Relaxation Effects of Auricular Vibration Stimuli Synchronized with Music

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Abstract: When people listen to music, vibratory stimuli that are synchronized with sounds enhance the affective effects of music. We investigated the effects of vibratory stimuli on relaxation. Vibratory stimuli were delivered to the cymba concha, an auricular part, concentrating on the vagus nerves. Five vibration patterns were prepared based on music that evoked relaxation. A user study involving nine participants found that they felt more relaxed under the condition in which a vibration stimulus was generated from sounds lowered by one octave than under the condition with no vibratory stimuli applied. This effect was more prominent for one of the two musical sounds tested.

Keywords: *Vibration, vagus nerve, cymba concha*

1. INTRODUCTION

The emotional experience when viewing music or videos is an antecedent to determining the value of the content. Thus far, various studies have been conducted to enhance the emotional experiences evoked by music and videos by presenting haptic stimuli to the viewer's torso [1–5]. For example, the presentation of vibration stimuli to the upper body while viewing a horror movie increased the sense of fear [1]. Emotional valence and arousal increase when listening to music using a vibration-imparting chair [2]. In general, vibrational stimuli applied to the torso are used as haptic stimuli. Most earlier studies have reported that vibratory stimuli to the upper body increase arousal status, such as fear and excitement; however, few studies have reported an increase in non-arousing emotions, such as relaxation.

Some studies have shown that mechanical stimulation of the external ear, where the vagus nerve is located, activates the parasympathetic nervous system and induces relaxation. Lee et al. [6] reported that air pressure stimuli to the external ear increased parasympathetic nerve activity. Boehmer et al. [7] reported that acupuncture of the cymba concha, where the vagus nerve is densely distributed, reduced heart rate. Vibration stimulation of the cymba concha exhibited physiological effects similar to those observed when the auricular vagus nerves were activated by electrical stimulation [8]. These studies suggest that mechanical stimulation of the ear effectively affects the parasympathetic nervous system, causing relaxation.

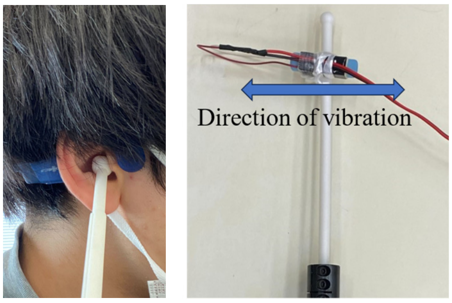

Figure 1: Experimental apparatus. Left) Experimental scene. Right) Resin rod with a vibrator.

In this study, we investigated the relaxation effects of vibration stimulation on the cymba concha while listening to relaxing, voiceless music. Vibratory stimuli were synthesized by referring to music, and five types of vibration patterns were tested. Through a questionnaire-based experiment, we investigated the degree of relaxation experienced through the combination of music and vibrations. This study extend the authors' earlier studies [9–11], where the affective effects of stroking stimuli to the ear were demonstrated. The findings of this study are expected to provide a basis for designing new emotional haptic interfaces.

2. METHODS

2.1 Apparatus

Figure 1 shows the contactor that vibrates the cymba concha. The main components are a 3D-printed resin rod with a sphere of 8 mm in diameter at its tip and a recoiltype voice coil motor (Haptuator MM3C, Tactile Labs Inc., Canada). The motor is fixed 30 mm from the tip of the resin rod. It fits into the groove of the rod and is fixed by a string. The rod vibrates perpendicular to its longitudinal direction. The shape and size of the tip are designed to fit the cymba conchas.

The voice coil motor was controlled using MATLAB (MathWorks, USA) through a data acquisition board (USB-6212, National Instruments Co., USA) and an audio amplifier (FX-2020A+ CUSTOM, North Flat Japan Co., Ltd., Japan). During the experiment, participants held the grip of the contactor with their left hand. Vibrations were administered to the left ear. Bone-conduction earphones (Aeropex, Shokz, USA) were used to play the sound stimuli. Sound and vibratory stimuli were synchronized using MATLAB.

