An EEG study on music listening with ICA approach
独立成分分析手法を用いた音楽鑑賞における脳波研究

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***Abstract*:** Music listening is one of the most popular and convenient entertainment method for human beings. When listening to music, people can get relaxed by soothing music or become excited by rock music. As we know that mental feelings are generated by the human brain, studying the human brain activities when they are listening to music may reveal the mechanism of mental processes for generating these feelings. In this paper, we conducted experiments to measure the brain activities when the subjects were listening to classic music, using a portable EEG (Electroencephalogram) system. The EEG data were analyzed using ICA (independent component analysis) approach. Occipital alpha band, frontal midline theta band, occipital-temporal or frontal beta band activities were observed in the experiments. These experimental results suggest that the subjects were under a relaxed condition when they were listening to classic music with their eyes closed. At the meantime, they engaged in the music listening and enjoyed the music with imagery or memory recalling.

***Keywords*:** EEG (electroencephalogram), ERP (event-related potential), ICA (independent component analysis), music listening

要旨 ： 音楽鑑賞はさまざまな娯楽活動の中でも、もっとも容易で広く享受されている娯楽活動である。癒し音楽は聴く者の心をリラックスさせ、ロック音楽は聴く者を興奮した気分にさせる。人間の感情は脳内で生み出されるので、音楽鑑賞する際の脳活動を研究することで、そうした感情が生起する過程や仕組みの解明につながる可能性がある。本研究では、携帯型脳波計を用いてクラシック音楽を聴いている際の被験者の脳活動を計測し、その EEG データを収集、さらに独立成分分析手法を用いてデータ分析を行った。その結果、後頭部のアルファ波、前頭正中線シータ波、側頭または前頭部のベータ波が観測された。これらの実験結果から、閉眼でクラシック音楽を鑑賞しているときには、被験者の心はリラックスしていると同時に、音楽に集中し、想像や想起などを伴いながら音楽を楽しんでいることが推察される。

***キーワード*:** EEG、脳波、事象関連電位(ERP)、独立成分分析(ICA)、音楽鑑賞

1. Introduction

Music listening is one of the most popular and convenient entertainment method for human beings. When listening to music, people can get relaxed by soothing music or become excited by rock music. Why can music have such a power to influence people's feelings? As it is known that the brain activities determines the behaviors and feelings of human, understanding the brain activities when listening to music will be an effective way to reveal the power of music on peoples' affective feelings. Several researches have been conducted to study the brain activities on music listening (Adamos, D., et al., 2016, Poikonen, H., et al., 2016, Daly, I., et al., 2014, Jatupaiboon, N., et al., 2013, Lin, Y. P., et al., 2010), where the happiness or emotion related to the music listening was detected using neural networks based on EEG. In the research by Jatupaiboon group, besides of the music stimuli, the subjects also watched the visual stimuli when they were listening to the music (Jatupaiboon, N., et al., 2013). In the research conducted by Lin group, multimedia stimuli were presented (Lin, Y. P., et al., 2010). Different from these researches, we conducted experiments using audio stimuli only, without any other types of stimulus added upon them. The experimental results focusing on the event-related potential (ERP) analysis of EEG data were reported (Zhang, Q. & Yoshimine, N., 2015). In this paper, we analyze the data using the independent component analysis (ICA) approach. The independent components of the brain activities are examined in several typical frequency ranges.

2. EEG Data Analysis Methods

The EEG data are the potentials recorded on the scalp. These potentials are regarded as the reflection of neuron activities. It is known that human brain consists of billions of neurons. When human beings perform cognitive or/and motor tasks, neurons produce spikes of voltage to form electrical pulses travelling in the brain. These electric currents produce the potentials on the scalp. EEG measurement is the method to record these potentials over time by the electrodes placed on the scalp. By analyzing these EEG data, the corresponding brain activities can be inferred. There are several methodological approaches to analyze EEG data (Makeig, S., et al., 2004). Among them, ERP and ICA approach are the two of the most popular analysis methods.

