COCHLEA: GAMIFYING EAR TRAINING FOR COCHLEAR IMPLANT USERS

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ABSTRACT

Cochlear implants (CI) have been remarkably successful in restoring the ability to understand speech-in-quiet in profoundly deaf patients. However, due to a number of device limitations music perception with CIs remains generally poor. Training different musical aspects like rhythm, pitch and melody recognition, timbre discrimination, etc., may improve CI users' music perception, appreciation and enjoyment, which can lead to an improvement in life quality and further improve speech recognition. The gamification of music training for CI users can make the process more approachable and engaging, functioning as a great complement for in-person therapy. In this paper, we present a game to train rhythm and pitch that is aimed for CI users of all ages and degrees of impairment. The game was tested on 3 adult CI users. Testing proved the concept of gamification for music training for CI users to be relevant, approachable and fun; with a positive feedback from both CI users and audiologists. This same feedback was considered for further improvements and implementations to the game.

***Keywords*—** c ochlear implant, gamification, rhythm, pitch

1. INTRODUCTION

Cochlear implants (CIs) are hearing restoration devices, aimed for people who are provoundly deaf or severely hard-of-hearing. A CI consists of two units, one externally placed and one placed internally just above the ear. A radio frequency (RF) antenna is placed externally just above the ear and adjacent to the internal unit. The internal unit includes the electrode array, which is implanted down the ear canal to allow electrical stimuli of auditory neurons via the cochlea. These electrical stimuli act as a proxy for sound pressure waves, which a normal hearing (NH) person would perceive and decode as sound [1].

CIs have become more common and substantially improved in the last 25 years. They were initially used to assist users solely in speech perception providing a rudimentary auditory stimulus approximating a person's speech. However, this has been improved dramatically over the years and now the focus has shifted towards trying to enable CI users to perceive music more effectively. CI users can perceive rhythm on average as well as NH people but when it comes to identifying melodies and timbre performance is poor [2]. Preliminary evidence suggests training can improve CI users' ability to recognise melodies more accurately and to increase music appreciation. For this reason others have attempted the gamification of music training for CI users [3].

1.1 Related Work

In order to combine gamification and CI training, we examine serious games related to music training and popular music games for the general audience. The main goal was to implement a game appealing to both young and adult CI users, with an attractive concept and an achievement system that can potentially engage the user in both the game and the therapy.

We took into consideration the proposed model for the design of a serious game in a therapy context used by [4]. The model is described by having a relationship between all of the involved elements (user-game, user-therapy, game-therapy) that aims to implement gamification to the therapy process, engaging the user in the game and therapy. With the consideration of this relationship between elements, the main goals of the therapy are identified and implemented to the game in such a way that the mechanics of the game produce both a therapeutic, and an immersive, engaging effect on the user. The model also involves the therapist in the game through a feedback system, where the therapist can track the performance of the user as well as the effectiveness of the therapy. As noted in [5], the storing of information gathered from the user's in-game performance is very convenient and time saving for the therapist. In [4] it is stated that tablet based games are more appealing from a user perspective. A general review of the available app games for music training for CI users revealed the need for a more simplistic approach, where music training could be divided into more fundamental concepts like rhythm, pitch, timbre, etc. and that the users? had a simplistic interactivity with the game (user-touch screen based controls-tablet). The games proposed in [5] and the music appraisal game for CI users in [6] were regarded too complex, comprising too many features and requiring the presence of the therapist.

2. DESIGN

Based on literature review and the intention for the serious game to be an inclusive game for both post and prelingual deafened users, the first levels of the game need to

cover fundamental aspects like rhythm and pitch recognition, beginning with an entry level difficulty. We decided upon the concept of an endless runner game with a horizontal perspective where visual cues signaled a tapping on the screen, synced to a musical rhythm. The visual cues for the rhythm patterns (coins) spawn from the right end of the screen, giving some aid to the player. The player is also aided by having the rhythm played initially before the note spanning starts. The concept for the pitch game was developed to follow the horizontal "runner" perspective of the rhythm game. The mechanics of this game were based on the pitch direction discrimination test presented in [7], [8], and [9].

