The Effect of the Audio Signals on the Brain for EEG-Based Attentiveness Recognition

Jiaming Cai, Pinzhen Chen, Yunyang Yuan, and Zecheng Li

Abstract Nowadays, people are living in a world filled with all kinds of voice and noise. However, when trying to focus on work, the external noise and sounds will interrupt and prevent us from concentrating, thus, this paper investigates the neural activities related to the working attentiveness by using EEG (electroencephalography). The purpose is to use the collected data to build an EEG-based BMI (brain-machine interface) to detect which kind of noise is distracting the person and then use this information to shield the correlated noise or create another kind of audio to cancel the noise. Our work indicates that the level of people concentrating on their work will decrease rapidly when the outside noise reaches a certain level. And with the help of technology, it is able to detect the changes of people's attentiveness and then choose whether to block the outside noise to increase the level of attention.

Keywords Brain-machine interface (BMI) · Electroencephalography (EEG) · Alpha wave · Beta wave · Attention

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C.-C. Wang, A. Nallanathan (eds.), *Proceedings of the 5th International Conference on Signal Processing and Information Communications*, Signals and Communication Technology, https://doi.org/10.1007/978-3-031-13181-3_3

1 Introduction

1.1 Brain-Machine Interface and EEG

Brain-machine interface (BMI) is a relatively burgeoning technology that links the human brain with outside equipment to enable users to communicate or control the external equipment by using stimulated signals [1]. Our brain-machine interface analyzes the signals collected by electroencephalography (EEG), which records the neural activity and transfers them to visible figures to determine what command should be executed next to complete the purpose.

1.2 Attention

As we all know, the external sound and noise will affect human beings, including their emotions, activities, and attention. Humans' attention can be affected by different sound frequencies, which can be analyzed by EEG. There are research about the effects of classical music on people's attention through EEG technology, and there is a well-known phenomenon called the "Mozart effect" [2].

Our goal is to show participants' attentiveness by analyzing EEG signals and to find the appropriate periods of frequency of audio signals to be blocked. Thus, people can enhance their level of attention without the external noise and become more efficient on their tasks.

Most of neural activities emitted from our brain can be transformed into the form of EEG signals. After amplifying and filtering the raw EEG signal into different frequencies, one can access humans' attentiveness. There are several basic types of brain waves which are called alpha, beta, delta, and theta waves. Alpha waves range from 8 Hz to 14 Hz, and it only occurs when individuals are highly calm. People who are meditating, reading, or awake might generate strong alpha waves. Theta waves range from 4 Hz to 7 Hz and only exist while people are sleeping. Delta waves have the lowest frequency, which is under 3.5 Hz, and only occurs during deep sleep. Beta waves range from 12 Hz to 30 Hz, and it's the reflection of people's attention [3]. Moreover, beta waves will be in higher abundance when a participant is focused on some types of tasks or thinking. Thus, it is the main type of waves this study will focus on.

2 Methodology

This experiment sets a blank control group and two experimental groups and recruited 20 healthy subjects aged 18–25, including 10 boys and 10 girls. They are college students, with normal hearing and normal or corrected vision. All signed an informed consent before the experiment and received after the experiment a certain reward.

2.1 Specification of Experiment

The experiment was carried out in a shielded room. The subjects were 50 cm away from the computer, kept in a comfortable sitting position, and looked at the center of the screen. Ten subjects (5 boys and 5 girls) were randomly selected from the 20 subjects for a blank control experiment. Each subject was required to read two English test documents, each of which was between 200 and 300 words. The reading time was 5–6 minutes, with a 1–2-minute break between the two readings. Meanwhile, their brain waves were recorded.

