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The effectiveness of neural feedback on executive functions, behavioral problems and clinical symptoms of attention deficit / hyperactivity disorder

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Abstract

Introduction: Research has shown that neural feedback creates a kind of two-way communication between mind and body that changes abnormal cognitive processes to normal cognitive processes. Therefore, the aim of this study was to evaluate the effectiveness of neural feedback on executive functions, behavioral problems and clinical symptoms of attention deficit / hyperactivity disorder.
Methods: The research is quasi-experimental design with pre-test post-test and three-month follow-up with experimental and control groups. The statistical population of this study included all children aged 9 to 12 years in Hamedan in 2009-2010. Purposeful sampling method was used and the samples were matched in terms of level of intelligence and type of disorder. Each participant in the experimental group received 24 sessions of neural feedback twice a week. Participants were assessed using the Swanson, Nolan, and Pelham-IV Questionnaire -Fourth Edition to assess the clinical symptoms of ADHD, Coolidge Neuropsychological Inventory to assess executive function, and Rutter Children's Behavioral Problems Questionnaire. Multivariate analysis of variance (MANOVA) was used to test the research hypotheses.
Results: The results showed that there was a significant difference between the experimental group and the control group in all post-test variables of executive functions, behavioral problems and clinical symptoms and their components ($P \leq 0.05$).
Conclusion: According to the results, it seems that neural feedback is an effective intervention for the treatment of these variables.

Keywords: Attention Deficit / Hyperactivity Disorder, Neural feedback, Executive Functions, Behavioral Problems

Introduction

Childhood is an influential period in people lives due to the speed of growth and developmental processes (1). During this period, children may experience problems and disorders due to factors such as attention deficit / hyperactivity disorder, the effect of which is lasting throughout the life (2). Attention deficit/hyperactivity disorder, like other psychiatric disorders, has been investigated over the past 50 years, since the introduction of Second Edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-II) to what has been described in DSM5 as a neurodevelopmental disorder with specific criteria in children and adults and in The International Classification of Diseases of the World Health Organization (ICD-11) (3). A German physician named Huffmann (4) first identified the disorder in 1845. Attention deficit / hyperactivity disorder is currently one of the most common developmental disorders in life with three main symptoms of hyperactivity, attention deficit and impulsivity that interfere with one's growth and function (5). This disorder has consequences for personal and individual functions, academic performance and quality of life (6). Attention deficit / hyperactivity disorder is a neurological syndrome that is usually characterized by impulsivity, distraction, and hyperactivity (7). In addition, in the field of neurophysiology, this disorder is described by a deviant pattern of electrocortical activity, especially at rest, with an increase in theta activity and a decrease in beta activity (8). Studies suggest high activity of slow theta brain waves in the central and frontal regions. Increased activity of slow theta waves is often associated with low activity of fast beta waves. This indicates a low level of arousal, especially in the combined type of ADHD (9). Among the non-pharmacological interventions for the group with attention deficit / hyperactivity disorder, neural feedback has been considered as a promising strategy since the early 1970s (10). Despite wide application of pharmacological and behavioral therapies for hyperactivity, recent extensive studies and meta-analysis have shown the limitations of pharmacological and behavioral therapies. Therefore, research and development of non-pharmacological therapies such as neural feedback is recommended. However, the clinical value of neural feedback is still under question (11). Neurofeedback logic is rooted in neurophysiological studies that have shown an association between electroencephalography and the underlying thalamocortical mechanisms responsible for electroencephalographic rhythms and frequencies. Through neurofeedback training, people learn to change the pattern of their brain waves through agent conditioning (12). Therefore, neurofeedback therapy has been considered as a possible alternative treatment for children with ADHD for more than one decade (13). Based on meta-analyses and randomized controlled trials (multicenter), three standard neural feedback training protocols, namely theta / beta TBR, sensorimotor rhythm (SMR), and slow cortical potential (SCP) are efficient and specific (11). The most common method is the theta / beta protocol. Beta waves are reduced in children with attention deficit / hyperactivity disorder, but theta waves are increased in them. Reduced beta waves and increased theta waves reduce attention and concentration in children with attention deficit / hyperactivity disorder. Thus, one of the neural feedback programs tries to increase beta waves and reduce theta waves (14).

