

CollarBeat: Whole Body Vibrotactile Presentation via the Collarbone to Enrich Music Listening Experience

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Abstract

There are numerous proposals for whole body tactile displays that aim to improve the sense of immersion in audio contents. However, these devices commonly have problems, such as long setup times due to numerous actuators, and user confinement to the system. To address these issues, we proposed to present the vibration to a wide area of the body via bone conduction. In this paper, we first investigated whether presenting vibration to the bone really contributes vibration transmission to wider areas of a user's body. Next, we performed a psychophysical experiment to evaluate subjective vibration feeling with music listening experience using our setup. Results suggest that presenting vibration through the collarbone induces vibration transmission more widely through the user's body and enhances subjective music listening experience.

Categories and Subject Descriptors (according to ACM CCS): H.5.2 [Information Interfaces and Presentation]: User Interfaces—Haptic I/O

1. Introduction

When we try to enrich music listening experiences, one important factor is a sense of immersion. Audio technologies such as binaural recording, multi-channel sound field reproduction, etc., exist not only to reproduce high fidelity sound, but also to enrich the sense of immersion.

However, not only audible sound, but also tactile sensation associated with sound plays an important role for the immersive experience of music. When we go to a live music festival, we feel things that we cannot feel through the mere use of headphones, and one such thing is the sound pressure that permeates the whole body. This tactile sensation directly tells us we are surrounded or embraced by the music.

Therefore, creation of whole-body tactile displays for enriching music experience is a natural idea, and jacket-[LPC*09] or chair-[KBN*10] type devices have been developed for this purpose. However, certain problems commonly arise. First, these devices are necessarily huge and heavy because they require many transducers to present vibration to the whole body. Also the user's body is highly restricted by the device because each transducer needs to contact the body all the time. To address this issue, Kurihara et al. tried to reduce the number of transducers by using a vibration transmission medium [KKOH14], but the user's constraint has not been resolved.

In this study, we aim to develop a whole-body tactile device that is non-restrictive, lightweight, small, and easy to attach and detach. Our innovation is to use bone conduction. The bone conduction conventionally used in hearing aids for deaf people, or for noisy circumstances, is

a transmission of vibration from the bone to the ears. [IKT*04] In contrast, in this study, we use bone conduction as "a technique to transmit vibration to the whole body through the skeleton". Since there are several points of the body surface where bone protrudes against the skin, it should be easy to make the transducers directly drive the bone.

In this paper, we carried out two experiments. First, we examined whether presenting vibration to the bone actually contributes vibration transmission to a wider area of a user's body. Second, we presented vibration to selected bones and some other parts of the body to evaluate the effects on music listening experience.

2. Experiment

Since bones are rigid and widespread throughout the human body, it is to be expected that a vibration presented to one bone would transmit to another bone, and then spread through a large area of the body. From the results of a preliminary experiment, we found that it is indeed possible to induce perception of vibration inside the body by presenting vibrations to bones.

We therefore carried out the next experiment to examine whether our method has better transmission efficiency compared with presentation of vibrations to the skin surface, which is the method conventionally used in previous tactile presentation studies.

2.1 Experiment 1: measurement of vibration transmission efficiency

In this experiment, we investigated vibration transmission efficiency of the body by presenting vibration to two different types of areas: the bones and their nearby

soft tissues such as muscles. Our hypothesis is that due to bone conduction, the bones should transmit vibration to a larger area of the body.

To observe both the objective and subjective transmission of the presented vibration, we employed two different evaluation criteria. Physical vibration transmission was measured by acceleration sensors attached to the participant's body; and subjective vibration area was measured by asking participants to mark locations where they felt vibration on a human body diagram sheet.

2.1.1 Apparatus

The system comprised a PC, a digital audio amplifier (M50, MUSE, China), a vibro-transducer (Vp210, Acouve Lab, Japan), five 3-axis acceleration sensors (KXR94-2050, Akizuki Densho, Japan), and a micro-computer (mbed lpc-1768, ARM, UK).

The vibration signals were generated from the PC using MAXMSP, and outputted from the vibro-transducer through the audio amplifier.

2.1.2 Stimuli

To observe the transmission efficiency of vibrations with different frequencies, we prepared four sinusoidal frequencies (50 Hz, 100 Hz, 200 Hz, 400 Hz). Each vibration stimulus was always presented with constant intensity of about 93.8 m/s^2 with the vibro-transducer alone.