In the two experimental groups, the remaining ten subjects read the same two English articles as the blank control group in the same test environment. Each group read the article for 5–6 minutes, with a rest of 1–2 minutes between the two groups. In experimental group 1, no audio interference was applied during the first minute then from the second minute an audio interference was applied from minute 2 until the end of reading. In experimental group 2, no audio interference source was applied in minute 1, and another given audio interference source 2 was applied in minute 2 until the end of reading. The brain waves of the two groups were recorded. Before the formal experiment, each subject was given a practice test of ten times. During the experiment, subjects were asked to keep their heads still and blink as little as possible.

Below are the specifications of the audio.

Audio interference source 1: No audio interference source was applied in 1 minute.

Audio Interference Source 2: Based on the audio interference source 1, from 0 to 10s, a combination of ambient noise and fixed-frequency audio, including random noise sources, rushing cars, airplanes, people's noise, and other sources of ambient noise. Fixed audio frequencies that were used are 50–200 Hz, 400–600 Hz, 1000–1300 Hz, and 3000–3200 Hz. When it comes to the specific period of time, human is used to seeing difference in magnitude of brain waves, remove mixed audio frequencies of 50 Hz from 10s to 20s, solid audio frequencies of 400 Hz from 20s to 30s, solid audio frequencies of 1500 Hz from 30s to 40s, and solid audio frequencies of 3000 Hz from 40s to 50s.

One thing that needs to be noticed is that after reading of the blank control group, mean-variance analysis was performed on the concentration values of the subjects after two readings. If the variance was too large, the blank control group was added, and another group of English articles was read until two articles with similar concentration for the same subject were screened out.

2.2 Equipment of the Experiment

In our experiment, we used the NeuroSky MindSet headset as a data collection device as shown in Fig. 1. Traditionally, electromagnetic waves are collected according to the international 10–20 electrode placement system (10–20 system), which involves 37 electrodes on the skull. However, human beings' level of attentiveness are only controlled by the cerebral cortex in the forehead at Fp1; applying the tradition 37-electrode headset to testers is inconvenient and impractical to the research. Though the device carried one dry sensor at Fp1 on the skull as shown in Fig. 2, it can fulfill our experiment's setup. And the reference sensor is placed on the testees' left ear. This device also attached with a research tool box including NeuroView software and Neuroskylab MATLAB module, which can make it easier to connect, graph, view, and record the signals in real time. The NeuroSky MindSet Research Tools (MRT) is cost effective, portable, and user-friendly. This device uses a ThinkGear AM chip module technology to identify and digitize weak EEG signals and filter the electrical signal from the surrounding, but it will also detect the EMG signal on the forehead. So the muscle movement of the testees should be controlled to simplify the data analyse later. It will collect, filter, process, and analyze EEG signals and deliver processed and digital EEG signals in the alpha, beta, delta, gamma, and theta bands at 512 Hz sample rates. The headset is connected to the computer through the wireless Bluetooth connection, so we ensured all subjects were sitting at the same distance from the computer during the experiment to avoid the errors of the signal amplitude. The detected signal was then sent to the NeuroView platform or the MATLAB Neuroskylab module, as the example in Fig. 3.

