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# Effects of Anodal Prefrontal tDCS on Behavioral Symptoms and Cognitive Flexibility in Children with Learning Disabilities: A Quasi-Experimental Study

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## Abstract

**Background & Objective:** This study examined the effectiveness of transcranial Direct Current Stimulation (tDCS) applied to the prefrontal cortex in enhancing behavioral symptoms and cognitive flexibility among children with learning disabilities (LD).

**Materials & Methods:** A quasi-experimental pre-test–post-test design was adopted. The statistical population comprised all students with learning disabilities in Tabriz during the 1402–1403 academic year. Using purposive sampling, 30 students were selected and randomly allocated to experimental and control groups. Data were collected using the Stroop Test, the *Achenbach Behavioral Problems Test* (parent version), and a tDCS stimulation device. For the intervention, a 1.5 mA direct current was delivered across ten 20-minute sessions, with a 5 × 5 cm² anodal electrode positioned at F3 and a 5 × 7 cm² cathodal electrode placed at Fp2, both administering the same 1.5 mA current. Data were analyzed using multivariate analysis of covariance (MANCOVA) in SPSS.

**Results:** Significant improvements were found in internalizing behavioral problems ($F = 91.39$, $p < 0.001$, $\eta^2 = 0.76$), externalizing behavioral problems ($F = 29.75$, $p < 0.001$, $\eta^2 = 0.51$), and cognitive flexibility ($F = 39.80$, $p < 0.001$, $\eta^2 = 0.58$). These findings extend the application of tDCS to behavioral outcomes in children with learning disabilities, a population less frequently examined with respect to prefrontal stimulation compared to children with dyslexia, for whom reading-focused interventions are more common.

**Conclusion:** This non-invasive intervention appears promising as an adjunct to cognitive-behavioral therapies aimed at improving behavioral and cognitive symptoms in children with learning disabilities. The moderate-to-large effect sizes underscore its potential clinical significance. However, the absence of a sham control group, the small sample size (n = 30), and the lack of long-term follow-up assessments require caution when interpreting the causal implications and generalizing the findings.

**Keywords:** transcranial Direct Current Stimulation, dorsolateral prefrontal cortex (DLPFC), Child Behavior Checklist (CBCL), cognitive flexibility, learning disabilities.

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## Introduction

Children with specific learning disabilities (SLD) experience academic difficulties in areas such as word recognition, perception, reading, arithmetic, reasoning, spelling, word formation, and writing (1). This disorder, classified as a neurodevelopmental condition (2), affects approximately 5%–15% of children across various cultures (3). This disorder is diagnosed when individuals display specific deficits in their ability to effectively and accurately process information and perform at a lower level than their peers in

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basic academic skills such as reading, writing, or mathematics (4). Symptoms such as short attention span, difficulty concentrating, poor memory, difficulty following instructions, poor hand-eye or body coordination, difficulty reading and comprehension, difficulty understanding new concepts, and difficulty learning the alphabet are also prominent features of this disorder (5).

The results of studies show that a significant number of children experience behavioral problems and have difficulty adapting to their environment (6). Researchers consider behavioral problems to be a direct consequence of learning disabilities, which is primary for children with these disabilities. However, scholars have also proposed that dyslexia, as a specific learning failure, may affect children's emotional states and subsequently contribute to behavioral problems, including aggression, limited social skills, anxiety, depression, and conduct difficulties (7-9). Behavioral disorders are usually characterized by difficulties in emotional and behavioral control (10). Thus, the behavioral problems of children refer to behavioral and emotional maladjustments that are outside the normative range, persistent, and not age-appropriate. These problems often lead to academic and social difficulties (11).

Children with SLD often exhibit deficits in cognitive flexibility, a core executive function that enables adaptive thinking and behavioral adjustment (12). Theoretical models, such as the dual-pathway hypothesis of executive functions, posit that impaired cognitive flexibility contributes to heightened vulnerability for both internalizing (e.g., anxiety, depression) and externalizing (e.g., aggression, conduct issues) behavioral problems by disrupting emotional regulation and social adaptation (13). Empirical evidence supports this link, showing that lower cognitive flexibility in LD children predicts increased behavioral maladjustment across home and school contexts (12, 14). Thus, interventions targeting cognitive flexibility may concurrently alleviate associated behavioral symptoms. Recent RCTs and systematic reviews have explored transcranial Direct Current Stimulation (tDCS) for reading deficits in pediatric dyslexia, often targeting temporo-parietal regions with sham controls (15, 16).

