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EEG Analysis of the Neurofeedback Training Effect in Algorithmic Thinking.

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Abstract

Although significant advances have been made in understanding several cognitive states, the algorithmic thinking ability is yet to be analyzed in terms of neuroscience and brain imaging techniques. Studies on the effects of neurofeedback on learning disabilities especially mathematics disorders are limited. The objective of the present study is to evaluate the brain activity and activation differences between neurofeedback trained participants and controls, during the overall EEG analysis during continuous algorithmic tasks performance. A study of 182 children of upper education is proposed to assess the efficacy of two protocols of neurofeedback training as means of algorithmic thinking ability evaluation. Results suggest statistical significant variation in the mean SD values in terms of several brain waves ratios during algorithmic task solving epochs.

Keywords: Neurofeedback training; learning disabilities; alpha waves; beta waves, algorithmic thinking, EEG

Introduction

This study focuses on the algorithmic thinking ability evaluation with the use of neurofeedback training approach. The purpose of the research is to evaluate the different human mental behavior through Electroencephalogram (EEG) signal with time-frequency analysis by receiving information from the internal changes of brain state. Several EEG signals have been collected for these states and analyzed using the Acqknowledge software. Participants were asked to deal with interactively presented algorithmic procedures in order to assess their ability in algorithmic processing stimuli. While engaging in the given tasks, EEG signals of the brain are recorded by means of a sensor system in order to study and analyze their brain activity. This is carried out by protocols based on neuroscience and mainly in neurofeedback methods. In specific two protocols based on neurofeedback were employed namely the Alpha-Theta and the Beta SMR protocol in order to reinforce Alpha and Beta frequencies respectively during the various stages of the neuroeducational approach. Statistical measures, like mean values and standard deviation, in each sub-band, are chosen in order to analyze different mental states of participants while dealing with the Att-Oncee test.

Related work

Jacob's study in 2006 on two children with learning disabilities using neurofeedback treatment showed that neurofeedback is a successful treatment for this disease (Jacobs 2006). Fernandez in 2007 showed that neurofeedback is an effective treatment for children with learning disabilities, with a high abnormal ratio of Alpha-Theta (Fernández et al. 2007). Becerra in follow-up study performed on children with learning disorders showed that neurofeedback is an effective treatment for a long period (Becerra et al. 2006). According to Hashemian et.al study of 28 third grade primary school children, the 14 received neurofeedback treatment and the 14 non-real neurofeedback treatment. This approach was based on enhancement of Beta-Theta ratio in CZ region and was conducted with 20 sessions that lasted 30 minutes for 10-12 weeks. In this case, the comparison between real and sham groups showed that the effect of real neurofeedback therapy was significant versus sham group (Hashemian & Hashemian 2015)

Participants

The sample of 182 participants was randomly selected (convenience sample) while the participants were voluntarily evaluated and two equal groups were formulated. 91 subjects were allocated to neurofeedback group and 91 participates were allocated to control group. Participants of this case study are adults graduate students of the Department of Informatics of the Ionian University in Corfu. An IQ pre-test had conducted in order to match two groups according to the degree of intelligence. In addition, the two groups were matched for age, sex, and learning disabilities. Participant's brain activity and their ability of algorithmic lesion stimuli were evaluated with engaging with the given problems. The training was conducted within 20 sessions that lasted from 60-80 minutes for approximately six months. Ten algorithmic tasks were provided, mainly derived from the computer science, graph and game theory. Both control group and neurofeedback trained participants brain activity were recorded while dealing with the above given algorithmic tasks. Therefore ten epochs were created for each participant of both control and neurofeedback group and they were further analyzed statistically with ANOVA analysis (Cohen & Cohen 2008).

