INTERNSHIP REPORT

Emmanouil Dimogerontakis
Multisensory Experience Lab
edimog21@student.aau.dk

ABSTRACT

The design of a new musical device is proposed in this report with the aim of creating accessible ways for children with hearing impairment to engage in musical training. This ADMI (Accessible Digital Musical Instruments), is specifically designed to meet the needs of children with cochlear implants (CI). The device consists of a tangible 8-step sequencer that utilizes wooden cube tokens as the interactive medium. It also includes haptic feedback via two actuators, which improves the musical experience. The main goal of the ADMI is to find joyful and engaging interactions for CI children to learn and compose simple melodies while reducing cognitive load. This is achieved through the use of the wooden cube tokens, which allow children to physically manipulate and arrange the musical notes, and the haptic feedback, which provides a physical sensation to the musical experience. The ADMI represents a unique approach to musical training for children with hearing impairment, and has the potential to significantly enhance their musical education and enjoyment. It is a first step towards creating more accessible and effective musical instruments for this population, and we hope to continue refining and improving the ADMI in the future.

1. BACKGROUND

This project is a continuation of the research of ME-lab of Aalborg University that the author was part of during his internship. The initial points of this project were the recent advantages of music technology and the insights from studies about the perception of hearing in CI users and the psychological benefits of musical training in children with hearing loss.

A recent study has provided evidence that musical training can have positive effects on the psychological well-being and quality of life of children with hearing loss. Cochlear implants (CIs) are a common treatment for severe to profound hearing loss, and much of the research on auditory training in children with CIs has focused on improving speech perception. However, it has been assumed that music may not be a suitable activity for these children due to their hearing loss.

Contrary to this assumption, several studies have shown that musical training can have numerous benefits for children with CIs. When conducted with the involvement of parents, teachers, or other children, musical training can improve musical skills, increase engagement and interest in music, strengthen the parent-child bond, promote socialization with peers, and increase levels of inclusion. In fact, some studies have even found that musical training can lead to better psychological outcomes and an improved quality of life for children with CIs. [1] [2] [3]

It is important to note that while the evidence suggests that musical training can have positive effects for children with hearing loss, more research is needed to fully understand the extent and limitations of these benefits.

There is a growing interest within the field of New Interfaces for Musical Expression (NIME) in creating accessible Digital Musical Instruments (DMIs) and promoting the inclusion of individuals with impairments in musical activities. The idea of using music technology for inclusion can be traced back to the creation of the Fender Rhodes electric piano, and with the advancement of technology, it is now possible to customize DMIs to meet the specific needs and abilities of individual users or groups. In fact, some DMIs even have the capability to adjust the interaction for each user in real-time [4].

Only 6% of the existing ADMIs are focused on people with hearing impairment [4]. This project aims to include in the design perceptual and intellectual barriers of CI children in music-making and training. Music and hearing perception of the CI users, in general, is difficult to be understood as it varies from the user. Music appreciation differs from CI users, while it seems that their desire for music is strong, and based on this study [5] there is evidence that it could be higher than people with NH (normal hearing). Although, music listening is described as unsatisfactory and the way that CI users perceive music faces a lot of limitations compared to NH [6]. Overall, perceptual and intellectual barriers are difficult to be detected and tend to withdraw themselves from the observer, making clear the need for iterative process design. Many design choices are taken based on this study [6].

Based on the points :

- Musical training helps CI children.
- Musical training increases musical skills in CI children.
- CI users desire to listen to music.
- Lack of a framework for musical training in CI children.

The author decided to create and build an ADMI focusing on the musical training of CI children, although the instrument could be used by NH children too.

2. RELATED WORK

Recent ADMIs focus on specific abilities of particular groups, using a wide range of different technologies and touchless or tangible interactions, like eye sensors [7], touch sensors [8], breath sensors,etc.

It seems that there are no existing ADMIs with vibrotactile feedback [4], although several tries in the form of interactive installation and Haptic Music Players have been introduced [9]. Another worth to mention device that use haptic feedback for musical training in CI users is [10]. Existing tangible sequencers similar to this design are the *Reactable* [11]and the *Tquencer* [12], with the difference that these two are targeting to the complex interactions that could be used from professionals or people with a background in music technology. Here, the goal is to create linear sequences without high complexity and technical knowledge.

3. DESIGN

Adaptive Music Technology is adopted recently as a term in the field of Music Technology and remains relatively unexplored in the academic literature. In this study, [13] the authors present a set of principles for the development of musical instruments for people with disabilities. Extending these principles, Frid made a collection of properties for designing and evaluating an ADMI. These 9 properties are *Expressiveness*, *Playability*, *Longevity*, *Customizability*, *Pleasure*, *Sonic quality*, *Robustness*, *Multimodality* and *Causality* [14]. Other aspects of this design can be considered the following, educational possibilities, plug-and-play, adopting the musical preferences of the children, inspiring external design, and use together with acoustical instruments in a group.

