if the switch is directly connected to the keyboard, the switch needs to be held for the duration of the sustained note. The switch or its custom software only sends 1(on)/0(off) messages, the keyboard will receive this input and manage the sustain. For the transposing, two ultrasonic sensors in strong housing will be connected as an input to an Arduino. A custom software will transfer the distance values into movement categories. These will be programmed into MIDI messages for transposing, which are sent to the keyboard. Alternatively, the same MIDI messages will be linked to values of eyebrow movement using camera input. If the latter is done, a mount for the head should be made, so that the expressive head movements Ella makes do not lead to errors. This ensures that the eyebrow movement is unobtrusive. To change the sounds on the keyboard, an existing application that can send programme changes will be used. In this application, sound settings can be pre-programmed and ordered in a setlist. Two light pressure buttons near Ella's hands will be used to go through this setlist. The design process will be done in the order described here. Thus, the solution to turn on the keyboard comes first. Then, the bite switch is connected to the sustain. Afterwards, hands-free transposing is implemented. Lastly, the changing of additional settings on the keyboard is implemented. The plan described here is preliminary. It may change due to new knowledge, technical difficulties, evaluation results, or other aspects that are not yet considered. The final prototype is described in the following chapter. Then, chapter 9.3 and 9.4 cover the evaluations of this prototype. Based on these and earlier findings, a conclusion will follow in chapter ten.

8. Implementation

This chapter describes the developed prototype. In the first subchapter, its hard- and software and their connections are introduced. Then, subchapters will zoom in on the interaction and technology of separate parts. The connections will be illustrated with schematics, the interactions will be shown in pictograms, and the feel of the prototype will be shown in pictures. Furthermore, at the end of the chapter an overview of the associated costs is given.

8.1 Product and Connections

The prototype uses multiple types of hardware and software, which are connected as follows. Firstly, the light-playing keyboard Ella already used is connected to a smart plug that can be turned on with a remote controller to turn the keyboard on. Secondly, a bite switch is rewired and connected to the sustain input of the keyboard. Thirdly, ultrasonic sensors, which are housed in wooden pedals, and a light pressure button are connected to an Arduino, which sends transpose values to a Max MIDI effect. Fourthly, Ableton Live receives MIDI input from the keyboard (including the sustain state) and sends this through the MIDI effect using Max for Live. Fifthly, the Max software causes a transpose in the MIDI note, and the changed MIDI message is sent back to Ableton Live. Sixthly, the Ableton Live set can be controlled using a mouse that is easy to use for Ella, which she already owns. In this set, she can change volume, voices, effects, and many more settings. Lastly, the Ableton Live audio output can be sent to a speaker or back to the keyboard, which will then play the sounds. Figure 25 portrays these connections in a schematic view. Figure 26 shows the connections of the breadboard and Arduino.

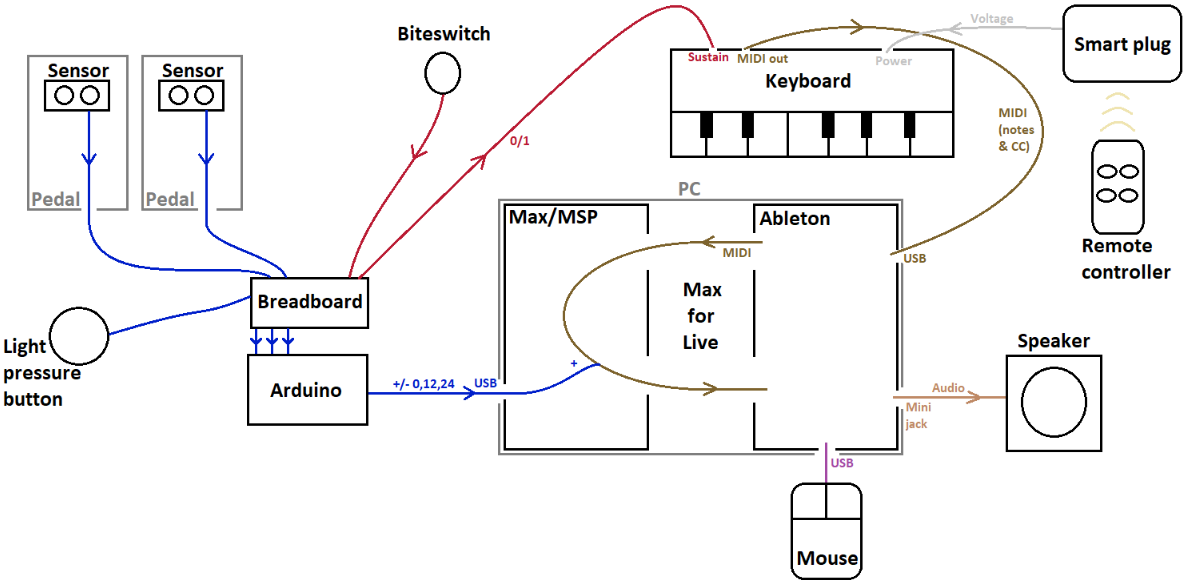

Figure 25: Schematic of full prototype

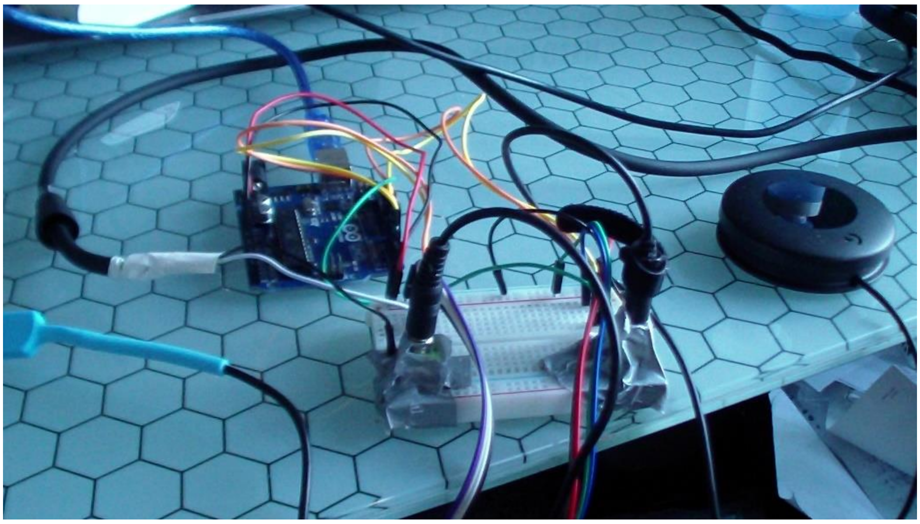

Figure 26: Arduino and breadboard wiring

8.2 Smart Plug

Figure 27: SecuFirst smart plug. Adapted from [48]

One of the design goals was to enable Ella to turn her keyboard on independently. For this, a smart plug with remote controller is used. A SecuFirst SEC24 set[48], seen in Figure 27, was ordered and sent to Ella's residence. The choice for this smart plug was motivated by three main aspects. Firstly, it should be useable with the technology Ella has access to. Ella does not own a smart home hub, which excluded a lot of smart plugs. Furthermore, Ella owns Apple devices that operate on old software. Smart home applications are a more recent trend, and therefore incompatible with old operating systems. Secondly, the smart plug should be easy to set up, as Ella cannot do this herself. If the smart plug is easy to install and set up, Ella does not need a helper with specific skills. Furthermore, little effort is required of a helper. This, in practice, means Ella experiences less dependence and can start using the prototype

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[48] https://www.bol.com/nl/nl/p/sec24-schakelaarset-met-afstandsbediening-wit-3-delig-met-randaarde-alleen-geschikt-voor-nederland-haf760s/9200000102763138/?s2a=

more quickly. This is again beneficial if she ever purchases a new keyboard, places her keyboard elsewhere or changes residence. Lastly, the plug has a convenient shape and size, which allows it to be used without blocking other sockets. This way, it can remain plugged in without problems. Figure 28 shows schematics of the connection of the smart plug. The power cable of the keyboard is connected to a smart plug, which is connected to a wall socket. With the remote controller, the smart plug can be turned 'on' and 'off'. When the smart plug is on, it sends the voltage of the wall socket to the keyboard. When it is off, it does not transfer this voltage. The power button of the keyboard is kept in the on state. The remote controller should be kept in a place that is accessible for Ella. The smart plug solution does not work with every keyboard. When purchasing a new keyboard, Ella should keep this in mind.

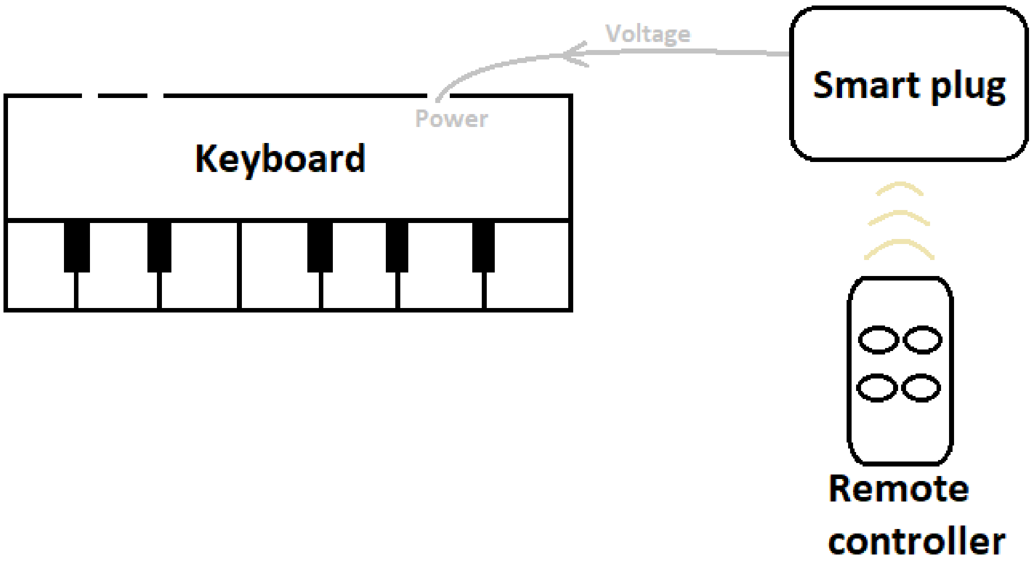

Figure 28: Schematic of smart plug connection

8.3 Sustain

The sustain can allow for more expressive music making and lower the physical demands of keeping keys pressed. When the sustain is triggered, the key can be released and will keep sounding. In this prototype, the sustain is controlled with a bite switch instead of the usual sustain pedal. The sustain switch can function with only the keyboard, as well as with the Ableton Live software.

8.3.1 Interaction

The bite switch sustain works like a regular sustain pedal. When the bite switch is pressed, the notes on the keyboard are sustained, within the limits of the selected voice (type of sound). When the bite switch is released, the sustain stops. Figure 29 shows this interaction schematically. The switch is placed in between the front teeth, as can be seen in Figure 30. A click can be felt when the switch is pressed. The bite switch that is used requires only a small movement of the mouth, with the pressure of biting through a small carrot.

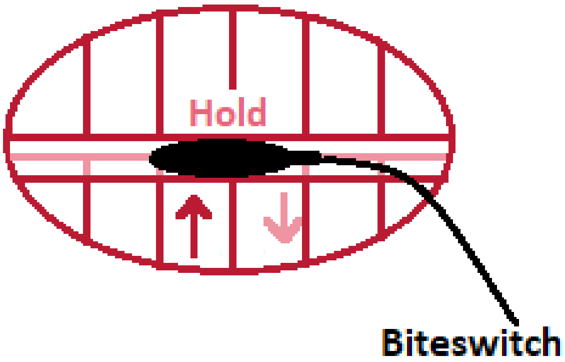

Figure 29: Schematic of bite switch interaction

Figure 30: Bite switch placed in mouth

8.3.2 Technology

The keyboard has a standard 6.3mm jack input for sustain pedals. The bite switch has a 3.5mm mini stereo jack as output. While the mini jack looks stereo, the data that is transferred is of mono type with an uncommon mapping. A schematic of how the signal is sent can be seen in Figure 31. Due to this mapping, a regular mini jack to jack plug does not suffice to send the signal into the keyboard. Therefore, the stereo mini jack is connected to a breadboard using a mini jack to breadboard socket. From here, it is connected to the keyboard using two jump wires soldered to the wires of a 3-meter jack cable. In the process of wiring, the bite switch is kept intact. Another possibility would have been to cut the mini jack plug off and solder the wires to those of a jack cable directly. This would, however, void the warranty and make the switch more difficult to replace if problems occur. The switch is the most used part of the sustain solution, and therefore likely to need replacement before the jack cable. The connection of the bite switch and keyboard can be seen in Figures 32 and 33. The jack cable goes into the sustain input of the keyboard. The internal software of the keyboard manages the input and turns the sustain on and off. The cable and switch form a circuit with the keyboard, as seen in Figure 34, which constantly sends a small voltage to the jack output. The circuit is open when the switch is not pressed. The voltage cannot go through, which means there is no signal and the sustain is off. When the switch is pressed, the circuit closes, letting the voltage through, which means the sustain is on. When the keyboard is connected using MIDI cables, the state of the sustain is sent as a Control Change (CC) MIDI message upon trigger and release. The sustain corresponds to the CC 64 message, and comes with a 127 (sustain is turned on) or 0 (sustain is released) message. Figure 35 shows the MIDI monitor in Ableton Live in which the sustain states are sent.

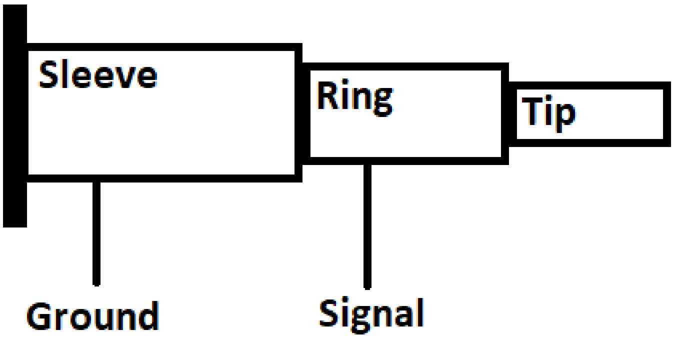

Figure 31: Schematic of mini jack output

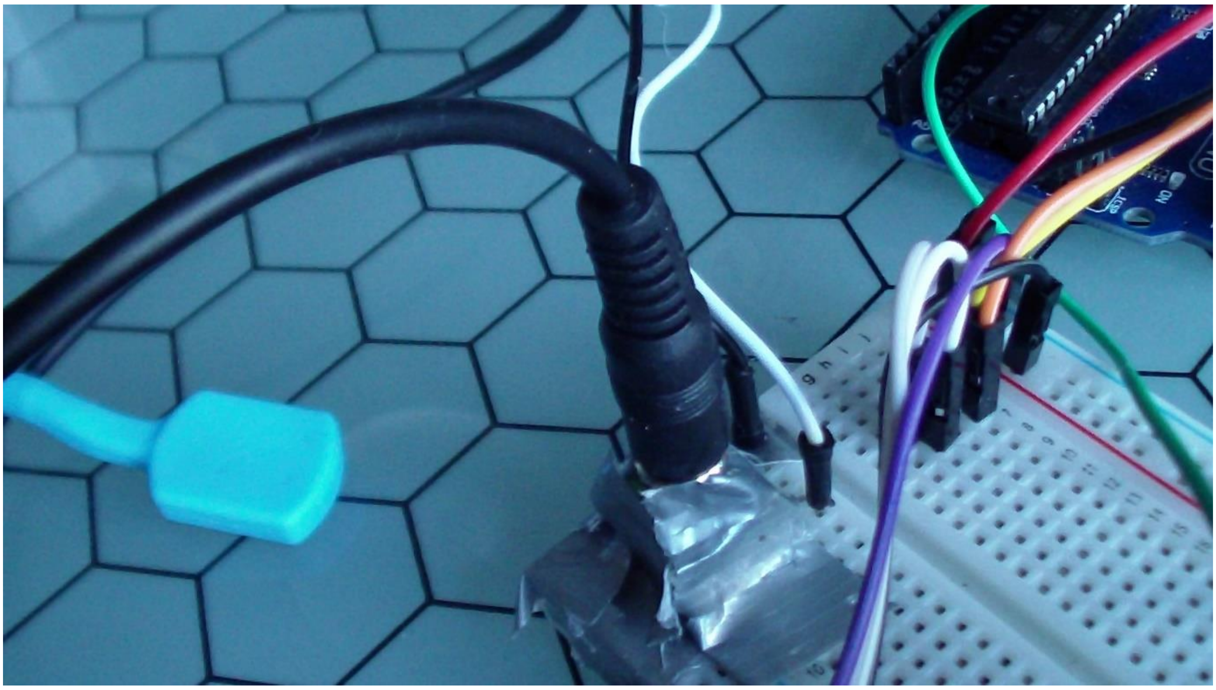

Figure 32: Wiring of mini stereo jack to jack cable

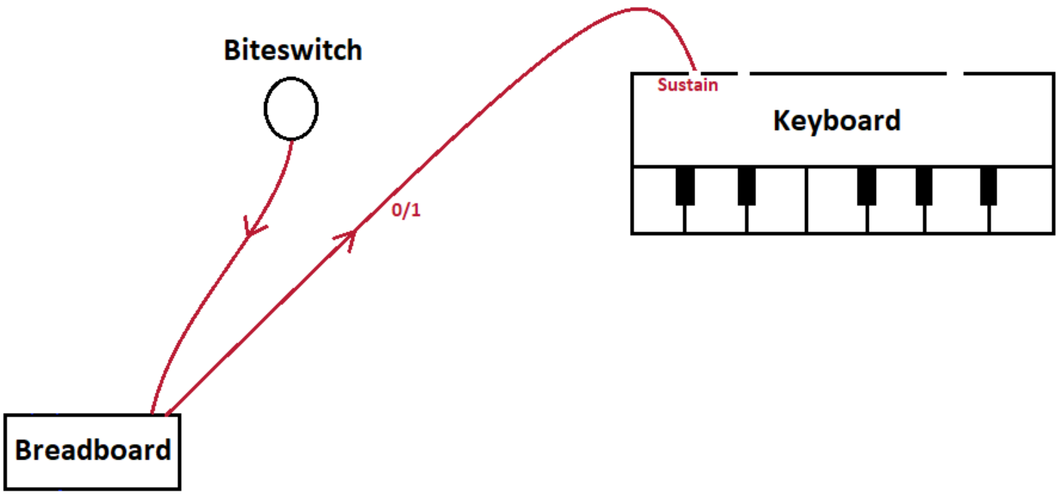

Figure 33: Schematic of sustain switch connection

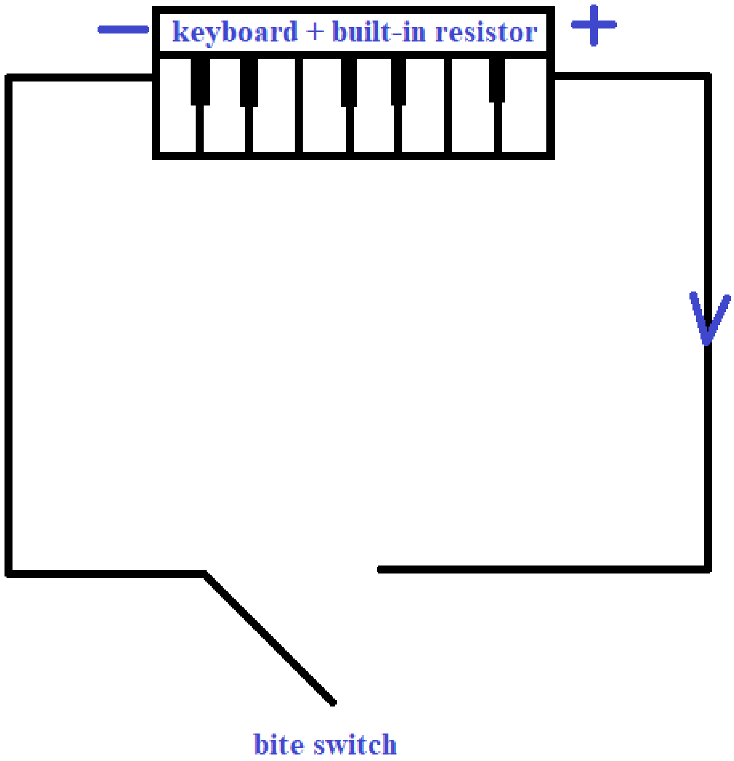

Figure 34: Electrical circuit of the sustain function

Figure 35: Ableton Live MIDI monitor showing incoming MIDI messages

8.4 Transpose Pedals

In keyboard playing, transposing means that all keys are set to different notes with a predetermined number of semitones. For example, all keys sound three semitones higher than usual. Some small keyboards have two simple buttons for transposing an octave up and down to increase the range. Since the goal is to enlarge the range of Ella, the transposing used in this project will be comparable to the function of these octave buttons. However, this prototype will allow Ella to change these settings handsfree. This way, she can individually play a full range keyboard without having to pause to change transpose settings. The transpose settings are controlled by two pedals that react to small foot movements.

8.4.1 Interaction

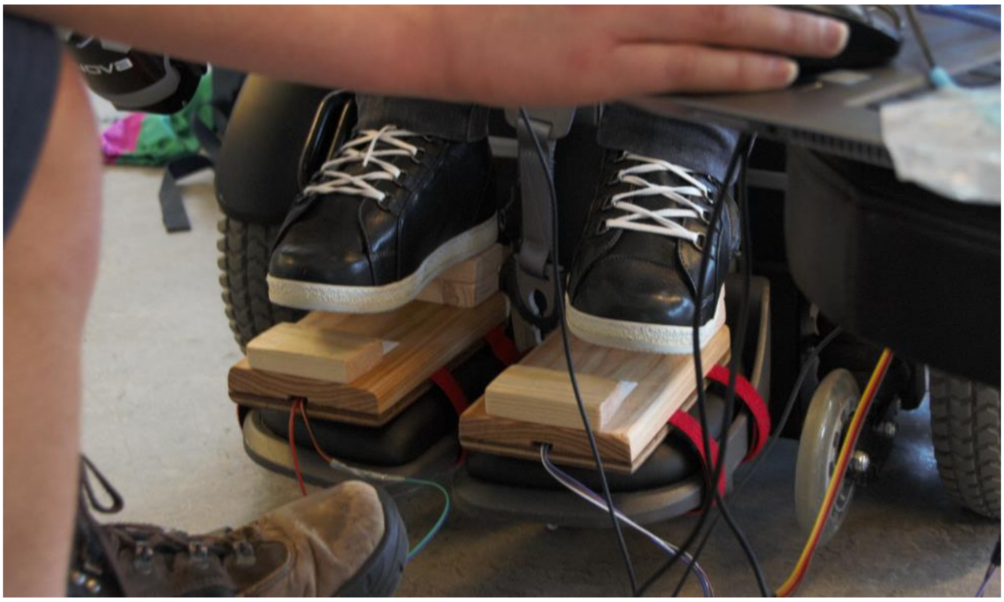

Figure 36: Transpose pedals attached to wheelchair footrests

The pedals are attached to the footrests of Ella's wheelchair, using the attached Velcro bands, as can be seen in Figure 36. Her feet are placed on the pedals in a position and at an angle that is comfortable. This is achieved by setting the footrests with the existing functions of the wheelchair. Once her feet are placed, she presses a light-pressure button. This is repeated when measurements are inaccurate or inconsistent. It can also be done in between songs to limit inaccuracies of measurements. Ella can transpose an octave by moving the front of one foot up and down calmly, as shown in Figures 37 and 38. If the foot is held up for a longer period, the notes will be transposed multiple octaves. It is therefore important to put the foot back down after reaching the desired transpose level. The required movement can be set to a quicker or slower pace in the software code, and the size of the required movement can be set to larger or smaller. Ella has two such pedals, one for each foot. The right foot can be used to transpose up, and the left foot to transpose down. This can easily be switched if desired. When Ella has both feet up and both feet down, no change occurs. A schematic overview of what changes occur with which foot movement can be seen in Figure 39.

