A preliminary study to analyze the brain wave patterns during listening to comfortable and uncomfortable music by using a simple electroencephalograph

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Abstract

In this paper, the experiments were conducted to measure effect of music on brain waves and emotions with a simple brain sensor. 10 male university students participated in the experiments. They listened to four types of music (Comfortable music 1 and 2, Uncomfortable music 1 and 2). were used. Paired t-test on T-scores of POMS for each sound source before and after listening to the source showed a significant difference. The electroencephalography (EEG) was calculated and analyzed through signal averaging and FFT to compare component rates of δ, Θ, α and B waves. The results showed the Comfortable sounds tend to increase positive feelings. The value of Wave δ +θ+ α was high for Comfortable sound 1 (Wave δ + θ + α: Wave β = 63.7: 36.2) and Comfortable sound 2 (Wave δ + θ + α: Wave β = 61.2: 38.7).

Key words
psychological state, brain wave, EEG, POMS, FFT

1. Introduction

Our daily life is filled with various sounds and music. With the spread of portable music devices and smartphones, more people are listening to music while commuting to work or to school or on the street. In addition, there are sounds called environmental sounds, such as the sounds of cars and trains running, the sound of construction sites, and the sound of rain, and BGM (Back Ground Music) played in department stores and supermarkets. BGM improves work efficiency, brightens mood, and liberates mind (Yalch and Eric, 1990).

Department stores and restaurants use music that is appropriate for their business. Some stores use upbeat music to stimulate purchase (Matsui et al., 2003). More and more hospitals are using BGM to relax their doctors and patients and remove anxiety. When the tempo of music played in a store is reduced from about 100 beats per minute to 60 beats per minute, shoppers slow down their walking pace and the number of purchases increases by 30 to 40 %. (Shiwa et al., 2008). This is due to a calming effect from a tempo of one beat per second.

Givaudan, the world's largest fragrance manufacturer in Switzerland, uses EEG measurement to analyze the emotions unconsciously aroused when smelling a scent and the characteristics of scent that cannot be expressed in words (Hagiwara, 2013). The company combines the obtained data with subjective assessment data, such as questionnaire response and regional/cultural data, to build a mapping system for the relationship between scents, moods and emotions. It establishes a system that allows appropriate scents to be blended according to customer needs. Thus, more and more companies are applying new findings in brain science and psychology to their business activities.

Music is also used for medical purposes, especially for treating mental illness (Hinohara et al., 1998). Music therapy uses a wide variety of music to treat different types of illness. Music therapists have to select the appropriate music for the patient, but the selection requires a considerable amount of time. (Ogawa et al., 2007).

The purpose of this study is to clarify the relationship between brain activity, emotion and music. For the electroencephalogram measurement, a simpler and cheaper measuring device than the conventional device is used. Specifically, the measurement device used in this study is a non-invasive EEG measurement with a small number of channels, and measures EEG from two points on the forehead and one point on the ear. Conventionally, invasive measurement has been used for medical purposes and an electroencephalograph capable of recording and writing ink on about 24 channels, which is expensive, has been used for brain wave measurement. Further, the sampling rate is about 1,000 Hz in a normal electroencephalogram measurement apparatus, whereas it is 512 Hz in the simplified electroencephalogram measurement apparatus used in this study. Note that the filter characteristic is represented by a frequency response. If the same results as those of the conventional measurement device can be obtained in this experiment, it will be possible to substitute inexpensive and simple sensors in brain wave measurement in the future. It is hoped that this will lower the subject's restraint and make experiments on the brain more accessible to many, leading to further spread and development of brain science.

2. Related stduies

Kawakami and Kobayashi use healing music to investigate relationship between music and brain activities (Kawakami & Kobayashi, 2008). They employ the international 10-20 system for EEG measurement (Jasper, 1958). They confirmed that α-waves were induced by the music stimulation for every subject, although there were individual differences in EEG changes.

