Wearable Musical Haptic Sleeves for People with Hearing Impairment

Urvish Trivedi†
Department of Mechanical Engineering
University of South Florida
Tampa, Florida, USA
udt@mail.usf.edu

Redwan Alqasemi
Department of Mechanical Engineering
University of South Florida
Tampa, Florida, USA
alqasemi@usf.edu

Rajiv Dubey
Department of Mechanical Engineering
University of South Florida
Tampa, Florida, USA
dubey@usf.edu

ABSTRACT

Music is a multi-dimensional entity and can be experienced in different forms, such as sound, vibrations or visual displays. This experience is typically confined to people without hearing impairments, but for people with hearing impairments, it can be difficult or impossible to enjoy and experience this form of art. Recent technological advancement offers some opportunities through which attempts can be made to provide musical experience to people with hearing impairment. The purpose of this research is to develop an affordable wearable haptic device for people with hearing disabilities to experience music. This device can be helpful for people with reduced hearing as well as with complete deafness. In this project, we adopt a design development strategy which is based on testing different assistive technologies and to check their efficacy to transmit musical notes into other human sensory inputs.

The final prototype consists of Vibrotactile sleeves with bone conduction speakers. These sleeves provide sensory input of vibrations via bone conduction speakers. The prototype is developed based on subjects' surveys and feedback on different assistive technologies. To test our prototype, we developed a visualization system which gives visual clues that represent the given musical notes. A formal user testing with five participants suggests that this system can be used to provide the musical experience to people with hearing impairments.

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CCS CONCEPTS

• CCS → Hardware → Communication hardware, interfaces and storage → Tactile and hand-based interfaces → Haptic devices

KEYWORDS

Haptics, Vibrotactile device, Bone conduction, Hearing Impairment.

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1 INTRODUCTION

Every listener interprets music according to his/her own understanding of it. In everyday life, music has different forms and people react to it based on genre or class of music [1]. It is the kind of art in which the feelings or emotions are expressed via sound. People with intact hearing can react to music in several ways, such as tapping their feet, moving their head back and forth or moving rhythmically in response to musical stimulus [2][3]. Listeners can even recognize the composer or artist and can easily identify the instruments involved.

Though music is very much part of a natural experience for a person with intact hearing abilities, people with hearing impairments are often deprived of this unique natural experience. However, music can also be felt and enjoyed by people with impaired hearing, if the right technology is utilized for that purpose. The sound transmitted through air and other mediums, while mostly experienced through ear drums, can also be felt over the whole body, which helps in perceiving sound in a different way [2].

Existing research suggest that people with deafness often process vibrations sensed via touch and it involves the part of the brain where average human beings process sound [1]. These findings suggest that people with hearing impairment can sense music and can enjoy musical events or concerts, if a mechanism or system can be developed for people with hearing impairments. This project uses the concept of cross-modal display [6] to develop a system to assist people with deafness. The cross-modal display involves the human-computer interaction, where the information that is designed to be presented to one sensory modality is displayed using an alternative modality. A cross-modal display can present audio signals using visualization and haptic displays.

2 RELATED WORKS

Music can be used as a form of input for many sensory substitution techniques, which can be interpreted through different modes, such as visualization or tactile vibrations [1][4]. The idea behind sensory substitution refers to substituting environment information, which would normally be processed by human sensory system, and translate this information into stimuli for some other sensory system [3]. This substitution can be of many types, such as tactile to vision substitution, vision to auditory substitution, auditory to tactile substitution, etc. Many researchers are trying to enhance the musical experience of the user by using cross model display. In this regard, mapping is the main challenge of making a multimodal system effective and meaningful [3]. There are many technologies that have been developed in the past to assist people with hearing deficiencies in their normal life. Previous work has been done to enhance the sense of awareness for people with hearing impairments by altering their surroundings [3], however, there is very little research on such system that can help improve musical experience for this population.

The main challenge for making a vibrotactile system is to keep music accessible to the user by determining an effective and meaningful mapping [6]. This mapping should appropriately represent the emotional elements of the music. Sound waves are small vibrations that reach the eardrums by traveling through air or other medium. Eardrums, in return, vibrate and transmit these vibrations to the cochlea. The cochlea transmits sound vibrations to our brain through auditory nerve [6][8]. However, in some cases, vibrations are heard directly by the cochlea, bypassing the eardrums. This mode of transmission is known as Bone Conduction [2][8]. The bone conduction speaker/transducer acts as an eardrum which decrypts sound waves and converts them into vibrations that can be received directly by the cochlea. In many cases, hearing loss happens due to the damage caused to the eardrums [2][4][6]. Since the Bone Conduction method does not use eardrums, people with hearing impairment would be able to "hear" with bone conduction, provided that their cochlea is in healthy condition.