Research findings indicate that children with SLD, in addition to behavioral problems, also face cognitive challenges. These problems lead to lower academic performance compared to other children (17, 18). A study by Senobar et al. (19) showed that cognitive flexibility in students with SLD is weaker than in other children, and these children report more executive function problems. Other studies have also reported that children with LD have more cognitive weaknesses compared to typically developing children. These children are inflexible and have difficulty changing their perspectives. As a result, they struggle with representing different situations (20). The Stroop test, primarily assessing inhibitory control and interference suppression, also evaluates cognitive flexibility through task-switching demands (21).

Cognitive flexibility is one of the main components of executive function, and weakness in this component is associated with problems such as perseveration, repetitive movements, difficulty regulating and modulating motor activities, and reduced ability to change thoughts and actions in response to environmental changes (12). Cognitive flexibility is also recognized as the ability to effectively adapt to changing tasks and is closely related to avoidance and direct confrontation with problems in an individual's life. An individual with cognitive flexibility can use a wide range of responses and effectively deal with problems. In fact, cognitive flexibility can be considered the opposite of avoidance (22). Some also view cognitive flexibility as the ability to change thinking (cognition) or a set of thoughts to adapt to new situations. This ability is also considered as the skill and ability of the mind to switch between two different topics and to think about different concepts simultaneously (13).


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In neuroscience, this term is sometimes referred to as *shifting attention*, *cognitive shifting*, *mental flexibility*, *changing focus*, and *switching between tasks* (23).

Given the detrimental effects of behavioral problems and lack of cognitive flexibility in children with LD and the impact of these issues on various aspects of their lives, this study aims to reduce the effects of behavioral problems and lack of cognitive flexibility by using non-invasive therapeutic methods in children with SLD. One of the non-invasive treatments examined in this study is tDCS. The tDCS is a non-invasive and sub-threshold method that aims to create favorable conditions for changing neural excitability. This method generally uses two large plate electrodes and an electric current (maximum 8 mA). tDCS has been used as a therapeutic method in clinics for treating neurocognitive disorders such as Parkinson's, stroke, Alzheimer's, and psychiatric problems such as depression, sleep disorders, and dementia (24). Additionally, research has shown that this method can enhance cognitive functions of the brain such as attention, planning, decision-making, learning, and memory. Some studies have also shown that tDCS is more cost-effective and simpler compared to other neural activity regulation techniques such as alternating current and non-invasive ramps (25, 26). tDCS may modulate GABA levels (reduced by anodal stimulation, per MRS evidence); (27) and dopamine release in prefrontal-striatal pathways (28).

In this regard, Massoni's (29) study showed that transcranial direct current stimulation reduces behavioral problems and increases attention in children. Dumontoy et al.'s (30) study also showed that transcranial direct current stimulation changes brain waves and consequently improves behavioral problems in subjects. Additionally, Aghaziarati et al.'s (31) study showed that electrical stimulation of the dorsolateral prefrontal cortex has a significant effect on reducing behavioral and neuropsychological symptoms. The results of Soleymani's (32) study showed that transcranial direct current stimulation of the brain with direct electric current improves cognitive flexibility in children with SLD. Other studies have also shown that transcranial direct current stimulation of the prefrontal cortex improves cognitive flexibility activities in subjects (33-36).

Given that LD among students cause various social and psychological harms such as depression, difficulties in establishing social relationships, aggression, anxiety, and poor self-concept, all of which may exert long-term and potentially irreversible effects on their academic and personal lives, providing therapeutic strategies to reduce these problems and enhance cognitive flexibility in these children is essential. The dorsolateral prefrontal cortex (DLPFC) plays a key role in behavioral regulation and cognitive flexibility by modulating executive control, attention shifting, and emotional regulation through fronto-limbic networks (24). LDs are one of the most common neurocognitive disorders in children that can have long-term effects on their academic and social performance. Various treatments have been proposed for these disorders, but many of these methods still require careful evaluation. The aim of this research is to investigate the effects of tDCS in the prefrontal cortex on improving behavioral symptoms and cognitive flexibility in children with LD.

