Tactile Tone System: A Wearable Device to Assist Accuracy of Vocal Pitch in Cochlear Implant Users

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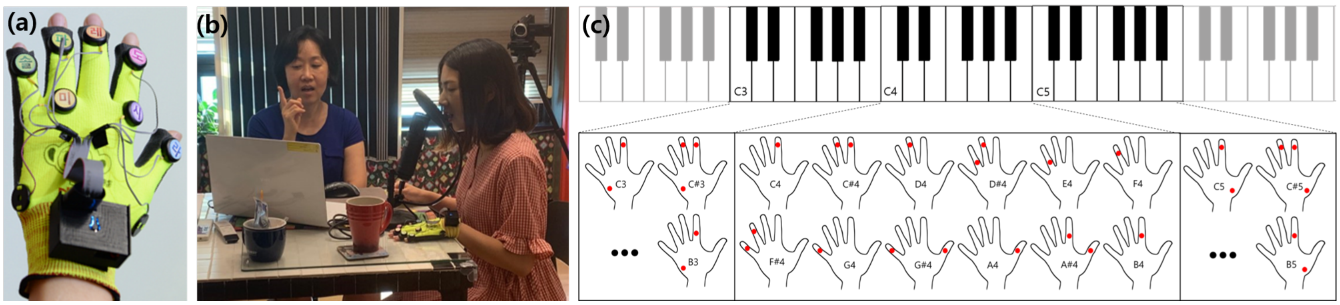

Figure 1: (a) Prototype, (b) vocal training and (c) tactile layout of the Tactile Tone System.

ABSTRACT

Cochlear implantation is an effective tool in speech perception. However, activities such as listening to music and singing remain challenging for cochlear implant (CI) users, due to inaccurate pitch recognition. In this study, we propose a method for CI users to recognize precise pitch differences through tactile feedback. The proposed system encodes real-time audio signals to 36 musical tones (from C3 to B5), represented by tactile codes using nine vibration motors in a glove-type device. Two CI users participated in 15 h of training using our system and showed significant improvement in pitch accuracy while singing. In addition to the quantitative results, both participants expressed satisfaction in distinguishing and vocalizing musical tones, which led to increased interest in music. This study provides opportunities for CI users to engage more deeply and participate in musical education as well as achieve improved aural rehabilitation.

CCS CONCEPTS

• **Human-centered computing** → **Accessibility technologies**.

KEYWORDS

sensory substitution; tactile feedback; wearable system; deaf people; music education; vocal pitch, cochlear implant

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1 INTRODUCTION AND RELATED WORK

Activities such as listening and singing improve the auditory, perceptual, and cognitive performances of cochlear implant (CI) users, and help increase the quality of life [1] [15] [3] [13]. However, CI users experience difficulties in musical activities, because they cannot distinguish the musical tones [7] [16] due to the limited resolution of the implanted electrodes [10] [17].

Sensory substitution [2] using tactile feedback could be an alternative method to solve this problem and improve sound perception for deaf people. Unlike vision, tactile feedback does not disturb the user's sight, and can be implemented anywhere in the human body. This makes it an effective method for wearable systems used in everyday life. Previous studies have demonstrated that converting sound to tactile information is promising for improving sound perception for deaf people [12], and can be used with CI to improve speech recognition [4]. Although previously reported tactile systems for CI users have only focused on improving speech recognition, Sakajiri [14] used tactile feedback to improve music perception in deaf–blind cases; here, a braille-based tactile layout that is not suitable for CI users and has limitations in implementation as a wearable system was used in the study. Other studies [11] [9] using tactile feedback for music have been proposed to enhance how music is experienced, but these have limitations when used for musical training.

To encourage musical activities in CI users, studies on wearable devices to assist CI users in differentiating pitch and improving vocal accuracy are necessary. Therefore, in this study, we propose a wearable system to assist CI users' perception of pitch in musical activities using tactile feedback.

2 TACTILE TONE SYSTEM

The main objective of the proposed system is to convert real-time audio data from a microphone to a predefined tactile code that represents musical tones (a steady pitch that is predefined to a musical note). Audio streams from the microphone are buffered for 20 ms, and fast Fourier transformed to produce frequency data. Then, a peak detection algorithm calculates the peak frequency and maps the audio stream to the closest musical tone. Finally, vibration motors corresponding to the detected tone are activated. As a result, the user can match the sound they hear to a particular musical tone. To verify the system's effect on CI users, we developed a software to train users to recognize tactile encoded musical tones (tactile tones), and used it for improving pitch identification and vocal pitch accuracy in singing.

2.1 Prototype Implementation

The design of the wearable system and location of the tactile sensations are significant for the user to easily learn the tactile tones. Therefore, we designed intuitive tactile feedback suitable for musical tones using a glove-type system that demonstrated remarkable performance in tactile reading in previous studies [5] [8].

Figure 1(c) illustrates the location of the vibration motors in our implemented system. The system uses nine eccentric rotating mass vibration motors (Precision Microdrives, model 310-101) to encode musical tones from C3 to B5. The seven motors located in the fingers determine the seven musical tones(C, D, E, F, G, A, and B). Furthermore, the two motors located at the back of the hand were used to determine the octave, and they activate simultaneously to represent semitones between musical tones. To minimize confusion between the two vibrating motors, musical tones without semitones (E-F and B-C) are located on the same finger, which prevents the semitones from vibrating in the same finger. We also designed a sequential location to start at the upper part of the index finger to physically locate a single motor in the smallest fingers (the thumb and little finger). When using multiple vibration motors per tactile tone, we modified the overlapped spatiotemporal (OST) patterns [8]. We used a 5 ms gap and changed the encoding only when a musical tone was changed (or stopped) to reduce the feedback latency the user might encounter, while providing time for the vibration motor to work at full intensity.