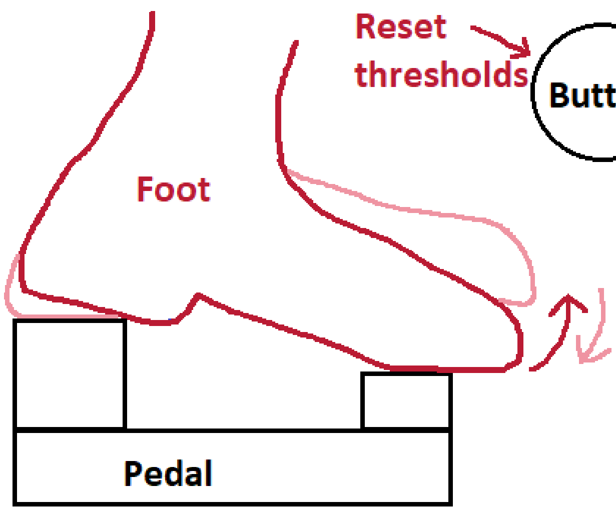

Figure 37: Schematic of required foot movement

Figure 38: Foot movement default and trigger, subsequently

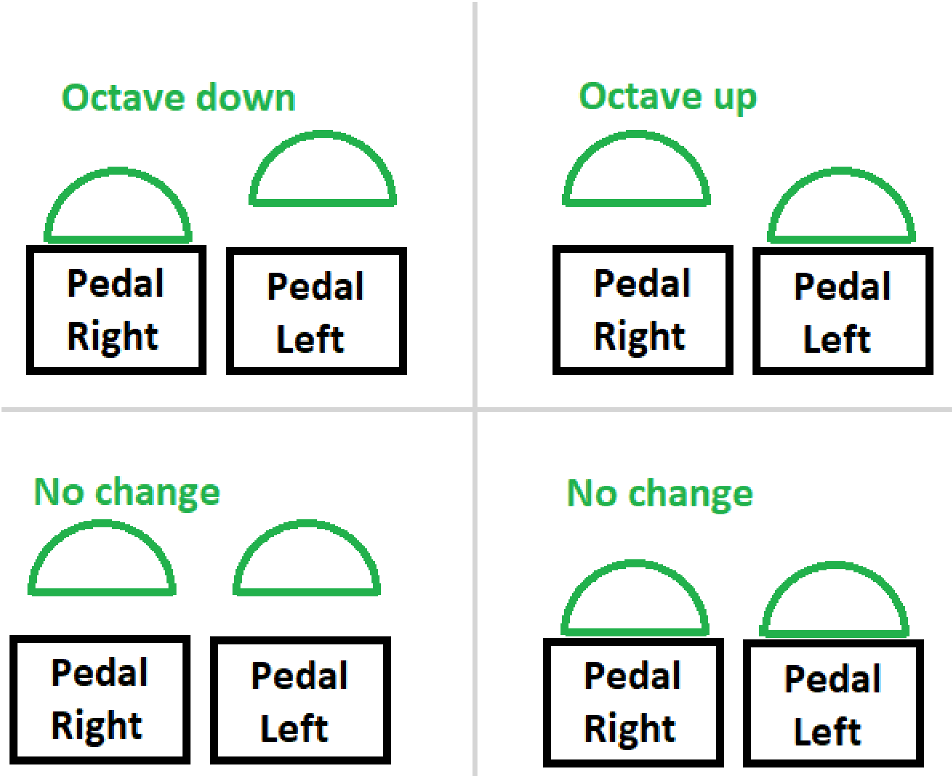

Figure 39: Schematic of transpose changes corresponding to movement (front view)

8.4.2 Technology

The pedals consist of ultrasonic sensors with housing. The housing is handmade from Canadian wood using hand tools. Figure 40 shows which parts the pedals consist of. The top wood layer of the base has two holes, one for the sensor, and one for the cables to exit the pedal. The transmitter and receiver of the sensor need to remain unblocked, but a simple sticker is used to conceal the other parts of the sensor. This offers some protection from dirt and damage and helps the accuracy of the measurements by limiting interference from other angles. On the bottom of the base, a thinner plank is attached, which has a small cavity to ensure straight and steady placement of the sensor. The two planks are attached using screws. This way, they can easily be taken apart if there are issues with the sensor or wiring. Bands of Velcro are clamped in between the planks, so that the pedals can be attached to the footrests of Ella's wheelchair. On top of the base, three wooden blocks are attached to ensure an appropriate distance from the sensor, which leads to more consistent readings and protects the sensor. Furthermore, the blocks enable an ergonomic position and angle for the foot, at which little force is needed to make the necessary movement.

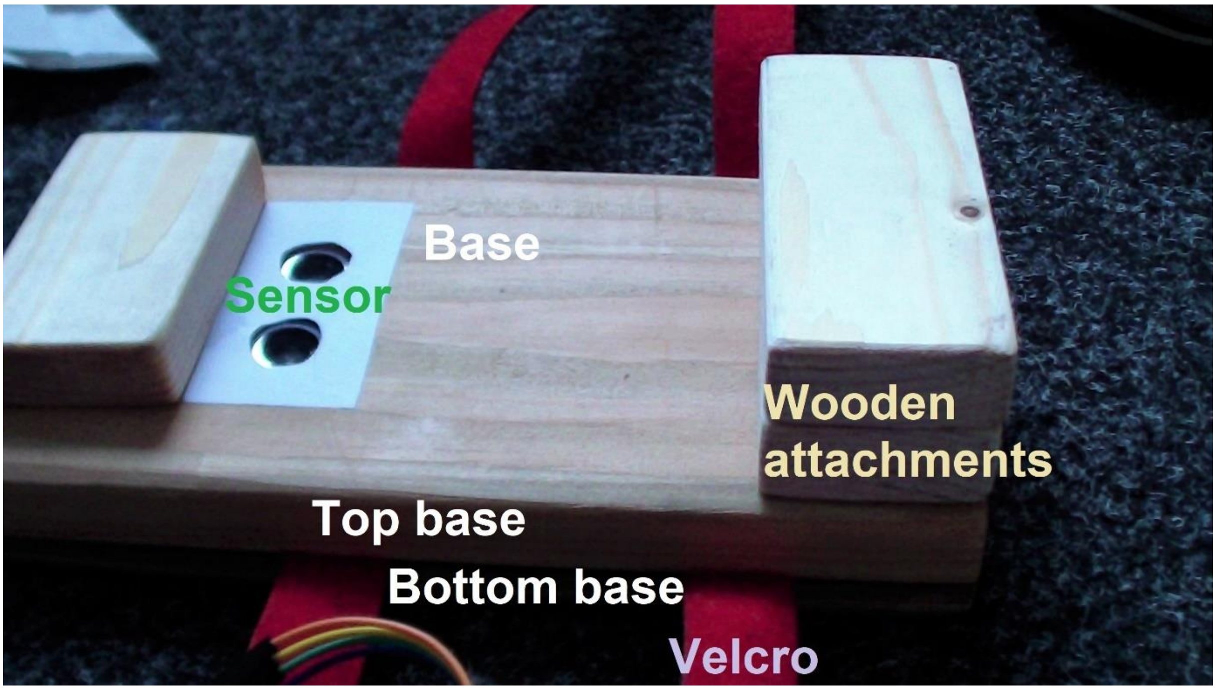

Figure 40: Transpose pedal and its separate parts

Both ultrasonic sensors are wired to an Arduino breadboard, to which a light-pressure switch is also connected. The latter is done with a mini jack to breadboard socket. Through the breadboard, the sensors and switch are connected to an Arduino Uno, which is connected to an USB input of the PC using a serial cable. The Arduino receives its power from the PC and sends data to the PC. A schematic overview of these connections can be seen in Figure 41. When the code is launched or the light-pressure button is pressed, the Arduino software sets the current position of the feet as the default position. The threshold for movement, which decides when the transpose function is triggered, is set to this default plus a pre-determined value. This value can easily be adapted to require larger or smaller movements and can also differ per foot. A higher value requires larger movements and is thus more physically demanding but will lead to a higher accuracy. A lower value is less demanding, but may give more inconsistent readings. The values of the sensors are measured at a regular interval, which can be changed to require slower or faster movements. The interval should give the user just enough time to place the foot back down after triggering a transpose. A lower interval allows for quicker changing of settings, but decreased accuracy due to accidental retriggering. With a higher interval, physical demands decrease, and accuracy increases, but more time is needed to change the settings.

A function in the code is triggered when a foot is moved up so that the measured value of the sensor surpasses its threshold value. This function sends a value to the PC, depending on which foot is moved up. This value is either +12, when only the value of the right sensor surpasses the threshold, -12 when only the value of the left sensor surpasses the threshold, or 0 when both or neither value surpasses the thresholds. This is shown schematically in Figure 42. The amount of change is then added to the current transpose value, which is sent to the PC after every measurement. The pluralities of 12 allow for octave changes, meaning the height of the sound is changed, but the key remains the same. Technically, this plurality can be changed for certain purposes, but this goes beyond the original goal of the transpose values. The maximum and minimum transpose values can be customized. For this prototype, the user can go two octaves lower and higher, allowing for five octave settings in total. This range can easily be changed, if it suits the needs, preferences, and repertoire of the user.

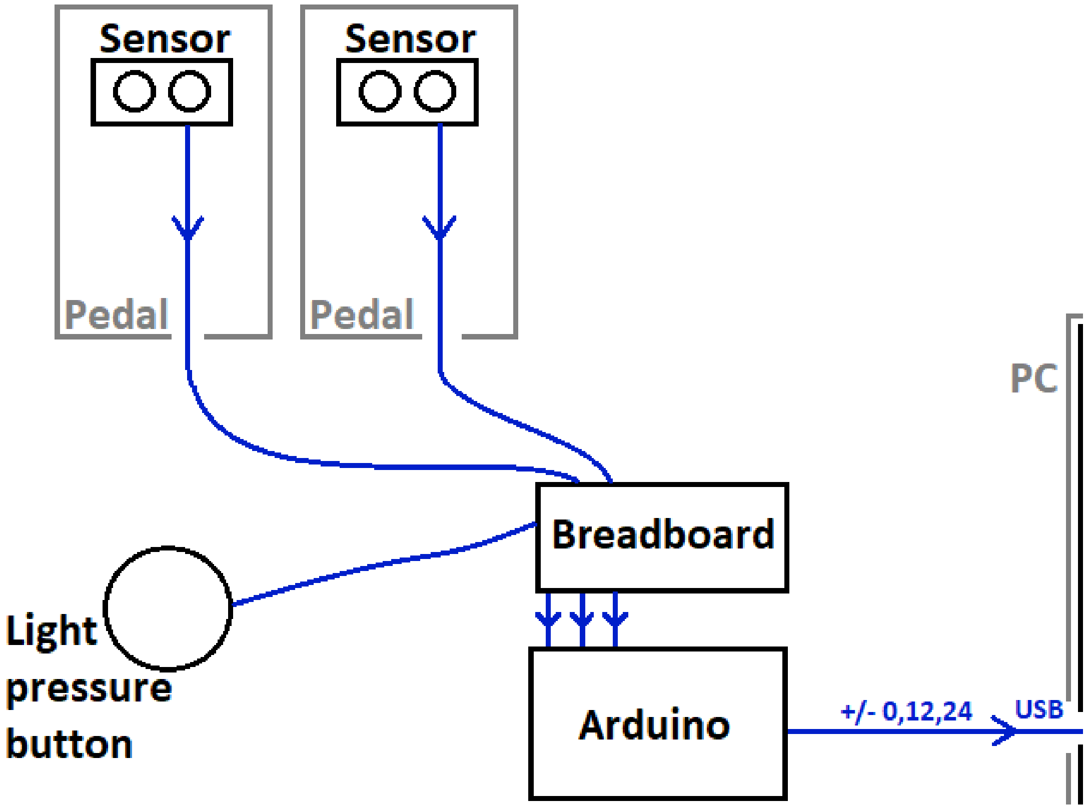

Figure 41: Schematic of transpose pedal connections

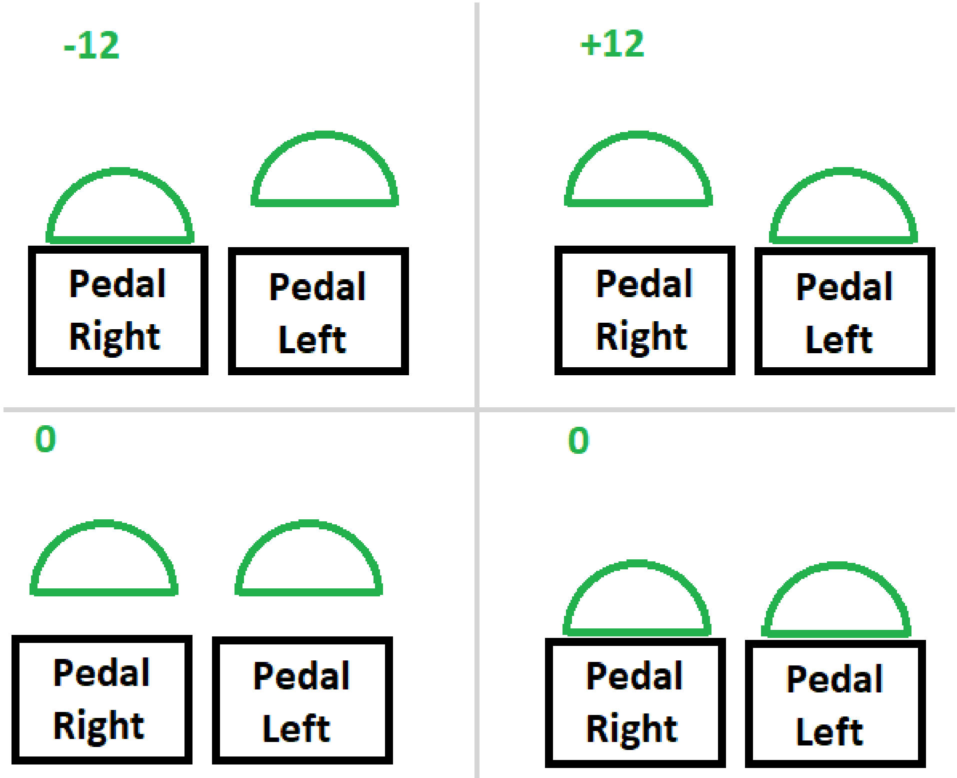

Figure 42: Changes of transpose amount corresponding to movement

8.5 Max Software

Max/MSP is a visual programming language, that can easily be connected to Ableton Live using a Max for Live plug-in. In this prototype, a plug-in is written which receives information about the transpose states from the Arduino and alters the notes received from the keyboard accordingly. The keyboard is connected to a laptop using MIDI (see chapter 5.3), and its MIDI messages are received by Ableton Live and sent into a Max for Live MIDI effect, in which the note information is altered. The alternative to a MIDI effect is an audio effect, where the keyboard information is already turned into audio, then sent into the Max effect. With an audio effect, the timbre of the sound can change and noise may occur. The bigger the transpose value, the larger these changes. With a transpose of two octaves, there is an obvious reduction in sound quality. A MIDI effect does not have problems with noise or change of the sound's timbre. Furthermore, a MIDI effect causes no considerable latency. The MIDI effect contains a toggle button which can be pressed to turn on the Arduino input. Before receiving input, the transpose value is 0. When the Arduino input is turned off, the last received value remains. The Arduino input is received through serial communication. At the same time, MIDI messages from the keyboard are received with a MIDI to USB interface. These messages are immediately sent into the MIDI effect using Ableton Live and the Max for Live plug-in. The MIDI message is unpacked into its separate elements, after which everything but note information is repacked. The note information is unpacked into its two separate elements, note number and velocity. The value received from the Arduino (-24, -12, 0, 12, 24) is added to the note number. The new value is repacked with the unchanged velocity and the packed values are added to the rest of the MIDI information, which is sent back into Ableton Live. In Figure 43, a schematic overview of the connection between the Arduino input, MIDI input and Max MSP programme is shown. In Figure 44, the Max MSP code for the MIDI effect is visible, including some notes on which parts manage each functionality. In Figure 45, an Ableton Live MIDI monitor is placed before and after the MIDI effect, to show the note changes that occur. With the received transpose value of 12, the notes on the second monitor become an octave higher (C4 instead of C3).

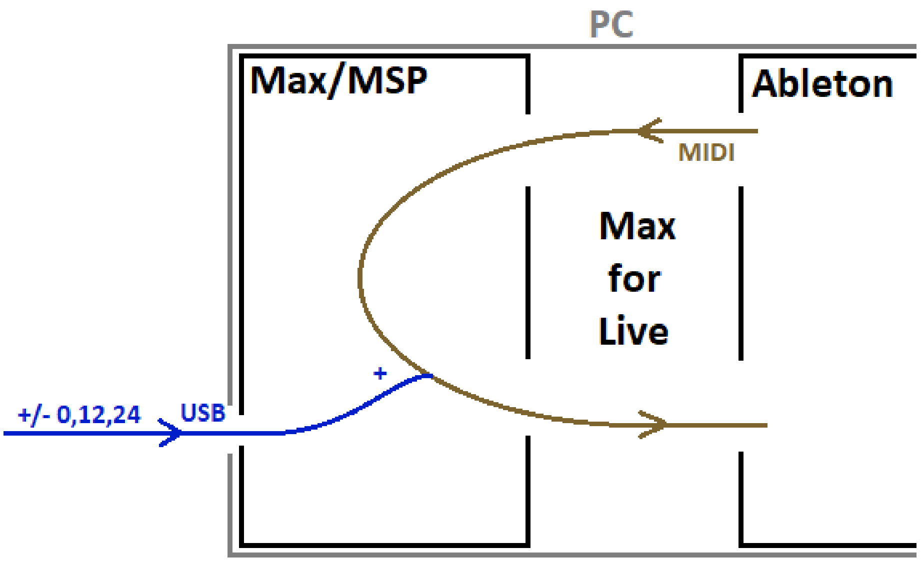

Figure 43: Schematic of Max software connections

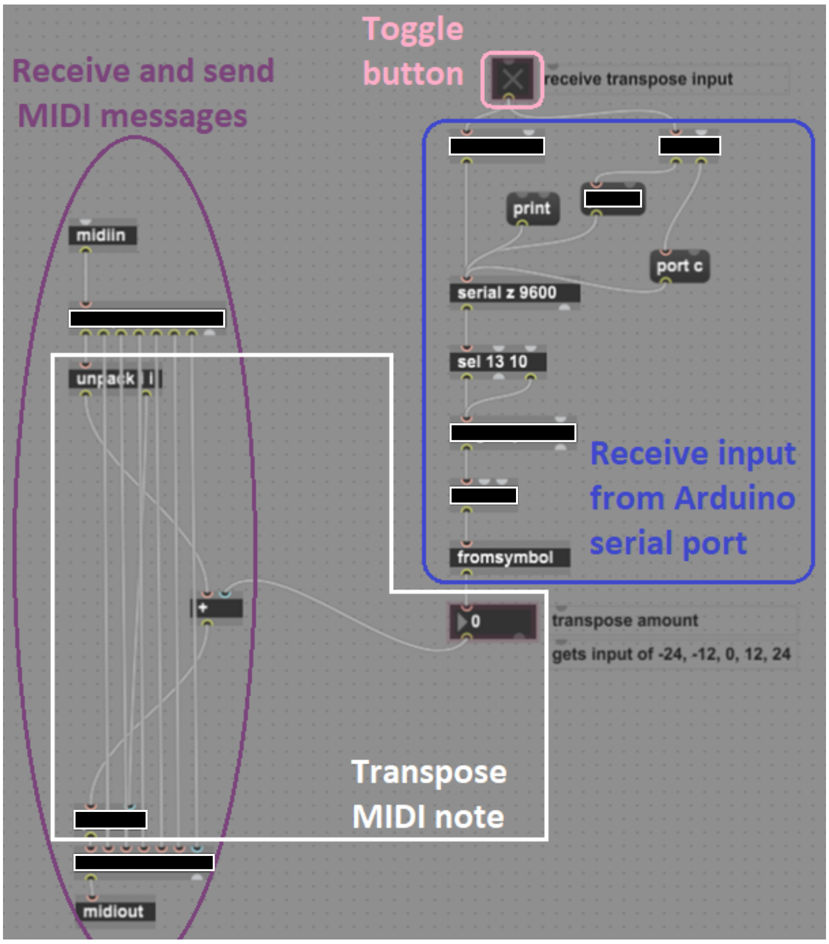

Figure 44: Written Max/MSP code (complete code in ownership of MBMM)

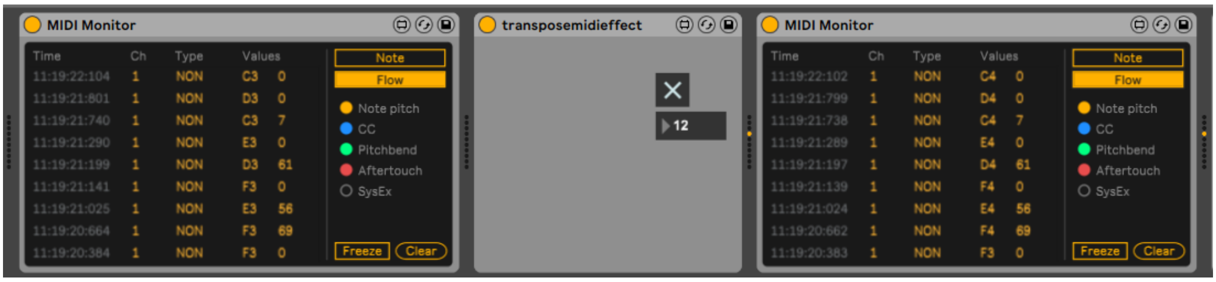

Figure 45: MIDI monitors of the Max MIDI effect

8.6 Ableton Live

Ableton Live, a popular music making software, is used to turn the MIDI messages of the keyboard into actual sounds. Since Ella cannot use most functionalities, this will mostly exist of note and sustain information. The prototype is coupled with Ableton Live for four main reasons. Firstly, it can easily be connected to the Max software that allows for transposing. Secondly, it gives a lot of opportunities to change sounds and effects. In fact, it has much more options than the keyboard itself can offer. The number of possibilities, especially in combination with Max for Live functionalities, is so large that nearly everything is possible. This way, Ella can manage to do anything she would want or need to do with the accessible PC mouse she already owns. She can select from select an incredibly wide range of sounds, effects and more. If desired, extra MIDI effects can be added before or after the Max MIDI effect. The desired sound can be added after the transpose effect. Then, optionally, one or multiple audio effects can be added. The keyboard functions as a MIDI controller and can thus control many different things, among which Ableton Live drum sets. These drum sets, as well as some other settings in Ableton Live, are often mapped to the lower notes of the keyboard and would therefore not be easily accessible for Ella by default. However, by adding the Max transpose effect, she can still access these possibilities using the pedals. After changing the transpose settings using the pedals, she could toggle the Arduino input off so that she would not have to focus on limiting foot movements. She can then play with the settings using the middle part of her keyboard. This is only an example of the many possibilities that are made available by connecting the prototype to Ableton Live and Max for Live. In principle, if Ella wants to do something, anything, there will be a way to do it.

Thirdly, all these possibilities can be prepared so that only minor interactions are necessary during a performance. An entire live set with different MIDI tracks can be prepared. In each MIDI track, the Max transpose effect should be added if transpose changes are necessary. If the live set is prepared before a performance, all necessary changes can be made with a simple mouse click in between songs. Fourthly, Ableton Live is high-quality software that has been in development for a long time. This ensures a steady, undisturbed playing experience with a certainty that new custom software could not offer. There will be a minimum latency. This is important, because a noticeable latency between pressing a key and hearing its sound would be detrimental to the music playing experience, where rhythm is crucial (see chapter 3.2.3). Ableton Live is expected to manage the demands without noticeable latency. Figure 46 shows the process of MIDI messages to audio.

