Mental Health and Lifestyle Journal

Year 2025
Volume 3
Issue 1

Comparison of the Effectiveness of Neurofeedback and LORETA Neurofeedback in Improving Executive Functions and Sustained Attention in Children with Attention-Deficit/Hyperactivity Disorder

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Article type:
Original Research

Article history:
Received 04 August 2024
Revised 15 December 2024
Accepted 21 December 2024
Published online 1 January 2025

ABSTRACT

Attention-Deficit/Hyperactivity Disorder (ADHD) is one of the most common neurodevelopmental disorders in childhood, characterized by deficits in sustained attention and executive functions. In recent years, neurofeedback has gained attention as a non-invasive method for improving cognitive performance in children with ADHD. The present study aimed to compare the effectiveness of traditional neurofeedback and LORETA neurofeedback in improving sustained attention and components of executive functioning in this group of children. This study employed a quasi-experimental pretest-posttest design with a control group. The statistical population consisted of all children aged 8 to 12 years diagnosed with ADHD who attended Mehrdoostan Psychological and Counseling Clinic in Tehran in 2024. Sixty children were randomly selected and assigned into three groups of 20 participants each: traditional neurofeedback, LORETA neurofeedback, and control. The measurement instruments included the Continuous Performance Test (CPT), Stroop Test, Tower of London Test (TOL), NEPSY-II, and the Conners' Parent Rating Scale. The neurofeedback interventions were conducted over 20 sessions of 45 minutes each. Data were analyzed using analysis of variance (ANOVA), post-hoc tests, and within-group t-tests. The results indicated that both interventions led to significant improvements in sustained attention, working memory, response inhibition, and cognitive flexibility ($p < .001$); however, LORETA neurofeedback demonstrated greater effectiveness compared to traditional neurofeedback. The therapeutic effects were sustained during the three-month follow-up period. Post-hoc analyses confirmed significant differences between the LORETA group and the other groups across all variables ($p < .05$). The findings suggest that LORETA neurofeedback can serve as an effective and lasting method for enhancing executive functions and sustained attention in children with ADHD. It is recommended that this approach be incorporated alongside other interventions in comprehensive treatment programs.

Keywords: Attention-Deficit/Hyperactivity Disorder (ADHD), Neurofeedback, LORETA Neurofeedback, Executive Functions, Sustained Attention.

How to cite this article:
Samadi, F., Jafari Chayjanj, S. M., & Khoshakhlagh, M.. (2025). Comparison of the Effectiveness of Neurofeedback and LORETA Neurofeedback in Improving Executive Functions and Sustained Attention in Children with Attention-Deficit/Hyperactivity Disorder. *Mental Health and Lifestyle Journal, 3*(1), 1-10. https://doi.org/10.61838/mhlj.3.1.1

Introduction

Attention-Deficit/Hyperactivity Disorder (ADHD) is one of the most common and costly psychiatric disorders of childhood. This disorder is characterized by three core symptoms: excessive inattention, motor hyperactivity, and cognitive-behavioral impulsivity, which often persist into adulthood (1). Epidemiological evidence estimates the global prevalence of ADHD in children at approximately 5% to 7% (2), and domestic studies have similarly shown that about 7% to 9% of Iranian children exhibit symptoms of this disorder (3). ADHD not only disrupts academic processes but also leads to broad social, behavioral, and emotional challenges for affected children and their families.

From a cognitive perspective, researchers have placed particular emphasis on executive functions and sustained attention as key cognitive components that are widely impaired in children with ADHD. Executive functions comprise a set of higher-order cognitive abilities such as behavioral inhibition, planning, working memory, and cognitive flexibility, which are essential for voluntary control of behavior and emotion (4). Likewise, sustained attention, defined as the ability to maintain focus on a specific task over an extended period, plays a critical role in academic achievement and social adaptation. Deficits in these domains can result in problems such as poor academic performance, difficulties in interpersonal relationships, impaired problem-solving skills, and increased risk-taking behaviors (1, 5).