Material

The recording of the brain's activity obtained by using electrodes is called electroencephalogram or EEG. The EEG records the signal of the specific brain region where the electrodes are placed. Five major brain waves can be distinguished by their frequency ranges, namely Delta (δ) 0.5–4 Hz, Theta (θ) 4–8 Hz, Alpha (α) 8–13 Hz, Beta (β) 13–30 Hz and Gamma (γ) 30–128 Hz (Basar et al. 1995). In this

research, the BIOPAC data acquisition unit (MP150) and AcqKnowledge 4.3 software from Biopac Systems Inc. are used for data acquisition, analysis, storage, and retrieval. Silver chloride electrodes were applied following the 10–20 system. The EEG is recorded at 500 samples/sec with a resolution of 12 bits/sample. The data is digitally filtered using 1–50 Hz band pass filter. Each of the participants underwent continuous electroencephalographic record of their brain wave activity, at rest with eyes closed for 3 min, and during a continuous performance task of approximately from 60 to 80 minutes long. The neurofeedback training sessions took place in a quiet, dimly lit room in the Bioinformatics and Human Electrophysiology Laboratory in Corfu to ensure reduced distraction (Howells et al., 2012).

Methods

Neurofeedback treatment was performed based on enhancement of Alpha-Theta ratio in the C4 region and SMR-low Beta ratio enhancement in the P4 region. EEG biofeedback training is an operant conditioning technique used to reinforce or inhibit specific forms of EEG activity. In the Alpha-Theta protocol employed by the Peniston studies, low-frequency EEG activity was reinforced. The efficacy of Alpha-Theta EEG biofeedback may lie in its ability to allow participants to better tolerate stress, anxiety, and anxiety-eliciting situations, which are particularly evident during the initial phases of recovery (Scott et al. 2005).

The Alpha-Theta state is believed to promote self-awareness, as well as a spiritual and intuitive enhancement (Gruzelier 2009). During the neurofeedback training and while participants are dealing with the algorithmic tasks, a visual guidance is provided in order to keep stress effect and anxiety at low levels. Recurrent audiovisual reminders of encouragement are provided to the participants in order to remain calm and stay focused. In addition, they were frequently repeatedly to check their breathing and breathe tranquility with the use of audiovisual guidance which is related to performance expectancy effect.

At the initial phase of neurofeedback training, Alpha-Theta ratio is enhanced while participants relax with their eyes closed while hearing pleasing sounds, such as waves gently crashing on the beach or a babbling brook. In this stage, the low frequencies are reinforced, namely Alpha ratio (8-12Hz) and Theta ratio (4-8 Hz) respectively while Delta ratio (0.5-4Hz) and Gamma ratio (32-60 Hz) were suspended (Basar et al. 1995). The participants remain for a time interval in a relaxing state, which is essential in order to feel calm, to minimize the stress effect and enhance the quality of learning during the neurofeedback training. Participants are guided in relaxing situations, to reinforce the intuitive perception and to come into deeper levels of consciousness (Holten 2010).

After this stage, the participants are considered to be free of stress and in the state of mental clarity in order to deal with the algorithmic tasks in order their performance to be evaluated. During their engagement with the given processes, the Beta SMR protocol is applied and signals of their brain are recorded. According to the Beta SMR training protocol the low Beta ratio (12-15 Hz) is enhanced and this is

related to high alertness, concentration and focused attention. The Beta SMT protocol is often used for treating ADHD, and other disorders (Holten 2010).

The analysis of the electrical signals obtained from the brain to assess cognitive effects is used in order the learning ability of the brain on the algorithmic thinking to be understood and to provide suggestions for novel and improved learning methods and learning approach. An essential element of the research is the use techniques for the reduction of artifact effects and the elimination potential conflicts and limitations of the above process (Delorme et al. 2007).

EEG Analysis

In the case of this work, identical features of the EEG signals such as mean and standard deviation have been extracted using statistical analysis to detect the predetermined mental states. Mean computes the mean amplitude value of the collected EEG data samples between the endpoints of the selected area. Equation (1) is used to extract the mean value of EEG signal, where, n_s represents starting point and n_e represents the ending point of the sample of data and the total number of samples and i represents the values of points at horizontal axis and $X_{i\ EEG}$ is the values of points of a curve on the vertical axis (Islam et al. 2015).