2.1.3 Vibration presentation positions

To compare the vibration transmission efficiency of the body at two different input areas, we chose four pairs of bones and their close soft tissues as vibration presentation positions. Each pair consisted of a bone protruding to the body surface and soft tissue that lie close to the bone: pair A, the collarbone and trapezius muscles; pair B, the ribs and the external oblique muscles; pair C, the scapula and the latissimus dorsi; and pair D, the ulna and triceps. Figure 1 shows the location of each pair. Red dots represent bones, and blue dots represent their neighboring soft tissue.

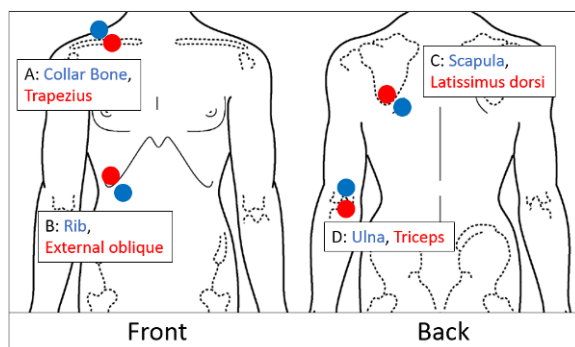


Figure 1 Location of the vibrator

2.1.4 Measurement positions of transmitted vibration

To measure transmitted vibration through the body, acceleration sensors were attached to four locations of the upper body along the midline; the solar plexus, abdomen, thoracic spine, and lumbar spine. We added the upper arm as a measurement position, but those data are not discussed in this paper. The orange dots in Figure 2 show the locations of acceleration sensors.

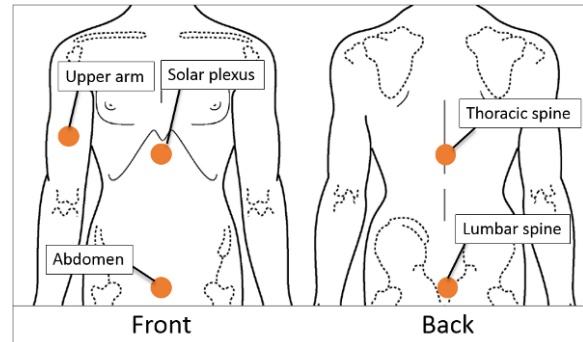


Figure 2 Location of acceleration sensor

2.1.5 Procedure

First, we attached the vibro-transducer to one of the eight vibration presentation positions and placed the five acceleration sensors on the participant's body. To eliminate possible effects of the participant's clothing, both the vibro-transducer and acceleration sensors were directly attached to the participant's bare skin with curing tape (Figure 3). To minimize the effect of the experimental device itself, we used lightweight cable (4.38 g/m) to connect the acceleration sensors.

At the beginning of each trial, one of the four sinusoidal stimuli (50 Hz, 100 Hz, 200 Hz, 400 Hz) was presented for 10 seconds. During presentation, the participant was instructed to stand upright, relax, and breathe normally. After presentation, the participant marked the area on the human body diagram sheet corresponding to the subjectively felt vibration transmitting area. There were 32 trials (8 vibration presentation positions \times 4 frequencies) for each participant. The order of trials was random. Six individuals took part in this experiment (21–24 years old, all males).



Figure 3 Overview of experiment 1

2.1.6 Results and Discussion

To observe the difference of vibration transmission efficiency between bone and nearby soft tissue, we organized the raw data and obtained 20 pairs of results among the participants.

Figure 4 shows an example of this comparison for transmitted vibration of pair A (collarbone vs trapezius), measured at the solar plexus. The X axis shows the vibration presentation position and input frequency. The Y axis shows the intensity of the transmitted vibration. Vibrations transmitted from the collarbone were much greater compared with those from the trapezius, especially with relatively low frequencies such as 50 and 100 Hz. A similar trend was found in Figure 5, which shows the transmitted vibration difference of pair B (rib vs external oblique muscle), measured at the solar plexus.

These results support our hypothesis that bones contribute wider vibration transmission to a user’s body than do muscles.

However, in the case of pair B measured at the abdomen, the opposite tendency was observed (Figure 6). This may be because the small distance between the soft tissue (external oblique muscle) and the measurement position allowed the vibration to be delivered directly through the skin surface. This type of result was sometimes observed, but the general trend clearly shows that bone transmission is an efficient way of producing a whole- body vibration.