Treatment for ADHD typically involves a combination of pharmacological and non-pharmacological approaches. Although pharmacological treatments such as stimulants like methylphenidate have proven effective in symptom reduction, concerns remain regarding side effects, limited durability of effects, and non-responsiveness in some children (6). Consequently, alternative and complementary approaches, particularly neurophysiological therapies such as neurofeedback, have gained increasing attention. Neurofeedback is a type of training based on neural feedback, where individuals learn to regulate and modulate their brainwaves by observing their EEG patterns. Studies have shown that neurofeedback can significantly enhance executive functioning, attention, and emotional self-regulation by improving coordination of brain activity (7).

LORETA neurofeedback (LORETA NF) is a more advanced generation of neurofeedback that utilizes neuroimaging algorithms to target and train deeper and functionally significant brain regions. Unlike traditional neurofeedback, which primarily addresses surface-level brainwaves, LORETA neurofeedback allows for the modulation of deeper neural networks such as the prefrontal cortex, anterior cingulate cortex, and other areas associated with the brain's executive network (8, 9). This potential advantage may lead to enhanced treatment effectiveness and more comprehensive improvements in the cognitive functioning of children with ADHD.

Despite the growing body of research on neurofeedback efficacy, existing data on the direct comparison between traditional neurofeedback and LORETA neurofeedback—especially concerning executive functions and sustained attention—remain limited and, in some cases, contradictory. Some domestic studies, including that of Hosseini et al. (2023), has indicated that LORETA neurofeedback offers superior outcomes due to its more precise targeting of brain regions (10). These discrepancies highlight the need for more rigorous comparative studies in this domain.

Accordingly, the present study was designed in response to this scientific and clinical need. Comparing the effectiveness of traditional neurofeedback and LORETA neurofeedback in improving executive functions and sustained attention in children with ADHD can contribute to the development of more effective treatment interventions, personalization of care, and informed decision-making regarding non-invasive therapeutic options. Therefore, the aim of this study is to evaluate and compare the effectiveness of traditional neurofeedback and LORETA neurofeedback in enhancing executive functions and sustained attention in children diagnosed with ADHD.

Methods and Materials

Study Design and Participants

The present study was a quasi-experimental design employing a pretest-posttest format with a control group, using a between-subjects comparative approach. In this study, participants were randomly assigned to three groups: traditional neurofeedback, LORETA neurofeedback, and control. The independent variable was the type of intervention (traditional neurofeedback, LORETA neurofeedback, or no intervention), and the dependent variables included components of executive functions (working memory, response inhibition, cognitive flexibility) and sustained attention. Controlled variables included age, gender, ADHD symptom severity, and history of medication use to minimize their impact on the results. The statistical population consisted of all children aged 8 to 12 years diagnosed with ADHD who visited the Mehrdoostan Psychological and Counseling Clinic in Tehran during 2024. ADHD diagnoses were made by a psychiatrist based on DSM-5-TR criteria. A convenience sampling method was employed among eligible clients, and then simple randomization was used to assign participants to three equal groups. Based on previous studies and using the sample size determination formula for experimental research (Cohen's formula with 80% power and a 0.05 alpha level), a sample size of 20 participants per group was set (totaling 60 participants).

Inclusion criteria were:

- Official diagnosis of ADHD by a psychiatrist
- Absence of comorbid disorders (e.g., autism, intellectual disability, or severe neurological disorders)
- No previous neurofeedback or similar cognitive interventions within the past six months

Exclusion criteria included missing more than two intervention sessions or withdrawal from continued participation.

Data Collection

Conners' Parent Rating Scale (CPRS-48): Developed by Keith Conners in 1997, this is one of the most widely used tools for assessing symptoms of ADHD in children. The scale includes 48 items completed by parents and consists of subscales such as hyperactivity, inattention, oppositional behavior, and anxiety. Items are scored on a 4-point Likert scale (0 = never to 3 = very often), with higher scores indicating greater symptom severity (11). The Persian version was translated and standardized by Jafari in 2006. The test-retest reliability for the total scale is reported at 0.85, and between 0.70 to 0.82 for subscales. Content validity has been confirmed by clinical psychology experts (12).

Continuous Performance Test (CPT): Originally developed in the 1980s by Barkley and colleagues, the CPT is used to assess sustained attention, concentration, and response control in both children and adults. This computerized test presents a sequence of stimuli (typically 150 to 200), requiring participants to respond to target stimuli while inhibiting responses to non-targets. Key indices include omission errors, commission errors, reaction time, and attention variability (13). The culturally adapted Persian software version was introduced by Amini in 2010. The test has demonstrated test-retest reliability of 0.83 and a Cronbach's alpha of 0.78 in domestic studies. Its discriminant validity in distinguishing ADHD from typically developing children has also been reported as acceptable (14).