Matsui et al show that the strength of α-waves emitted was proportional to the degree of relaxation of the subject. (Matsui et al., 2003)

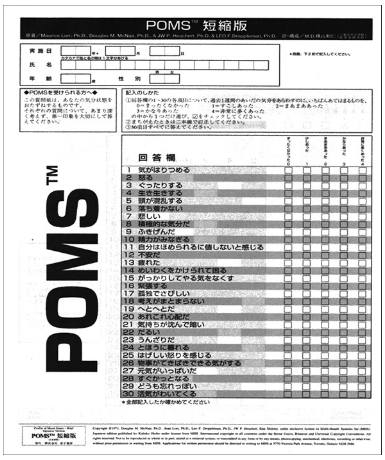
These studies used objective index for evaluating brain activities. However, both subjective and objective evaluations are necessary to understand psychological state of a person (Yokoyama et al., 2002). In this study, a psychological questionnaire survey called the Profile of Mood States (POMS) is used as a subjective evaluation, and the electroencephalogram (EEG) characteristics are measured as an objective evaluation to evaluate brain activity for emotion aroused by music stimulations.

3. Measurement methods

If it becomes possible to objectively evaluate the change in the psychological state given by music to humans, it is expected that more appropriate music effects will be obtained. Therefore, we propose to examine the EEG characteristics and psychological state when listening to comfortable sounds and uncomfortable sounds. The purpose is to clarify how listening to pleasant and unpleasant sounds affects the mood.

Specifically, the following steps are performed:

- Step 1: Select sounds to be presented to subjects (two comfortable sounds and two uncomfortable sounds).
- Step 2: Measure EEG characteristics (δ-wave, θ-wave, α-wave, β-wave) when listening to the presented sound using a simplified electroencephalograph.
- Step 3: Perform Fourier transform on the measured electroencephalogram data followed by evaluation based on frequency components.
- Step 4: Measure the psychological state (mood) using the shortened version POMS.



POMS™ 短縮版

実施日　年　月　日

氏名

年齢　歳　性別　男　女

◆POMSを受けられる方へ◆

この質問紙は、あなたの気分状態をおたずねするものです。それぞれの質問について、あまり深く考えず、第一印象を大切にして答えてください。

記入のしかた

①回答欄の1～30の各項目について、過去1週間のあいだの気分をあらわすのに、いちばんあてはまるものを、0=まったくなかった　1=すこしあった　2=まあまあった　3=かなりあった　4=非常に多くあった の中から1つだけ選び、☑をチェックしてください。

②まちがえたときは二本線で訂正してください。

③30項目すべてに答えてください。

回答欄

1 気がはりつめる
2 怒る
3 ぐったりする
4 生き生きする
5 頭が混乱する
6 落ち着かない
7 悲しい
8 積極的な気分だ
9 ふきげんだ
10 精力がみなぎる
11 自分はほめられるに値しないと感じる
12 不安だ
13 疲れた
14 めいわくをかけられて困る
15 がっかりしてやる気をなくす
16 緊張する
17 孤独でさびしい
18 考えがまとまらない
19 へとへとだ
20 あれこれ心配だ
21 気持ちが沈んで暗い
22 だるい
23 うんざりだ
24 とほうに暮れる
25 はげしい怒りを感じる
26 物事がてきぱきできる気がする
27 元気がいっぱいだ
28 すぐかっとなる
29 どうも忘れっぽい
30 活気がわいてくる

＊全部記入したか確かめてください

POMS™

Figure 1: POMS-Brief form Japanese version

The POMS is a scale to measure psychological state of a subject and the original version is composed of 65 item questions regarding mood state over past one week. In this paper, a shortened version with 30 items (POMS-Brief Japanese Version, Figure 1) is used. The reliability of the shortened version is similar to the original 65 item version (Yokoyama, 2005).

