KMANPUB | Health Nexus Vol. 1 No. 2 (2023): 44-50

Article history:
Received 06 January 2022
Revised 13 March 2023
Accepted 18 March 2023
Published online 01 April 2023

Investigating the Effect of Electrical Stimulation (tDCS) of the Prefrontal Cortex of the Brain on the Improvement of Behavioral and Neurological Symptoms of Children with Specific Learning Disabilities

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A r t i c l e I n f o

Article type:
Original Research

How to cite this article:
Aghaziarati, A., Rajabi Fard, F., Rahimi, H., & Parsakia, K. (2023). Investigating the Effect of Electrical Stimulation (tDCS) of the Prefrontal Cortex of the Brain on the Improvement of Behavioral and Neurological Symptoms of Children with Specific Learning Disabilities. *Health Nexus, 1*(2), 44-50.
https://doi.org/10.61838/kman.hn.1.2.6

A B S T R A C T

The aim of the current research was to investigate the effect of electrical stimulation of the dorsolateral prefrontal cortex on improving behavioral and neuropsychological symptoms in children with specific learning disorders. The research method was quasi-experimental. The study population comprised all children aged 7 to 12 years with specific learning disorders attending a private psychotherapy center in Tehran during 2022. From this group, 20 individuals were selected as the statistical sample using convenient random sampling, with 10 placed in the experimental group and 10 in the control group. Research tools included an electrical stimulation program for improving behavioral and neuropsychological symptoms in children with specific learning disorders, the Symptom Checklist-90-Revised (SCL-90R), and the Conners' Neuropsychological Questionnaire (2004). Statistical data analysis was performed using SPSS software and mixed analysis of variance with repeated measurements. The findings showed significant differences between the behavioral symptom scores and neuropsychological signs of the experimental and control groups in the pre-test and post-test phases. The results indicated that electrical stimulation of the dorsolateral prefrontal cortex had a significant effect on reducing both behavioral symptoms and neuropsychological signs in the experimental group. The effectiveness of this intervention was also sustained in the follow-up phase according to the Bonferroni post-hoc test. Based on the findings, it can be concluded that electrical stimulation of the dorsolateral prefrontal cortex can be used to reduce behavioral symptoms and neuropsychological signs in students with specific learning disorders. Therefore, it is suggested that this method be used in child and adolescent counseling centers and rehabilitation facilities.

Keywords: *Electrical stimulation of the dorsolateral prefrontal cortex of the brain, behavioral syndromes, neuropsychological symptoms, specific learning disorders.*

1. Introduction

According to the Federal Regulation definition in 1997, Specific Learning Disorder means a disorder in one or more basic psychological processes involved in understanding or using spoken or written language, which may manifest as a deficiency in listening, thinking, speaking, reading, writing, spelling, or performing mathematical calculations (1). This term includes conditions such as perceptual deficits, brain injury, minimal brain dysfunction, dyslexia, and developmental aphasia (2). However, children whose learning problems are due to visual, auditory, or motor deficits, or due to mental retardation, emotional disturbance, or environmental, cultural, or economic disadvantage, are not included in this definition (3). Achenbach have categorized children's behavioral problems into two categories: internalizing and externalizing behaviors. Children with externalizing behaviors typically exhibit aggressive and belligerent actions; conversely, children with internalizing behaviors have immature and often withdrawn behaviors (4). These types of behaviors are more frequently reported in children with learning disorders (5).

Recent approaches have shifted towards neuropsychological interventions and targeting executive functions (6). From a neurocognitive perspective, executive functions refer to a set of cognitive and metacognitive processes employed in managing goal-directed behavior (7, 8). Some studies indicate that deficiencies in executive functions in elementary school children persist into later ages, posing serious challenges for them in school tasks and personal affairs (9); thus, clinical specialists are interested in recognizing the elements and components of neuro-psychological through understanding executive dysfunctions especially in common developmental neurological disorders in childhood (10). Neurocognitive executive functions are significant because they are related to psychological processes responsible for regulating alertness and thinking in action. They regulate and organize behavioral outputs (11). Waller and Sidman (2006) and Osterrieth (2013) have noted the deficiency in attention and working memory as components of neuro-psychological executive functions in children with learning disorders (12).

