MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

A Study on Sound Quality Evaluation Method for Vehicle Using Vital Information

Date, Yuki[1]
Yamagiwa, Natsuki[2]
Morimoto, Yuta
Tanimoto, Noriyuki
Ishimitsu, Shunsuke
Graduate School of Information Sciences Hiroshima City University
3–4–1, Ozuka-Higashi, Asa-Minami-Ku, Hiroshima, 7313194 Japan

ABSTRACT

The sound environment is an important factor determining the value of automobiles. Sound quality evaluation is important for enhancing the sound environment. We conducted an analysis with respect to two aspects: subjective evaluation and objective evaluation. In the subjective evaluation, we evaluated five types of engine sound with different timbres by using the semantic differential (SD) method. Three factors were obtained by factor analysis, namely, excitement, brightness, and responsiveness. The factor score of the excitement factor increases as the sound pressure of the order component of the stimulus sound increases.

We conducted heart rate variability (HRV) analysis by using heart sounds as an objective evaluation index. The HRV analysis method using heart sounds has a problem that it is easily influenced by body movement noise. Therefore, we proposed an HRV analysis method that is robust to noise. From experiments using HRV analysis, we confirmed that as the order component of the stimulus sound increases, the rate of change of the low-frequency and high-frequency components also increases.

Keywords: Sound design, HRV analysis, Engine sound
INCE Classification of Subject Number: 60

1. INTRODUCTION

The production concept for car engine sound has been changing, from reducing noise to designing sound. It is expected that product values will be improved by the development of car engine sound. An auditory impression evaluation is necessary for developing engine sound. Moreover, it is said that car engine sound influences a driver's concentration and stress. Furthermore, many researchers are focusing on estimating stress and concentration states from biological information [1]. It is expected that drivers are led to a zone by the engine sound using biometric information. Therefore, in this study, we evaluated auditory impressions and biometric information in the context of listening

1 yuki08851@gmail.com
2 n-yamagiwa@hfce.info.hiroshima-cu.ac.jp

to car engine sound. In addition, we examined the physiological indexes of concentration with a race game.

In general, assessment of sound quality has been carried out using subjective psychological tests, such as the paired comparison method and the semantic differential (SD) method. The SD method has the advantage of multiple evaluation axes. In this study, we used the SD method as the subjective evaluation method. Meanwhile, objective tests measure physiological indicators, such as brain activity from an electroencephalogram (EEG), heart rate, body-surface temperature, skin electrical resistance, and respiration [2]. To conduct these physiological measurements simultaneously, it is necessary to pay attention to the burden on the participants. In an EEG, various electrode arrangements are defined according to the purpose or the measurement site, and it is difficult to handle them without medical personnel or knowledgeable persons [3]. In addition, if sweat or dirt adheres to the skin, skin conductance increases, and measurement precision falls. In a phonocardiogram, the heart sound is recorded only at a point, using a microphone or an electronic stethoscope. It is more robust to dirt and sweat on the body surface, and the burden on the participants is reduced by a few measuring points. Therefore, we employed the heart sound. However, the heart sound measurement is vulnerable to body movement noise. Therefore, we proposed a noise robust heart sound analysis method.

2. Improvement of the heart sound interval extraction algorithm

Even at rest, a heart rate interval changes continuously around its mean value. Neural mechanisms account for a part of this variability. Therefore, heart rate variability (HRV) analysis has been investigated as an index, to evaluate the balance between the autonomic nervous sympathetic and parasympathetic nerves.

2.1 Principle

In the previous method, we performed HRV analysis as follows:

・Extract the valve sound (1st sound/2nd sound) of the heart sound activity, using a low-pass filter from the recorded heart sound data.

・ Calculate heart sound intervals by extracting the interval of the 1st sound.

・Perform autoregressive (AR) and fast Fourier transform (FFT) analyses on the heart sound interval to find fluctuations of the cardiac cycle.

