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EVALUATING EMOTIONAL RESPONSES TO SOUND IMPRESSIONS USING HEART RATE VARIABILITY ANALYSIS OF HEART SOUNDS

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Abstract. *Sound imparts various emotions or feelings, such as comfort or discomfort. It is difficult to evaluate these impressions because each feeling is different for each person; thus, subjective evaluation is widely used. Although this method has had some success in evaluating such impressions, it is demanding for participants. A more objective measure is by analysis of heart rate variability, correlated with the fluctuations in autonomic nerve activity. In this study we investigated the effectiveness of measuring impressions in response to sound using phonocardiography. We measured the heart rate variability of participants while they listened to music. The results showed similar trends for each participant according to the music type. These results suggest that analysis of heart rate variability is a useful way of measuring the impression evaluation index of sounds.*
Keywords: HRV analysis, Heart sound, Impression evaluation, Phonocardiogram

1. **Introduction.** There are many types of sound in our daily lives. When we hear a sound, we have feelings, emotions or impressions, such as comfort or discomfort. As sounds can evoke many different impressions and feelings, a range of methods are used to evaluate such sounds, including electroencephalography, magnetoencephalography and subjective evaluation. In particular, subjective evaluation is widely used and accepted as an evaluation method for this type of examination [1]. However, many questions are often required to establish a correct evaluation, and this can become laborious for the participant. Thus, we focused on analysing heart rate variability (HRV), which is often used to measure fluctuations in the autonomic nervous system. Heart-rate activity is strongly related to autonomic nervous system activity, disorders of which can change the behaviour of the heart. Fluctuations in sympathetic nervous system activity are mainly caused by stress or by external factors, which can cause the parasympathetic nerves to excite, even when the participants are feeling relaxed [2]. Heart-rate activity increases when sympathetic nerves excite, and decreases when parasympathetic nerves are activated. For this reason, fluctuations in autonomic nerve and heart rate activity occur upon hearing a sound. Thus, we can expect to evaluate emotional responses to sound by examining autonomic nervous system activity data extracted from variations in heart rate activity. Generally, electrocardiography is used to analyse heart rate activity, but phonocardiography is another lesser used method. Thus, in this study, the effectiveness of phonocardiography to evaluate emotional responses to sounds was investigated.

2. **Experimental Method.**

2.1. **Experimental outline.** The participant was a healthy male, and the measurement was performed using a device we created, as shown in Figure 1 [3]. The signals were measured around the fourth intercostal space, close to the sternum edge. The participant was required to sit on a chair, with his eyes closed while the measurements were recorded.

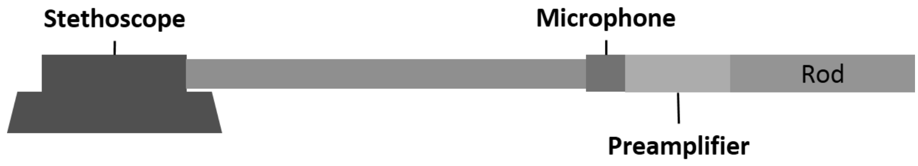

FIGURE 1. Measuring device

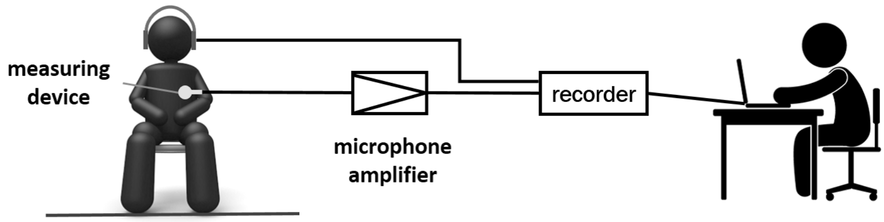

FIGURE 2. Experiment environment

Sounds were presented through headphones (Figure 2). In this experiment, the duration of each sound was 3 min, with a 1-min interval between stimuli [4]. After each experiment, over five minutes rest was allowed before subsequent experiments were performed.

2.1.1. *Experiment 1: Evaluation of sound discomfort.* Experiment 1 examined the effectiveness of evaluating sound discomfort by analysis of heart rate activity. This experiment comprised one participant. Participant is a healthy male in the twenties. Heart sounds were recorded under conditions of silence, and on hearing wasp buzzing sounds and classical music. Subjective evaluation was conducted by the participant, who allocated a rating to each sound. Five rating levels were used, with '1' being most uncomfortable and '5' being most comfortable [5].

2.1.2. *Experiment 2: Dependence on music type.* Experiment 2 comprised four participants. Participants are healthy males in the twenties. To confirm dependency on different types of music, house music and classical music were presented to the four participants, after which their heart-rate activity was monitored. Three evaluations were conducted per participant. The average level of sound pressure was 70 dB (A) near the participant, and evaluation was performed at seven levels. Comfort level and favorable level of each situation were presented by participants. The difference between comfort level and favorable level is included elements. Favorable level included some factors, for example, excitement factor and desirable beat. The other side possessed only relaxation element.

