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Brainwave Analysis of Auditory Stimulation from Brain Dynamics Audio Music in Sleep Induction Process

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In this study, we primarily utilized brain dynamics audio as a source of musical stimulation, applying auditory stimuli to participants to observe the effects on their sleep states. A total of 36 participants were involved in the experiment. Through the analysis of the participants' brainwave activity, we found that brain dynamics audio indeed helps them enter sleep more rapidly; this is evident from their sleep stage patterns. This suggests that brain dynamics audio can serve as a novel approach to overcoming sleep disorders. Additionally, we will provide a detailed introduction to the concept of brain dynamics audio based on the principles of brain dynamics.

1. Introduction

Among various sleep disorders, "insomnia" is the most common. Research indicates that approximately 10% of the global population is affected by insomnia.(1) Addressing sleep quality has become an urgent healthcare issue. According to the third edition of the International Classification of Sleep Disorders, insomnia is defined as (1) difficulty initiating or maintaining sleep or waking up earlier than desired, (2) significant personal distress or impairment in daily life caused by sleep disturbances, and (3) symptoms occurring at least three times a week for a minimum of three months.(2)

Sleep is an essential activity for humans, and insomnia, a common pathological sleep condition, can lead to physical and psychological health issues over time.(3) There have been many studies about sleep disorder treatments in the past.(4–10) Binaural beats are a popular technique for treating sleep disorders. However, a study by Zhong *et al*. in 2024 indicated that binaural beats did not have a significant effect on adult brain activity.(11) In our study, we employed different frequency combinations as auditory stimulation to treat insomnia, referred to

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as brain dynamic audio stimulation. Using electroencephalogram (EEG) analysis, we demonstrated the effectiveness of this method in promoting rapid sleep induction and proposed a novel theory, brain dynamics, to explain its efficacy.[12–14] Brain dynamic audio stimulation modifies neural activity, making this music therapy viable for physiological or psychological improvements.

2. Materials and Methods

2.1 Materials

Thirty-six healthy right-handed adults (18 males, 18 females) participated in this study. Participants signed written informed consent and met the following criteria: (1) no prescription medication use, (2) no history of epilepsy, (3) no diagnosed sleep disorders, and (4) no hearing impairments. The study complied with the Helsinki Declaration and was approved by the Ethics Committee of National Kaohsiung Normal University.

In our experiment, we used a Nuamps 40-channel digital amplifier system manufactured by Neuroscan to monitor EEG and electrooculography (EOG) signals for sleep analysis. EEG signals were collected from 36 electrode sites based on the extended international 10–20 system.[15] Impedance was kept at 5000 Ω, and the sampling rate was 1000 Hz. The experiment consisted of three sections: (I) three minutes of resting with eyes closed, (II) 18 minutes of music listening, and (III) another three minutes of resting. The laboratory was kept quiet and dark throughout the experiment.

A signal filter (FIR, 0.1–35 Hz, 12 dB/octave, and zero phase shift) was used to filter the data, capturing sleep-related physiological signals while excluding high-frequency noise. EEG signals from left (F3, C3, O1, M1) and right (F4, C4, O2, M2) brain electrodes were analyzed for sleep stages and spectral energy. The auditory stimulus was produced using patented brain dynamic audio devices developed by Prof. Ming-Chung Ho of National Kaohsiung Normal University.[12–14]

2.2 Method: Sleep stage analysis

We categorized the sleep process into five stages based on the classification by the American Sleep Association: wakefulness before sleep onset (stage 0), sleep onset (stage 1), light sleep (stage 2), deep sleep (stage 3), and rapid eye movement (REM) sleep.[16]

Brainwaves are multifrequency waves that can be divided into different frequency bands: α, β, δ, θ, and γ. The combination of these frequency bands reflects various human behavioral states. According to the American Academy of Sleep Medicine (AASM) Manual[16] for the Scoring of Sleep and Associated Events by the AASM, the primary EEG features distinguishing adult sleep stages are as follows. Wakefulness (stage 0) is dominated by alpha waves. When a person is relaxed but awake, EEG displays waves in the 8–12 Hz range. Sleep onset (stage 1) is characterized by low-frequency theta waves (4–7 Hz) accompanied by a slight reduction in alpha waves (8–12 Hz). Light sleep (stage 2) is identified by the presence of sleep spindles (12–16 Hz, lasting 0.5 to 2 s) and K-complexes (large-amplitude, rapid waveforms). Deep sleep (stage 3) predominantly exhibits sustained delta waves (0.5–4 Hz) in the EEG, which are high-amplitude and low-frequency waves. In REM sleep, brainwave activity resembles wakefulness, primarily showing theta waves and low-amplitude beta waves (>13 Hz). Additionally, this stage is marked by reduced eye movement and muscle tension, with REM changes observable in the EEG.

