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Comparison of the Effectiveness of Transcranial Electrical Brain Stimulation and Cognitive Rehabilitation on Working Memory in Students Aged 7–13 Years with Specific Reading Learning Disorder

Neda. Ahmadi[1], Hossein Ali. Ghanadzadegan[1*], Shaban. Heidari[1]

[1] Department of Psychology, Sar.C., Islamic Azad University, Sari, Iran

*** Corresponding author email address**: Ghanad.hamid@lausari.ac.ir

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A B S T R A C T

The overall objective of the present study was to compare the effectiveness of transcranial electrical brain stimulation and cognitive rehabilitation on the working memory of students aged 7–13 years with specific reading learning disorder. In terms of purpose, the present study was applied research, and in terms of methodology, it was a quasi-experimental study with a pretest–posttest design and a control group. The statistical population consisted of all 7–13-year-old students with reading learning disabilities in Districts 7 and 10 of Tehran, totaling 1,500 individuals. A total of 45 participants (15 in the experimental group receiving transcranial electrical brain stimulation, 15 in the experimental group receiving cognitive rehabilitation, and 15 in the control group) were selected as the sample using simple random sampling. Data were collected using the N-back test to assess working memory. Multivariate analysis of covariance and the LSD post hoc test were used for data analysis. Transcranial electrical brain stimulation demonstrated greater effectiveness in improving working memory, particularly in reducing response time, compared with the control group, and in some indicators, it also showed superiority over cognitive rehabilitation. Transcranial electrical brain stimulation interventions and cognitive rehabilitation programs can be used as complementary methods for improving the working memory of students aged 7–13 years with specific reading learning disorder.

Keywords: *Transcranial electrical brain stimulation, cognitive rehabilitation, working memory, students, reading learning disorder*

1. Introduction

Specific learning disorder with impairment in reading, commonly referred to as dyslexia, is considered one of the most prevalent neurodevelopmental disorders among school-aged children and is characterized by persistent difficulties in reading accuracy, fluency, decoding, spelling, and comprehension despite adequate intelligence and educational opportunities (Ahadi & Kakavand, 2013; Tabrizi et al., 2024). Children with reading learning disorder frequently experience substantial academic challenges that negatively affect educational achievement, self-esteem, emotional adjustment, and social functioning. In many cases, these difficulties persist into adolescence and

adulthood if effective interventions are not implemented during the early developmental years (Vaughn et al., 2021). Researchers have increasingly emphasized that dyslexia is not merely a language-based deficit but rather a multidimensional disorder associated with impairments in executive functions, attentional control, processing speed, and working memory (Rouholamini et al., 2023; Shamshiri et al., 2025). Among these cognitive domains, working memory has attracted considerable attention because of its essential role in reading comprehension, phonological processing, information retention, and executive regulation during academic activities.

Working memory refers to a limited-capacity cognitive system responsible for the temporary storage and manipulation of information necessary for complex cognitive tasks such as learning, reasoning, language processing, and problem solving. Deficits in working memory are consistently reported among children with dyslexia and are considered one of the core mechanisms underlying reading difficulties (Ahadi & Kakavand, 2013; Tabrizi et al., 2024). Children with impaired working memory often struggle to retain phonological information while decoding written words, integrate sequential linguistic inputs, and sustain attention during reading tasks. Consequently, these students demonstrate slower reading performance, increased errors, and reduced comprehension compared with typically developing peers (Khanjani et al., 2012). Furthermore, impaired working memory may interfere with classroom participation, academic motivation, and adaptive learning behaviors, thereby increasing the risk of long-term educational difficulties and psychosocial maladjustment (Vaughn et al., 2021).