In designing this ADMI, we have carefully considered the bidirectional relationship between musical training and the potential for children with hearing impairment to feel overwhelmed. Based on previous research [6] and our own observations, we have aimed to find a balance between these factors in order to create a device that is both effective at improving musical perception and enjoyable for the child to use. To achieve this, we have designed the ADMI to introduce musical features in a gradual and controlled manner, allowing the child to become familiar with them without feeling overwhelmed. By carefully considering the needs and limitations of CI children, we hope to create a device that effectively enhances their musical education and enjoyment without causing undue stress or frustration.

The design aims in the training of the rhythm, pitch, musical intervals, recognition of different musical cues from different instruments, and also in spatialization.

3.1 Tangible Interaction and Sequencing

Firstly, the decision to create a sequencer is made based on simple rhythms, as music features are well-perceived by CI users. Additionally, simple sequencers have a low entry level, and they don't need some kind of virtuosity. The instruments consist of two rows with 8 steps per row, and each row is a different instrument. The tangible medium is a cube that the user can place in each individual step and activate a note. Each side of the cube is activating different notes. With the use of tangible objects and this specific mapping, the author aimed to make the interaction more playful, and have a clear causal relationship between action and sound production. The decision to have only two instruments/rows is made due to the barrier that CI users don't enjoy polyphonic music with different instruments being involved at the same time

3.2 Sound Synthesis

Thi ADMI is a tangible sequencer that allows children to physically manipulate and arrange musical notes through the use of wooden cube tokens. Each side of the cube corresponds to a different musical note, and when a cube is placed into a step on the sequencer, that note is triggered. The sound engine of the ADMI is based on audio samples, which were carefully selected based on the preferences of children with hearing impairment as identified in previous research [6]. It was found that piano and drum sounds were generally preferred over instruments with higher natural frequencies. By incorporating these preferred sounds into the ADMI, we aim to create a more enjoyabl,e and engaging musical experience for CI children. Overall, the use of preferred sounds in the design of the ADMI aims to make musical training more accessible and pleasant for children with hearing impairment.

3.3 Feedback

Multimodal feedback is important for the design of DMIs in general. Acoustic instruments include a variety of multisensory instant feedback (haptic/visual/sonic). Potentially, multisensory feedback enhances the musical interaction and the sensation of controlling the sonic outcome. Recent studies suggest that vibrations play a significant role in music perception and improve the music experience.

The audio output consists of two channels and plays back the two chosen instruments separately, with the upper 8 steps assigned to the left channel and the bottom 8 steps assigned to the right channel. In addition, the haptic feedback from the device is mapped to the left and right wrist pillows, with the left channel being mapped to the left wrist pillow and the right channel being mapped to the right wrist pillow. This can be seen in the 3D model of the current iteration, which is depicted in Figure 3

Vibro-tactile feedback has been added to the design in the form of wrist pillows. In these, two actuators have been placed underneath of a wood plate and a layer of stiff foam is attached on top of it. The output vibrations aren't directly produced by the sonic outcome, although a two-layer mapping is implemented. In the first layer, the reproduced notes are driven into sinusoidal oscillators with a fixed frequency. The range of the frequencies is chosen based on the peak frequency of tactile sensitivity (250 Hz) and the usable frequency bandwidth (50-500 Hz) [15]. Each vibration frequency has more than 3 semitones distance from the previous one. In the second layer, the oscillations are driven to the output (actuators), depending on the triggered note, a different oscillation is vibrating the wrist pillows. In Table 1 the notes with the corresponding vibrations are presented.

Also, visual feedback is added in the form of LED lights and colors on the sides of the cubes. The LED lights are used as an indicator for knowing the current step that is triggered, and the colors are mapped to different notes.

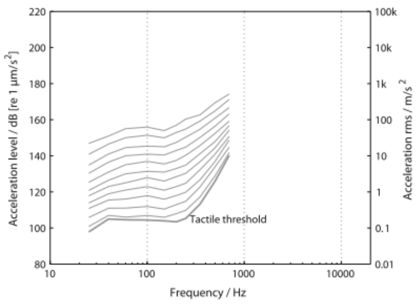

Figure 1. Curves of the tactile sense. Taken from [15].

Notes	Vibration Frequencies
A4	175 Hz
B4	209 Hz
C5	250 Hz
D5	297 Hz

Table 1. Notes and the mapped vibration frequencies

3.4 Calibration

4 controllers (faders) have been placed in the design, two for controlling the audio volume of each sequence and two for adjusting the sensation of the vibrations in each wrist.