4. Experiments

4.1 Equipment

The device used in the experiment was a small simple electroencephalograph B3 (B-Cube) Band (BAK-004-J50/60, Manufacturer: B-Bridge). The sampling rate was 512 [Hz], and brain waves were measured from three points, two on foreheads and one reference electrode at the ear. Since it is a band-type sensor, the restraint of the subject and the physical stress to be given are considered to be smaller than the conventional type. This B3Band transmits the measured brain waves to a PC using Bluetooth, and converts the information into data in real time using a software called Neuro View. R language was used for data analysis. Before and after listening to each sound, the POMS was measured. When listening to sound, subjects wore earphones (AH-c260-K, Manufacturer: DENON). Figure 2 shows the B3Band device, and Figure 3 shows the state when the B3Band is attached to a subject.

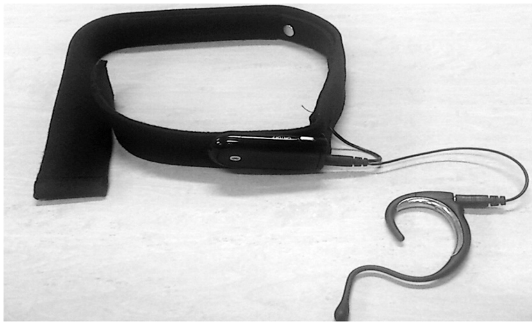


Figure 2: B3Band

Figure 3: State when B3Band is attached

4.2 Location and Subject

The experiment was conducted in the laboratory on the 7th floor of a building in University X. The subjects were 10 healthy male students aged from 21 to 22. The measurement was performed on weekdays for approximately one month. In order to reduce stress on the subjects, the measurement was done once a day. In total, each subject was asked to listen to four sound sources five times.

4.3 Sound source

Four types of sound source, two comfortable and two uncomfortable, were used in this study.

A music CD titled "Sleep deeply (McCraty et al., 1996) " containing 8 songs was used as a sound source considered to be comfortable. A questionnaire on these 8 songs was given to the subjects in order to select two most comfortable songs. As a result of the questionnaire, we adopted two songs titled "safe and sound" as comfortable sound 1and "midnight blue" as comfortable sound 2 according to the ranking.

As a study on uncomfortable sounds, Reuter and Oehler (2011) reported on the components of uncomfortable sounds such as sounds from scratching blackboards and rubbing styrofoam. When the subject listened to a sound excluding a specific frequency band or a sound excluding only a noise component, the degree of discomfort to the subject was evaluated. The result showed that the frequency band between 2,000 Hz and 4,000 Hz was most uncomfortable. We recorded two sound sources, "sound of scratching the blackboard (uncomfortable sound 1)" and "sound of rubbing the styrofoam (uncomfortable sound 2)", and used them in the experiment.

4.4 Measurement procedure

In order to unify the experiment conditions for each subject, measurements were performed on all subjects under the following conditions:

- Measurements were done in same time slot (2 p.m. - 4 p.m.)
- The subjects were asked not to do intense exercise on the day before or on the day of the measurement
- The subjects were asked to have enough sleep time (6 hours or more)
- The subjects were asked to have lunch from noon to 1p.m.

Figure 4 shows the measurement procedure.

The POMS was measured twice, before and after listening to the sound, to measure mood changes. After the first POMS, alcohol disinfection was applied to the subject's forehead and ears where the sensor and skin were in direct contact in order to reduce possible noises due to human sweat or sebum. After the disinfection, the subject wore the EEG sensor.

Before the measurement, each subject was allowed to adjust the volume according to his preference. The EEG is disturbed after the sensor is attached. Hence 30 to 60 seconds were spared to let the EEG stabilize. The subjects were asked to keep their eyes closed and not blink during the measurement in order to reduce unnecessary electrical signals generated by eye movements being mixed in the EEG sensor (Miyamoto et.al, 2007). After the stability of the EEG was visually confirmed, the measurement was conducted.