2.2 Training Software

Singing includes the ability to recognize the musical tones in music, and accurately reproduce sound with one's voice. Therefore, the main objective of the training software is to assist and improve vocal pitch when singing. We developed the software based on requirements gathered from a pilot test by an audiologist and a social worker that uses CI. As a result, the training software comprises three parts: tactile tone recognition, controlling the vocal pitch, and listening to or singing a song with tactile feedback. Tactile tone recognition comprises two modes: training and testing. The training mode allows users to choose from 36 musical tones, and feel the tactile tone with a visualized location of the feedback. The testing mode generates a random tactile tone, and awaits the user's answer for which musical tone is generated. Moreover, training to control vocal pitch has two modes. The free mode encodes the users' voice to musical tones and provides tactile tones in real-time. In the guide mode, the user can choose a musical tone and feel a guided tactile tone for 2 s to match their vocal pitch. The listening mode plays a predefined song ("Twinkle Twinkle") in tactile tones. The singing mode plays the song and provides visual (text) information of the correct musical tones, the user's vocal pitch in real-time, and the tactile tones of the user's current vocal pitch. The audiologist selected the predefined song from a list of songs used in a previous study for developing music perception tests [6].

3 VOCAL TRAINING USING TACTILE TONES

3.1 Participants

We selected two participants (ID01: female, age 16 and ID02: female, age 28) using CI. Both participants lost hearing at the age of four, and underwent CI surgery at the age of six (ID01) and fifteen (ID02). They could easily understand and speak Korean and used spoken language as their main communication method. They had never experienced listening to or singing using melodies; therefore, they were unfamiliar with the melody of "Twinkle Twinkle." The training was devised and implemented by a professional audiologist with experience in aural rehabilitation for CI users. Participants commenced training after signing a research consent form; they were provided sufficient guidance regarding the study and received appropriate compensation for participation.

3.2 Training

We divided the training into fifteen sessions over the course of a month, with each session lasting an hour. Each session started with training for recognizing tactile tones. The audiologist started to train the participants with random tactile tones, and moved on to focus on tactile tones that frequently confused the participants. After supervised training, the participants spent time on self-learning, to be able to select and feel the tactile patterns without supervision.

Controlling vocal pitch was the most important aspect of the training. The training process was implemented by starting with a comfortable vocal pitch, and asking the participants to increase or decrease their vocal pitch, while feeling the changes in tactile tones.

For singing, the training started with listening to the song using tactile tones to memorize the melody and rhythm. After listening to the song a few times, they sang along and received tactile feedback on how their vocal pitch changed while singing.

3.3 Results

For quantitative analysis, we used dynamic time wrapping to calculate the improvements in vocal pitch. Figure 2 presents the change in pitch before and after training, compared to the reference musical tones. The key tone of the song was lowered by four semitones to match the vocal range of ID01. After 15 h of training, both participants could follow the sequential musical tones of the song, which

Table 1: Survey results

Questions	ID01	ID02	Comments
Comfortable to wear	3	2	"I found myself humming music in my house."
Distinguishing tones	4	4	"After training, I think I could practice by myself."
Time provided to learn	4	5	"I now understand how to vibrate my throat
Easy to vocalize	4	4	to produce high notes."
Interest in singing	5	5	"I would like this training for my aural rehabilitation."

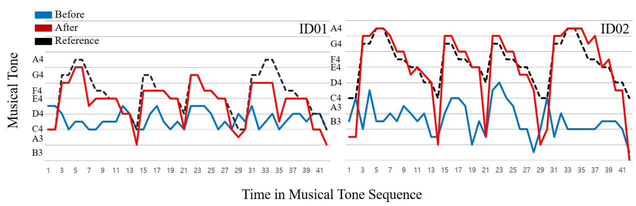

Figure 2: Comparing vocal pitch in singing before and after training.

was not possible before training. The average difference from the reference musical tones improved from 3.56 tones to 1.80 tones for ID01 and 2.92 tones to 0.80 tones for ID02.

Moreover, we conducted a simple survey and short interview about the impressions of each participant regarding our system. Table 1 represents the survey results and some interesting comments from the interview. The score is on a scale of 1 to 5, "1 " being the most negative score and "5" being the most positive score. The results show that the system improved the participants' confidence in distinguishing and vocalizing musical tones, which led to increased interest in singing.

4 CONCLUSION

We propose a method to convert pitch into intuitive tactile tones in a wearable system to assist CI users with musical activities. Two CI users participated in the training using the proposed system, and their improvement in vocal pitch was analyzed. From our results, both participants showed satisfactory performance in controlling their vocal pitch while singing. Although the system is a prototype, this study proves that musical tones encoded as tactile feedback are capable of assisting CI users in distinguishing pitch and improving their vocal pitch in singing. Through improvement, we expect that this system can be applied in music education and aural rehabilitation for CI users.

Although results from two participants were sufficient to prove the proposed concept, more participants are needed to statistically prove the effects of the proposed system. Therefore, we expect to conduct training with more participants in the future.

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