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Effect of neurofeedback on anxiety, dyslexia, and dysgraphia in elementary students affected by attention deficit hyperactivity disorder: a pilot study

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Abstract

Background: Neurofeedback as a behavioral technique has an important role in attending to internal changes alongside strengthening and increasing the focus and attention of children in certain fields.

Objectives: To investigate the effect of neurofeedback on anxiety, dyslexia, and dysgraphia in elementary students affected by Attention Deficit Hyperactivity Disorder (ADHD).

Methods: Five elementary school students from Yazd, Iran, with ADHD were included in this pilot study. Based on their EEG patterns, brainwave training was carried out using the neurofeedback method. The participants received 30 sessions of neurofeedback treatment, three times per week, for 10 weeks. Before and after neurofeedback training, the participants' performance was evaluated using EEG, the Beck Anxiety Inventory (BAI), the Conners' Parent Rating Scale (CPRS) for ADHD, and the Conners' test for dyslexia and dysgraphia.

Results: Neurofeedback improves dyslexia and dysgraphia, indicating significant improvement in the participants' learning performance after neurofeedback ($p = 0.000$ and $p = 0.001$, respectively). However, there was no significant difference in anxiety levels ($p = 0.178$) before and after neurofeedback.

Conclusion: Neurofeedback enhances dyslexia and dysgraphia but does not have a significant impact on anxiety in elementary school students.

Keywords: Neurotherapy, Neurofeedback, Attention Deficit Hyperactivity Disorder (ADHD), Dyslexia, Dysgraphia.

Introduction

Many experts believe that partial injuries to the brain, as part of the central nervous system, and biochemical and genetic factors are the major causes of learning disorders.[1] According to these studies, there is a specific role for the frontal lobe in learning disorders.

The frontal lobe has administrative functions in designing and organizing sources. Additionally, it plays a crucial role in mediating intermediate preventive behaviors such as controlling movement behaviors and preventing fixation on irrelevant or distracting stimuli.[2] Furthermore, evidence suggests that right frontal lobe

dysfunction underlies attention deficit disorders.

Learning disorders begin in preschool and persist throughout adulthood.[3] Learning disorders are among the most prevalent issues faced by students, with dyslexia being the most significant and affecting approximately 75% of children and adolescents with learning disabilities.[4]

Dyslexia is characterized by difficulties in word recognition, slow and incorrect reading, and poor comprehension. Studies estimate the prevalence of dyslexia to be between 2% and 8%, with boys being three to four times more likely to be clinically referred than girls. However, recent epidemiological studies have shown that the incidence of dyslexia is similar in both boys and girls.[5-7] A meta-analysis found that the prevalence of dyslexia among Iranian students is 4.58%.[3]

Regarding this issue, psychological interventions can play a crucial role in reducing children's fear and anxiety. One such method and treatment is neurofeedback. The neurofeedback method has been used for treating anxiety since 1970. Kamiya and Klitman were among the early researchers who explored this approach. Alpha waves, characterized by high and smooth voltage waves between 8 and 12 Hz, have been shown to promote relaxation.[5] Neurofeedback leverages the brain's electrical activity to create an optimal state of functioning in any given individual.[6,7]

The process of neurofeedback involves learning or teaching self-regulation of the brain's activity. The brain regulates blood flow through the expansion or contraction of blood vessels, and blood flow to specific areas of the brain is increased based on the level of activity in these areas during self-regulation.[8]

The neurofeedback objective is to normalize abnormal neural frequencies by raising awareness of EEG patterns.[9,10] Neurofeedback provides us with computer-based information by recording brain function and presenting the physiological information that has been emitted through brainwaves.

A computer's output is based on operant conditioning theory and positive and negative reinforcement. Neurotherapy generates the electrical impulses, and the amplitude is achieved through separate filtered frequency bands. Therefore, the client is provided with visual and auditory information during the session, and the use of a computer enables individuals to modulate their brainwave activity within a specific bandwidth. During a neurofeedback training session, the client can learn to modify their brainwave patterns and enhance their optimal level.[11,12]

The studies suggest that the highest frequency of EEG abnormalities in children with learning disorders is associated with increased theta activity compared to typical peers and decreased alpha activity in children with a learning disorder during rest. This highlights the importance of these brainwaves for proper mental task performance in relevant areas in both normal children and adults. These findings imply that strengthening theta/alpha reductions through training can help normalize EEG patterns and improve cognitive and behavioral functions in children with learning disabilities.[11]