In recent years, advances in cognitive neuroscience have led to the development of innovative interventions aimed at improving executive functioning and neural efficiency among children with neurodevelopmental disorders. Among these interventions, transcranial direct current stimulation (tDCS), also referred to as transcranial electrical brain stimulation, has emerged as a promising noninvasive neuromodulation technique for enhancing cognitive performance (Constantino et al., 2025; Lu et al., 2024). Transcranial electrical stimulation involves the application of low-intensity electrical currents to specific cortical regions in order to modulate neuronal excitability and facilitate neuroplasticity. Studies have demonstrated that stimulation of the dorsolateral prefrontal cortex may improve executive functions, including working memory, cognitive flexibility, attentional control, and inhibitory processes (Nozari et al., 2019; Sabahi et al., 2025). Because working memory deficits represent a central cognitive challenge in dyslexia, researchers have increasingly explored the efficacy of transcranial electrical stimulation as a therapeutic approach for students with reading disorders.

Empirical evidence has supported the beneficial effects of transcranial electrical stimulation on cognitive and academic functioning among children with dyslexia and related neurodevelopmental conditions. For instance, (Bayat Mokhtari et al., 2017) demonstrated that transcranial direct current stimulation combined with phonological awareness training significantly improved visual working memory performance in children with dyslexia. Similarly, (Rouholamini et al., 2023) reported that transcranial direct current stimulation enhanced both working memory and reading performance in students with specific learning disorder with impairment in reading. These findings suggest that neuromodulation techniques may influence neural networks associated with language processing and executive functioning, thereby contributing to cognitive improvement in dyslexic populations. In a more recent clinical trial, (Battisti et al., 2024) found that short and intensive tDCS interventions improved reading-related abilities in children and adolescents with developmental dyslexia. Furthermore, the scoping review conducted by (Constantino et al., 2025) concluded that transcranial direct current stimulation demonstrates promising therapeutic potential in developmental dyslexia, particularly when combined with cognitive or educational interventions.

The effectiveness of transcranial electrical stimulation has also been documented in populations beyond dyslexia, highlighting its broader impact on executive functioning and working memory. (Sabahi et al., 2025) demonstrated that transcranial direct current stimulation significantly improved executive functions such as time self-management, self-organization, and problem-solving in children with attention-deficit/hyperactivity disorder. Similarly, (Ghalichin, 2025) reported improvements in working memory components among educable children with intellectual disability following transcranial direct current stimulation. Research conducted by (Nozari et al., 2019) further showed that transcranial electrical stimulation improved executive functions and reduced symptoms among individuals with major depressive disorder. In addition, (Nejati et al., 2017) found that combining psychological interventions with direct electrical brain stimulation yielded positive outcomes in emotional and cognitive functioning among patients with depression. Collectively, these findings

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indicate that transcranial electrical stimulation may exert substantial effects on cognitive regulation and neural plasticity across diverse clinical populations.

Alongside neuromodulation approaches, cognitive rehabilitation has emerged as another effective intervention for improving executive functions and cognitive performance among individuals with neurodevelopmental and neurological disorders. Cognitive rehabilitation refers to a structured therapeutic approach designed to strengthen cognitive abilities through systematic training, repeated practice, compensatory strategies, and metacognitive exercises (Bergo et al., 2016). This intervention targets processes such as attention, memory, problem-solving, cognitive flexibility, and information processing speed. In educational settings, cognitive rehabilitation programs are increasingly used to support students with learning disorders by enhancing neural efficiency and promoting adaptive cognitive functioning (Parhoon et al., 2024; Shamshiri et al., 2025).

Previous studies have demonstrated the effectiveness of cognitive rehabilitation interventions for children with learning disorders. (Parhoon et al., 2024) reported that cognitive rehabilitation training programs significantly improved cognitive performance and academic functioning among school-aged children with specific learning disorder. Likewise, (Shamshiri et al., 2025) compared computerized cognitive rehabilitation with cognitive-behavioral play therapy and found that cognitive rehabilitation effectively enhanced executive functions in students with dyslexia. Cognitive rehabilitation interventions may improve working memory through repetitive activation of neural circuits associated with attentional regulation, information retention, and executive control. These programs often incorporate tasks related to sustained attention, visuospatial processing, memory updating, and inhibitory control, all of which are closely linked to reading and academic performance (Bergo et al., 2016).