The brain waves were measured and recorded for a total of 6 minutes consisting of 180 seconds without sound and 180 seconds with sound. With sound and without sound were alternated repeatedly for 20 seconds in order to avoid habituation effect caused by continuously listening to the same sound (Hirasaw et al., 2010). After the measurement for 6 minutes was completed, the POMS was filled in again.

This procedure was conducted once a day for each subject.

4.5 Evaluation Method

For subjective evaluation, T scores were calculated from the POMS questionnaire. Specifically, the psychological states before and after listening to the sound source were evaluated using the six mood profile scales.

For objective evaluation, EEG was calculated and analyzed as follows. First, signal averaging method was applied to each EEG. Then FFT was applied to these average scores to calculate four components listed in Table 1. Finally, the scores were

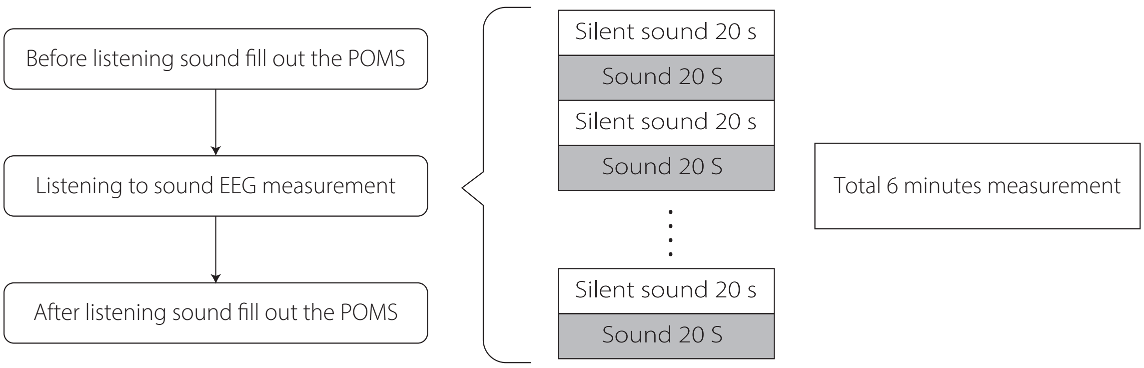


Figure 4: Measurement procedure

Table 1: EEG types

EEG types	Frequency	Mental state
Delta (δ) wave	0.5 Hz or more and less than 4 Hz	Deep sleep
Theta (θ) wave	4 Hz or more and less than 8 Hz	Light sleep
Alpha (α) wave	8 Hz or more and less than 13 Hz	Relaxed state
Beta (β) wave	13 Hz or more	State of daily life

normalized to compare rates of each component.

5. Experimental results

5.1 Results of the POMS

T-scores were calculated for each sound source, and the scores before and after listening to the sound source were verified for a significant difference by paired samples t-test. Figures 5 to 8 show the results.

- T-score differences before and after listening to Comfortable sound1 were statistically significant for all 6 items, with 5 items out of 6 showing 5 % significance level.
- T-score differences before and after listening to Comfortable sound 2 were significant in three items (Tension/Anxiety, Depression/Dejection, and Confusion). Tension/Anxiety showed a significance level of 1 % and the other two items showed a significance level of 5 %.
- T-score differences before and after listening to Uncomfortable sound 1 were statistically significant in two items (Anger/Hostility and Vigor). Increases in Anger/Hostility scores showed a significance level of 1 % and decreases in Vitality scores showed a significance level of 5 %
- T-score differences before and after listening to Uncomfortable sound 2 showed no significant differences in all 6 items.