Parameters such as filter roll off [10], implementation of percussive sounds [11], [8], [9], implementation of fundamental tones [9], and max and min number of intervals in the pitch game [12], [9] , were taken from studies related to music perception in CI users.

3. IMPLEMENTATION

The Unity game engine [13] was used to design and implement the music training game.

Based on the requirements established in [14], for a game to develop rhythm and coordination in children with hearing impairments, we set the following requirements for our game:

- The game should be tablet and mobile based.
- Levels start off with an easy difficulty, which then increases as the game progresses, enhancing motivation in the user.
- User and therapist should have the flexibility to modify the game's difficulty, according to the user's needs and skills.
- Games should rely on both auditory and visual cues, but special focus should be given to the auditory cues.
- Games should be score based, and displayed as part of the UI, to give some in-game feedback to the user about their progress.
- Relevant data should be stored to keep track of the users' progress and for further use by the therapist.
- The game should include a character customization system to provide a more personalized experience.
- A general concept (in terms of design or story line) should encompass all of the intended games into one.

3.1 FMOD

The FMOD audio middleware platform was used for the audio in the game. This audio middleware platform was chosen as it allows for more control over dynamic audio than the Unity audio engine [15]. Given the need of CI users to be exposed to simple sounds, a kick drum sample was used exclusively for the rhythm level and a sine wave was used exclusively for the pitch level. FMOD was integrated into the Unity project by executing the FMOD package file available at [15]. The file path for the FMOD project was set in the Unity inspector window enabling communication between FMOD and Unity. FMOD projects are organised in a hierarchical structure much like the Unity editor. Audio files are organised into soundbanks and events. All the soundbanks and events are organised in the master bank. The master soundbank is then exported to be dynamically controlled using FMOD functions within the script component in the Unity editor. In the pitch game, for example, the pitch and gain parameters of the audio component (a sine wave) in FMOD are dynamically controlled from Unity's scripting using FMOD functions.

3.2 Rhythm

Rhythm is considered to be the easiest concept of music to grasp by both: people learning music theory and people learning to hear with CIs. [11]
For that reason we have chosen to make a simple, yet entertaining way to make people listen and understand rhythms. As an introduction to rhythm, our game has a character in a cave, running and collecting coins. Coins are spawned synchronously with an underlying beat that is generated from a MIDI sequence. To collect the coins, the player will have to match taps on a screen with the underlying beat.

As an introduction to game mechanics, coins are moving into the collection circle at every beat. Each rhythm is being played twice: the first time it is played, the player has to listen and memorise it, then after a short pause the rhythm will start playing again, where the player will tap synchronously with it and collect coins for successful taps. The rhythm game does not have a lot of steps of increasing difficulty, since it is an easy concept for CI users to grasp and usually they do not have trouble hearing rhythms. Thus increasing the rate at which notes are playing and making more complicated rhythms quickly becomes a task of coordinating precise movements and less of a listening and hearing task. Nevertheless, we have made some difficulty scaling for the rhythm game.

For the first few times the person is playing the rhythm game, coin movement is shown, in order to augmented auditory information with visual one. Later, when the player is familiar with the game mechanics, and is better at matching taps with beats, the player can move to a higher difficulty, where visual cues while the player is performing rhythms are removed. Visual cues are left during the listening part, because we want to establish a strong connection between coins and the beat, as well as to give more information to make it easier to memorise rhythmic patterns. In addition to making beats faster or slower, it is possible to change the speed at which coins are moving, which changes the time window, at which the player can tap to collect coins, which means that taps have to be tighter with the rhythm.

3.2.1 *Implementation*

Figure 1: Screenshot from the rhythm game. The two yellow coins pass from right to left. As they pass over the collision point (above the players head) the kick drum is played and a tap is expected from the user

The rhythm game was chosen to take place in a cave [16] (Figure 1), where sudden lighting changes will be logically accepted by player and not seen as an unnatural disappearance of visual cues. In order to have coins move from right to left synchronously with the rhythm, we are applying an algorithm made by Yu Chao [17]. To adjust the window at which taps will be registered we are changing variable "beatsInAdvance" in the algorithm by Yu Chao, which changes by how many beats in advance coins are spawned [17]. MIDI data was generated with the 'Drummer' plugin in Logic X, which generates MIDI drum sequences automatically allowing editing of the generated MIDI. Only the kick drum MIDI data was used.