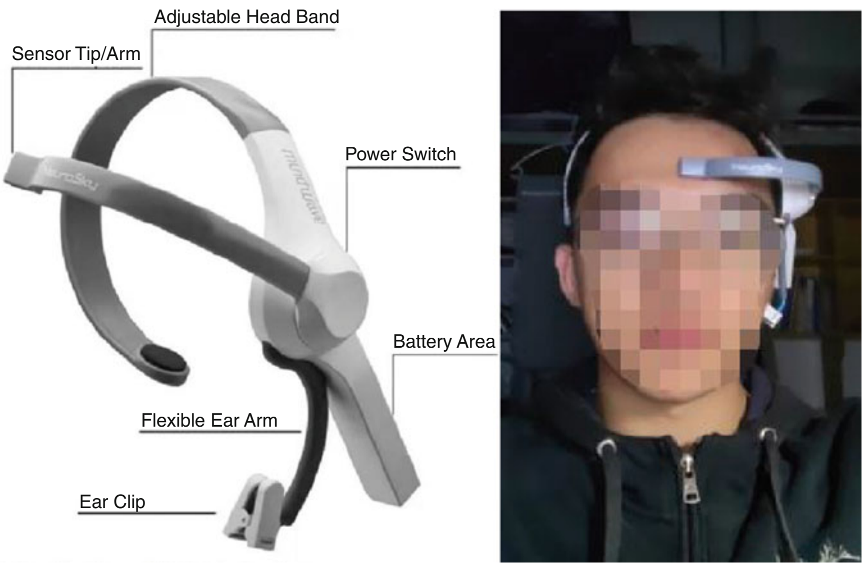

Fig. 1 The Neurosky MW1000 device design and application method

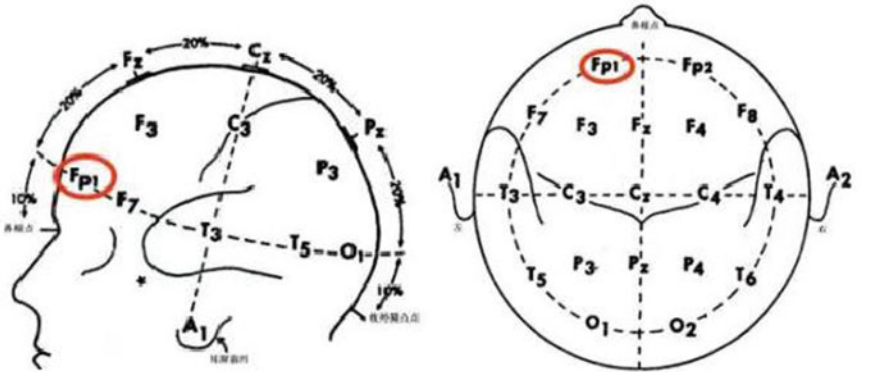

Fig. 2 International 10–20 electrode placement system

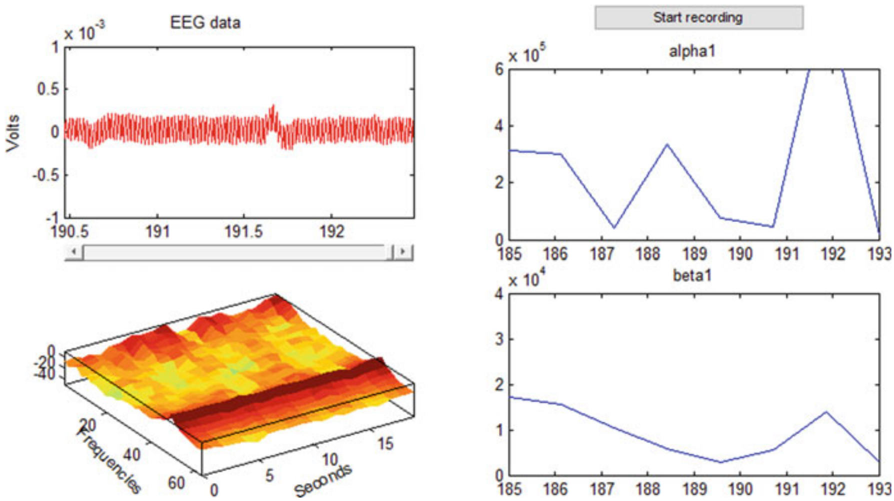

Fig. 3 The collected data on MATLAB Neuroskylab module

3 Data Acquisition and Preprocessing

The NeuroScanSynAmps2 system was used to collect EEG signals from the subjects. The system amplified and bandpass filtered (0-100 Hz) the signal prior to sampling it at 512 Hz. The impedance between scalp and electrode was less than 5KOhm. The behavioral data (whether the subjects responded to the key and the time from the beginning of the stimulus to the response) were recorded using E-Prime 3.0. Before ERP analysis, the collected EEG data needed to be preprocessed by EEGlab as follows: the reference potential was converted to the average value of the left and right mastoid processes, and the original signals were bandpass filtered at 0.1 HZ–30 Hz. The filtered signals were divided into three groups according to the time of stimulus presentation, and the wrong segments were manually eliminated by combining with behavioral data. At the same time, the segment containing large artifacts was also removed. Finally, independent component analysis (ICA) was used to remove the EEG artifacts. However, in the study of classification performance, the 8th-order bandpass filter of 0.1–20 Hz was applied to the data 1 s after stimulation, and all data segments were retained.

