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The effectiveness of neurofeedback on attention, working memory, processing speed, and anxiety in dyslexic children

Roya Chegini[1], Sadegh Taghiloo[2], Javid Peymani[1], Peyman Hassani-Abharian[3]

1 Department of Psychology, Karaj Branch, Islamic Azad University, Karaj, Iran
2 Department of Psychology, Astara Branch, Islamic Azad University, Astara, Iran
3 Department of Cognitive Rehabilitation, Brain and Cognition Clinic, Institute for Cognitive Science Studies, Tehran, Iran

Original Article

Abstract

BACKGROUND: Presently, some treatments such as neurofeedback therapy (NFT) have become of great importance in the treatment of psychological disorders. Therefore, the aim of this study was to determine the effectiveness of NFT on attention and working memory, processing speed, and anxiety of dyslexic children.

METHODS: The research design was a quasi-experimental unbalanced control group with pre-test, post-test and follow up. The statistical population was all dyslexic children of 7-10 years of age in Karaj, Iran, from December 2021 to January 2022. The participants included 45 dyslexic children who were randomly divided into 3 groups of 15 people. The first and second groups received cognitive rehabilitation and NFT, respectively, and the third group received no treatment (control group). NFT was presented in 15 sessions (30-minutes) in the experimental groups. The instruments included the Integrated Visual and Auditory Continuous Performance Test (IVA+Plus), Wechsler Memory Scale (WMS), Clinical Q Assessment, and the Spence Children's Anxiety Scale (SCAS). SPSS software was applied for data analysis.

RESULTS: The findings showed that after NFT, the scores of the experimental group in all outcomes decreased in the posttest and follow-up phases ($P < 0.0001$).

CONCLUSION: It can be concluded that the educational content of NFT can be used to increase attention, working memory, and processing speed, and to reduce anxiety in dyslexic children. Therefore, it is suggested that the results of such studies be applied in educational fields.

KEYWORDS: Neurofeedback; Attention; Memory; Anxiety

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Introduction

Undoubtedly, reading is the most important and complex educational activity for children in the early years of school. Dyslexia is one of the most common types of Specific Learning Disabilities (SpLDs). In English-speaking countries, it is estimated that 10 to 12% of students have this disorder.[1] One of the important cognitive components that is effective in reading performance is executive functions. Executive functions, in particular the constituent components, can predict to some extent the development of individuals' academic skills.[2] It is believed that learning disabilities in SpLDs are caused by defects in the information processing system of people

Corresponding Author:
Sadegh Taghiloo; Department of Psychology, Astara Branch, Islamic Azad University, Astara, Iran
Email: taghilo@yahoo.com

with this disease, which include areas such as attention, memory, organization or other cognitive processes, inhibition, working memory, planning, and attention. As components of executive functions, they play an important role in the development of academic skills and, in particular, the performance of the individual in school.[3] Theoretically, Wankat argues that students with dyslexia have a short attention span. Their poor cognitive processing is associated with poor frontal lobe function. Decreased synaptic communication is another reason for poor cognitive processing.[2] Based on the theoretical framework, frontal and prefrontal areas are responsible for regulating sustained attention and cognitive processing of high-level functions.[1] Historically, research has shown that a large number of dyslexic students suffer from internalized and externalized disorders such as withdrawal, physical complaints, anxiety and depression, social problems, thinking disorders, aggression, and delinquent behaviors.[4]

Attention is the directing of resources to a subset of existing information that is necessary for perception and without which there would never be sensory information.[8] Sustained attention refers to the maintenance of attention over time, which is the most basic and simplest level of attention and other types of attention need it. For this reason, a possible defect in it can indicate a defect in other types of attention.[9] Another factor that seems to be a major barrier to learning for children with learning disabilities is anxiety.[10] Anxiety has many negative effects on children. One of these effects is that working memory function decreases in children with high anxiety. As children with learning disabilities have poor learning skills and working memory function, it is likely that they have higher levels of anxiety than their healthy counterparts.[11]