$$mean = \frac{1}{n_e - n_s} \sum_{i=n_s}^{n_e - n_s} x_{i_{EEG}} \quad (1)$$

Standard deviation measures the amount of variation or dispersion from the average of the selected EEG data Standard deviation computes a standard deviated value from the mean value of the EEG data samples between the endpoints of the selected area. The formula used to compute standard deviation is shown in Equation (2) where X_{EEG} is the mean value of the EEG data set (Islam et al. 2013).

$$Stddev = \sqrt{\frac{1}{n_e - n_s - 1} \sum_{i=n_s}^{n_e - n_s} (x_{i_{EEG}} - \overline{x}_{EEG})^2} \quad (2)$$

ANOVA analysis results - Mean values of EEG signal

The comparisons were conducted with analyses of variance (ANOVA), alpha was set at P (0.05). The obtained data were analyzed using STATA software, version 13.0 (StataCorp L.P. 2007). A post hoc analyses were conducted for each epoch (Holmbeck 2002). The epochs that were compared in this analysis concerns the time period that participants were dealing with the algorithmic tasks. The difference between the control and neurofeedback group is also evaluated by determining the mean values of the each epoch respectively. In the case of the overall EEG signal evaluation, the p-value of the mean value was computed to be 0.8025 suggesting no

significant difference between the groups. No significant difference was found is the case of the mean Alpha ratio in the same epochs (p-value=0.1600). The mean Beta wave comparison between the two groups suggest no significant difference in this ratio as well (p-value=0.1968). In the case of the Theta and Delta, mean value results reveal no significant difference (p-values 0.5357and 0.5130 respectively). The overall differences are not considered to be significant, therefore no further analysis is conducted.

ANOVA Analysis results – Mean SD values of EEG signal

A post hoc analyses were conducted for significant interactions for the task solving phase (Holmbeck 2002) . In the case of computing the Standard Deviation (SD) of the overall EEG wave the mean values of SD for the control and neurofeedback group are 871959.2 and 1.2e+06 while the standard deviation for these values is 765448.7 and 963976.2. This difference is considered to be highly statistical significant whereas the p-value is 0.0450. As noticed in Figure 1, in the 3rd epoch the EEG Standard Deviation for the CG and NFB group differ significantly (p-value = 0.0636). In particular, the mean value of the SD for the CG and the NFB group is 761042.6 and 1918752 respectively, while the standard deviation between these values is 409981.8 and 2107168 respectively. The difference between the mean values of SD for the overall EEG recording for the two groups is statistically high significant for the 5th epoch where the p-value was computed to be 0.0170. The mean of the SD value is 644995.8 and 1259369 for the control and neurofeedback group respectively. In reference to the 6th epoch the difference is significant as well (p-value = 0.0553) and the corresponding values for the mean of SD values for the CG and NFB group respectively are 900777.2 and 1478930. Additionally, the difference of the SD between the two groups is additionally significant (p-value = 0.0463) in the 8th epoch (mean SD values 791376.8 and 1363176 for the CG and NFB group respectively). The p-value is computed to be 0.0255 for the 8th epoch and the mean SD values are 647943.2 and 1247700 respectively for the two groups). A highly significant difference is also noticed in the 10th epoch (p-value =0.0057) where the mean of the SD values were 651702.2 and 1020758 in respect with the two groups. In Figure 1 the mean SD values of EEG signal for each epoch for neurofeedback and control group is presented.

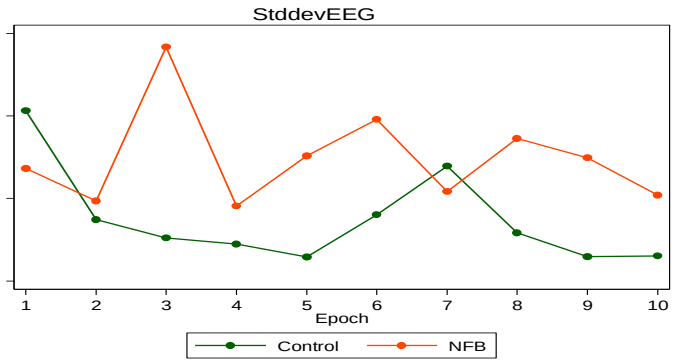

Figure 1: Mean SD values of EEG signal and epochs (p-value= 0.0450)