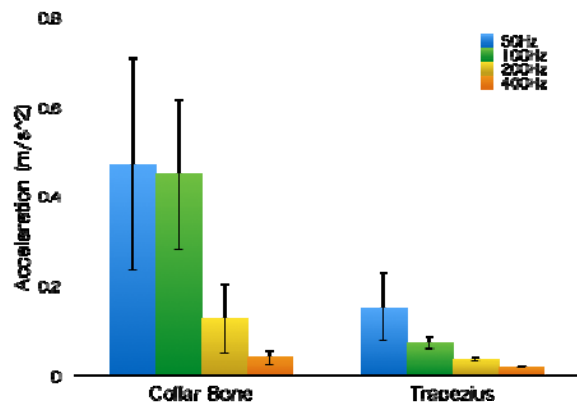


Figure 4 Pair A with measurement position of solar plexus

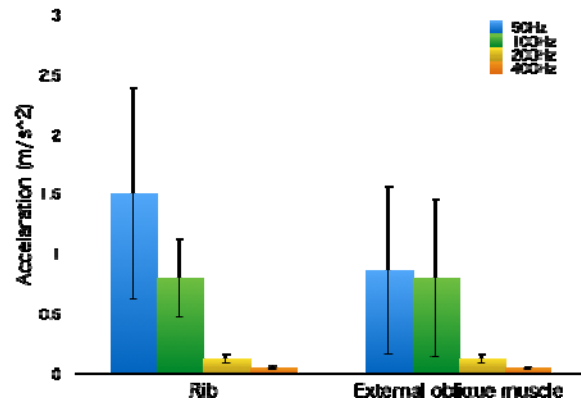


Figure 5 Pair B with measurement position of solar plexus

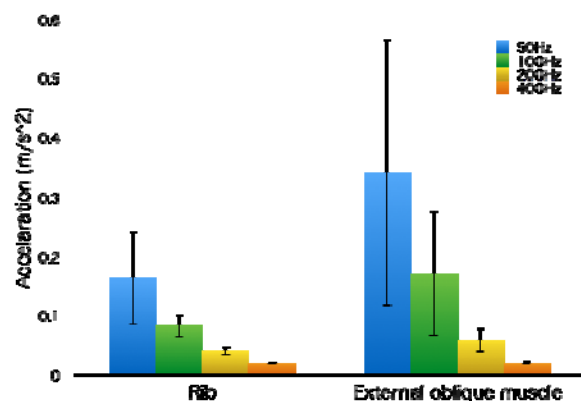


Figure 6 Pair B with measurement position of abdomen

2.2 Experiment 2: Vibration evaluation presented with music

The results of previous experiment suggested the possibility that bones could be a good medium to transmit vibration to the body. As a next step, we investigated the effects of transmitted vibration to the body during a music listening experience.

In this experiment, we focused on the effect of vibration through the bones in terms of the user’s subjective comfort in a music listening experience. Participants wore vibro-transducers and listened to music, after which they were asked about the comfortableness of the experience and how the impression changed with the vibration.

2.2.1 Apparatus

The system comprised a PC, two vibro-transducers (Vp210, Acouve Lab), a digital audio amplifier (M50, MUSE, China), and headphones (QuietComfort3, BOSE, USA).

The vibration signals from the computer were separated to the left and right channels. One audio channel powered the two sides of the headphones, and the other channel powered the vibro-transducers via an amplifier. The vibration amplitude could be controlled independently from the sound of the headphones (Figure 7).

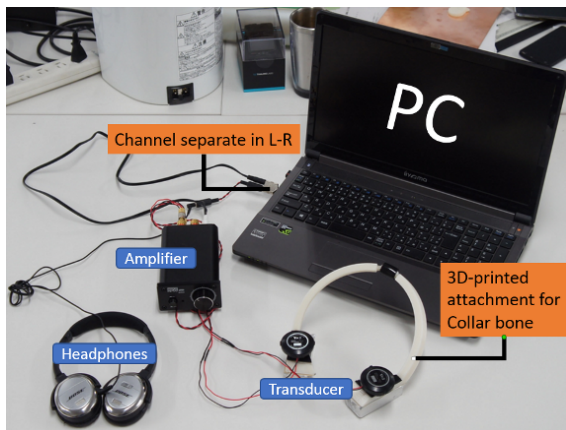


Figure 7 *The experimental apparatus*

2.2.2 Position of presentation

We chose four body areas for presentation of vibration; the collarbone, buttocks, head, and palms. We chose the collarbone because in both our preliminary and previous studies, we found that the collarbone is one of the most suitable bones for presenting vibration because of its connection to other bones, which allows the vibration to spread extensively. The collarbone also protrudes against the skin, which makes attachment of transducers easy. This location is also accessible when users are clothed.