Tower of London (TOL) Test: Designed by Shallice and McCarthy in 1982, this test measures cognitive planning, problem-solving, working memory, and mental flexibility. It usually includes 10 to 12 problems requiring the child to move colored balls from a start position to a goal configuration in as few moves as possible. Scoring is based on the number of moves, errors, and time taken to solve each problem. The Persian version was translated and adapted by Alipour in 2011 and has been widely used in Iranian studies. Construct validity has been supported via correlations with intelligence and executive function tests, and test-retest reliability has been reported at approximately 0.75 (15).

Stroop Test: Developed by John Ridley Stroop in 1935, this test assesses cognitive inhibition, attentional control, and cognitive flexibility. It consists of three stages: reading color words, naming ink colors, and naming the ink color of incongruent words. Each stage includes approximately 100 items, and participants must quickly name the ink color instead of reading the word. Scoring includes correct responses, errors, and reaction times. The computerized Persian version was developed by Nosrati et al. in 2013 and has been used in multiple theses and domestic articles. Reported test-retest reliability ranges from 0.78 to 0.86, and discriminant validity in differentiating children with ADHD from typical peers has been confirmed (16).

NEPSY-II Cognitive Software: NEPSY-II, developed by Korkman, Kirk, and Kemp in 2007, is one of the most comprehensive tools for assessing cognitive and neuropsychological development in children aged 3 to 16. It includes 32 subtests across six major cognitive domains: attention and executive functioning, language, memory and learning, sensorimotor skills, social perception, and visuospatial processing. Depending on research goals, the researcher may select appropriate subtests. Subtests such as "Auditory Attention and Response Set," "Numeric Working Memory," "Tower," and "Conceptual Sorting" are specifically designed to assess executive functioning and working memory. Scoring is done manually or via software, including raw scores, standard scores, and age-based norm comparisons (17). The Persian version was provisionally translated and culturally adapted by Shokrkon colleagues in 2018. According to international reports, NEPSY-II demonstrates construct and convergent validity with other neuropsychological assessments such as WISC-IV and BRIEF, with most subtest reliabilities ranging between 0.77 and 0.89. Preliminary Iranian studies have also supported its factorial structure and psychometric adequacy (18).

Interventions

Traditional Neurofeedback: This group received traditional neurofeedback over 20 sessions, each lasting 30 to 45 minutes (three sessions per week). The treatment protocol involved increasing beta wave amplitude (15–18 Hz) and decreasing theta waves (4–7 Hz) in the Cz and Fz regions using a two-channel EEG system.

LORETA Neurofeedback: Participants in this group also completed 20 similar sessions. This method used NeuroGuide software in combination with a 19-channel QEEG system to target deeper brain regions.

The regulation protocol focused on activating the prefrontal cortex (BA 10), anterior cingulate cortex (BA 24), and posterior parietal area (BA 7).

Data analysis

Data were analyzed using SPSS version 26. In the first step, descriptive statistics including means, standard deviations, and scatterplots were provided for preliminary data exploration. To examine group differences, one-way ANOVA was conducted, and if significant, Tukey's or LSD post hoc tests were used for pairwise comparisons. Paired t-tests were employed to compare pretest and posttest scores within each group. The significance level was set at $\alpha = 0.05$.

Findings and Results

The findings of this study are presented in two sections: descriptive and inferential statistics, as detailed below.

Table 1. Demographic and Clinical Characteristics of Participants

Variable	Traditional Neurofeedback	LORETA Neurofeedback	Control Group	Statistic	p-value
Age (Mean ± SD)	10.3 ± 1.2	10.5 ± 1.1	10.2 ± 1.3	F = 0.28	0.76
Gender (Male/Female)	13 / 7	14 / 6	15 / 5	χ^2 = 0.40	0.82
Symptom Severity	66.2 ± 7.8	65.9 ± 8.0	66.5 ± 7.7	F = 0.16	0.85

The results indicate no significant differences among the groups in terms of age (p = 0.76), gender distribution (p = 0.82), or ADHD symptom severity (p = 0.85), confirming the homogeneity of the groups.

