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Tactile Identification of Non-Percussive Music Instruments

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Summary
In this paper, an experiment is described to investigate if a person could discriminate non-percussive music instruments (clarinet, trumpet, violin, guitar, piano and organ) by their fingertips using audio-driven tactile feedback. The audio signal was adapted to generate a vibration signal (tactile feedback) taking into account the limited capabilities of the tactile modality. A systematic approach to find the different adaptation parameters is discussed. The vibrations were created by an electro-dynamic shaker mounted behind a touch-sensitive screen. Results indicate that only instruments with strong transients (guitar and piano) can be distinguished from the others. Identification errors for single instruments can not be avoided using the described adaptation algorithms.

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1. Introduction

Today, customizable touch screens more and more replace traditional audio mixers. It has been shown that the usability and quality of these touch sensitive systems can be improved by adding vibration feedback, using e.g. electro-dynamic exciters [1]. However, it is difficult to simulate the intuitive tactile feedback that physical buttons, knobs and sliders provide. E.g., the direct contact with a real fader knob ensures the sound engineer not to lose contact. In this paper, an experiment is described to investigate if additional information can be transferred using vibrations reproduced at the fingertip. Which instrument is assigned to the fader in contact? Is it a guitar, a trumpet or a violin?

There have been attempts incorporating tactile feedback with motorized faders [2, 3]. However, these systems were limited by the slow mechanics of the fader. A first experiment that examines the ability to distinguish between different musical signals using audio-driven tactile feedback reproduced with an electro-dynamic shaker was described by Merchel et al. [4]. It was found that percussive audio loops can be discriminated under certain conditions.

2. Auditory and Tactile Perception

The auditory and tactile modalities have different capabilities and restrictions (e.g., different frequency and intensity range), which must be considered when generating audio-driven tactile feedback. The perception of sound and vibration is a complex area that has been studied for several decades. For a detailed comparison of both modalities see Merchel et al. [5]. The frequency range of the auditory sense is much larger than for the tactile sense. The ability to discriminate between frequencies for perceived sounds is better compared with perceived vibrations. The auditory system works within a dynamic range up to 100 dB and can discriminate intensity differences less than 1 dB. In comparison, the tactile system has a much smaller dynamic range, operating between 35 dB and 50 dB. The reported values for vibrotactile intensity discrimination are similar to the auditory system and vary from 0.4 dB to 2.3 dB [6]. In addition, tactile sensitivity depends strongly on time of exposure, the size of the contact area [7] and the individual subject [8].

However, the auditory and tactile frequency range overlaps up to several hundred Hertz. Similar psychophysical effects have been observed in both modalities (e.g., masking or iso-perception contours). If the audio signal is adapted accordingly, enough information could be transferred through the tactile modality.

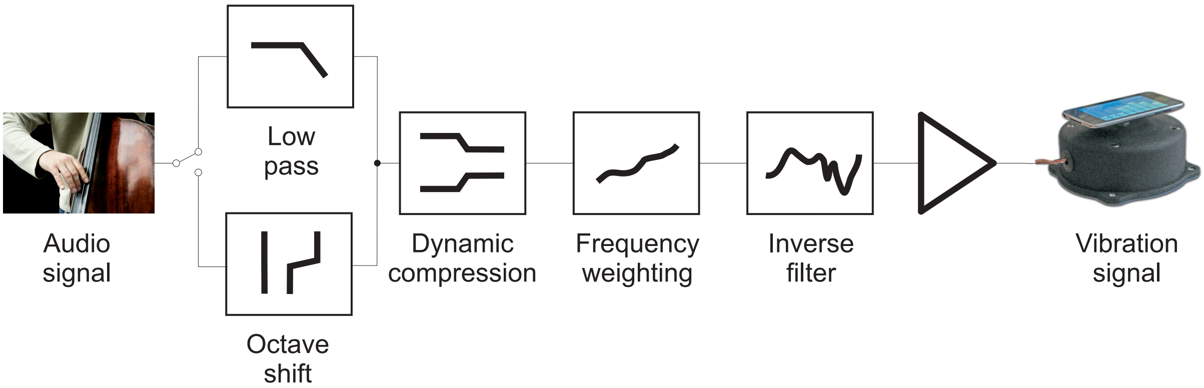

Figure 1. Two approaches to generate audio-driven tactile feedback. Top: The audio signal was low-pass filtered at 1 kHz. Bottom: Frequencies were shifted down one octave using granular synthesis.