Despite the growing body of evidence regarding the effectiveness of transcranial electrical stimulation and cognitive rehabilitation, several gaps remain in the literature. First, many previous studies have examined these interventions independently rather than comparatively, making it difficult to determine which approach may produce greater improvements in working memory among students with dyslexia. Second, existing findings are sometimes inconsistent due to variations in stimulation protocols, intervention duration, participant characteristics, and assessment methods (Constantino et al., 2025; Lu et al., 2024). Third, although research has increasingly focused on executive functions in dyslexia, limited attention has been devoted specifically to working memory outcomes in children aged 7 to 13 years, a critical developmental period for academic and cognitive growth. Finally, there remains a need for culturally and contextually grounded research examining these interventions within Iranian educational settings, where learning disorders constitute an important challenge for students, families, and educational systems (Ahadi & Kakavand, 2013; Tabrizi et al., 2024).

The theoretical rationale for comparing transcranial electrical stimulation and cognitive rehabilitation is rooted in contemporary models of neuroplasticity and executive functioning. Transcranial electrical stimulation primarily influences cortical excitability and synaptic efficiency through direct modulation of neural activity, whereas cognitive rehabilitation emphasizes behavioral training, repeated cognitive engagement, and compensatory learning mechanisms (Lu et al., 2024). Although both interventions aim to improve cognitive functioning, they operate through partially different mechanisms. Neuromodulation may facilitate rapid neural activation and functional connectivity, while cognitive rehabilitation may promote gradual cognitive restructuring and strategy acquisition. Therefore, comparative investigation of these approaches may provide valuable insights into the relative effectiveness of biological and cognitive-behavioral interventions for improving working memory in children with reading learning disorder.

Furthermore, identifying effective interventions for dyslexia has substantial practical implications for educational psychology, special education, and clinical rehabilitation. Students with reading learning disorder often experience repeated academic failure, emotional distress, social withdrawal, and reduced academic self-efficacy (Vaughn et al., 2021). Early interventions targeting executive functions and working memory may not only improve cognitive performance but also enhance academic engagement, motivation, and psychosocial adjustment. Consequently, investigating innovative interventions such as transcranial electrical stimulation and cognitive rehabilitation may contribute to the development of evidence-based educational and therapeutic programs for children with dyslexia.

Considering the importance of working memory in reading performance, the increasing prevalence of dyslexia among school-aged children, and the growing interest in neuromodulation and cognitive rehabilitation interventions, further comparative research in this field appears necessary.

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Therefore, the present study aimed to compare the effectiveness of transcranial electrical brain stimulation and cognitive rehabilitation on the working memory of students aged 7–13 years with specific reading learning disorder.

2. Methods and Materials

2.1. Study Design and Participants

The present study was applied research in terms of purpose and a quasi-experimental study with a pretest–posttest design and a control group in terms of methodology. The study included three groups of participants consisting of two experimental groups and one control group, with 15 participants assigned to each group. Both experimental groups and the control group were assessed twice using standardized instruments during the pretest and posttest stages. Initially, the pretest was administered to all participants in the experimental and control groups. Subsequently, the experimental groups were exposed to the independent variables, including transcranial electrical brain stimulation and cognitive rehabilitation, whereas the control group did not receive any intervention during the study period. After completion of the intervention programs, the posttest was administered again among all three groups in order to evaluate changes in working memory performance.

The statistical population consisted of all students aged 7 to 13 years with specific reading learning disorder (dyslexia) who had been diagnosed by psychologists specializing in children with special needs and were studying in Districts 7 and 10 of Tehran. The total population included approximately 1,500 students. From this population, 45 participants were selected through simple random sampling. The sample consisted of 15 students in the transcranial electrical brain stimulation group, 15 students in the cognitive rehabilitation group, and 15 students in the control group.