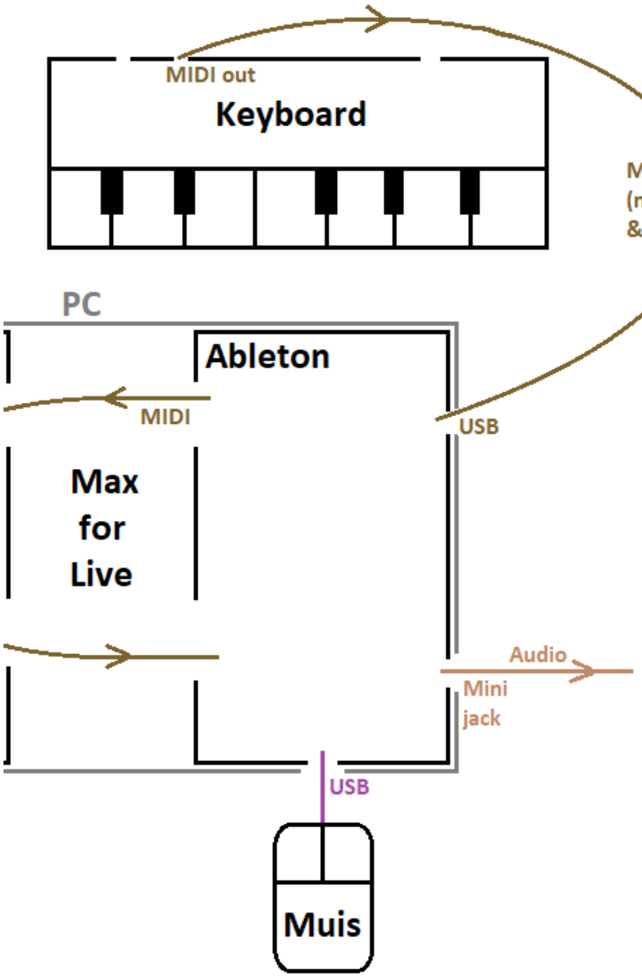

Figure 46: Schematic of Ableton Live connections

8.7 Associated Costs

An overview of the costs can be seen in Table 2. The necessary material components are included, as well as costs necessary for testing and sending the product. Only a limited number of materials is not used due to changes in the design, namely several MIDI to breadboard sockets. The biggest costs are associated with the necessary software, Ableton Live and Max for Live. There may be possibilities to get the software for free or at a discount due to the nature of this project. If the software needs to be purchased, the costs of the product are about 660 euros. However, the hardware alone leads to costs of around 150 euros.

Table 2: Project and product costs

Product	Costs (roughly)	Comments
Arduino Uno	40	
Ultra Sonic sensors	7	
Max MSP (optional)	199	Price for lifetime subscription when already owning Max for Live, not necessary for minimum viable product.
Ableton Live	349	Standard package (minimum that works with Max for Live); Suit package: 539 (includes Max for Live), 3 month trial available
Max for Live	149	69 when already owning Ableton Live and Max MSP
Bite switch	40	
Smart plug	22	Includes 2 year waranty
Cables	30,4	Jack cable and MIDI to USB cable
Sockets (MIDI to breadboard)	3,5	Not used
Arduino wires	8	Quite some left
Breadboard	7	
Pedals	12	Velcro bands
Mouse	x	Already owned by Design Partner
USB hub	x	Already owned by Design Partner
Travel costs	50	
Package delivery prototype	9,2	
Full product costs (incl. crucial software)	660,4	This includes Ableton Live standard package and Max for Live software.
Product costs (excl. software)	149	It may be possible to get software deals, or even get some software for free, given the purpose of the project.
Total spent for project	229,1	Including purchases that are not used, or only necessary to produce and test the prototype (i.e. travel costs). Excluding software (trials are used for development).

This prototype will be evaluated with the design partner in context. First, pilot evaluations are conducted, which are described in chapter 9.3. Then, in 9.4, the final prototype evaluation is described. The findings of this evaluation, along with earlier findings, will lead to a conclusion, which is described in chapter ten.

9. Evaluations

This chapter describes the four evaluations of this research project. The first subchapter regards an evaluation of the design ideas, introduced in chapter 7. As a result of this evaluation, an evaluation on suggested interaction methods is conducted, which is described in chapter 9.2. Chapters 9.3 and 9.4 regard the pilot and final evaluation of the developed prototype.

9.1 Evaluation Design Ideas

Before making investments on behalf of the client and making designs that will impact the design partner’s interaction with the keyboard, it is important to gather their opinions on the provisional design plan. This subchapter synthesizes the relevant information from the interview, which was fully discussed in chapter 7.

9.1.1 Goal

Going from conceptualizing to an elaborate prototype requires a lot of time and financial resources. The later in the design process, the less flexible the design becomes. Therefore, it is important to check whether the plans are feasible and satisfactory for the relevant stakeholders early in the process. It is important that Ruud van der Wel is convinced about the solution, since he provides the necessary financial resources and set the project up, which comes with expectations. It is valuable to know whether he thinks this plan meets these expectations or whether adaptation of the plan is necessary. It is also important that Ella is convinced the solution will be accessible and non-obtrusive to her since the solution will impact her hobby. If she is not excited to work with the product, it does not have sufficient value. The goal is to gather their thoughts on this plan and alter it accordingly.

9.1.2 Approach

In a meeting on the 7th of May 2021, the provisional design plans were presented to Ella and Van der Wel. The meeting was online with a semi casual setting. There were three points that were discussed for this evaluation. Firstly, Van der Wel was asked what the minimal viable product would look like, thus what is necessary at a minimum to feel like the main problem are solved. Then, he was asked what an ideal product would look like for him. Ella and Van der Wel were explained that the actual prototype would be in between the minimal and ideal product with the available resources. Secondly, the provisional plan was explained, with space for questions and comments. Their thoughts, opinions and preferences were heard, and any concerns were noted. Thirdly, the accessibility of this idea was discussed. Ella was asked whether she thought the suggested movements and forces were manageable for her. Besides whether it would work, she was asked if they seemed non-obtrusive and sufficiently intuitive for her. The client was also asked for feedback on the suitability and feasibility of the design ideas.

9.1.3 Results

The minimum viable product would enable Ella to use the sustain function. Furthermore, it would allow her to turn on her keyboard by herself, so she can practice whenever she wishes. If only this was implemented, there would be a considerable impact of the project on Ella’s life. An ideal product would also allow her to transpose during songs to enable a full range, and to change settings in between songs by herself. It would be easy to transport and set up, as well as sturdy, durable and consistent. Ideally, parts of it could easily be implemented to help others too. The provisional plan met the expectations of Van der Wel and Ella. They showed surprise and excitement for the ideas. They thought it was a complete, appropriate, and feasible plan with the available resources. When it comes to the accessibility, Ella was sure that the sustain would work. She expects to be able to bite a 5-millimetre-thick object with the force of a small carrot with little to no fatigue occurring. For the transpose function, eyebrow movement or breath interaction was suggested. However, Ella expressed that she could use her foot movement as interaction if no force is required. She would prefer this over the other interaction methods that were discussed as she expects these movements to be sufficiently accessible, and more intuitive. Part of the reason foot movement was considered undesirable is because of the progression of Ella's disease, during which the legs usually worsen more quickly. Ella explained she is on medication that will limit the progression of the disease. It is thus expected that her level of ability will remain steady for the foreseeable future. To ensure accessibility and give due weight to Ella's opinions, the researcher suggested to try the interactions out first in an evaluation session, which the stakeholders unanimously agreed with. For this evaluation, Ella will be given relevant tasks to conduct during an entire practice session. Then, the researcher and Ella will have a quick meeting to discuss experiences, among which comfort and level of fatigue. This evaluation will be described in chapter 9.2. The level of accessibility of the foot movements will decide if and how the foot movements are implemented.

9.1.4 Conclusion

Client and design partner were receptive to the provisional design plan. Their reactions to the ideas for interaction were positive and seemed confident. They did not see any problems in feasibility. The information that Ella's disease progression is blocked with medication is valuable. It gives more options for interaction and means the product does not need to be as adaptable as expected. The provisional design plan can be executed as it is, except for one area that first requires further research. This regards the accessibility of small foot movements that do not require force as interaction method for a transpose of sustain function. This evaluation is described in chapter 9.2. During the design process, it is likely that unexpected problems or situations occur leading to changes in approach and plan.

9.2 Evaluation Interaction Methods

Before starting on the actual design, as described in chapter 7 and 9.1, it is important to know if Ella can use the functions through the planned interaction methods. For this, an evaluation without prototype is done, to evaluate the foot movements and biting interaction on accessibility.

9.2.1 Goal

The value in the product designed for this project is for a large part in the useability for Ella. For this, the interaction methods and their physical demands play the largest role. If an unsuitable prototype is designed, a lot of work must be redone. Unusable design can also cause a lot of doubts and frustrations throughout the process, for designer and target user. Therefore, the suggested interaction methods of foot movement and biting should be evaluated before designing a product. Based on this evaluation, the design plans can be tweaked to ensure a better fit, if necessary.

9.2.2 Approach

In the week of the evaluation, Ella was sent a preparation document for the evaluation. She was asked to review the feasibility of its tasks, in terms of physical demands and time resources. After her evaluation of the preparation, some changes were made. A new document was sent, which Ella approved of. This document can be found in appendix C2. The evaluation took place one day later. The evaluation existed of four parts, namely warming up, biting interaction, foot movement and an interview. Ella was asked to start with her regular practice as a warm-up. After this, she was asked to proceed to the tasks for biting interaction. For this, Ella was first asked to bite on a small object when she would like to use a sustain. This works like a regular sustain pedal, she would bite and keep biting for as long as she desires the sustain. Secondly, she was asked to use the biting interaction in a different manner, namely, to bite once when she would want to start a sustain and bite again when she would want to turn it off.

After doing both biting tasks for about two songs, she proceeded to the foot movement part of the evaluation. This part was altered after reviewing the preparation with Ella, who made clear that some of the suggested movements would not be accessible for her. Two suitable interactions remained, which both contained two movements. The first interaction only included the right foot, specifically moving the front and back of the right foot up independently. The second interaction included both feet, specifically moving the front of the left and right foot up independently. For both interactions, she was asked to calmly do one of the movements every first count of every second bar for 15 minutes or as long as she reasonably could. She could decide the amount and speed of movement that feels manageable. After this, she was asked to do the two movements as quickly after one another as possible, again every first count of every second bar for one song or as long as she reasonably could. After this, she was asked to take a break, then contact the researcher to discuss her experiences in a semi structured interview. The questions that were going to be discussed were included in the preparation document, so Ella knew what to focus on while practicing the interactions. She was also offered a moment to take a break and evaluate by herself before the interview, leading to more considered answers.

The evaluation was done remotely. During the tasks, Ella was alone in her usual practicing environment. There was no video, call, or similar means of sharing her experience. This way, she was not dependent on help. The available resources were not the only reason for the lack of observations. Another reason was that the practice would be closer to her usual practicing context, and thus relevant. It also ensures she is comfortable to experiment and does not feel any pressure. The semi-structured interview, however, was done over a brief video call. This interview included questions on how accessible the movements of the tasks were, considering control, speed, and fatigue; how intuitive the movements were; how easy it would be to learn the movements; and whether the testing excited her to use these interaction methods for the designated functionalities. The interview ended with an explanation of how the movement types would likely be implemented based on the results.

9.2.3 Results

The biting interaction was easy for Ella, and the force of biting a small carrot is very manageable. Ella would need to get used to the interaction in context before comfortably using it. She expects she will be able to do so, as she already made progress when trying out the interaction. Out of the two biting methods attempted, it was easier to keep the bite switch pressed to keep the sustain, than to bite it a second time to turn the sustain off. Both movements would be equally accessible, but the easier movement is more intuitive, and therefore preferred. Trying the interaction while imagining a sustain gave Ella excitement to experiment and play around with an actual bite switch sustain.

The foot movements were less easy than the biting interaction, and more difficult than Ella expected. The movement is possible, but fatigue occurs when she does it often. For transposing, she expects it is manageable, as she does not expect to need this that often. For a sustain it is less manageable. If still used for sustaining, it would be best if Ella can trigger the sustain by putting her foot down and keeping it down, instead of putting it up and keeping it up. This would also be easier than making the movement twice, once to turn the sustain on and once to turn the sustain off. This is because she expects to use the sustain a lot, even most of the time. Moving the fronts of the left and right foot is physically less demanding than moving the front and back of the right foot. It also seems more intuitive. When it comes to speed, triggering both ‘pedals’ after each other, so switching up and back down or the other way around, can be done quickly if it only occurs sometimes. At the average speed of the songs Ella plays, this switch can be done with two notes in between. She is satisfied with this speed and expects it is fast enough. Playing around with the foot movements while imagining it would transpose the notes she played, gave her excitement to evaluate an actual prototype that implemented this movement.

9.2.4 Conclusion

The biting interaction is very accessible, even if used a lot. Though Ella would need to get used to the interaction, it seems suitable for the sustain. The foot movements are more fit for transposing octaves up and down. This can best be done by moving the fronts of the left and right foot up in small movements that do not require force. The required speed of the movements should not be too quick, but a satisfying speed can be reached. These interactions are accessible, intuitive, and exciting for Ella. This conclusion is reached based on Ella’s own judgment of her capabilities. Though this is expected to be an adequate measure, the lack of observations in this research activity may lead to issues in the design process. It can be difficult to determine an appropriate required size and speed of movements based on a description. Measurements and observations could help with this. Additionally, a mock-up is used for this evaluation, which differs from the product in numerous ways. Expectations of a required force for the biting interaction, for example, may differ from the actual required force. This can lead to a less accurate judgment by Ella. It is therefore valuable to make an adaptable prototype and evaluate it appropriately.

9.3 Pilot Evaluation Prototype

9.3.1 Goal

During the evaluation of the prototype with Ella, limited time is available. Furthermore, the travel time makes it undesirable to have to plan a second evaluation session. Any technical or practical difficulties would delay the process and limit the time available for testing. Thus, the goal of the pilot evaluation is to evaluate the functioning of the prototype in context, as well as predict technical difficulties and inconsistencies. Additionally, the pilot gives an idea of practical aspects, such as how much time is needed to set up the prototype and what additional materials should be brought to account for common problems. This can help to plan the evaluation session more accurately. Furthermore, the pilot test can help identify important aspects and information that can improve the preparation of the evaluation, including suitable tasks, missing steps, and valuable questions.

9.3.2 Approach

An able-bodied participant who plays and owns a keyboard with sustain input is selected. Throughout the project, this participant has been up to date on the progress of the design. She was asked whether she is available and willing to do a test evaluation with the prototype and was informed on the need to sign an informed consent form. This consent form can be found in appendix A3. Furthermore, the participant is asked to take on the role of Ella, the design partner, after being given a description. The prototype is brought to their residence and set up. The evaluation preparation (see appendix C3) is initially used as a guideline but deviated from quite a bit. The participant was excited and curious, and already started trying out the sustain (with plastic covering to limit COVID-19 related risks) when only parts of the prototype were correctly connected. Furthermore, her excitement caused her to make big and fast movements, which were not representative for Ella's abilities. A lot of time went into setting the prototype up correctly. After this, the functioning of the pedals was explained. Then, the pedals were evaluated, starting with the audio results of the movements. Due to inconsistency in results and a corresponding need to customize values in the code, the software was temporarily altered to inspect the values coming in during movements. When the inconsistency remained, multiple types of shoes and movement were assessed. Then, some tests were done with putting the feet at different angles. While the pedals were altered, the participant was playing around with the sustain bite switch. The evaluation was not fully finished and turned into a brainstorm session on how to solve the inconsistency issues.

A second pilot evaluation was attempted with a different participant, who owns a MIDI keyboard with sustain input. This pilot was done after the inconsistency issues were taken care of. The prototype, again, took a while to set up. After a bit of testing, issues with the sustain were discovered. Instead of testing, most time was spent on trying to resolve these issues. The participant only got the chance to try out the pedals for a short while. Observations were made and noted down. A short, casual, third pilot evaluation with the first participant and her classmate was done when the product fully functioned. They evaluated the functionality and were asked a few questions on the experienced consistency, as this had been an issue before, and the overall interaction experience.

9.3.3 Results

During the first pilot evaluation, large inconsistencies in the reactions of the pedals were discovered. They were most inconsistent when using bare feet or highly textured shoes. Shoes with flat soles lead to the best results, especially when they were firm. However, the results were still not consistent enough. Part of this had to do with the quick and careless movements of the participant, for which the pedals were not designed. When trying to account for this, however, there were still unacceptable inconsistencies. Each time a movement occurred, the foot had to be placed back in the exact same position, which is difficult and frustrating in practice. This was already partially accounted for with a reset button, which can reset the threshold values. This button was used a lot and led to some increased useability for small periods of time but was not sufficient to resolve the issues. Furthermore, the angle that the pedal was in made the foot movements quite demanding, even for the able-bodied participant. To account for the inconsistency and lack of ergonomics, an attempt was made to place the feet slightly further away from the sensors, and at a straighter angle. This was done by placing small objects (with the thickness of a deck of cards) underneath the heals. This led to some improvement in consistency and made the foot movement less demanding. Especially when thicker objects were explored, meaning the feet were in a slight downward angle when the pedals were not triggered, the movement became much easier to make. When reading the input from the sensors, these adaptations also seemed to lead to more consistent values, due to the changed distance and angle relative to the sensors. When used with bare feet, however, the results were still less consistent. A less temporary version of the adaptations to the pedals was made before the second pilot evaluation. Though the actual second pilot evaluation did not take place as expected, the pedals were evaluated a bit by the participant. There seemed to be considerable improvements in consistency.

During the first pilot evaluation, it was also found that the sustain did not always function. The sustain worked well on the keyboard in the beginning but stopped working on some occasions. The sustain worked again when some pressure was put on the mini jack socket on the breadboard. Attempts to apply this pressure using duct tape were insufficient and not long-lasting but led to improvement, nonetheless. After this issue was expectedly resolved, the second pilot evaluation was conducted. In this evaluation, the sustain did not work at all. Different than with the first pilot, the keyboard of this evaluation had no volume output of itself and only functioned as a MIDI controller. Since the sustain worked earlier on a different keyboard, this was expectedly an issue with the MIDI connection or software. By adding a MIDI monitor on Ableton, it was found that the sustain input came in adequately. The sustain connection itself, and its handling by the keyboard, were thus functioning appropriately. There was a problem in the software instead. Finally, when adding a MIDI monitor before and after the Max for Live plug-in, it was discovered that the problem was in the code. MIDI messages other than note information, were not transferred through the plug-in.

During the last pilot evaluation, both the pedals and sustain were consistent. Furthermore, the interactions of the prototype were intuitive for the participants. They could get used to it when playing with the prototype. When trying to discover options in Ableton, some extra possibilities of the prototype were found, such as being able to play drum sets in the middle range of the keyboard, instead of the lower range they are mapped to by default. It seemed that the prototype increased options, invited to play and experiment, and functioned well. There were some problems within Ableton when adding the Max for Live effect to multiple tracks at the same time and switching in between these tracks. It is expected these issues can be resolved with more expertise on Ableton Live.

The approach of the evaluation was vastly different from what was planned. Firstly, the participants of the pilot evaluations were present in the room while the prototype was being set up. Though the participants reacted to this very differently, in the first and second pilot evaluation it led to inefficiency and some annoyance. Secondly, evaluation did not occur according to the steps in the preparation. The preparation was used as a rough guideline only, and not looked at regularly. The preparation was useful to check if all important aspects were considered. However, a very planned approach turned out to be unsuitable when excitement is involved. It would block the flow of playtesting and experimenting. This experimenting is valuable when finding a new interaction with your hobby, as it can show whether the new interactions are intuitive, easy to get used to and expanding the experience. Additionally, a more flexible approach that is steered by enthusiasm seemed to lead to a more meaningful and fun testing experience for the participants. If Ella has a positive experience during her first interactions with the prototype, she is more likely to be motivated to use it again.

9.3.4 Conclusions

Improvements were made on two aspects, namely on the prototype and the approach of the evaluation session. When it comes to the prototype, a different 3.5mm mini jack to breadboard socket was used. The earlier used socket had the mini jack input on the side, and when the bite switch was connected, the mini jack plug tended to push the socket away from the breadboard, leading to signals not being received as the circuit remained open. In contrast, the newly used socket had the mini jack input on the top, meaning it could not influence the placement of the socket. The problem with the sustain signals not being caught by Ableton Live was found to be an issue in the Max for Live plug-in. Namely, the Max code altered the MIDI notes it received and sent these back out, but totally disregarded the other signals that were being sent in. The sustain MIDI signal is a control change (CC) message, and though it came into the Max programme, nothing was done to send it out again. Thus, it got lost in the written software. This issue is solved by sending all other MIDI messages that came in directly to the MIDI out function, with only changes being made on the note messages.

The pedals were altered by adding two extra blocks on the backside (see Figure 40, chapter 8.4). This created an angle that was more ergonomic, as the movement costs less energy. Furthermore, due to an increased distance from the sensors, the consistency increased significantly. After altering the hardware of the pedals, the incoming values of the sensors were assessed in the Arduino serial monitor. After inspection, some of the customizable values were changed to values that were expectedly suitable for the new distance and angle, based on trial and error. These changes led to consistent reactions in the third pilot evaluation, especially if flat shoes were worn. Furthermore, during the pilot evaluations it was found that the reset button was even more valuable than expected, even after the accuracy had increased. In this prototype, the reset button was just a small button on the breadboard, used for practicality. However, if the button needs to be used more often to reset the values for increased accuracy, Ella should be able to use the reset button independently. Thus, a plan was made to attach a light pressure switch instead of the standard breadboard button. This can be done while setting up the prototype for the evaluation, at the location of My Breath My Music, where they already have a switch available. An extra 3.5mm mini jack to breadboard socket with the socket on top is required.

These steps ensure that the prototype is ready for evaluation. When it comes to changes in the evaluation method, it became clear that a flexible and intuitive approach would be best. It is expected that there is some excitement involved that will otherwise be blocked. Furthermore, it is a music playing experience, which is usually improved by expressivity and experimenting. An evaluation session that enables, or even stimulates, this would come closer to the final context the prototype will be used in. During the evaluation, the preparation write-up will only be used to check if all aspects and tasks are done. The write-up also contains sections on what to bring and in what order to set the prototype up. These parts are altered to include the changes to the prototype. Another change that is made and communicated is that Ella should wear shoes with a flat, firm sole to increase accuracy. The pilot evaluations confirmed that it is best to set the prototype up before the participants are present. This way, there are less distractions and the flow of interaction is not blocked.

9.4 Evaluation Prototype

On the 10th of June, the prototype (as described in chapter 8) is evaluated at the My Breath My Music location in Rotterdam. This could be done safely and in line with COVID-19 regulations. A self-test was conducted the evening beforehand, masks were worn when commuting inside, the prototype was sanitized, and an appropriate distance was kept.

9.4.1 Goal

The first goal of the evaluation is to evaluate whether the prototype reaches its goals, namely that of accessibility, useability and transparency. Thus, whether Ella can physically use the product, easily navigate the product, and understand the effects of her movements. The transparency aspect will also be considered from the perspective of a bystander. The second goal of the evaluation is to get an idea of how the product can impact her playing experience now and on the long term. For example, whether it will change the type of songs she plays or the way she interacts with the musical instrument. Additionally, whether it impacts her perceived amount of expressivity, control, and freedom. The third goal is to get a grasp on how and to what extent this prototype, or parts of it, can be used to benefit other people who run into similar problems of being able to only use part of the functionalities of a musical instrument.

9.4.2 Approach

An appointment was made with the client, Ruud van der Wel, at a moment that Ella could also be available. The researcher arrived 1.5 hours before the actual evaluation session to set up the prototype. This was done in a step-by-step manner, as determined in the evaluation preparation (see appendix C3). When Ella arrived, the pedals were attached to the footrests of her wheelchair, after which she adjusted the footrest angle to be comfortable and suitable for the required movement. Then, Ella was introduced to how the bite switch works and invited to try it out. When she understood this interaction, the functioning of the pedals was explained. Before trying them out in context, she was asked to make the motion a few times. The values of the sensors were tracked in the serial monitor of Arduino. Based on these values, the customizable values were altered. After this, the Ableton Live software was opened, and the volume of the keyboard was set to zero. The Max MIDI effect was turned on, along with a basic piano voice on the MIDI track. After understanding the foot interaction, Ella was explained the basics of Ableton Live, such as how to change sounds, add new MIDI tracks, add the Max MIDI effect to these tracks, and switch between them. Then, she was given the space to experiment.