3. Audio Driven Tactile Feedback

In this study, the goal is to identify a specific music instrument by touch feedback. This would help an audio engineer or an electronic music artist not to confuse different mixing channels. The vibration signal, acting as a sign carrier, should relate to the audio source from which it was generated. To achieve this aim, identification features characteristic of the instrument must be maintained in the adaptation process. These features can be the frequency and level structure (e.g., harmonic / inharmonic tone structure, noise background) or time structure of individual tones (e.g., starting transients or decay times). Two approaches were chosen to generate audio-driven tactile feedback in real-time using Pure Data. They are illustrated in Figure 1. The first approach was to purely low pass filter the audio signal at 1 kHz. In the second approch frequencies were shifted down one octave using granular synthesis. In addition, the dynamic range was compressed by a factor of two (with 20 ms attack and release) and the difference between the frequency dependent auditory and tactile perception threshold was compensated. Also, the transfer function of the electro-dynamic shaker was compensated with an inverse filter.

4. Experiment

4.1. Stimuli

Figure 2 shows the fundamental frequencies of music instruments and voices. For this study, six instruments were selected (clarinet, trumpet, violin, guitar, piano and organ). Chromatic ascending and descending scales were recorded for each instrument over two full octaves (196 Hz - 784 Hz). Note onset timing and loudness was aligned between different scales afterwards. Using the low pass filter approach, several harmonics are in the perceivable frequency range of the tactile sense at the lower end of the scale. With increasing frequency, fewer overtones might be perceived.

4.2. Setup and Procedure

Tactile feedback was reproduced using an electrodynamic vibration actuator (Monacor, BR-25) coupled with a touch sensitive device (Apple, iPod). The device was connected to the computer using TouchOSC, an application that can send Open Sound Control messages over a Wi-Fi network. The user interface was divided into six buttons. Each button corresponded randomly to a specific music instrument. When the finger of the participant came in contact with a button, tactile feedback for the respective audio signal was rendered, while simultaneously, the sum of all six scales was played on closed headphones (Sennheiser, HDA 200). The task of the participant was to associate the vibrating buttons to the music instruments.

4.3. Subjects

Twenty subjects (16 male and 4 female) voluntarily participated in the experiments. Their ages ranged from 20 to 40 years. None had participated in previous audio-tactile experiments, and all indicated to have no hearing damage or hand disorders.

5. Results and Discussion

5.1. Low Pass

Using the first approach, the six vibration signals were generated by low pass filtering the scales at 1 kHz. All vibration signals were perceivable over the whole scale. The association matrix (stimulus and response plot) between the six stimuli and the responses are