Based on the literature, Becker et al. found abnormal brain activity, mostly in the amplitude of theta and alpha waves, in children with learning disabilities. The brain of these people goes to theta waves when performing cognitive tasks such as reading, calculating, or listening. Slow waves, such as theta, indicate disturbed brain activity, distraction, and lack of concentration.[12] Many researchers consider emotional disorders to be a direct consequence of dyslexia and its resulting failures, so dyslexia has an undeniable role in the development and exacerbation of mental disorders, but it is very difficult to determine its direct or indirect consequences. For these children, dyslexia is a type of failure that affects their emotional state and causes a range of anxiety and mood disorders.[5]

Numerous studies have shown that learning disabilities are related to how information is processed and cognitive processes in the brain.[6] Among the components of executive functions, working memory is a part of the high-level cognitive actions that are responsible for selecting, actively manipulating, and temporarily storing information input in the cognitive system using processing systems.[7]

Various methods can be used to examine brain waves and measure them, including Clinical Q. Clinical Q is a two-channel brainwave recording method that records EEG data in a series of steps and during several activities, including open eye, closed eye, and performing cognitive activity. The advantage of this method is the extraction of information from Clinical Q and their use in determining the neurofeedback treatment protocol, and finally, the treatment of clients. The information obtained from it is a guide to identifying the problems and characteristics of the individual.[13]

Students with dyslexia have many problems in the field of education, so there is a need to improve and increase their abilities with effective educational and therapeutic

methods. One of the relatively new methods in this field is neurofeedback therapy (NFT).[14] This approach is presented as a non-drug treatment strategy and a new self-regulatory approach that serves to increase self-control and self-regulation.[15] Theoretically, in the field of cognitive rehabilitation, NFT is a type of operant conditioning that teaches a person to increase or decrease their brain activity. Lubar as a pioneer of this approach argues that cognitive rehabilitation is achieved through making changes in the frequency of brain waves.[16]

Wang and Hsieh found that NFT is effective on beta/beta ratios, theta/beta ratio, beta balance, increase in alpha (Clinical Q) and attention, sequential processing, concurrent processing, and mathematical skills.[17] In another research on the effect of NFT on attention and working memory, the results showed that, in the educational group, attention scores increased significantly, and in the experimental group, NFT increased the performance of working memory.[18] The results of another research on NFT in elementary school students or children with specific disorder suggest that this treatment has a significant effect on improving their attention span and working memory.

Dyslexia is prevalent in around 8% of children according to statistics, and this issue affects their other educational and developmental dimensions. In addition, 25% of students experience interpersonal problems and academic failure. Moreover, most of them are weak in other personal and social areas. The parents of these children also complain about their aggression and impulsivity at home.[15] Psychologically, helping to alleviate the problems of these students will improve their educational, interpersonal, and social levels. It also improves their self-esteem and emotional problems.[12] In sum, this disorder can affect other individual and social functions of children and cause emotional problems for children. Furthermore, NFT is a non-invasive and very low-risk treatment option in therapeutic situations. Moreover, a large body of research has shown the effectiveness of NFT on increasing executive functions. In addition, due to the novelty of this study, most previous studies have focused on the effect of neurofeedback on improving attention and processing speed, and it seems that there are no detailed experimental studies on the effect of this new treatment in dyslexic children. Therefore, the field of NFT in increasing executive functions and reading levels in children with reading disorders has not been studied thus far. Thus, this research can help to expand the understanding of experts, including psychologists, counselors, and education specialists, in solving children's cognitive problems and ultimately help these students.

Thus, the aim of this study was to determine the effectiveness of neurofeedback on attention, working memory, processing speed, and anxiety in dyslexic children.

Methods

The design of the present study was a quasi-experimental group of unbalanced control groups with pretest, posttest, and follow-up. The statistical population of the study included all dyslexic children in schools in Karaj, Iran, who were referred to the Irana Counseling Center from December 2021 to January 2022. All participants were matched in terms of age, educational status, economic status, and other socio-economic variables. They were matched in three groups (Exp 1: cognitive rehabilitation, Exp 2: NFT, and Control group). Moreover, SPSS software (version 22, IBM Corp., Armonk, NY, USA) was applied for the analysis of the data. In addition, the significance level was considered less than 0.05.