Table 2. Comparison of Pretest Scores of Dependent Variables Among Groups

Variable	Traditional NF	LORETA NF	Control	F(2,57)	p-value
Sustained Attention	42.5 ± 6.4	42.0 ± 6.7	43.0 ± 6.2	0.14	0.87
Working Memory	38.7 ± 7.1	39.4 ± 6.8	38.2 ± 7.4	0.13	0.88
Response Inhibition	45.8 ± 7.9	46.4 ± 7.7	45.2 ± 8.1	0.18	0.84
Cognitive Flexibility	40.3 ± 6.6	41.2 ± 6.4	40.0 ± 6.8	0.16	0.85

Pretest results showed no significant differences among the three groups for the dependent variables—sustained attention, working memory, response inhibition, and cognitive flexibility ($p > 0.05$). This confirms initial cognitive equivalence, enabling valid post-intervention comparisons.

Table 3. Comparison of Posttest Scores and Within-Group Changes in Dependent Variables

Variable	Group	Pretest (M ± SD)	Posttest (M ± SD)	t (within)	p-value	Effect Size (d)
Sustained Attention	Traditional	42.5 ± 6.4	49.0 ± 5.8	5.45	<0.001	0.85
	LORETA	42.0 ± 6.7	53.0 ± 5.4	8.02	<0.001	1.28
	Control	43.0 ± 6.2	44.0 ± 6.0	0.92	0.37	0.13
Working Memory	Traditional	38.7 ± 7.1	44.5 ± 6.3	4.78	<0.001	0.74
	LORETA	39.4 ± 6.8	48.2 ± 5.7	7.05	<0.001	1.10
	Control	38.2 ± 7.4	39.0 ± 7.2	0.80	0.43	0.11
Response Inhibition	Traditional	45.8 ± 7.9	51.7 ± 7.2	5.02	<0.001	0.77
	LORETA	46.4 ± 7.7	55.0 ± 6.4	7.28	<0.001	1.14
	Control	45.2 ± 8.1	46.0 ± 7.9	0.74	0.47	0.09
Cognitive Flexibility	Traditional	40.3 ± 6.6	46.8 ± 5.9	5.15	<0.001	0.80
	LORETA	41.2 ± 6.4	49.7 ± 5.6	7.60	<0.001	1.18
	Control	40.0 ± 6.8	40.7 ± 6.6	0.85	0.41	0.10

Paired-sample t-tests showed that both intervention groups (traditional and LORETA neurofeedback) had statistically significant improvements in all dependent variables—sustained attention, working memory, response inhibition, and cognitive flexibility ($p < 0.001$). The effect sizes for the LORETA group were very large (Cohen's d = 1.10 to 1.28), indicating strong intervention efficacy. Traditional neurofeedback also showed moderate to large effects (d = 0.74 to 0.85). The control group showed no significant changes ($p > 0.05$). ANCOVA results also confirmed significant between-group differences in posttest scores for all variables ($F(2,56) > 11.0$, $p < 0.001$).

Table 4. Post Hoc Pairwise Comparison Results (Tukey or LSD)

Variable	Pairwise Comparison	Mean Difference	p-value	Effect Size (d)
Sustained Attention	Traditional vs. Control	5.0	<0.01	0.67
	LORETA vs. Control	9.0	<0.001	1.25
	LORETA vs. Traditional	4.0	<0.05	0.58
Working Memory	Traditional vs. Control	5.5	<0.01	0.72
	LORETA vs. Control	9.2	<0.001	1.18
	LORETA vs. Traditional	3.7	<0.05	0.54
Response Inhibition	Traditional vs. Control	5.7	<0.01	0.70
	LORETA vs. Control	9.0	<0.001	1.20
	LORETA vs. Traditional	3.3	<0.05	0.52
Cognitive Flexibility	Traditional vs. Control	6.1	<0.01	0.75
	LORETA vs. Control	9.0	<0.001	1.24
	LORETA vs. Traditional	2.9	<0.05	0.50

LORETA neurofeedback demonstrated significantly greater improvement in all variables compared to both the control group and traditional neurofeedback ($p < 0.05$). Traditional neurofeedback also showed significant improvements over the control group ($p < 0.01$), though with smaller effect sizes compared to LORETA.

