Ad-Hoc Access to Musical Sound for Deaf Individuals

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Figure 1. Development of MuSS-Bits: (a) prototype iteration 1, (b) prototype iteration 2, (c) latest prototype

ABSTRACT
Learning a musical instrument can be a challenging task for a deaf person due to limited access to sound. Prior work has developed visual and vibrotactile approaches to provide music-to-sound feedback to deaf people. However, these systems are not designed for ad-hoc access to sound, which enables a deaf person to explore sound from various audio sources and receive real-time feedback. In this paper we present the development of a music sensory substitution system that enables ad-hoc access to musical sounds. It provides the technical basis to study deeper research questions about understanding and creating sound.

Categories and Subject Descriptors
K.4.2 [**Computers and Society**]: Social Issues – *Assistive technologies for persons with disabilities*

Keywords
Music; Sensory Substitution; Assistive Technologies; Deaf

1. INTRODUCTION
Music is an important part of our daily life. We listen to the radio, enjoy concerts or make music. This excessive exposure of music makes even children experts in music-listening [6]. In music-making activities, this expertise enables humans to compare the created with the intended sound and completes the feedback-loop for music-making (play, listen, evaluate, adjust). However, this is a challenging task for a deaf (deaf, deafened or hard of hearing) individual interested in learning to play an instrument.

Exploration is an important part of learning [3]. Learning about sound and its relationships through exploration requires the ability to sense sound from different *sound sources* at different *places* and perceive *feedback in real-time*. Prior work has developed visual and vibrotactile sensory substitution systems that enable access to musical sounds for deaf people [2,4,7]. While those systems are well studied and deliver accurate musical information in real-time, often the input possibilities (sound sources) and portability are limited or pre-defined. Wearable electronics, such as smartwatches, mobile phones and MUVIB [5] could provide pervasive access to sound through vibrations. However, they use pancake motors with a slow response (lag time: ca. 40ms; rise time: ca. 100ms). These are not able to provide real-time feedback with the accuracy needed for musical sounds. The Basslet Kickstarter project[1] (a technology still being built) seems to be promising, enabling high temporal resolution in a wearable product, and able to be connected with different audio capturing mechanisms. This paper addresses the research question:

> *How can we provide a deaf person with an easy ad-hoc access to sound and music in particular?*

In this work, we present the design process of Music Sensory Substitution (MuSS) Bits (see Figure 1). MuSS-Bits consist of wearable sensor-display pairs that were to allow ad-hoc access to sound. Best to our knowledge, we did not find a technology, that provides real-time feedback from different audio sources, such as instruments, digital devices or environmental sounds, and is made portable to cater for ad-hoc sound access. The focus of this paper is the detailed description of the challenges, problems and design decision for MuSS-Bits.

2. Development of MuSS-Bits
2.1 Initial Goals
Our main goals were to provide (1) real-time feedback, (2) input from different audio sources and ensure (3) wearability to allow ad-hoc sound access. Further initial goals were:

- **Support for Rhythm**: Designing a mapping for a sensory substitution system (e.g. audio-to-vibrotactile) is a challenging task, but crucial for the system's success. In the terms of music, our goal was to use a mapping that at least provides access to rhythm information, since steady-beat and rhythm are commonly introduced first in deaf music lessons [1].
- **Audio Source Selection:** We aimed to make it easy for the users to select a specific audio source, such as an instrument.
- **Simple to Operate:** We assume that this technology will be used by non-experts, and therefore we aimed to keep the interaction with MuSS-Bits simple and intuitive. At the same time, the use of MuSS-Bits should be un-obstructive to ease exploration and music performances.

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[1] https://www.kickstarter.com/projects/basslet/the-basslet-a-wearable-subwoofer-for-your-body

2.2 Iteration 1

Our first prototype (see Figure 1a) used vibrotactile feedback, which has been successfully applied in previous music sensory substitution systems for deaf people [4,7]. Different actuators can be used to implement vibrotactile feedback (see Table 1). We used ERM motors (model 307-103 from precisionmicrodrives[2]) in our prototype, since these are light weighted, responsive (important for real-time feedback) and have a high amplitude.