To determine the sample size, the following formula was used:

$$n_1 = n_2 = \frac{(S_1^2 + S_2^2)(Z_{1-\frac{\alpha}{2}} + Z_{1-\beta})^2}{(\bar{X}_1 - \bar{X}_2)^2}$$

X1 = 2.75, X2 = 2.44, S1 = 0.7, S2 = 0.4,
Z1-a/2 = 1.96, Z1-B = 0.84, a(alfa) = 0.05,
B(beta) = 0.2, N = 45

The inclusion criteria for the intervention program were receiving a diagnosis of dyslexic disorder, no history of psychosis and disorder according to the psychiatrist, age range of 7 to 10 years, not receiving medication or other psychological treatment at the time of diagnosis, lack of acute psychiatric disorder and other comorbidities, and not having the consent and declaration of conscious and voluntary readiness to participate in the research. The exclusion criteria were lack of exposure to drug poisoning or drug withdrawal.

Written informed consent was obtained from parents in their native language. All activities of this trial from the beginning to the end have been approved by the ethics committee of Karaj Islamic Azad University, Iran. Moreover, its process was in accordance with the Declaration of Helsinki and its principles.

Integrated Visual and Auditory Continuous Performance Test (IVA+Plus): Integrated Visual and Auditory (IVA) + PLUS test is based on the DSM-IV Diagnostic and Statistical Manual of Mental Disorders and is used to diagnose and distinguish attention deficit hyperactivity disorder (ADHD) types including ADHD (Impulsive), combined type and type unknown (NOS). In addition, this test is used to examine other problems and disorders such as self-control problems related to head injuries, sleep disorders, depression, anxiety, learning disabilities, dementia, and other medical problems. This test is applicable for people 6 years and older and adults. The duration of this test (including the training section) is about 20 minutes. The test task includes answering or not answering (inhibiting the answer) to 500 test stimuli. Each stimulus is delivered for only one and a half seconds. Therefore, the test requires maintained attention. The results of studies show that the IVA + PLUS test has sufficient sensitivity (92%) and correct predictive power (89%) to correctly diagnose ADHD in children. The validity of the test in the open test method shows that the 22 IVA scales have a direct and positive relationship with each other (88%-46%). In general, the findings show that this test has good and high validity and validity in assessing attention, accuracy, and diagnosis of ADHD.

Wexler working memory software: This software was designed by Wexler in 2003 based on a subscale of the Wechsler Memory Scale (WMS) with the ability to measure general verbal comprehension, perceptual reasoning, working memory processing speed, and overall IQ, and can be used to measure memory in children and adults. The internal consistency coefficient of the WMS is very high and has a validity coefficient higher than 90. Test validity was assessed using pretest-posttest assessment, and showed a validity coefficient of 80-89.[20] In Iran, the reliability of this test was 0.74 using Cronbach's alpha method and 0.75 using the halving method.[13]

Clinical Q Assessment: Clinical Q is a method of evaluating and determining the treatment protocol for neurofeedback. This method is not weaker than Quantitative electroencephalography (QEEG), 19 channels, the purpose of using clinical Q is to make the neurofeedback treatment process more effective, using this method reduces the number of neurofeedback sessions.[23] The advantage of this method is that in the process of evaluation and treatment, harmonies are played and the brain's response to them is measured. The four harmonies of CERN, SWIP, Mozart, and Amen are used in this process. The recording process is done in 4 steps through 2 channels; in addition, 2 electrodes are installed on the head and 2 electrodes are installed on each ear. In the first

stage, the electrode of channel A is on F4 and channel B is on CZ. Clients were told to count down from 1 to 20, and then, open their eyes for 15 seconds and play the harmony for 30 seconds. In the second stage, the electrode of channel A is fixed and channel B is transferred to O1, and the first 30 seconds of open eye, the next 20 seconds of closed eye, and the last 20 seconds of closed eye are recorded. In the third stage, channel A is fixed and channel B is transferred to point 3 F, and the blindfold recording is performed for 45 seconds. In the fourth stage, channel A is fixed and channel B is transferred to point Z F and the blindfold recording is performed for 45 seconds. The whole process takes 5 minutes and 20 seconds.