4. IMPLEMENTATION

The instrument consists of a wooden frame 55cm x 30cm, in the middle there is a lower layer, in which the placements of the cubes/steps are engraved. The design of this lower layer is added because the author believes that can deliver better affordance for wrist positioning. The wrist pillows are installed in the bottom part of the interface, one for each hand. Moreover, the *Bela IO* board is used along with the *Multiplexer Capelet*, which includes 8 analog multiplexers (CD4051B) with 8 channels each and in total offers up to 64 channels for analog readings with a sampling rate of 2.75kHz. In the current implementation, the option of 32 channels is used with a sampling rate of 5.5kHz. 2 actuators are placed on the bottom of the wrist placements which are connected with an audio amplifier, which is receiving the oscillations from the *Bela IO* board. There are also four faders that allow users to control the audio volume and vibrations for each channel or wrist position. This allows users to customize the audio and vibration parameters to their preference

The interaction surface of the instrument is designed to be intuitive and engaging for users. Engraved positions for cubes are located on the surface to provide clear guidance and affordance for users, helping them to easily locate and interact with the instrument. At the center of each position, a small hole has been made to fit female pongo connectors, which connect the cubes to *the Multiplexer Capelet*.

Inside each cube, passive potentiometers are mounted to 4 sides of the cube with the male pongo connectors. When a cube is placed in a position on the surface, the potentiometer sends an analog reading to the Bela IO board, which is responsible for processing and mapping these values. Different values of the potentiometers are assigned to each side of the cube to correspond to different notes, allowing users to create a wide range of musical melodies and rhythms by simply moving the cubes around the interaction surface.

To ensure a strong and stable connection between the cubes and the interaction surface, magnets have been added to both surfaces. This helps to keep the cubes securely in place and allows for smooth and seamless interaction. To simplify the construction of the instrument, a PCB has been designed to be mounted on the back of the interaction surface. The PCB drives all the analog readings from the cubes to the analog input of the multiplexer and includes pull-up resistors for each connection, helping to reduce complexity and improve reliability.

In the current iteration, the instrument does not include LED visual feedback, haptic feedback calibration controls, or audio volume controls. However, these features will be added in future iterations to enhance the user experience and provide even more flexibility and customization options. Overall, the interaction surface of the instrument is designed to be a fun and engaging way for users to create music and explore the creative possibilities of the device.

Inside the *Bela IO board*, a *Pure Data* patch is running. *Pure Data* provides a flexible and open-source programming platform that allows the designer to quickly create prototype code. The patch includes a number of different components and features that work together to enable users to create music.

The patch includes a simple sequencer for triggering audio samples. This allows users to create melodies and rhythms by triggering different audio samples in a specific order. The sequencer also uses a technique proposed by Giulio Moro [1] to dynamically load audio files. This not only helps to improve the performance of the instrument, but also allows for the possibility of adding more audio files in the future without running into memory constraints.

In addition to the sequencer, the patch also includes a procedure for reading the 32 values from the multiplexer using the `table` object. The multiplexer is responsible for receiving analog readings from the cubes on the interaction

[1] https://patchstorage.com/dynamic-load-file/

surface and sending them to the Bela IO board for processing. By reading these values, the patch is able to determine which cubes are currently being interacted with and what notes they correspond to.

To enhance the transformation of audio into vibrations, an envelope follower has been implemented using the `env` object. This helps to transfer the amplitude envelope of the playback audio to the vibration oscillations, as shown in figure 10. The envelope follower ensures that the vibrations match the dynamics of the audio, creating a more immersive and expressive music-making experience for users. By following the envelope of the audio, the vibrations can respond to changes in volume, attack, and decay.

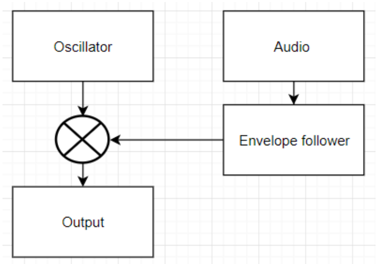

Figure 2. The diagram explains how the follower envelope is used.

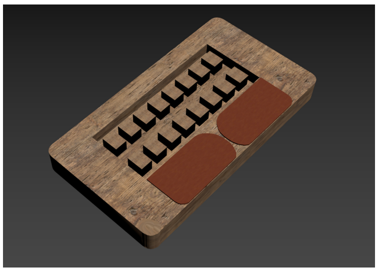

Figure 3. 3D model of the current iteration.

