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Neuro-Feedback System Enhancing the Level of Symmetry in Left and Right Brain Activities

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ABSTRACT Usually, the level of asymmetry between the left and right brain caused by the difference between left and right brain functions is seen in an EEG analysis, as we see in the literature. A prerequisite for optimizing brain function is appropriate symmetry between the left brain and the right brain. In this paper, we developed a neurofeedback system to improve emotional disorders, such as anxiety and depression, and to optimize the brain function. Our experiment confirmed an enhancement in the symmetry of left/right brain activities and EEGs in each training section. A comparison of the results for the first and third weeks of the experiment showed a considerable increase in alpha and beta waves, and we found that the symmetry between the left and right brain activities was improved. The system might be applied in various fields, including education programs improving concentration for children and medical treatments to improve depression and insomnia for adults.

INDEX TERMS Neurofeedback, EEG, brain activity, brain symmetry.

I. INTRODUCTION

Recently, the study of the human brain has rapidly advanced in areas such as brain science, brain engineering, and brain medicine. As is well known, the human brain comprises the cerebrum, cerebellum, brain stem, etc. The cerebrum in particular is made up of a left and right brain, or two hemispheres. Each hemisphere has developed to perform different functions involving logical problems in the left brain and sensory problems in the right brain. The differences between the left and right sides of the brain is referred to in brain science as the differentiation of brain function [1]. Typically, the level of left and right brain asymmetry caused by the differentiation of brain functions can be seen in an EEG analysis. A prerequisite to optimize brain function is proper symmetry between the left brain and right brain [2]. Asymmetry of the left and right hemispheres causes emotional tendencies to be different, and an increase in this difference can produce symptoms such as anxiety and depression [3].

Interfacing with brain waves to improve these mental disorders has been attracting attention in a variety of business areas, including games and ubiquitous healthcare [4], [5].

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This method can be used to determine the status of patients with mental or physical disorders and is commonly used for prevention and treatment programs through training to control brain waves. A typical example is neurofeedback. Neurofeedback is used as a game interface that reflects the potential improvement of emotional states through training using EEG [4]. Neurofeedback has also been conducted to improve clinical symptoms in patients [3]. Currently, a variety of effects have been identified in several areas related to brain function, brain injury, and attention deficit hyperactivity disorder (ADHD). Thus, relevant clinical studies are still being announced [6]–[8].

In this study, we aimed to develop a neurofeedback system to improve emotional disorders such as anxiety and depression and to optimize brain function. Motivational content may be required, because patients with emotional disorders are reluctant to accept the technique. Therefore, we propose a system that provides interesting content and a customized training schedule for users based on their rate of increase.

The rest of this paper is organized as follows. Section 2 discusses the previous research in this area, and section 3 describes the structure of the neurofeedback system and content composition. Then, section 4 describes the test methods, data analysis, and results of applying the system.

TABLE 1. Conversion protocol.

Type	Frequency band	State of Mind
Delta	0~4Hz	generating deep sleep
Theta	4~8Hz	meditation, being sleepy
Alpha	8~12Hz	relaxation, calm state
Low Beta (SMR)	12~15Hz	attention, concentration
Mid Beta	15~20Hz	active awareness
High Beta	20~30Hz	stress, tension, mental strain

Finally, we discuss future research and conclusions in section 5.

II. RELATED WORK

Brainwaves are electrical flows that are created when signals are delivered from the nervous system to the cerebral nerve. They vary according to the person's psychological state and are the most important indices of brain activity. Electroencephalography (EEG) is a method for neurophysiologically measuring and recording cerebral electrical activities via electrodes attached to the scalp. Depending on the situation, electrodes are attached to the cortex [9].

Brainwaves vary from one person to another, and even normal brainwaves vary according to age. Brainwaves also differ between a waking state and a sleep state. The general brainwave pattern of normal adults primarily consists of 8-30 Hz alpha waves and a small quantity of beta waves. Brainwaves are classified into δ waves (delta: 0-4 Hz), θ waves (theta: 4-8 Hz), α waves (alpha: 8-12 Hz), and β waves (beta: 12-30 Hz) [10]. Table 1 lists the characteristics and classifications of brain waves.