Spence Children's Anxiety Scale: The Spence Children's Anxiety Scale (SCAS) was developed by Spence et al. and has been translated into Persian by Mousavi et al.[22-24] and has 39 questions that the educator or parents must answer.[25-27] This questionnaire has four factors, which are thoughts of general unhappiness and social inadequacy, worrying about others' awareness of anxiety, fear of negative evaluations, feeling of involuntary arousal and performance anxiety. The internal consistency of this questionnaire is 95% and the validity is consistent. The score of the Anxious Thoughts Inventory (AnTI) is 58%, and the Fear of Negative Evaluation Scale (FNE) of Watson and Friend is 60%.[28,29,8] These factors are positively and significantly associated with depression, anxiety, and indicators of mental distress in the General Health Questionnaire (GHQ). The internal consistency and the test-retest reliability of this scale were also desirable and satisfactory.[30]

Mousavi et al. reported a Cronbach's alpha of 87% for the Iranian version of the SCAS. They used two main tools of the metacognitive model, namely the Thought Control Questionnaire (TCQ) and the Anxiety Thoughts Questionnaire.[25] In another study, the Beck Depression Inventory-Second Edition (BDI-II), Beck Anxiety Questionnaire (BAI), Mental Health Questionnaire, TCQ, and Anxiety Thought Questionnaire were distributed among Students of Qazvin University; 528 students participated in the retest process after 2 weeks. Using exploratory factor analysis, the 5 interpretable factors of distraction, anxiety, social control, punishment, and re-evaluation were identified for the TCQ. Distraction was inversely related to the symptoms of depression, anxiety, physical symptoms, and social dysfunction. The factors of worry and punishment had a direct and significant relationship with the scores of depression and anxiety and all subscales of public health. Moreover, the internal consistency of the questionnaire factors and their test-retest reliability were satisfactory.

Neurofeedback training: In neurofeedback, sensors called electrodes are placed on the patient's scalp. These sensors record the electrical activity of a person's brain and show it in the form of brain waves (often in the form of a simulation, in the form of a computer game, or video film). In this case, playing a movie or directing a computer game is done without the use of hands and only with a person's brain waves. In this way, by seeing the progress or stopping of the game, receiving rewards or losing points, or changes that occur in the sound or play of the film, the person discovers the favorable or unfavorable conditions of his brain waves and tries to direct the game or film. For example, if the person is going to reduce their alpha wave, the game is played if the alpha wave is less than a specified limit. In this method, the child sits in front of a monitor and the electrode on the child's head receives the brain waves and directs them to the computer. The child can adjust and control the brain waves by seeing them on the monitor screen, and in all these steps, the therapist sits next to the child and gives the child instructions on how to do

this. Students are treated in 15 to 30-minute sessions.[35]

Cognitive Rehabilitation: The Cognitive Rehabilitation Training Package in this study was based on the 2010 Cognitive Rehabilitation Computer Program, which includes working memory enhancement, selective attention enhancement, sustained attention enhancement, and transitional attention enhancement. This program is a kind of software program that includes a group of hierarchically organized tasks that strengthen the various dimensions of working memory, including storage, transfer, instantaneous, and information control. Working memory tasks included the 3 types of updating, maintaining and transferring, tasks of searching for house stimuli to enhance selective attention, and tasks of finding similar images to enhance sustained attention, and tasks of sorting faces based on emotional manifestations to enhance transitional attention. The program was performed in 16 sessions of 31 minutes 2 days a week.[22]

All activities of this trial from the beginning to the end have been approved by the ethics committee of the Islamic Azad University, Karaj Branch (Approval ID: IR.KIAU.REC.1399.876).

Results

In total, 45 children (children of 7–10 years of age) were screened. The students were of both sexes. There is no significant difference in baseline characteristics of patients in term of age between the 3 groups (2 experimental groups and 1 control group). In order to evaluate the effectiveness of neurofeedback therapy on increasing attention, working memory, and processing speed, and reducing anxiety in dyslexic children, multivariate analysis of covariance (MANCOVA) was used. The significance level was considered to be 0.05. The results of MANCOVA along with the examination of its assumptions (Box's M test) were as Box's M = 15.014, F = 1.328, degree of freedom-1 (df1) = 10, df2 = 3748.207, P = 0.241.