Despite extensive research on the use of tDCS in treating various disorders, there are still gaps in understanding the precise effects of this method, especially in children with LD. Most previous research has focused on the effects of this treatment on adults and other disorders, and only a limited number of studies have examined its effects on children with LD. This study attempts to fill these gaps and provide new information in this field. We hypothesized that anodal tDCS applied over the left DLPFC would produce significant reductions in internalizing



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and externalizing behavioral problems and meaningful improvements in cognitive flexibility compared to the control group.

## Materials and Methods

The present study used a quasi-experimental, pretest–posttest design. The study population comprised all students with LD in Tabriz during the academic year 1402–1403 who had been diagnosed with LD by a psychiatrist. Participants were elementary school students (grades 3–5) attending public schools in Tabriz, aged 8–11 years (M = 9.33 years, SD = 1.2), with full-scale IQ scores between 85 and 115 (assessed using the Wechsler Intelligence Scale for Children–IV), and without comorbid neurodevelopmental disorders such as ADHD or autism. Randomization was carried out using computer-generated random numbers implemented via SPSS (seed = 12345 for reproducibility), with allocation concealed in sequentially numbered, opaque, sealed envelopes prepared by an independent administrator.

### Research Procedure

Parents of children with LD were first provided with detailed information about the tDCS procedure and its mechanism via an informed consent form, including potential side effects and benefits. Pretest assessments, including the Achenbach Behavioral Problems Test (parent version) and the Stroop test, were then administered to all participants.

The experimental group (n = 15) underwent ten sessions of tDCS, delivered five days per week over two weeks (20 minutes per session). A weak direct current of 1.5 mA was applied using saline-soaked sponge electrodes (5% NaCl): the anode (5 × 5 $cm^2$) positioned over the left dorsolateral prefrontal cortex (F3, according to the 10–20 EEG system), and the cathode (5 × 7 $cm^2$) placed at Fp2 to minimize current spread to motor areas and to optimize prefrontal–limbic modulation.

Electrode impedance was maintained below 10 kΩ, monitored continuously, and stimulation ramp-up/ramp-down lasted 30 seconds to ensure participant comfort. Current density was 0.06 $mA/cm^2$ at the anode and 0.034 $mA/cm^2$ at the cathode (38). Skin was inspected before and after each session. Sessions were conducted by a licensed clinical psychologist under the supervision of a cognitive neuroscience specialist at a specialized treatment center in Tabriz, Iran. Safety monitoring included assessment of vital signs pre- and post-session and administration of an adverse-event questionnaire (e.g., tingling, headache); no adverse events were reported, consistent with pediatric guidelines (38).

The control group (n = 15) received no intervention but completed pre- and posttests at equivalent intervals. This no-treatment control design, rather than a sham-controlled design, may introduce expectancy effects; the absence of sham stimulation is acknowledged as a key limitation (see Discussion). The study was single-blind: participants and parents were unaware of group allocation. However, test administrators were not blinded due to the no-treatment control design, which may introduce experimenter bias (acknowledged in the Limitations).

Parents were informed of study participation without disclosure of group assignment. They were instructed to report any side effects (e.g., tingling, headache, skin irritation) immediately; none were reported. Participants refrained from any additional behavioral or educational therapies during the study period. Posttests were administered immediately after the tenth session for the experimental group (or at the equivalent timepoint for controls); no long-term follow-up was conducted, thereby limiting assessment of effect durability. Data were analyzed using multivariate analysis of covariance (MANCOVA) in SPSS version 26.

The inclusion criteria were: a psychiatrist-confirmed diagnosis of learning disability, age 8–11 years, full-scale IQ between 85 and 115 (assessed using the Wechsler Intelligence Scale for Children–IV), no psychological treatment in the preceding 6 months, and no evidence of



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a serious or chronic physical illness requiring treatment. SLD was operationalized according to DSM-5 criteria and confirmed by standardized achievement tests (e.g., Woodcock–Johnson IV, with a discrepancy > 1.5 SD below IQ) and psychiatrist diagnosis. No SLD subtypes were targeted. The small sample size (n = 30) reflects recruitment constraints within the local Tabriz population. Participant flow: 50 approached, 30 assessed eligible, 15 per group randomized; zero exclusions post-randomization. The exclusion criteria included: participation in educational or therapeutic workshops aimed at improving behavioral symptoms outside the treatment sessions, missing two consecutive or three nonconsecutive treatment sessions, and comorbid psychiatric disorders (e.g., ADHD, autism). Comorbidities were screened out via structured interviews (K-SADS) and screening instruments (Conners-3 for ADHD, SCQ for autism spectrum traits).