ERP analysis method focuses on the potential changes of EEG data that are elicited by the sensory, motor or cognitive events. The EEG data corresponding to the specific events are extracted from the continuous recordings as the epoch data. ERPs can be obtained by averaging a series of epoch data for the same type of events. The averaging process are assumed to remove the spontaneous potentials with various phases, which are not related to the cognitive or motor events. ERPs are calculated on single electrode (also called single channel) basis. Researches on ERPs usually examine the potential changes at certain latency range, such as 100 ms or 200 ms after the stimulus was presented (Poikonen, H., et al., 2016)

On the other hand, ICA approach presupposes that the EEG signals are the summation of the postsynaptic potentials produced when a large number of similarly oriented cortical neurons fire in synchrony. ICA decomposes EEG data based on a spatially transformed component basis (Onton, J. & Makeig, S., 2006, Makeig, S. & Onton, J., 2011). Instead of examining a single channel data, the whole multi-channel data are processed together using spatial filters. In the ICA decomposition, the independent component filters are chosen to produce the maximally temporally independent signals available from the channel data. These are, in effect, information sources in the data recorded at the scalp channels. By this means, ICA identifies the distinctive information sources which are independent of each other. In addition, ICA also can separate the sources of artifacts which are not related to the brain activity at all, such as those from eye-blinks, breathing, heartbeat, or 50 Hz line noise. In summary, ICA is an effective method for removing artifacts and separating sources of the brain signals.

In the authors' previous work (Zhang, Q. & Yoshimine, N., 2015), ERP analysis was conducted on the EEG data. But the ERP results were lack of repeatability due to the limitation of current portable system, and the data was contaminated by artifacts. Therefore, in this paper, we apply ICA to analyze our experimental EEG data measured to remove the artifacts and examine the independent components of the brain activities when the subjects were listening to classic music.

3. Experiment Methods

The EEG data used in this paper are from the same experiments reported in the authors' another paper (Zhang, Q. & Yoshimine, N., 2015). The experimental conditions and analysis methods are described as the follows.

3.1 Experiment apparatus

A portable EEG system of Emotiv EPOC (Emotiv Inc., 2014) was utilized in our experiments. It is a wireless EEG system and able to be applied for researches in entertainment, market research, usability testing and neuro-therapy. This system has 14 channel electrodes and is the first commercial EEG measurement device not employing dry sensor technology. The electrodes are located at the positions of AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4, according to the international 10–10 system (American Electroencephalographic Society, 1991).

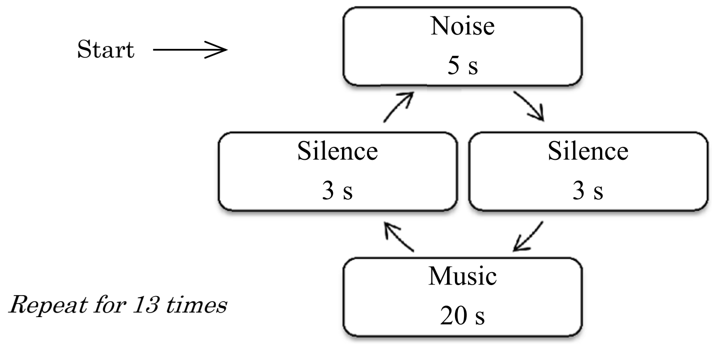


Fig. 1: Stimulus sequence in one experiment session

3.2 Experiment stimuli and data acquisition

During the experiments, subjects listened to the audio stimuli with their eyes closed. The audio stimuli consisted of 13 types of music clips, 6 types of noise clips and silence clips. The music clips were cut from 13 pieces of classic music, and lasted for 20 seconds. Each music clip was played once in one experiment session. As the contrast stimulus, 6 types of noises were created, and each were repeated twice except for one type, which was repeated for three times. Each noise clip lasted for 5 seconds. All these music clips and noise clips were presented randomly during an experiment session. Between every music and noise clips, a 3 second silence clip was inserted. Figure 1 shows the stimulus sequence in one experiment session.

The EEG data were acquired when the subjects were listening to the audio stimuli described as the above. An Emotiv EPOC headset was mounted on the subject's head, and the contact quality of the electrodes was adjusted so as to get good signals. During the data acquisition, the subjects were sitting on a chair in a comfortable way. They wore the stereo earphones, and were asked to concentrate on the sound stimuli with their eyes closed and be quiet without body movements. The EEG data collected by the emotiv EPOC were sent to a PC via the wireless connection. Three subjects participated in the experiments. One subject was measured for 3 experiment sessions, and two subjects for 2 sessions. Each subject took part in only one session one day, and the multiple sessions for each subject were measured in different days.

3.3 Data analysis

After the EEG data were acquired from the experiments, we analyzed the data using the open source software EEGLAB (Delorme, A. & Makeig, S., 2004). First, the pre-processing was conducted. A high-pass filter with the lower edge of the frequency as 1 Hz and a low-pass filter with the higher edge of the frequency as 40 Hz were applied to the EEG data. After that, epochs of the music listening were extracted from the entire EEG data. In addition, the mean baseline value during the time range of one second ahead of the stimulus was removed. Then the ICA was applied to the EEG epoch data. Because the number of the subjects and sessions is small, the group analysis may not bring about effective results. Hence, we analyze the EEG data for each subject and session respectively.