Since Box's M test value (0.241) was greater than the significance level (0.05) required for rejecting the null hypothesis, the null hypothesis is confirmed based on the homogeneity matrix of covariance.

The Levene's test results are not significant in any of the variables. Therefore, the null hypothesis for the homogeneity of variance of the variables is confirmed (Table 1).

Table 1. Levene's test results in examining the homogeneity of variances

Variable	F	df1	df2	P
Attention	0.076	1	28	0.785
Working memory	0.967	1	28	0.334
Processing speed	3.350	1	28	0.078
Anxiety	3.651	1	28	0.066

df: Degree of freedom

Table 2 shows the results of the analysis of covariance (ANCOVA).

Table 3 shows the results of the inter-subject effects test regarding the comparison of attention, working memory, processing speed, and anxiety in the control and neurofeedback groups in the posttest stage.

According to the results presented in table 4, the value of F is significant for all variables at the level of 0.01 (P < 0.01). Therefore, the null hypothesis is rejected and the research hypothesis is confirmed.

Table 2. The results of multivariate analysis of covariance in the comparison of attention, working memory, processing speed, and anxiety in control and neurofeedback groups in the posttest stage

Effect	Tests	Amounts	F	df effect	Degree of error freedom	P	Effect size
Group	Pillai's effect	0.827	25.132	4	21	0.001	0.827
	Wilks' Lambda	0.173	25.132	4	21	0.001	0.827
	Hotelling's effect	4.787	25.132	4	21	0.001	0.827
	The largest root on	4.787	25.132	4	21	0.001	0.827

df: Degree of freedom

Table 3. Test of inter-subject effects in the comparison of attention, working memory, processing speed, and anxiety in the control and neurofeedback groups in the posttest

Variable	Source	Total squares	df	Average squares	F	P	Effect size
Attention	Between groups	61.277	1	61.277	36.891	0.001	0.606
	Error	39.864	24	1.661			
Working memory	Between groups	483.627	1	483.627	33.422	0.001	0.582
	Error	347.286	24	14.470			
Processing speed	Between groups	33.411	1	33.411	43.706	0.001	0.646
	Error	18.347	24	0.764			
Anxiety	Between groups	64.130	1	64.130	38.008	0.001	0.613
	Error	40.495	24	1.687			

df: Degree of freedom

Comparison of the mean scores of the two groups showed that in the neurofeedback treatment group, compared to the control group, there was an increase in scores of attention, working memory, and processing speed, and in contrast, a further decrease in anxiety scores in the posttest stage.

Discussion

The aim of the present study was to determine the effectiveness of NFT on attention and working memory, processing speed, and anxiety of dyslexic children. Findings showed an increase in scores of attention, working memory, and processing speed, and in contrast, a decrease in anxiety scores in the neurofeedback experimental group. The results of the follow-up test also showed that neurofeedback training led to significant differences in attention, working memory, processing speed, and anxiety of the tested group, indicating the continuation of the effectiveness of NFT. This finding is in line with the findings of Abbasi et al. (2020),[16] Wang and Hsieh (2013),[17] Crandon et al. (2022),[24] Smid et al. (2020),[27] and Singh et al. (2020).[31] Moreover, these results are inconsistent with that of some previous studies by Karamalian et al. (2020),[3] Sorrells and Dennis (2020),[5] Rahmani et al. (2022),[8] and Gordon et al. (2020).[13]