Low frequency (LF) components and high frequency (HF) components are defined as components between 0.05 to 0.15 Hz and 0.15 to 0.4 Hz, respectively. Sympathetic nerve activity is reflected in both the LF and HF components, whereas parasympathetic nerve activity is reflected only in the HF component. Generally, the HF component indicates the activity index of the parasympathetic nerves, whereas the ratio of LF/HF indicates the activity index of sympathetic nerves [4].

2.2 Conditions for possible errors

In the previous method [4], the components exceeded the threshold values for finding the first sound, which was extracted with a minimum separation interval of 0.5 s to calculate the heart sound interval. In this case, the heart sound interval could not be calculated correctly when the first sound was less than the second sound, as it was assumed that the reverse was the case. Moreover, the heart sound interval could not be calculated correctly in the presence of noise in the recorded sound. Therefore, we propose a calculation method using a wavelet.

2.3 Proposed method

In the proposed method for extraction, only the time change point in the heart sound was extracted using a wavelet. The proposed method is as illustrated below. First, the heart sound signal is analyzed by the wavelet and converted into an envelope of a power-waveform. At this time, the Morlet waveform was used as the mother wavelet. We choose ¼ or more of the sampling frequency from the amplitude of each frequency obtained by the wavelet, and obtain the sum of them. The power waveform was obtained by squaring the sum. The envelope was obtained by linearly interpolating all extreme values of the power waveform. Figures 1 and 2 show the waveform before and after the envelope. Then, the first and second sound peaks are extracted from the envelope. The heart sound intervals are calculated from the first sound, after which a trendgram is created by calculating the interval of the heart sound. The proposed method reduces noise, and the heart sound interval can be correctly extracted even under conditions where it would have conventionally been impossible. A comparison of the trendgrams from the conventional method and the proposed method is shown in Figure 3. As seen from the trendgrams, it can be confirmed that the pulse-like fluctuations of the cardiac cycle are reduced by the proposed method.