Understanding how to train neural feedback is not difficult. The focus of this training is on gradually learning to increase the level of some EEG components or decrease other components. The key point here is the gradual nature of the training, which requires multiple sessions. These sessions are reported between 30 and 40 sessions. Some noticeable changes may be seen after 10 sessions or more. If the changes during this period are small, the person should not be disappointed because these changes will increase over time and with increasing the number of sessions (15). In general, neural feedback has been welcomed again in recent years in response to the lack of long-term effects for the pharmacological and behavioral therapies and side effects of the medication (11). Some refer to it as effective and specific therapy (13), but some others do not consider this therapy effective (16). Given what was stated above, researchers aim to investigate the effectiveness of neural feedback on executive functions, behavioral problems and clinical symptoms of attention deficit / hyperactivity disorder.

Methods

The research is quasi-experimental design with pre-test post-test and three-month follow-up with experimental and control groups. It is also an applied study in terms of aim. The statistical population of this study included all children aged 9 to 12 years in Hamedan in 2019-2020 who received the results of psychological and clinical tests in the diagnosis of ADHD disorder based on interviews. The subjects were selected using a purposeful sampling method. Children with ADHD were selected according to predetermined inclusion and exclusion criteria. Inclusion criteria included receiving ADHD diagnosis based on clinical interview, psychiatrist diagnosis, having an age between 9 and 12 years old, having IQ above 90, necessary parental cooperation and commitment. Exclusion criteria included having severe comorbid disorders, autism syndrome, Asperger syndrome and depression, having a medical condition that forces a person to seek immediate treatment. Conscious consent was obtained from the parents of the children entered the research project and the children were matched in terms of severity of the disorder. Finally, the matched people were allocated to two groups of pharmacological therapy and control group according to random allocation method. The size of each group was 15 people. After this stage, pre-test, post-test and three-month follow-up measurements were performed according to the specified schedule. In this study, two tools were used to screen / identify comorbidities and confirm inclusion criteria and to measuring dependent variables. Research tools include: Children Symptoms Inventory (CSI-4): This inventory is a behavior grading scale designed to screen for behavioral and emotional disorders in children aged five to twelve years. This scale, like previous versions, has two parental and teacher forms. The parent form contains 112 questions designed to screen eighteen emotional behavioral disorders. These disorders include attention deficit hyperactivity disorder, oppositional defiant disorder,

behavioral disorder, generalized anxiety disorder, social panic, separation anxiety disorder, obsessive-compulsive disorder, phobia, major depression disorder, dysthymia, pervasive developmental disorder, acoustic and motor tics, post-traumatic stress disorder and defecation disorders. The criteria for selecting the diagnostic categories mentioned in the Children Symptoms Inventory are mainly based on its prevalence and application. The questions were grouped based on the fourth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV). It facilitates a regular and general interview and helps to reduce errors in diagnosing the type of disorder, so that parents complete the form in about 10 to 15 minutes (17). In this study, the scoring method for the Child Symptoms Inventory was in the form of screening cut-off. Accordingly, on a two-point scale, the answers of “never” and “sometimes” receive the score of zero and answers of “often” and “most of time” receive a score of 1. Then, the sum of the scores of each question gives the score of severity and based on the cut-off point, each disorder with code one had this disorder and each disorder with code zero did not have this disorder. In Iran, the studies conducted in the area of children symptoms inventory showed a validity of 0.29 for social phobia to 0.76 for behavioral disorder. Also, the correlation coefficients for each of the disorders of inventory similar to those of Gado and Sprafkin studies were reported between 0.41 for dysthymia to 0.77 for attention deficit hyperactivity disorder (18).

Wechsler Intelligence Scale for Children- Revised (WISC-R): Wechsler Intelligence Scale for Children- Revised (WISC-R) test consists of 2 verbal and performance sections and 12 subtests (6 verbal subtests and 6 practical subsets). Two subtests have a complementary role and are not performed in normal conditions (numerical memory subtests in the verbal section and mazes subtests in the performance section). Since the implementation of the long form requires much time (about 60 to 90 minutes per person), it was decided to use the short form of this test to match the screened children in terms of IQ score. Shahim (19) in Iran reported reliability coefficient of the best quadratic form (vocabulary, information, cubes and completion of images) of WISC-R subtests at 0.91 based on the data obtained from the normative selection of this test in Shiraz and by McNemar Test. The sum of the obtained balanced scores can be converted to deviant IQ using the following formula: Deviant IQ = 1.5 (x) + 40

The IQ classification agreement coefficient obtained from the best short quadratic form and the complete form has been reported at 63% (19).

