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Studying The Influences of Visual Neurofeedback Below the Range Of Δ Frequency Band

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ABSTRACT

The treatment of conditions like attention deficit disorder through visual neurofeedback not only alleviates the side effects linked with medications but also empowers the brain to autonomously regulate its functions. Numerous research studies employ visual neurofeedback targeting standard EEG bands, especially the beta band, for addressing attention deficit issues. These studies argue that such neurofeedback protocols specifically modulate brain function, exerting the most pronounced influence on the 0.5 to 1.5 Hz EEG band. Consequently, our study delves into the impact of visual neurofeedback on the 0.5 to 1.5 Hz band with the aim of enhancing the visual attention of normal adult subjects. Two distinct neurofeedback training protocols were implemented: the relative beta-I band power and fractal dimension. Subjects underwent 12 training sessions, each lasting 15 minutes. Visual attention assessment utilized the Test of Variables of Attention (TOVA). The results demonstrated significant improvements in the visual attention of subjects for both protocols (DRT = 37.3 ms and 19.6 ms for the beta-I protocol and fractal dimension protocol, respectively). Moreover, an analysis of the data indicated a noteworthy decrease in the relative band power of 0.5 to 1.5 Hz across all subjects throughout the 12 training sessions (DRP = 1.19±0.36 and 0.63±0.39 for the beta-I protocol and fractal dimension protocol, respectively). This implies that this specific band could be an effective approach for enhancing visual attention in visual neurofeedback or eye biofeedback, potentially mitigating eye movements.

1. INTRODUCTION

In recent years, the field of neuroscience has experienced a surge in interest regarding the utilization of Visual Neurofeedback (VNF) as an innovative approach to modulate brain activity. This method, which involves real-time visual feedback of electroencephalographic (EEG) signals, shows promise in enhancing cognitive functions and addressing neurological conditions. While existing research has explored various frequency bands, our study ventures into a specific and less-explored realm – the influences of Visual Neurofeedback below the δ frequency band (0.5 to 4 Hz).

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Understanding the neurophysiological implications of targeting brain activity in the sub-δ frequency range is pivotal for unraveling potential cognitive and clinical applications. This paper aims to synthesize the current knowledge on VNF, with a specific focus on its application within the lower frequency spectrum. By elucidating the effects of neurofeedback in this particular band, we aim to contribute to a more comprehensive understanding of brain modulation techniques and their potential therapeutic benefits.

Currently, numerous investigations have been undertaken within the realm of neurofeedback. [1-3]. Ground-Penetrating Radar (GPR) stands out as a widely used tool for object detection in various applications, including landmine detection [4], Buried Pipe Detection [5], and Detecting oil under snow [6]. GPR is adept at detecting metallic objects, and similarly, the human brain, as a principal subsystem of the nervous system, employs various feedback mechanisms to interact with the environment. This open subsystem [6] organizes its functions by processing internal and external feedback information.

Ivan Pavlov's experiments with dogs unveiled the concept that classical conditioning can alter an animal's response. By repeatedly ringing a bell before feeding his dog, Pavlov conditioned the dog to salivate in response to the bell rather than the food [7, 8]. This reflex led him to introduce the scientific concept of conditioning, later developed by others. For instance, Eric Kandel and his colleagues [9, 10] demonstrated through the Aplysia gill-withdrawal reflex that a specific learning task over time can produce a type of synaptic plasticity known as habituation. These learning tasks form the basis for learning principles across various disciplines, particularly in computer science. Therefore, learning tasks administered via external feedback methods, such as neurofeedback, play a pivotal role in regulating brain function. Presently, researchers [5, 11-13] are actively exploring various neurofeedback-based learning tasks with the aim of addressing behavioral disorders such as attention deficit. The findings of this study indicate that the foundational principles of three theories - control, artificial intelligence, and cybernetics - can provide a coherent definition of the information (learning task) delivered to brain controllers through neurofeedback [14-17]. Essentially, these theories posit that neural feedback should supply consistent, repetitive, and essential information to brain controllers. Without such input, the brain may struggle to modify fundamental types of synaptic plasticity (new state) necessary for improving attention deficits. Consequently, gaining a comprehensive understanding of the brain becomes imperative to initiate a transformative new state.