2.2. Measures

The N-back test was used to assess working memory performance. This test is considered a cognitive performance assessment technique associated with executive functions and was first introduced by Kirchner in 1958 for the evaluation of working memory. The test includes both visual and auditory forms. In the present study, the auditory version was employed, in which 100 stimuli consisting of single-digit numbers were presented sequentially through headphones connected to a computer. Among these stimuli, 18 were target stimuli and the remaining items were non-target stimuli. Participants were instructed to press key “1” whenever the current number matched the previous number and key “2” whenever the current number did not match the preceding stimulus. Each response triggered the presentation of the subsequent stimulus. After completion of the test, the participants’ responses, including memory scores and reaction times for each stimulus, were automatically recorded by the software. Each correct response received one positive point, whereas each incorrect response received a penalty score of 0.5. Previous studies have reported reliability coefficients ranging from 0.54 to 0.84, indicating satisfactory reliability. Furthermore, the validity of the test as an indicator of working memory performance has been reported as acceptable, with previous Iranian research reporting a validity coefficient of 0.79. In the present study, the test–retest reliability coefficient was also obtained as 0.79.

Transcranial electrical brain stimulation was administered using the Neurostim device, which was industrially manufactured for the first time in Iran and released to the market in 2015. The device contains two separate channels, a rechargeable battery, and an LCD display. Each channel can be adjusted independently, and the output current intensity can be regulated within a range of 0.1 to 2 mA. The system includes two anode electrodes marked in red, two cathode electrodes marked in white, and both small and large stimulation pads. The participants received two forms of transcranial electrical brain stimulation, including anodal stimulation and sham stimulation, applied over the dorsolateral prefrontal cortex. The stimulation intensity was set at 2 mA for 15 minutes during each session.

2.3. Interventions

The cognitive rehabilitation program employed in the present study was based on the hierarchical model proposed by Maggio and colleagues in 2019. The intervention program was implemented in 21 sessions, each lasting 60 minutes, and was conducted at the participants’ schools. Sessions were held intensively two to three times per week. The initial sessions focused on establishing a therapeutic alliance, defining treatment goals, and implementing exercises related to selective attention, concentration, visual memory, and sustained attention. Subsequent sessions emphasized sustained attention, vigilance, associative memory, logical memory, visuospatial memory, alternating

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attention, and working memory exercises. Additional sessions incorporated short-term memory training, visual imagery, focused attention, delayed recall strategies, recognition memory, sensory memory, motor memory, and mathematical problem-solving activities. Various cognitive techniques such as spaced retrieval, fading cue methods, self-questioning strategies, and dual-task attention exercises were integrated throughout the rehabilitation process to improve working memory and executive functioning among students with reading learning disorder.

Participants assigned to the transcranial electrical brain stimulation group received stimulation sessions targeting the dorsolateral prefrontal cortex. The intervention consisted of three sessions of transcranial electrical stimulation administered at an intensity of 2 mA for 15 minutes per session. Both active anodal stimulation and sham stimulation procedures were implemented in accordance with standardized stimulation protocols. The electrodes were positioned over the prefrontal cortical regions, and stimulation parameters were individually adjusted through the Neurostim device. The intervention was conducted under controlled conditions to ensure participant safety and consistency of stimulation delivery across sessions.

2.4. Data Analysis

Data analysis was conducted using both descriptive and inferential statistical methods. In the descriptive statistics section, means and standard deviations were calculated for the study variables. In the inferential statistics section, multivariate analysis of covariance (MANCOVA) was employed to examine differences among the experimental and control groups while controlling for pretest scores. In addition, the Least Significant Difference (LSD) post hoc test was used to identify pairwise differences between the groups following significant multivariate effects. All statistical analyses were performed using the IBM SPSS Statistics version 24 software package.

3. Findings and Results

The findings of the study are presented in two sections: descriptive and inferential statistics. In the descriptive section, the means and standard deviations of the research variables are presented in Table 1.