2.3 Welch's method

We also utilized Welch's method to analyze brain energy patterns across different sleep stages. By Welch's method, we estimated the power of signals at various frequencies, and it is based on periodogram estimation, transforming signals from the time domain to the frequency domain. Its advantage lies in reducing noise in power spectrum estimation. The calculation process of Welch's method involves dividing a time series into M segments, each with a length of N points, and multiplying each segment by a window function that is nonzero only over a specific time interval.

$$x_m(n) = w(n)x(n + mR),\ n = 0, 1, \cdots, N-1,\ m = 0, 1, \cdots, M-1 \tag{1}$$

Here, $w(n)$ is the total length of the window function N, x_m is the mth time series after cutting, and R is the time series displacement length.

The power spectral density (PSD) of each N-point time series in the mth segment is

$$Px_{m,M}(f) = \frac{1}{N}\left|\sum_{n=0}^{N-1} x_m(n) e^{-\frac{j2\pi nk}{N}}\right|^2. \tag{2}$$

Then, the PSD of the entire time series can be expressed as

$$P_w(f) = \frac{1}{M}\sum_{m=0}^{M-1} Px_{m,M}(f). \tag{3}$$

Next, the PSD of various brainwave bands (α, β, θ, etc.) at cortical locations across different sleep stages was calculated for analysis and comparison.

3. Results

Figure 1 shows the sleep stage transitions of a participant during the experiment. From 0 to 180 s (Phase I), the participant rested with eyes closed without performing any tasks. From 180 to 1260 s (Phase II), the participant listened to the experimental music. During this phase, the participant's body and mind relaxed, and they even entered a sleep state. From 1260 to 1440 s (Phase III), the music stopped, and the participant rested further.

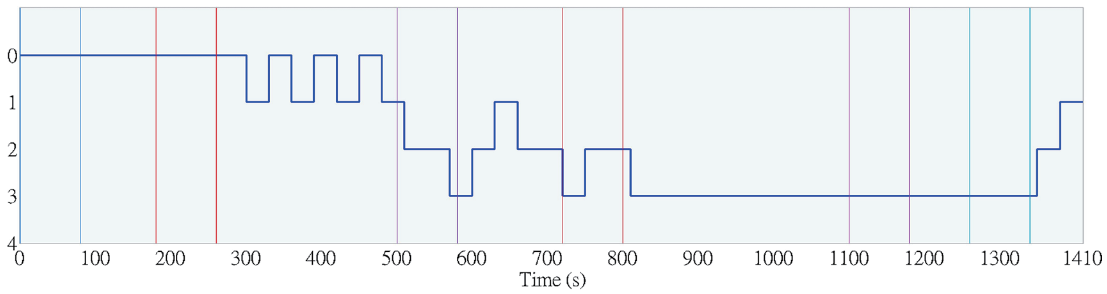

Fig. 1. (Color online) Sleep stage transitions of a participant during the experiment.

The experimental results showed that in Phase I, the participant's brainwave energy corresponded to stage 0, indicating a wakeful state. Shortly after the start of Phase II, between approximately 300 and 500 s, intermittent stage 1 activity appeared, suggesting the initial influence of brain dynamic audio, as the participant gradually transitioned into a sleep state. Between approximately 500 and 800 s, the participant transitioned further into stages 2 and 3. After about 800 s, stage 3 was maintained until the end of the music. During Phase III, the participant gradually returned to stage 1 but did not immediately awaken, indicating that the physiological effects of the music stimulation might have persisted into the rest phase. Additionally, entering REM typically requires a longer duration of stable deep sleep, approximately 70–90 min per sleep cycle.(17)

A comparison of the α waves in Figs. 2(a) and 2(b) reveals that the spectral energy of brainwaves increased during auditory stimulation compared with the initial resting state. This increase can be attributed to the feedback effect of auditory stimulation on the brain. A comparison of the θ waves in Figs. 2(c)–2(e) indicates that the spectral energy of θ waves gradually increased during sleep compared with the presleep state. Even during sleep, the brain continues to perform functions such as transmission, processing, maintaining life, and vigilance. In other words, when the brain is in an active working state, the spectral energy of its brainwaves increases.