We employed the other three regions for the sake of comparison with reports from previous studies or commercial products. The buttocks are a region frequently used in whole-body tactile presentation [MES11]. The head is quite close to the ears and commonly used for conventional bone conduction. The palm, including fingers, is one of the most sensitive regions in terms of tactile sensation and is commonly used for audio-tactile interactions [OKK14]. In this experiment, we employed two vibro-transducers to present the stimuli symmetrically across the spine in each region.

To attach transducers on the collarbone, we fabricated a 3D printed device and equipped it with transducers at both ends (Figure 8). Weights (100 g) were installed on both ends of the device to maintain stability of contact between transducers and skin.



Figure 8: *Vibration presentation to the collarbone*

For the buttocks, we placed transducers on a soft chair, and participants sat on them. For the palms, participants gripped the transducer in each hand. For the head, we placed transducers at participants' temples and fixed them with an elastic cloth band. (Figure 9)



Figure 9: *Vibration presentation to the head*

2.2.3 Stimuli

To observe the effects with different genres of music, we used three genres: rock, electronic, and classical. We chose Jailhouse Rock (Elvis Presley) for rock, Technologic (Daft Punk) for electronic, and New World Symphony (Dvorak) for classical. We extracted about 20 s from each piece of music for the experiment.

2.2.4 Procedure

In this experiment, it was necessary to calibrate the vibration intensity for each region. We therefore separated the experiment into three phases. In the first phase, the participants were asked to adjust the intensity of both sound and vibration by using the computer's volume

control and digital audio amplifier until they felt that the sound was at a “clear, but not uncomfortable” level. The adjusting time was about 10 seconds. In the second phase, only the sound was presented from the headphones. In the third phase, both vibration from transducers and sound from headphones were presented. The participants evaluated how the impression of the music was changed by vibration using a 7-point Likert scale. The questions were: Q1. “Did you feel comfortable with the vibration?”, Q2. “Did you feel vibration to your whole body?”, Q3. “Did the vibration change the impression of the music?”.

All three musical pieces were presented to each of the four regions, giving 12 trials per participant. The order of music was randomized. Six individuals participated (22–24 years old, all males).

2.2.5 Results and Discussions

Figure 10, Figure 11, and Figure 12 show the experimental results for each question. The vertical axis represents the 7-point Likert score, where larger numbers signify positive results. The horizontal axis shows the three musical genres (rock, electronic, and classic) and the four regions (collarbone, buttocks, head, and palm). The upper and lower edges of the blue boxes represent the third and first quartiles. The red dot represents the median, and the yellow dot represents the average score. The error bar shows the maximum and the minimum values. To verify the difference among music region conditions, multiple comparison analysis (Steel-Dwass method) was performed.