To explain the results, it must be acknowledged that the human brain is capable of self-healing, that is, the ability to learn or re-learn the self-regulating mechanisms of brain waves that play a key role in the normal functioning of the brain. Abbasi et al. (2020) on an Iranian sample of 25 children with dyslexia showed that brain waves are regulated after rehabilitation exercises.[16] Furthermore, Wang and Hsieh (2013) by examining the executive functions in 45 Chinese students with learning disabilities confirmed their emotional and cognitive dysfunction, and neuro-rehabilitation with the help of neurofeedback was able to help improve their cognitive functions.[17] Moreover, Singh et al. showed in a clinical study of 35 Singaporean students with hyperactivity and impulsivity symptoms that neurofeedback can help improve executive function by regulating brain waves by giving feedback to the student.[31] Thus, NFT actually strengthens the underlying self-regulatory mechanisms for effective functioning by giving feedback to the brain about what the person has done in the past few seconds and what the normal bioelectrical rhythms of the brain were, modifying the brain to correct its rhythms and encouraging the maintaining of proper activity. As a result, the brain is asked to manipulate different brain waves by producing more of some waves and producing fewer of others.[28] Rivera Perez et al., in an experimental study on 30 participants with dyslexic disorder, have suggested that the regulation of brain waves is the main component of NFT.[10] It should be noted that the findings of some studies have been

inconsistent with the results of the present study and have shown that neurofeedback is not effective in improving the executive functions of people with dyslexia. For example, Rahmani et al. (2022) in a meta-analysis in Iranian students found no significant benefits for NFT compared with other treatments or control conditions.[8] In determination of these findings, it should be noted that this study examined the evaluation of parents and teachers, and the undeniable point is that there may certainly be errors, misconceptions, and unrealistic expectations in their assessments.[8] Furthermore, in a 2020 study on a sample of 45 students with dyslexia, Gordon et al. (2020) did not confirm the effectiveness of neurofeedback in 10 sessions.[13] One possible explanation for this ineffectiveness could be sample heterogeneity and limited number of neurofeedback sessions.[5] The underlying mechanism of this change may be explained by the theory of factor conditioning, so that if a change in stimulus (amplitude of brainwaves) based on a predetermined contract is accompanied by the desired outcome (motion of video images or sound production), it will lead to learning, and this learning will be more effective when it uses simpler stimuli (such as NFT) that lead to receiving reinforcement. NFT alters the frontal lobe, affecting the cortex, motor sensory, and cingulitis in three parts. Sensory cortical action is more than just guiding sensory-motor functions, and it helps the cortex to encode cognitive and physical activity. Thus, people with cognitive tasks can benefit from the effects of neurofeedback on the left motor sensory cortex.[29] Rahmani et al., using an experiment design on 40 students with dyslexia disorder, have shown cognitive tasks and cognitive educations can be a practical part of NFT. Neurofeedback can also help the brain function properly by altering the profile of brain waves. This compensation for the abnormality helps the individual become more alert and able to increase his/her attention, and thus, show better cognitive function.[8] Moreover, using an experimental design for evaluating working memory and executive functions in dyslexic children, Finell et al. (2021) have confirmed the effectiveness of NFT. Neuropsychological studies have shown that people with ADHD show deficiencies in the development of synapses and neural connections. Thus, proper stimulation of the brain can help them to expand their synapses, establish normal activities, and improve their cognitive functions.[34] The results of another study showed that in clients with more severe social anxiety disorder who probably had high resistance to performing techniques and coping with anxiety situations, neurofeedback changed the expectation of clients, caused them to face anxious situations, and with reduced their anxiety symptoms.[18]

The present study had some limitations, that is, lack of a placebo-controlled trial. These limitations should be addressed in future trials. As a result, future randomized placebo-controlled trials can conduct more rigorous evaluations of patients during the process of treatment. Given the role of executive functions and attention and information processing in the creation, persistence, and exacerbation of dyslexia, it is recommended that children be examined for these structures before entering school. In addition, due to the effectiveness of NFTs in the treatment of dyslexia, it is suggested that treatment centers for learning disorders be equipped with neurofeedback and counselors and educators in the field, and have these therapies in their agenda. In future research, it is suggested that the effect of this treatment method on other groups of learning disabilities such as visual and auditory processing disorders and writing disorders be examined, or instead of examining the primary school level in general, a specific year group (such as the third year etc.) be researched.

Conclusion

The present study findings showed that after NFT, the scores of the experimental group compared to the control group were associated with increased attention, working memory, and processing speed, and decreased anxiety scores in the posttest and follow-up phase compared to the pretest. Therefore, based on the obtained results, NFT can be relied on as a complete and comprehensive treatment in the treatment of dyslexia symptoms.

Conflict of Interests

Authors have no conflict of interests.

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