After some time, Van der Wel suggested playing a song from the school band's repertoire with the band members that were present. For this, the laptop was connected to a speaker. The researcher did some observations during the music making session, and later joined in. A second song was played. Afterwards, Ella received an explanation about some additional possibilities, such as using the pedals to access drum sets on Ableton Live. The playtesting was supposed to last about 45 minutes, but Van der Wel and Ella decided to make extra time, enabling a total of one and a half hours to learn and experiment. After Ella left, the client was interviewed about his view on the success of the prototype, its cost efficiency, and how it can be used to help others. The morning after, a short online interview was conducted with Ella about her experience, perception, and expectations.

9.4.3 Results

This section combines the results from all parts of the evaluation, including observations, interviews, and comments following a few days later. Firstly, there was a clear initial excitement, from both the client, who had asked a photographer to take pictures and videos of the set-up and evaluation, and Ella, who was very eager to try out the prototype. Ella also showed initial joyful surprise with every new function she was able to control. These first interactions were her favourite moments of the evaluation session. There was a lot of curiosity in her interaction with the prototype, as she kept experimenting with different settings and combinations of interactions. When provided with additional information, she was very eager to learn about the possibilities and try out functionalities. She learned quickly and showed significant improvement throughout the session. The excitement was still present a day later, when she spoke about the prototype and testing experience positively and with an eagerness to learn.

Secondly, the interactions of the prototype were very accessible. The bite switch was easy to use, and more intuitive than expected. Little energy was required to press the switch and keep it pressed, thus no fatigue occurred. However, the bite switch easily fell out of Ella's mouth when not actively used. To temporarily solve this, the wire of the bite switch was duct taped to a camera stand that was present at the office. This reduced the weight of the bite switch, as the cable was no longer hanging from it, and solved the problem of the bite switch falling. When it came to the pedals, the default values of the customizable values barely needed changing to be comfortably useable. Values that were sufficiently accessible were quickly found. More iteration is possible but was not necessary for testing and using the product. Ella needed some help to place her feet on the pedals correctly and comfortably after they were attached to the footrests. After initial help with placing her feet, she could independently use the pedals for the remainder of the session. She needs to get used to the precision of the movements, but the movements were manageable in context. During the evaluation session, she already used the pedals instead of moving her hand sideways when she normally would in the song. For this purpose, the pedals were easier to use than her hands. Additionally, the reset button was placed on her wheelchair and was easy to use without getting in the way. In contrast, Ableton Live was harder to navigate, which was mostly due to unfamiliarity with the software and use of an unsuitable mouse. Navigation was still manageable with some initial guidance. From the interview, it became clear that she has a good understanding of the functionalities and interactions of the prototype. The transparency of the prototype, thus the clearness of what movements correspond with what changes, was high for both Ella and external observers. All movements logically led to audible changes.

When it comes to the prototype itself, it functioned well and consistently. All movements were successfully measured with the desired result. There were no unusual changes or other occurrences in the sound. When the keyboard was connected to Ableton Live on the laptop, with the MIDI effect running, no noticeable latency occurred. When the output was changed to a speaker, however, there was a significant latency. The client expects this to be due to the sound card of the laptop, which might be unsuitable. He has ideas for a workaround using external sound cards. Another issue occurred upon switching MIDI tracks in Ableton Live. When the transpose Max for Live effect was connected to multiple MIDI tracks, switching led to Arduino input not being received. The Ableton Live set could be saved and reopened, which would allow input to be received on the new MIDI track.

However, this is cumbersome and should be avoided. Expectedly, there are workarounds within Ableton Live to solve this issue. In general, Ella needs to learn more about Ableton Live to use the prototype more comfortably. She is eager to learn this and get used to the prototype, despite that it may take some time.

Ella looks forward to spending more time experimenting and learning. With what she has tried already, she does not think anything is missing for her. She experienced maximum control with the prototype, which is a big contrast with before. Furthermore, she experienced much more freedom and possibilities than without the prototype. She also noticed a change in her amount of expressivity while playing, especially because of the sustain switch. The prototype can enable her to play certain classical songs she could not play before, as they require a sustain and changes in hand placement. When it comes to her playing style, she does not expect many changes. Van der Wel, who leads the school band, expects the repertoire of the band and Ella will not change a lot, but the prototype will allow her to play with more variation within the repertoire.

Van der Wel is incredibly pleased with the product and thinks the solution fits Ella well. He thinks the price-quality ratio is good. The costs are manageable and appropriate for the field, and the benefits of the prototype are clear. The largest costs are related to Ableton Live and Max (for Live) software. Van der Wel knows the boss of Ableton Live personally, and it is expected that something can be arranged. Even if this would not be the case, the investment of a life-long subscription is clearly worth it for him, as it substantially increases long-term possibilities. If any changes are made to the prototype, it would be better to add things than to attempt to lower the costs. During the interview he mentioned that it would be ideal to create a suitable tripod or stand for the bite switch. This would allow Ella to leave the bite switch out of her mouth when she does not need it. This would be more comfortable than having to keep the bite switch in her mouth for a full two-hour performance. Furthermore, he later messaged to ask if it was possible to make a 3D printed case for the Arduino and breadboard, as the wiring is quite fragile. This would help Ella to safely transport the product for a performance. In another comment, he asked about possibilities to link the Max transpose software to Reason (Propellerhead), which is the main musical software they use at My Breath My Music. According to the client, the most ideal product would not have been dependent on a computer with Ableton running. Instead, it would be an external controller that can send MIDI commandos such as programme changes to the keyboard. Thus, the product would only exist of hardware connected to the keyboard, so that the keyboard can be controlled using, for example, an accessible custom pedal for effects.

When it comes to broad applicability, Van der Wel emphasizes that no handicap is the same. The product is custom made and very suitable for Ella, who can perform the required foot movements. The possibilities of applicability are limited by the accessible movements that are unobtrusive for a musician's existing interaction with the musical instrument. Van der Wel expects that parts of the prototype can be applied for other people. This would be people with similar disabilities, namely ones that lead to muscle weakness. The product would need to be slightly different for another user, thus a custom derivative of this prototype. As an example, he inquired for the possibilities of using the non-force pedals as a sustain pedal. If this prototype can help lead to a suitable solution for even two or three people, this would be magnificent. There is an enormous added value of offering someone possibilities they did not have before. Van der Wel shows interest in discussing how exactly this further value can be realised after the end of this project. He already has some ideas of possibilities to further build upon the work. Furthermore, he expressed interest in hiring the designer for similar projects in the future.

9.4.4 Conclusion

The prototype is very suitable for Ella, as it helps her reach her goals with accessible interactions. She went from a limited way of playing the keyboard, to an amount of control and freedom she did not expect to reach. On top of that, the expressivity of the musical instrument has noticeably increased. This allows for changes in her personal repertoire, and increased variation within the repertoire of the school band. The prototype is intuitive and transparent for both Ella and observers. Though the prototype functions well, there are some valuable improvements that can be made, mentioned here in non-chronological order. Firstly, some research should be done into the problem of not receiving Arduino input when changing MIDI tracks in Ableton Live. It is likely that this is an issue that others have experienced as well, and someone may have figured out a solution or work-around. Secondly, some research should be done into possibilities to connect the transpose pedals to Reason (Propellerhead). If this is possible and offers the same benefits, the research into Ableton Live may not be necessary. Thirdly, a tripod or stand for the bite switch should be implemented. This can be an existing stand, perhaps altered a bit. It is important that the tripod is of comfortable height, is stable, can be controlled independently by Ella, and can be turned away from her face if she does not use the switch for a while. Fourthly, a protective case for the Arduino and breadboard should be created. This will protect the fragile wiring and be more aesthetically pleasing as well.

After the evaluation, the founder of Ableton was called. As he did not initially pick up the phone, a short (1 minute) video explaining the prototype was made and sent to Ableton's founder. The Ableton software can be received for free for the purpose of this prototype. Furthermore, on the day of the evaluation, Cyclin '74, the company behind Max/MSP, is contacted by the designer. The prototype is introduced to the management, and an extension of the free trial is requested to finish the project more easily. The response was positive and contact information of My Breath My Music were given to the management to discuss further possibilities. The designer will first focus on the final steps of the graduation process, including documentation and presentation of the results. After this, there will be further contact with My Breath My Music to investigate possibilities to improve and build upon the current prototype.

There are possibilities to use part of the prototype for other people who experience muscle weakness and are unable to use all functionalities of a musical instrument. They would require a custom derivative of the current prototype. There would be a lot of added value in building upon the prototype to help even a few others. There are clearly possibilities for this, and both designer and client express a wish to explore these further. When there is more clarity on how the prototype can help others, appropriate ways to share the work with those who could benefit from it will be investigated. The evaluations in this chapter, and knowledge that is gathered at earlier stages of the project, will be synthesized into a conclusion in the next chapter.

10. Conclusion

This project regarded a customization of a musical keyboard to enhance accessibility for a 15-year-old keyboardist with SMA Type II. This is done in collaboration with the foundation My Breath My Music. Through interviews, observations and evaluations with target user, client and music teacher, a prototype is developed. This prototype enables the target user to turn the keyboard on and off by herself, use the sustain function, access the full range of the keyboard, and change settings. This prototype is evaluated in context. This chapter describes the findings of the evaluation, limitations of the research, and possible further work.

10.1 Review of the Requirements and Goal

This section reviews the requirements and main goal of this project, and to what extent these are reached. In Table 1 of chapter 7.4, the requirements and evaluation methods of the prototype were given. A derivative of the Table is provided below, including the results of the design and evaluation. If the requirement is not fully met, the explanation is written in *italics.*

Table 3: Evaluation of requirements

Requirement	How to evaluate	Evaluation results
The prototype is sufficiently accessible for Ella.	Ella can effectively control every functionality the prototype is meant to control. She does not get too fatigued to continue during her regular practice session, which lasts 2 hours.	All interactions are manageable. Acceptable fatigue occurs when intensively using the pedals for a prolonged period.
The prototype works with a light-playing keyboard.	The prototype functions with her current keyboard or a new keyboard that does not require more force.	The prototype functions with her keyboard and any MIDI keyboard that has a sustain input. The prototype components can function with other types of MIDI controllers as well.
The prototype functions well.	All functions of the prototype can be used during performances, rehearsals, and practices without new frustrations. Ella does not notice a latency while playing.	Most components function well. There is no latency and the interactions do not lead to new frustrations. *However, a software issue occurs when switching MIDI tracks in Ableton Live if both MIDI tracks have the Max for Live effect attached. This can easily be solved for each individual occurrence but requires extra time. This error only occurs in between songs. Furthermore, when the laptop was connected to an external speaker, there were latency issues.*
The prototype is durable.	A scientific evaluation is outside of the scope of this project, as the project is short	Most components seem durable. The fragile aspects are replaceable without further damage. *However,*

	term. However, there should be no damage to the prototype during the practice sessions that take place during the project. Furthermore, products that are expected to be durable should be used. Fragile parts and parts that are used a lot, such as sensors and connectors, should be replaceable without damage to other parts.	*the Arduino, breadboard and wiring are fragile. A few wires came loose when Ella unpacked the prototype after receiving it through mail.*
The final material costs are under 900 euros.	The final costs are 400 euros. If this is exceeded, this is explicitly discussed with the client with as much information as available. The exceeding of this budget should lead to a significant improvement in another requirement, such as durability, accessibility, or independent control over functionalities.	See Table 2 in chapter 8.7. Given that the software will be provided for free, the costs of the prototype are 150 euros. This does not include a MIDI cable, USB hub, mouse, laptop and keyboard, which Ella already owns, as well as travel costs and materials that were not used. The project costs were around 230 euros in total.
Ella can turn on her keyboard independently at home.	Once set up, Ella can turn on the keyboard without help.	Ella can turn on her keyboard by herself when she is at home. The solution can easily be integrated in other places and devices, given the devices remain in the same place. *The solution can be transported to other places, but she would require help to set it up, along with the rest of her keyboard. It would not take extra time.*
The prototype replaces the sustain.	Ella can successfully sustain notes when desired for as long as desired.	Ella can use the sustain function as desired.
The prototype allows Ella to change common settings.	After set up, Ella can use the prototype to change settings such as volume, type of sound and effects independently.	Ella can change the settings in Ableton Live independently, with more options than her keyboard alone would give. *Changing these settings does not change the settings of the keyboard.*
The prototype enables Ella to transpose octaves without pausing.	Ella can use the transpose function when desired with a latency that is not noticeable for an audience.	Ella can use the transpose pedals and already made improvements during the evaluation session. She only needs to get used to the precision of the pedals and expects to be able to.

The transpose and sustain functionalities can be used at the same time.	Ella can trigger the transpose while the sustain is already triggered.	Transpose and sustain are managed separately and can therefore be used at the same time.
The solution is easy to learn and use.	Ella makes noticeable progress within three regular practice sessions.	Ella already made noticeable progress during the first evaluation session.
The documentation on the prototype is clear enough for the prototype to be recreated.	The client understands the main workings of the product and understands the details when inspecting the relevant documentation. He should feel confident that he could recreate the product for someone else using the documentation as main source.	*Due to changes in the COVID-19 situation, evaluation could be done in person. This and other changes in the planning led to a discussion on priorities with the client. Consequently, the documentation is postponed to a later stage. These evaluations could therefore not take place.* .
The set-up is simple and can be created and fixed by amateur digital musicians and engineers.	If the documentation is shown to someone in the first year of Creative Technology, they are confident they can recreate the set-up within a week.	

As can be seen in Table 3, most of the requirements of the prototype are met. Four requirements are not sufficiently met, two of which due to changes in priorities. The initial goal was to design an accessible prototype that enables Ella to use more functionalities independently. This goal is met according to client, design partner, bystanders, and designer. Thus, client and user satisfaction have been met. The expectations of the client are also met, and even surpassed. He has claimed in an interview that even a small improvement in independence and accessibility can have tremendous value, meaning that adding only an accessible sustain interaction and method to turn the keyboard on would make the project worth it. This and much more has been reached at a cost much lower than the budget and standard for similar projects. As a result, Ella experiences more control, freedom, expressivity, and opportunity, as well as a new excitement within her hobby, which is connected to her sense of identity. By helping her preserve her identity, increasing accessibility, creating more equality of opportunity, and enhancing participation, this project supports human rights.

10.2 Limitations

In the research activities, there were three main limitations that have impacted the research and results. Firstly, due to the COVID-19 regulations and physical distance, most of the research activities were done remotely. This included observations, which were therefore more limited, as not all angles and body parts can be in frame at the same time. It also led to a lack of observations in some research activities. In these cases, the design choices were based solely on feedback of the design partner. Secondly, due to the nature of the project, the product was evaluated with this one participant only. This has a strength, as it increases the focus on the specific end user that is customized for. It, however, also has the weakness that the participant might not consider all necessary aspects or has problems phrasing comments accurately. It also gives less practical knowledge on how this product could benefit others. Thirdly, the participants of the pilot test could be selected more carefully. They were already more acquainted with the work than the design partner, as they had seen aspects of it in development. Additionally, they were well acquainted with the designer, making the atmosphere unrealistically casual. Though the tests led to useful insights, it might have been useful to also do a pilot test with a more appropriate participant.

10.3 Further Work

10.3.1 For Design Partner

There are three areas of further work related to the design partner, namely to improve the prototype, transition to using the product, and research the long-term needs and impact. One of the aspects of the prototype that should be improved is its durability. This can be increased by using a Veroboard instead of a breadboard. In a Veroboard, the necessary connections can easily be soldered, making them much stronger and permanent. The Veroboard can also be cut, making the product more compact. The durability can then be improved even more with a protective case around the Veroboard and wiring. Furthermore, longer wires should be used to connect the pedals to the Veroboard, to reduce the number of weak points in between wires. Another aspect for improvement is the prototype's comfort of use. This can be increased with a tripod or similar type of stand for the bite switch. With a tripod, the design partner does not have to hold the bite switch in her mouth for hours on end, but only when she needs to use it.

Thirdly, the freedom and possibilities can be further increased. Currently, the transpose pedals can only transpose the entire keyboard up and down. This is insufficient for certain songs that require a larger distance in between the hands. More options could be created, by reprogramming the reactions of the pedals in Arduino. For example, where the right pedal transposes only the right hand up and back down, and the left pedal controls the left hand. In such remapping, you can never consider all the options, meaning the design partner is likely to find limits and require help to solve these. Instead, it could be good to alter the code so that it is easy for anyone to customize the necessary functions. Then, after learning how the program works, the design partner can create her own mappings of the transpose function. Further improvement requires a change of the type of prototype. The client stated that it would be much better to have a prototype that does not rely on external hardware, such as a laptop, to function and change settings. Instead, everything should connect to one box that enables the design partner to change settings on the keyboard. It requires a lot of extra work to make reliable software for this, and an expected problem is the transpose function, as there are no existing programme changes to alter the transpose settings. There is a workaround on certain keyboards that have a built-in transpose up and down function. The design partner's keyboard does not have this, and her choices for keyboard would be limited with this solution. Ella will already have to pay attention when purchasing a new keyboard, as the smart plug solution will not work with every keyboard. Even when using keyboards for which this work, which also contain transpose octave up and down buttons, it would be difficult to connect the prototype to another keyboard, as these buttons would have to be rigged on each keyboard. This will also void the warranty of the keyboard. To find other workarounds, more research is necessary.

In the prototype, a problem with functionality arose. Expectedly, there is a workaround in Ableton Live. In general, there are many possibilities of Ableton Live that are hard to access without prior knowledge. For the design partner, it is valuable to get familiar with Ableton Live to get as much benefit from the solution as possible. For this, a basic class in options, adapted to the functionalities she needs, can be efficient. In this course, keyboard shortcuts should be avoided, as the design partner will usually use a mouse to control the software. The customized course should be combined with practice and experimentation. If the design partner is to receive such a class or course, it is likely that she or the teacher can find a solution for the Max MIDI effect problem. On top of that, the class can increase her fluidity, confidence, control, and freedom in interacting with the prototype and her musical instrument. It also benefits her musical development in general.

To fully assess her development and the benefits of this prototype, a long-term evaluation should be conducted. In this evaluation, her needs and limitations should be reconsidered, as these can change over time and level of playing. It is important to evaluate if the product is still sufficiently expressive for her. If the solution no longer suffices for what she wants to do, she might benefit from a new adaptation. The evaluation should also focus on the impact of the prototype on the life of the design partner. Health and therapeutic dimensions, as well as participation, accessibility, and equality should be considered. In an evaluation in context of a performance, the transparency of the prototype, as perceived by an audience, can be researched. This gives further insight into the expressivity of the prototype. It may also highlight functionalities or options that are missing. The ease of transporting, setting up and troubleshooting the prototype can also be evaluated in this context.

10.3.2 Broader Use of Product

Since this product is a customization, carefully designed for the abilities of the design partner, it is unlikely that the same product can be used by others with the same benefits. However, parts of it may be beneficial for other people who experience muscle weakness. A movement pedal can be used as sustain pedal or to control effects with only a bit of reprogramming. It could also be used in other musical instruments, to control the bass drum of an electric drum set, for example. Alternatively, the pedals could be turned into a new musical instrument, such as a theremin that can be controlled with the feet. Even outside of the music field, any device that requires digital or analog input can be controlled with a similar pedal, with minor reprogramming. In all applications, the two pedals can control four states, be used as three buttons, control two continuous variables, or control a continuous variable plus two states or one button. For efficiency, the housing of the pedal should be built in a way that is easy to reproduce, such as 3D print or laser cut. The pedal would be most durable if, like with the prototype, the housing can be taken apart to replace the sensor or wiring, as these are the most fragile parts. Extra adaptability can be implemented by making the add-on blocks easily resizable in the online design, to account for people with varying ergonomic needs. The size, precision and speed of the required movement is already adaptable in the code. Still, finding the ideal value may be cumbersome, as trial and error and analysis of incoming values are necessary. An alternative would be a simple Artificial Intelligence code that finds optimal values based on some practice movements and feedback. For devices requiring digital input, the rewired bite switch also offers possibilities. This can be useful as a sustain, as well as a bass drum, control of simple settings, and many other uses within and outside of the music field that can be controlled with a simple switch. This may offer possibilities for people with other types of disabilities, such as partial paralysis. There is more research and discussion required to determine the ways and fields in which these aspects of the prototype can be helpful. In this research, a crucial aspect is to determine the needs, limitations and capabilities of people who may require a solution. When possibilities for further implementations are determined, adequate documentation for reproduction should be created and published on an open-source basis to benefit others. It would be best to research ways to also spread the work outside of the reach of My Breath My Music, to people who can benefit from these solutions in different fields.

10.3.3 Within the Field

People with disabilities and the music field can benefit from a greater awareness of the discriminatory effect of musical instruments. This awareness may inspire more innovation, space for participation, and opportunities for people with disabilities, which can lead to more varying perspectives in the music field, as well as novel methods of interaction that can be used by many musicians. In ways, this can transform the way music is made. The field of innovation for accessibility of music is growing, though still niche. As a result, many of the designers know each other. This makes it easier to spread knowledge and innovations. As the field grows, there should be attention on how this sharing can be scaled up in efficient and ethical ways. To gain knowledge, the field of ADMIs can benefit from steady measures and methods for the evaluation of products. For performance-based ADMIs, focus should be on expressivity, and for therapy-based ADMIs, focus should be on therapeutical impact. In addition, context is important to research the ADMIs and how they can best be utilized. The audience perspective is often overlooked. The precise measures and methods could be found with an elaborate literature review, leading to guidelines that are complete, accurate, evaluated, accepted, measurable and achievable in terms of resources. As a result, ADMIs can be compared, leading to more knowledge on design aspects. Knowledge on separate design elements and how to combine these can also be reached by evaluating iterations of a product, with slightly varying interactions and mapping. Knowledge on how design elements contribute to the character and acceptation of ADMIs can inspire designs that are more effective and may lead to guidelines for ADMI design.

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Appendices

Appendix A: Consent Forms

Appendix A1: Consent Form Design Partner

Consent form - Design Partner *"Inclusive School Band"*

A Dutch version of this consent form can be created if necessary. If so, contact the researcher (contact details are given on the bottom of this page).
Een Nederlandse versie van dit toestemmingsformulier kan opgezet worden indien nodig. Contacteer in dit geval de onderzoeker (contactinformatie is onderaan deze pagina gegeven).

Purpose of the research

The end purpose of this project is the custom adaptation of a musical keyboard for a specific end user with SMA Type 2, hereafter referred to as the design partner. Certain functionalities can not be used and should be adapted, with the subgoal of increasing the level of possible participation in the school band. For this final purpose, practical background information is required. This information will be used to make appropriate design choices that best fit the abilities of the end user. Furthermore, prototypes will have to be tested on usability, user experience and further relevant aspects.

Benefits and risks of participating

There are no mental or physical risks considering this study, it will be conducted in a way that will be mentally friendly and with utmost care for the wellbeing of the interviewee. This will be safeguarded by the EEMCS ethics committee of the University of Twente, which has reviewed and approved this research. There is little to no increased risk of contracting COVID-19, as the research activities will take place remotely as much as possible and prototypes will be disinfected before delivery and usage. If research at location is necessary this will be done in close consultation with all parties involved, and safety guidelines will be taken into account.
Participation will help lead to a custom design keyboard interaction.

Physical tasks

To get a good grasp of possible interactions some observation of physical tasks will be necessary. These include short physical tasks such as small body movements, pushing buttons, and similar relevant tasks. Medium length physical tasks will also occur, such as playing the keyboard and testing of prototypes (on aspects such as performance, ease of use and user experience). Tasks will be adapted to the ability of the design partner, and can be altered throughout. Safety will continuously be taken into account. Breaks can be taken at any time. Performance is not graded or judged, and only used to gain information on possible interactions.

Procedures of withdrawal from the study

Any concerns can be discussed with the researcher or supervisor, contact information is provided on the bottom of this page. Researcher and supervisor can also be contacted to request more information on individual research activities, such as interviews and prototype testing. If at any moment or under any circumstances you, the design partner, do not feel comfortable, safe or wish to discontinue for any other reason, you can withdraw yourself from the study without having to explain or justify yourself to the researcher. You may also decline parts of the research if wished, without having to explain or justify yourself to the researcher.