5. FUTURE WORK

The hardware implementation of the ADMI, a music training tool designed specifically for hearing-impaired children, is currently in the prototyping phase and requires further development to overcome various hardware and software challenges. The author is actively seeking ways to improve the design and interaction of the ADMI, including finding ways to reduce complexity and cost. It is planned to use tokens with more sides, such as octahedrons, in order to provide a greater variety of notes and a more diverse musical experience. However, it should be noted that this will increase the overall cost of the build due to the price of the pongo connectors. One potential solution may be to explore alternative methods for object recognition, as the current analog input approach is less durable and may not be the most cost-effective option.

During testing, it was observed that vibrating the wood plate with audible oscillations had a negative impact on the original audio output, as the oscillations were out of tune with the corresponding notes. This can be a frustrating and

Figure 4. Snapshot from the *Pure Data* patch that runs on *Bela IO*.

disorienting experience for users, especially for hearing-impaired children, who may rely more on vibrations for musical feedback. To address this issue, the author is considering using smaller actuators inside the stiff foam, similar to the haptic pillow described in [9]. Or measure the acoustical properties of the wood plate that the actuators are attached to, and measure the frequency response of the actuators. These procedures will help to tune and calibrate the actuators with filters that are aiming to eliminate cancelations in the bandwidth of the vibration frequencies and amplify them. This may help to create more accurate and consistent vibrations that are in tune with the audio, improving the overall musical experience for users.

In terms of software improvements, it would be useful to create a simple and intuitive method for educators or users to change the instruments or audio samples used in the ADMI. This would allow them to explore different timbres and make the instrument more fitting to their needs and preferences. It is also planned to create a method for choosing different scales of the same instrument, which would allow users to explore a wider range of musical possibilities. In addition, other methods for transferring audio to vibrations should be explored and added based on the goals of the music exercises. This may include the ability to adjust tempo, as well as other controls to provide greater flexibility and customization options.

Finally, the selection of musical exercises for the ADMI is a crucial consideration. The current design allows for the creation of simple rhythm exercises, music interval exercises, general music exercises (such as different scales), and exercises for the recognition of simple musical cues from different instruments. However, there is still a need for further research and development.

6. CONCLUSIONS

In this project it is developed, a standalone hardware ADMI specifically designed for music training of children with cochlear implants. While the current iteration demonstrates promising potential, there are opportunities for further improvement in terms of hardware, software, and user interaction. The goal is to continue refining the ADMI in order to make it more accessible and effective for CI children, with the ultimate aim of breaking down social and psychological barriers and bringing these children closer to music. By continuing to advance the ADMI, we hope to empower CI children to fully participate in and enjoy the musical experience.

Acknowledgments

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7. REFERENCES

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8. APPENDIX

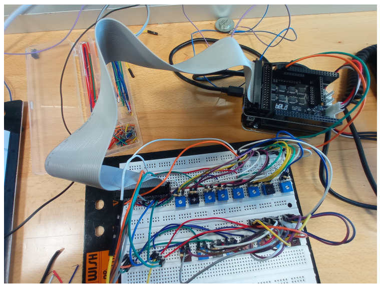

Figure 5. First realization of the idea.

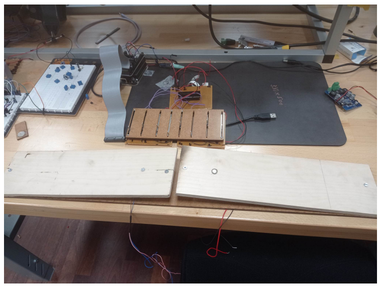

Figure 6. In this picture, a previous design is projected with the haptic feedback board, 1 row, 8 steps, and faders to activate the step and choose between different notes. This design was presented in a meeting with audiologists and experts from the Copenhagen Hearing and Balance Centre at Rigshospitalet and Bispebjerg Hospital. Primary useful feedback was given.

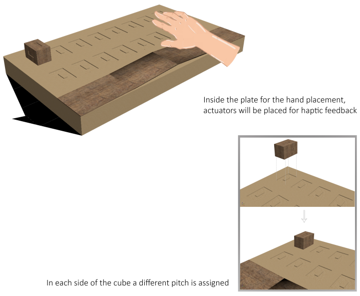

Figure 7. The first 3D design of the ADMI.

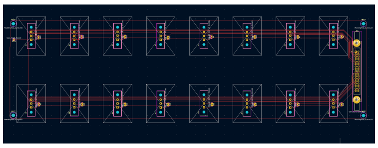

Figure 8. The design of the PCB in KiCAD.

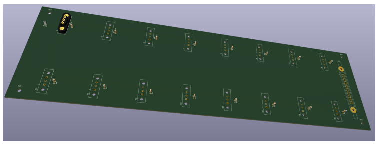

Figure 9. The 3d model of the PCB.

Figure 10. Current iteration in building procedure.