Contemporary researchers employing specialized neural-feedbacks, delivering consistent, repetitive, and essential information, strive to ameliorate attention deficits over a specified time course. For instance, Lubar and Lubar in 1984 [18], concurrently increased both the sensorimotor rhythm (SMR) and beta activities while suppressing gross movement, excessive EMG, and theta activity in six children with attention deficit disorder during a neurofeedback course. They reported that all children exhibited increased SMR or beta and decreased slow EEG and EMG activity upon completion of the neurofeedback course. Similarly, Egner and Gruzelier in 2004 [19], independently enhanced two indices: relative SMR power and relative beta-I band power of the Cz channel during a neurofeedback course. They evaluated the visual attention of subjects using the Test of Variables of Attention (TOVA) and ultimately found that the beta-I protocol resulted in faster reaction times compared to the SMR protocol. These findings are significant, as Lubar and colleagues [18] extrapolated that SMR training, coupled with the suppression of slower theta (4–8 Hz) components, can improve hyperactivity disorders [18, 20]. Consequently, hyperactive and impulsive behaviors are considered crucial factors in elevating the level of low-frequency activity in the EEG signal [19, 21-24].

The influence of low-frequency activity on visual attention is direct, where any issues within organs related to visual attention, such as various brain networks, sensors, and muscles, can exacerbate hyperactivity and impulsivity. Often, these manifestations are involuntary, with one notable component being involuntary eye movements (low-frequency activity), which significantly impacts the level of very low-frequency activity in the EEG signal. Despite this, the majority of studies on visual attention [11-13] have primarily concentrated on low (delta and theta) and middle (alpha and beta) frequency activities, overlooking activations below the range of the delta band, which experience substantial reduction during a neurofeedback training course. In this study, we specifically explore the influences of visual neurofeedback below the range of the δ frequency band. The structure of this paper is as follows: Section 2 provides comprehensive details on neurofeedback training protocols and data. Section 3 delineates the results of EEG analysis within the 0.5 to 1.5 Hz band, and Section 4 concludes with a detailed discussion.

2. MATERIALS AND METHODS

The study's dataset, as outlined in [24], encompasses two sets of information: TOVA data recorded both before and after neurofeedback sessions, and EEG signals acquired during neurofeedback. The data were gathered from a cohort of 10 male participants, sponsored by the Islamic Azad University in Mashhad, Iran, with a mean age of 24.6 ± 3.14 years. The Global Severity Index (GSI) from the Symptom Checklist-90 (SCL-90) questionnaires [25, 26] for all participants was at or below 50, indicating normalcy. None of the participants reported any neurological illnesses, and the majority of their activities predominantly involved the right side of the body. To ensure homogeneity, participants were divided into two groups of five based on their reaction time index measured by the TOVA before commencing neurofeedback training.

This study was meticulously designed to establish equal conditions for participants in both groups. The groups were designated as follows: 1) the band-I group, which underwent the neurofeedback training protocol for relative beta-I band power, and 2) the fractal group, which underwent the neurofeedback training protocol for fractal dimension. Figure 1 illustrates the methodology employed for assessing and training subjects during the neurofeedback sessions. It is crucial to note that filtering is an integral part of the processing block within the neurofeedback loop, as depicted in the figure 1.

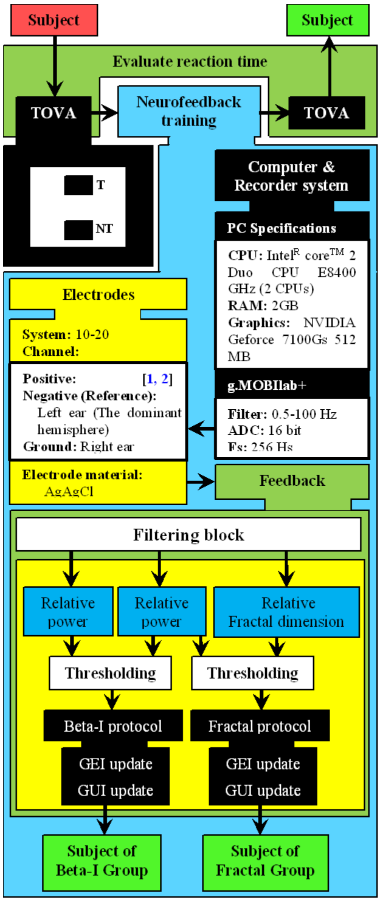

Fig. 1. The block diagram of method used for the evaluating and the training of subjects during a neurofeedback training course [24]