The neurofeedback mechanism arose from neurophysiological research that revealed a link between the EEG and the infra-thalamocortical systems that control EEG rhythms and frequencies. A neuronal injury can alter EEG rhythms and frequencies, while neurofeedback training can normalize these rhythms, leading to sustainable clinical improvements. Numerous studies have shown that individuals with learning disabilities, specifically dyslexia, have abnormal EEG readings, characterized by reduced or absent alpha 12 slow waves, primarily within the theta frequency range (13:1 ratio), when compared to their healthy peers. Neurofeedback, according to the researchers, works as a mechanism that uses feedback from the brain's electrical activity during operant training to change aberrant brainwave patterns.[11,13]

In fact, neurofeedback through operant conditioning leads to a simultaneous increase in the client's sensorimotor rhythm, or beta-brain waves, at specific brain points with no suitable frequency. This conditionality can decrease theta brain waves at the most common points, while SMR (sensory motor rhythm) or beta frequency increases.[11] Comprehensive exercises such as neurotherapy modify the underlying causes of disorders.[11,14] Neurofeedback can be used to treat

aggression,[15] anger,[16] depression, anxiety, and mood disorders.[17,18] Finally, considering the intensity of anxiety in children, it may develop into debilitating dimensions and a sense of impending helplessness, which can impact both the child and their family. Given the limited number of studies examining the effectiveness of the neurofeedback method in reducing such anxiety, this investigation is essential.

Objectives

The purpose of this study was to investigate the effectiveness of neurofeedback in anxious children with learning disorders.

Methods

This pilot study employed a pretest-posttest design on a single sample of five third-grade elementary students with learning disorders in Delhi. Using purposive convenience sampling, we selected five subjects with learning disorders from those referred to the center based on matching criteria including age, intelligence, school grade, and absence of seizures, anemia, or other disorders. We collected baseline measures of electroencephalography (EEG), writing ability, reading comprehension, and anxiety levels using standardized tests before the diagnosis of learning disorders by a physician at the center. Following diagnosis, the participants received neurofeedback training three times per week for ten weeks.

An EEG was collected first, followed by electrode placement based on the International 10-20 method and particular frequency spectrum. Each therapeutic session consisted of two 10-minute protocols. During the first protocol, the active electrode was connected to the FCz site, while the ground and reference electrodes were connected to the ears. Training was conducted according to the frequency spectrum of the EEG, involving a decrease in alpha (8–12 Hz) and theta band (4–7 Hz) activity. In the second protocol, the active electrode was connected to either the P4 or Pz site, while the other two electrodes were connected to the ears with increased alpha band activity.

Notably, Pz and P4 sites were used interchangeably between sessions. If a subject exhibited long beta waves in the specified areas, they were concurrently inhibited in both the occipital and frontal regions, or as an additional protocol, during therapy sessions lasting 20 to 30 minutes. A positive mark was awarded to a subject who maintained a decreased alpha (8–12 Hz) and theta wave (4–7 Hz) below the predetermined threshold for at least 0.5 seconds. This positive mark was visually displayed on an open page on a computer screen and verbally communicated to the subject as feedback. This process continued until the conclusion of the therapeutic session.

Statistical analysis

Data analysis was performed in two statistical levels, namely descriptive statistics (mean value and standard deviation) and inferential statistics (paired t-test) by means of SPSS software version 20. Data from electroencephalography was inserted into the NeuroGuide software, and the wave differences were calculated.

Ethical considerations

This article is an extract from a student's thesis submitted for a Master's degree at the Islamic Azadd University, Yazd Branch, which was registered with the Research Council under No. 920144491. Neurofeedback is generally acknowledged as a safe intervention for enhancing electroencephalographic flexibility; however, some individuals experience adverse effects (fatigue, depression, dizziness, headaches, low head pressure, muscle tension, social anxiety, and tiredness). Prior to initiating the intervention, we disclosed potential side effects to participants. Written informed consent was obtained from parents, and the principles set forth in the Declaration of Helsinki were followed.

Results

Five children were recruited for this pilot study from elementary school students with dyslexia and dysgraphia comorbid with ADHD, aged 10 years old. The sample consisted entirely of males (100%), with a mean age of 10.0 years. The assessment showed that neurotherapy was ineffective in reducing anxiety, as per the results shown in Table-1. According to the paired T-test (P = 0.178), the significance level is higher than 0.05, indicating no significant difference between the pre-test and post-test scores on the anxiety inventory. As such, we reject the

notion that neurotherapy is efficacious in treating anxiety. Furthermore, based on Table-2, the means of the anxiety variable (RQ) were found to be 14.2 and 14.6 for the pre-test and post-test, respectively. Consequently, it can be inferred that there was no notable improvement in the subjects' reading abilities following the neurotherapy intervention

According to the Table-3, the mean values of reading quality (RQ) pre-test and post-test were, respectively, 20.2 and 40. Therefore, the mean value of the subjects' reading quality did not increase significantly in the post-test based on descriptive statistics. Moreover, the mean values of writing quality pre-test and post-test were respectively 25.8 and 48.8, indicating a significant increase in the post-test regarding descriptive statistics [Table-4].