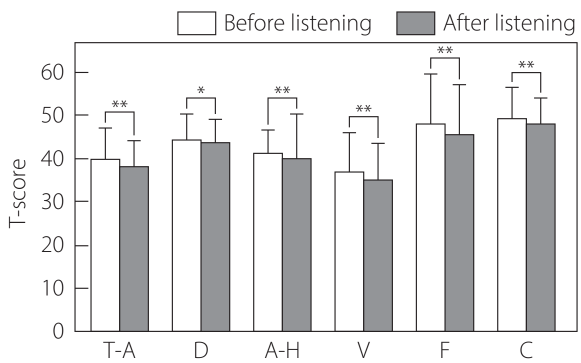


Figure 5: T-scores of comfortable sound 1

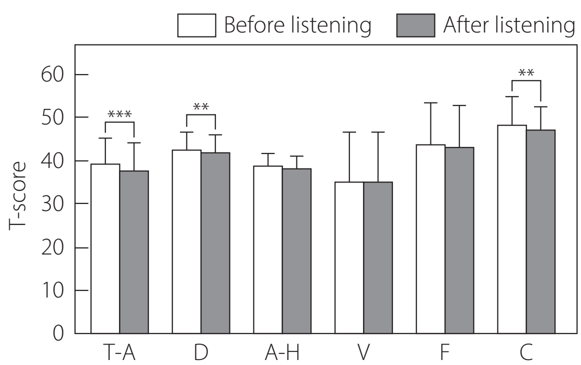


Figure 6: T-scores of comfortable sound 2

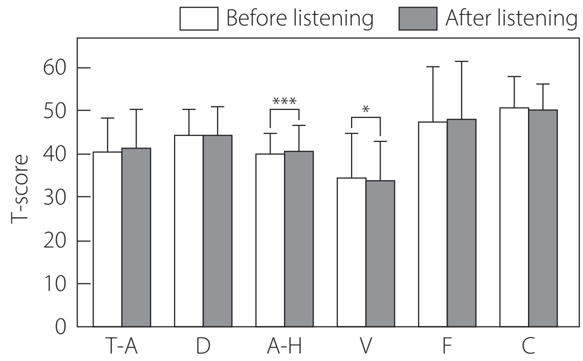


Figure 7: T-scores of uncomfortable sound 1

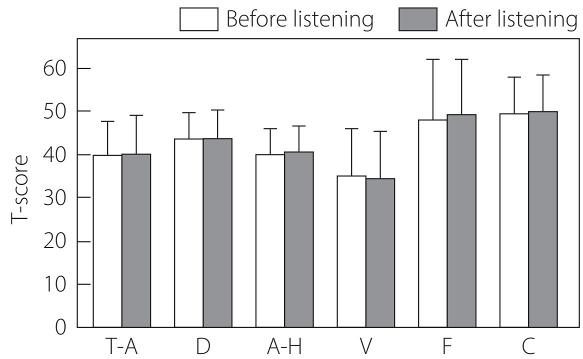


Figure 8: T-scores of uncomfortable sound 2

Both the Comfortable sounds 1 and 2 showed a decrease in T-scores for negative items, suggesting the sounds had the effect to calm down subjects' emotions. Uncomfortable sound 1 was confirmed to increase T-scores of Anger/Hostility. Uncomfortable sound 2 showed no significant difference in all six items. However, T scores for the negative items increased and those for the positive items decreased as in the case of Uncomfortable sound 1. The difference between Uncomfortable sounds 1 and 2 can be caused by a habituation effect by repeatedly listening to similar uncomfortable sounds during the experiment.

5.2 Results of EEG

Figures 9 to 12 show the ratio of each frequency component of the brain wave during listening to the sound sources. Figure13 shows differences of brain waves ratios between

Comfortable sounds and Uncomfortable sounds.

The results of comparing each sound source based on each frequency component are as follows:

- The content rates of δ-waves were higher in Comfortable sounds 1 and 2 than in Uncomfortable sounds 1 and 2. This shows that while the former has an effect of inducing sleep and relaxation, the latter has no similar effect.
- The content rate of θ-waves was higher in Comfortable sound 1 than in Uncomfortable sound 1. This wave is often observed during a light sleep. Therefore, Comfortable sound 1 can be said to have relaxation effect. On the contrary, Uncomfortable sound 1 is not much affected by the mental state. Since there is almost no difference between the comfortable sound 2 and the uncomfortable sound 2, it is considered that an individual has changed.