The following instruments were used to collect data:

**Stroop Test**

The Stroop test was administered to assess cognitive flexibility. This measure has acceptable validity and reliability in neuropsychological research. The Stroop software was developed by Sina Institute (Ravan Tajhiz) based on the traditional Stroop card test. The task requires participants to rapidly shift their perceptual set when confronted with color names that either match or conflict with the printed color. In prior work, test–retest reliability for the three trials of this version was reported as 0.61, 0.83, and 0.97, respectively (35). In the present study, cognitive flexibility was operationalized using the perseveration-error index.

**Achenbach Behavioral Problems Test (Parent Version)**

The *Child Behavior Checklist* assesses emotional–behavioral problems as well as academic and social competencies in children aged 6–18 from the parents' perspective (39). This questionnaire comprises 113 items covering a range of behavioral states. Responses are recorded on a three-point Likert scale (0–2). In this study, internalizing and externalizing behavioral problems were the primary outcomes. Overall reliability coefficients for the CBCL forms have been reported as 0.97 (Cronbach's alpha) with test–retest reliability of 0.94. Content, criterion, and construct validity have likewise been judged satisfactory. Other reports indicate internal consistency coefficients ranging from 0.63 to 0.95 (Cronbach's alpha), and Cronbach's alpha values for parent, teacher, and child forms of 0.90, 0.93, and 0.82, respectively (40).

**Transcranial Direct Current Stimulation Device tDCS**

The tDCS is a widely used, noninvasive neuromodulation technique that delivers a constant electric current, typically between 1 and 2 mA, through the scalp to modulate cortical excitability. By increasing or decreasing activity in targeted cortical regions, tDCS can transiently enhance or suppress specific cognitive and motor functions. In this apparatus, one electrode serves as the target electrode and the other as the reference electrode; during stimulation, current flows between these electrodes and traverses brain tissue to complete the circuit. tDCS has proven valuable for probing brain–behavior relationships across cognitive, motor, social, and emotional domains and, in healthy populations, can temporarily modify behavior, accelerate learning, and enhance memory. Typical session durations range from 20 to 40 minutes, and common treatment protocols involve 10 to 15 sessions (41).

## Results

Based on the obtained data, the mean age of participants in both the experimental and control groups was 9.33 years (SD = 1.2). An independent samples t-test revealed no significant difference in age between groups ($t = 0.15$, $p = 0.88$). In the experimental group, 60% of participants


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were male and 40% were female. In the control group, 66.7% were male and 33.3% were female. A chi-square test indicated no significant gender imbalance between groups ($\chi^2 = 0.12$, $p = 0.73$).

According to Table 1, the means and standard deviations of internalizing problems, externalizing problems, and omission errors are presented for both the pretest and posttest phases. The observed change in mean scores following application of tDCS to the prefrontal cortex reflects the effects of stimulation on task performance. To conduct a multivariate analysis of covariance (MANCOVA), the test assumptions were evaluated; the results indicated that both homogeneity of variances and homogeneity of the variance–covariance matrix for the dependent variables were satisfied.

As shown in Table 2, and after controlling for pretest scores, Wilks' Lambda reached statistical significance, indicating that pretest–posttest changes in the study variables differed significantly between the experimental and control groups. Furthermore, this difference implies that approximately 82% of the observed variance in the mean scores of the dependent variables is attributable to the effect of prefrontal tDCS.

Table 3 shows that, when pretest performance was entered as a covariate, tDCS produced significant between-group differences in behavioral problems and cognitive flexibility. Specifically, anodal stimulation significantly reduced internalizing problems ($F = 91.39$, $p < 0.001$, $\eta^2 = 0.76$), reduced externalizing problems ($F = 29.75$, $p < 0.001$, $\eta^2 = 0.51$), and decreased omission errors—indicative of improved cognitive flexibility ($F = 39.80$, $p < 0.001$, $\eta^2 = 0.58$). The corresponding effect sizes for tDCS on internalizing problems, externalizing problems, and omission errors were 76%, 51%, and 58%, respectively.