4. Discussion

The experimental results indicate that brain dynamic audio music is highly beneficial for sleep, and its mechanism can be explained using the theory of brain dynamics.(12–14) According to previous research, the experimental results show that not all brainwave energy is higher when awake than when asleep.(18)

Theories and inferences of the brain dynamics theory are established as follows. (1) First theory: sleep is a mechanism by which the brain resets at rest; at the moment, the brain is in an initial energetic ground state. (2) First inference: when the brain is in a resting and life-sustaining state, the spectral energy of brainwaves is in a ground state; when the brain works in an operation state, the spectral energy of brainwaves is improved. (3) Second theory: the brain certainly has a feedback effect when subject to audio stimulation; the spectral energy of brainwaves is higher

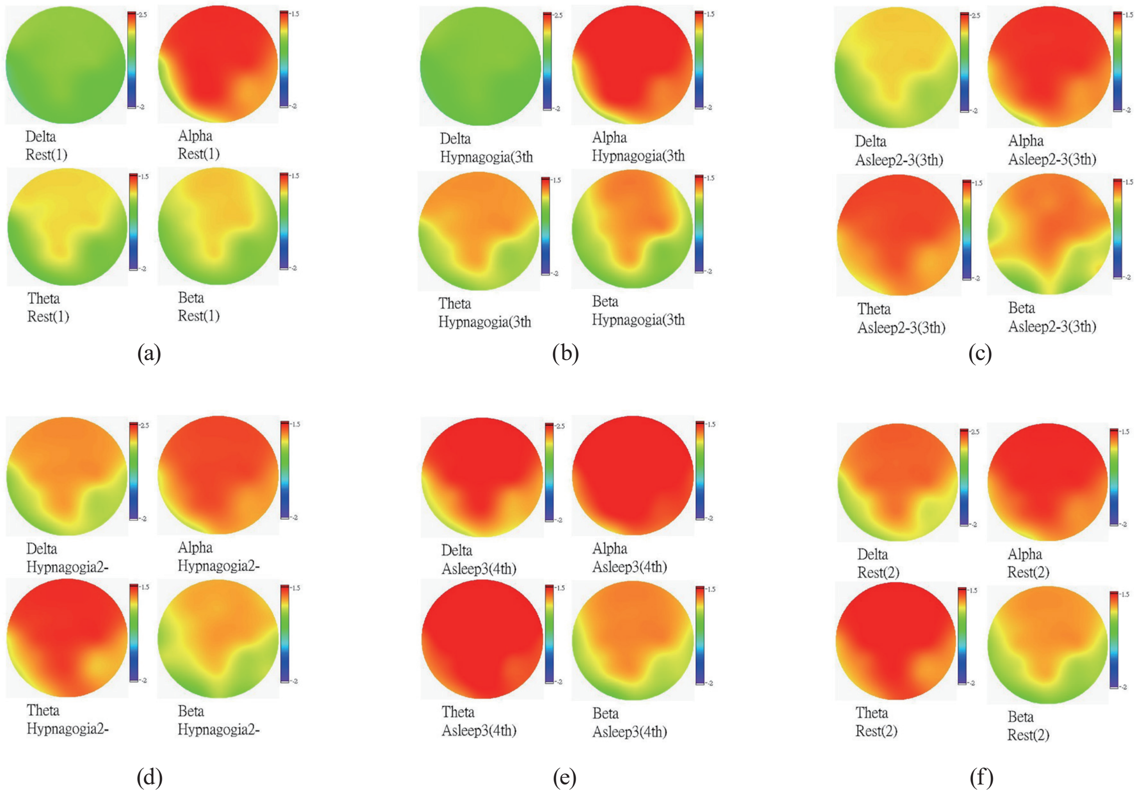

Fig. 2. (Color online) Spectral energy of brainwaves recorded from participants during the experiment. They correspond to the times within the six groups of boxes in Fig. 1.: (a) from 0–80 s, (b) from 100–180 s, (c) from 500–580 s, (d) from 720–800 s, (e) from 1100–1180 s, and (f) from 1260–1340 s.

(representing an enhancement function) than an initial working state, and the spectrum energy of brainwaves is lower (promoting resting and resetting) than the initial working state. (4) Second inference: the spectral energy of brainwaves during sleep is observed, and the channel block functionality, such as transmitting, processing, life sustaining (master control), and alert zone, may be determined according to the energy spectrum subjected to the stimulation. (5) Third theory: the brain releases rest information automatically after excessive work.

5. Conclusions

Brain dynamics audio stimulation provides a method of brain stimulation different from transcranial stimulation. This method aims to alter neuronal activity to improve symptoms, making brain dynamics audio music therapy a feasible approach. In the future, this method is expected to be applicable for alleviating physiological or psychological discomforts, such as insomnia, anxiety, depression, and high psychological stress, as well as brain-related issues such as migraines and dementia. Further medical research by relevant researchers is warranted.

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