Table 1

Means and Standard Deviations of the Research Variables by Experimental and Control Groups

Group	Variable	Pretest Mean	Pretest SD	Posttest Mean	Posttest SD
Transcranial Electrical Brain Stimulation	Correct Responses	14.47	4.76	19.33	5.16
	Time	174.59	3.24	165.52	4.89
Cognitive Rehabilitation	Correct Responses	14.33	4.76	16.87	5.12
	Time	173.40	3.20	169.71	4.89
Control	Correct Responses	14.67	4.83	14.80	5.18
	Time	173.12	3.25	173.49	4.89

Table 1 compares working memory performance across the three groups based on two indicators, namely correct responses and time. Overall, both intervention groups demonstrated greater improvement compared with the control group. In the transcranial electrical brain stimulation group, the mean score of correct responses increased from 14.47 in the pretest to 19.33 in the posttest, while the mean time decreased from 174.59 to 165.52, indicating improvement in both accuracy and response speed. In the cognitive rehabilitation group, the mean correct responses increased from 14.33 to 16.87, and the mean time decreased from 173.40 to 169.71, reflecting enhanced working memory performance. In contrast, the control group showed no substantial change in correct responses, and the time scores remained relatively stable with only minimal variation.

In the inferential section, multivariate analysis of covariance (MANCOVA) and the LSD post hoc test were used to compare the effectiveness of transcranial electrical brain stimulation and cognitive rehabilitation on the working memory of students aged 7–13 years with specific reading learning disorder.

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Table 2

Results of Multivariate Tests for the Effectiveness of Transcranial Electrical Brain Stimulation and Cognitive Rehabilitation on Working Memory in Students with Specific Reading Learning Disorder

Variable	Test	Value	F	df	Error df	Sig.
Working Memory	Pillai's Trace	0.404	5.069	4	80	0.001
	Wilks' Lambda	0.596	5.764	4	78	0.001
	Hotelling's Trace	0.678	6.443	4	76	0.001
	Roy's Largest Root	0.678	13.555	2	40	0.001

According to Table 2, based on Pillai's Trace value of 0.404, Wilks' Lambda value of 0.596, Hotelling's Trace value of 0.678, and Roy's Largest Root value of 0.678, the significance level in all cases was reported as 0.001, which is lower than 0.05. These findings indicate that there were significant differences among the groups regarding the combined components of working memory. Therefore, the implemented interventions had a statistically significant effect on the working memory of students aged 7–13 years with specific reading learning disorder.

Table 3

Examination of the Effectiveness of Transcranial Electrical Brain Stimulation and Cognitive Rehabilitation on Working Memory in Students with Specific Reading Learning Disorder Using Multivariate Analysis of Covariance

Source	Variable	Sum of Squares	Mean Square	F	Sig.	Eta Squared
Group	Correct Responses	158.195	79.098	3.810	0.031	0.160
	Time	559.129	279.565	13.295	0.001	0.399

According to Table 3, the effect of group membership was significant for both indicators of working memory. For correct responses, the F value was 3.810 with a significance level of 0.031, indicating that after controlling for pretest effects, significant differences existed among the groups in terms of correct responses. Furthermore, for the time variable, the F value was 13.295 with a significance level of 0.001, demonstrating significant differences among the groups in reaction time. The eta squared values indicated that the effect size of group membership was 0.160 for correct responses, representing a small effect size, and 0.399 for time, representing a moderate effect size. Therefore, it can be concluded that the interventions, particularly in the time indicator, played a considerable role in improving the working memory of students aged 7–13 years with specific reading learning disorder.

