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The Effectiveness of Neurofeedback Therapy on Executive Functions in 11- and 12-Year-Old Adolescent Boys with Anxiety Disorder

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ABSTRACT

Objective: The present study aimed to determine the effectiveness of neurofeedback therapy on executive functions in 11- and 12-year-old adolescent boys with anxiety disorder.

Methods and Materials: This quasi-experimental study employed a pretest-posttest-follow-up design with a control group. The participants were 34 adolescent boys diagnosed with anxiety disorders, selected through convenience sampling from three psychotherapy clinics in Tehran in 2022. They were randomly assigned to experimental and control groups. The experimental group received 20 sessions of neurofeedback therapy, each lasting 45 minutes. The cognitive abilities of participants were assessed using Nejati's (2013) Cognitive Abilities Questionnaire, which evaluates executive functions across seven domains. Data were analyzed using repeated measures ANOVA to compare changes in executive functions across the pretest, posttest, and follow-up stages.

Findings: The results indicated that neurofeedback therapy had a significant positive effect on executive functions, including memory, inhibitory control, decision-making, planning, sustained attention, social cognition, and cognitive flexibility ($p = 0.001$). Improvements were observed in the experimental group across all stages compared to the control group, suggesting that neurofeedback therapy effectively enhanced cognitive performance in adolescents with anxiety disorders.

Conclusion: Neurofeedback therapy was found to be an effective intervention for improving the executive functions of adolescents with anxiety disorders. The therapy's ability to regulate brain activity led to significant cognitive enhancements, providing a promising non-invasive treatment option. Future studies should explore the long-term effects and broader applications of neurofeedback in different populations.

Keywords: *Executive functions, Anxiety disorder, Neurofeedback therapy, Adolescent boys*

1. Introduction

Anxiety is a combination of unpleasant emotions and cognitions that tends to be more future-oriented and diffuse compared to fear, yet like fear, it involves not only cognitive/mental elements but also physiological and behavioral components (Mason et al., 2023). On the cognitive/mental level, anxiety includes negative mood, worry about potential future threats or dangers, preoccupation, and an inability to predict or control the threat if it occurs. On the physiological level, anxiety often creates a state of tension and heightened arousal, which may reflect readiness to respond to a possible impending danger. Anxiety disorders come in various forms, including separation anxiety, generalized anxiety, and social anxiety. Some studies have shown that anxiety, depending on its type, can affect certain aspects of executive functions and cause difficulties for the individual (Rahmatinia & Gorji, 2023).

Executive functions are high-level cognitive and metacognitive functions that include a set of advanced cognitive abilities such as inhibition, self-initiation, strategic planning, organization and monitoring, impulse and emotion regulation, with the task of self-regulating thought and facilitating flexible, adaptive behavior, which develop throughout childhood. All definitions of executive function share the common view that it involves a set of processes occurring at higher cognitive levels that control and modulate lower-level processes (Shiroud Aghaei et al., 2020). Executive functions represent a crucial aspect of cognitive development that is strongly influenced by brain growth and maturation, enabling the control of thoughts and actions in response to goals, which results in goal-directed behaviors. Some of the most important neurocognitive executive functions include organization, decision-making, working memory, maintaining and shifting attention, motor control, language perception, future prediction, reconstruction, inner speech, and problem-solving (Ahmed et al., 2023). Executive functions play a very important role in the development of mental abilities, academic success, personality, and social skills in children and adolescents, and problems in executive functions in these age groups can lead to various issues, including anger and emotional regulation problems (Abdolmohammadi et al., 2020).

Research has shown that neurofeedback therapy can be used to improve executive functions in children and adolescents. Shari et al. (2021) found in their study that neurofeedback training was effective in improving the executive functions of students with learning disabilities, particularly cognitive flexibility and attention (Shari et al., 2021).

In neurofeedback, sensors known as electrodes are placed on the scalp to record the brain's electrical activity and display brain waves (often in a simulated form, such as a computer game or video) to the person. In this process, the video plays or the computer game progresses without the use of hands, controlled only by the individual's brainwaves. Neurofeedback is essentially a training process through which the brain learns self-regulation. During the training, brain activity is controlled by both the conscious and unconscious mind, with conscious learning occurring when the individual realizes how the feedback signal relates to their mental state. A significant portion of the learning takes place at an unconscious level, where the brain gradually learns to control the feedback signal directly and automatically. The new skills acquired during training are internalized and transferred automatically to the individual's daily activities (Gevensleben et al., 2013). Neurofeedback has been shown to be effective in individuals with anxiety disorders, offering faster therapeutic effects with fewer side effects compared to pharmacological treatments (Biriukova et al., 2003).

