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Research article

Analyze the beta waves of electroencephalogram signals from young musicians and non-musicians in major scale working memory task

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HIGHLIGHTS

- Beta waves are significantly correlated with external stimulus and cognitive responses.
- EEG feature analysis and k-means algorithm are used to analyze the difference between young musicians and non-musicians.
- The feature value of response time, response intensity, and response power of the young musicians were superior than the non-musicians.

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ABSTRACT

Electroencephalograms can record wave variations in any brain activity. Beta waves are produced when an external stimulus induces logical thinking, computation, and reasoning during consciousness. This work uses the beta wave of major scale working memory N-back tasks to analyze the differences between young musicians and non-musicians. After the feature analysis uses signal filtering, Hilbert-Huang transformation, and feature extraction methods to identify differences, k-means clustering algorithm are used to group them into different clusters. The results of feature analysis showed that beta waves significantly differ between young musicians and non-musicians from the low memory load of working memory task.

1. Introduction

Musical competence depends on the ability to perform cognitive processing of musical sounds, and domain-general cognitive processes, including verbal and non-verbal skills [1,2]. Musicians also have enhanced working memory according measurements during *N*-back task [3]. They found that the consistent group difference was shown on the more difficult 2-back condition by behavioral and fMRI measures. This study developed a feature analysis method of EEG that can differentiate between musicians and non-musicians by 0-back and 1-back tasks.

Electroencephalograms (EEGs) have been widely used to diagnose various diseases and are now being used in innovative diagnostic methods [4–9]. The brainwave frequencies of EEGs are usually divided into five wavebands: delta (0–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), sigma (12–16 Hz), and beta (16–32 Hz). Many studies agree that, in various situations and conditions, beta waves significantly correlate with stimulatory and cognitive responses to external environments and mental states when awake, which vary among people according to individual differences and environmental factors [10–13]. For example, Hale [14] reported an abnormally increased rightward beta (16–21 Hz) asymmetry at the inferior parietal region in patients with attention deficit hyperactivity disorder performing continuous performance tasks. A study by Zaretskaya [15] analyzed the cognition and attention of participants and their correlation with beta waves when the patients viewed various rotational movement patterns of white and black dots. The analytical results showed that the beta-band power in the parietal areas of the participants decreased after the experimental tasks were completed. Perrier [16] indicated that the beta power of drivers with insomnia were lower than those of drivers without insomnia disorder.

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Cognition and responses are often assessed by performance of *N*-back memory tasks. In *N*-back memory tasks, the working memory in the brain is used as the primary EEG data. Participants perform a series of stimulatory tasks in pre-established test procedures so that data for their short-term memory can be collected [17–19]. In aural working memory task, it compares the working memory EEG physiological signals generated by participants in response to stimuli such sounds, music, and various tones and melodies. By using *N*-back memory tasks and event-related potentials to analyze the relationship between noise and arousal, Han et al. [20] indicated that the response speed of participants was faster with low arousal than with high arousal, and that the response speed decreased as task difficulty increased. In a study of the effect of music lessons on the aural working memories of children diagnosed with hearing disabilities, Rochette [21] found that long-term music lessons improved auditory performance. Strait [22] compared musical aptitude between people with average and below average reading abilities by using intermediate measures of music audition. The comparisons showed that music aptitude and reading and writing abilities correlate with aural working memory performance and attention.

The EEG feature analysis developed in this work was used to analyze the major scale working memories of musicians and non-musicians. A series of major scale working memory tasks were used to stimulate the EEG signals of the participants. Specifically, the feature analysis was used to analyze changes in the EEG features of the musicians and non-musicians performing the tasks. Finally, the post experimental EEG features were discussed based on different working memory tasks.

2. Methods

2.1. Participants

Sixteen trained musicians (4 males, age range: 18–30 yrs, mean: 22.9 yrs) from the department of music at Fu-Jen catholic university were enrolled to join the experiments. The mean duration of musicians had commenced musical study was 11.68 years. All musicians actively pursued multiple instruments while maintaining one principal instrument (piano: 6 persons, cello: 2 persons, viola: 2 persons, violin: 2 persons, France horn: 1 person, trombone: 1 person, clarinet: 1 person, oboe: 1 person). Sixteen non-musician students (4 males, age range: 20–30 yrs, mean age: mean: 21.6 yrs) from different department of the same university volunteered to participate in the experiment. All participants reported that they are right handedness. None had been diagnosed with a severe physical or mental illness.