Neurofeedback is a kind of brain workout during which users can monitor their brainwaves and view feedback of the information to improve their homeostatic self-regulation skills [11]. It is also a process that enhances and optimizes brain function. During this process, the brain studies and exercises itself according to the information collected, and the nerve-fiber networks connecting the brain cells become healthier, which improves the blood circulation and oxygen supply. Consequently, brain function significantly improves. Neurofeedback has been available since Hans Berger developed the EEG equipment, which made it possible for users to measure their own brainwaves [12]. Neurofeedback training has been shown to improve cognitive abilities not only in patients with mental illness but also in healthy people, including athletes. For example, Liu *et al.* proposed an experiment in which a new type of individual (beta-1/theta) based neural circuit training was conducted to identify uses for neurofeedback training in recruiting elite shooters and to improve the performance of rifle shooters [13]. Keavy *et al.* suggested that neurofeedback could be used as a treatment, and although results using biofeedback cannot compete with drug therapy, there are significantly fewer side effects when it comes to ADHD therapy [14]. Zolubak *et al.* proposed a prognostic

expert system using neurofeedback signals, in which they addressed preliminary diagnostics issues using policy-based computing [15]. Pandriad *et al.* assessed the impact of biofeedback and neurofeedback training on smokers working on smoking cessation projects, exploring possible correlations between subjective mood scores and training performance [16]. Murat *et al.* developed the brainwave balancing index (BBI), which uses the subject's ability to think and work as direct indicators to generate vast opportunities for improving human potential [17]. Cevat Unal *et al.* suggested that gamma activity was significantly higher on the right side of the brain compared to the left side [18], and Sümeyra Altan *et al.* suggested that neurofeedback can be used to restore sympathovagal imbalances. Neurofeedback may also be accepted as a preventive therapy for psychological and neurological problems [19].

Looking at the previous research on the asymmetry of the left and right brain activities and depression, Deslandes *et al.* identified the electric physiological changes in the brain waves that indicate depression and explained that asymmetry in the frontal lobe appeared as right frontal lobe hyperactivity and left frontal lobe dysfunction [20]. Davidson also suggested that this asymmetry is characteristic of depression [21].

III. NEUROFEEDBACK SYSTEM

In this study, we aimed to develop a neurofeedback system to improve emotional disorders such as anxiety and depression and to optimize brain function. Fig. 1 shows a configuration diagram of the system.

The neurofeedback system consists of the EEG Analyzer, Contents Viewer, Increase Rate Analyzer, and Results Viewer. First, the EEG Analyzer is linked to EEG measuring equipment and separates the incoming real-time EEG waveforms into the Alpha, Beta, Theta, and SMR waves. These are stored in the database to establish the user's personal profile. The Contents Viewer provides EEG training content for users. Content is taken from the existing neurofeedback system and is designed to generate a derived EEG for each specified category. The Brain Symmetry Analyzer calculates the rate of improvement by comparing the EEG data stored in the database and schedules training for users based on the rate of increase. Finally, the Results Viewer shows the training results for each category. It was also designed to compare the EEG data for the current and past training periods.

A. CONTENT COMPOSITION

The developed system consists of five categories and provides seven types of content to optimize brain function. Fig. 2 shows the execution screen of the cognitive development section, and Fig. 3 shows EEG raw data packet for data analysis.

The cognitive development section includes the contents of the associative memory training and color maze. It is aimed at developing frontal lobe function and serves to develop a well-balanced left and right brain.