Table 5. Three-Month Follow-Up Results in Dependent Variables

Variable	Group	Posttest (M ± SD)	3-Month Follow-Up (M ± SD)	t (within)	p-value	Effect Size (d)
Sustained Attention	Traditional	49.0 ± 5.8	48.2 ± 5.9	0.95	0.35	0.12
	LORETA	53.0 ± 5.4	52.4 ± 5.5	0.84	0.41	0.10
	Control	44.0 ± 6.0	43.7 ± 6.1	0.42	0.68	0.05
Working Memory	Traditional	44.5 ± 6.3	43.9 ± 6.4	0.82	0.42	0.09
	LORETA	48.2 ± 5.7	47.6 ± 5.8	0.77	0.45	0.10
	Control	39.0 ± 7.2	38.8 ± 7.3	0.31	0.76	0.03
Response Inhibition	Traditional	51.7 ± 7.2	51.0 ± 7.3	0.90	0.38	0.10
	LORETA	55.0 ± 6.4	54.4 ± 6.5	0.82	0.42	0.09
	Control	46.0 ± 7.9	45.7 ± 8.0	0.37	0.72	0.04
Cognitive Flexibility	Traditional	46.8 ± 5.9	46.1 ± 6.0	0.94	0.36	0.11
	LORETA	49.7 ± 5.6	49.1 ± 5.7	0.86	0.40	0.10
	Control	40.7 ± 6.6	40.4 ± 6.7	0.39	0.70	0.04

The effects of both traditional and LORETA neurofeedback interventions remained stable at the three-month follow-up ($p > 0.05$). The control group showed no significant changes over time ($p > 0.05$).

Discussion and Conclusion

The findings of this study demonstrated that both traditional neurofeedback and LORETA neurofeedback led to significant improvements in executive functions (including working memory, response inhibition, and cognitive flexibility) and sustained attention in children diagnosed with Attention-Deficit/Hyperactivity Disorder (ADHD). However, LORETA neurofeedback showed greater effectiveness compared to traditional neurofeedback. These effects were largely maintained at the three-month follow-up stage, indicating the relative stability of the interventions. These results are consistent with previous findings from both Iranian and international studies. For instance, Coben and Hudspeth (2020) indicated that LORETA neurofeedback is more effective than surface-level neurofeedback in precisely regulating neural networks, especially in prefrontal and anterior cingulate regions (9). Additionally, Hosseini et al. (2023) also reported strong efficacy of LORETA neurofeedback in enhancing executive functioning in children with ADHD (10). Conversely, the findings of the present study contradict some research that found no significant difference between the two approaches, which may be attributed to differences in training protocols, sample characteristics, or assessment tools.

From a theoretical perspective, the superiority of LORETA neurofeedback can be attributed to its higher precision in targeting deeper and functionally critical brain regions. Unlike traditional neurofeedback, which mainly focuses on surface EEG activity, LORETA utilizes three-dimensional algorithms to precisely modulate key areas such as the prefrontal cortex (BA 10), anterior cingulate cortex (BA 24), and posterior parietal cortex (BA 7), all of which play essential roles in attentional control and executive performance. Based on the findings of this study, it is recommended that LORETA neurofeedback be considered by clinical professionals as an effective and safe option within rehabilitation programs for children with ADHD. Furthermore, future studies are encouraged to explore the combined efficacy of LORETA neurofeedback with other interventions, such as parent training or cognitive rehabilitation, and to investigate its effects in more diverse populations (in terms of age and gender). Incorporating neuroimaging indices could also help elucidate the underlying mechanisms of this technique. Overall, the results suggest that LORETA neurofeedback can serve as a reliable, non-pharmacological approach for enhancing executive functioning and attention in children with ADHD, playing an important role in the development of individualized and targeted treatment plans.

Despite its positive results, this study had some limitations, including a relatively small sample size, lack of full control over concurrent pharmacological treatment, and absence of objective neurophysiological data such as QEEG. Additionally, the duration of the intervention (20 sessions) may have been insufficient to fully address some cognitive components.

Acknowledgments

We would like to express our appreciation and gratitude to all those who cooperated in carrying out this study.

Authors' Contributions

All authors equally contributed to this study.

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. Written consent was obtained from all participants in the study.

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.

Funding

This research was carried out independently with personal funding and without the financial support of any governmental or private institution or organization.

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