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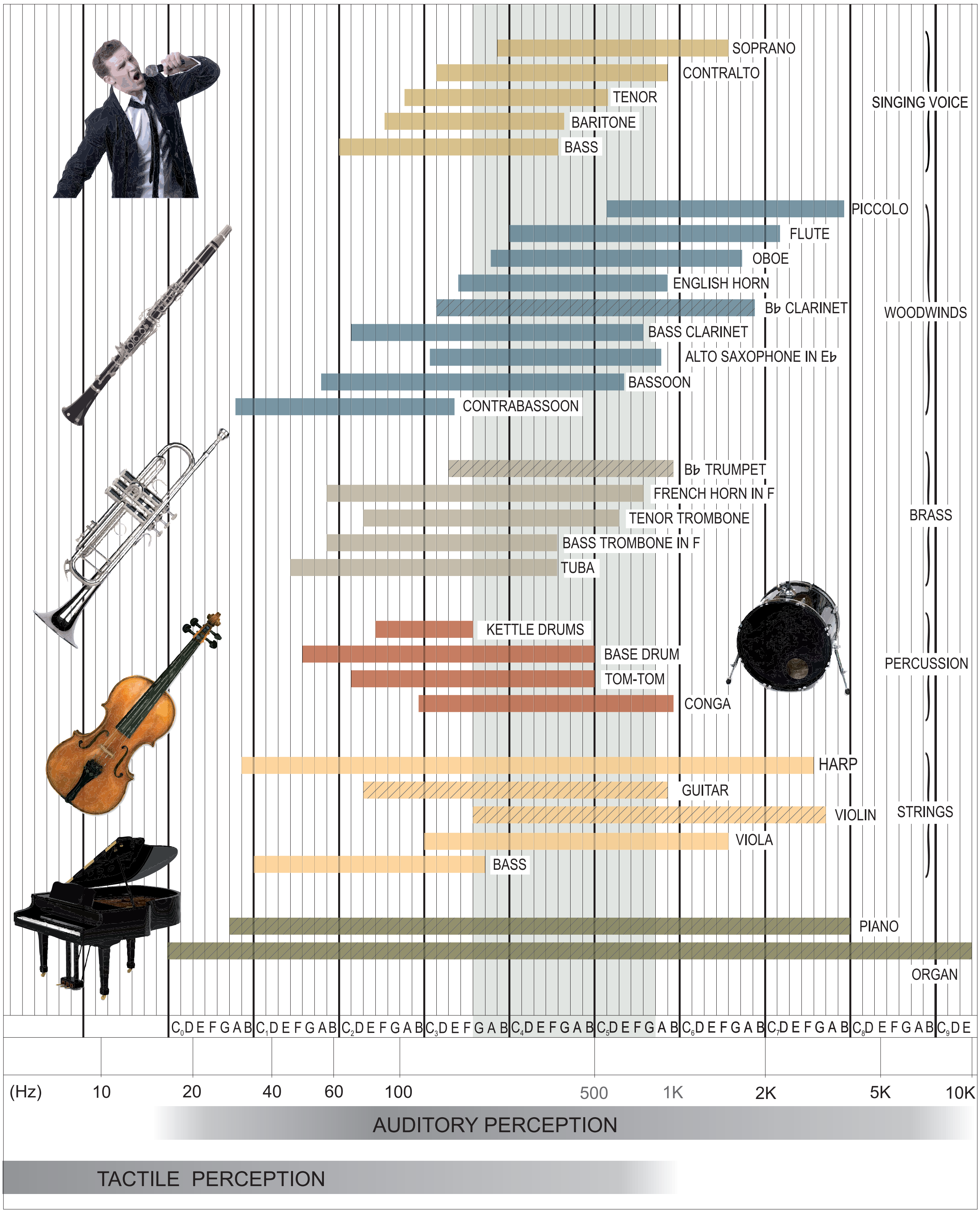

Figure 2. Fundamental frequencies of instruments and voices adapted from [9]. The music instruments (clarinet, trumpet, violin, guitar, piano and organ) and the scale (G3 to G5) applied in this study are shaded. The ranges for transients, noise, harmonics or partials are not indicated.

