Tactile Melodies: A Desk-Mounted Haptics for Perceiving Real-time Musical Experiences

ABSTRACT

This paper introduces a pilot user study exploring the realm of musical haptics through the translation of MIDI data from a Digital Audio Workstation (DAW) into tactile sensations, employing a set of haptic actuators. Our integrated haptic system enables real-time conversion of MIDI information into nuanced vibrations, featuring multiple haptic actuators and a microcontroller. These haptic actuators, positioned on their fingertips, allowed users to perceive musical compositions. This work presents a practical implementation of the system and a corresponding user study, emphasizing responses to a set of haptic stimuli intended to replicate sonic musical compositions. Additionally, the paper incorporates a comparative study assessing the accuracy of users, differentiating between those with prior musical background and those without, in identifying the auditory counterpart solely through haptic inputs. This comparative analysis delves into how users with varying musical familiarity perceive and interpret haptic feedback within the context of musical compositions. The study showed promising results in enriching our understanding of user responses to haptic feedback in musical scenarios and exploring the intricacies of user experience with the system and its impact on musical interpretation.

Author Keywords

Haptics, Haptic Interface, DAW, MIDI, Tactile, audio-tactile mapping

CCS Concepts

• **Applied computing → Sound and music computing**; • **Human-centered computing → Interaction devices** → Sound-based input / output, Haptic devices; • **Human-centered computing → Accessibility** → Accessibility technologies

1. INTRODUCTION

Humans have perceived music through auditory sense for a long time now [1]. Most musical pieces are created by people with hearing abilities [2]. The ones with hearing impairment since childhood could hardly perceive the idea of music, though they perceive the notion of rhythm through haptic experience [3]. We aim to explore the mapping of music to haptics, which leverages the potential of multisensory experience in music. While there are tools like TouchDesigner [4] available to visualize audio, there are few methods available for converting audio to haptics [5]. We developed a tool from scratch to map music to haptics. We envision creating a universal platform where people with different abilities and disabilities come together, create, and experience music in different media.

Existing studies have delved into the integration of haptic feedback within music-centric exercises. As evidenced by multiple sources [13][14], most musical haptic interfaces find utility in instrumental training and as feedback mechanisms tailored for musicians, with a noticeable dearth of applications designed explicitly for enriching the overall musical experience. Investigations have been conducted to design meaningful ways to convey musical information via the sense of touch, emphasizing the importance of transparent and immersive musical experiences facilitated by vibrotactile feedback and stimulation [12]. The predominant mode for delivering vibrotactile feedback involves the utilization of small and lightweight eccentric rotating mass (ERM) vibration motors. This choice aligns with the goal of enhancing the haptic interface's portability, catering to the practical needs of musicians and users [15][16].

Our research is motivated by the potential of haptic feedback devices to be used as an alternative modality for music perception and music listening experience, particularly for individuals with hearing impairments. Initially, we developed a hardware prototype from scratch and conducted preliminary tests to investigate the efficacy of haptic mapping for music. The following section explains the design and working of our interface. Section 3 explains the user study, followed by a discussion and conclusion in sections 4 and 5, respectively.

2. DESIGN OF THE SYSTEM

We developed a tactile feedback system mounted on a desk, accessible by the right hand. This system incorporates five Eccentric Rotating Mass (ERM) Coin Vibrators positioned to stimulate the fingertips of the fingers. The activation and intensity control of these vibrators are managed by an Arduino Mega 2560 Rev3. Initially, our approach involved processing audio input and mapping frequency ranges onto the motors, aiming to convey the melody of music. However, challenges emerged in translating polyphonic tones accurately. Hence, a shift to MIDI protocol was employed. The working of the entire system is illustrated in Figure 1.