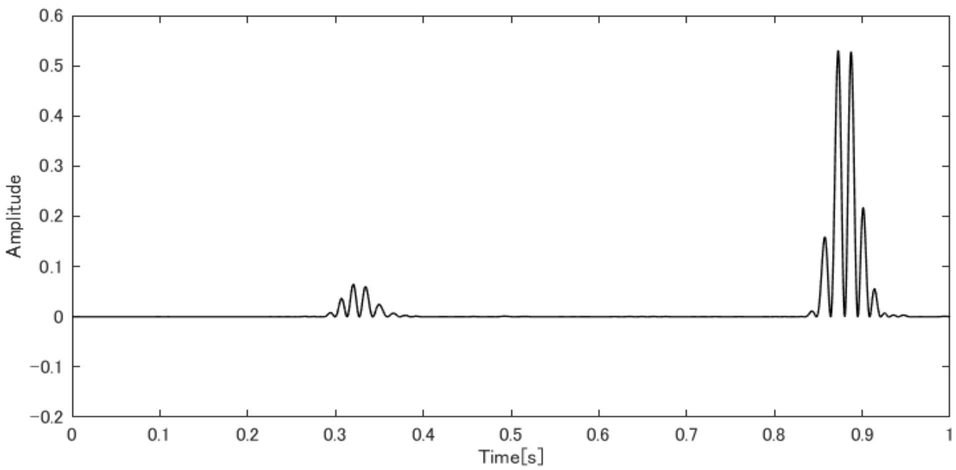

Figure 1: Waveform before envelope

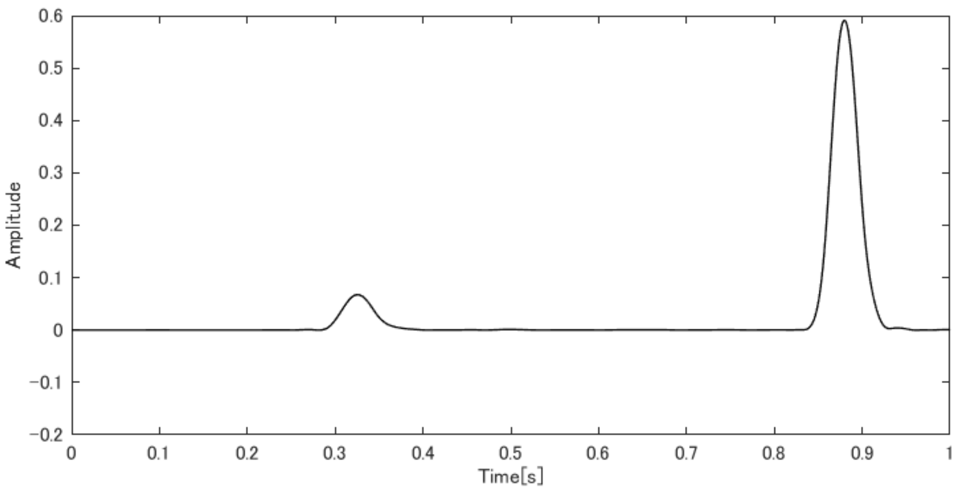

Figure 2: Waveform after envelope

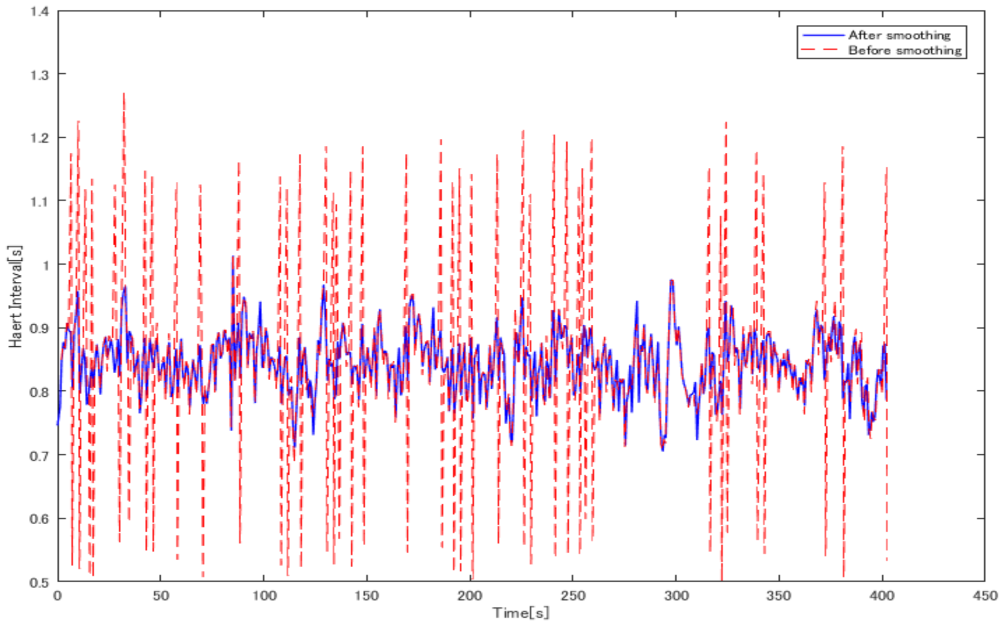

Figure 3: Comparison of trendgrams before and after envelope

3. Experiment of sound quality evaluation

We conducted an auditory test for five kinds of engine sound, and measured the physiological indexes using a driving simulator.

3.1 Experiment 1: Hearing impression evaluation

In experiment 1, we evaluated auditory impressions for the stimulus sound. The participants evaluated impressions from listening to five kinds of engine sounds using the SD method (seven methods). We used 14 kinds of adjective pairs selected from the previous research [5].