Collection, processing and purposing of any personal data

Some information on health status (concerning relevant practical limitations of SMA Type 2) may be gathered to the point of relevance during the research. These include current physical abilities and expected near future physical abilities relevant to the custom design. This will always be in consultation with the design partner. Aspects of the data set can be reviewed and omitted upon request from the design partner and/or their legal guardians.

Usage of personal data and anonymity

Testing of prototypes and interviews can be recorded (audio and/or visual) upon consultation, and will be used for observation and transcription only. The footage will not be made public, and may only be used by the researcher. Answers and data collected will be saved with care and made anonymous before further usage. Unidentifiable segments relevant to the project purpose may be used in a thesis that will be made public.

Retention period of data

As per rules of the GDPR the collected data will be archived up to 10 years in a secure location at the University of Twente campus. After these 10 years are over, the data will be systematically destroyed.

Contact details of researcher

In case of any questions or requests, you can contact (in Dutch or English)
Researcher: *(left out in thesis for privacy reasons)*
Supervisor: *(left out in thesis for privacy reasons)*

Contact Information for Questions about Your Rights as a Research Participant

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee "Computer & Information Sciences" of the University of Twente, *(left out in thesis for privacy reasons)*

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated [04-02-2020], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	□	□
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	□	□
I understand that taking part in the study involves observations and an interviewer who will engage in conversation. From these procedures, certain aspects or answers that are important for the product development will be written down. There may be video and audio recordings, these will be transcribed and anonymized.	□	□
Use of the information in the study		
I understand that the information I provide will be used for a research paper, which will be in the hands of the **University of Twente, My**	□	□

Breath My Music and the researcher and might be referenced by third parties.		
I understand that personal information collected about me that can identify me, such as [e.g. my name or where I live], will not be shared beyond the researcher.	□	□
Future use and reuse of the information by others		
I give permission for the anonymized transcripts to be archived in the repository of the University of Twente, so it can be used for future research and learning.	□	□

Signatures

I have accurately provided the information sheet to the potential design partner and, to the best of my ability, ensured that the participant understands what they are freely consenting.

__________________________ _______________________

Name of design partner Signature

__________________________ _______________________

Name of legal guardian of design partner Signature

__________________________ _______________________

Name of researcher Signature

Date: ____-____-_______

Appendix A2: Consent Form Interviews

Consent form - Interviews *"Inclusive School Band"*

A Dutch version of this consent form can be created if necessary. If so, contact the researcher (contact details are given on the bottom of this page).
Een Nederlandse versie van dit toestemmingsformulier kan opgezet worden indien nodig. Contacteer in dit geval de onderzoeker (contactinformatie is onderaan deze pagina gegeven).

Purpose of the research

The end purpose of this project is the adaptation of a musical keyboard for a specific end user with SMA Type 2, in order to increase the level of participation in the school band. Certain functionalities of the keyboard can not be used and should therefore be adapted. For this final purpose, theoretical and practical background information is required, mainly focusing on physical abilities and disabilities.

The main purpose of this phase is to grasp the types of interactions that can currently and in the near future be used by the design partner. This information will later be used to make appropriate design choices that best fit the abilities of the end user.

Benefits and risks of participating

There are no mental or physical risks considering this study, it will be conducted in a way that will be mentally friendly and with utmost care for the wellbeing of the interviewee. This will be safeguarded by the EEMCS ethics committee of the University of Twente, which has reviewed and approved this research. There is no increased risk of contracting COVID-19, as the research activities will take place remotely.

Procedures of withdrawal from the study

If at any moment or under any circumstances you, the interviewee, do not feel comfortable, safe or wish to discontinue for any other reason, you can withdraw yourself from the study without having to explain or justify yourself to the researcher. You may also decline parts of the research if wished, without having to explain or justify yourself to the researcher.

Collection, processing and purposing of any personal data

In case of experience experts (patients), some information on health status (concerning relevant practical limitations of SMA Type 2) may be gathered to the point of relevance before and during the interview, at all times in close agreement with the participant (and legal guardians if applicable). Aspects of the data set can be reviewed and omitted upon request from the participant and/or their legal guardians.

Usage of personal data and anonymity

Interviews can be recorded (audio and/or visual) upon consultation, and will be used for transcription only. The footage will not be made public, and may only be used by the researcher. The audio/video files will be deleted after transcription. Answers and data collected will be saved with care and made anonymous before further usage. Unidentifiable segments relevant to the project purpose may be used in a thesis that will be made public.

Retention period of data

As per guidelines of the VSNU the collected data will be archived up to 10 years in a secure location, and where relevant according to the rules of the GDPR. After these 10 years are over, the data will be systematically destroyed.

Contact details of researcher

In case of any questions or requests, you can contact (in Dutch or English)
Researcher: *(left out in thesis for privacy reasons)*
Supervisor: *(left out in thesis for privacy reasons)*

Contact Information for Questions about Your Rights as a Research Participant

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee "Computer & Information Sciences" of the University of Twente, *(left out in thesis for privacy reasons)*

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		

I have read and understood the study information dated [03-02-2020], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	□	□
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	□	□
I understand that taking part in the study involves an interviewer who will engage in a conversation. From this conversation certain aspects or answers that are important to the product development will be written down. There will be audio recordings, these will be transcribed and anonymized, then deleted.	□	□
Use of the information in the study		
I understand that the information I provide will be used for a research paper, which will be in the hands of the **University of Twente, My Breath My Music and the researcher** and might be referenced by third parties.	□	□
I understand that identifiable personal information is not required and, if given, will not be shared beyond the researcher.	□	□
Future use and reuse of the information by others		
I give permission for the anonymized transcripts to be archived in the repository of the University of Twente, so it can be used for future research and learning.	□	□

Signatures

I have accurately provided the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands what they are freely consenting.

__________________________ _______________________

Name of participant Signature

__________________________ _______________________

Researcher name Signature

Date: ____-____-_______

Appendix A3: Consent Form Pilot Evaluation

Consent form – Pilot Test *"Inclusive School Band"*

A Dutch version of this consent form can be created if necessary. If so, contact the researcher (contact details are given on the bottom of this page).
Een Nederlandse versie van dit toestemmingsformulier kan opgezet worden indien nodig. Contacteer in dit geval de onderzoeker (contactinformatie is onderaan deze pagina gegeven).

Purpose of the research

The end purpose of this project is the adaptation of a musical keyboard for a specific end user with SMA Type 2, in order to increase the level of participation in the school band. Certain functionalities of the keyboard can not be used and should therefore be adapted. For this purpose, a prototype is created. In order to ensure a well-functioning prototype and fitting user research method, a pilot test is necessary. The main purpose of this pilot test is to prepare for the evaluation session with the design partner.

Benefits and risks of participating

There are no mental or physical risks considering this study, it will be conducted in a way that will be mentally friendly and with utmost care for the wellbeing of the participant. This will be safeguarded by the EEMCS ethics committee of the University of Twente, which has reviewed and approved this research. There is no increased risk of contracting COVID-19, as the research activities will take place remotely in case of no priorly existing contact.

Procedures of withdrawal from the study

If at any moment or under any circumstances you, the participant, do not feel comfortable, safe or wish to discontinue for any other reason, you can withdraw yourself from the study without having to explain or justify yourself to the researcher. You may also decline parts of the research if wished, without having to explain or justify yourself to the researcher.

Collection, processing and purposing of any personal data

Personal information may be gathered to the point of relevance before and during the research activity. Aspects of the data set can be reviewed and omitted upon request from the participant.

Usage of personal data and anonymity

Interviews can be recorded (audio and/or visual) upon consultation and will be used for transcription only. The footage will not be made public and may only be used by the researcher. Any audio/video files will be deleted after transcription. Answers and data collected will be saved with care and made anonymous before further usage. Unidentifiable segments relevant to the project purpose may be used in a thesis that will be made public.

Retention period of data

As per guidelines of the VSNU the collected data will be archived up to 10 years in a secure location, and where relevant according to the rules of the GDPR. After these 10 years are over, the data will be systematically destroyed.

Contact details of researcher

In case of any questions or requests, you can contact (in Dutch or English)
Researcher: *(left out in thesis for privacy reasons)*
Supervisor:

Contact Information for Questions about Your Rights as a Research Participant

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee "Computer & Information Sciences" of the University of Twente, drs. *(left out in thesis for privacy reasons)*

Please tick the appropriate boxes	Yes	No
Taking part in the study		
I have read and understood the study information dated [03-06-2020], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
I understand that taking part in the study involves a researcher who will engage in a conversation. From this conversation certain aspects or answers that are important to the product development will be written down. There may be audio recordings, these will be transcribed and anonymized, then deleted.	☐	☐
Use of the information in the study		
I understand that the information I provide will be used for a research paper, which will be in the hands of the **University of Twente, My Breath My Music and the researcher** and might be referenced by third parties.	☐	☐
I understand that identifiable personal information is not required and, if given, will not be shared beyond the researcher.	☐	☐
Future use and reuse of the information by others		
I give permission for the anonymized transcripts to be archived in the repository of the University of Twente, so it can be used for future research and learning.	☐	☐

Signatures

I have accurately provided the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands what they are freely consenting.

______________________ ______________________

Name of participant Signature

______________________ ______________________

Researcher name Signature

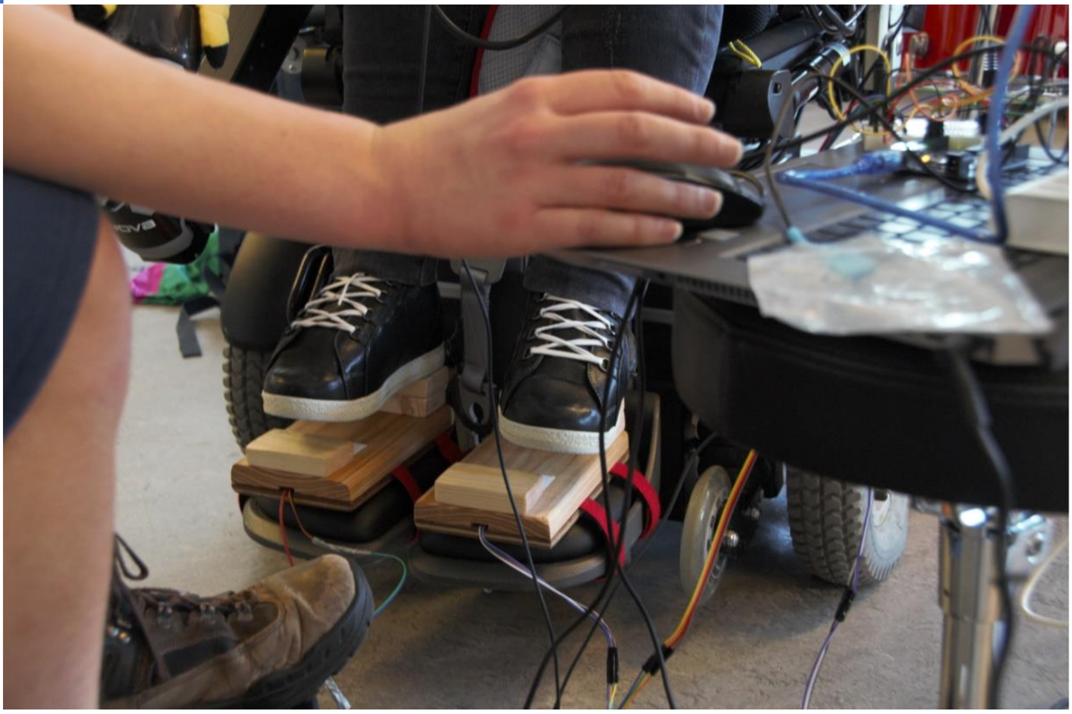
Date: ____-____-_______

Appendix B: Reflection II Report

University of Twente | Creative Technology | Reflection II

Report on Ethical Considerations in Design of Musical Assistive Devices

Inclusive School Band: An Adapted Keyboard



M. Geelen
17-6-2021

Contents

1. The Project and its Vision

1.1 Challenge

The graduation project *"Inclusive School Band"* focuses on adapting a musical keyboard for a teenager with SMA type 2. This is a progressive neuromuscular disease which causes gradual decrease in muscle function due to destruction of nerve cells. The teenager started playing the keyboard roughly a year ago. She receives private classes and is member of her school band. She can still press the keys on a light-playing keyboard to produce sounds, but many settings and functionalities are unavailable for her. For example, when her mother is not home she is not able to practice, since she needs help to turn the keyboard on. Furthermore, it is hard to control functions such as volume and type of sound. She is also only able to physically reach the middle part of the keyboard. Additionally, she can only play a small range of the keyboard, limiting her to two octaves. In addition, regular sustain pedals are too heavy to use.

This project aims to solve the most important issues this musician faces, which are found to be the small octave range, the lack of access to the sustain, and her inability to turn the keyboard on independently. The design attempts to create a handsfree, accessible way to change the octave while playing, to allow a larger range of tones without having to move the arms sideways. Furthermore, an alternative, accessible, unobtrusive switch will be created to replace a sustain pedal. Additionally, an off-the-shelf smart plug will be combined with a small keyboard adaptation, which will enable the musician to turn the keyboard on herself.

1.2 Current Status

In general, traditional musical instruments are relatively inaccessible, as they often require controlled movement of limbs. Technological advancements increase opportunities to make musical instruments more accessible by measuring accessible movements and mapping them to sounds [1]. This creates a lot of opportunities, as nearly any movement can be tracked. The mapping of these movements to sound changes can lead to expressivity in music playing. Even small changes in mapping can turn the same interaction into a very different musical instrument [2]. Products that enable musical interaction for people with disabilities through technology are called ADMIs, accessible digital musical instruments. The sector that is involved with ADMIs is still quite small, and most of the inventors know each other [3]. There are numerous charity organisations that focus on making the musical sector more accessible to those with disabilities, among which My Breath My Music[49] (client of this project), The OHMI (One Handed Musical Instruments) Trust[50], Drake Music[51], and Muziekotheek[52].

The organization My Breath My Music started an inclusive school band, in which many ADMIs and adaptations are used. The final user of this graduation project plays in this school band. She owns two light-playing keyboards of which she can not use all functions. At the beginning of the project she has not yet experimented with MIDI connection to enlarge her options. There is currently no suitable adaptation, nor considerable progress towards one. There are some thoughts from the music teacher and client (My Breath My Music) on what is necessary, but the start has never been made. There is no pre-research done with the intended user as of now, except some practical experience. This practical experience is considered in this graduation project's research in terms of interviews with client, music teacher and intended user.

[49] https://mybreathmymusic.com/en/
[50] https://www.ohmi.org.uk/
[51] https://www.drakemusic.org/
[52] https://www.muziekotheek.nl/

1.3 Importance

It has become clear that a good assistive device can reduce stress and enhance the quality of life for the user [4]. Assistive devices can increase the independence of people with disabilities, which can help enable interaction with others [4]. In playing music, this can mean that someone can play their musical instrument without needing a helper, making it easier to play music with other people as an equal [3]. This is a valuable experience for all people involved, not only the individual with disability [3]. The combination of independence and interaction with others can also increase participation in community life [4]. A number of musical and non-musical benefits of participation in music for families with disabled children have been found [5].

The declaration of Human Rights [6] states "All human beings are born free and equal in dignity and rights. They are endowed with reason and conscience and should act towards one another in a spirit of brotherhood. Everyone is entitled to all the rights and freedoms set forth in this Declaration." Thus, we should respect one another as equals, and the human rights, among which the ones mentioned here, apply to every human. Article 27.1 of the Human Rights declaration covers the right to participation, stating "Everyone has the right to participate freely in the cultural life of the community, to enjoy the arts and to share in scientific advancement and its benefits." People with disabilities are specifically covered in the UN Convention on the Rights of Persons with Disabilities [7], which is signed by 164 countries [7]. Article 3 of its general principles includes principles c: "Full and effective participation and inclusion in society", e: "Equality of opportunity", f: "Accessibility" and h: "Respect for the evolving capacities of children with disabilities and respect for the right of children with disabilities to preserve their identities." Thus, accessibility, participation and inclusion are human rights. Children with disabilities should get an equal opportunity to practice music and receive music education.

To summarize, this graduation project and projects alike, that create assistive technologies to increase opportunities for children with disabilities, are valuable from multiple standpoints. Firstly, it can increase the quality of lives for these individuals. Secondly, it can provide valuable experiences to their social environment. Thirdly, it can help to reach multiple commonly accepted human rights.

The motivation to start this project was not as rational as the above paragraphs. It was a combination of a love for music, experiences with inaccessibility, and a long held belief of equality. Personally, I have experienced both inclusion and exclusion, and have always tried to live in such a way that would increase the inclusion people around me experience. This has not been limited to accessibility issues, but also for example racial implications and playground bullies. Furthermore, since more recently, I have experienced visible as well as invisible disability. Though I see a lot of improvements in accessibility and an increasing wish for inclusion, a lot of work is still necessary. Even though regulations exist, some public spaces are not easily accessible for a range of physical disabilities, which also applies in Enschede. Some of these spaces are working on improvement, such as NS (Dutch monopoly on trains) which has plans to only use wheelchair accessible sprinter trains by 2025 and make all train stations wheelchair accessible by 2030 [8]. In the mean time travel assistance can be booked. However, two weeks ago a conductor told me that wishes to cut costs mean that travel assistants will get discharged and untrained workers may take over the job. This further increases the lack of awareness of mobility issues. Though there is a wish for improvement, and some action is taken, people of expertise do not seem to drive the organizational decisions. The actions that are taken are often marketed and made very visible, in many cases turning people and anti-discrimination into marketing opportunities. What has become evident to me in daily experience, is that individuals are willing to help each other out when necessary. I have not been turned down by individuals when needing help. Individuals seem willing to improve the situation when problems arise. However, the awareness, systematic opportunities and default accessibility are lacking.

This graduation project aims to increase accessibility for an individual, but will also be made available open-source for anyone who can benefit from it. Thus, accessibility to musical instruments will be increased for people with neuromuscular disability. As their participation increases, able-bodied counterparts can become more aware of the needs of people with neuromuscular disability. This awareness can further increase accessibility. An increase in opportunities and participation can also lead to an increase of accessibility, and the other way around.

My own disability has limited me in numerous ways, some of which music related. However, I have always found some meaningful way to still interact with music during all stages of life. For the past 1.5 year, it helped me manage the many emotions that illness and disability can cause. Bonde [9] describes this with the term 'health musicing'. Health musicing does not only occur during music therapy, but is also present in collaborative and individual practice where music experiences are used to find meaning and coherence through hardships [9]. Thus, it means to use music to regulate and promote emotion, connection, and well-being [9]. For health musicing, participation is a very important aspect [9]. This project is motivated by my wish to give people who are more limited better access to music and all the benefits it has given me. I strongly feel that everyone who is passionate about music should be able to access it in a way that fits their needs.

2. Driver For Change

2.1 Health

An assistive device aims to increase the level of functioning for a disabled person, being the efficiency and effectiveness in reaching a goal, in a 'mode' or method that is not the norm [10]. It is hereby different from curative devices, which aim to "cure" the disability, meaning one functions at the same level and in the same way as what is seen as normal functioning [10]. This graduation project aims to create an assistive product. Namely, the target user uses a different method to reach the same result. For example, a bite switch is used where the normal mode would be a sustain pedal, yet the target user will be able to sustain at the same level as a pedal would allow an able-bodied person to. As described in chapter 1.3, successful assistive design can increase participation for the individual by combining accessibility with interaction with others [4]. Participation is a health dimension as determined by the International Classification of Functioning, Disability and Health [11] (see figure 1). When viewing the relations in health dimension, it becomes clear that participation has a valuable influence on aspects such as activity, body functions & structure, and indirectly health condition [11]. These aspects also influence participation and the other health dimensions [11]. Due to such relations, increasing participation can cause a positive loop, where scores on all health dimensions increase for the individual [11]. Participation can be increased by improving accessibility [4], therefore this project can have a positive effect on the health of the user. A study on a newly designed ADMI [12] showed that the device expanded horizons of ICF dimensions, along with further therapeutical improvements. The user research of another ADMI [13] showed improvement of self-awareness, as well as physical, cognitive, communicative, emotional, behavioural and social functioning. The TouchTone [14] was tested in individual and group music sessions by occupational and music therapists, findings included progress in coordination and prolonged attention and concentration. This supports the claim that, as stated earlier in chapter 1.3, a successful assistive device can reduce stress and enhance one's quality of life [4]. The interrelation between mental well-being and physical health is further supported in [15], which reasons that the mind and body are interwoven, and that no process is purely mental or purely physical. This means that improvements in mental well-being, such as emotions that come with being able to interact with music in a desired way, also influence the body and its physical aspects. On top of the benefits assistive devices can give, this adaptation increases the access to health musicing, which was described in chapter 1.3.

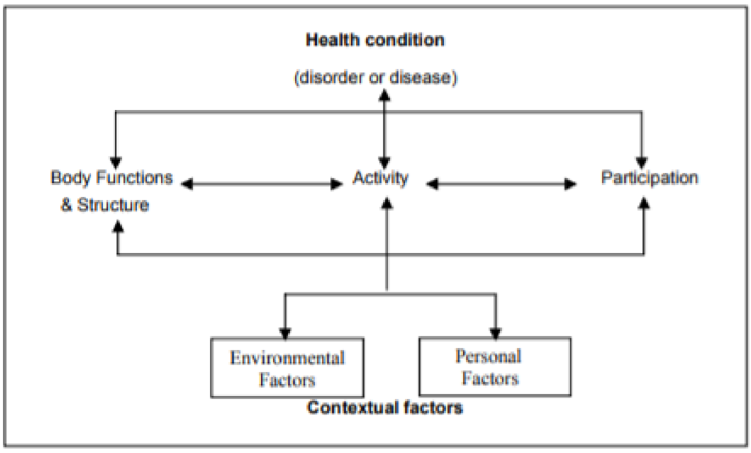


Figure 1: ICF Health Dimensions and their relations

2.2 Access, Participation and Inclusion

In chapter 1.3, the declaration of Human Rights is introduced, with focus on article 27.1 covering the rights to participation. Furthermore, article 3 of the UN Convention on the Rights of Persons with Disabilities is mentioned, which covers rights relating to equal access and participation. From these articles, we can conclude that people with disabilities have the right to equal access to arts, which includes music. Not only access, but also effective participation, inclusion and equal opportunity are described as rights. Though the target user of this graduation project already reaches participation by being a member of a school band, she does not have equal access or opportunity due to the inaccessibility of her own musical instrument, as well as many alternative musical instruments. Article 3h ("Respect for the evolving capacities of children with disabilities and respect for the right of children with disabilities to preserve their identities.") is interesting to consider, and especially becomes interesting when considering SMA Type 2 is progressive. The target user chose to play the keyboard and to play in the school band, a hobby and role that she has made part of her identity. If her disease progresses and this disables her from playing music in the school band, this will not help with the preservation of her identity. When designing a prototype, it would be valuable to create interactions using movements she will likely be able to make for a long time and/or to incorporate an element of adaptability, which can assure she can use the prototype long-term.

The UN Convention of Children's Rights [16] also addresses the right to access the arts. This right is outlined in three different articles. The convention addresses recreation and participation in art in article 31, stating

"Article 31

1. States Parties recognize the right of the child to rest and leisure, to engage in play and recreational activities appropriate to the age of the child and to participate freely in cultural life and the arts.

2. States Parties shall respect and promote the right of the child to participate fully in cultural and artistic life and shall encourage the provision of appropriate and equal opportunities for cultural, artistic, recreational and leisure activity."

When it comes to rights for children with disability specifically, which include participation, the following article is relevant:

"Article 23

1. States Parties recognize that a mentally or physically disabled child should enjoy a full and decent life, in conditions which ensure dignity, promote self-reliance and facilitate the child's active participation in the community."

Furthermore, the convention states the right to freedom of expression, including art if so desired, in the following article:

"Article 13

1. The child shall have the right to freedom of expression; this right shall include freedom to seek, receive and impart information and ideas of all kinds, regardless of frontiers, either orally, in writing or in print, in the form of art, or through any other media of the child's choice."