4 Feature Extraction and Analysis

For data analysis, the raw data, which is at a sampling rate of 512 Hz with a 15-bit quantization level [4], needs to be preprocessed before analysis; there are two ways to process the raw data: by using the filter provided by EEGlab to sift a raw data or delete the spikes caused by other movements such as blink manually.

4.1 The Filtering in the EEGlab

We used the filtering option in EEGlab to get the data in a specific frequency band associated with the α, β, δ, θ, and γ signals, with the help of the low-pass filter.

4.2 Manually Filtering

According to the related research [4] using mobile sensors to detect attention, it was recommended to recorded also the facial image and the surrounding sounds at the time of the experiment. This is done to facilitate post-experimental data analysis and to accurately record the EEG signals of the test subjects and to identify their level of attentiveness. After comparing the data graphs with facial expressions, it was easy to find out the spikes or fluctuations caused by other factors.

4.3 Data Analysis

We used FFT (fast Fourier transform),

$$X_k = \sum_{n=0}^{n-1} x_n e^{-i2\pi kn/N} \quad k = 0, \ \ldots, N-1 \tag{1}$$

to convert the original signal into individual spectral components and have the graph which contains frequency information. Therefore, it is easy to tell if there is a dominant frequency that exists when applying a special frequency on the subjects. Moreover, it is necessary to calculate the average amount of the amplitude for it as a reflection of attention as an example. Finally, the attention should be defined by many factors including the average of the amplitude for the EEG signals, the dominant amplitude, and the ratio between α waves and β waves.

5 Discussion

5.1 Mixed Signals

In this study, all the EEG signals are detected from only one electrode—Fp1—on the forehead, which makes the subjects feel more comfortable with the experiment. However, using only a single electrode sacrifices the accuracy because every single facial expression would have a magnificent effect on the EEG signal. The signal extracted by the machine is a mixture of EMG and EEG signals. As a result, any blink of the eye will affect the waveform of the signal, as shown in the Fig. 4, which clearly demonstrates the dramatic changes in waveform amplitudes when subjects blink. To solve this problem, filtering out EMG signals with the help of EEGLAB is indispensable.