2.2. **Analysis method.** Noise from heart sound measurements was filtered with a bandpass filter, after which two peaks – the first and second heart sounds – were extracted. The first heart sound was extracted, and the time intervals between the heart sounds were calculated (Figure 3). A trend graph was used to calculate heart rate interval times, after

TABLE 1. Type of presentation music

Experiment number	music type	name
Experiment 1	classical music	Piano Trio No.4 "Dumky"
	–	hum of bee
Experiment 2	classical music	Nocturne No.20 in C-sharp Minor Op.Post., "Lento con gran espressione"
	house music	"Aftermath" by TOWA TEI

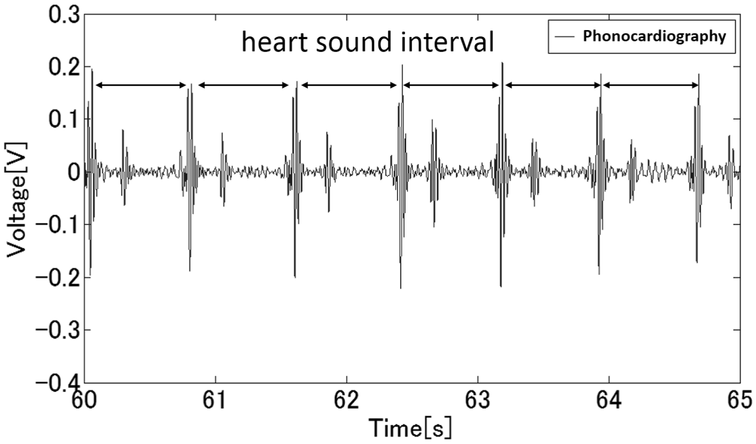

Figure 3. Heart sound interval

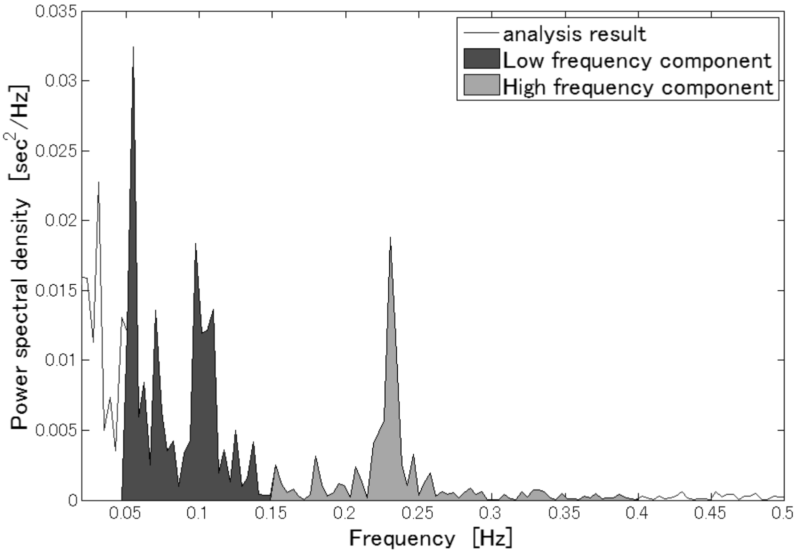

Figure 4. Defined range of LF and HF

which third-order spline interpolation and re-sampling with 1 Hz were introduced. Low frequency (LF) and high frequency (HF) components of trend graph frequency result were defined as 0.005.15 Hz and 0.15.4 Hz, respectively. Sympathetic nerve activity is reflected in LF and HF component values, whereas parasympathetic nerve activity is reflected only by the HF component. Frequency analysis was conducted using a 256-point fast Fourier transform (FFT) method for 3 min, which corresponded to the duration of the trend graphs. LF and HF components were gained with defined area. Next, the LF/HF ratio was calculated by dividing the LF and HF areas for each condition, as shown in Figure 4.

3. Experimental Results.

3.1. **Experiment 1: Evaluation of sound discomfort.** From the results of the comparison of silence with two different types of sound, it was confirmed that the HF component of classical music was 22% lower than that of the silence condition. Moreover, the HF component of the wasp buzzing sounds was 28% lower than that of silence. When the LF/HF ratio was used to represent the activity index of the sympathetic nervous system, the rate was found to be twice that of silence for both classical music and wasp buzzing sounds. Thus, there were no differences in discomfort caused by presenting classical music or wasp buzzing sounds to the participants. However, it was confirmed that the LF/HF ratio for wasp buzzing was slightly higher than that for classical music. The results of impression evaluations revealed that classical music scored a slightly more comfortable score of '4' compared with wasp buzzing, which had a score of '3'.