Figure 2 provides additional details regarding the filtering component of the processing block. This block encompasses five digital filters, with one of the filters being a band-pass filter tuned to 0.5-1.5 Hz. Despite the fact that a significant portion of the information extracted from this filter pertains to organ movements, particularly the eye muscles, researchers have traditionally not overlooked this information. Instead, they have often constrained this information within a specific range by employing a threshold. In the following section, we demonstrate that the output signals from this filter carry valuable information.

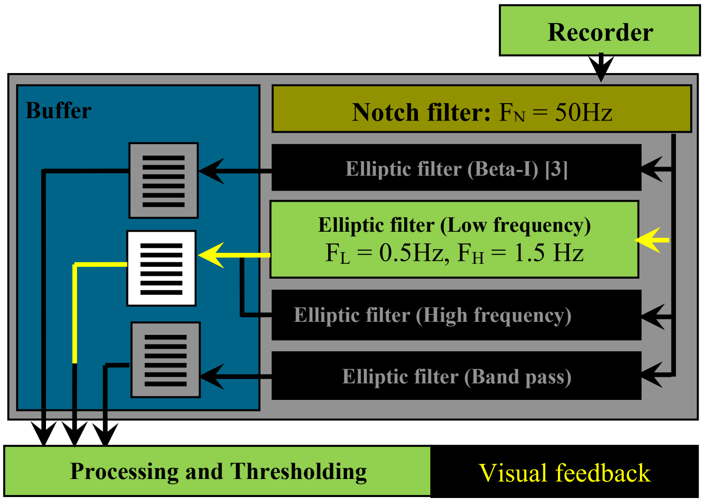

Fig. 2. The filtering block in neural-feedback [24]

3. EXPERIMENTAL RESULTS

As depicted in Figure 1, we assessed each subject before and after the neurofeedback training using the TOVA test. Table 1 presents the difference in reaction time (DRT) improvement for both groups after completing the neurofeedback training course. The data in this table underscores that both neurofeedback protocols led to enhanced reaction times. However, the beta-I protocol demonstrated greater efficacy in improving the subjects' reaction time. On average, this protocol reduced reaction time by 37.32 ms, compared to 19.56 ms for the fractal protocol. Following the TOVA evaluations, subjects underwent 12 training sessions, each lasting 30 minutes, comprising two 15-minute periods with a 15-minute resting period in between. These periods were labeled as the first and second training halves for clarity.

During the sessions, the scalp was fitted with a Cz electrode following the 10-20 international system for feedback collection. Additionally, A1 and A2 electrodes served as ground and reference values in grams. The MOBIlab+ recorder [27] was utilized throughout the process.

Figure 3 illustrates two 15-second EEG signal segments extracted from the initial and final sessions of subject MH. It is evident from this figure that the variance in the EEG signal during the first session is more pronounced than that during the last session. The high variance observed in the first session is typically attributed to very low-frequency components present in the EEG signal. Visual neurofeedback tends to attenuate these components and concurrently reduce the movements of various organs, particularly the eye muscles, during the training sessions.

Table 1. Amount of difference created in the reaction time (DRT) of subjects after a neurofeedback training course

Beta-I group						
Subject	**MH**	**ME**	**MR**	**MM**	**MG**	**Mean**
DRT (ms)	77.4	36.6	28.0	24.2	20.4	**37.32**
Fractal dimension group						
Subject	**HN**	**MF**	**MS**	**LH**	**AF**	**Mean**
DRT (ms)	47.7	33.2	8.6	4.9	3.4	**19.56**