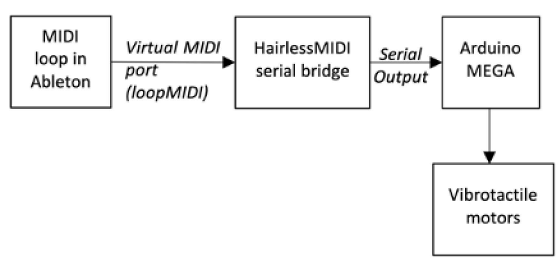


Figure 1. Working of the system

2.1 Utilizing MIDI Protocol for Signal Transmission to Arduino

In this strategy, signals are transmitted directly to the Arduino from a Digital Audio Workstation (DAW), specifically Ableton, where haptic patterns are created and edited. To validate the functionality of the MIDI protocol, a preliminary test was conducted using Supercollider [6]. A sample project was implemented to generate MIDI Continuous Controller (CC) messages that interacted with a graphical user interface (GUI), simulating drum playback (Figure 2). The MIDI output from this test was then linked to a virtual MIDI port through loopMIDI [7]. Given that communication between the Arduino and PC occurred through a USB Serial port, integration with the MIDI protocol was facilitated by the utilization of a MIDI to USB Serial bridge program named HairlessMIDI [8].

Figure 2. SuperCollider Custom GUI window

2.2 Arrangement of Haptic Feedback on the Palm

The literature review on touch receptor sensitivity across the body, with a focus on the palm of the hand, underscores the heightened tactile sensitivity of the hands, particularly the fingertips. Studies indicate that the hands, along with the soles of the feet and the larynx region, exhibit notable sensitivity to vibration, with the glabrous skin of the palm demonstrating a marked responsiveness to vibrotactile stimulation [9][10]. This heightened tactile acuity observed in the fingertips is attributed to the abundant presence of mechanoreceptors, including Pacinian and Meissner's corpuscles, rendering them particularly adept at processing vibrotactile stimuli [10][11]. Placing vibro-tactile motors to stimulate music on the fingertips of the palms is ideal due to the high tactile sensitivity of this area (Figure 3). It is essential to also recognize the potential for exploring different configurations that cover a wider area of the palm for mapping haptic feedback, guided by subtle variations in sensitivity across specific anatomical regions.

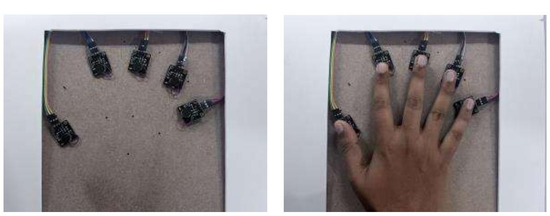


Figure 3. Haptic Interface (left) and Fingertips on Interface (right)

2.3 Experiment Setup

The participant was instructed to listen to a short piano snippet taken from John Thompson's Modern Course for Piano: first grade in audio format. The test was designed to find whether the participant could identify the song correctly when the music snippet was played through the haptic ERM motors. Figure 4 shows the experimental setup containing the DAW and our haptic interface for testing.

Figure 4. Experimental Setup

3. USER STUDY

The experiment was conducted to test the efficacy of translating music to haptics, and to understand musical haptics by evaluating the functionality, usability, and user experience of haptic feedback devices. The data from the participants was obtained using a Likert scale to measure their responses.

3.1 Participants

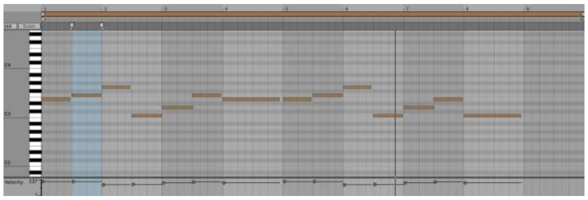
A set of 8 participants from in and around the campus with an average age of 23.5 years (7 male and 1 female) participated in the experiment. 3 out of them were musically trained, of which 2 of them were able to play piano. The rest of the remaining 5 participants did not have any music training. Prior consent and approvals necessary for the experiment were taken.