The prefrontal cortex is recognized as an important part of the brain network regulating mood and emotion. Studies have also pointed to the role of the dorsolateral prefrontal cortex in processing emotions related to perceived stimuli; such as faces or images inducing emotion, as well as processing cognitive and non-emotional information (13). The prefrontal cortex plays a role in the neural network involved in processing mood and emotion. Additionally, there are differences between the two hemispheres of the brain in processing positive and negative emotions, such that the right hemisphere is more involved in processing negative emotions, and the left hemisphere is more involved in processing positive emotions (10, 14). Transcranial Direct Current Stimulation (tDCS) is one of the therapeutic methods based on the neuroplasticity of the central nervous system in treating various psychiatric and neurological diseases. This non-invasive treatment method aims to stimulate the function of neurons in the brain based on the ability of electric current to pass through the skull and brain membranes, thereby inducing electric current in brain tissue. The effectiveness of tDCS depends on the direction of the electric current; anodal stimulation increases brain activity and excitability, while cathodal stimulation decreases it (15, 16). The effect of tDCS on different brain regions depends on several factors, including electrode montage, size of the electrodes, intensity and duration of the induced current, shape of the participants' head, amount of fat tissue on the head, and thickness of the skull. Consequently, the amount of induced current in brain regions may vary among individuals, and the regions under the electrodes in cognitive performance are affected. Ultimately, stimulation of specific brain regions causes widespread changes in brain activity that can have multiple effects on cognitive functions simultaneously (10, 17, 18). For example, studies suggest that stimulation of the DLPFC using tDCS is associated with a shift in mood to a positive emotional state (19, 20). The durability of the effect of electrical brain stimulation depends on the duration and intensity of the electrical current applied to the targeted brain area. It appears that electrical brain stimulation through the skull, by a mechanism similar to long-term potentiation, strengthens synaptic connections (15, 16). The effect of these changes on brain functions and the role of different cortical areas of the brain in cognitive functions, individual performance in various cognitive tasks during or after the application of electrical brain stimulation from the skull in different prefrontal cortex areas are being evaluated by specialists (19).

Thus, the aim of the current research was to investigate the effect of electrical stimulation of the dorsolateral prefrontal cortex on improving behavioral and

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E-ISSN: 2981-2569

neuropsychological symptoms in children with specific learning disorders.

2. Methods and Materials

2.1. Study Design and Participants

The present study is applied in purpose and quasi-experimental in method, employing a pre-test, post-test, and follow-up design with one experimental group and one control group. The study population consisted of all 7 to 12-year-old children with Specific Learning Disorder who visited a private psychotherapy center in Tehran in the second half of 2021 and the first half of 2022. Out of these individuals, 20 were randomly selected as the sample, with 10 placed in the experimental group and 10 in the control group. Inclusion criteria: diagnosis of one or more Specific Learning Disorders by a specialist, parental consent for participation, absence of other psychiatric disorders and specific physical problems, no use of particular medication. Exclusion criteria: non-cooperation in participating in sessions, parental withdrawal of consent, diagnosis of other disorders or diseases during the research period. The research initially involved administering the Symptom Checklist-90-R (SCL-90R) and Conners' Neuropsychiatric Questionnaire (2004) to all 20 participants. Then interventions were conducted for the experimental group while the control group received no intervention. After the intervention sessions, both groups again responded to the research instruments. Finally, after two months, a follow-up phase was conducted where both groups completed the questionnaires.

2.2. Measures

2.2.1. Behavioral Symptoms

The Symptom Checklist-90-R (SCL-90R) includes 90 items scored on a 5-point Likert scale (from 0 to 4), yielding total scores ranging from 90 to 360. It measures nine dimensions: somatization, obsessive-compulsive, interpersonal sensitivity, depression, anxiety, hostility, phobic anxiety, paranoid ideation, and psychosis. Internal reliability was calculated using Cronbach's alpha, with coefficients for all subscales above 0.70, indicating good internal reliability. Test-retest reliability over one week showed coefficients between 0.87 and 0.90. The validity of this questionnaire has also been confirmed by its creator and colleagues and other researchers (21, 22). In the current study, Cronbach's alpha was used to assess reliability, and the lowest alpha obtained was 0.73, indicating good reliability of the questionnaire.

2.2.2. Neurological Symptoms

Conners' Neuropsychiatric Questionnaire (2004) aims to assess neuropsychiatric skills including attention, sensory-motor function, language, executive functions, memory, learning, and cognition. In this study, it was completed by the parents of the children. The questionnaire contains 48 items scored on a 4-point Likert scale ranging from 0 (not at all) to 3 (very much), with the lowest score being 0 and the highest 144. In Iran, researchers reported construct validity using factor analysis and internal reliability with Cronbach's alpha at 0.72, and test-retest reliability over eight weeks ranging from 0.60 to 0.90 (12). In the present study, the Cronbach's alpha indicated at 0.74, suggesting good reliability for the questionnaire.