4. Results and Discussions

4.1 Experimental results

Figure 2 shows the scalp map of the ICA components after the ICA processing for Subject A. Fourteen components were plotted with their scalp map projection. The scale uses arbitrary units. Among them, there were independent components (such as IC1, IC2, IC4, and so on) from the brain activities, as well as components (such as IC6) due to artifacts.

When we examined the properties of each independent component (IC), it is found that IC2, IC5, IC13 and IC14 showed a clear peak at the frequency of 8 Hz in the power spectra, located in the range of alpha rhythm (8-13 Hz). As a representative, the details of the properties for component IC2 are shown in Fig. 3 (a). The top left figure is the topoplot showing the component values across the scalp. The top right figure is the decomposition of the signal in the experiment session, which shows in which trial the component is more evident. The bottom figure shows the power spectrum of the component. In Fig. 3 (a), we can see that the alpha oscillations are spread in all the trials from the right top figure of the component activities, and a clear peak at 8 Hz in the range of alpha band from the bottom spectrum figure. The positive potentials are located in the occipital areas of the brain from the left top topoplot.

Besides of the alpha band activities, it is also found that there was a peak appeared at about 6 Hz in spectrum for component IC1, IC4, IC9, and IC12 of subject A. The peak is located in the range of theta rhythm (4-7 Hz). The details of properties for IC4 is shown in Fig. 3 (b). The positive potentials are located in the frontal midline areas of the brain.

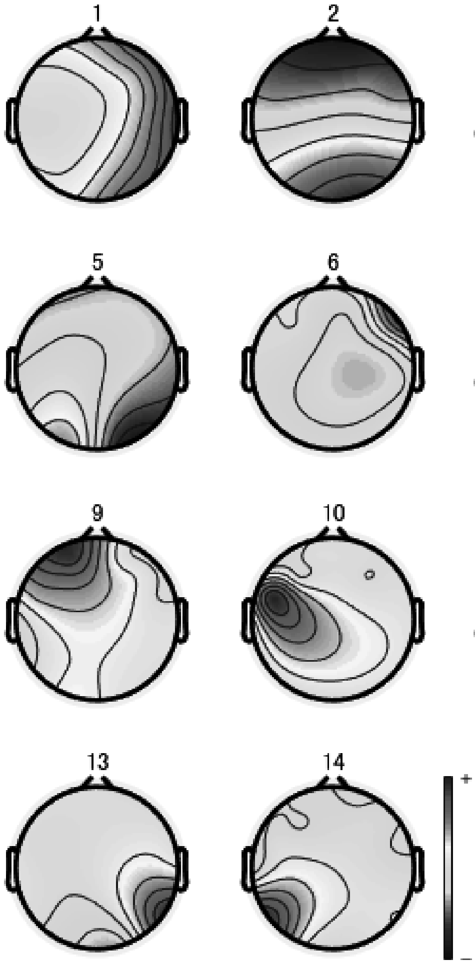
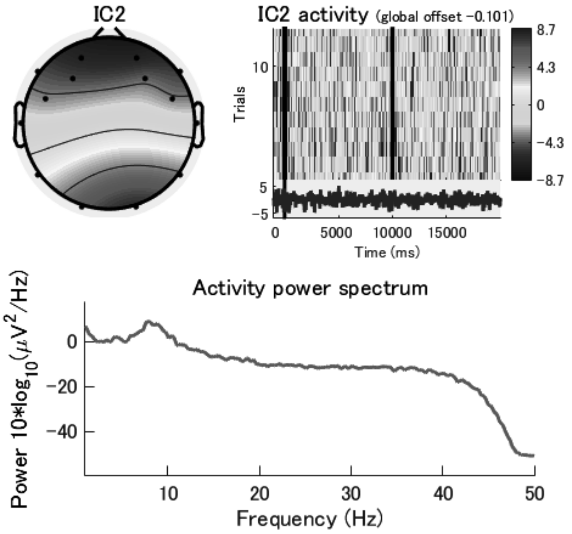
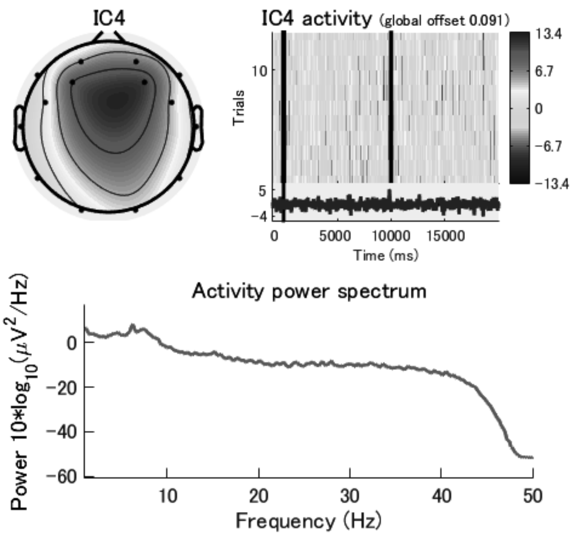


Fig. 2: 2-D scalp maps for 14 components from ICA processing of Subject A.