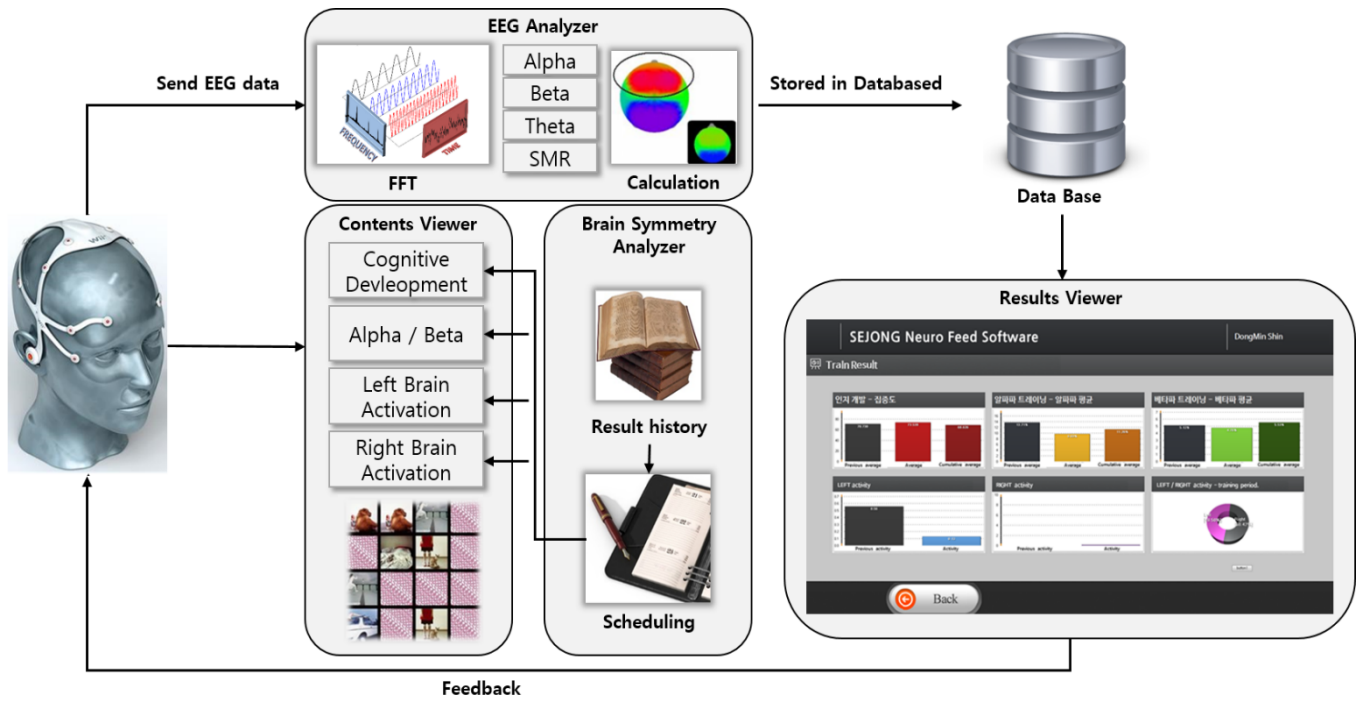


FIGURE 1. Structure of neurofeedback system.

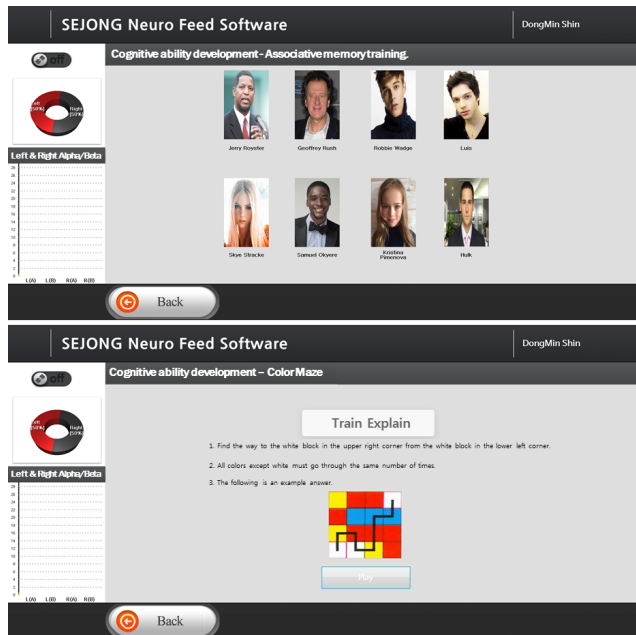


FIGURE 2. Content for cognitive development.

This method is also effective for improving anxiety, depression, and attention disorders, because it increases the brain’s activity during information processing. Fig. 4 and Fig. 5 show the execution screen of the alpha and beta wave training sections.