The mean value of reading quality pre-test was 20.2, which increased to 40 in the post-test. Similarly, the mean value of writing quality in students with learning disabilities was 25.8 in the pre-test and 47.8 in the post-test.

Table-1. The results of paired t-test (dependent t-test) on the mean value difference between pretest and post-test of subjects' anxiety

Mean value	Standard deviation	Standard error of the mean	95 % confidence level		T	Degree of freedom	Significance level
			Lower limit	Upper limit			
-1.633	4	0.178	-1.08009	0.28009	-1.633	4	0.178

Table-2. Descriptive statistics to compare pretest of anxiety inventory with its post-test

Test	Mean value	Number of subjects	Standard deviation	Standard error of the mean
ADHD pretest	14.2000	5	4.65833	2.08327
ADHD posttest	14.6000	5	4.77493	5.13542

Table-3. Descriptive statistics to compare pretest of reading disorder with its post-test on the subjects

Test	Mean value	Number of subjects	Standard deviation	Standard error of the mean
Reading quality pretest	20.2	5	6.42	2.87
Reading quality posttest	40	5	5.15	2.30

Table-4. Descriptive statistics to compare pretest of writing disorder with its post-test on the subjects

Test	Mean value	Number of subjects	Standard deviation	Standard error of the mean
Writing disorder pretest	25.8	5	5.40	2.42
Writing disorder posttest	47.8	5	5.98	2.67

As has been shown in Figure-1, there is an increase in previously enhanced occipital alpha waves. Similarly, frontal alpha waves, corresponding to ADHD, display a substantial reduction. Hence, it can be expected that with subjects' better focus on the reading disorder test, their performance in the reading post-test will enhance. As a consequence, neurotherapy proves to be effective in alleviating anxiety in children with learning difficulties.

In accordance with Table-5, the significance level of the paired t-test (P=0.178) is higher than 0.05, and thus, there is no considerable disparity between the pretest and post-test scores regarding anxiety inventories. Neurotherapy is also effective in improving dyslexia and dysgraphia in children with reading difficulties. Contrarily, the significance level of the paired t-test (P=0.000) is lower than 0.05, implying that students' reading proficiency has considerably advanced after neurotherapy [Table-6]. Furthermore, based on Table-7, the significance level of the paired t-test (P = 0.001) is lower than 0.05, resulting in a conclusive statement that the written work quality of students has appreciably improved after neurotherapy.