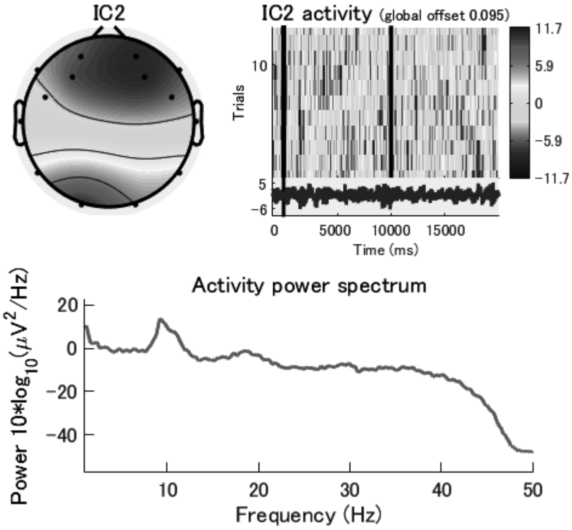


(a)

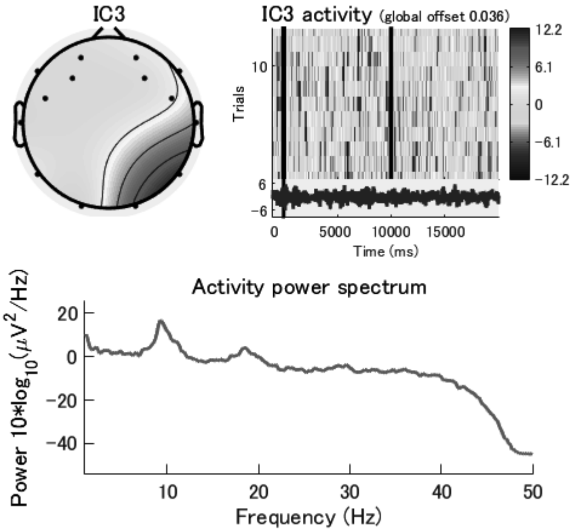


(b)

Fig. 3: Properties of the independent components for Subject A. The top left figure is the topoplot showing the component values across the scalp. The top right figure is the decomposition of the signal in the experiment session, which shows in which trial the component is more evident. The bottom figure shows the power spectrum of the component. (a) Properties of the independent component IC2. (b) Properties of the independent component IC4.

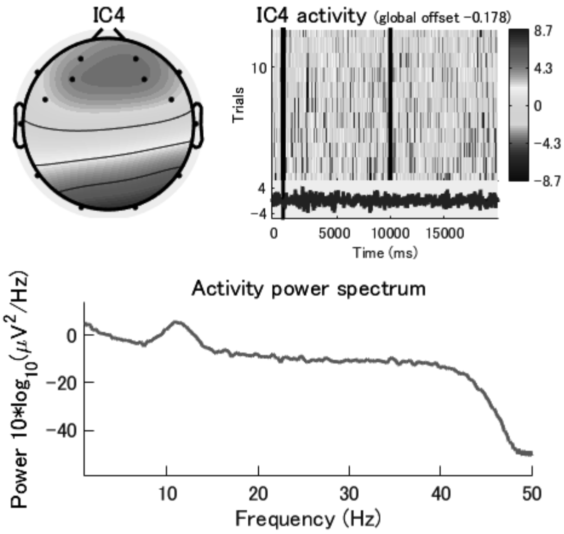


(a)

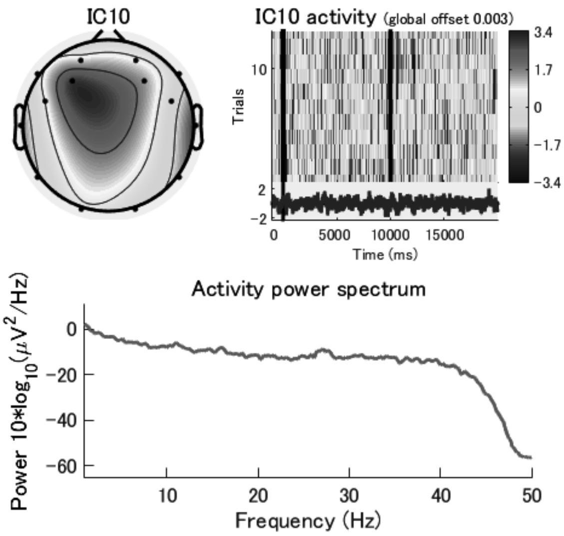


(b)