3.3 Pitch

As stated in prior research [9] [12], it is a common struggle for CI users to be able to perceive different pitches. This is due to the CI not being able to represent the entire frequency spectrum [10]. However, pitch has a very important role when it comes to musical structure. Melodies, harmonies of choirs and tuning of instruments are all essential factors in being able to enjoy music and not perceive it as static noise. Therefore translating this concept into a gamified form was very important, since it could help CI users to both distinguish pitch, but also memorize different pitches.

3.3.1 *Design*

For this level, it was decided to keep the 2D perspective of the rhythm level, in order to maintain consistency throughout the game by keeping the form and instructions similar from level to level. It was also decided that this level would take place after the rhythm level meaning that the player is now outside the cave system [18] as explained in section 3.2. This progression is consistent with the abilities of CI users in that pitch is more challenging than rhythm. Here the player has gained the ability to fly, and this element plays into how the entire gameplay loop works by being able to fly up and down vertically and then fly towards a specific path horizontally. With this type of movement system, it is possible to create a classical type of puzzle where the player is presented a puzzle and has multiple decisions to take, however, only one decision leads towards the reward. For this puzzle algorithm, it was decided that two specific notes would play, and the player would need to identify where the pitch of the last note is compared to the first note they heard in terms of pitch and interval. There are only three ways that the interval and pitch can go, either it goes up or down, or remains unchanged.

3.3.2 *Pitch game difficulty scaling*

The scaling of how difficult the pitch level would play out is governed by how small and how big the interval between reference pitch and next pitch is, thus training them to differ pitches. Additionally, the higher the possible sets of intervals goes, the more the game is going to challenge the CI user to guess correct.

For the procedural audio, a synthesizer was scripted through the FMOD API. FMOD was set up to have two parameters, that can be controlled with Unity: frequency - that pitch shifts the sine wave sample in FMOD with the automated pitch shift wheel, and time - automated gain knob in the shape of ADSR without the decay part. To play different frequencies we just need to set frequency variable to the value we want. The frequencies we can play using 440Hz sine sample are from 220Hz to 880Hz. For the game logic, there are three spheres on their own individual 2D vector position as seen in figure 2. Depending on whether the interval played was ascending, descending or not, one of those positions is tagged to be the correct sphere that the player's transform position should touch, while the two others are incorrect if the player should collide with those.

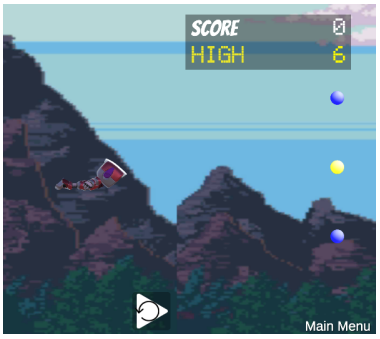

Figure 2: Screenshot from Pitch Game. The three spheres vertically placed on the right represent the interval heard. The spheres turn yellow to indicate which sphere the player has currently selected, the center represents no change in pitch, the sphere at the top represents an ascending interval and the bottom one represents a descending interval. The loop button in the bottom middle is used to play the interval again.

3.4 User Interface

A user interface was designed to enable users to select a character and have control over the difficulty and the level they will play. This enables users to play in a predefined structure, which goes from a rhythm based level to a pitch

based level or to jump from one level to another depending on their skill. These elements were suggested as imperative for a serious game in that their is self representation customisation with character selecting and there are defined levels one can accomplish by completing the previous level, while also having access to more difficult levels to accommodate players with more or less abilities in music perception [14].

3.4.1 Character Selection

A 3D fully rigged character was downloaded and selected as the player character. [19]

From the main menu, it is also possible to select a sub menu where 4 different variations of the character is displayed. For each variation of the character, the main texture colors have been changed on the character's uniform as well as the emission colors of the character's eyes.