**Table 1.** Mean (M) and Standard Deviation (SD) of Internalizing Problems, Externalizing Problems, and Omission Errors (number of errors) in Control and Experimental Groups (Pre- and Post-Test).

| Variable | Component | Experimental Group | | | | Control Group | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Pre-test | SD | Post-test | SD | Pre-test | SD | Post-test | SD |
| Behavioral Problems | Internalized | 62.2 | 4.04 | 43.13 | 4.96 | 61.13 | 4.81 | 61.33 | 5.44 |
| | Externalized | 56.8 | 4.57 | 43.33 | 6.98 | 54.87 | 4.24 | 54.67 | 3.99 |
| Cognitive Flexibility | Omission Errors (number of errors) | 10.00 | 2.33 | 6.73 | 1.28 | 10.07 | 1.58 | 10.27 | 1.75 |

**Table 2.** Results of Multivariate Analysis of Covariance for Dependent Variables.

| Test Name | Value | F | Significance | Eta Squared |
|---|---|---|---|---|
| Pillai's Trace | 0.82 | 100.062 | 0.0001 | 0.82 |
| Wilks' Lambda | 0.080 | 100.062 | 0.0001 | 0.82 |
| Hotelling's Trace | 11.546 | 100.062 | 0.0001 | 0.82 |
| Largest Root | 11.546 | 100.062 | 0.0001 | 0.82 |

**Table 3.** Results of Covariance Analysis for Behavioral Problems and Cognitive Flexibility.

| Variable | Source of Variation | Sum of Squares | Degrees of Freedom | Mean Square | F | Significance | Eta Squared |
|---|---|---|---|---|---|---|---|
| Internalized Problems | Group | 2484.3 | 1 | 2484.3 | 91.39 | 0.0001 | 0.76 |
| Externalized Problems | Group | 963.3 | 1 | 963.3 | 29.75 | 0.0001 | 0.51 |
| Error of Omission | Group | 93.63 | 1 | 93.63 | 39.804 | 0.0001 | 0.58 |



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To illustrate these differences more clearly, bar graphs depicting pretest and posttest mean scores for internalizing and externalizing behavioral problems and for cognitive flexibility were prepared for the experimental and control groups (Figures 1–3). These visualizations underscore the greater improvement observed in the experimental group following tDCS relative to controls. Although all effects were statistically significant, the magnitude of the effect sizes ($\eta^2 = 0.51–0.76$) indicates moderate to large practical significance, suggesting that the observed changes may have meaningful behavioral implications for children with LD in real-world contexts.

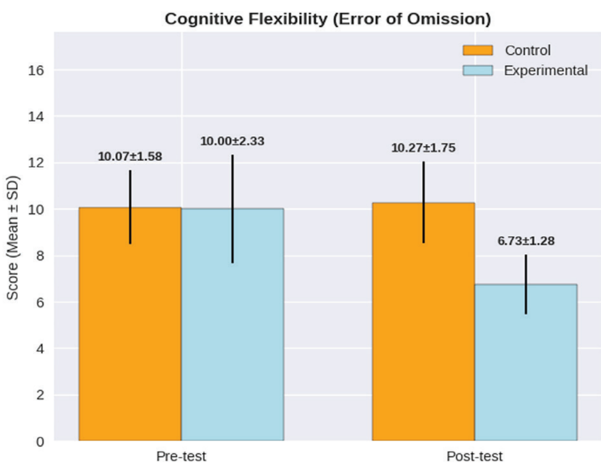


**Figure 1.** Mean ± SD scores for internalizing behavioral problems pre- and post-tDCS in the experimental (n=15) and control (n=15) groups. Error bars represent standard deviation (SD). *Significant differences: $p < 0.001$ vs. pre-test experimental group; †$p < 0.001$ vs. control group (post-hoc comparisons after MANCOVA).

## Discussion

The aim of this study was to investigate the effectiveness of transcranial direct current stimulation (tDCS) applied to the prefrontal cortex in improving behavioral symptoms and cognitive flexibility in children with LD. The results indicated that anodal tDCS over the prefrontal cortex led to a reduction in behavioral problems, including internalizing and externalizing problems (by 76% and 51%, respectively), thereby improving behavioral symptoms in children with LD. This finding is consistent with Massoni's (29) study, which demonstrated that tDCS reduces behavioral problems and enhances attention in children. Unlike prior sham-controlled trials that focused on reading (15), our DLPFC montage specifically targeted behavioral symptoms.