Several studies have been conducted in the field of neurofeedback therapy, some of which are as follows: Mayer et al. (2016) conducted a study on the effects of neurofeedback on symptoms of attention-deficit/hyperactivity disorder (ADHD) in adolescents and concluded that this therapeutic method significantly improved sustained attention in adolescents (Mayer et al., 2016). Smit et al. (2023) conducted a study to determine the effects of FM theta neurofeedback on executive functions in a sample of 58 adults (aged 20–60 years) with subjective complaints in daily life. The results showed that neurofeedback was effective in enhancing executive functions in healthy adults (Smit et al., 2023). Mamazandi et al. (2018) compared the effectiveness of neurofeedback and mindfulness training on improving planning executive functions in student athletes, showing that both methods equally improved planning executive functions in these students (Mamazandi et al., 2018). Kianizadeh et al. (2022) investigated the effects of beta neurofeedback on executive functions and problem-solving ability in elementary school boys with attention-deficit/hyperactivity disorder (ADHD) and concluded that neurofeedback therapy, through providing biological feedback and increasing individuals' awareness of mental and cognitive processes, can be an

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effective method for improving executive functions and problem-solving ability in children with ADHD (Kianizadeh et al., 2022).

Given that adolescence is a period characterized by fundamental transformations in the psychological, social, and biological domains and a critical time for the development of neurobiological-cognitive processes underlying higher cognitive functions, social behavior, and emotions, and considering the results of some studies indicating that many adolescents with anxiety disorders exhibit deficits in executive functions (Orbach et al., 2020), this study aimed to determine the effectiveness of neurofeedback therapy on the executive functions of 11- and 12-year-old boys with anxiety disorder. This study seeks to answer the question: Is neurofeedback therapy effective in improving the executive functions of adolescent boys with anxiety disorder?

2. Methods and Materials

2.1. Study Design and Participants

The research method was quasi-experimental with a pretest-posttest-follow-up design and a control group. The statistical population of this study included all adolescent boys who visited clinics and psychotherapy centers during the summer and fall of 2022 and were diagnosed with an anxiety disorder through interviews and evaluations conducted by a psychologist. The sample size was determined using G*Power software, with 2 groups (u = 2), a 95% confidence level, a test power of 0.8, and an effect size of 0.4, resulting in a sample size of 12 participants per group. Considering the potential for attrition, the final sample size was set at 17 participants per group (Kang, 2021). From this population, 34 adolescents were selected through convenience sampling from Yara Clinic in northeast, Jahan Hekmat Clinic in west, and Salamat Clinic in central Tehran, and were randomly assigned to experimental and control groups. The inclusion criteria were: diagnosis of at least one anxiety disorder, not receiving concurrent treatments, concurrent use of medications, and absence of chronic physical diseases or intellectual and physical disabilities. The exclusion criteria included withdrawal from participation and failure to complete the questionnaire. Additional exclusion criteria were 1) discontinuation or withdrawal from the study, 2) missing more than two sessions, and 3) being late for more than three sessions and withdrawing from cooperation.

2.2. Measures

2.2.1. Executive Functions

The Cognitive Abilities Questionnaire developed by Nejati (2013) consists of 30 items assessing seven components: memory, inhibitory control and selective attention, decision-making, planning, sustained attention, social cognition, and cognitive flexibility. The Cronbach's alpha for the questionnaire was 0.83, and Pearson's correlation between two test administrations in Nejati's study was significant at the 0.01 level (Nejati, 2013).

2.3. Intervention

2.3.1. Neurofeedback Therapy

The neurofeedback therapy method was implemented using computer-equipped devices under the supervision of the researcher. The hardware used in this study was the ProComp2 four-channel neurofeedback and biofeedback device. The goal of neurofeedback is to alter brain function by training EEG and regulating brainwaves. To implement the changes, electrodes were placed on the scalp in accordance with the 10-20 system, where the electrodes are positioned at specific percentages of the distance between cranial bone landmarks. In this study, the therapy protocol was conducted at the PZ area. According to this protocol, two electrodes were attached to the ears, and the main electrode was placed on the head at the PZ location (to regulate alpha, beta, and theta waves). Each participant underwent 20 sessions, each lasting 45 minutes. The therapeutic protocol aimed to adjust the alpha wave range (8 to 14 Hz), the beta wave range (15 to 20 Hz), and the theta wave range (< 10 Hz) to achieve the desired therapeutic outcomes.