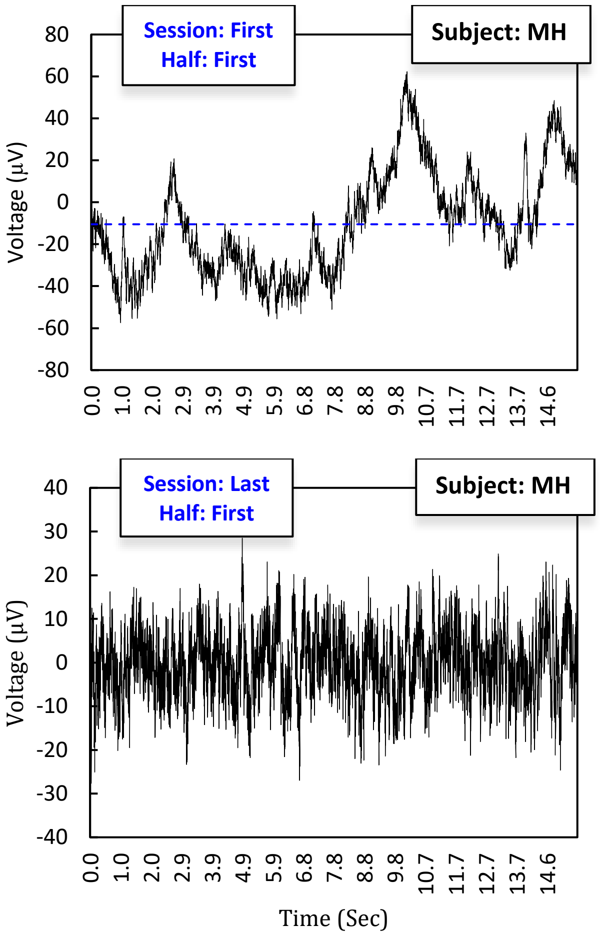

Fig. 3. Two 15-second segments of EEG signal recorded in the first and last sessions of subject MH

Fig. 4 shows the trend of relative power of band 0.5-1.5 Hz in two training halves for the best subject of beta-I group. Similarly, Fig. 5 shows these trends for the best subject of the fractal group. We used the following equation to calculate the relative power of band 0.5-1.5 Hz.

$$RP_i = \frac{\sum_{n=1}^{N} x_{Band,i}[n]^2}{\sum_{n=1}^{N} x_i[n]^2} \qquad i = \{1,2,\ldots,12\} \tag{1}$$

Where x_i and $x_{Band,i}$ are the EEG signal and the signal of band 0.5-1.5 Hz in ith session, respectively.

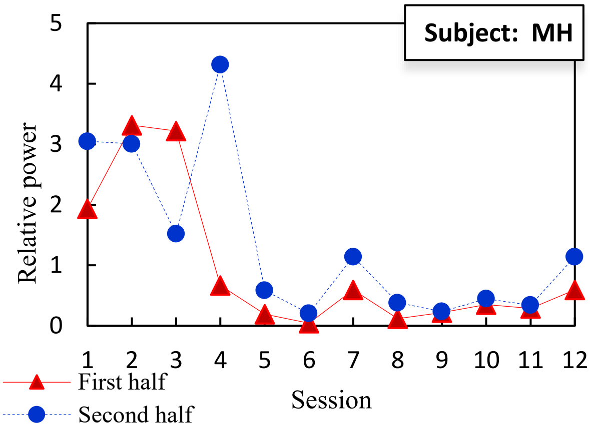

Fig. 4. Trend of relative power of band 0.5-1.5 Hz for the best subject of beta-I group

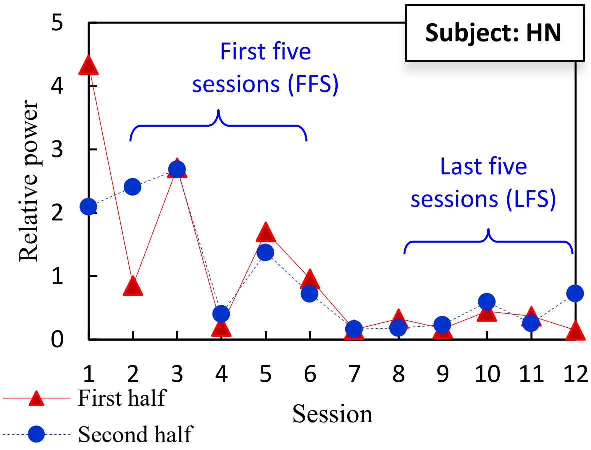

Fig. 5. Trend of relative power of band 0.5-1.5 Hz for the best subject of fractal group