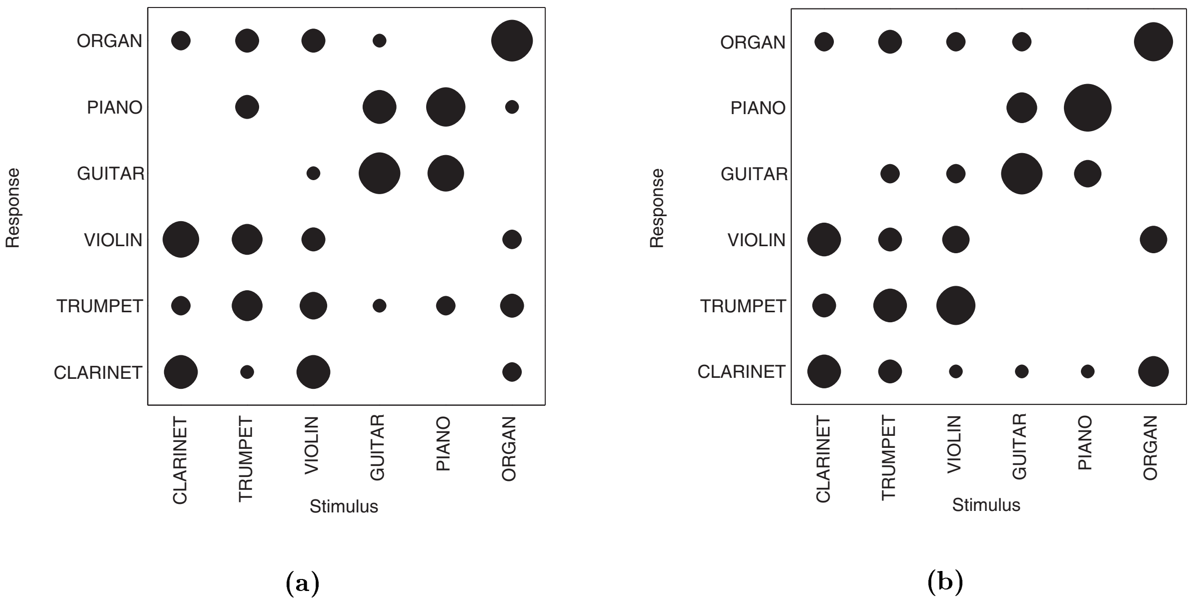

Figure 3. Association matrix for the identification of the six music instruments. The vibration was generated using **(a)** a 1 kHz low pass and **(b)** the octave shifted signal. The area of each circle is proportional to the number of answers given for a particular combination of stimulus and response.

shown in Figure 3(a). The area of each circle is proportional to the number of answers given for a particular combination of stimulus and response. A full circle would correspond to correct identification of an instrument by all 20 subjects. With the low pass filtering approach, considerable errors can be seen. Instruments with strong transients (guitar and piano) can be distinguished from the other, but are confused with each other.

5.2. Octave Shift

The vibration was generated by shifting the frequencies down one octave using the second approach. As expected, the perceived quality of the vibration stimuli changed. However, the identification rate did not improve. The resulting association matrix is plotted in Figure 3(b).

Only strong features of the time structure (e.g., starting transients) seem to help identification. However, spectral features (e.g., harmonics) are very important for music instrument discrimination [10]. The results indicate, that these features cannot be discriminated sufficiently in the tactile modality. A possible explanation can be the strong tactile masking towards higher frequencies [11]. Thus, vibratory harmonics could be predominantly masked through the fundamental.

6. Conclusions and Outlook

In contrast to percussive loops [4], music instruments cannot be differentiated well using the described approaches. The limitations are not surprising because the tactile sense is more limited than the auditory sense. The results indicate that this holds especially true in terms of spectral perception. However, not much is known about tactile perception of spectral variations.

It has been shown earlier that speech can be understood to some extend with the help of tactile vocoders (e.g., [12]). The audio signal is normally devided into a number of frequency components using band pass filters. These components are than processed and reproduced via an array of vibrators or electrodes. The present study used only one vibration actuator. It might be possible to achieve better discrimination results, if acoustic frequency is coded into vibratory space using multiple actuators. However, this transfer is no longer intuitive and may require considerable learning.

In the present study, closed headphones were used for audio reproduction. If this is not the case, audio radiation of the vibration reproduction system might be problematic, especially in quiet environments like a studio. Thus, alternative, quieter tactile reproduction methods should be considered, such as using horizontal instead of vertical vibrations or electro-tactile stimulation [13, 14, 15].

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