3.1.1 Participants

The participants were 22 healthy males (age: 21–24 years). We explained the purpose of our research to each participant and obtained their cooperation. They were classified as “driver who drives a car every day,” “rider who usually takes a motorcycle,” or “rarely–driver that does not usually drive a car.”

3.1.2 Apparatus

The participants were seated in the vehicle cabin of a driving simulator. The stimulus sounds were accelerated engine sounds recorded and processed from a real car. They consisted of processed engine sounds that were increased or decreased by only the 1st-order component, 1st- and 2nd-order components increased or decreased by 20 dB, and the originally recorded engine sound (Table 1). The stimulus sounds were presented through open-type headphones (HD 650, SENNHEISER Co.), and amplified using a headphone amplifier (HC6S, RANE).

Table 1: Stimulus sounds

Order component of the engine sound	Sound pressure
Original	±0 dB
1st-order components	+20 dB
1st-and 2nd-order components	+20 dB
1st-order component	−20 dB
1st-and 2nd-order components	−20 dB

3.1.3 Procedure

Participants performed all five trials. For each trial, participants listened to one type of stimulus sound when they stepped on the accelerator. The experimenter read out adjective pairs to them, and they evaluated each pair orally while driving on a virtual straight road. The stimulus sounds were presented even during the evaluation. They scored each element using 7 grades (+3, +2, +1, 0, -1, -2, -3).

3.2 Experiment 2: Evaluation using HRV analysis

In Experiment 2, we recorded the heart sound while the participants listened to the stimulus sound. The experimental environment was the same as in Experiment 1.

3.2.1 Participants

The participants were 10 healthy males (age: 21–24 years). We explained the purpose of the research to each participant, and obtained their cooperation and agreement for the heart sound recording.

3.2.2 Apparatus

Participants were seated in the vehicle cabin of the driving simulator, as in Experiment 1. The heart sounds were recorded around the fourth intercostal space left sternal border with the microphone.

3.2.3 Procedure

We asked the participants to be in a state of rest for 5 min, and then to operate the driving simulator for approximately 6 min. They drove on a straight road and performed five trials by changing the stimulus sound. The stimulus sounds were the same as those used in Experiment 1. We recorded the heart sounds of the participants at rest and while driving.

3.3 Data analysis

3.3.1 Factor analysis

Hearing impression evaluation was conducted using factor analysis. We used a maximum likelihood method for the analysis, and selected the varimax rotation. The adjective pairs can be divided into two- or four-dimensional groups with factor analysis. In this study, we decided to use three dimensions from the scree plot result.

3.3.2 HRV analysis

The recorded heart sounds were analyzed using the method proposed in chapter 2. We used the LF/HF change rate from rest time to operation time as an evaluation index for the sympathetic nerve. An increase in the change rate implies a feeling of excitement, whereas a decrease implies a feeling of relaxation. We analyzed the data obtained from each stimulus sound, and considered the relationship between the stimulus sounds and the factor analysis results.

4. Results of sound quality evaluation

4.1 Factor analysis

Table 2 shows the results of the factor analysis, whereas Figure 4 and Figure 5 show the scatter plot of each factor score. The following three parameters were obtained from the factor analysis: exciting factor, brightness factor, and response factor. The exciting factor included excitement, luxury, and sporty feelings. The brightness factor included brightness and the pitch of sound. The response factor refers to sound responsiveness. As the order components of the pressure level of the sound increased, the factor score of the exciting factor tended to increase too. Conversely, as the order components of the pressure level of the sound decreased, the brightness factor score tended to increase. The response factor did not correspond to any changes in the order of the pressure level of the sound. From the ongoing results, it was suggested that participants tended to feel excited when they heard amplified LF sound from the engine. From Figure 5, it can be confirmed that the score of the response factor is dispersed, regardless of the type of stimulus. In other words, it was suggested that the change of the order component had less influence on the responsiveness.