For whichever version of the character that the user picks, that value is stored in a static integer which will update the appropriate materials to that specific version of the character for each level. The animation assets for the character were retrieved from the rigging website, Mixamo. [20]

4. TESTING

The test was conducted onsite at Oticon Medical in Smørum, Denmark. For the test, the target group (CI users) was to try out the game and evaluate it. The game would be played by the participants on a tablet device to authenticate the portable experience. Hereby through observation, results would be gathered and discussed.

4.1 Participants

All of the participants were sampled from Oticon Medical, who produced their CIs.:

1. **Participant #1**
   Female, 45 years old. She has been using her CI for 2 years. She explained that listening to music for her makes it sound like it comes out of a "grinder", therefore it's very hard to enjoy it. She uses software like audio book apps on her tablet to train her hearing and was open to see what applications could be employed to assist her in training her CI hearing.
2. **Participant #2**
   Male, 75 years old. He is one of the first patients to have retrieved a CI from Oticon Medical. He has been wearing his CI for 4 years, and feels confidently attuned to it by now. For example, he has always enjoyed listening to music and can still enjoy it with his CI depending on the room acoustics. He uses a hearing aid alongside his CI and the only software assistant tool he uses is a volume control for his hearing aid on his smartphone.
3. **Participant #3**
   Female, 80 years old. She has been using CI for 4 years as well. She explains to have difficulties hearing people speak, especially children. However, she also with time been trained to enjoy music which has improved her quality of life, since classical music helps her relax. She hasn't used any hearing assistant software and would prefer to do any CI-related training in a social setting.

All three participants had acquired their deafness, with the youngest participant (#1) becoming deaf in their 20s whereas the two others became deaf over time.

4.2 Procedure

We evaluated the game with three cochlear implant users, via a qualitative analysis in order to both get to know each of our participants' background, but also understand what works and doesn't work with the prototype.

A semi-structured interview approach was chosen in order to have an open discussion about the prototype with each of the participants. The interview consisted of two rounds: one with questions being asked about their background with using CI prior to trying out the prototype, and then a second and final round of questions related to the overall prototype after they had tried it. Between those two rounds of interviews, the participants tried either the rhythm or pitch level, in a randomized order. After they were done with playing a level, 11 reaction cards were randomly spread on a table. This method was inspired by the Microsoft Desirability Toolkit [21]. Each participant was asked to pick 5 cards related to the current level that they had just played and explain their decision. The reaction cards were used in order to capture the user's feedback in the moment that they choose a card.

4.3 Evaluation

Cards Chosen	***Rhythm***	***Pitch***
Easy	**2**	**1**
Fun	**3**	**2**
Exciting	**2**	**3**
Interesting	**2**	**3**
Motivating	**1**	**1**
Confusing	**1**	**1**
Irritating	**1**	**2**
Uninteresting	**0**	**1**
Potential	**2**	**0**
Difficult	**1**	**1**

Table 1: Table over each card that was picked after the gameplay session. In total, 20 cards were picked.

A total of 10 out of 11 cards were chosen with "discouraging" not being picked at all. In the rhythm level, the cards with more than one pick the participants chose *Easy, Exciting, Interesting* and *Potential*. *Fun* ended up being picked by all of the participants (3).

In the pitch level, for cards with more than 1 picks the participants chose *Fun, Irritating* with *Exciting, Interesting* being chosen by all of the participants. A full table can be seen in Table 1

For the last round of questions related to the prototype, the user was tasked to give the audio quality a score and the quality was met with general praise with the average score being 4.16 out of 5.

For the question related to how clear the instructions were for each level, was also met with general praise, however, participant #1 said that the use of words like "tapping and swiping" were confusing.

In terms of difficulty, 2 of the participants (#1 & #3) expressed that the pitch level was hard for them to navigate around in due to unresponsive swipe controls.

When asked about if this type of application would fit well for the training of CI users, all the participants agreed that there is definitely potential. Participant #1 said that this is definitely needed, but it is difficult to make a 'tool' which fits all ages. Participant #2, however, expressed that he felt that the training presented in this app was too basic for him, so it was more suited for new users of CI. Participant #3 would like something like this but in a more social setting.