The alpha wave training section includes meditation content, such as listening to classical music, which induces alpha waves in the user through brain relaxation. The beta wave training section includes the contents of 1-25 and archery and

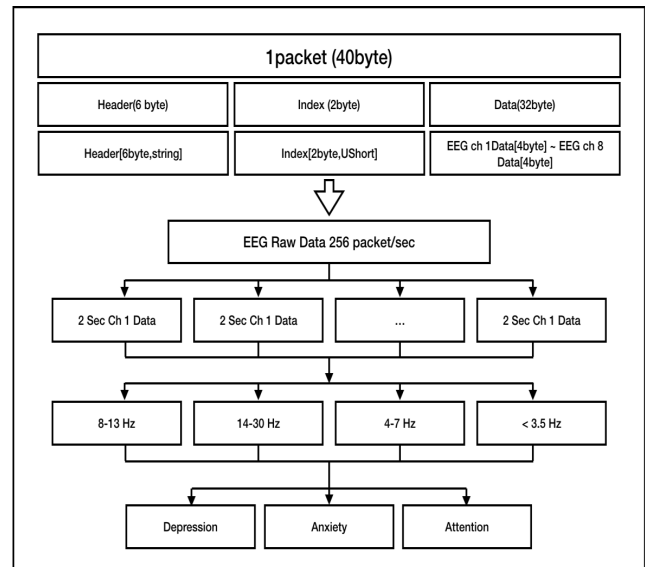


FIGURE 3. EEG raw data packet.

aims to increase beta waves through brain activation. Each of the waveform training activities is designed to provide the user with the correct EEG distribution. Fig. 6 shows the execution screen of the content for the left and right brain activations.

Table 2 shows various training contents used in the experiment. Contents that activate the left brain are centered on finding association rules for operation training. Contents that activate the right brain include finding matching cards to process spatial and holistic information. Left and right brain asymmetry is a key characteristic of patients with



FIGURE 4. Content for alpha waves training.

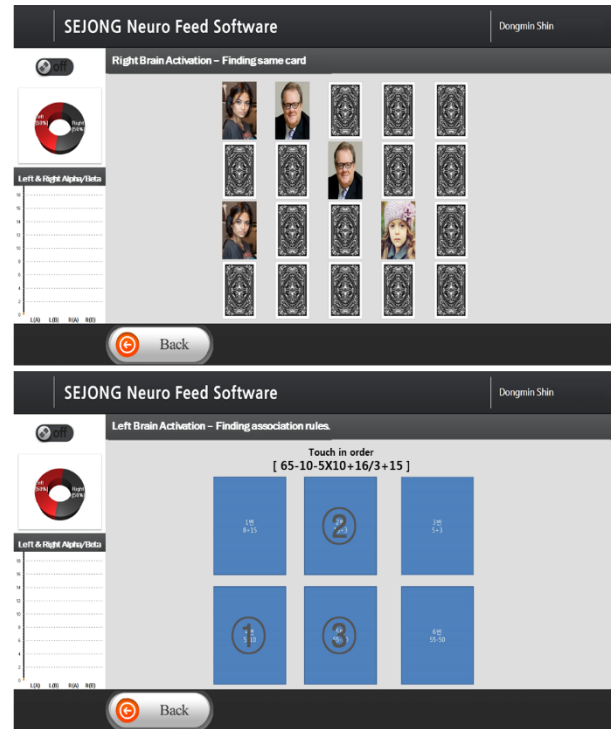


FIGURE 6. Content for left and right brain activation.

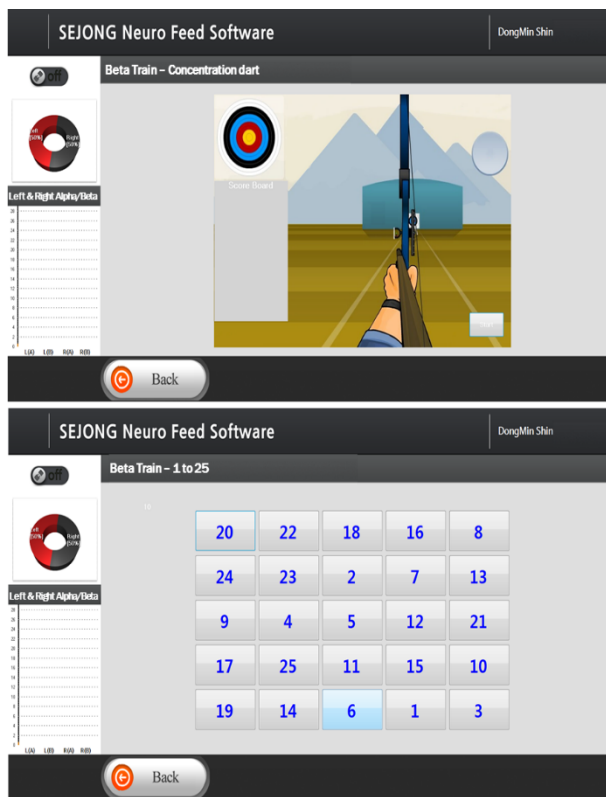


FIGURE 5. Content for beta waves training.

emotional disorders. The lower part of the activity is increased through training, which promotes symmetry between the left - and right brain activities.