3.2. **Experiment 2: Dependence on music type.** For each participant, we compared the results obtained from listening to classical and house music with the same conditions of Experiment 1. The results between subjective evaluation and an LF/HF frequency analysis are shown in Figures 5 and 6. This result was calculated by the regression analysis using least squares method. We compared the results of the subjective evaluation and the time-frequency analysis. From these, we confirmed a similar tendency for all the conditions. When participants listened to music that they had rated as having a high comfort level, we observed a tendency towards a decreasing LF/HF value (Figure 5). For classical music, a correlation coefficient of -0.78513 was found between comfort level and LF/HF ratio; for house music, the correlation coefficient was -0.35832. Similarly, when participants listened to music that they had rated as highly favourable, we observed a tendency towards a decreasing LF/HF value (Figure 6). For classical music, a correlation coefficient of -0.46282 was found between preference level and LF/HF ratio; for house music, the correlation coefficient was -0.52242.

4. **Discussion.** In Experiment 1, when an evaluation was conducted using the HF component and LF/HF ratio, the HF component of the wasp buzzing sound was low, and the LF/HF ratio was high compared with those of the classical music. Although it was possible to analyse the difference between the silence and different sounds, the difference between classical music and wasp buzzing could not be analysed. Both sounds may have induced similar reactions because of the same stress being felt by the participants.

In Experiment 2, we confirmed a negative correlation between the time-frequency analysis result and the subjective evaluation. As in Experiment 1, the LF/HF ratio decreased with music of a high comfort level and high favorable level, and a reaction was evoked

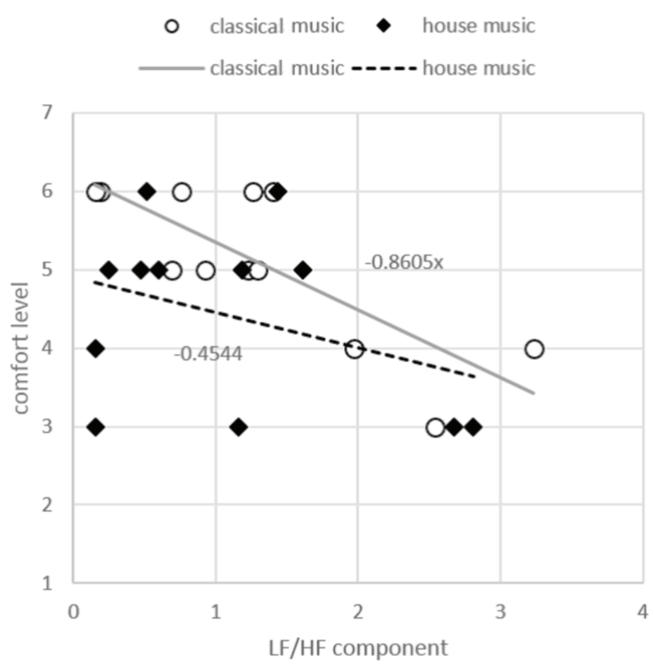

Figure 5. Experiment 2 result (comfort level)

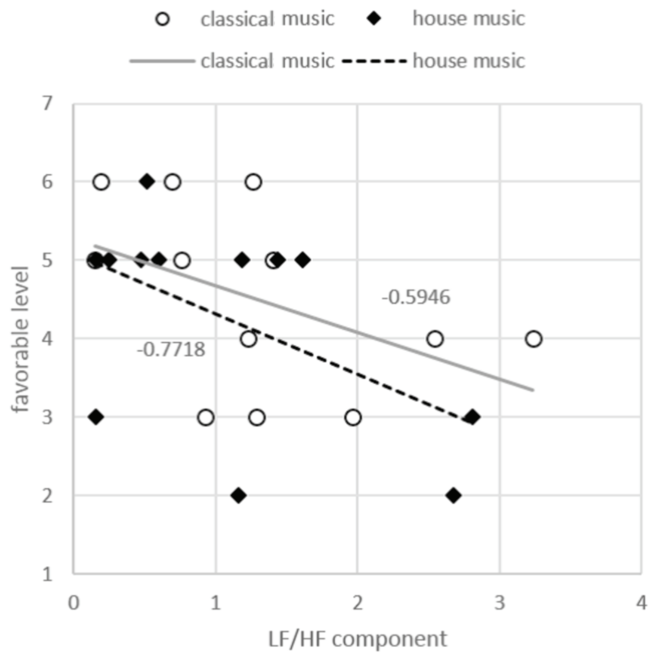

Figure 6. Experiment 2 result (favorable level)

with each music type. This trend suggested that HRV analysis could capture a variety of autonomic nervous system responses. However, in terms of participant reactions, we observed contrast case between the HRV analysis results and the subjective analysis results. The cause of those cases where the subjective evaluation did not correlate with the HRV analysis, this may have occurred because the participants were unable to concentrate or because the listening time was short.

5. **Conclusion.** In this study, we evaluated emotional responses to sounds using HRV analysis of heart sounds. HRV was observed for each sound, and the relationship between the participant reactions and impression evaluations was also confirmed. Thus, phonocardiography has a potential use in evaluating auditory impressions by analysis of HRV.

Future studies are required to improve the accuracy of phonocardiography and to evaluate emotional responses to sounds using a larger number of participants and stimuli.

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