2.4. Data analysis

Data analysis was conducted using repeated measures analysis of variance (ANOVA) to evaluate the effects of neurofeedback therapy on executive functions across three stages: pretest, posttest, and follow-up. This statistical method was chosen to assess within-group changes over time and between-group differences (neurofeedback and control groups). The Shapiro-Wilk test was used to check the normality of the data, and Levene's test confirmed the homogeneity of variances. When the assumption of sphericity was violated, Greenhouse-Geisser corrections were applied. Effect sizes were calculated using Eta squared

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(η^2) to determine the magnitude of the intervention's effect. All analyses were performed using SPSS-27 software, with significance levels set at $p < 0.05$.

3. Findings and Results

In the neurofeedback group, 7 participants (41.18%) were 11 years old, and 10 participants (58.82%) were 12 years old. In the control group, 8 participants (40.06%) were 11 years old, and 9 participants (52.94%) were 12 years old. In the neurofeedback therapy group, 4 participants (23.53%) had generalized anxiety disorder, 6 participants (35.29%) had separation anxiety disorder, and 7 participants (41.18%) had social anxiety disorder. In the control group, 3 participants (17.65%) had generalized anxiety disorder, 8 participants (47.06%) had separation anxiety disorder, and 6 participants (35.29%) had social anxiety disorder.

Table 1

Mean, Standard Deviation, Shapiro-Wilk Statistic, and p-value for Executive Functions in the Neurofeedback Therapy and Control Groups at the Pretest, Posttest, and Follow-up Stages

Variable	Stage	Group	Mean	Standard Deviation	Shapiro-Wilk Statistic	Shapiro-Wilk p-value
Memory	Pretest	Intervention	8.88	0.31	0.913	0.113
		Control	9.05	0.31	0.895	0.056
	Posttest	Intervention	16.17	0.31	0.890	0.046
		Control	9.11	0.30	0.908	0.094
	Follow-up	Intervention	16.05	0.29	0.900	0.068
		Control	9.11	0.28	0.916	0.128
Inhibitory Control & Selective Attention	Pretest	Intervention	12.00	0.42	0.955	0.548
		Control	12.76	0.37	0.918	0.137
	Posttest	Intervention	16.23	0.39	0.912	0.106
		Control	12.35	0.35	0.917	0.134
	Follow-up	Intervention	16.76	0.44	0.932	0.238
		Control	12.41	0.37	0.925	0.182
Decision Making	Pretest	Intervention	9.58	0.25	0.904	0.080
		Control	9.88	0.28	0.889	0.045
	Posttest	Intervention	15.17	0.34	0.924	0.171
		Control	10.17	0.28	0.919	0.140
	Follow-up	Intervention	15.29	0.40	0.906	0.085
		Control	10.11	0.28	0.903	0.075
Planning	Pretest	Intervention	10.41	0.22	0.893	0.052
		Control	9.88	0.30	0.894	0.055
	Posttest	Intervention	15.82	0.36	0.900	0.069
		Control	10.47	0.31	0.897	0.060
	Follow-up	Intervention	16.17	0.37	0.903	0.077
		Control	10.35	0.32	0.929	0.210
Sustained Attention	Pretest	Intervention	5.76	0.27	0.919	0.142
		Control	6.58	0.25	0.904	0.080
	Posttest	Intervention	10.29	0.36	0.902	0.073
		Control	6.82	0.29	0.913	0.114
	Follow-up	Intervention	10.88	0.35	0.894	0.053
		Control	6.70	0.31	0.901	0.070
Social Cognition	Pretest	Intervention	5.70	0.29	0.920	0.147
		Control	5.70	0.26	0.923	0.168
	Posttest	Intervention	11.52	0.43	0.937	0.286
		Control	5.52	0.28	0.911	0.102
	Follow-up	Intervention	12.52	0.48	0.914	0.116
		Control	6.58	0.33	0.941	0.333
Cognitive Flexibility	Pretest	Intervention	8.88	0.41	0.955	0.532
		Control	9.76	0.48	0.912	0.109
	Posttest	Intervention	14.70	0.25	0.918	0.138
		Control	9.41	0.44	0.917	0.132
	Follow-up	Intervention	14.70	0.26	0.923	0.168
		Control	9.64	0.46	0.898	0.064

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Furthermore, Levene's test was not significant for any stage of the study, indicating that the assumption of homogeneity of variances was met for the executive function components across the three stages. The results of Mauchly's sphericity test indicated that the assumption of sphericity for cognitive flexibility was violated. In such cases, Greenhouse-Geisser or Huynh-Feldt corrections are used. For the Greenhouse-Geisser test, the epsilon for cognitive flexibility was <0.75, so this test was used to evaluate the hypothesis.