The question regarding if the game was entertaining to play, participant #1 expressed she wouldn't sit with a game like this often at all, simply because she felt too old to play it. Participant #2 could see it being entertaining for new patients with hearing disabilities and participant #3 found it entertaining in the way that she really enjoyed the graphics and visuals of the game.

For the last question, whether this game was catchy or not, the overall answers were both yes and no. Participant #3 said she could see herself sitting with it once it had finished development, but only if it was being deployed in a social setting. Participant 2 felt that when sitting with it in the moment, it was quite catchy, but he would get tired of it quick since it was basic for him. Participant #1 said that if a game would release that was targeted for her age, she could definitely see herself playing it from time to time. She said that this type of research is on the correct path to make training more entertaining for CI users, even asking us when it would release on the mobile app stores.

Additionally, from the observations gathered, the users did not have a hard time understanding the instructions that the gameplay communicated to them. They all had an idea on how to navigate through each level. However, one thing working against them was some input instability of the levels themselves which included both unresponsive tap and swipe controls appearing frequently.

4.4 Discussion

Two of the participants had CIs for 4 to 5 years, the other participant had it for 2 years. One of the participants was already very adapted stating that he can hear as well as he could before loosing hearing. Participants said, they enjoyed this game, but it was more relevant for people who just got their CIs. The swipe controls in pitch game were perceived as irritating as some of the participants couldn't make them work. The observations gathered also backs up this notion. Making a game, that is suited for all age groups was proven to be difficult, but gave us an idea that changing the design of the game to fit different age groups while keeping game mechanics the same could work. Additionally, it was also difficult for the participants to understand whether if they performed well or not based on a score system, as mistakes didn't get subtracted but instead they were not counted to the total score. We feel that a training application for CI users should not be intimidating and punish mistakes they make due to inability of hearing the sounds properly. We thereby propose to reward repetitive training by providing the player with unlockablek in-game items such as cosmetics for the player character or unlocking more difficult versions of each stage to entice motivation.

It's worth noting that all the participants acquired their deafness, which means they posessed an ability to reference the sounds they heard. Thereby, for future iterations of the test, participants with congential deafness should be sampled to measure the effect of game on a broader range of CI users.

4.5 Audiologist's Feedback

After the testing process at Oticon, we met with two audiologists, Mathilde Lumbye and Charlotte Thostrup from Specialcenter Roskilde Kommunikation, in regards to both rhythm and pitch games. About the rhythm game, they approved the approach of the endless runner dynamic, especially because of the visual aid provided. They stated that according to their experience in therapy for CI users, rhythm is a relatively easy task for CI users, which was also confirmed with the testing process. In regards to the pitch game, they said its mechanics (identification of upward or downward movement) was a good approach for pitch training, stating they use the same approach with a piano instrument for training. The scoreboard system was mentioned to be a great complement to both the therapist and the user, stating that the latter could be greatly benefited by keeping track of its own performance.

In regards to further implementations for the game, three main ideas were discussed:

- Having a multiplayer game where the user could play cooperatively with other users or the therapist (either locally or online, asynchronous or synchronous).
- Having a practice level for some of the games where extra aid and no scores would be supplied.
- Implementing a music theory game where specific topics could be covered (notated rhythms, notated music, harmony, etc.). They mentioned that music theory is highly beneficial for the training, stating that a big part of enjoying music is being able to understand it.
- A completelly separate application made for audiologists to track the progress of their patients. There they would see the data (graphs) from the game

of each of their patient this way the improvements would be easily tracked.

Their general feedback was quite positive. They stated that a game like this could be highly beneficial as a complement for the type of therapy they provide and their goal of having CI users enjoying and understanding music, allowing them to approach music with more knowledge and less of a "guessing process".

5. CONCLUSION

The design and implementation of a serious music training game for CI users was described and the results from interviews and testing were presented. The game was seen to have potential with valuable insights gained on what could be done to improve it in future iterations. The input from audiologists and CI users concluded that more training exercises in timbre and music theory would be helpful. The responsiveness of the user input could be improved as well as the difficulty scaling and instructions.

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