Table 2: Results of the factor analysis

Factor name	Adjective pair
exciting	Excited - Not excited
	Satisfying - Unhappy
	Expensive - Inexpensive
	Sporty feeling - Non-Sporty feeling
	Growing - Not growing
Brightness	Bright - dark
	High - Low
	Urban - Wild
	Positive - Negative
	Soft - Hard
Response	Good response - Bad response
	Good rise - Poor standing up

4.2 Results from the HRV analysis

The LF/HF change rate at rest and while driving through the simulator is shown in Figure 6 for each stimulus sound. As seen from the figure, the LF/HF ratios recorded during operation were lower than those while at rest, as the average values of each result were lower than 0%. Moreover, we confirmed that LF/HF approached 0% as the sound pressure level of the order components increased.

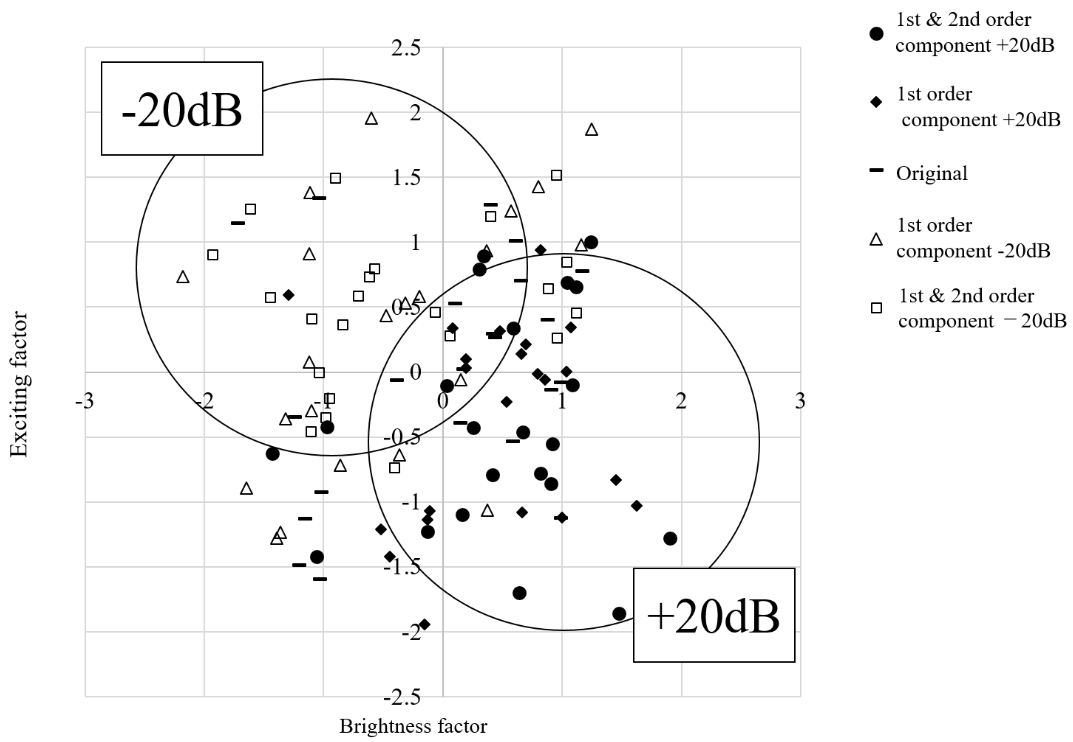

Figure 4: Exciting factor – Brightness factor scatter plot

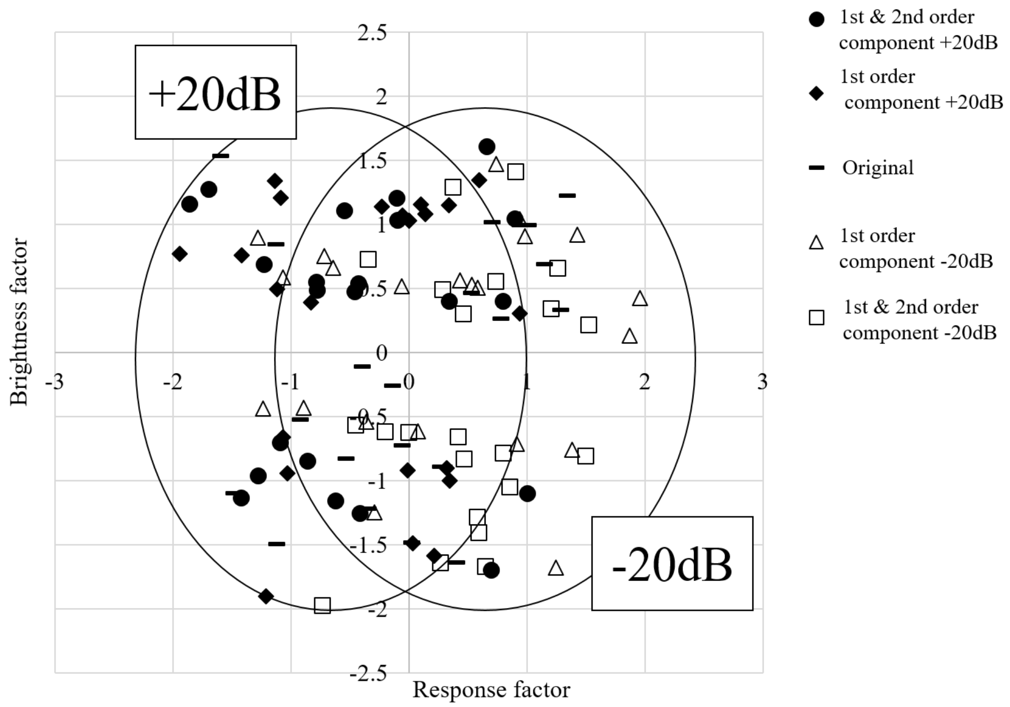

Figure 5: Brightness factor – Response factor scatter plot