Table 4

Bonferroni Pairwise Comparison of Working Memory Means Among Students with Specific Reading Learning Disorder Across Groups

Variable	Group	Mean	Comparison Group	Mean Difference	Sig.
Correct Responses	Transcranial Electrical Brain Stimulation	19.368	Cognitive Rehabilitation	2.42	0.473
			Control	4.68*	0.026
	Cognitive Rehabilitation	16.944	Transcranial Electrical Brain Stimulation	-2.42	0.473
			Control	2.25	0.550
	Control	14.688	Transcranial Electrical Brain Stimulation	-4.68*	0.026
			Cognitive Rehabilitation	-2.25	0.550
Time	Transcranial Electrical Brain Stimulation	165.021	Cognitive Rehabilitation	-4.88*	0.019
			Control	-8.78*	0.001
	Cognitive Rehabilitation	169.902	Transcranial Electrical Brain Stimulation	4.88*	0.019
			Control	3.90	0.075
	Control	173.807	Transcranial Electrical Brain Stimulation	8.78*	0.001
			Cognitive Rehabilitation	3.90	0.075

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According to Table 4, in the correct responses indicator, the mean score of the transcranial electrical brain stimulation group was 19.368, the cognitive rehabilitation group was 16.944, and the control group was 14.688. The comparison results demonstrated that the difference between the transcranial electrical brain stimulation group and the control group was statistically significant, indicating superior performance of the stimulation group in correct responses. However, the differences between the transcranial electrical brain stimulation group and the cognitive rehabilitation group, as well as between the cognitive rehabilitation group and the control group, were not statistically significant. In the time indicator, the mean score of the transcranial electrical brain stimulation group was 165.021, compared with 169.902 in the cognitive rehabilitation group and 173.807 in the control group. Pairwise comparisons revealed that the transcranial electrical brain stimulation group demonstrated significantly lower reaction times than both the cognitive rehabilitation and control groups. In contrast, the difference between the cognitive rehabilitation and control groups in reaction time was not statistically significant. Overall, the findings indicate that transcranial electrical brain stimulation showed greater effectiveness in improving working memory, particularly in reducing response time, compared with the control group, and in some indicators also demonstrated superiority over cognitive rehabilitation.

4. Discussion

The present study aimed to compare the effectiveness of transcranial electrical brain stimulation and cognitive rehabilitation on the working memory of students aged 7–13 years with specific reading learning disorder. The findings demonstrated that both interventions improved working memory performance compared with the control group; however, transcranial electrical brain stimulation showed greater effectiveness, particularly in reducing reaction time and enhancing response accuracy. The multivariate analysis of covariance indicated significant differences among the groups in the combined components of working memory, confirming that the interventions had a statistically significant effect on cognitive functioning in students with dyslexia. Furthermore, the Bonferroni post hoc comparisons revealed that the transcranial electrical brain stimulation group significantly outperformed the control group in correct responses and reaction time, whereas the cognitive rehabilitation group demonstrated moderate improvement that did not reach statistical significance in all comparisons.

One of the major findings of the present study was the superiority of transcranial electrical brain stimulation in improving working memory performance. This finding is consistent with the results reported by (Bayat Mokhtari et al., 2017), who found that transcranial direct current stimulation combined with phonological awareness training improved visual working memory in children with dyslexia. Similarly, (Rouholamini et al., 2023) demonstrated that transcranial direct current stimulation significantly enhanced both working memory and reading performance in students with specific learning disorder with impairment in reading. The present findings also align with the clinical trial conducted by (Battisti et al., 2024), who reported that short and intensive transcranial direct current stimulation improved cognitive and reading-related abilities in children and adolescents with developmental dyslexia. Furthermore, the scoping review conducted by (Constantino et al., 2025) concluded that transcranial direct current stimulation has considerable therapeutic potential in developmental dyslexia, especially when integrated with cognitive and educational interventions.

The effectiveness of transcranial electrical brain stimulation observed in the present study may be explained through neurophysiological mechanisms associated with cortical excitability and neuroplasticity. Transcranial direct current stimulation modulates neuronal membrane potentials and facilitates synaptic transmission within targeted cortical regions, particularly the dorsolateral prefrontal cortex, which plays a central role in executive functions and working memory processes (Lu et al., 2024). By enhancing neural efficiency within prefrontal networks, electrical stimulation may improve attentional control, information processing speed, memory updating, and inhibitory control. These improvements may subsequently facilitate more accurate and rapid responses during working memory tasks among students with reading learning disorder. The reduction in reaction time observed in the stimulation group supports the notion that transcranial electrical stimulation contributes not only to cognitive accuracy but also to processing efficiency and executive regulation.