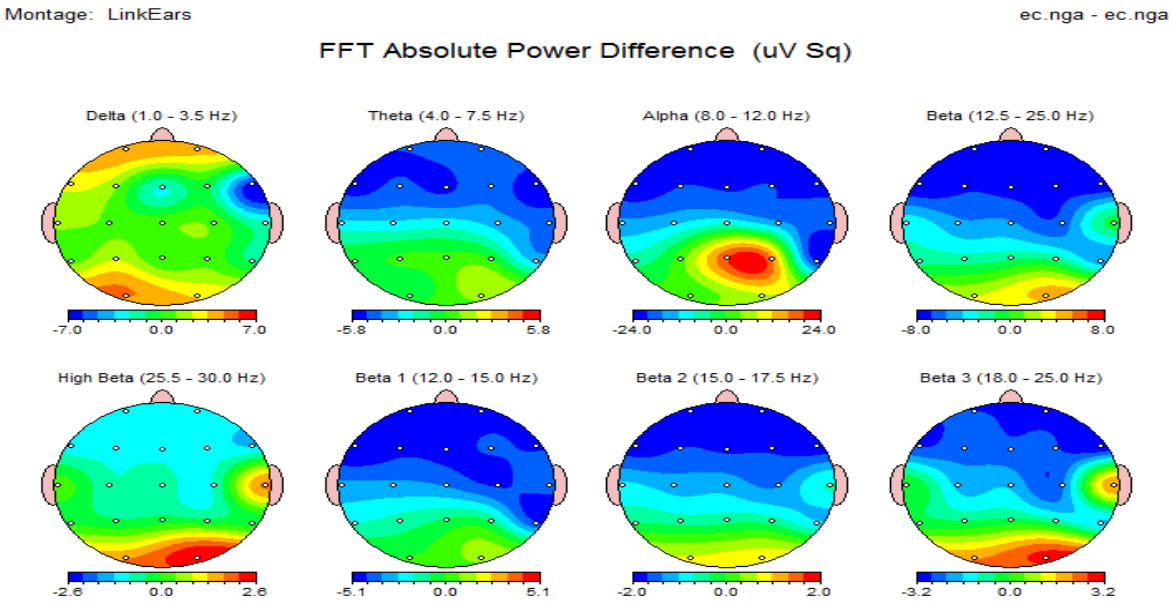

Figure-1. Analysis of data from EEGs and wave differences in pretest and post-test performed by NeuroGuide software

Table-5. The results of paired t-test (dependent t-test) on the mean value difference between pretest and post-test of subjects' anxiety

Mean value	Standard deviation	Standard error of the mean	95 % confidence level		T	Degree of freedom	Significance level
			Lower limit	Upper limit			
-1.633	4	0.178	-1.08009	0.28009	-1.633	4	0.178

Table-6. The results of paired t-test (dependent t-test) on the improvement of reading disorder in children with learning disorders

Mean value	Standard deviation	Standard error of the mean	95 % confidence level		T	Degree of freedom	Significance level
			Lower limit	Upper limit			
-19.8	3.49	1.56	-24.14	-15.46	-12.68	4	0.000

Table-7. The results of paired t-test (dependent t-test) on the improvement of writing disorder in children with learning disorders

Mean value	Standard deviation	Standard error of the mean	95 % confidence level		T	Degree of freedom	Significance level
			Lower limit	Upper limit			
-22	6.04	2.70	-29.50	-14.50	8.14	4	0.001

Discussion

The current research has piqued the interest of other scientists in the field of biofeedback to conduct similar studies to highlight the significance of this approach for treating not only learning disorders but also other psychiatric conditions. Our primary objective was to assess the efficacy of biofeedback in treating psychiatric disorders, particularly learning disorders. Specifically, our study aimed to investigate the impact of neurofeedback therapy on dyslexia, spelling disorder, IQ levels, attentional difficulties, and anxiety degrees in individuals with learning disorders. The differences in pre-test and post-test scores and t-test results showed that neurofeedback led to a reduction in the severity of dyslexia and spelling disorder symptoms. Additionally, neurofeedback had an impact on increasing IQ levels and decreasing attention deficit symptoms, although it had no significant effect on the anxiety levels of learning disorder patients. Our findings were contrary to previous research that has shown the effectiveness of neurofeedback in

reducing anxiety, as it demonstrates that individuals can be conditioned to improve their psychosocial responses and gain anxiety control skills. While all studies agree that neurofeedback can reduce anxiety and mood disorders by conditioning brainwaves in various age groups, our results indicate that individuals can decrease their anxiety by focusing on animated stimuli in a specific context and increasing their relaxation time through repeated sessions. It is worth noting that, through effective anxiety-reduction protocols, people typically experience relaxation within 5 minutes. By practicing and repeating certain techniques, an anxious individual can increase their ability to relax once they are aware of their body's physiological and nervous responses. The recommended method is safe, painless, and has not caused any adverse effects. Moreover, this technique allows individuals to learn how to reduce their anxiety without using any chemicals. Conscious and voluntary efforts are required to achieve this goal. It is also worth mentioning that neurofeedback can help a person regulate their mental state in a safe manner and develop strategies for dealing with anxiety-related thoughts throughout daily life.[18] Our study found that neurofeedback had no significant impact on the participants' anxiety levels, contradicting previous studies by Jahanian et al.[19] Conducted research titled 'Examining the Effect of Neurofeedback Training on Anxiety Reduction in Patients Attending Psychology Clinics in Isfahan.' The sample consisted of 18 male participants, aged 34 years on average, selected using the convenience sampling method. The inclusion criteria were anxiety scores above 35 on the scale. Participants underwent 15 neurofeedback sessions (each lasting 30 minutes). Age and gender were included as moderator variables. Subjects were then randomized into two groups: control and experimental. Both groups continued to receive pharmacotherapy throughout the trial, with no dose reductions or discontinuations. The treatment protocol involved using the FP1 site as bipolar and the CZ site as monopolar, per the International 10-20 system. Twenty sites were measured and selected based on this system.[20]

The method to be used was as follows: An Electroencephalographic Study of Neurofeedback Training for Anxiety Disorders