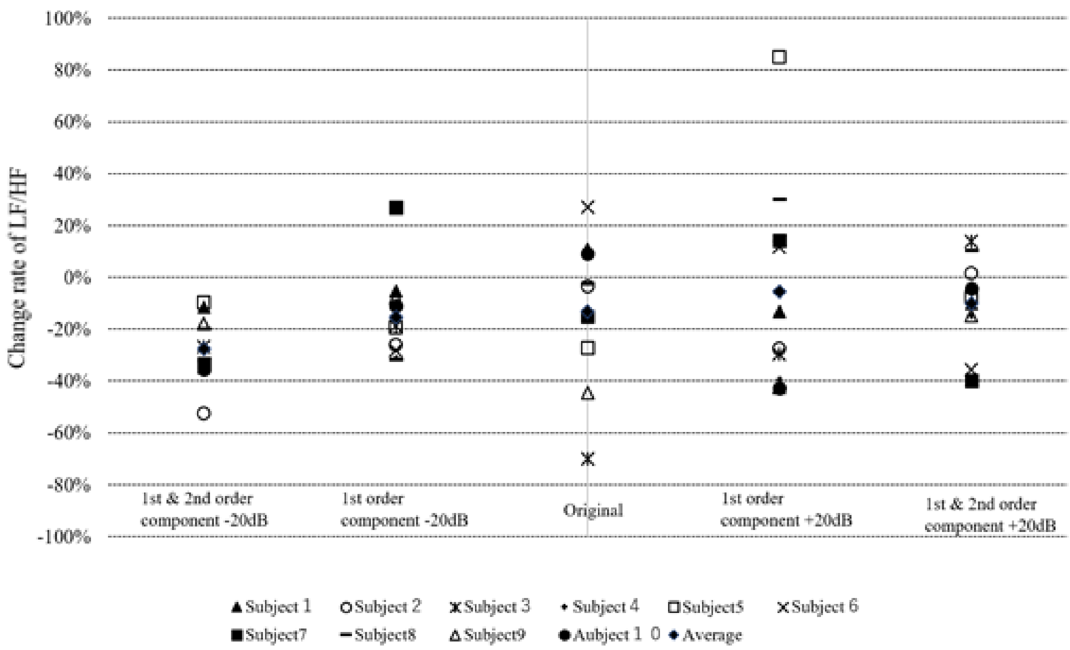

Figure 6: Results from the heart rate variability (HRV) analysis

5. Study of concentration state

To evaluate a concentration state from the HRV analysis, it is necessary to clarify heart activity regarding concentrating. In this case, a concentration state means a state of strong concentration at the expense of other things, e.g., forgetting about the time. For example, the state appears when competing in games and sports. Therefore, we analyzed the HRV while the participants were concentrating on the race game "Mario Kart." The purpose of this experiment is to clarify the physiological state of concentrating.

5.1 Participants

Nine healthy males (age: 21–24 years) participated in this study. We explained the purpose of the research to each participant, and obtained their cooperation and agreement for the heart sound recording.

5.2 Apparatus

The experiment was conducted in a soundproof room. The experiment environment is shown in Figure 7. The heart sounds were recorded around the fourth intercostal sternum edge with the microphone. We selected Mario Kart 8 (Nintendo) as the race game.