Fig. 4: Properties of the independent components for Subject B. The top left figure is the topoplot showing the component values across the scalp. The top right figure is the decomposition of the signal in the experiment session, which shows in which trial the component is more evident. The bottom figure shows the power spectrum of the component. (a) Properties of the independent component IC2. (b) Properties of the independent component IC3.



(a)



(b)

Fig. 5: Properties of the independent components for Subject C. The top left figure is the topoplot showing the component values across the scalp. The top right figure is the decomposition of the signal in the experiment session, which shows in which trial the component is more evident. The bottom figure shows the power spectrum of the component. (a) Properties of the independent component IC4. (b) Properties of the independent component IC10.

Similar to Subject A, a peak around 10 Hz located in alpha rhythm range was also observed for Subject B (Fig. 4 (a) and (b)). The positive potentials are distributed in the occipital brain areas. Besides of the alpha waves, another weaker peak was observed at about 19 Hz (Fig. 4 (a) and (b)), which belonged to the low beta band rhythm (Kropotov, J., 2008). In Fig. 4(b), the peak is a little more remarkable, and the positive potentials are located from the occipital areas to the temporal areas of the brain.

For Subject C, the alpha rhythm peak was also observed (Fig. 5(a)). The positive activities are located in the occipital brain area which is the same as that for the other two subjects. However, the obvious peaks of theta wave or beta wave around 20 Hz were not observed. Instead, a small peak at the frequency about 27 Hz was observed (Fig. 5(b)), which is located in the high beta band (Kropotov, J., 2008). The positive activities of this high beta frequency are distributed mainly in the frontal brain areas.

4.2 Discussions

From the above experimental results, we can see that occipital alpha rhythm, frontal theta rhythm, occipital-temporal or frontal beta rhythm were observed in the subjects' brain activities when they were listening to music.

These frequency ranges have been studied for decades. Alpha rhythms (8-13 Hz) usually appear in normal adults during wakefulness, under relaxation and mental inactivity conditions. They are best seen with eyes closed, most observed in the occipital locations (Kropotov, J., 2008). In our experiments, alpha band activities were observed. It confirmed that the subject were under relaxed mental conditions. Because the subjects closed their eyes when they were listening to the music, the contributions from the music listening or eye closing need to be clarified further in future work.

Theta band is the frequency band from 4 to under 8 Hz. Theta activity is usually observed with a maximum amplitude around the frontal midline. It is usually observed under the state of a dream, vivid imagery. A research on auditory and visual working memory (Kawasaki, M., et al., 2010) reported that both alpha and theta activities increased during the working memory tasks. In our study, the music stimuli were the famous classic music, and they may be familiar to subjects. Hereby, we may assume that the theta rhythm observed in one subject's brain activities may be related to the working memory process when the subject recalled of the related memory of the music stimuli or enjoyed the music with imagery.

In addition, beta band is a band between 13-30 Hz, which can be divided into smaller categories: low beta band from 13 to 21 Hz and high beta band from 21 to 30

Hz. Beta rhythm is usually associated with focused attention, active thinking. Low-beta is related to high engagement and high beta is related to complex thought, integrating new experiences, high anxiety, or excitement. In our experiments, the beta peaks appeared in two subjects' brain activities. It implied that the subjects were engaged in the music listening during the experiments. To reveal the details of the relations between the mental conditions and these beta activities, further studies involving psychophysical questionnaire survey are necessary.

Finally, in our experiment, the number of the subjects and trials are small. It is necessary to increase the number of subjects and sessions to make the experimental results more credible in future work.

5. Conclusions

In this paper, we studied the brain activities when the subjects were listening to music. A 14 channel portable EEG system (Emotiv EPOC) was used in the experiments. The independent component analysis was applied to the measured EEG data. From the experimental results, occipital alpha band activities were observed in all subjects' brain activities. In addition, the frontal midline theta band, occipital-temporal or frontal beta band activities were observed in some subjects. These results suggest that the subjects were under a relaxed condition when they were listening to the music with their eyes closed. At the meantime, they engaged in the music listening and enjoyed the music with imagery or memory recalling. Further work is in plan to increase the number of subjects and sessions to make the experimental results more credible.

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