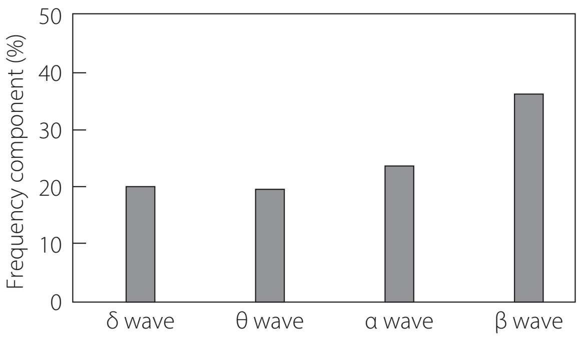


Figure 9: Frequency component in Comfortable sound 1

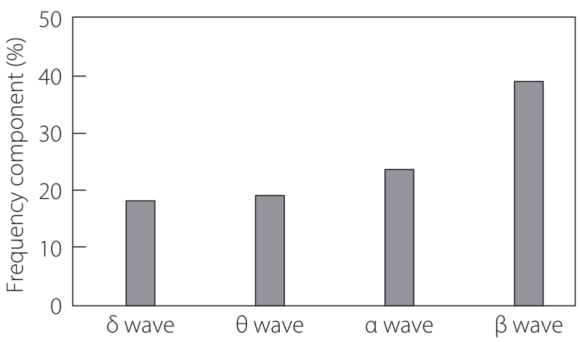


Figure 10: Frequency component of Comfortable sound 2

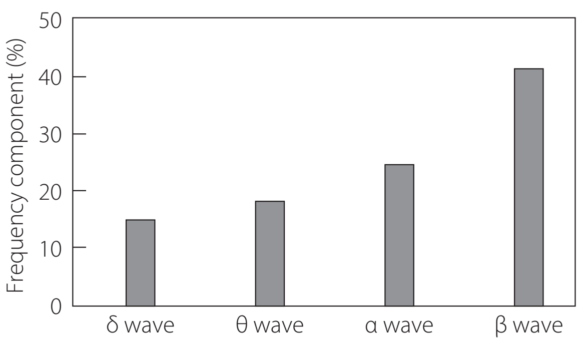


Figure 11: Frequency component of Uncomfortable sound 1

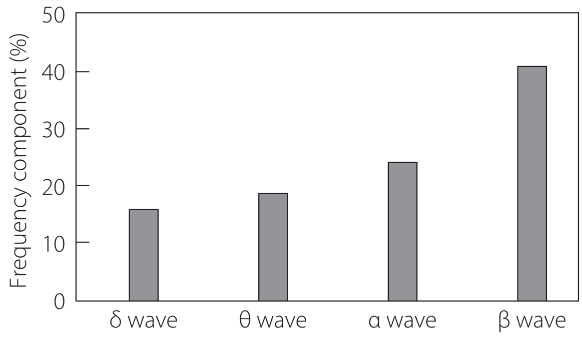


Figure 12: Frequency component of Uncomfortable sound 2

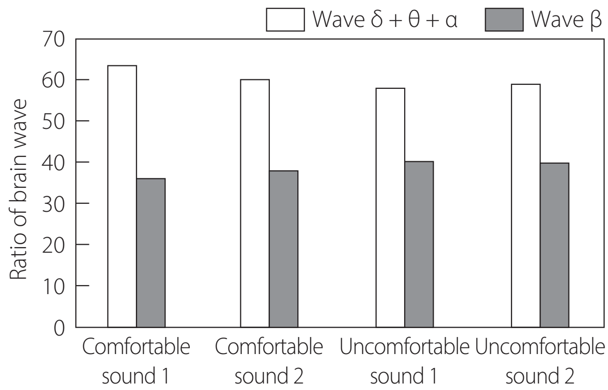


Figure 13: Ratio of brain wave between comfortable sound and uncomfortable sound

- The content rates of α-waves were high in all the four sound sources. Since Comfortable sounds 1 and 2 are music that has a relaxing effect, the subjects were considered to be comfortable or in calm state. This could be one reason why α-waves were strongly emitted (Matsui et al., 2003). However, the subjects emitted α-waves even after listening to Uncomfortable sounds. Some subjects told after the experiment that they get used to the sound and feel less uncomfortable since they had listened to uncomfortable sounds several times during the experiment. This habituation effect can be one cause for relatively high contents rate of α-waves during listening to Uncomfortable sounds.
- The content rates of β waves were higher in Uncomfortable sounds 1 and 2 than those in Comfortable sounds 1 and 2. After listening to the Uncomfortable sounds, the subjects felt uncomfortable as shown in the increase in Tension/Anxiety and Anger/Hostility scales in the POMS results.
- The combined ratio of the δ, θ, and α-waves (Wave δ + θ + α), which are observed in sleep / relaxed state, was compared with the ratio of the β-waves (Wave β), which are observed in daily life. The value of Wave δ + θ + α was high for Comfortable sound 1 (Wave δ + θ + α: Wave β

= 63.7: 36.2) and Comfortable sound 2 (Wave $\delta + \theta + \alpha$: Wave β = 61.2: 38.7). However, the value of Wave $\delta + \theta + \alpha$ was low for Uncomfortable sound 1 (Wave $\delta + \theta + \alpha$: β wave = 58.7: 41.2) and Uncomfortable sound 2 (Wave $\delta + \theta + \alpha$: Wave β = 59.4: 40.5). The result shows Comfortable sound sources used in the experiment had relaxing effects on the subjects.

6. Conclusions and future directions