While developing an affordable wearable device, three categories of hearing loss are addressed in this work, which include conductive hearing loss, perceptive hearing loss, and mixed hearing loss [5]. Bone conduction speakers/transducers convert input audio signals into the tactile sensation which can augment music with vibrations. However, music is a highly expressive form of art that transmits different associated information such as beats, melody, and rhythm.

3 PROTOTYPE DESIGN

For this research, our goal is to design a flexible prototype device that can be tested with different types of input systems, on different body locations, with different methods of distributing sound signals. We have developed a music visualization system along with a vibrotactile sleeves, which help the user to identify music through vibration and visual clues. In the following sections we will describe both the vibrotactile system and visualization system.

3.1 Vibrotactile System

The vibrotactile system consists of vibration motors, audio speakers, and bone conduction speakers. It can map the musical notes over different body locations to effectively convey the emotional content expressed through music.

The vibrotactile sleeve is designed to amplify vibrations produced by the music and use those vibrations as input for our cross-modal system. We used four, 4 Ohm impedance speakers of 3W on either side of a leg to test the technique. Frequency range for these speakers is 70Hz - 20000Hz which is close to the normal ear frequency range. In order to find out the most effective form of vibration to use in our system, we tested the technique of mapping musical notes over lower leg muscles to achieve best possible outcomes. We recruited seven healthy subjects to test three different mapping techniques. Figure 1 shows the survey results. From the results, it is clear that the bone conduction speaker's technique was the most effective one.

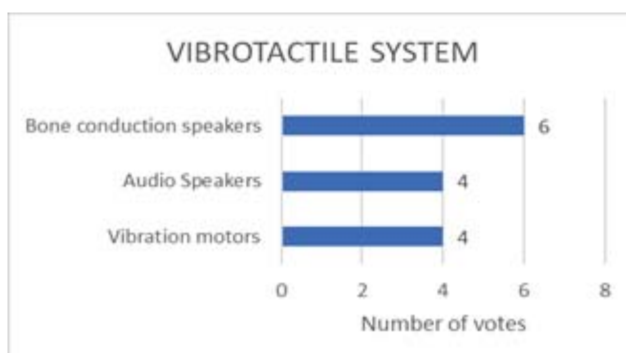

Figure 1: Survey Results for the Best Vibrotactile System

As shown in Figure 1, people surveyed were more inclined to using bone conduction speakers due to better transmission mode. Our final design utilized four bone conduction speakers, two on either side attached near the Tibia bone, as shown in Figure 2. Each pair of speakers are powered by MAX98306 class D Audio amplifier.

Existing research suggests that piano notes and frequencies follow a logarithmic relationship [6][7][9]. It also specifies that the above relationship can be expressed through a normal distribution, which has a standard deviation of one octave on a keyboard We have adopted the methodology suggested by Karma et.al. [5] and designed the bifurcation for providing sound frequencies as follows: (1) If the sound frequency is more than 450 Hz, it goes to the upper speaker, and (2) if it is less than 450 Hz, it goes to the lower speaker.

Figure 2. The Locations of the Bone-Conduction Speakers on the Vibrotactile Sleeve

3.2 Visualization System

Literature shows that many synesthetic artists can visualize different colors while hearing different musical notes [4][8]. Keeping this relationship in mind, we have developed a visual display system through the mapping of musical keys to the background color. Using the concept developed by Jones & Nevile [9], we mapped high & low frequency notes with small & large note alphabets and shapes (see Figure 3). The visual information remains on the screen until the sound is audible. We have used LabView and Unity as our software development platform [11][13]. The basic function of LabView is to process MIDI input and ensure equal distribution of signals in each of the speakers. For this project, we used FL Studio [12], which has many features for recording, editing music, by handling notes and performance information in several forms.

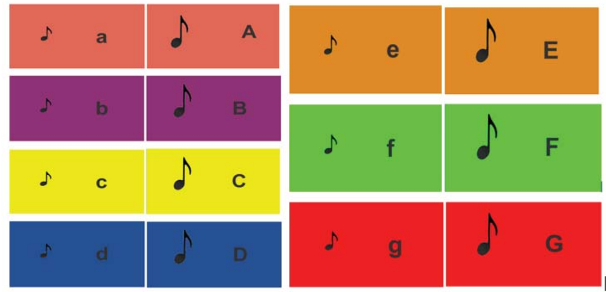

Figure 3. Unity Visualization Display

3.3 Assistive device with Vibrotactile sleeve and Visualization System

During entire system testing, the subjects had to wear the vibrotactile sleeve, as shown in Figure 2. Subjects then sat in front of the visualization system where they received visual prompts on the screen. Subjects would respond to the musical input through a connected computer keyboard. The computer system was connected to a musical keyboard through a MIDI connection while the vibrotactile sleeve was connect through a USB port. The overview of the entire system is shown in Figure 4.