ANOVA Analysis results – Mean SD values of Alpha ratio

A post hoc analyses were conducted for each epoch in the case of the Alpha ratio for the tasks solving phase as well (Holmbeck 2002). A highly significant difference is noticed in the case of evaluating the SD value in reference to the group Alpha wave recording. In particular, the p-value was computed to be 0.0164 and the mean of the SD values of the overall Alpha wave was 276621.9 to 390334.2 and the standard deviation 239091.2 to 235885.3 for the CG and NFB group respectively. In Figure 2 the significant differences in several epochs between the two groups are presented. Specifically, for the 3rd epoch, the p-value is 0.0493 and the SD mean values 238317.6 and 461278.7 for the control and neurofeedback group. In the 4th epoch, the difference was not highly significant (p-value = 0.1949) while the mean of the SD values for the CG and NFB group was 225396.4 and 299390.8 respectively. Highly significant was the difference in the Alpha SD values in the 5th epoch (p-value = 0.0046), namely the mean SD value is 200000.6 (control group) and 420857.9 (NFB group). In the case of the SD values in the 6th epoch, the difference is considered to be statistically significant (p-value = 0.0431) while the SD mean values are 288489.7 and 499927.3 for the CG and neurofeedback group respectively. A significant difference is noticed as well in the 8th epoch where the p-value was computed to be 0.0960. The mean value of the standard deviation of the Alpha wave is 259401.5 for the control and 399353.1 for the NFB group. A statistical high difference comparing the Alpha ratio standard deviation is noticed in the 9th epoch (p-value = 0.0039). More specifically the mean value of the control group is 200599.1 and 407196.4 for the neurofeedback trained group. For the 10th epoch, the difference is statistically significant as well (p-value = 0.0083). The SD mean values were computed from 221756.3 to 330295.5 for the control and NFB group respectively. In Figure 2 the mean SD values of Alpha ratio of each epoch in respect with the neurofeedback and control group is presented.

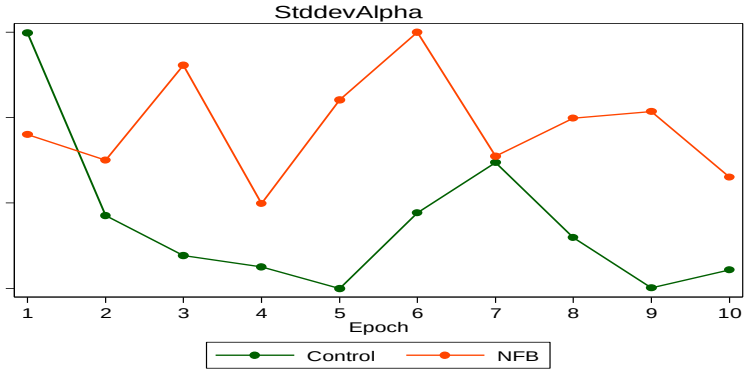

Figure 2: Mean SD values of Alpha ratio and epochs (p-value= 0.0164)

ANOVA Analysis results – Mean SD values of Beta ratio

In reference to the overall standard deviation for the Beta ratio the mean SD values for each epoch are evaluated. A post hoc analyses were conducted for each of the ten epoch (Holmbeck 2002). The overall difference between the mean SD values is presented in Figure 3 and is considered to be statistically significant (p-value=0.00184). The Beta ratio standard deviation mean values were measured to differ significantly, namely 306497.4 and 418220.8 for the SD values of the control group and the neurofeedback group respectively. While checking specific epochs of interest interesting findings are noticed. Namely for the 4th epoch, the p-value was computed to be 0.0656 suggesting that there is a significant difference for the analyzing variable. Respectively the control group SD means value was 247671.9 while for the Neurofeedback group was 342117.8. The p-value for the 5th epoch was 0.0043 suggesting the strong difference between the control and NFB group SD value of Beta rhythm. In particular, the mean SD value for the two group respectively was 227943.1 and 476191.8 for the CG and NFB group. In the 6th epoch, a significant difference occurs where the p-value was 0.0101. The mean SD values 276166.7 and 544131.2 for control and neurofeedback trained group respectively. The difference noticed in the 8th epoch is a result of the difference of the control group mean value in reference to the standard deviation of Beta rhythm (298722.1) and the NFB group mean value 421896.5 (p-value is 0.0792). The p-value (0.0029) for the 9th epoch suggest a statistically significant difference, namely, mean SD values 236203.8 and 422940.5 for the CG and NFB group respectively. Finally, the p-value computed to be 0.0007 in the 10th epoch suggest the statistical strong difference between the two groups in terms of mean SD values (243514.8 and 360507.1). In Figure 3 the mean SD values of Beta ratio of each epoch and both groups is presented.