Swanson, Nolan, and Pelham-IV Questionnaire -Fourth Edition (SNAP-IV): This test was developed by Swanson, Nolan and Pelham in 1980 and has a single form for parents and teachers to answer. The test had 18 questions, the first 9 questions are related to ADHD-I identification and the second 9 questions are related to ADHD-H identification. All 18 questions are used to identify ADHD-C. This test has good reliability and validity. Its Cronbach's alpha has been reported at 0.94 for the whole scale and 0.90 and 0.79 for the subscales (20).

Coolidge Neuropsychological Inventory: Coolidge Neuropsychological test is a test that diagnoses several neurological and behavioral disorders in children and adolescents aged 5 to 17 years. Each disorder has distinct subclasses, three of which evaluate executive functions with 19 items.

The test is answered by the parents on a Likert scale. These three subscales measure executive functions in the three areas of organizing, decision-making, planning, and response inhibition. This scale is scored in such a way that the option “never” receives score 0 and the option “sometimes: receives a score of 1, the option “usually” receives score 2 and the option “always” receives score 3. Therefore, the highest and lowest scores in this test are 57 and 0, respectively. Obtaining a higher score indicates more problems in executive functions. The obtained reliability for the subscale of organizing and decision-making was 0.85 and it was reported 0.66 for the inhibition subscale. The internal consistency of the two subscales using Cronbach's alpha was obtained at 0.91. The obtained internal consistency was reported 0.81, 0.82, and 0.52, respectively, for organizing, decision-making, and inhibition (22). In the present study, the reliability of decision-making, organizing, and inhibition was reported at 0.94, 0.88, and 0.93, respectively.

Rutter Children's Behavioral Problems Questionnaire: This questionnaire was developed by Michael Rutter in 1975 and includes versions A and B. Version A has 31 items and is completed by parents. Parents answer the question for about 20 minutes according to the child's behavior. A score of 13 in this form is the cut-off point, and children who score 13 or higher are considered problematic. The reliability of this questionnaire using the split half method and test retest method was reported at 0.85 in a study conducted by Mehryar in Iran in 1994 (23). In the present study, the reliability of aggression and hyperactivity anxiety and depression, executive maladaptation, antisocial behaviors, and attention deficit disorder, respectively, was reported at 0.92, 0.93, 0.87, 0.88, and 0.86. After selecting the participants, the research questionnaires were completed by all parents before the intervention and were completed again by them in the post-test and three-month follow-up stages. In the neural feedback group, each participant received 24 sessions of neural feedback twice a week. The beta / theta program was used for all participants. In the experimental group, the procedure was completely explained to children. After adjusting the chair and installing the electrodes, the baseline brain waves (stage in which no feedback is provided) were recorded and the treatment protocol of each person was determined.

After quantitative electroencephalographic interpretation, waves that needed to be amplified or inhibited were identified and electrodes and references were attached to the desired places according to the 10-20 system. The training protocol was such that the beta band (15 to 20 Hz) was first used as the incremental band and the theta and long beta bands were used as the decreasing bands. In the second half of the treatment, instead of the beta band, the low beta band was used (12 -15 Hz) as an incremental band. In the next stage (intervention stage), animation was presented for children. As the children's brain waves moved away from the target (i.e., decreasing theta waves and increasing the beta waves), the animation stopped moving, and for moving the animation again, the children had to change their brain waves in the direction of the set goal. The animations were selected based on the children's preference and interest. Multivariate analysis of covariance (MANCOVA) and multivariate analysis of variance (MANOVA) were used to analyze the data. In this study, ethical standards including confidentiality of information, obtaining informed consent, ensuring the privacy and their right to select to continue or withdraw from participation in intervention sessions or answering questionnaires were observed. During completing the questionnaires, while emphasizing on answering all the questions, the participants had complete freedom to withdraw from research at any time and provide personal information.