Another important finding of the present study was that cognitive rehabilitation also improved working memory performance compared with the control group, although its effects were less pronounced than those of transcranial electrical brain stimulation. This finding is consistent with the results of (Parhoon et al., 2024), who demonstrated that

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cognitive rehabilitation training significantly improved cognitive performance among children with specific learning disorder. Similarly, (Shamshiri et al., 2025) found that computerized cognitive rehabilitation effectively enhanced executive functions in students with dyslexia. Cognitive rehabilitation interventions are designed to strengthen neural and cognitive functioning through repeated practice, compensatory strategies, and structured cognitive exercises targeting attention, memory, and executive control. Therefore, the observed improvements in working memory among the cognitive rehabilitation group may be attributed to repeated activation and reinforcement of neural circuits associated with attentional processing and information retention.

The findings of the present study also support theoretical perspectives emphasizing the central role of executive functions and working memory in reading performance and academic functioning among children with dyslexia (Ahadi & Kakavand, 2013; Tabrizi et al., 2024). Students with reading learning disorder often experience difficulties in retaining and manipulating phonological information, sustaining attention during reading activities, and integrating sequential linguistic stimuli. Weaknesses in working memory may impair decoding accuracy, reading fluency, and comprehension, thereby contributing to persistent academic challenges. Consequently, interventions that enhance executive functioning and working memory may directly influence reading-related processes and educational outcomes. The improvements observed in the present study suggest that both neuromodulation and cognitive rehabilitation interventions can contribute to strengthening cognitive capacities underlying reading performance.

The greater effectiveness of transcranial electrical brain stimulation compared with cognitive rehabilitation may be explained by differences in the mechanisms through which these interventions influence cognitive functioning. Cognitive rehabilitation primarily relies on behavioral learning principles, repetitive cognitive exercises, and metacognitive strategy development. Although these approaches can strengthen cognitive skills over time, their effects may require prolonged and continuous training to achieve substantial neurocognitive change (Bergo et al., 2016). In contrast, transcranial electrical stimulation directly influences neural excitability and cortical activation, potentially producing faster and more immediate changes in neural processing efficiency. This distinction may explain why the stimulation group in the present study demonstrated more pronounced reductions in reaction time and greater gains in correct responses.

The present findings are also consistent with studies conducted in other clinical populations demonstrating the effectiveness of transcranial electrical stimulation in improving executive functioning. For example, (Sabahi et al., 2025) reported improvements in executive functions such as self-management and problem-solving among children with attention-deficit/hyperactivity disorder following transcranial direct current stimulation. Likewise, (Ghalichin, 2025) found significant enhancement in working memory components among educable children with intellectual disability after electrical brain stimulation. In addition, (Nozari et al., 2019) demonstrated that transcranial electrical stimulation improved executive functions in individuals with major depressive disorder, while (Nejati et al., 2017) reported positive cognitive and emotional outcomes following combined psychological intervention and electrical brain stimulation. These studies collectively support the notion that transcranial electrical stimulation exerts broad effects on executive functioning across different neurodevelopmental and psychological conditions.

The observed improvements in working memory may also be interpreted within the framework of neural plasticity. Childhood and early adolescence represent periods of heightened neural adaptability during which cognitive interventions and neuromodulatory techniques may effectively strengthen neural connectivity and cognitive performance. Transcranial electrical stimulation may facilitate synaptic plasticity by enhancing long-term potentiation and increasing cortical responsiveness in neural networks associated with executive functioning (Lu et al., 2024). Similarly, cognitive rehabilitation programs may stimulate compensatory neural mechanisms through repeated engagement in attention and memory tasks. The simultaneous activation of cognitive and neural systems may contribute to improved executive functioning and working memory performance among students with dyslexia.