2.2 Sound stimuli

Two pieces of stereo music, Lune [12] and Samidare [13], were used to evoke relaxation. Lune is jazz music with guitar and bass as the main instruments. Samidare primarily includes string instruments, such as violin and koto. In a preliminary study, seven participants rated 11 pieces of music, including Lune and Samidare, on how relaxing each piece was. Lune and Samidare received the highest scores. The lengths of these pieces were truncated to 30 seconds, and the sampling frequency was 44100 Hz.

2.3 Vibration stimuli

The vibrator was actuated by applying voltage signals based on sound. Three audio-to-vibration conversion methods were used, as shown in Figure 2.

The first method transmitted sound signals directly to the vibrator. Because the vibrations were presented to the left ear, sound signals for the left channel were used.

The second method transmitted a sound source one octave lower than the original sound to the vibrator. Previous studies used a method to reduce the frequency of sounds to convert them into vibrational stimuli [3,14]. In a preliminary test, we used vibrations based on sounds lowered by one and two octaves, as well as vibrations one octave higher than the original sound stimuli. Among these, the one-octave-lowered vibration was found to potentially induce relaxation. In the main experiment, the left channel of the original stereo sound was lowered by one octave, and this audio signal was presented to the vibration actuator.

The third method involved amplitude modulation of the original sound signal. First, the absolute value of the sound signal was obtained; then, its envelope was

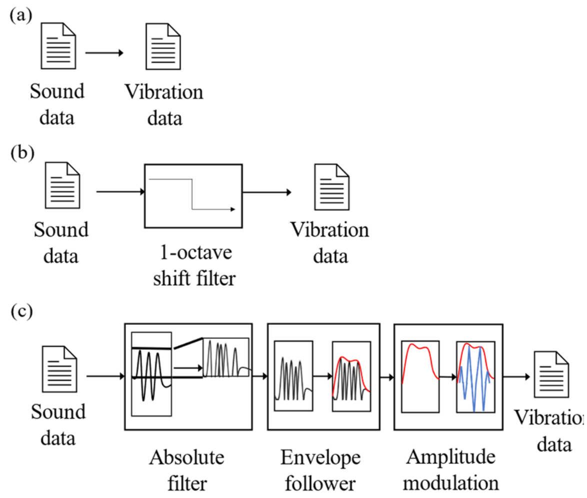

Figure 2: Methods of generating the vibration stimuli. a) Vibration stimuli was the direct transmission of sound stimuli. b) The sound stimulus was lowered by one octave and used as the vibration. c) Amplitude-modulated vibration.

calculated using MATLAB's envelope function, and amplitude modulation was applied. Carrier-wave frequencies were set at 60, 100, and 140 Hz. A lower limit of 60 Hz was determined considering the frequency characteristics of the vibrator; vibrations at frequencies lower than this were perceptually weak. Preliminary experiments showed that carrier frequencies above 150 Hz significantly diminished the music experience due to the sound generated by the vibration, setting the upper limit at 140 Hz.

The subjective intensities of the vibrations were equalized among all stimulation methods through a preliminary subjective evaluation test.

2.4 Site of vibration stimuli presented

The site for presenting the stimulus was the cymba concha, where the vagus nerve is densely distributed [15]. Previous studies have shown that vibratory stimulation of this region elicited physiological reactions similar to those caused by electrical stimulation of the same area [6, 8]. Vibratory stimuli to the external ear spatially coincide with sound stimuli. Moreover, noise generated during vibration stimulus presentation is less likely to be heard, potentially causing minimal disturbance to the music listening experience due to vibration-related noise.

2.5 Participants

Nine participants in their early 20s participated in the experiment after providing written informed consent. None of the participants were aware of the experiment's purpose.