Table 2

Results of Repeated Measures ANOVA for Within-Group, Between-Group, and Interaction Effects for Executive Function Components and Neurofeedback Therapy

Variable	Source of Effect	Sum of Squares	Degrees of Freedom	Mean Square	F	p-value	Eta Squared
Memory	Time	Within-groups	301.54	2	150.77	454.83	0.001
	Time * Groups	Within-groups	291.90	2	145.95	440.28	0.001
	Group	Between-groups	541.42	1	541.42	132.83	0.001
Inhibitory Control	Time	Within-groups	97.54	2	48.77	226.78	0.001
	Time * Groups	Within-groups	136.02	2	68.01	316.21	0.001
	Group	Between-groups	158.12	1	158.12	20.78	0.001
Decision-Making	Time	Within-groups	198.05	2	99.02	145.20	0.001
	Time * Groups	Within-groups	164.29	2	82.14	120.45	0.001
	Group	Between-groups	276.70	1	276.70	74.74	0.001
Planning	Time	Within-groups	212.31	2	106.15	76.86	0.001
	Time * Groups	Within-groups	145.96	2	72.98	52.84	0.001
	Group	Between-groups	388.24	1	388.24	154.24	0.001
Sustained Attention	Time	Within-groups	142.60	2	71.30	74.93	0.001
	Time * Groups	Within-groups	124.49	2	62.24	65.41	0.001
	Group	Between-groups	131.92	1	131.92	42.39	0.001
Social Cognition	Time	Within-groups	270.60	2	135.30	119.10	0.001
	Time * Groups	Within-groups	202.02	2	101.01	88.91	0.001
	Group	Between-groups	404.01	1	404.01	92.89	0.001
Cognitive Flexibility	Time	Within-groups	177.19	1.25	141.74	85.20	0.001
	Time * Groups	Within-groups	208.25	1.25	166.59	100.13	0.001
	Group	Between-groups	254.12	1	254.12	41.63	0.001

Table 2 shows that neurofeedback therapy had a significant and increasing effect on executive functions including memory, inhibitory control and selective attention, decision-making, planning, sustained attention, social cognition, and cognitive flexibility (p = 0.001). The effect of time led to an increase in memory capacity, inhibitory control and selective attention, decision-making, planning, sustained attention, social cognition, and cognitive flexibility (p = 0.001) compared to the pretest stage. The interaction of time and groups resulted in an increase in memory capacity, inhibitory control and selective attention, decision-making, planning, sustained attention, social cognition, and cognitive flexibility (p = 0.001) compared to the control group.

4. Discussion and Conclusion

The hypothesis testing concluded that neurofeedback therapy is effective in improving the executive functions of adolescent boys with anxiety disorders. These findings are consistent with the results of previous studies (Afi et al., 2019; Alizadeh et al., 2018; Biriukova et al., 2003; Castro & Hill, 2002; Drechsler et al., 2007; Escolano et al., 2011; Farid et al., 2021; Gevensleben et al., 2013; Kianizadeh et al., 2022; Mamazandi et al., 2018; Mayer et al., 2016; Moein et al., 2018; Shari et al., 2021; Smit et al., 2023; Soltani Kouhbani, 2015; Thatcher et al., 2023).

Cognitive rehabilitation methods are based on two key principles: restoring functions or regaining the individual's abilities, with the aim of improving cognitive processes for normal brain functioning during activities, based on the notion that the human brain has the capacity for self-regulation and self-repair. Alternatively, the goal is to compensate for cognitive deficits using various tools. In fact, proper or improper brain functioning leads to normal or abnormal brainwave production. Therefore, like any other complex system, the brain requires regulation and correction of its deficiencies. The important and interesting point is that the brain has the ability to regulate itself and optimize its functioning once it becomes aware of its own state (Deh Abadi et al., 2021).