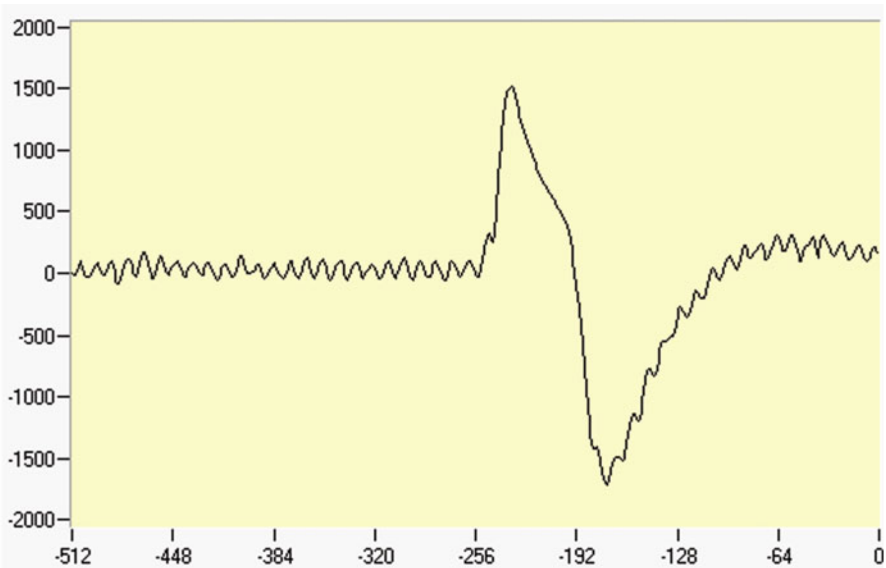

Fig. 4 Influence of eyeblink on signal

Thus, during data analysis, the first step is to filter out all the noise beyond 50 Hz [5]. Using EEGlab, the absolute value of the audio waveforms with a power-law compression with exponential of 0.6 was taken to obtain the audio envelopes, followed 8 Hz low-pass filtering [6]. Envelopes were extracted from the clean audio signals for each speakers [7]. Because of the low accuracy of the experiment equipment, it was necessary to analyze more data and then get the conclusion to improve accuracy and credibility.

By taking the average, checking the dominant frequency for each group and comparing the data with other groups, it was easy to find out the wrong data.

5.2 Distance

It's confusing that the amplitude of the signal could be easily affected by the distance between respondents and the computer which is used to process signals. Making sure that the distance between the respondents and computer could be at a specific value before testing is a useful way to avoid these signal variabilities.

5.3 Insensitivity of the Equipment

The graphs shown in Figs. 5 and 6 is the magnitude of attention measured by a software called NeuroView. Due to the lack of sensitivity of the equipment, the value of the attention could occasionally be a very low value and affect the testing result. These abnormal statistics made it difficult to analyze data, as a set of example statistics shown in Table 1.

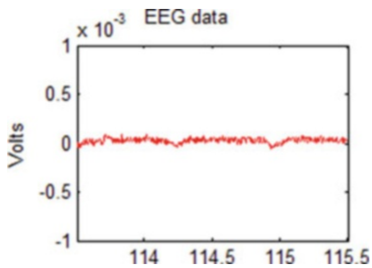

Fig. 5 Magnitude of attention

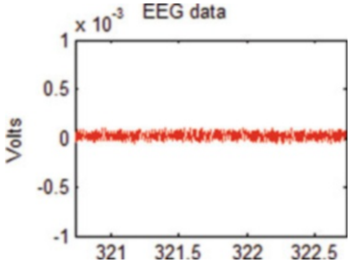

Fig. 6 Magnitude of attention

Table 1 Abnormal statistics during experiment

14:08:51	17
14:08:52	13
14:08:53	1
14:08:54	1
14:08:55	1
14:08:56	14

6 Conclusion

To summarize, when all periods of frequency are shown, at the first 10 seconds, the magnitude of beta wave is around 1 (unit of 10^4), and it doesn't change much along as time goes by, which means that people's attention is low. However, when it comes to the next 20 seconds, as the 50–600 Hz period of frequency of the audio is blocked, the magnitude of beta waves increases above 4 (unit of 10^4). After 30s, the magnitude of beta wave drops rapidly, which shows that user's attention lowers. Thus, people's attention are much higher when low-frequency periods of the audio are blocked.

When looking at the whole picture of this research, the benefits of figuring out how the brain reacts to different kinds of external stimuli at the same time can be detected. The first half of BMI structure is collecting and processing the data, which helped us determined what stimulus triggers what kind of reaction in our brain wave. After understanding the principle of such neural activities, the stimulation of our brain waves can be improved. Currently, this study is only aiming at doing the first half of the brain-machine interface due to the restriction of equipment and areas. Thus, the further study are going to complete the study. After figuring out how is the best way that make people have higher attention, this study can start to construct the second half of the BMI project. The finished product will be like a headphone or earphones but with the function that can block the specific frequency of the noise, helping users to focus on their work. When the signal collector detects that user's beta waves are dropping, it will automatically block the noise that affects the user.

Acknowledgments The authors contributed equally to this work and should be considered co-first authors. The authors would like to thank Professor Jan Van der Spiegel and Ruoyan Zhang for useful suggestions and discussions.

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