IV. EXPERIMENTAL RESULTS AND ANALYSIS

To validate the system, we conducted an experiment over a period of three weeks with 20 male subjects (age from 23 to 32). The EEG measuring device used in the experiment was Emotiv’s EPOC, which is composed of 14 channels and two ground sensors and receives data at the rate of 128 Hz.

TABLE 2. Training contents.

Type	Training Contents (number)
alpha	classical music (100)
beta	archery (2), racing (2)
left brain	rule game (2)
right brain	card game (2)
cognitive development	associative memory training (1) and color maze (1)

We used an EEG from channels AF3, F3, AF4, and F4 based on the existing theory that an EEG is closely related to the frontal lobe, and thus is associated with concentration and depression. EEGLAB was used to analyze the measured data. Fig. 7 shows the EEG channels that were used.

Fig. 8 shows the EEG data analysis process. The preprocessing includes artifact removal and segmentation. Each kind of training divides 10 minutes of EEG data. The EEG artifacts were removed by using independent component analysis. To prevent problems resulting from memorization, the contents of the system are designed to change each training session. In addition, the team was composed of a subject and a supervisor. The supervisor checked the input of the EEG data and left markers at the beginning and end of the training section. These markers served to increase the classification accuracy.

The data measured by the EEG measuring device were analyzed by category. An EEG waveform can be represented by multiple separate sine waves or cosine waves with different amplitudes and cycles. Based on the Fourier theory,

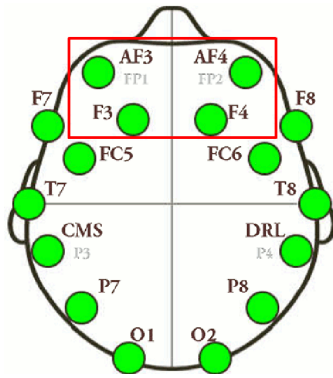


FIGURE 7. Selected channels.

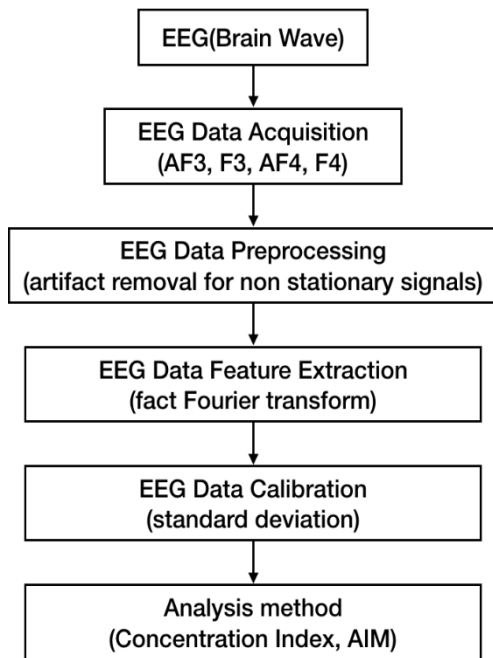


FIGURE 8. EEG data analysis process.

we used a fast Fourier transform analysis method to separate these multiple waves. The analysis processing method used the following equations:

$$H(f_n) = \sum_{k=0}^{N-1} h_k e^{-\frac{j2\pi kn}{N}} = H_n \quad (1)$$

$$h_k = \frac{1}{N} \sum_{n=0}^{N-1} H_n e^{-\frac{j2\pi kn}{N}} \quad (2)$$

The time series signal changes over time are converted into frequency domain signals, and the signals patterns are determined with respect to the frequency changes. Using this analysis method, the data were classified using the frequency composition, and the density and distribution of the frequency components were classified. The indexes for each category are applied to the information. Due to individual differences, the amplitudes of EEG signals from different subjects can vary significantly under the same conditions. It is necessary