Articles 31 and 23 regard States Parties specifically, which is in line with the nature of the convention, of which much is aimed at responsibilities that the government has to ensure the well-being of children. Even so, the rights mentioning State Parties regard aspects that are important for children's well-being. With these articles, the United Nations clearly lays out the importance of participation in the arts, which includes music. The right to participation is approached from four different aspects, namely those of cultural life, recreational activity, participation and inclusion (specifically for people with disabilities), and freedom of expression. These are four main reasons why people with disabilities should receive equal access to music and musical instruments. This project aims at helping a teenager reach this access and can perhaps be further utilised to help multiple other children and adults gain more equal opportunities. By increasing access to music for at least one child, this project helps reach children's rights. Besides the equal participation in art being a right in itself, this participation can have other benefits, including health benefits described in section 2.1. Therefore, reaching these rights of inclusion and participation can also help reach other rights and goals, such as those that are health related.

Additionally, this graduation project can help enable a role model. There is currently a lack of disabled role models in the Dutch music sector [3]. As stated in an interview with the client [3], role models are necessary to increase inclusion. Role models can show children with disabilities and their parents that disabled people can play music too [3]. Furthermore, it can help normalise people with disabilities in the music sector [3]. Because of this, awareness for able-bodied counterparts can increase, which helps in reaching inclusion. The client of this graduation project specifically expects that the target user of this graduation project has potential to become a role model for many [3]. Therefore, this project can help increase participation and inclusion on a larger scale.

2.3 Sustainable Development Goals

Goal 4 of the Sustainable Development Goals describes inclusive and equitable quality education for all [17]. It focuses on equal access to all levels of education for vulnerable people, including those with disabilities [17]. One aspect is that educational facilities should be upgraded and built to be disability sensitive [17]. In my opinion, this equal access should also apply to musical education. As the tools currently used are often not designed to be accessible, people with severe disabilities do not receive this equal access. Some ADMIs have been developed to increase this, but their use is still more of an exception than the norm. The OctoTonic [18] is tested in special needs education as well as regular education and led to considerable independence. The TouchTone [14] is implemented in a learning module of individual and group music therapy sessions and was successfully adopted. Though development of ADMI is not enough, it is valuable and necessary in order to provide equal access to music education.

Furthermore, as described in section 2.1, a successful assistive device can reduce stress and enhance quality of life [4]. Therefore, the prototype developed in this project can help towards Sustainable Development Goal [19] 3: Good Health & Well-Being. Depending on the design process and customisability of the product, which will be discussed in chapter 3.2.6, the product might be able to do this with a limited discriminatory effect, helping towards SDG [19] 10: Reduced Inequalities. As further elaborated on in chapter 3.1.2, Wittkower [20] loosely defines a discriminatory technology as "a way of getting something done which produces a discriminatory effect". This effect occurs when a product is designed for a norm that is based on morally irrelevant aspects. The prototype of this graduation project will require minimal foot movement with no force, ability to bite, and controlled movement of fingers with little force. Personalisation regarding physical aspects such as the speed and size of foot movements is integrated, which will come with easy to understand documentation. Furthermore, personalisation of practical aspects, such as amount of octaves that can be reached or sounds to play with, is integrated. Additionally, with some small changes to the code, different sensors could be used with the prototype, meaning different movements can be tracked. Due to the software the keyboard and prototype will be connected to, namely Ableton Live with Max for Live, a very large amount of options is opened up for the user, all of which can be customised. The user can prepare Ableton Live sets with any settings, and quickly control them through the connected prototype. Furthermore, most of the prototype can work with any type of MIDI controller, which means it could also help people for whom a different controller is more accessible. The client of this graduation project, My Breath My Music, will also look into how the product can be used by other musicians. Perhaps some aspects can be reused and combined with other prototypes in development. If more integrations are found, this could lower the discriminatory effect of musical instruments further. The physical discriminatory effect is thus limited. Intellectually, some understanding of cause and effect in music is necessary. The prototype can be prepared with customised integrated Live sets so that little musical knowledge is necessary. However, it consists of multiple parts and interactions that have very different effects, and may therefore still be rather complex to use for some people with limited intellectual ability. Though it can still be useable for them and potentially offer meaningful possibilities, quite some of the value of the product will be lost, including the personalisation possibilities. There is limited discriminatory effect in the prototype, as it can be used by many people. However, it is not necessary for many people, meaning the product may still emphasize disability.

The product is a tool that can increase possibilities for some people who lack these now, and can therefore still help towards SDG [19] 10: Reduced Inequalities. However, there are economical and practical aspects, that may cause inequality in another aspect. The software, schematics and necessary documentary will be shared open-source on the website of My Breath My Music, so that people who can benefit from the solution are able to rebuild it. However, this does not automatically mean everyone who can benefit from the prototype will be able to own it. Firstly, material costs are substantial, and some people who can benefit from the product may not have the financial resources. This could be partially solved by My Breath My Music by choosing to let musicians borrow or cheaply rent the product, as they already do with musical instruments. This is mostly done in the Netherlands, so may not be available to people in other countries. Secondly, if materials are available, the user still needs electricity, a PC and a working internet connection in order to decently use the prototype. Worldwide there are many people who do not have such resources. Thirdly, many potential users would need help to create the prototype, for which some technical skill and knowledge are necessary, even if the documentation is easy to understand. This may make the solution unavailable to someone with a limited social network, or a social network with no technological skills. Thus, the potential user is first dependent on someone with the necessary skills in order to increase independence on a longer term. In conclusion, the prototype can reduce inequalities of disabled people versus able-bodied people, yet also increase inequalities between disabled people.

Some care is put into the use of responsible materials and limiting unnecessary use of electricity during the project. For example, by turning off and disconnecting devices that are not actively in use, and handmaking the housing for the sensors from wood using hand tools. However, non-green electricity is used for development, and likely will be for the usage as well. Furthermore, some materials used are not eco-friendly, and though some of the purchased products have a relatively responsible development process, not all companies purchased from have been researched to determine the ethics and eco-friendliness of their product development and store services. Furthermore, some of the products and materials have been ordered, and delivery was done with standard transportation companies, which are usually not very ecologically responsible. Further necessary transportation, such as that of further materials, delivery of the prototype, and travel to and from evaluation sessions have been done using public and mechanical methods of transportation. Though some consideration was present, I would say the prototype still goes against Sustainable Development Goal [19] 12: Responsible Consumption and Production and is disruptive from an ecological point of view.

In conclusion, when it comes to the Sustainable Development Goal, the project is both sustaining and disruptive. It is sustaining in terms of health and equality of opportunity for people with disabilities versus able-bodied people. It is disruptive when it comes to ecological impact and equality of opportunity within the group of people who could benefit from the product.

3. Moral values and Ethical Decision Making

In this chapter, five key ethical dilemmas will be described. Afterwards, one of these will be further analysed using the Ethical Cycle, as introduced by van de Poel and Royakkers [21]. Then, a section describing 4 key moral principles will follow. These will then be turned into a personal code of ethics relevant for the project.

3.1 Key Ethical Dilemmas

3.1.1 Responsibility

When doing research, a key question that erose is who should be responsible for increasing accessibility. The Dutch Ministry of Education, Culture and Science ordered research into the accessibility of cultural institutions for people with a disability in the Netherlands [22]. In this report, multiple involved organisations are mentioned, including the UN (conventions regarding equal access), EU (Arts & Disability Cluster, suggesting a budget to remove limitations for artists), Dutch government (carrying out research and creating laws for accessibility), individual institutions (responsible for abiding these laws), and organisations such as LCM (national contact of museum consultants) (providing rules of thumbs and information). Furthermore, Dutch municipalities provide funding for increasing accessibility of companies and organisations [23]. Woods [24] suggests that artists themselves are best at increasing accessibility, which goes for both able-bodied artists and artists with disabilities. This is because there will always be artists looking for new ways to create art. This graduation project's client states that everyone directly working in the field of increasing accessibility of the music sector is responsible when it comes to accessibility within music [3]. With so many different people and organisations involved, it is hard to determine who is responsible for what aspect. Groups can point fingers to one another and avoid taking initiative, as it seems to be someone else's task.

Furthermore, one can wonder to what extent people should increase accessibility for themselves, as well as what level of responsibility should lie in their direct environment. To what extent should society adapt to the minority and to what extent can we expect this minority to adapt to society? A question that arises with 'equal opportunity' is what should happen when someone does not use the opportunities. Some people with disabilities may not be motivated to increase their own participation, which can be for a range of reasons. If so, to what extent should governments, organisations and helpers be expected to improve accessibility for these individuals? Sometimes exclusion happens due to someone's own behaviour and it can be hard to determine to what extent this is the case. Inclusion can be extra hard for some able-bodied individuals, due to personality, negative experiences, or location. Should the organisations involved with accessibility and inclusion be involved with the inclusion of individuals or solely the inclusion of groups?

In determining to what extent people with disabilities and their direct environment (such as family and neighbours) should be held responsible, there may be differences in reasons for disability. For example, some become disabled due to driving under influence, some are permanently injured in their job environment, some have a genetic illness, some have developmental issues due to alcohol use during pregnancy, and some have lasting effects of a virus such as COVID-19. Here, level of responsibility for becoming disabled can be considered. Should someone who is disabled due to a dangerous decision be helped to the same extent as someone who could not have avoided their disability or someone who became disabled when saving the lives of others? Should the same effort towards accessibility be expected of parents who were aware of a 50% chance of severe disability in their child as of parents who could not have reasonably expected a child with disability? When people's social network can not help them, should organisations focus on informing, strengthening, or replacing the social environment? If someone's level of responsibility is determined, and they do not meet up to it, what should happen? Surely, punishing someone for not helping can have detrimental results. Furthermore, forcing someone to help another gives a different nature to the help given, which can lower confidence of people with disabilities. Even if any clear decisions would be made, doubtful cases and exceptions will keep arising. This list of questions and concerns regarding responsibilities is not exhaustive, but gives an idea of the implications involved.

3.1.2 (Positive) Discrimination

The lack of accessibility of traditional musical instruments can be viewed as discriminatory, a problem that is introduced in chapter 2.3. Wittkower [20, p. 15] loosely defines a discriminatory technology as "a way of getting something done which produces a discriminatory effect." This effect is caused when design is created for a norm which is based on morally irrelevant characteristics [20]. Privilege means to fall under this norm, which means one is 'invisible' as their characteristics are not viewed as being 'different from the norm' [20]. The development of traditional musical instruments has been for able-bodied users, as it assumes bodily functions such as controlled movement of limbs, muscle strength and the ability to see. There are quite a number of people who do not fall into this group, which is long viewed as the norm. Product developers often do not purposefully exclude these people, and may not be consciously aware that they are designing for the privileged group. Most able-bodied people also do not actively realise that the musical instruments are designed for them. However, many people with disabilities come across the issue that the products are not fit for them. Attempting to play traditional musical instruments often emphasizes that the instruments are not designed with them in mind. Without much reconsideration, musical instruments remain to be created in similar ways, for the same norm and with the same assumptions. This show the privilege of able-bodied participants, who are privileged as they are the norm, versus the lack of privilege of people with disabilities, who are actively noticed as different from the norm (which is emphasized when using these instruments). The issue of inaccessibility is starting to gain more awareness and the speed at which alternative musical instruments are being created is increasing [3]. However, traditional musical instruments are still the common way to access music, and alternatives are not widely available. More ADMI designs, and an increased access to these, are necessary to further normalise accessible musical instruments. If there are sufficient accessible alternatives to traditional musical instruments, people with disabilities can just as easily reach musical interaction, which limits the discriminatory effect of traditional musical instruments.

However, ideally, the alternatives should not be designed solely to address the difficulties of those affected. Wittkower [20] describes how manufacturing accommodating artifacts to solve the difficulties faced does not avoid the discriminatory effect of the technology. He also claims that we cannot design artifacts that are accessible for everyone, yet should attempt to design for most people to avoid a negative discriminatory effect. Therefore, especially adaptable musical instruments could lower the discriminatory level of musical instruments, as these can accommodate people of different abilities. Examples of this are M2M [12] and musical improvisation interface [13], which are improvisation interfaces that use web-cameras that can easily be customized to track any voluntary movement, ranging from limbs to eyebrows and more. The Octotonic [18] is a non-contact device that can be adapted to different ranges of mobility, though requiring some movement of the extremities or limbs. An older example, from 1996, is Composability [25], which is a custom composing software which can be used with different controllers, including mouse, console keyboard, and one or multiple switches. Composability is also appropriate for users with visual impairments by changing a few settings. In this graduation project, the potential to change common practices of discriminatory musical instruments can be increased by not creating just a customisation for one specific target user, but by creating an accessible and adaptable system that can fit people of different abilities, including that of the target user. In such a way, the product can be designed to be accessible for many people, which is, according to Wittkower [20], the best way to avoid discriminatory design. Furthermore, though the focus of this project is the target user, the ideal situation would be to create something that can help more people. This was discussed with the target user and client, who both agreed that a product that could be used and implemented for others too would be most desirable. Additionally, the client stated that the product will be made available online on an open-source basis, meaning people worldwide can build and implement the product (see also chapter 2.3). This can be done by or for people with different levels of ability. Though it is not necessary for many people, when finished it will likely work for most. In this way, the project may help increase accessibility of musical instruments on the long term with a limited discriminatory effect.

This graduation project, however, is still a custom adaptation for a specific person with a disability, which unavoidably causes discrimination during the process. On the one hand, increasing accessibility will lower discrimination, as more people can partake in the same activities at the same locations as able-bodied people. On the other hand, to increase accessibility, (positive) discrimination is often necessary. The IEEE Code of Conduct [26] is a widely accepted document describing the ethical standards in the field of engineering. The code states "We will not discriminate against any person because of characteristics protected by law" [26, p. 1], among which disability. There is a pay-off between current discrimination in the design process to decrease future discrimination. However, the product resulting from this project may also emphasize the user's disability on the longer term, as the customization underlines that there is a need for customization. The emphasis on the disability does not solve, and may even add to, a larger scale problem.

3.1.3 Vulnerability of Participant

The target user of this research project is underaged and thus considered vulnerable. Permission from the Ethics Committee of University of Twente to carry out research activity has been granted. The vulnerability of the target user has also been considered during preparation and carrying out of the research activities.

The Convention of Children's Rights [16] is created because of the vulnerable nature of children and specific children's needs, which are different from general human needs [27]. Thus, children should be considered differently than adults. One of the articles in the convention regards the right to be heard, as follows:

> "Article 12
>
> States Parties shall assure to the child who is capable of forming his or her own views the right to express those views freely in all matters affecting the child, the views of the child being given due weight in accordance with the age and maturity of the child."

Thus, the state has a responsibility to give children a saying in aspects relevant to them and should give appropriate weight to such expressions. Furthermore, [27] explains that children should also be involved, and even participate as actively as possible, in research that affects them. Poretti [27] states three reasons for this, namely the UN convention, the efficiency of the research, and the empowerment children experience due to participation. In case of this graduation project, the results directly affect the target user, thus she should be given appropriate chances to express her views. The target user is 15 years old and intellectually relatively mature, therefore, her input should be weighted heavily. This does not mean the target user should make the actual design choices, as future users can not always know and express what they need. Most users are not trained to make such decisions, may not know the possibilities that well, and often did not do the same level of research as the designers did. However, the user perspective in this research is very important, as it can help ensure accessibility and useability for the target user. Furthermore, small changes in an expressive musical instrument can greatly influence the experience of making music. These changes should thus be unobtrusive to keep the user's appreciation of the instrument, or even improve it. This project uses active user involvement, as it has many benefits and includes the target user in a project that affects her. In this involvement, the target user is accommodated more carefully than averagely, due to their vulnerability.

Week 6 of University of Geneva's course on Children's Human Rights [27] is dedicated to "participation rights". Morrow describes ethical research procedures in child participation in research. In setting up research there are ten main important topics to consider. The first of these is the purpose of the research. In case of this graduation project, the purpose is increasing accessibility of the musical keyboard for the target user. The second topic mentioned is assessment of the harms and benefits for the children and any other people involved in the research. In this research the most obvious benefit for Ella is the custom adaptation, but the benefits also include contributing to something that concerns her, being actively listened to, and having someone attempting to solve a problem for her. The risks are limited as much as possible in the preparation and throughout the process, by letting the supervisor check the safety of prototypes. Furthermore, as much of the work as possible is done remotely to limit the risks of the spreading of COVID-19. There is some risk of fatigue or disappointment. The third topic Morrow describes regards respecting privacy and confidentiality. In this graduation project, all standards, including safe storage and anonymisation, for handling sensitive data are applied. Furthermore, the target user and her parents have explicitly been informed that they can request deletion of certain or all data. This topic also regards a responsibility to act when children report being at risk or danger, which is not expected during the scope of this research. If something like this would occur, this will be discussed with the supervisor first, then an appropriate action will be taken. The fourth topic regards selection and participation, including issues of poor communication and representativeness. In this project, the target user has been suggested by the client. There is sufficient reason to believe the client is capable of ethical selection of musicians to design for. The fifth topic regards economic matters, including whether funding is taken from an ethical source and whether children are compensated for their effort and time. The funder of this project is My Breath My Music, an organisation that actively advocates for children with disabilities, and is thus an ethical and relevant sponsor. The target user receives a suitable adaptation as a reward for participation. If she refuses to participate in some of the research, she will still receive this, but it may fit less well. The sixth topic regards the review of aims and methods of the research, including review by an Ethics Committee and influence of the participants. For some research activities, such as evaluation of interaction methods, the target user is asked to review a preparation. In this graduation project, there is a lot of open communication with the target user. Though the main activities are chosen by the researcher, there is flexibility to adapt to preferences of the target user. The seventh topic that Morrow describes is the information that is provided, which should be relevant and accessible. This also relates to the eighth topic of informed consent. The target user has been provided with an elaborate leaflet with attached consent form, to be read and signed by her and a legal caregiver, at the beginning of the research. Furthermore, throughout the process, she is provided with a description of each expected research activity, both before planning the activity and at the beginning of each activity. Additionally, some of her rights are repeated at the beginning of each activity, including the rights to take breaks at any time, refrain from answering questions without having to justify oneself, and withdraw from the research without significant consequences. The ninth topic regards the way research findings are used and presented, which should be representative and fair. In the thesis of this project, lot of effort and thought is put into representative and respectful reporting of results. Furthermore, the target user was given the opportunity to review chapters that regard her. The final topic is the researcher's impact on children in general. This graduation project may lead to an invention that can help children and adults with disability gain access to functions of musical instruments. Furthermore, the client expresses that the target user has potential to become a role model for other children with disabilities, which can further promote and normalize music making for children with disability [3]. There is thus reason to believe that the research will have a positive influence on some children. There is no reason to believe there is a significant negative influence.

3.1.4 Sustainability

Accessibility and adaptability are often increased by using technological solutions, such as custom software combined with off-the-shelf interaction systems using sensors. These materials use electricity and are often not reusable. [22] implies that improving accessibility is often concerned with customization. The customization of musical instruments is expensive [28] and though there are organisations to help with financing, such as Muziekotheek[53], some of the costs usually still need to be covered by the individual. Sustainable design often increases costs, at least at first, and is generally less widely available. If, on top of putting a lot of time and effort into accessibility, designers want to work towards climate friendly solutions, it is likely that the access to assistive devices will lower. There is thus a trade-off between larger-scale accessibility and sustainability when it comes to assistive devices for people with disabilities.

Often, it seems designers of ADMIs are not aware of the ecological impact of their design (judging from the lack of mention of such issues in all papers analysed for the graduation project so far). They focus on the social and psychological impact of their design. Sustainability and accessibility do not go hand in hand, and since the purpose of the project is accessibility, it is likely that sustainability and the goal of this project can not both be realised as much as desired. Fleddermann [29] describes three ways to deal with conflicting values, the first of which is that it is often obvious which one is more important. In this case, it is hard to determine this. While sustainability is very important for communal survival, this project will only have a small impact on the issue. On the contrary, while accessibility can be viewed as less important (it is a value that does not directly relate to survival), the project will have a larger impact on the issue. Surely, the initial focus of the project assignment is on accessibility, but this may not have much worth if it jeopardizes survival. The second way to deal with conflicting values is to find a creative middle way, which is often not easy to find [29]. If this can not be done, a hard choice needs to be made [29]. Since the key purpose of this project is an increase in accessibility, the hard choice will likely be to disregard sustainability, though a creative middle way is worth looking into.

3.2 Ethical Cycle

The Ethical Cycle is described by van de Poel and Royakkers [21] and gives guidance for a more systematic process of ethical judgment. It is a structured and disciplined method that can help with analysis. In this section, the ethical cycle will be applied to an ethical dilemma based on section 3.1. The ethical cycle consists of a moral problem statement, problem analysis, options for action, ethical judgment, and reflection. To start the ethical cycle, the case of the project is considered. After multiple iterations of the cycle, a morally acceptable action is decided. This chapter describes the results per phase, which are built up over multiple iterations. The results are described without documenting the iterations for reasons of clarity.

3.2.1 Case Scenario Summary

There's a problem of lack of accessibility of traditional musical instruments, because of design that does not account for physical and intellectual disabilities. I am developing an adaptation of a musical keyboard for a specific teenager with progressive neuromuscular disease, who plays keyboard in her school band, to address this. Ideally, the keyboard adaptation is created as such that it can be used for multiple years. A relevant subgoal is to create the adaptation in such a way that it can be used to also increase accessibility for other musicians with similar cases. For this project, I am working with My Breath My Music, a charity organisation focused on making music more accessible for children with disabilities.

3.2.2 Moral Problem Statement

How can reaching accessibility and avoiding discrimination be balanced (in this project)?

Someone's disability not being taken into account will lead to accessibility issues, while someone being viewed as only their disability is discriminatory. It is important to balance special needs (directly relating to disability) and personal needs (relating to personality, preferences, social context). Sometimes, a product that is slightly less accessible fits a person better than something they can easily use but does not

[53] https://www.muziekotheek.nl/

fit their personal goal. In this project, it is important to make a product that is sufficiently useable, but also make something that offers expressivity, feels intuitive to use, fits the context it is used in, and compliments the experience of playing a musical instrument.

3.2.3 Problem Analysis

Stakeholder	Interests	Value
People with neuromuscular disabilities	- Being able to join activities - Being able to do things themselves - Being seen as who they are as humans, equally and accurately	- Participation - Independence - Dignity and equality
Designers of assistive devices	- Making a useable product - Solving a problem users face	- Accessibility - Charity
Caregivers of people with neuromuscular disabilities	- For their loved one to have meaningful activities - Time for themselves	- Participation - Independence
Charity organizations	- Solving a problem people face - Providing meaning to others, including meaningful activities - Having a good image	- Charity - Participation - Dignity
Sponsors and sellers of assistive devices	- Making profit - Selling useable products - Having a good image	- Growth - Efficiency - Dignity

Participation: It is valuable for people with disabilities to be able to participate in activities, as it creates meaningful experiences and connections. Furthermore, as described in chapter 2.1, participation can lead to a number of health benefits. For caregivers, it is valuable to see the one they care for experience the benefits of participation. Furthermore, people with neuromuscular disabilities participating in activities means that they gain some independence. For charity organizations it is valuable to help others, in case of people with disabilities as target group the help can include increasing accessibility, participation and inclusion, as this creates meaning for the people they wish to benefit.

Independence: Independence gives a sense of autonomy that comes with confidence, which is valuable for people with disabilities. As disabled people tend to also face some discrimination in various aspect, this confidence may even be more necessary than for most able-bodied people. For caregiver an increased independence for their loved one means that they have to invest less energy and can take more time and space for themselves. Independence helps in establishing healthy relationships for both parties involved [30].

Dignity: In much of Western society, ones value in society depends on how they treat people of minority, due to the Christian values the society is based on [31]. Dignity is important to determine your role in society. This role in society can be important for various reasons. For sponsors and sellers this role can decide their likeability, which influences revenue. For charity organizations their dignity strongly influences the amount of donations they receive. When their dignity gets damaged, they will lose out on donations, and face doubt from faithful sponsors. Thus, a charity's dignity very much impacts the resources with which they can work to create meaning to reach their goals. For people with disabilities a role of dignity can help with their confidence and inclusion. Disabled people often face pity, dependence and other experiences that lower their dignity, while increasing this dignity can help them feel closer to their community.