In this study, we conducted an experiment using a simple electroencephalograph to clarify the effects of listening to sound on psychological states changes. To measure the changes, the simplified POMS was used as a subjective evaluation method and EEG was used as an objective evaluation method.

Regarding the POMS results, the Comfortable sounds 1 and 2 and the Uncomfortable sound 1 showed significance differences in T-scores between pre- and post- listening measurements. However, Uncomfortable sound 2 showed no significance difference. Despite the small experiment with 10 subjects, good results were obtained from the three sounds.

With regard to brain waves compositions, signal averaging was calculated and frequency components were derived from each sound stimulus. The values of Wave $\delta + \theta + \alpha$, which are observed in sleep/relaxed state, were higher in Comfortable sounds 1 and 2 than in Uncomfortable sounds 1 and 2 and the values of Waveβ, which are observed during daily activities, were higher in Uncomfortable sounds 1 and 2 than in Comfortable sounds 1 and 2.

In this study, we used a simple electroencephalograph to analyze the brain wave patterns during listening to comfortable and uncomfortable music. However, the results of EEG were not conclusive, especially regarding α-wave. In our experiments, Uncomfortable sounds increases α-wave, which is considered to have relaxing effects. This discrepancy can be resolved when investigating α-wave in more detail. Specifically, the wave can be subdivided into $\alpha 1$, α slow component, and $\alpha 2$, α fast component (Ishikawa et al., 2012). $\alpha 1$ responds specifically to changes in stress. A future direction of our study is to incorporate the subdivision so that the influence of the sound on the change in the psychological states of a person can be objectively grasped.

Another direction is to enhance validity and reliability of the experiments using simplified electroencephalograph. Since brain wave changes differ between gender and among individual. Hence the number of participants, especially female, should be increased. The comparison of the results should be conducted between the experiment using an advanced electroencephalograph and the one using the simplified electroencephalograph proposed in this paper.

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