Results

Table 1 presents the age and gender of the subjects.

Table 1- Frequency distribution in the sample according to the age status of the pharmacological therapy group and the control group

Gender	Group	Level	Frequency	Percentage of frequency
Age	pharmacological therapy group	9-10 years	5	33.33
		10-11 years	6	40
		11-12 years	4	26.67
	Control group	9-10 years	6	40
		10-11 years	4	26.67
		11-12 years	5	33.33
gender	pharmacological therapy group	Female	6	40
		Male	9	60
	Control, group	Female	7	46.67
		Male	8	53.33

Table 2-Result of analysis of variance of executive functions of neural feedback group and control group in post-test stage

Source of variance	**Squared sum SS**	**df**	**Mean squared MS**	**F**	**Significance level**	**Mean of differences**
Decision-making and planning function	200.554	1	200.554	88.543	0.0005	5.451
Error	120.048	53	2.265			
Organizing	205.127	1	205.127	117.752	0.0005	5.513
Error	92.327	53	1.742			
inhibition	208.193	1	208.193	95.039	0.0005	5.554
error	116.101	53	2.191			

The results of Table 2 showed that there was a significant difference between the experimental group that received neural feedback and the control group that did not receive any training in the adjusted means of the variables of decision-making and planning function, organization and inhibition. By comparing the variables of decision-making and planning function in the two groups, it was found that the decision-making and planning, organizing and inhibition in the neural feedback group is more than the control group.

Table 3- Analysis of variance covariance of behavioral problems of neural feedback group and control group in post-test stage

Source of variance	Squared sum SS	df	Mean squared MS	F	Significance level	Mean of differences
aggression	80.651	1	80.651	55.280	0.0005	-3.480
Error	74.407	51	1.459			
Stress and depression	139.894	1	139.894	120.498	0.0005	-4.583
Error	59.209	51	1.161			
Social maladaptation	145.184	1	145.184	193.171	0.0005	-4.669
Error	38.331	51	0.752			
Antisocial behaviors	128.943	1	128.943	252.373	0.0005	-4.400
Error	26.057	51	0.511			

Attention Deficit Disorder	138.549	1	138.549	17.074	0.0005	-4.561
Error	41.304	51	0.810			

The results of Table 3 show that there is a significant difference between the experimental group that received neural feedback and the control group that did not receive any training in the adjusted means of aggression, anxiety and depression, social maladaptation, antisocial behaviors and attention deficit. Comparing the means of the behavioral problems of the two groups revealed that the variables of the behavioral problems of the neural feedback group are lower than the control group.

Table 4- Results of covariance analysis of the variable of clinical symptoms of neural feedback group and control group in post-test stage

Source of variance	Squared sum SS	df	Mean squared MS	F	Significance level	Mean of differences
Identification of ADHD-I	125.452	1	125.452	72.613	0.0005	-4.171
Error	93.295	54	1.728			
Identification of ADHD-H	102.952	1	102.952	60.863	0.0005	-3.778
error	91.343	54	1.692			

The results of Table 4 show that there was a significant difference between the experimental group that received neural feedback and the control group that did not receive any training in the adjusted means of the clinical symptoms variable. By comparing the mean variables of clinical symptoms in these two groups, it was found that the clinical symptoms of the neural feedback group were less than the control group.