2.3. Intervention

2.3.1. Transcranial Direct Current Stimulation (tDCS)

In the current study, the brain stimulation device (ActivaDoseIontophoresis Delivery Unit) was used. This device includes two electrodes, cathode and anode, connected by cables to the main unit. Each electrode, consisting of carbon plates sized 1×1 cm, is placed in a saline-soaked sponge. The electrodes are then fixed on the participant's head in the target brain area using two narrow bands wrapped around and over the head. The current intensity (in milliamps) and duration (in minutes) are determined for a continuous electric current to be directly applied to the brain at a specified level. The electric current flows from the anode (positive) electrode to the cathode (negative) electrode. In the active stimulation condition, a current of 6 milliamps is applied for 60 minutes to the right and left dorsolateral prefrontal cortex areas through the anode and cathode electrodes. In the sham condition, while electrodes are placed on the participant's head in the right and left dorsolateral prefrontal cortex areas, a ramp-up process of the current is applied for 30 seconds, followed by a ramp-down and then discontinuation (10, 13, 23).

2.4. Data Analysis

Statistical analysis of the data was performed using SPSS software and mixed ANOVA with repeated measurements.

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3. Findings

The Table 1 reports descriptive statistics data at three stages: pre-test, post-test, and follow-up.

Table 1

Results of Descriptive Statistics

Variable	Stage	Pre-test		Post-test		Follow-up	
	Group	Mean	SD	Mean	SD	Mean	SD
Behavioral Symptoms	Exp.	191.18	38.31	102.60	33.33	101.55	35.21
	Control	195.22	36.64	201.23	39.56	199.10	38.48
Neurological Symptoms	Exp.	94.40	14.54	62.40	13.73	63.99	13.35
	Control	91.50	16.32	93.10	14.85	93.33	15.77

As observed in the Table 1, there is no significant difference between the mean scores of behavioral symptoms and neuropsychological signs at the pre-test stage between the two groups; however, the scores of the experimental group have decreased for both variables, while the control group's scores remained unchanged. To test the significance of the effectiveness of dorsolateral prefrontal cortex electrical stimulation on the experimental group, multivariate mixed ANOVA with repeated measurements at three stages was used. For this purpose, the necessary assumptions first had to be examined.

Table 2

Results of Normality Distribution of Scores and Homogeneity of Variance Tests

Variable	Group	Shapiro Wilk's Test		Levene's Test		Mauchly's Test	
		Df	Statistics	Df 2	Statistics	X^2	W
Behavioral Symptoms	Exp.	10	0.79	18	0.75	9.40	0.53
	Control	10	0.87				
Neurological Symptoms	Exp.	10	0.76	18	0.78	5.12	0.25
	Control	10	0.81				

According to the Table 2, the Shapiro-Wilk test indicates the normality of the data. Based on the results of the Levene's test, the condition of homogeneity of variances is met, and the Mauchly's test confirms the sphericity of the data at the significance level of 0.01 (P = 0.00). Hence, the use of multivariate mixed ANOVA with three-stage repeated measurements is permissible.

Table 3

Results of Between-Group Effects

Variable	Source	SS	Df	MS	F	p	Effect size
Behavioral Symptoms	Time	598376.25	1	598376.25	601.71	0.000	0.74
	Group	4320.13	1	4320.13	69.42	0.112	0.11
	Error	7402.23	1	367.38			
Neurological Symptoms	Time	134875.75	1	134875.75	445.41	0.000	0.72
	Group	2158.51	1	2158.51	82.44	0.171	0.10
	Error	2509.16	1	2509.16			

The Table 3 shows the between-group effects in the mean scores of behavioral symptoms and neuropsychological signs at the pre-test, post-test, and follow-up stages in both experimental and control groups due to dorsolateral prefrontal cortex electrical stimulation, indicating the significant impact of the intervention on reducing the scores of the variables of the study. Subsequently, the results of ANOVA with repeated measurements are shown.

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Table 4

The Summary of Pillai's Trace Test

Variable	Source	Statistics	F	Df hypo.	Df. Err.	Sig.	Effect size
Behavioral Symptoms	Time	0.71	198.46	2	17	0.00	0.73
		0.67	198.46	2	17	0.00	0.73
		13.32	198.46	2	17	0.00	0.73
		13.32	198.46	2	17	0.00	0.73
	Time*Group	0.74	201.13	2	17	0.00	0.74
		0.69	201.13	2	17	0.00	0.74
		15.98	201.13	2	17	0.00	0.74
		15.98	201.13	2	17	0.00	0.74
Neurological Symptoms	Time	0.78	214.71	2	17	0.00	0.78
		0.60	214.71	2	17	0.00	0.78
		21.13	214.71	2	17	0.00	0.78
		21.13	214.71	2	17	0.00	0.78
	Time*Group	0.73	178.12	2	17	0.00	0.73
		0.43	178.12	2	17	0.00	0.73
		21.21	178.12	2	17	0.00	0.73
		21.21	178.12	2	17	0.00	0.73

Based on the findings reported in the Table 4, the significance level indicates that the intervention had a significant effect on the study variables.