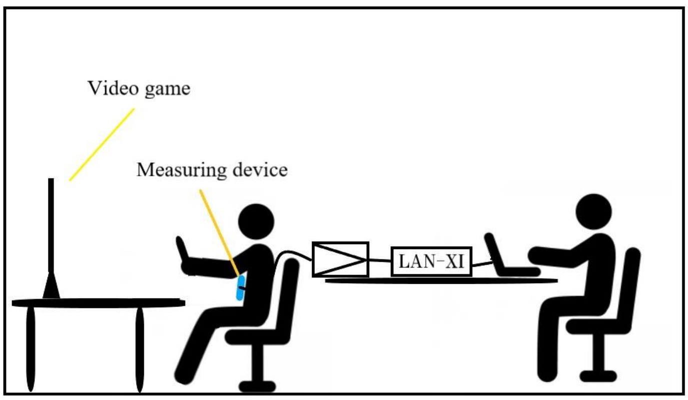

Figure 7: Experiment environment

5.3 Procedure

We asked participants to keep a state of rest for 5 min, and then to play the game for 3 min. We asked them to do these tasks twice. Participants could play the game with their favorite course and character for each. We recorded the participant's heart sound during these tasks, and analyzed the heart sound using the HRV analysis.

5.4 Experimental result

The LF/HF conditions for each task are shown in Figure 8. Each value shows the average of all participants. We compare the LF/HF rate in keeping in rest, and at playing the game. It is confirmed that the value of the LF/HF rate when playing the game becomes smaller than that at rest. Furthermore, the standard deviation when playing the game is also small. It was suggested that the LF/HF rate at a concentration state appears near 2.5.