Table 1. Overview of vibrotactile actuators we considered

	Frequency Span	*Lag Time**	*Weight*	*Power*
Voice Coil	20Hz – 20kHz	Instant	++	++
LRA Motor	20Hz	ca. 40ms	--	--
ERM Motor	0 – 250Hz	ca. 8ms	-	+

* time until the motor reaches 0.08G

As a starting point we used a simple mapping inspired by MUVIB [5]. Auditory loudness was mapped to the motor's intensity. This was sufficient to convey rhythmical information and therefore fulfills our goal for rhythm support.

We gave this first prototype to 2 deaf musicians and interviewed them in separate sessions. We explained our intention to develop a technology for music teaching sessions and access to sound. The prototype was wired to a computer. We played music videos and used the computer's microphone to demonstrate the prototypes functionality. The musicians held the prototype in their hands.

Both musicians liked the vibrotactile feedback, but they stressed that we should add visual effects, since deaf people appreciate those a lot. Furthermore, they confirmed that in their teaching sessions they introduce rhythm first (as Fawkes [1]) before they go on to tuned instruments, such as a guitar. During these sessions we also observed that the wires became obstructive thereby drawing our attention towards a wireless approach.

2.3 Iteration 2

We decided to split the sensing from the feedback part (Sensor-Bit and Display-Bit) for the second prototype (see Figure 1b). This enables intuitive audio source selection by attaching a Sensor-Bit to the audio source and also provides feedback on the user's body.

Input and Output: The Sensor-Bit embodied one omni-directional in-air microphone and an audio jack to provide ad-hoc access to air-conducted sound and to digital devices and instruments. The Display-Bit contained one ERM motor and a single pixel display (RGB LED) to provide visual feedback. The LED's brightness (we used white as color) changed according to the loudness, complementing our existing mapping.

Communication: We decided to implement a wireless approach for the second prototype to avoid obstruction through entangled cables. We used WiFi (ESP8266-12F) to establish a wireless connection that allows us to transmit real-time audio. We used a one-to-one relationship between Sensor- and Display-Bit. To identify a pair we color coded the casings.

Form Factor: We used a rectangular shape to fit the electronics inside it, minimizing the size (LWH: 5cm x 5cm x 3cm; weight: 65 – 70g). Furthermore, we implemented various attachment mechanisms to simplify the deployment of MuSS-Bits: (1) sticky tape, (2) slots for velcro band, (3) magnets, and (4) sewing holes.

User Feedback: We gave this prototype to 4 deaf children (12-17 years) at a residential deaf school (group 1) and to 7 deaf young adults (17 – 25 years) of a local music group (group 2). They explored MuSS-Bits with instruments and music teaching videos.

We received positive and constructive feedback. Group 2 said that MuSS-Bits could help new group members to follow the rhythm. However, they stressed that there is no difference in the feedback between voice and instruments. Furthermore, they raised aesthetic concerns and suggested to reduce the prototype's size and make it look like a garment. In group 1 the participants mixed up Sensor- and Display-Bits due to their similar shape.

2.4 Iteration 3

The latest prototype (see Figure 1c) was reduced in size (LWH: 4.4 cm x 3.5 cm x 1.5 cm) and looks closer to a smartwatch. The Display- and Sensor-Bit can be easier differentiated by the shape. The single LED was replaced with four Nano Pixel LEDs to improve the visual effect's visibility. WiFi was replaced by Bluetooth module to reduce power consumption and allow to connect e.g. a mobile phone. Further, we integrated a contact microphone, to provide a better audio signal from instruments through directly sensing the instrument's sound from its surface.

3. Limitations and Future Work

In this work, we presented MuSS-Bits that aim to enable intuitive audio source selection and provide real-time rhythm information to a deaf user. MuSS-Bits enables to study further questions, such as: *Does MuSS-Bits help a deaf person to build a conceptual model of sound? Does MuSS-Bits support music-learning for a deaf person? Does MuSS-Bits support collaborative music play among deaf musicians?* We plan to investigate these questions in the future with MuSS-Bits.

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