Equality: Equality is a human right for multiple reasons. It is important to feel like there is a place for everyone, including you, in society. This can be good for well-being and a community feeling, as well as increase feelings of confidence and brotherhood. It often happens that people with disabilities are applauded for the wrong reasons if they accomplish anything. On the other hand, it regularly occurs that people with disabilities need to work way harder to even come close to reaching the same level of appreciation an able-bodied counterpart would receive. If people are seen as equal in value (not in ability or personality), and judged on aspects relevant to the individual (i.e. not judging a fish on how well he can climb a tree), the learning environment and process of disabled people can improve. Furthermore, people will feel less need to go through drastic actions to prove their worth. Inequality can come with frustrations, that can lead to for example increases in crime rate [32]. More equality can lead to more satisfaction, as ones role in society feels valid and valuable.

Accessibility: An increase in accessibility can improve independence, inclusion and participation. Furthermore, it can increase efficiency in getting around for people with disabilities. This narrows the gap between disabled and able-bodied people. Increased accessibility helps reach the human right of equal access, which is more deeply described in chapter 2.2.

Charity: Helping other people comes with a good feeling, as it triggers the rewards centres of the brain [33]. Appreciation and success in helping can come with a sense of satisfaction and confidence. Helping others can also influence how you see yourself and your value in your community. Giving back to the community gives the feeling that you are part of the community and have something to offer in it.

Growth: Profitability of a company can lead to an increase in resources, which can be used for growth. When production increases, the individual products often require lower production costs, which also increases the efficiency. Resources come with possibilities, which can enable growth. Companies need to make sure their revenue is higher than the costs of for example labour and materials.

Efficiency: When products are useable, the user can more easily navigate the product. They can more easily reach their goals using the products. Furthermore, efficient products can avoid frustrations that create a negative attitude towards the product. High useability and efficiency will make users more inclined to use the product more, and experience it positively.

Competing values:

For growth, not only profits are important, but also establishing a good name that is well-known in relevant fields. For this, quality products and a good image can help. Another aspect that can help is marketing. In marketing, it can be beneficial for the company to advertise the good things they bring to society. With this sentiment, it occurs that people with disabilities turn into marketing opportunities. In this process, it is likely that the disability of the person will be emphasized to some extent. This can increase discrimination, as it may show a deviation from the norm. Many companies do not hire people with sufficient awareness for this, and end up creating “inspiration porn”. In many of such advertisement, participants will be selected based on morally irrelevant aspects, namely disability. Depending on the casting criteria and process, it may also occur that a very one-sided image of disability is given. This can increase inequality between people with different disabilities, or even different levels of the same disabilities, or in similar condition with very different views. Even if it can be positive discrimination if done well, being marketed with emphasis on your disability does not show equality. Thus, there may be competing interests of marketing for growth versus equality and non-discrimination.

Another clash of interests can occur when it comes to growth. People with disabilities often require adaptation to reach a good level of accessibility. Some products may be easily integrated for many, but there are cases where off-the-shelf or standardized products can not suffice. In these cases, customization of a product can be necessary, which lowers possibilities for mass production. Product developers have to spend more time per product, and not all materials can be purchased in bulk. Furthermore, more expertise is necessary to ensure that products work for the target group. Additionally, expertise in sensitive user research is necessary (which will be further discussed in the next conflict of values). All this increases the costs of making a product, which will either lower profitability, or lead to more expensive products. As mentioned in chapter 3.1.4, in some cases, sponsors or charity organisations can sponsor the increased costs. An example for a charity organisation that offers financial support for musical instrument adaptations is the earlier mentioned Muziekotheek[54]. Though such organisations can also increase equality and participation, it will always lead to decisions on who is eligible. This can be limited to a very one-sided image of disability, and lead to criteria that are standardized. In practice, it may give people with disabilities the idea that someone else has to judge whether they are sufficiently disabled to receive aid. This reduces dignity, causes frustration and lowers trust. Often, advice and reference from a music therapist and/or ergo therapist are necessary for the application. This requires good health care, which is not available for everyone. Overall, determining who is and is not eligible can be influenced by existing inequalities within people with disabilities, which may then grow. Even if organisations succeed in managing the applications well, there is always a limit to how much financial support they can offer. Some people may need to pay out of pocket entirely, or provide contribution. This can also pose limits for those with less financial resources. The need for growth may increase socioeconomic and resulting accessibility inequalities.

Adaptation to specific special needs calls for a very user focused approach. There are often more ethical considerations in research when it comes to people with disabilities, as some groups may be vulnerable. Furthermore, some research may require health data, which is of sensitive nature. Unfortunately, there is often a lack of awareness from able-bodied people, which may lead them to handle situations insensitively or too sensitively. Gaining this awareness is possible, but requires time and training. In the approach, the special and personal needs should be balanced. Furthermore, focussing on the limits instead of possibilities is unhelpful for both potential users and designer. Thus, instead of being too focused on the disability, it is important to look at what is possible. However, if only ability is taken into account, and not any preferences, social context or other relevant aspects, the target user is reduced to their disability. This is discriminatory and frustrating. Additionally, it is ineffective as this can lead to a product that does not fit the target user. The user may be able to use it very well, but it may not help them reach their goals, the method may be obtrusive to them, or they may simply not want to use it. Someone's disability not being taken into account will lead to accessibility issues, someone being viewed as only their disability is discriminatory and insufficient for good design choices. Thus, there is a conflict, or more a trade-off, between reaching maximum accessibility and having a non-discriminatory design process. It is important that this is balanced and considered, though it may require resources that are not always easily available, including expertise and experience.

3.2.4 Options for Action

In this section, options for action to handle the trade-off between ensuring accessibility and avoiding discrimination are outlined. The ethical implications and benefits of these options are described in section 3.2.5.

<u>Follow a discriminatory process:</u> In the trade-off it is possible to choose one of the two ends. In this case, a discriminatory process. This will ensure that the end product is accessible and has high physical useability for the design partner. Since the design partner does not have any intellectual disabilities, the focus would then be on the physical possibilities. Every button she can not reach on the keyboard can be replaced in a way that she is physically able to use them.

<u>Follow a non-discriminatory process:</u> The other end of the trade-off is to follow a completely non-discriminatory process. In this case, only personal goals are taken into account, and a design will be made based on that. This will ensure that the target user's personality and preferences are given value. The person will be approached like an able-bodied counterpart.

[54] https://www.muziekotheek.nl/

Make something easily customizable: Instead of choosing one of the values in the trade-off, an interface that can easily be customized can be created. For example, an interface that one can easily connect different controllers to and/or an interface that allows one to map the input of controllers to desired sound changes. In this, only the problem the specific target user faces should be considered, and not the user's characteristics. Then, a customizable product can be made that can solve this problem through multiple interaction types and mappings. The target user can then choose an interaction and mapping that is accessible and satisfying for them.

Give control: To avoid wrongfully dealing with the trade-off, leading to psychological harm, a researcher could give the target user nearly full control over the interactive research activities, such as interviews, observations and evaluation sessions. The target user can then discuss topics they are comfortable with that they think are relevant to make a fitting design. Some follow-up questions can be asked, as long as the target user remains in control. The interviews would mostly be monologues, and the participant would have the role of a consultant.

Design partner: Instead of giving or taking full control, an approach that combines both can be found. Namely to treat the target user as an equal colleague who has part of the expertise necessary to come to a successful prototype. This requires some social skills, as well as patience and listening. Semi-structured interviews are fit for this approach, as it gives some structure but does not become rigid. During all parts of the process, the target user should be made aware that she can make requests or refuse to answer questions. Furthermore, most questions will be open and allow for a level of detail that feels comfortable. When the target user goes off track, initially the designer should follow and give space for their thoughts. If it becomes very off-topic, the designer can guide back with prepared questions. This way, the interviews will be made into a conversation in which knowledge is requested and shared. The evaluation sessions can also be flexible, allowing the target user to explore as feels good. Preparation can ensure that all relevant aspects are considered and looked into, but should not be treated rigidly. This will give space for the social and emotional aspect of the activities, and allow the target user to be open in a way that fits her. Suggestions and requests should be taken seriously and tried out. This does not mean every request and suggestion can be integrated, but it does mean everything is reasonably considered. In this approach, the target user is a design partner, and the expertise of designer and target user are combined to create a prototype. It is working together with, instead of for someone.

Inform and ask feedback: It is hard to determine how a participant experiences any user research without asking them. Furthermore, it is hard to prepare a research activity if you are not sure what is possible and comfortable. Therefore, it can be helpful for both parties if the participant is asked for feedback. When planning an activity, the designer can make sure to inform the target user as well as possible on the nature of questions and type of tasks they may expect. For the initial planning of an activity, information on the type of activity and its goals can suffice, but when nearing the date some preparation is required. Ideally, the preparation of the research activity is sent to the participant for reviewing prior to the activity. If parts are demanding, uncomfortable, or not reasonably possible, they should be changed beforehand. If these aspects are of large concern or substantial changes are made, a new version of the preparation can be reviewed. During the activity, the participant should always be informed on what is happening and why. Furthermore, they should be clearly allowed to take breaks or refuse parts of the research at any moment. After each part of an activity, the designer can ask how the participant experienced the activity so far, and offer an extra break. Debriefing is also important, and allows for a good moment to ask feedback on the process. A day to a week after the activity the participant can again be asked how the activity was experienced and what can be done to improve the experience.

Be a friend: The designer can choose to be an understanding social factor in the target user's life. This way, information sharing is experienced differently. Furthermore, actions become more nuanced and there is a clear care for the target user's well-being. A friend who is helping you find a way to play a musical instrument can be less threatening or alienating than a designer doing so. The friend role can be achieved through sharing personal experiences, listening well, allowing for getting side tracked during research activities, and having conversations instead of interviews. This way, on top of the researcher and designer roles, the designer has the role of a sort of friend.

3.2.5 Ethical Judgment

Follow discriminatory process: The keyboard itself already addresses the target user's personal needs of expression, sound and possibilities. She choose to play a keyboard for personal reasons, and specifically choose this one similarly. Thus, if something is designed to help her use the keyboard through a discriminatory design process, the end product will be useable and still help her reach a personal goal. By following a discriminatory process in this project, both special and personal needs are met.

Follow non-discriminatory process: The keyboard likely had a design process that had no focus on disability. Though it matches the design partner's goals and preferences, it is not useable for her. When going through a similar process where her disability is not taken into account, a similar thing will likely happen, such as has happened with most traditional musical instrument. A product that matches the design partner's needs, but is not useable, can not suffice for this project at all. Furthermore, if taking a person into account without taking into account their disability, the self and disability are viewed as distinct from each other. Edwards [15] describes how disability and the self are related, and that seeing them as distinct is inaccurate for multiple reasons. Specifically, all processes are interwoven, there are no distinct mind and body, and there is no unaffected self trapped in a disabled body [15]. Seeing the person as entirely distinct from their disability is inaccurate and emphasizes a long-believed idea linked to a lack of awareness. Entirely ignoring ones disability when considering them is also discriminatory.

Make something easily customizable: Making something entirely and easily customizable is valuable in design for disabilities, both to increase accessibility for more people and to ensure accessibility over time for ones with a progressive illness, which is also discussed in chapter 2.2. Furthermore, something customizable may put less emphasis on one's disability, especially if it is created in such a way that it can also benefit able-bodied counterparts. When making a customizable prototype, it is still important that the specific target user can also use the product. There is surely added value in making an adaptive device to solve the problems the design partner faces if she can not use it while others can. However, this does not suffice for the current project. The client and user requirements would not be met. It would show disrespect to both of them to stop aiming at making something that is directly useable for the design partner. Thus, even with this option, the possibilities for customization should allow for the customization that the design partner needs. Furthermore, the design should fit the scope of this research project. It is likely that only one version can be created. There is added value in making it customizable, but a full integrated customizable project may not fit the scope and end up in a poor-functioning product. This will also not meet the requirements. When designing a prototype, it would be valuable to create interactions using movements she will likely be able to make for a long time or to incorporate an element of adaptability, which can assure she can use part of the prototype on the longer term.

Give control: A problem with this approach is that the target user is not a designer, and thinks differently. They may not see possibilities similarly, or understand the relevance of certain information. Furthermore, the approach will be less structured, which increases possibilities of misinterpretation or skipping of important aspects. Furthermore, it may be awkward or exhausting for a non-designer with no experience in user research to manage the setting. Though it is good to give space to the target user and respect their suggestions and information, giving them no guidance or structure is not ideal. Besides this approach potentially negatively impacting the results, the approach can also cause unnecessary stress for the target user and increase demands of research activities.

Design partner: In this approach, mutual trust is important. Trust from the design partner that they are being taken seriously and that the information they provide is handled sensitively. Trust from the designer that the design partner is open and honest, and has valuable knowledge to contribute. Furthermore, trust in each other's contribution. If this trust is set up, and the target user can communicate comfortably, this approach can lead to more relevant knowledge than an approach in which the researcher or target user takes control. Furthermore, being given a collaborative role leads to active involvement in an issue that regards the target user, which is important in research with children [27]. This can come with dignity, confidence and a sense of control. Furthermore, this approach can make the target user feel listened to, which enhances confidence and comfortability within the process, which is important when handling sensitive data. Additionally, a collaborative role can emphasize equality and mutual respect.

Inform and ask feedback: It can give a sense of control and autonomy to be informed and invited to provide feedback for improvement. This increases the target user's sense of control, which can increase their comfortability within the research. This is further increased because communicating openly with the target user and taking their suggestions seriously likely creates trust. Furthermore, as described in chapter 3.1.3, it is valuable to actively involve children in matters that concern them. Communicating behind their back, or barely at all, does not actively involve them. The experience of being involved can be empowering, especially if suggestions are taken seriously. Besides increasing comfortability for the participant, it can also increase confidence of the researcher during the process, as they will have some guidance on a sensible approach through the received feedback. This feedback also helps the researcher learn and improve their attitude, which can help increase awareness of special needs.

Be a friend: The friend role should be used with caution due to numerous reasons, four of which are given here. Firstly, (accidental) insensitivity from a friend figure is experienced differently than that of a researcher. This can be in the positive sense, as the researcher's good intentions may be more clear, but can also be experienced more negatively, due to being closer to the participant. Secondly, the friend role can lead to an approach that is unhelpful for the design task at hand. It is possible that not all relevant information is discussed, due to a very flexible method which provides less control for the designer. Thirdly, the friend role can lead to a lack of structure for both parties. This can be distressing, messy, and overall complicate the process. Lastly, it can be hard and inefficient to balance multiple roles. Information gathering, including note taking, can mismatch with being a friend and create an awkward situation. Furthermore, it may be unusual to write about someone academically if you are better acquainted. Additionally, this balancing of roles can lead to feedback of lesser quality and quantity. The target user may be more sensitive to the feelings of the designer and avoid harsh but necessary critics. The designer may even be held to different expectations altogether. There are benefits to the friend role, but only if the researcher has sufficient skills to balance their roles adequately and respectfully. If the researcher does not have these skills, it is better to not take the friend role than to only take the friend role.

3.2.6 Reflection

The dominant value in this project is accessibility, as the whole assignment is based on making something that is accessible. However, this directly relates to discrimination on the larger-scale, a value which should thus also be considered as much as possible. The larger-scale, long-term inclusion of people with disabilities seems more important than a perfect approach during the design process. However, though accessibility is the key motivation of design choices, respect for the target user is of great importance. The target user is made aware beforehand that some discriminatory process will occur to provide the necessary accessibility. She and her caregivers gave informed consent regarding this. Still, the target user should be approached sensitively and unnecessary discrimination should be avoided. All discrimination during the process should clearly lead to an improve in the accessibility of the prototype, and therefore noticeably benefit longer term inclusion.

Usage of line drawing to analyse ethical aspects is described by Fleddermann [29]. This technique will now be applied to the discrimination paradox of this graduation project. The discrimination paradox is that a custom design calls for a discriminatory design process, and may also lead to an end product that emphasizes disability, which may further enhance discrimination. At the same time, the product increases accessibility, which can ease participation, which in turn leads to inclusion and therefore lowers discrimination. Without any discrimination it is hard to ensure accessibility, however, moral principles call to avoid discrimination.

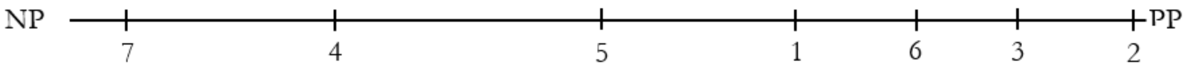
Negative paradigm: The product significantly increases discrimination on the short and long term.

Positive paradigm: The product significantly decreases discrimination on the short and long term.

The following situations can occur in between these paradigms:

1. The process and product emphasize the disability, but increases accessibility and participation for the individual
2. The development process is non-discriminatory and the product can increase accessibility on a larger scale without emphasizing disability
3. The product development process is a bit discriminatory, but the end result increases inclusion for multiple people without emphasizing the disability
4. The process is discriminatory, the product emphasizes disability, the product increases accessibility by only a bit
5. The development process and product emphasize disability but improve accessibility and participation
6. The product development process and product emphasize disability to a reasonable extent, the product can be adapted on a wider scale to fit different levels of ability
7. The product development process is not discriminatory, the end result is not sufficiently accessible

The situations can be placed between the negative and positive paradigm as follows.

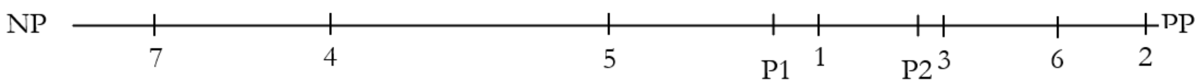


Depending on the level at which the design can be implemented for other people than the target user, the following two problems can be determined.

Problem 1 (P1):
- The design process is discriminatory
- The end result is an adaptation, thus emphasizes the need for adaptation, thus emphasizes disability
- The product is accessible for the design partner
- Participation becomes easier for the design partner

Problem 2 (P2):
- The design process is discriminatory
- The end result is an adaptation, thus emphasizes the need for adaptation, thus emphasizes disability
- The product is accessible for the design partner
- The product is adaptable to fit other users with a range of physical abilities
- Participation becomes easier for multiple people

Adding these problems in the situations gives the following line chart:



This shows that both results would be positive. Thus, the design process can be discriminatory if this leads to more accessibility, assuming that accessibility can increase participation. If participation on the long-term is increased by short-term discrimination, there is still a decrease in discrimination. This project is therefore an example of positive discrimination, which can be done ethically. An outcome of an adaptable product that can be implemented for multiple people would be desirable, as this leads closer to the positive paradigm. In this case short-term discrimination of one consenting person could lead to long-term decrease of discrimination for multiple people. It is important that the design partner is consenting at all stages and has sufficient information and comfort throughout the project. The harm should be limited by only discriminating where it is beneficial, thus only to the necessary extent in aspects which have direct relation to the product development.

In the case of this project, following a discriminatory process is better than following a non-discriminatory effect. In a way, the target user's personal goals are already accounted for by the keyboard, which she chose. Through a discriminatory process accessibility to this instrument can be offered. The full musical instrument would than account for disability and non-disability related needs. The downside would be that the target user may feel discriminated against and not listened to during the design process. Furthermore, even if the interaction is useable the product may still be unsuitable if it does not fit the personal goals and preferences of the target user. Most able-bodied people have more choice in how to interact with a keyboard, and can choose a method they can access and prefer. The target user does not have this opportunity, and will only have one method that is sufficiently accessible for her. However, a lack of options will not feel like a limitation if the available option is suitable. By ensuring that the prototype fits her personal needs as well as special needs, she can reach similar opportunities as an able-bodied counterpart, even though her amount of possibilities are still less. Furthermore, the product would be more appreciated, and her experience in music would be more positive. This can help in participation and recreational activities, and create meaningful moments.

Thus, it would be better to find a balance where preferences and personality are also taken into account. When it comes to the role the target user should have, a design partner role would be more suitable than a friend. In the design partner role, the researcher does not have to balance an additional role. Furthermore, sufficient trust can be established, which can create openness in the design partner. This openness, combined with the structure the researcher can offer, will lead to the researcher gathering sufficient information. The design partner will have space, but not take full control. Furthermore, as each keeps their role, it will be more logical to write about the design partner in report form. Giving the target user a role as design partner includes taking their suggestions seriously and viewing them as someone with necessary knowledge for the success of the product. This is a role that gives a sense of confidence and gives the target user an active role in something she values. This can be empowering and give a sense of control and influence. Some discrimination should still take place, but the intention and goal will be clear. The design partner will be aware of why certain questions are asked, and what the information provided will contribute to. Furthermore, she will get updates throughout the process, as she is actively involved. This can make the process of collaboration a positive experience, and not something to have to go through in order to reach a certain result. The design partner role is better than that of a friend, as it gives the benefits of trust and openness, without creating a hard-to-balance role. Furthermore, the design partner role emphasizes the importance of giving feedback, while the friend role may make the target user biased. The friend role is hard for researchers with little experience, so it is better to remain on the safe side to avoid unnecessary harm.

In the design partner role, the provision of information and asking of feedback should be implemented. This should be done from a collaboration viewpoint, with the idea that the design partner is an expert on her abilities and preferences. Not every bit of progress should be reviewed, but the design partner should feel comfortable to provide feedback even when not asked. The feedback consists of three main stages, namely providing feedback on preparation, during the activity, and afterwards. The design partner should be inquired about the feasibility of research activities. Furthermore, she should be made to feel comfortable to express discomfort or disagreement during the research. Additionally, the design partner should be allowed to review any part of the report, and be explicitly offered to review the chapters that regard her directly. This includes the written out results from interviews and evaluations. This further emphasizes her role as a contributing colleague. Getting used to giving feedback is also convenient for the evaluation sessions of the prototype. If the design partner is already comfortable with being asked for opinions and providing suggestions, this can make it easier to evaluate results.

Making something extremely customizable to avoid choosing trade-offs may not guarantee a useable product within the scope and assignment of this project. Furthermore, nearly anything customizable still has limits. Some research into the design partner would still be necessary to assure she can manage within those limits. Additionally, to sufficiently meet the requirements of the client, a customized, directly useable version should still be created for the target user. Thus, this option for action will not solve the trade-off between avoiding a discriminatory process and accessibility. Customizability can still be valuable when looking to limit the discriminatory effect of the end product, as described in chapter 3.1.2. If the prototype is easily customizable, it can be integrated for more people, further increasing the equality of opportunities and access for people with decreased muscle strength. Furthermore, the prototype may put less emphasis on one's specific disability, as it can be used in numerous ways. Additionally, since parts can be reused and do not need to be redesigned, a lot of time, labour, and further resources are saved. This means that, on the long term, a customizable product can lower production costs, meaning less resources are required to help more people. When it comes to progressive illness, a customizable product can develop along with a person, so that they can keep using the same interface with only some changes. This can, as described in chapter 2.3, be beneficial for the identity preservation of people with progressive disabilities. Thus, even if it does not solve the trade-off within this project's research process, there should still be focus on making something that is customizable, as it can increase accessibility and limit discrimination on the larger-scale.

Decreasing discrimination on the long-term by short-term discrimination of one person fits the utilitarian view. Utilitarianism is, simply put, going for the most happiness for the most people. In this, the quality of the pleasure that is experienced is important, and not just the level. Thus, some types of pleasure or harm weight more heavily than others. It can be hard to weight different types of happiness, and it is even believed to be impossible for people who have not experienced both types. I have experienced both initial discrimination to enhance possibilities of participation, and being treated exactly like an able-bodied counterpart. Though both are pleasurable and can give benefits, I would weight the pleasure of active participation over that of being approached without difference. Inclusion does not mean that everyone is the same and treated exactly the same, more so it means that people can participate on their own terms. If someone is considered while their disability is disregarded, this presents a view of disability having no influence on the self, which is described to be inaccurate in chapter 2.1. Of course, the approach in gathering information about one's disability matters. In my experience, it is important that the disabled person understands the relevance of questions. The knowledge should directly help increase chances of participation, and this should be the reason one asks. Furthermore, the approach should not show pity or no empathy at all. Additionally, the person should experience clearly that they can refuse to answer questions without being interrogated or otherwise disrespected. Not only words, but also body language should be considered when minding someone's boundaries. Lastly, it should not be the first thing you ask, or the only focus in trying to create participation. There should also be room for personal needs. From a utilitarian view, I would state the greatest happiness comes from positive discrimination that leads to active participation. In this graduation project, this can even mean that one person experiencing positive discrimination can help lead to active participation of multiple people. However, from an utilitarian viewpoint, unnecessary harm in this should also be avoided, so the positive discrimination should be done carefully. Furthermore, it should only be applied if it leads to benefits, such as improvement in design choices.