Figure 4. One of the Subjects Wearing Vibrotactile Sleeve and Seating in Front of the Screen During Testing.

4 EVALUATIONS

Testing and evaluation for the designed wearable musical sleeve was conducted with five healthy individuals, (four males and one female) with age ranging from twenty to twenty-seven years. Our evaluation metrics include (1) correct note recognition rate, and (2) the total average time taken by a participant to recognize each musical note (in seconds). The experimental procedure was divided into three major steps as follows:

1. Speaker Calibration: In the area of wearable technology, researchers always consider human JND (Just Noticeable Difference) [4] as an important factor in designing a new product. In our testing, each speaker is placed in a location where the participant is most comfortable and can perceive all the vibrations distinctively. This step preceded any data collection.

2. Testing: Our testing was divided into two sessions, which we outlined in the following sub points. In each session, the vibrotactile sleeve was placed on the participant's leg muscles, and the participant was asked to fill the post study survey questionnaire about his/her experience. The duration of each test was approximately 45 minutes. The session consisted of 15 minutes of training with the assistive device, followed by 30 minutes for the actual test and data collection. During the test session, participants were asked to remember each note based on its vibration pattern according to their own understanding.

    a) Vibration System without Visuals: The first session was divided into two sets, based on their pitch of sound. For lower pitch of sound, we chose 3rd octave, and for higher pitch, we chose 5th octave. In this session, the participants were asked to wear noise canceling headphones to avoid hearing any sound. They were then exposed to random notes for identification of each note using tactile vibration.

    b) Vibration and Visual System: This session was also divided into two parts. The first part was similar to that in the previous session, in which high octave pitch was selected, and participants were asked to identify each note using the vibrotactile sleeve. In the 2nd part, participants were subjected to both Vibration and Visual information regarding each keyboard note.

3. Post Study Questionnaire: After successful completion of all the testing, participants were asked to fill out post study questionnaire, which helped us gather qualitative and quantitative data related to our system and their experience.

5 RESULTS AND DISCUSSION

5.1 Notes Recognition Rate

The results of each session are depicted in Figure 5. From session one, we can conclude that the average recognition rate of higher octave is more than lower octave. Session two shows that the combination of vibrotactile sleeve and visualization method combined, provide much better understanding of different musical notes. During the post survey session, many subjects indicated that at higher octave, speakers were making noticeable vibration patterns in comparison to lower octave.

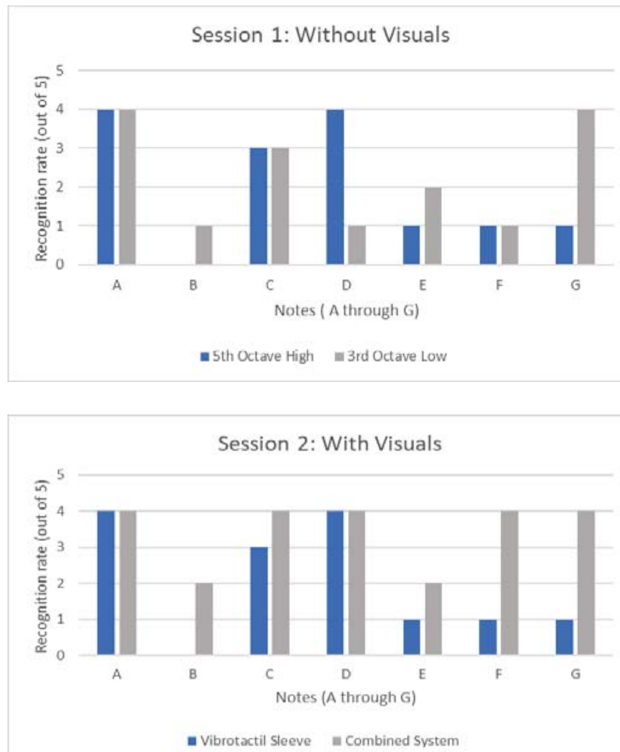

Figure 5. Notes Recognition Rate

5.2 Total Average Time

'Time Factor' plays a crucial role in measuring success rate of our multimodal sensory substitution system. The success rate of the system is highly dependent on the total average time taken to recognize the musical notes. Lower average time suggests higher success rate, and vice versa. The results in Figure 6 shows that in session one, higher octave has less recognition time rate compared to lower octave. In session two, the vibrotactile and visual combination takes less time in recognizing musical notes compare to vibrotactile only system.