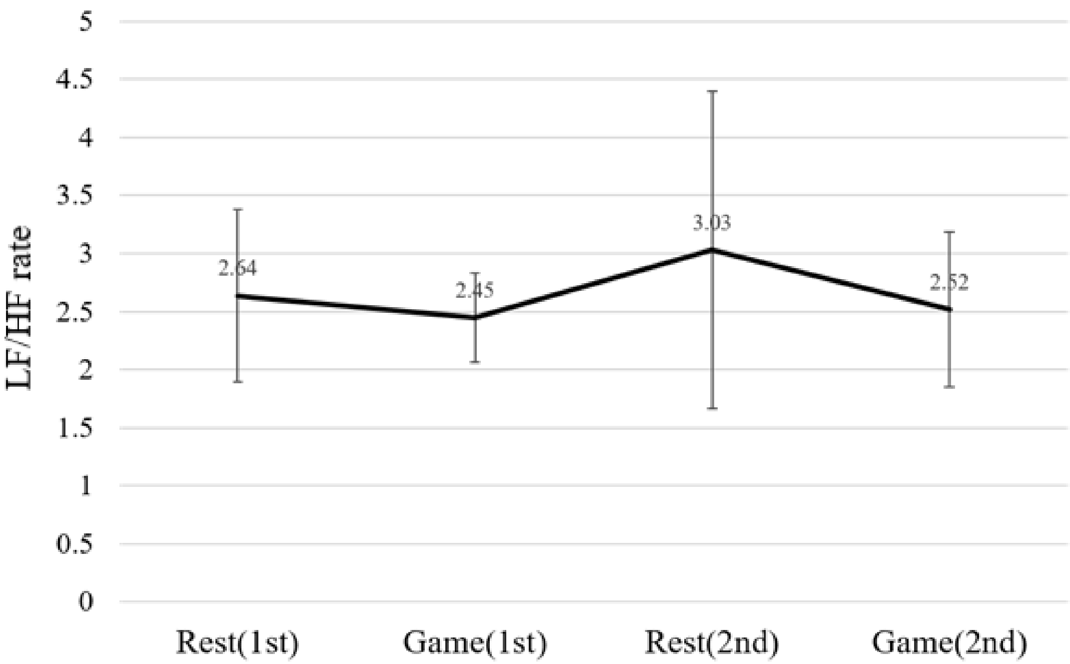

Figure 8: The low-frequency (LF)/high-frequency (HF) condition of each task

6. CONCLUSIONS

In this study, we introduced a wavelet for heart sound analysis to calculate the heart sound interval more accurately. Results from the HRV analysis suggest that the change in the sound pressure level of the order components affects the autonomic nervous system. Moreover, a factor analysis revealed that the LF/HF values under feelings of excitement tend to be almost the same as those under a state of rest. The results from Experiments 1 and 2 agree with the respective evaluation results from subjective and objective evaluation using the SD method and HRV analysis. Agreement between subjective and objective evaluations is important for sound design. Hence, it is believed that this method can be applied to automobile sound design. Additionally, we examined the physiological state of concentration. The LF/HF values when people are concentrating on the game were obtained by an HRV analysis experiment. It is expected that we can use the value of LF/HF as the evaluation index of concentration. However, this result is simply a case in point, and it is necessary that we investigate heart activity in various scenes.

7. REFERENCES

1. F. Obayashi, S. Ozawa, K. Kozuka, “A measurement of driver’s behavior and a proposal of evaluation index of driver’s concentration”, IEICE Technical Report, ITS2010-12(2010).

2. N. Iwabuchi, K. Oda, M. Suzuki, T. Tanaka, S. Nakamura, M. Koshiba, “A trial of visualization of individual psychological state based on neurophysiological dynamics. Correlation analysis between EEG, ECG, body-surface temperature and emotional dynamics.”, THE INSTITUTE OF ELECTRONICS, INFORMATION AND COMMUNICATION ENGINEERS, IEICE Technical Report TL2009-26 (2009-10)

3. K. Oue, S. Ishimitsu “Study on auditory impression evaluation using heartbeat sound”, Hiroshima city university Master's thesis, March 2016.

4. S.Watanabe, Y.Matsumoto, M Tomita, Y.Mori“Heart Rate Variability Analysis and the Subjective Evaluation by Visual Analog Scale for Subjects Listening 1/f Fluctuation Music”, Biomedical Fuzzy Systems Association,Vol15, No2, pp.1-10(2013)

5. K. Oue, S. Ishimitsu, M. Nakayama, “A STUDY ON SOUND QUALITY EVALUATION USING HEART RATE VARIABILITY ANALYSIS”, Proceedings of the 22nd International Congress on Sound and Vibration 470(Invited), 5 pages, Florence, Italy, from 12 to 16 July 2015.