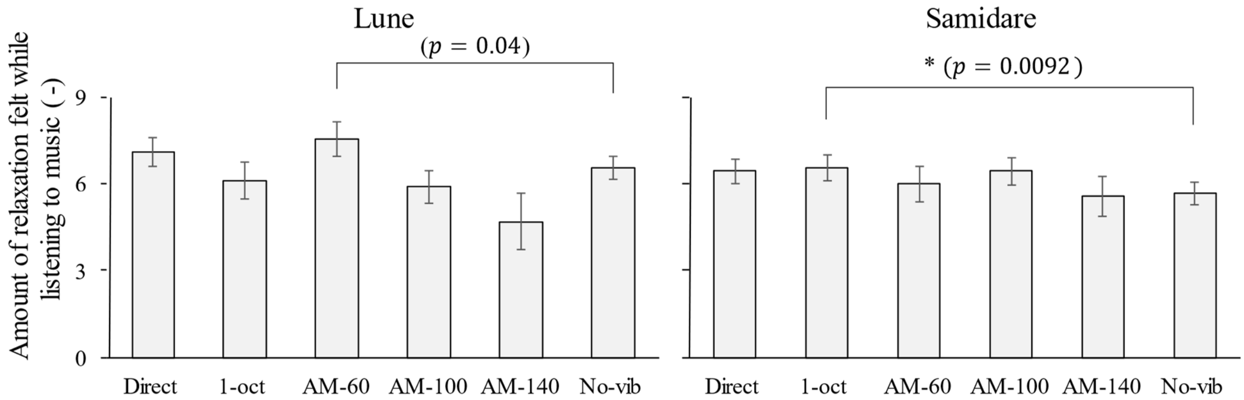

Figure 3: Experimental results. Means and standard errors for each stimulus condition. The value in parentheses is a p-value without Bonferroni correction. 1-oct stands for one octave lower. AM-60, 100, and 140 stand for the amplitude modulated vibration with the career frequency of 60, 100, and 140, respectively.

2.6 Ethical statement

The study protocol was approved by the Institutional Review Board of the Hino Campus of Tokyo Metropolitan University (approval number H23-11).

2.7 Procedures and tasks

Participants listened to music under six different vibration conditions: in the first condition, the vibration was directly converted from the sound; in the second, the vibration was made by sound lowered by one octave; in the third, fourth, and fifth conditions, amplitude-modulated vibrations with carrier frequencies of 60 Hz, 100 Hz, and 140 Hz, respectively, were used; in the sixth condition, only sound was presented. The stimulus length for all conditions was 30 seconds.

After experiencing each stimulus, participants answered a questionnaire. They rated the degree of relaxation they felt while listening to the music using a 9-point Likert scale (1–9). A score of 1 indicated that they did not feel relaxed during the stimulus period, while higher scores indicated greater relaxation. This procedure was repeated 12 times in total (two musical pieces × six stimulus conditions) in random order. During the experiment, participants were asked to close their eyes.

2.8 Data analysis

For each musical sound, the ratings between the no-vibration condition and each of the five with-vibration conditions were compared using a one-sample t-test with a Bonferroni correction for multiple comparisons.

3. RESULTS

Figure 3 displays the relaxation scores for each sound and vibration condition. A significant increase in relaxation was observed in Samidare under only one condition. The vibration designed with the one-octave lowered sound significantly increased subjective reports of relaxation ($p < 0.05$) compared to the no-vibration condition.

4. DISCUSSION

The one-octave-lower vibration was effective for only one of the two musical sounds tested in this study. This finding suggests that the optimal vibration synthesis method may vary among different sounds. The two musical sounds tested were distinctly different from each other. A key difference between them was the frequency of the main sound. Although research on the effects of vibratory frequency in stimulating the cymba concha is limited, certain vibratory frequency bands may be more effective. For Samidare, the one-octave lowered vibration might have aligned with such effective bands.

Determining whether the vagus nerve mediated the relaxation effects demonstrated in this study is challenging. Thus, future research should experimentally compare different body sites with varying densities of the vagus nerve.

5. CONCLUSION

In this study, we investigated whether vibrational stimulation of the cymba concha enhanced participants' relaxation while listening to two relaxing musical pieces. Five vibration-generating algorithms were tested. The results showed that, for one of the two sounds, the subjective report of relaxation increased with the vibration generated by the sound lowered by one octave compared to the audio-only condition.

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