Table 5

Results of Between-Group Effects

Variable	Follow-up – Post-test			Follow-up – Pre-test			Post-test – Pre-test		
	Mean diff.	SE	p	Mean diff.	SE	p	Mean diff.	SE	p
Behavioral Symptoms	1.05	0.29	1.00	89.63	0.55	0.00	88.58	0.60	0.00
Neurological Symptoms	1.59	0.31	1.00	30.41	0.40	0.00	32.00	0.33	0.00

The data from the Table 5 indicate that based on the Bonferroni post-hoc test, the effects of dorsolateral prefrontal cortex electrical stimulation have a suitable stability at the follow-up stage while the effects were significant according to the post-test results.

4. Discussion

The aim of the current research was to examine the effectiveness of dorsolateral prefrontal cortex electrical stimulation on behavioral symptoms and neuropsychological signs in students with Specific Learning Disorder. The results of the statistical analysis of the research data showed that electrical stimulation of the dorsolateral prefrontal cortex improved behavioral and neuropsychological symptoms in children with Specific Learning Disorder, significantly reducing scores for both variables in the experimental group. These findings are consistent with previous research (10, 14, 15, 19)

In interpreting the findings of the current study, it can be said that executive functions as cognitive processes guiding other cognitive processes can represent the neuropsychological characteristics of individuals, including inhibition, working memory, planning ability, organization, and control. These cognitive activities are more associated with the functioning of the frontal and prefrontal cortex (14). Also, tDCS by stimulating the DLPFC can modulate a wide range of cognitive functions from relatively simple and low-level activities like attention processing to high-level and complex cognitive functions such as decision-making and working memory. tDCS applied to the dorsolateral prefrontal cortex can cause a wide range of

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E-ISSN: 2981-2569

modifications in behaviors and cognitive functions, and the physiological effects of tDCS on the brain are highly diverse and dependent on individual characteristics (10). While the mechanism of tDCS's impact on cognitive functions is complex, theoretically, anodal tDCS stimulation increases excitability beneath the anode electrode and enhances the function of that area, while cathodal effects occur conversely, reducing excitability in the targeted area (13). Further explication of findings can refer to Nitsche et al. (2012), which demonstrated that anodal stimulation of the left dorsolateral prefrontal cortex increases both positive emotion-related brain states and performance in recognizing faces with positive emotions, i.e., self-related and other-related emotions (15). Additionally, any activity resulting from tDCS occurs in the context of baseline neural activity or a specific state (18). On the other hand, due to the intensity of firing neurons, the current induced by tDCS may not be strong enough to significantly modulate network activity and create behavioral changes (17). Nevertheless, since a major part of behavioral symptoms is related to emotions and mood states, it is expected that mood and emotional changes induced through electrical stimulation of the dorsolateral prefrontal cortex can reduce behavioral symptoms in children with Specific Learning Disorder. Essentially, if the effect of tDCS is dependent on network conditions, then it should be contingent upon a specific task or function that individuals are engaged in. Consequently, the cognitive function targeted is more likely to change and modulate, and it is expected that the tDCS protocol leads to varied outcomes (10, 20).

5. Conclusion

In conclusion, the research advocates for the consideration of tDCS as a valuable addition to clinical psychotherapy practices, particularly for children with Specific Learning Disorder, while also calling for more comprehensive studies to validate and understand the full scope of its effects, mechanisms, and potential in various cognitive and behavioral interventions.

However, the study also acknowledges the limitations inherent in its methodology, including the non-experimental design and convenience sampling, which may affect the generalizability of the findings. Despite these limitations, the study's findings contribute to the growing body of literature supporting the clinical application of tDCS and suggest further exploration into its utility as part of a broader treatment strategy for learning and behavioral disorders.

Authors' Contributions

A. A.: Conceptualization of the study, Methodology design, Supervision of the research, Writing of the article; F. R. F.: Data collection, Data curation, Formal analysis and investigation, Writing of the article; H. R.: Contributed to the study design, Literature review, Writing assistance and editing; K. P.: Statistical analysis using SPSS software, Interpretation of statistical results.

Transparency Statement

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

Acknowledgments

We would like to express our gratitude to all participants helped us to do the project.

Declaration of Interest

The authors report no conflict of interest.

Funding

According to the authors, this article has no financial support.

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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E-ISSN: 2981-2569