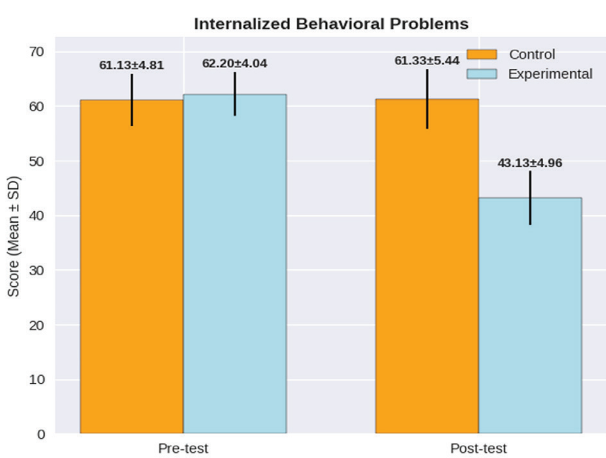


**Figure 2.** Mean ± SD scores for externalizing behavioral problems pre- and post-tDCS in the experimental (n=15) and control (n=15) groups. Error bars r epresent standard deviation (SD). *Significant differences: $p < 0.001$ vs. pre-test experimental group; †$p < 0.001$ vs. control group (post-hoc comparisons after MANCOVA).

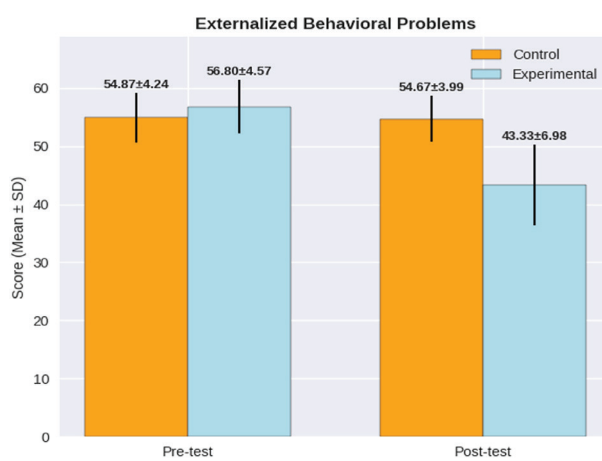


**Figure 3.** Mean ± SD omission error scores on the Stroop test pre- and post-tDCS in the experimental (n=15) and control (n=15) groups. Error bars represent standard deviation (SD). *Significant differences: $p < 0.001$ vs. pre-test experimental group; †$p < 0.001$ vs. control group (post-hoc comparisons after MANCOVA).



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Similarly, Dumontoy et al. (30) found that tDCS alters brain waves and improves behavioral symptoms in participants. Additionally, Aghaziarati et al. (31) reported significant effects of tDCS over the dorsolateral prefrontal cortex in reducing behavioral and neuropsychological symptoms.

However, our findings should be interpreted with caution in light of contradictory evidence. For instance, Turker and Hartwigsen (16) reviewed several pediatric dyslexia trials that reported null effects of tDCS, potentially owing to differences in montage, stimulation parameters, or sample characteristics; these discrepancies underscore the need for replication in LD-specific populations. Such inconsistencies highlight the importance of larger, rigorously sham-controlled studies to confirm tDCS efficacy in children with LD.

Several mechanistic accounts can help explain the observed effects. First, tDCS over the prefrontal cortex may attenuate negative emotional processing (42), thereby reducing externally directed behaviors such as aggression and other externalizing symptoms in children with LD. Second, by diminishing maladaptive negative emotional processing, tDCS may also reduce anxiety and related internalizing problems. At the cellular level, tDCS modulates neuronal excitability by shifting the membrane potentials of superficial cortical neurons toward depolarization or hyperpolarization, which respectively increase or decrease neuronal firing. In particular, anodal stimulation enhances cortical excitability and may facilitate normalization of dysfunctional neural circuits in children. Specifically, anodal tDCS over the left dorsolateral prefrontal cortex appears to mitigate aggressive behaviors (43).

Moreover, the present study found that tDCS over the prefrontal cortex reduced omission errors (by 58%), indicating improved cognitive flexibility in children with LD. This outcome aligns with multiple reports, including those by Soleymani (32), Stonsaovapak et al. (33), Arefian et al. (34), Nandi et al. (35), and Rajaeipour (36), which also documented enhancements in cognitive flexibility following prefrontal tDCS.