3.2 Material

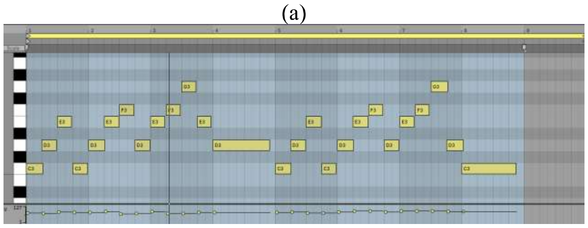
The experiments were performed on a Windows 11 PC with a 3.7 GHz Intel Core-i3 12th gen processor and 8.0 GB RAM. The vibrotactile feedback is generated through five Eccentric Rotating Mass (ERM) Coin Vibrators (5V, 60mA, 9000RPM). The communication between PC and ERM is done via an Arduino Mega using a Serial USB port. The music is composed and played on Ableton and sent the MIDI out through a virtual MIDI port using LoopMIDI. Hairless MIDI is then used as a bridge between MIDI to Serial to send the data to said Arduino Mega. The system is mounted on a wooden plank for comfortable resting of participant's hands.

3.3 Design

For this research study, we selected three musical snippets from John Thompson's Modern Course for Piano: first grade [17]. The three snippets chosen were Music Land (Song 1), Patterns (Song 2) and Traffic Cop (Song 3). The treble clef notes of these snippets were transcribed into a digital audio workstation (DAW) as MIDI data for analysis (Figure 5). The haptic mapping of each ERM motor was employed based on the right-hand finger positions outlined in John Thompson's instructional material. If a note is played in MIDI, the motor-in-contact with the finger corresponding to the finger number (w.r.t John Thompson) will be triggered. Given the variability in finger positioning among musicians, influenced by individual comfort and dexterity levels, we aimed to establish a standardized mapping function applicable to all participants. We chose to refer to John Thompson's instructional material due to its inclusion of simple and recognizable melodies with corresponding finger positions tailored for beginner pianists.



(a)



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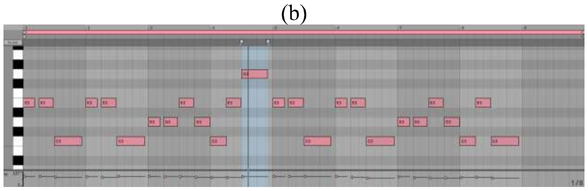

(c)

Figure 5. MIDI of (a) Song 1, (b) Song 2 and (c) Song 3

3.4 Procedure

Participants were first introduced to the three songs through auditory exposure until they were able to memorize the melodies. Subsequently, participants were required to accurately identify the song labels by listening to the audio, thus mitigating the likelihood of recall failure. Following this auditory familiarization phase, participants were introduced to haptic renditions of the melodies.

Following each trial, participants were prompted to recognize the song label when its haptic version was played in our interface as shown in Figure 6. This iterative process ensured the participants' ability to recognize song labels with minimal errors. Upon achieving proficiency in the practice session, participants were tasked with ten additional trials aimed at identifying the song labels corresponding to the perceived haptic versions. Responses, categorized as correct or incorrect labels, were recorded in a spreadsheet. Subsequent analysis focused on assessing the accuracy of participants' identification of the correct song label. Additionally, participants were asked to rate their confidence levels in label identification.

Figure 6. Participant undertaking trial

3.5 Results

In this section, we discuss the results in terms of the accuracy and confidence of the participants, corresponding to their musical training. We also discuss the recall and precision data of each song based on the responses. The results are as follows:

3.5.1 Accuracy of recognition

The participants were given 10 trials each, playing the three songs through haptic systems in a random sequence. Their answers were recorded to see how many were correctly identified. We also noted the participants' musical training. In Figure 7, we can infer that 5 of the participants were 100% accurate in recognizing the songs. We also found that 3 musically untrained participants made few mistakes and had an accuracy of 80% compared to the 100% accuracy of musically trained participants.