Discussion and Conclusion

The aim of this study was to evaluate the effectiveness of neural feedback on executive functions, behavioral problems and clinical symptoms of attention deficit / hyperactivity disorder. The results showed that there was a significant difference between the experimental group that received neural feedback and the control group that did not receive any training in the adjusted means of executive function variables (decision-making and planning function, organizing and inhibition). By comparing the means of executive function variables in these two groups, it was found that the executive functions of the neural feedback group were more than the control group. This result is in line with results of the studies conducted by Khaksarian et al. (24), Khatib Sands Kashani et al. (25), Moin, Asadi Gandomani, and Amiri (26), Fauzan and Nazaruddin (27), Wangler, Gevensleben, and Albrecht (28) and Zoefel, Huster, and Herrmann (29), which reported neural feedback was effective in executive functions. In explaining the results of the present study, we can refer to self-regulatory effect of brain waves. This mechanism is important for the normal functioning of the brain and leads to improved attention and concentration and a reduction in the symptoms of hyperactivity in patients. The human brain has mechanisms for regenerating and regulating itself. In other words, by learning self-regulatory mechanisms, self-regulation command can be given to brain and the underlying neurofeedback mechanism is strengthening the brain self-regulatory mechanisms. In this study, teaching the self-regulatory mechanism to brain led to improvement of executive functions in patients. By providing effective feedback to person and giving bioelectrical rhythms to the brain, neurofeedback encourages and reinforces executive functions such as attention, concentration, decision-making, and inhibition. Implementing a beta / theta program for patients commands brain to produce more of some waves and less of some other waves (30). It can also be stated that neurofeedback training changes the frontal lobe, so that it affects three parts of motor cortex, motor sensory and cingulitis. The act of motor-sensory cortex is more than just guiding the motor-sensory functions, and this part helps to encode the cognitive and physical activities of the cerebral cortex. Thus, people who have problems in cognitive tasks may benefit from the effects of neurofeedback on the left sensory-motor cortex (31). Neurofeedback can help the proper function of brain by altering the profile of brain waves. This abnormality compensation helps the person become more alert and able to increase his or her attention and thus show better cognitive function (32).

This result is not in line with the result of the research conducted by Steiner et al. (33) who stated that neural feedback training has no effect on cognitive function, especially the level of attention. The reason for this contradiction is the difference in the methods of implementing neural feedback training and it must be noted that this method is not useful for all people. Other results showed that there was a significance difference between the experimental group that received neural feedback and the control group that did not receive any training in adjusted means of the variable of behavioral problems (aggression, anxiety and depression, social maladaptation, antisocial behaviors, and attention deficit disorder. By comparing the means of variables of the behavioral problems in the two groups, it was found that the behavioral problems of the neural feedback group were less than the control group. This result is consistent with that of the study conducted by Ghasemzadeh et al. (34), Walker (35), and Leins et al. (36). In explaining this result, it can be stated that since theta waves are associated with distraction, inattention and anxiety, in neurofeedback, computer games are played without hands and only with brain waves and person notices his or her abnormal brain waves and tries to correct his or her brain waves. The person consciously notices the association of external processes with his or her brain waves. At the subconscious level, the brain learns how to place its waves in specific position. Conscious and unconscious skills are gradually learned, transferred to real life, and affect one's performance (26). Therefore, the performance of children with this method is improved and symptoms and behavioral problems such as anxiety, inattention and aggression are reduced. The results also showed that there was a significant difference between the experimental group that received neural feedback and the control group that did not receive any training in adjusted means of the variable of clinical symptoms (attention deficit symptoms and hyperactivity / impulsivity symptoms). By comparing the means of clinical symptoms in these two groups, it was found that the clinical symptoms of the neural feedback group were less than the control group. Other studies have reported the effectiveness of neural feedback on clinical symptoms of ADHD, such as Seilsepour, Hamounpeyma, and Pirkhaefi (32), Riesco-Matías et al. (37), Enriquez-Geppert et al. (11), Holtmann and Stadler (38). In explaining these results, it can be stated that theta is associated with impulsivity, distraction, inattention, and anxiety, and investigation of brain waves in children with ADHD shows extreme theta in these children. Accordingly, neurofeedback therapists teach the theta reduction protocol and neurofeedback suppresses this rhythm and facilitates brain growth. In fact, neurofeedback increases beta waves and decreases theta waves, thus improving the symptoms of the disorder. Improving the symptoms of the disorder can lead to better cognitive function. On the other hand, increasing beta waves can improve cognitive functions by increasing alertness, concentration and metabolism (39). However, this result inconsistent with that of some other studies that have reported its effectiveness at limited and low level, such as Nemati and Alizadeh (39) and Sollie, Larsson, and Mørch (40). Considering the discrepancy between the results of the two studies, it can be stated that some patients are not able to communicate effectively with the system and adjust their wave pattern, so symptoms are not reduced in them (38).

One of the limitations of the research is the purposeful selection of the samples of this research and the emphasis on the statistical population of Hamadan, which limits the generalizability of the results. Conducting research by using other sampling methods, especially random sampling, can improve the generalizability of future research results.

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