As observed in Figures 4 and 5, subjects generally exhibited a reduction in the relative power of the mentioned band during the initial sessions. While the number of these sessions varied among subjects and training protocols, the relative power of this band typically decreased within the first five sessions. Consequently, we computed the difference in the average relative power between the first five sessions (FFS) and the last five sessions (LFS).

$$D_M = \frac{1}{5}\left(\sum_{i=1}^{5} RP_i - \sum_{i=7}^{12} RP_i\right) \tag{2}$$

Figure 6 illustrates the DM parameter for the two training halves of subjects in both groups. The figure highlights a general reduction in the relative power of the 0.5 to 1.5 Hz band for all subjects, with the exception that the DM parameter of the beta-I group (1.19±0.36) surpassed that of the fractal group (0.63±0.39). Consequently, the beta-I protocol exhibited a greater capacity to enhance the relative power of the 0.5 to 1.5 Hz band, attributable to the feedback type. The feedback parameter of the beta-I protocol provided more constant, repetitive, and essential information compared to that of the fractal protocol, given that the relative beta-I band power is derived from a component-oriented approach.

In the subsequent section, we offer a brief discussion and conclusion regarding the results obtained in this section.

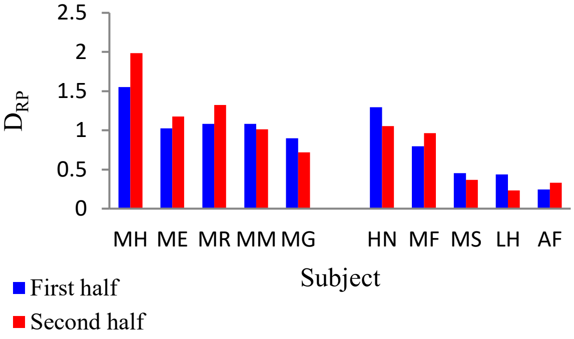

Fig. 6. The D_{RP} parameter for the subjects of two groups

4. DISCUSSION AND CONCLUSION

The study's findings propose that the disharmony observed in various brain functions poses a challenge to the neural system, leading to involuntary movements in multiple organs. These movements can trigger hyperactivity and impulsivity in the organs, consequently influencing the frequencies of EEG signals. Hence, modifying these involuntary movements in the organs becomes a potential avenue to optimize brain functions for specific purposes.

Visual feedback, a form of neurofeedback, is a method that fine-tunes brain functions through the eyes. Among the organs involved in visual neurofeedback, the eye muscles exhibit the highest degree of involuntary movements among external body organs and exert the most significant effect on EEG signals. In essence, a visual neurofeedback course induces substantial alterations in both voluntary and involuntary eye movements, ultimately improving the reaction time index.

Comparing the variance in EEG signal values between the initial and final training sessions reveals that visual neurofeedback, employing both beta-I and fractal group protocols, typically diminishes very low-frequency components. Furthermore, an examination of the relative power of the 0.5-1.5 Hz band (see Fig. 6) confirms that visual feedback reduces the aforementioned variance (DRP = 1.19±0.36 and 0.63±0.39 for the beta-I and fractal dimension protocols, respectively), with the beta-I protocol proving more effective at enhancing reaction times.

Nevertheless, this reduction in variance alters the 1/f spectrum of the EEG signal, leading to both the beta-I and fractal protocols enhancing middle-frequency components. Consequently, the results underscore that visual neurofeedback is a fusion of neurofeedback and eye biofeedback. Therefore, subjects necessitate several eye biofeedback training sessions to mitigate the effects of eye biofeedback on visual neurofeedback and amplify the impact of visual neurofeedback.

5. ETHICAL APPROVAL

The neurofeedback used in this study was as non-invasive, so that we recorded the EEG signal by using electrodes located on the scalp and applied the features of EEG signal through visual feedback. Meantime, we used the g.MOBIlab recorder of g.tec Company that is according to IEC 60601-1. On the other hand, we gave comprehensive information about the neurofeedback training to each of the participants and obtained an informed consent from each participant before beginning the neurofeedback training.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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