An electroencephalography (EEG) active electrode sensor was placed on the T3 site, and a flexible (Flex) electrode sensor was placed on the fronto-peronal (FP1) site. The reference electrode of both sensors was also located on the left ear, and two ground electrodes were located on the right side. Then, the participant's excitatory frequency was first obtained. In other words, the given frequency was suppressed within the range of 1 to 9 Hz, and the frequency of 10–13 Hz was amplified, while the frequency of 14–20 Hz was suppressed for eight sessions. Additionally, the frequency range of 1 to 11 Hz was suppressed for seven sessions at the central zygomatic (CZ) site, the frequency range of 12–15 Hz was amplified, and the frequency range of 21–30 Hz was suppressed in a monopolar style. After the end of 15 training sessions, Cattell's anxiety post-test was administered to the same subjects. The results of the present research indicate that neurofeedback significantly reduces participants' anxiety. These findings are consistent with the discoveries of previous studies conducted by Heidari and Saeidi[21] and Moore.[22]

According to Isotani et al., simultaneous increases in the client's sensorimotor rhythm or beta brain waves in certain brain areas with no adequate frequency are ineffective.[23] Conditionalization results in a decrease in theta brain waves in these areas while boosting the frequency of SMR, or beta waves. Overall, the study demonstrates that neurofeedback can minimize the occurrence of anxiety and mood disorders by training brain waves in various age groups. People will reduce their anxiety by focusing on the animations provided in specific situations and prolonging their relaxation sessions through repetition. According to our findings, anyone can experience relaxation within approximately 5 minutes of engaging in relaxation exercises. Anxious individuals can further enhance their relaxation through exercises once they are aware of the physical and nervous system changes they experience. Our research has disproved a previous hypothesis, and it may be due to the fact that our protocol, which involves reducing alpha and theta waves in front of the head while increasing alpha waves at the back of the head, is not effective in treating anxiety.

We observed that reduced frontal alpha waves associated

with ADHD were restored and increased occipital alpha waves boosted their attention based on a study of data from the post-test and the individuals' EEG. Additionally, reducing frontal alpha waves and increasing occipital alpha waves likely improved the memory abilities of the subjects. Consequently, they could concentrate more effectively during reading and writing tests and might perform better in the post-test. In summary, it appears that neurotherapy can serve as an approach to ameliorating dysgraphia in individuals with learning difficulties. Furthermore, our findings agreed with those of earlier studies conducted by Othmer et al.,[24] Fatollahpour et al.,[25] and Mousavi et al.[26] on the effectiveness of neurotherapy on dyslexia in children with learning disabilities.

On the contrary, our study findings indicate that the protocol of frontal alpha and theta reduction and occipital alpha enhancement may not be effective in treating anxiety. This contrasts with the findings of Heidari and Saeidi[21] and Moore.[22]

This research differs from Hammond et al.'s[18] and Heidari's[21] and Moore's[22] work, and our findings suggest that our hypothesis is effective in addressing learning disorders. Despite the need to test smaller sample sizes in studies on neurodevelopmental disorders, including randomized controlled trials evaluating treatment efficacy in learning disorders, it is important to acknowledge that plausible effect sizes in this field tend to be small. This is due both to the inherent limitations of psychological interventions and to the possibility of overestimating effect sizes when working with small samples. However, we hope that this article serves as a guide for future research involving larger samples and encourages further exploration of the potential benefits of neurofeedback training for enhancing cognitive function and neural dysfunction.

The limitations of this study include the use of convenience sampling and the small number of participants involved.

Conclusions

This study's findings suggest that our protocol of frontal alpha and theta reduction and occipital alpha enhancement may not be effective in treating anxiety.

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Competing interests

The authors of this manuscript have no invested interests in products described or used in this article. The authors have no conflicts of interest.

Abbreviations

Attention Deficit Hyperactivity Disorder: ADHD; Electroencephalogram: EEG; Beck Anxiety Inventory: BAI; Conner's Parent Rating Scale: CPRS.

Authors' contributions

ZJN and HM were responsible for study concept and design and also they Led data collection and analysis and interpretation of data. ZJN, HM, MY, RB, EH, AJ, ASH and SAG Wrote the first draft. RB, ASH, MY, SAG and AJ Contributed to the writing of the second and third draft drafts. All authors read and approved the final manuscript. All authors take responsibility for the integrity of the data and the accuracy of the data analysis.

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Availability of data and materials

The data used in this study are available from the corresponding author on request.

Ethics approval and consent to participate

The study was conducted in accordance with the Declaration of Helsinki. Institutional Review Board approval was obtained.

Consent for publication

By submitting this document, the authors declare their consent for the final accepted version of the manuscript to be considered for publication.

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