2.2. Measures

All participants performed *N*-back memory tasks of tones in this study. According to the Western tonal music theory, the five tones of major scales were used as the stimuli. The task included two blocks: 0-back and 1-back. Participants were asked to decide whether later the presenting tones matched the single specific tone presented at first (0-back) or the previous one tones (1-back). In each block, 128 stimuli were given (32×4 rounds). Each block was separated by a break of 10–20 s. After the fixation, each stimulus was shown for 1200 ms, and the interstimuli interval was 800 ms. In each block, the presentation of five tones was random and could not composed into any familir music or songs.

2.3. EEG

The electroencephalogram was measured in a quiet room at Fu-Jen catholic university. Data were recorded with a 32 Ag/AgCl electrodes mounted on an electrode cape using SynAmps amplifiers (Neuroscan Labs, Sterling, USA) and arranged according the international 10/20 systems. Sampling rate was 500 Hz. A 0.1–30 Hz bandpass filter was applied.

2.4. EEG feature analysis

The EEG feature analysis contains two main tasks: signal preprocessing and feature analysis. First, the signal preprocessing step mainly captured EEG signals, filtering noise, and calculating the proportions of the beta waves in the signals. After the C3-A2 signals were extracted from the original EEG signals, the noises were filtered, and the baseline was corrected [9]. To filter the noise, a band pass filter was used to extract the EEG signals from the 0.5–32 Hz band of the original signals for baseline correction by using the following equation:

$$L_{new}\,[\mathrm{t}] = L_{old}\,[\mathrm{t}] - L_{base}\,[t] \tag{1}$$

where $L_{\mathrm{new}}\,[t]$ represents the corrected signal, $L_{\mathrm{old}}\,[t]$ represents the filtered C3-A2 signal, and $L_{\mathrm{base}}\,[t]$ represents the signal baseline. The equation for the baseline was as follows:

$$L_{base}\,[t] = medFilt\,(medFilt\,(L_{old}\,[t]\,, T_1)\,, T_2) \tag{2}$$

where $L_{\mathrm{base}}\,[t]$ is the signal baseline, *medFilt*() is the median filter function, and T_1 and T_2 are the numbers of frequency points of the filtered samples.

The proportions of the beta waves in the EEG signals [9] were calculated using Hilbert-Huang transform [23] and smoothed using the following equation:

$$\beta_{ratio}\,[t] = \frac{R_\beta\,[t]}{R_\delta\,[t] + R_\gamma\,[t] + R_\alpha\,[t] + R_{\sum}\,[t] + R_\beta\,[t]} \tag{3}$$

where $\beta_{\mathrm{ratio}}\,[t]$ represents the proportion of Hilbert-Huang transform beta waves and where $R_\delta\,[t]$, $R_\gamma\,[t]$, $R_\alpha\,[t]$, $R_{\sum}\,[t]$, and $R_\beta[t]$ are the proportions of delta, theta, alpha, sigma, and beta waves, respectively. Fig. 1 shows the beta waves in *N*-back testing. Notably, the starting test time begin at the 30 s.

The feature analysis included the features of response speed (S), response intensity (I), and response power (P) of the beta waves. The response speed (S) was defined as the first descending time of the beta waves after the beginning of the *N*-back memory tasks.

$$S = \mathrm{Ratio}(i+1) - \mathrm{Ratio}(i) < 0,\ \text{if i} \geq 30 \tag{4}$$

where Ratio(i) represents the amplitude of beta wave at the ith second of *N*-back task and 30 is the starting time of *N*-back task. The response intensity (I) was defined as the area under the beta waves of the participants at the beginning of the *N*-back tasks. The interval from the starting point of the test to 30 s after the starting point was adopted, and the area under the curve in the interval was calculated.

$$I = \int_{i=30}^{60} Ratio(i) \tag{5}$$

where Ratio(i) represents the amplitude of beta waves at the ith second of *N*-back task. The response power (P) was computed as the power spectral density [24] during the first 30 s of the test.

$$\mathrm{P} = \left| \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} \mathrm{f}(t)\, e^{-i\omega t} \mathrm{d}t \right|^2 = (\mathrm{F}(\omega) \times \mathrm{F}^*(\omega))/2\pi \tag{6}$$

where $f(t)$ is the finite energy signal, ω is the angular frequency, t is a random real number, F(ω) is the continuous Fourier transform of $f(t)$, and $\mathrm{F}^*(\omega)$ is the conjugate function of F(ω).