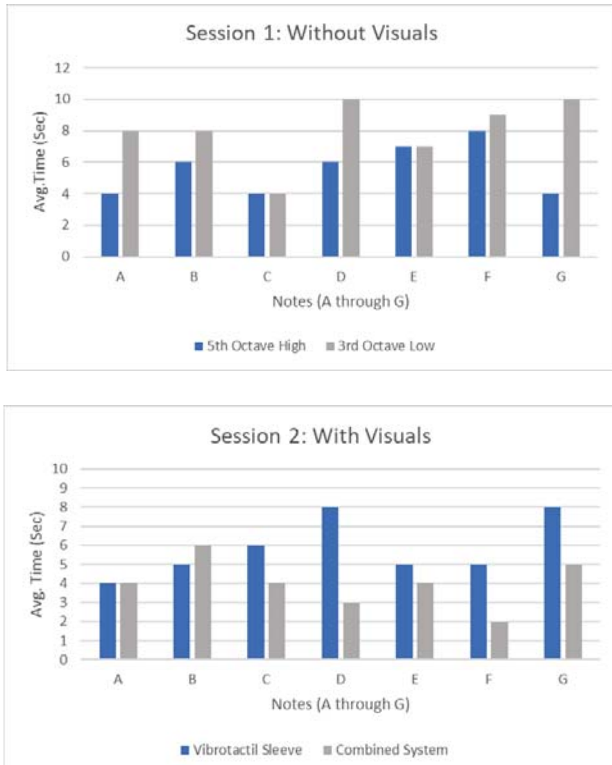

Figure 6. Average Time of Recognition

5.3 Post-Testing Survey

Post-testing survey suggests that some of the musical notes (Note A, C, D and G) were easy to recognize in both testing sessions. Tested subjects advocated for vibrotactile and visual combination, which they found to be better in recognizing musical notes than using only vibrotactile sleeves. Figures 7 (A)(B) show the post testing survey results.

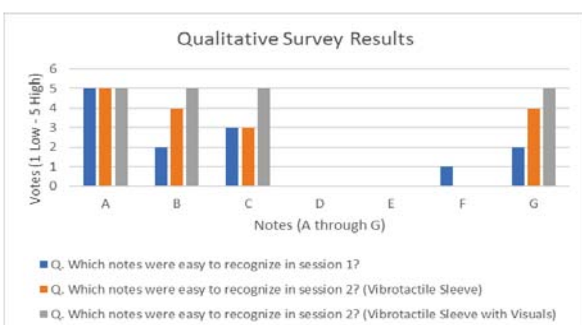

Figure 7(A). Survey Results

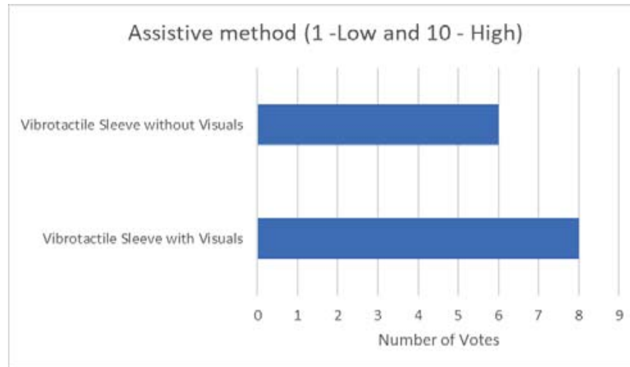

Figure 7(B). Survey Results

6 CONCLUSION AND FUTURE WORK

The wearable vibrotactile sleeve and visualization system is intended to be applied as a sensory substitution technique for translating audio signals into tactile and visual sensations for persons with hearing impairments. We designed a prototype that consists of four bone conduction speakers that are attached to a compressive sleeve. An experimental study of the vibrotactile sleeve with visualization system suggests that our design is effective in communicating basic musical information. In our study, we focused on the understanding of actual musical content rather than the identification of musical genre.

Future work will aim at expanding our current understanding of emotion and vibrotactile stimuli by developing more user-friendly wearable prototype and visualization system. It will incorporate more testing with different musical instruments. This will help researchers to get better understanding of human emotions through wearable haptic devices.

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