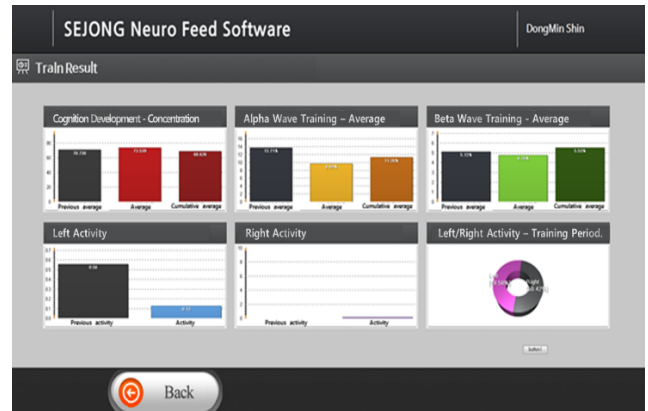


FIGURE 9. Results viewer.

to revise the functions of other states in order to eliminate individual differences. We used mean and standard deviation correction as shown in Equation 3.

$$s = \sqrt{\frac{1}{N-1} \sum_{i=1}^N (x_i - \bar{x})^2} \quad (3)$$

The cognitive development section determines the user's concentration by applying a concentration index. Equation 4 is the concentration index.

$$\text{Power Ratio of (SMR + Mid - Beta)} / \theta \quad (4)$$

In a state of concentration, the theta wave is reduced, and the mid-beta waves are the focused attention. The SMR waves, meaning the unfocused attention, are increased. Therefore, the concentration index is quantified by the SMR and mid-beta ratio of the theta waves using the formula in Equation 5.

Next, the alpha and beta wave training section obtains the average of the alpha and beta waves of the measured EEG data and calculates the rate of improvement compared with the average of the measured EEG data in the previously conducted training.

Finally, the left and right brain activity applies the Alpha Inactivity Mechanism (AIM). This is based on the existing theory that brain activity is generally inversely proportional to the alpha waves, as shown in Equation 5.

$$\text{actLeft} = \frac{1}{P_{aL}} \quad \text{actRight} = \frac{1}{P_{aR}} \quad (5)$$

Here, P_{aL} and P_{aR} represent the size of the left and right alpha waves, respectively. To show a comparison of the left and right brain activities, the Results Viewer displays the figure obtained from equation 4 as a percentage. Fig. 9 shows the execution screen of the Results Viewer showing the results of training. The user can confirm their brain waves in each section and compare the previous and current training sessions. The system schedules the next training session based on the lowest improved category after comparing the training sessions. The session is scheduled so



FIGURE 10. Individual participant results.

TABLE 3. Experimental results.

		1 week	2 weeks	3 weeks	Improvement (%)
Cognitive Development		0.28	0.29	0.39	39.28
Alpha Training		10.84	11.81	13.21	21.86
Beta Training		4.25	4.65	4.99	17.41
Symmetry (%)	Left	45.24	44.49	48.09	
	Right	54.76	55.51	51.91	

that the additional training proceeds by adding the contents of the lowest-improved categories. Thus, the next session can provide an optimized system that shortens the training time according to the user's progress.

The real-time EEG data input based on the relative power values of the alpha, beta, theta, and SMR waves were separated and stored. The EEG activity of each section was determined by applying the indexes, and the rate of brain symmetry improvement is determined by comparing the data for each training period.

Fig. 10 shows the individual results of all participants, and table 3 provides a summary of the results. The table lists results for the index of each section. The rate of improvement was calculated using the average values of the first and last weeks. As a result, the concentration index in the cognitive development section increased by 39.28%, and the brain activity of the alpha and beta waves increased by 21.86% and 17.41%, respectively. In addition, we found that the symmetry of the left and right brain activities improved as a result of the experiment.

V. CONCLUSION

In this study, we developed a neurofeedback system to improve emotional disorders, such as anxiety and depression, and to optimize brain function. The system attracts participation by increasing the user's interest and allows the user to create an EEG during the training section. An index is calculated using the relative value of the EEG, and the training results are analyzed. We confirmed improvement in the symmetry of the left/right brain activities and EEG in each training section through an experiment.

The system developed in this paper is expected to be applicable to various fields. For example, the system could be used in education to help improve a student's concentration during learning or in the medical field to improve depression and insomnia in adults.

Future research should supplement the contents for long-term experiments. The algorithm is currently being studied using naive Bayesian data classification. A future training experiment will be conducted for more than two months to increase the reliability of the data. There is also a need to perform a post-investigation to determine the continuity of the system's effect.

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