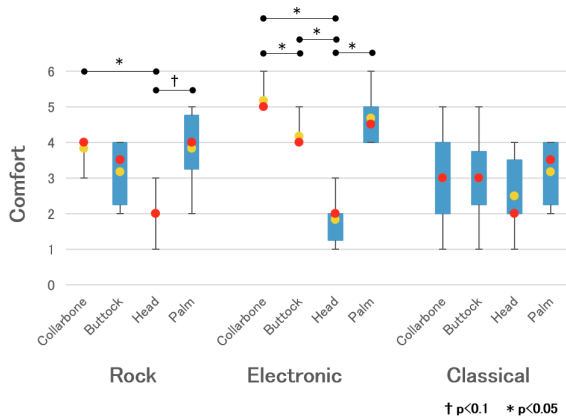


Figure 10: Experimental results for comfort

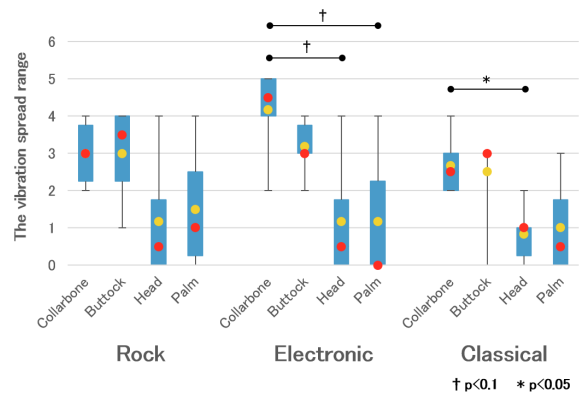


Figure 11: Experimental results for vibration transmission

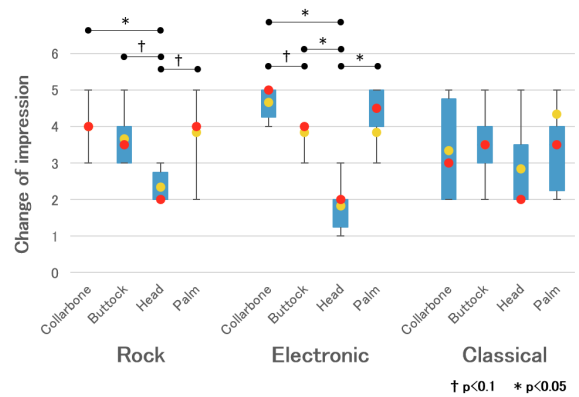


Figure 12: Experimental results for the change in musical impression

The first question, “Did you feel comfortable with the vibration?” (Figure 10), revealed that transmissions to the head with rock and electronic music presented significant discomfort compared with, for example, transmissions to the collarbone ($p < 0.05$). Similar results were observed in comparisons of head with palm for rock music ($p < 0.1$) and electronic music ($p < 0.05$). This may be due in part to the whole skull vibration’s affecting the sense of balance, which were less likely to occur with vibrations to the collarbone or palm.

Data from the second question, “Did you feel vibration to your whole body?” (Figure 11), showed that vibration to the collarbone felt as if it spread to the whole body more than did vibration to the head or palm with electronic music ($p < 0.1$). Similarly, the collarbone produced a feeling of greater spread in vibration than did the head with classical music ($p < 0.05$).

The third question, “Did the vibration change the impression of music?” (Figure 12), produced similar responses to those of the first question.

In summary, presenting vibration through the collarbone is more efficient way to improve the musical listening experience than using other body sites: the vibrations felt more comfortable, more widespread, and more desirable.

2.2.6 Conclusion

This study aimed to develop a whole-body tactile device for enriching musical experience and to make it as non-restrictive, lightweight, small, and easy to attach and detach as possible. Our idea to achieve this goal was to use bone conduction as “a technique to transmit vibration to the whole body through the skeleton”.

In this paper, we first compared the transmission efficiency of bones versus soft tissues. The results suggested that bones could be a good medium to transmit vibration to the body.

Then we evaluated the effect of vibration from the collarbone and other representative sites in terms of subjective evaluation of comfort, feeling of spread, and impression of the music. The results showed that presenting vibration to the collarbone significantly improves the music listening experience. Our future work includes pursuit of a fuller understanding of how vibrations are transmitted through the collarbone, further development of our prototype mobile collarbone device, and expansion of its uses to other applications such as video games, or internet live concerts.

References

- [IKT*04] ISHIMITSU S., KITAKAZE H., TSUCHIBUSHI Y., YANAGAWA H., FUKUSHIMA M.: A noise-robust speech recognition system making use of body-conducted signals. *Acoust. Sci. & Tech*, 25 (2004), pp.166-169. doi: 10.1250/ast.25.166
- [KBN*10] KARAM M., BRANJE C., NESPOLI G., THOMPSON N., RUSSO F. A., FELLS D.I.: The Emoti-chair: an interactive tactile music exhibit. *Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems*. (2010) Extended Abstracts, pp. 3069-3074. doi: 10.1145/1753846.1753919
- [KKOH14] KURIHARA Y., KOGE M., OKAZAKI R., KAJIMOTO H.: Large-area tactile display using vibration transmission of jammed particles. *IEEE Haptics Symposium* (2014). doi: 10.1109/HAPTICS.2014.6775474
- [LPC*09] LEMMENS P., PHILIPS RES. EUR, CROMPVOETS F., BROKKEN D., VAN DEN EERENBEEMD J., DE VRIES G.-J.: A body-conforming tactile jacket to enrich movie viewing. *Proceedings of the IEEE World Haptics Conference* (2009), pp. 7-12. doi: 10.1109/WHC.2009.4810832
- [MES11] MERCHEL S., ERCAN ALTINSOY M., STAMM M.: Just-noticeable frequency differences for whole-body vibrations. *Proceedings of inter-noise* (2011).
- [OKK14] OKAZAKI R., KURIBAYASHI H., KAJIMOTO H.: The effect of frequency shifting on audio-tactile conversion for enriching musical experience. *Proceedings of Asia Haptics Conference* (2014). doi: 10.1007/978-4-431-55690-9_9