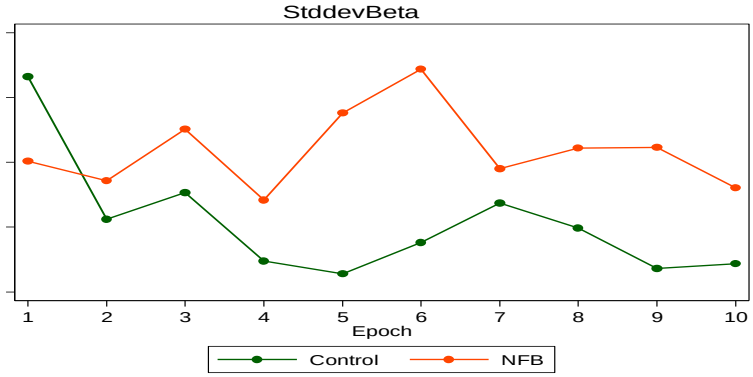

Figure 3: Mean SD values of Beta ratio and Epochs (p-value= 0.0084)

ANOVA Analysis results - Mean SD values of Theta ratio

A post hoc analyses were conducted for each epoch of the Theta wave as well (Holmbeck 2002). While referring to the difference noticed between the overall standard deviation values of the Theta ration the p-value was computed to be 0.1025 while the mean SD value of the control group was 354919.2 and mean SD value of the neurofeedback group was 343866.9. For the 3rd epoch in the case of the Theta overall standard deviation, the p-value was computed 0.0445 suggesting a significant difference between the two groups and the mean SD values, were computed 277031.2 and 652867.1 for the CG and NFB group respectively. For the 5th epoch, the overall p-value of the Theta ratio mean SD values was 0.0298 suggesting that the difference is statistically significant while the mean SD value were 271783.1 for the control group and the 492101.2 for the NFB group. In the case of the 9th epoch, the p-value = 0.0250 suggests a significant difference between the mean SD values (247834.8 and 478178.7) of the two group respectively. The difference in the 10th epoch is less significant (p-value = 0.0989) thought the mean SD values differ for 273075.5 to 372330.4 for CG and NFB group respectively. In Figure 4 the mean SD values of Theta ratio of each epoch and both groups is presented.

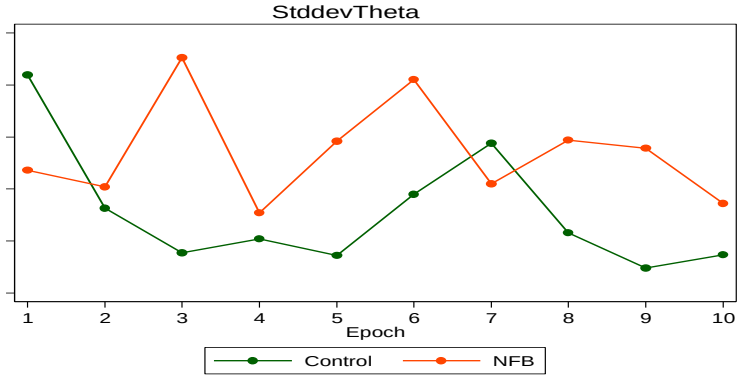

Figure 4: Mean SD values of Theta ratio and epochs (p-value= 0.1025)