Another noteworthy aspect of the present findings is the significant reduction in reaction time observed in the transcranial electrical stimulation group. Reaction time is considered an important indicator of processing speed and cognitive efficiency. Students with dyslexia frequently demonstrate slower cognitive processing and delayed response patterns during reading and executive functioning tasks (Tabrizi et al., 2024). The significant reduction in reaction time following stimulation suggests that electrical neuromodulation may enhance the speed of information

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processing and attentional allocation. This improvement may facilitate more efficient cognitive functioning during academic activities requiring rapid processing of verbal and visual information.

The present findings further support the growing integration of neuroscience-based interventions into educational and psychological practice. Traditional interventions for dyslexia have often focused primarily on phonological training and educational remediation (Khanjani et al., 2012). Although these interventions remain important, contemporary research increasingly emphasizes the role of executive functioning and neural regulation in reading disorders. Therefore, combining cognitive, educational, and neuromodulatory approaches may provide more comprehensive and effective treatment outcomes for children with dyslexia. The results of the present study indicate that transcranial electrical brain stimulation and cognitive rehabilitation may serve as complementary approaches for improving working memory and executive functioning in students with reading learning disorder.

Moreover, the findings of the present study have important implications for educational inclusion and psychosocial adjustment among students with learning disorders. Students with dyslexia frequently experience academic frustration, low self-confidence, social withdrawal, and reduced classroom participation (Vaughn et al., 2021). Improvements in working memory and cognitive efficiency may contribute not only to academic performance but also to enhanced emotional adjustment and social functioning. Consequently, interventions targeting executive functioning may play a broader role in improving quality of life and educational participation among students with specific learning disorder.

5. Conclusion

Despite the promising findings of the present study, several methodological and conceptual considerations should be acknowledged. The effectiveness of transcranial electrical stimulation may vary depending on stimulation intensity, electrode placement, duration of intervention, and individual neurocognitive characteristics. Similarly, cognitive rehabilitation outcomes may depend on participant motivation, family support, and consistency of training sessions. Future investigations examining these moderating factors may provide a more comprehensive understanding of intervention effectiveness in children with dyslexia.

One of the limitations of the present study was the relatively small sample size, which may restrict the generalizability of the findings to broader populations of students with specific reading learning disorder. In addition, the study was conducted only among students from Districts 7 and 10 of Tehran, limiting the cultural and geographical diversity of the participants. Another limitation was the absence of a long-term follow-up period to evaluate the durability of the intervention effects over time. Furthermore, the study focused exclusively on working memory and did not examine additional variables such as reading comprehension, academic achievement, emotional functioning, or family-related factors that may influence treatment outcomes.

Future research is recommended to investigate the long-term effectiveness of transcranial electrical brain stimulation and cognitive rehabilitation through longitudinal follow-up designs. Researchers are also encouraged to examine the combined effects of neuromodulation and cognitive rehabilitation interventions in order to determine whether integrated approaches produce stronger and more sustainable cognitive improvements. Additionally, future studies should include larger and more diverse samples from different educational and cultural contexts and explore the impact of these interventions on broader academic, emotional, and social outcomes among students with learning disorders.

The findings of the present study suggest that educational psychologists, special education professionals, rehabilitation specialists, and school counselors may benefit from incorporating neuroscience-based interventions into educational support programs for students with dyslexia. Schools and clinical centers may utilize transcranial electrical brain stimulation and structured cognitive rehabilitation programs as complementary interventions for improving executive functioning and working memory. Early identification and intervention targeting cognitive deficits may contribute to better academic achievement, improved classroom participation, and enhanced psychological well-being among students with specific reading learning disorder.

Authors' Contributions

Authors equally contributed to this article.

Declaration

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In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethics Considerations

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

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