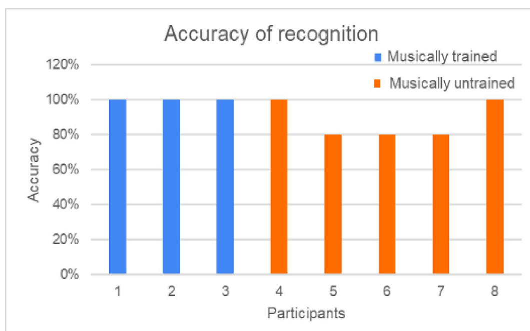

Figure 7. Accuracy of recognizing songs

3.5.2 Confidence in recognition

After each trial, the participants were also prompted to provide a self-assessment of their confidence level regarding the accuracy of their song label identification. The confidence ratings were collected on a Likert scale, ranging from 1 to 10, with participants indicating their perceived confidence in their ability to correctly identify the given song, with 10 being most confident and 1 being least confident. From Figure 8, we see that the musically trained participants were more confident than the musically untrained participants.

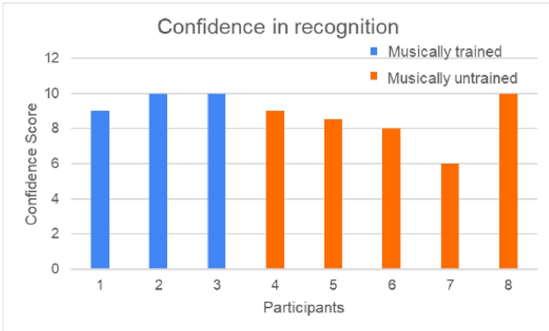

Figure 8. Confidence scores of reconising songs

3.5.3 Precision and Recall

We calculated the precision and recall for each song based on the recognition results by the participants. We calculate the precision and recall for a song (song 1) as follows.

$$\text{Precision} = \frac{\text{Total number of correct ones}}{\text{Total number of detected ones}}$$

$$\text{Recall} = \frac{\text{Total number of correct ones}}{\text{Total number of given ones}}$$

Similarly, we calculated precision and recall for songs 2 and 3 and reported the values in Table 1.

Table 1. Precision and recall for recognizing each song

Song Label	Precision	Recall
1	0.94	0.94
2	0.91	0.83
3	0.92	1.00

4. DISCUSSION

From the results we can infer that the difference in accuracy of recognition between musically trained and untrained participants was less (20%). In most of the trials, the participants were able to correctly recognize the song from the haptic version played on the interface. When the participants were asked how they felt about the interface and their experience in identifying the songs, they said they were able to make out the differences in the pattern of haptics for each song and identify. The musically trained participants reported that they were able to identify the rhythm corresponding to each song through haptics and were able to recognize the songs accordingly. This clearly indicates our interface could translate certain musical elements via characteristics inherent to haptics.

The confidence scores show that the musically trained participants were more confident in recognizing the songs than the musically untrained. This might be due to the influence of their musical skills and aptitude in perceiving rhythm compared to the untrained.

The precision and recall values indicate that song 2 has the least recall value. This might be due to the confusion between songs 2 and 3 as reported by some of the participants.

Overall, the participants liked the interface and were able to recognize the songs and musical patterns through haptics without audio through our interface. Hence, we plan to further investigate complex musical structures and mapping with different textures for more resolution and enhanced experience in upcoming studies. We also plan to investigate our interface for people with hearing impairment and see if it has a potential in sensory substitution.

5. CONCLUSION

We developed a haptic interface that can translate a musical piece from MIDI to haptics, which can play the song in audio as well as haptic versions. We conducted a user study to investigate the efficacy of our interface in terms of accuracy of recognizing a song played in the interface without audio. We found promising results in terms of accuracy, precision and recall values in recognizing a song through haptics. Though the participants liked the interface and gave positive feedback on their experience, the interface still has room for improvement. We plan to further study the different complexities of musical mapping to haptics and plan to investigate our interface for people with hearing impairments in the future.

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