Since neurofeedback regulates brain function, it enhances various mental and cognitive abilities such as optimizing decision-making, increasing creativity, strengthening memory, and improving concentration (Alizadeh et al., 2018; Biriukova et al., 2003). Additionally, neurofeedback enables skill acquisition in self-regulation, which leads to increased self-awareness. The most important aspect is that individuals learn how to reach an advanced mental state without using neurofeedback devices in the future (Drechsler et al., 2007). The brain controls the blood flow it receives through the expansion and contraction of blood vessels, directing blood flow to specific areas that are more active in self-regulation. Neurofeedback training, by teaching the brain self-regulation, leads to changes in blood flow (Kianizadeh et al., 2022).

The effectiveness of neurofeedback is based on the principle that repeated practice improves cognitive operations related to attention. These practices lead to adaptation and modification of the neural networks associated with these processes, and most attention-training programs are based on neuropsychological theories that suggest stimulating the structures associated with executive functions leads to their improvement (Castro & Hill, 2002). Christopher and Fisher (2010) explain that neurofeedback, as an intervention that does not rely solely on correlation, manipulates brain states. Neurofeedback enhances EEG activity, leading to long-term changes (Christopher & Fisher, 2010). Hence, neurofeedback, through neurological feedback, regulates brain function, increasing creativity, aiding memory, improving attention, optimizing decision-making, and enhancing coordination between brain and body.

Neurofeedback modifies the prefrontal lobe, influencing three areas: the motor cortex, the sensory-motor cortex, and the cingulate cortex. The sensory-motor cortex's function is not limited to guiding sensory-motor functions but also assists in encoding cognitive and physical activities in the cortex. Neurofeedback also increases beta waves and reduces theta waves, which can improve the symptoms of disorders. Improving these symptoms can lead to better cognitive performance. On the other hand, increasing beta waves is associated with increased alertness, focus, and metabolism, which can improve cognitive functions. In contrast, theta waves are associated with distraction, inattention, and anxiety. In neurofeedback, computer games are controlled without hands, solely by brainwaves. The individual becomes aware of their abnormal brainwaves and attempts to adjust them by maintaining control of the game and receiving reinforcement. Consciously, the individual recognizes the connection between external processes and their brainwaves. At the unconscious level, the brain learns how to adjust its waves to a specific state. Gradually, both conscious and unconscious skills are learned and transferred to real-life situations, influencing the individual's performance. Neurofeedback can help improve brain function by altering the brainwave profile. This compensation for abnormalities helps individuals become more alert, increase attention, and consequently demonstrate better cognitive performance (Thatcher et al., 2023).

5. Limitations & Suggestions

One limitation of this study is the relatively small sample size, which may limit the generalizability of the findings to a broader population of adolescents with anxiety disorders. Additionally, the use of convenience sampling from specific clinics in Tehran might introduce selection bias. The lack of long-term follow-up after the neurofeedback intervention to assess the durability of improvements in executive functions is another limitation. Furthermore, the study did not consider potential confounding factors such as participants' prior treatments or individual differences in neurodevelopmental stages that could influence the outcomes.

Future research should aim to replicate the study with larger and more diverse samples to increase the generalizability of the findings. Studies should also include longer follow-up periods to examine the long-term effects of neurofeedback on executive functions. Moreover, future research could explore the comparative efficacy of neurofeedback with other cognitive-behavioral or pharmacological interventions in treating anxiety disorders. Investigating the neural mechanisms underlying neurofeedback's impact on executive functions through neuroimaging techniques could provide deeper insights into the processes driving cognitive improvements.

The findings of this study suggest that neurofeedback therapy can be an effective intervention for improving executive functions in adolescents with anxiety disorders. Clinicians and mental health professionals might consider incorporating neurofeedback into treatment plans for individuals with cognitive deficits related to anxiety. Additionally, schools and educational institutions could adopt neurofeedback as a tool to enhance cognitive skills such as attention, planning, and decision-making in students

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with anxiety or related disorders. Policymakers should also promote the integration of neurofeedback programs in clinical settings to provide non-invasive, evidence-based treatment options for youth with mental health challenges.

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Declaration of Interest

The authors of this article declared no conflict of interest.

Ethical Considerations

The study protocol adhered to the principles outlined in the Helsinki Declaration, which provides guidelines for ethical research involving human participants.

Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

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Authors' Contributions

All authors equally contributed in this article.

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