A plausible explanation for this improvement is that children with LD often exhibit deficits in sustained attention, which in turn constrain cognitive flexibility. Prefrontal tDCS may reduce cortical GABA concentrations and increase dopaminergic transmission in prefrontal–striatal pathways, neurochemical changes that have been linked to enhanced attentional control. Anodal tDCS has been shown to reduce GABA levels in cortical regions (35) and to potentiate dopamine release in prefrontal–striatal circuits (28). Consequently, improved attentional engagement likely accounts for fewer omission errors on tasks such as the Stroop test and for concomitant gains in cognitive flexibility.

Some researchers propose that prefrontal tDCS can modulate a broad array of behavioral and cognitive functions. Although the mechanisms by which tDCS influences higher-order cognition remain complex, theoretically anodal stimulation increases excitability beneath the anode, thereby enhancing the functional capacity of that cortical region; conversely, cathodal stimulation can reduce excitability when applied over a target region (44). Furthermore, the behavioral effects observed after prefrontal tDCS may reflect enhanced functional connectivity within the left DLPFC and between fronto-limbic networks, thereby improving executive control and emotional regulation. These neural changes likely interact with cognitive-behavioral processes such as task engagement and learning context, rather than constituting purely local neural effects.

Strengths and Limitations Strengths

This study employed a quasi-experimental design with rigorous pretest and posttest assessments in an understudied pediatric LD population, producing moderate-to-large effect sizes ($\eta^2 = 0.51–0.76$) that suggest potential clinical


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relevance. In addition, strict adherence to pediatric safety guidelines for tDCS (e.g., current density < 0.06 mA/cm²) and the absence of adverse events strengthen the methodological rigor.

A principal limitation is the absence of a sham-controlled arm, which may have allowed placebo or expectancy effects to influence outcomes and thus limits causal inference (46, 47 Ref 45???); future investigations should incorporate properly blinded active sham protocols. The small sample size (n = 30) reduces statistical power and constrains generalizability to broader populations. Reliance on parent-reported measures (CBCL) introduces the possibility of reporter bias, particularly within a single-blind framework in which assessors were not blinded. Finally, the lack of long-term follow-up prevents assessment of the durability of effects. Taken together, these constraints position the present findings as preliminary and exploratory.

Although preliminary, these results indicate that anodal prefrontal tDCS may constitute a promising adjunctive intervention for ameliorating behavioral symptoms and augmenting cognitive flexibility in children with LD. Nevertheless, translation to clinical practice requires evidence from larger, preregistered, sham-controlled randomized trials that incorporate multi-informant outcome measures (e.g., teacher reports, objective behavioral tasks), neurophysiological endpoints, and extended follow-up periods to evaluate persistence and functional significance of effects. Investigations that systematically vary montage, current intensity, and session number will be essential to optimize dosing and to elucidate mechanisms of action.

## Conclusion

In conclusion, anodal tDCS over the left DLPFC was associated with short-term improvements in parent-reported internalizing and externalizing behavioral problems and in Stroop task performance indicative of enhanced cognitive flexibility within this small sample of children with LD. This study is, to our knowledge, the first to examine simultaneously the effects of tDCS on both behavioral problems and cognitive flexibility in children with LD using objective measures (Stroop performance) alongside parent reports, thereby highlighting the intervention's potential to achieve clinically meaningful changes. Given methodological constraints—most notably the absence of a sham control and reliance on parent-reported outcomes—these findings must be interpreted cautiously. Prefrontal tDCS may be best regarded as an adjunct to established cognitive-behavioral and educational interventions rather than as a stand-alone treatment. Ultimately, sham-controlled, preregistered randomized controlled trials with multi-informant outcomes and long-term follow-ups are necessary before clinical recommendations can be made.

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## Conflict of Interest

The authors declare no conflicts of interest, and results are reported transparently and without bias.

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## Ethical Considerations

This research was conducted in accordance with applicable medical ethics procedures, and medical ethics approval (ID IR.IAU.TABRIZ.REC.1403.441) was obtained from the Islamic Azad University, Tabriz Branch.

## Code of Ethics

IR.IAU.TABRIZ.REC.1403.441

## Authors' Contribution

This article comprises part of Vahid Poursaeid's master's thesis, supervised by Seyed Mahmoud Tabatabaei. Poursaeid: Conceptualization, formal analysis, investigation (data collection), writing—original draft preparation. Seyed Mahmoud Tabatabaei: Validation, supervision, writing—review and editing, and project administration. All authors have read and approved the final manuscript.

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