In summary, to ensure an acceptable approach, that feels safe and fair for the participant, the participant can be given the role of a design partner. The process of research can then feel like a collaboration, in which both parties have part of the expertise necessary for a fruitful prototype. The design partner should be provided with sufficient information, and invited to provide feedback. Discrimination is morally acceptable, but should be applied carefully and only if it leads to a more accessible prototype.

3.2.7 Morally Acceptable Action

This section will outline two practical situations in which the described morally acceptable actions are or have been visible. These are only meant as examples, and not to be treated as an exhaustive list.

<u>Design partner (and asking feedback):</u> During an interview the target user said she can move her feet to some extent, and might prefer that over eyebrow interaction for a certain function. This does not

mean the design should surely use foot movement at the target user's request, as this is a design choice, which the design partner does not have expertise on. It does mean that there should be reasonable consideration. During this graduation project, the reaction was to do an evaluation to test if foot movement was indeed fit for the context. The researcher made a test preparation, which was reviewed by the design partner. Some physical tasks in relevant context were given, and a short interview was done afterwards. This showed that foot movement could be used for some functions, but only if they did not occur often.

Making something customizable: In the written software that deals with input from the movement sensors, there are certain values that can be tweaked, which will change the required speed and size of movements to account for special needs, as well as octave limits to account for personal needs. Furthermore, with only some small changes in one of the codes, different sensors can be linked to achieve the same results. Thus, if the interaction method is not accessible for someone, it is relatively easy to connect a different movement or tracking system. The mapping of the sensors to effect can also be changed, though this requires additional programming. Furthermore, the prototype is linked to Ableton Live and Max/MSP software, which offers nearly endless opportunities for adapting to personal needs.

3.3 Key Moral Principles

In this section, four key moral principles are mentioned. Most of these are not new and directly built on considerations discussed earlier in the report.

3.3.1 Equality

The IEEE Code of Conduct [26] states "We will not discriminate against any person because of characteristics protected by law", which includes disability. Furthermore, multiple human rights discuss equality of access and opportunity, among other relevant aspects. Increasing accessibility, as is done in this graduation project, can help lower discrimination on the longer run. In some cases, positive discrimination can also help lower discrimination in the future. This is a pay-off between current discrimination to decrease later discrimination.

3.3.2 Autonomy

The design partner is assumed to be knowledgeable on her own condition and abilities. Furthermore, she is expected to be able to communicate her needs and wishes. The design partner should be treated with respect and dignity, and provided with sufficient information to provide informed consent. Unnecessary harm should be avoided, and any possible risks should be known by the design partner. Furthermore, the design partner has the right to withdraw from (part of) the study if so desired. At any stage, the design partner is approached so that their contributions are experienced as voluntary.

3.3.3 Sustainability

The model code of professional conduct for designers [34] states "A designer accepts professional responsibility to act in the best interest of the ecology and of the natural environment." In this project, there is a trade-off between sustainability and accessibility, earlier described in chapter 3.1.4. Of these values, accessibility is prioritized, but sustainability implications should not be ignored entirely.

3.3.4 Fairness

The model code of professional conduct for designers [34] states

> "A designer shall not undertake any work at the invitation of a client or participate in competition with peers for any work without payment of an appropriate fee. A designer may, however, undertake work without a fee or at a reduced rate for charitable or non-profit organisations at the invitation of a client, when the designer will be publicly recognised as a sponsor of the project for the full value of the fees. A designer has the right to withhold recognition as a sponsor."

This article regards the fairness of employment. For this graduation project, I will not receive payment. Important to note is that this graduation project is carried out for the client My Breath My Music. This is a non-profit organisation, meaning working without payment would not disregard this code. Furthermore, I work on the project as a student and not as a full employee. Thus, the code does not seem too relevant. However, in arranging and signing the contract with the client there was a moment of doubt when transferring all ownership rights. This way I do not only work without a fee, but also withhold recognition as a sponsor. Though this is not a dilemma on the large scale, and morally acceptable in the professional environment, individually there was a considerable moment of a clashing of moral principles when I was asked to transfer all ownership rights. Nearing the end of the project it has become clear that the client would be interested in keeping me involved with the project. He has asked me for permission to publish videos that show the product, in which I explain how it works and what it does. This way, I still receive recognition for my work. Furthermore, we have been discussing ideas to make the prototype more widely accessible and available. During this, he has expressed a wish to hire me for projects, or even offer me a part time job. For this, fair payment should be discussed.

3.4 Code of Ethics

In this section, the moral principles mentioned in 3.3 will be put into a code of ethics specific for this graduation project. Fleddermann [29] presents three criteria for a code of conduct, namely a code of conduct states principles that are already well-established in ethical practice within the field, states these in a coherent, comprehensive and accessible manner, and identifies roles and responsibilities of professionals. The code of ethics provided below will attempt to meet these criteria. All the following articles are directly and clearly based on sections 3.2.5, 3.2.6 and 3.3 and will therefore not be elaborated on again in this section.

Equality:

- Positive discrimination should only be applied to the point of necessity and relevance. Any discrimination should have a clear reason and lead to significant benefits, such as an increase in accessibility and decrease in discrimination, on the long term.
- There should be a balanced focus on special needs and personal needs in designing an assistive product. One should not be reduced to their disability, but the disability should also not be ignored.

Fairness:

- All work that is necessary for and clearly benefits the graduation process can be done free of charge without reconsideration.
- For excessive work or any future projects, a fair payment arrangement should be discussed.

Sustainability:

- When there are multiple materials with similar functionality, pricing and delivery time, the most ecologically responsible alternative should be used.
- Electricity usage should be limited to reasonable amounts, unnecessary consumption should be minimized.

Autonomy:

- The target user should be treated as a contributing design partner who has valuable information that can benefit the design process. They should be trusted to be knowledgeable on their condition and their suggestions should be given due weight.
- The design partner (target user) should at all times be treated so that any contribution is experienced as voluntary.

4. Conclusion

4.1 Impact

This graduation project can increase the accessibility of a musical instrument for at least one child. An increased accessibility can lead to an increase in participation, and vice versa. Participation can have multiple benefits, among which health improvements, independence, and increased awareness. Awareness can be increased by a role model, such as potentially the design partner of this graduation project. In the field of ADMIs, a lot of improvement and development is still needed. This graduation project adds something to the existing attempts to make the music field more accessible, but is note the sole solution. It can, however, inspire further designs that will further close the gap between able-bodied and disabled people. The rights to equal access, equal opportunity, active participation in cultural life, recreational activity, preservation of identity and freedom of expression are laid out in the UN Conventions on Human Rights, Rights of Persons with Disabilities, and Children's Rights. This graduation project can help reach these rights in at least one case where they are not fully met. Furthermore, the product resulting from this project is sustaining for Sustainable Development Goals 4, 3 and 10, which relate to equal access to education, health & well-being, and reduced inequalities. However, it can also be disrupting when it comes to SDG's 10 and 12, as it increases inequalities within the group of disabled people and uses materials that are not environmentally friendly.

4.2 Conclusion

This graduation project requires positive discrimination to be successful. In combination with this, the target user is vulnerable, as she is underaged. If applied correctly, positive discrimination can be done ethically, even with a vulnerable participant. The choices in approach should consider this, and also the level of expertise of the user researcher. In this graduation project, an approach that treats the target user as colleague can best be used. The target user is assumed to have relevant knowledge on her condition, abilities, and preferences. This knowledge should be combined with the expertise of the designer to make a successful prototype. Thus, during the project, the target user is seen and described as a design partner. She receives information and updates on the state of the project, design choices, and future activities. Furthermore, she is asked to provide feedback on preparations, processes and reporting of research activities. The research activities will be flexible conversations in which knowledge and ideas are shared, along with casual observations within the relevant context. Very important is also the design partner's feedback on prototypes.

During the graduation project, there is focus on making a prototype that is customizable. This can ensure preservation of identity, as well as lead to a bigger increase in accessibility. Furthermore, it will put less emphasis on the disability of the users, as it can be used in multiple ways. This would lead towards a more positive paradigm. It would also create the pleasure of increased chances for participation for more people, which is in line with the utilitarian view of causing the greatest happiness for the most people. Furthermore, a customizable product will improve efficiency and decrease costs of individual products, making it easier to provide the adaptation to even more people. Additionally, it can help with identity preservation in case of progressive illness. Lastly, it would decrease the discriminatory nature of the end product.

When it comes to the conflict between avoiding discrimination and increasing accessibility, a balance that leads to positive discrimination is found. For the conflict between sustainability and accessibility, the latter is focused on, and sustainability only starts playing a role in decisions where multiple materials are suitable. The conflict between company or organisation's marketing needs and avoiding discrimination do not fit inside the scope of the research project, as I am not responsible for the marketing of the prototype. This will be handled by My Breath My Music, who are experienced in charity marketing, as well as personally involved with the target user. Unless serious concerns arise, My Breath My Music is therefore trusted with this task.

4.3 Limitations

This report is a theoretical analysis of a rather practical user research and design project. Situations are always different in practice than they are on paper. Many statements made in this report lack a certain nuance or applicability. Furthermore, disabled people are not one entity, and should not be seen as such. Even people with the same disability can have very different experiences and opinions. If the personal characteristics of the participant differ, a different approach may be more suitable. Throughout the project, unforeseeable situations may arise that demand intuitive social skills and a change in approach from the researcher. The ethical discussion of this report can inspire a way of handling the user research, and provide some guidance, but it is not reasonably possible to set up exhaustive guidelines. The code of ethics provided in this report is therefore also not nearly exhaustive. Additionally, though an attempt is made to meet the criteria of codes of ethics as described by Fleddermann, there is no guarantee these are met. Firstly, because I am a student who is starting out in the field, I do not have sufficient knowledge and experience to state for sure that the articles describe the established common practice within the field of engineering. Secondly, the code of ethics is provided in this report only, which will not be shared publicly. This may not matter, as this code of ethics is meant for this project specifically. Yet, still not all relevant people can access it by default, among whom my supervisor, client and design partner. The accessibility of the code of ethics is thus very limited.

In the scope of this report I was unable to analyse whose responsibility it is to increase the accessibility of the music sector, or any sector. Furthermore, I was unable to find a compromise which regards sustainability to the desired scope, without limiting the accessibility.

4.4 Future Perspective

This graduation project is done at a stage during which the development of ADMIs and overall attempts to increase accessibility are starting to speed up [3]. It is expected that this will continue to grow. In the Netherlands, the progress of increasing participation in the arts is behind on, for example, the UK, where more steps are currently being taken [3]. To increase action in the Netherlands, more role models are necessary [3]. The design partner of this project has good potential to become a role model to children with varying disabilities, as well as these children's caregivers [3]. Role models can increase awareness of both able-bodied and disabled people, and show the benefits of the progress currently made. This can inspire further inclusion, which will inspire further designs of accessible instruments. It is likely we will then see a similar progression of the field in the Netherlands as is currently happening in the UK.

Some ADMIs or adaptations may be able to build upon the prototype created for this project. With the technology used for the sustain, for example, nearly any type of switch can be connected, which can enable the sustain function for nearly every level of ability. Due to the customizable nature of the prototype, more changes can be made to widen the application possibilities. Ruud van der Wel, founder of My Breath My Music, expects that parts of the prototype can be used to help people with similar problems at different levels of ability. For the next few weeks, I will focus on my graduation process. After this, Ruud and I will look into how we can use this design to benefit a larger group of people.

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Appendix C: Research Activity Preparations

Appendix C1: Design Partner Interview

Interview 1: -datum-

Introductie:

3 onderdelen, elk wil ik maximaal 20 minuten laten duren.
1. Basisfunctionaliteiten van het keyboard, die aangepast moeten worden
2. Fysieke mogelijkheden in beweging en kracht zetten
3. Bekendheid met technologie, en wat je hierin wel en niet fijn vindt
We kunnen een pauze nemen of later doorgaan als het vermoeiend is, neem vooral de ruimte om te vertellen wat je wilt vertellen en als je vragen over wilt slaan kan dat ook.

Ik ga **wel/niet** een opname maken, deze sla ik veilig op en nadat ik een anonieme versie van het gesprek uitgetypt heb zal ik de opname verwijderen.
Het kan ook dat ik tussendoor al wat aantekeningen maak.

Deel 1: Keyboard max 20 min

- Welk keyboard(s) gebruik je? Wil je dit ook blijven gebruiken?
- Hoe belangrijk vind je deze punten op een schaal van 1-10?
    - Veel opties
    - Makkelijk te leren
    - Makkelijk gebruik
    - Expressieve beweging
    - Precieze mapping (bijv elk klein verschil in houding te horen. Voordeel: expressief spel. Nadeel: moeilijker te controleren)
    - Licht in gewicht
    - Simpel op te zetten
    - Compact formaat
    - Makkelijk aan te koppelen bij een ander instrument/setting
    - Esthetiek (dat het er mooi uit ziet)
- Hoe belangrijk vind je deze functionaliteiten zelfstandig kunnen besturen (schaal van 1-10)?
    - Sustain
    - Volume
    - Opnemen
    - Sampling
    - Aanzetten
    - Geluidseffecten aanpassen
    - “Bends”
    - Soort geluid kiezen
    - Effecten aanpassen
    - Metronoom
    - Transpose
- Wat wil je doen wat niet lukt?
- Wat kan maar kost veel energie?
- Per functie van 5+ importantie: Vooral relevant tijdens het spelen of vooral tussen liedjes door?

- Neem me door het proces van het eerste liedje gaan spelen, hoe pak je dit nu aan?
- Wat zou 1 aanpassing zijn die het proces voor je verbetert?

Deel 2: Fysieke mogelijkheden max 20 min

Per lichaamsdeel:

- Benen (incl voeten, enkels, knieën, heup)
- Bovenlichaam/torso (bijv naar voren/achteren/zij)
- Armen
- Handen/polsen
- Nek en hoofd
- Ogen
- Mond/ademhaling

Beweging:

- Mogelijk?
- Hoe veel? Hoe groot? Indicatie van centimeters?
- Hoe snel? Hoe soepel?
- Hoe gecontroleerd?
- Houd je dit lang vol? / Hoe vermoeiend is het? Hoe lang kun je geregeld de beweging maken (met kleine pauzes)?

Kracht zetten:

- Mogelijk?
- Hoe veel? Hoe zwaar? Indicatie van gewicht?
- Hoe snel? Hoe soepel?
- Hoe stabiel/gecontroleerd?
- Hoe vermoeiend is het? Houd je dit langer vol? Hoe lang? Hoe vaak binnen 20 minuten?

Ervaring met technologie max 20 min

Bekendheid algemeen:

- Wat voor technologie gebruik je in het dagelijks leven?
- Waar gebruik je het voor?
- Hoe veel uren per dag besteed je hieraan?
- Zijn er dingen die je lastig en/of storend vindt?

Muziek-specifiek:

- Wat voor muziekgerichte technologie gebruik je?
- Heb je nog andere dingen geprobeerd?
- Waarom ben je dit wel/niet blijven gebruiken?

Interactie:

- Welke interacties gebruik je nu met technologie?
- Heb je andere interacties geprobeerd?
- Waarom ben je dit wel/niet blijven gebruiken?

Appendix C2: Evaluation Interaction Methods

Het is nuttig om twee interactiemethodes die we al besproken hebben te testen, namelijk de gebruiksvriendelijkheid van bijten en de toegankelijkheid van voetpedalen. Het testen van het bijten is vooral om te merken of dit een fijne beweging is om ritmisch uit te voeren. Het testen van de voetpedalen is om te merken of je comfortabel snel kunt wisselen met minimale vermoeidheid. De volgende keer dat je oefent is het fijn als je deze twee dingen test met de liedjes die je al een beetje kunt spelen, zodat je kunt focussen op de interactie binnen context. Speel als je wilt even in voor het proberen van de interacties.

Bijten (20 minuten):
Stop kauwgom, of een voorwerp dat voldoende klein is en wat meebuigt, o.i.d. in de mond voor het gevoel dat je ergens op bijt. Zorg dat dit bij de tanden voor in de mond zit, op zo'n manier dat je er met een natuurlijke bijtbeweging op bijt. We gaan twee methodes testen om te kijken wat het fijnst speelt. Probeer eerst een paar liedjes (ong. 10 minuten) deze bijtbeweging te gebruiken zoals je een sustain pedaal zou gebruiken, dus indrukken en ingedrukt houden wanneer je een sustain wilt doen. Probeer hierna de tweede manier een paar liedjes (ong. 10 minuten), waarbij je je voor moet stellen dat de sustain begint wanneer je bijt en eindigt wanneer je opnieuw bijt (je hoeft het dus in de tussentijd niet vast te houden). Bedenk even hoe dit ging en ga dan verder met het testen van de voetpedalen.

Voetpedalen (40 minuten):
We testen, zoals eerder besproken, 2 verschillende manieren van 2 'knoppen' besturen met de voeten. In de standaardpositie van beide opties leunen allebei de voeten op de voetsteunen van je rolstoel of op de grond. Plaats als je dat fijn vindt voor je begint 2 stukken karton onder je voeten die ruim groter zijn dan je voet (een rechthoek, laat een aantal cm over aan elke kant), zodat ze zichtbaar zijn wanneer de voeten in de standaardpositie (dus plat op ondergrond) zitten. Dit is misschien fijn voor je eigen overzicht en het gevoel dat je ergens interactie mee hebt. Optie 1 die we gaan testen is het gebruiken van alleen de rechtervoet, waarbij de voorkant of de hiel van de voet omhoog bewogen wordt. De voorkant van de rechtervoet omhoog tillen is beweging 1A en hiel omhoog beweging 1B. Optie 2 is het gebruiken van beide voeten, met het optillen van de voorkant van de voeten. Het optillen van de voorkant van de linkervoet is beweging 2A (rechtervoet is beweging 1A).

Elke 1^{e} tel van elke 2^{e} maat een van de bewegingen en dan weer terug, op rustig beweegtempo. Wissel om de beurt af tussen de twee bewegingen. In optie 1 is dit 1A en dan 1B, in optie 2 2A en dan 1A. Doe dit per optie voor ongeveer een kwartier of zolang je het volhoudt. Doe bij elke optie na deze oefening een lied waar je elke 1^{e} tel van elke 2^{e} maat beide bewegingen zo snel mogelijk na elkaar doet (alsof je dus zo snel mogelijk op en neer wisselt tussen twee octaven).

Evalueer even voor jezelf hoe het ging en neem een pauze, bel me daarna op via Skype.

De belangrijkste vragen die we dan gaan bespreken:

Bijten:

- Is dit een voldoende toegankelijke beweging? (Lukt het met voldoende controle en snelheid, zonder dat je erg vermoeid raakt?)
- Vraagt het ingedrukt houden of het opnieuw indrukken fysiek meer van je? (ofwel welke optie is het zwaarst?)
- Welke van de 2 opties lijkt je op langere termijn het fijnst? Waarom?

- Voelt het na wat oefenen intuïtief om met bijten de sustain te doen?
- Zou je aan de interacties kunnen wennen?
- Denk je dat het goed zou werken?
- Hoe groot mag de bijtknop zijn?
- Krijg je van het testen zin om op deze manier met een sustain te spelen?

Voetpedalen:

- Is dit een voldoende toegankelijke beweging? (Lukt het met voldoende controle en snelheid, zonder dat je erg vermoeid raakt?)
- Welke van de 2 opties lijkt je fysiek het meest haalbaar?
- Welke van de 2 opties lijkt je het fijnst? Waarom?
- Hoe groot is de beweging die je comfortabel kunt maken in deze context?
- Hoe snel lukt het om de bewegingen achter elkaar te doen (per optie)? Ben je tevreden over deze maximale snelheid van op en neer wisselen tussen octaven?
- Krijg je van het testen zin om op deze manier met een transpose functie te spelen?
- Ik neem aan dat de pedaal/pedalen aan de voetsteun van je rolstoel vastgemaakt moet(en) worden? Zo ja, kun je mij binnenkort de maten van de voetsteun doorsturen?

Appendix C3: Evaluation Prototype

Evaluatie prototype sustain en transpose

Benodigdheden:

- *Camera*
- *Laptop + lader*
- *Transpose pedalen + sensoren + bedrading*
- *Bijtknop + sustain kabel*
- *Arduino + breadboard + kabel*
- *Klittenband banden*
- *WiFi verbinding*
- *Muis*
- *Schrift en schrijfsel voor aantekeningen (kan niet op laptop)*
- *USB hub*
- *(extra bedrading, schroevendraaier, jack socket, lijm, duct tape)*
- *Voor Design Partner: keyboard + MIDI kabel*

- Vastmaken en opzetten e.d.
    - Sustain kabel aan keyboard en breadboard
    - Bijtknop aan breadboard
    - Pedaaldraden aan andere pedaaldraden (en kijken wat welke is)
    - Arduino aan laptop
    - Keyboard aan laptop
    - Ableton MIDI connectie
    - Set up sustain in Ableton
- Evt liedje inspelen

- Uitleg over het product:
    - Bijtknop, bijten om sustain input te geven, ingedrukt houden
    - Transpose: voet kort omhoog om transpose te veranderen
- Tweaken:
    - Welke voet is intuïtiever voor transpose omhoog/beneden (ik verwacht rechts omhoog), zorg dat dit klopt
    - Tweaken transpose debounce
    - Tweaken transpose thresholds
- Even alle functies een paar keer testen, aan gewend raken, beetje oefenen en inspelen
    - Transpose 1 en 2 keer omhoog, naar beneden, etc
    - Sustain een paar keer gebruiken
    - Transpose zelf resetten
- 2 liedjes proberen te spelen met functies (eerst een makkelijk lied, dan een van het gemiddelde niveau dat ze speelt)
- Ruimte om even te improviseren (gaat ze dan op andere manier spelen?)
- Tijdens dit alles: observaties en opnames maken
- Interview met Design partner
- Kort interview met cliënt

Interview Design Partner:

- Was de werking goed te begrijpen?
- Hoe intuïtief zijn de bewegingen?
- Is het duidelijk wat voor effect elke beweging heeft?
- Ben je de interactie gewend geraakt?
- Geeft het prototype je zin om verder te oefenen?

- Hoe zou je het prototype aan een ander beschrijven?
- Wat probeerde je te doen?
- Wat was het meest frustrerende moment of gedeelte?
- Wat is je favoriete gedeelte?
- Is er iets dat nog mist?
- Als je zonder moeite iets toe zou kunnen voegen, wat zou je dan toevoegen?
    - Eventueel los van dit concept
    - Nieuwe dingen in je opgekomen
- Hoe veel controle ervaar je? Is er een verandering tegenover hiervoor?
- Hoe veel vrijheid ervaar je? Is er een verandering tegenover hiervoor?
- Hoe veel expressiviteit ervaar je? Is er een verandering tegenover hiervoor?
- Verwacht je nu ander soort liedjes te gaan spelen? Zo ja, wat verandert er?
- Verwacht je dat je speelstijl verandert? Zo ja, hoe?

Interview cliënt:

- Hoe duidelijk is het als toeschouwer wat voor effect elke beweging heeft?
- Als je dit zo ziet, denk je dat dit iets verandert in soort arrangementen dat de DP gaat spelen? Zal de rol in de band veranderen?

- In hoeverre denk je dat deze oplossing anderen kan helpen? Hoe breed toepasbaar is het? (met de kennis dat het werkt op bijna elk keyboard)
- Komt het prototype overeen met verwachtingen die je van het project had?
- Wat denk je van de prijs-kwaliteit verhouding?
- Als je zonder moeite iets toe zou kunnen voegen, wat zou je dan toevoegen?
    - Eventueel los van dit concept
    - Nieuwe dingen in je opgekomen
- Als ik nog iets toe kan voegen, wat zou dan ideaal zijn?
- Is het beter dat ik dat toevoeg of de prijs probeer te verminderen (door Ableton ertussenuit te halen of daar vervanging voor te vinden, limiteert dan wel het aantal geluiden dat gebruikt kan worden en maakt eventueel uitbreiden ook lastiger)