ANOVA Analysis results – Mean SD values of Delta ratio

A post hoc analyses were conducted for significant interactions for the specified epochs for Delta ratio (Holmbeck 2002). In the case of the overall Delta wave standard deviation evaluation, the p-value is 0.1047 suggesting no significant difference between the two groups. Specifically, the mean SD values vary from 625898 for the control group to 898491.3 for the NFB group respectively. In the 3rd epoch, the p-value was 0.1093 suggesting a difference between two group, namely from 552416.8 to 1452849 and respectively for the CG and NFB group. In the 5th epoch the difference is even more significant (p- value = 0.0645) and the difference between the mean SD values are from 458259.9 to 868494.4 for the CG and NFB groups respectively. The significance of the two groups is even higher in the 8th epoch (p-value = 0.0490) and the original differences between the two groups in reference with the mean values are from 550625 to 1046021. The difference is statistically important as well in the case of 9th epoch where the p-value is computed to be 0.0594. The difference in respect the mean SD values vary from 456918.7 to 945125.6 for the CG and the NFB trained group respectively. For the 10th epoch, the difference is statically significant (p-value = 0.0133) and the mean SD values are 454835.6 and 751535.4 for the control and neurofeedback group respectively. In Figure 5, the mean SD values of Delta ratio for each epoch of neurofeedback and control group is presented.

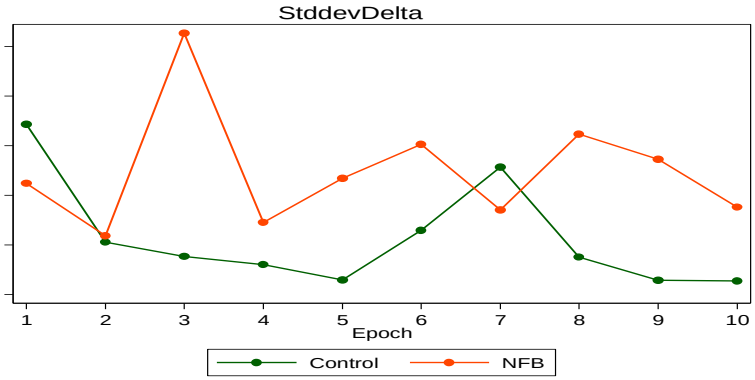

Figure 5: Mean SD values of Delta ratio and epochs (p-value= 0.1047)

Discussion and conclusions

The analysis of electrical signals obtained from the brain by means of a sensor system is conducted in order to assess the cognitive functions associated with algorithmic thinking in order to enhance the educational process. The comparison between neurofeedback and control groups showed that the effect of real neurofeedback therapy was significant versus the control group. The difference between the control and neurofeedback group was evaluated by analyzing the variations of the mean and standard deviation values of each ratio and epoch respectively. In the case of the overall EEG signal evaluation, the p-value of the standard deviation value was computed to be 0.0450 suggesting a highly significant difference between the groups with the NFB values to be higher. A highly significant difference was found is the case of the mean SD values of the Alpha ratio for each epoch (p-value=0.0164) while the NFB group values were significantly greater. The mean SD values of the Beta wave comparison between the two groups suggest a really high significant difference in this ratio with the NFB group values to be superior as well (p-value=0.0084). In the case of the Theta and Delta, standard deviation value results reveal a significant difference (p-values 0.1025 and 0.1047 respectively) with the NFB trained group values to be larger. These findings suggest that the variations of the brain activity in the case of the neurofeedback trained group are statistically significant. These findings are also related to the enhanced performance that the neurofeedback group posed while dealing with the given algorithmic problems. Not only the Mean SD values were noticed to differ significantly, moreover, the mean SD values of the NFB trained group are higher. Mean values in respect to the different recorded EEG sub-bands were noticed to vary as well, and the mean SD values are noticed to higher in the case of the neurofeedback trained group. Nevertheless, this difference was not considered to be significant, there for no further analysis was conducted. Author's future directions are addressed towards a follow-up study to confirm the overall signal variance stability over time.

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