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# Comparison of the Effectiveness of Transcranial Direct Current Stimulation and Cognitive Emotion Regulation Training on Impulsivity in Adults with Attention-Deficit/Hyperactivity Disorder

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A B S T R A C T

This study was conducted to compare the effectiveness of two non-invasive interventions, namely transcranial direct current stimulation (tDCS) and cognitive emotion regulation training, in reducing impulsivity among adults with Attention-Deficit/Hyperactivity Disorder (ADHD). The study employed a quasi-experimental design with a pretest–posttest control group. A total of 45 adults diagnosed with ADHD were selected through convenience sampling and randomly assigned to three groups of 15 participants each: a transcranial direct current stimulation group, a cognitive emotion regulation training group, and a control group. The transcranial direct current stimulation group received anodal stimulation over the left dorsolateral prefrontal cortex (DLPFC) at an intensity of 2 mA for 20 minutes across 10 sessions. The cognitive emotion regulation training group participated in 10 sessions of 90 minutes each, receiving cognitive emotion regulation training based on standardized protocols. The control group was placed on a waiting list. Data were collected using the Barratt Impulsiveness Questionnaire and the ADHD Impulsivity Scale during the pretest and posttest phases. Data were analyzed using analysis of covariance (ANCOVA) in SPSS version 26. The results of the ANCOVA indicated that, after controlling for pretest effects, significant differences existed among the groups in posttest impulsivity scores. Pairwise comparisons revealed that both transcranial direct current stimulation and cognitive emotion regulation training significantly reduced overall impulsivity and its subscales (motor impulsivity, cognitive impulsivity, and non-planning impulsivity) compared with the control group. Furthermore, cognitive emotion regulation training produced greater reductions in impulsivity scores than transcranial direct current stimulation, particularly in the cognitive impulsivity subscale. Based on the findings, both transcranial direct current stimulation and cognitive emotion regulation training are effective approaches for reducing impulsivity in adults with ADHD. However, cognitive emotion regulation training demonstrated greater effectiveness due to its influence on the cognitive-emotional mechanisms associated with impulsivity.

***Keywords:*** *Adult Attention-Deficit/Hyperactivity Disorder, Impulsivity, Transcranial Direct Current Stimulation, Cognitive Emotion Regulation Training, Non-Pharmacological Interventions.*

## 1. Introduction

Attention-Deficit/Hyperactivity Disorder (ADHD) is a neurodevelopmental disorder traditionally associated with childhood; however, accumulating evidence indicates that its symptoms frequently persist into adulthood and continue to affect multiple domains of functioning. Adult ADHD is characterized by persistent patterns of inattention, hyperactivity, impulsivity, and executive dysfunction that significantly impair academic, occupational, social, and emotional functioning. Recent evidence suggests that ADHD in adulthood is associated with substantial personal and societal burdens, including reduced occupational performance, impaired interpersonal relationships, lower quality of life, and increased psychiatric comorbidity (Cortese et al., 2025). Longitudinal findings further demonstrate that ADHD symptoms originating in childhood can exert enduring effects on psychosocial adjustment and occupational well-being throughout adulthood, influencing perceived stress, work performance, and job satisfaction (Park et al., 2026). Consequently, identifying effective interventions for the core symptoms of ADHD in adults remains a major clinical and research priority.

Among the defining characteristics of ADHD, impulsivity has received particular attention due to its pervasive impact on behavior and decision-making. Impulsivity refers to a predisposition toward rapid, unplanned reactions to internal or external stimuli without adequate consideration of negative consequences. Individuals with ADHD often exhibit elevated levels of motor impulsivity, cognitive impulsivity, and non-planning impulsivity, which collectively contribute to difficulties in self-control, emotional regulation, and adaptive functioning (Cortese et al., 2025). Research has consistently demonstrated that impulsivity is closely associated with deficits in executive functioning, including inhibitory control, working memory, attentional regulation, and cognitive flexibility. These deficits frequently interfere with academic achievement, occupational success, and interpersonal relationships, thereby reducing overall quality of life (Siqueira et al., 2025). Because impulsivity constitutes a central feature of adult ADHD and contributes substantially to functional impairment, interventions targeting impulsive behavior may produce meaningful improvements in long-term outcomes.

In recent years, growing attention has been directed toward understanding the emotional dimensions of ADHD. Although ADHD has historically been conceptualized primarily as a disorder of attention and executive functioning, contemporary perspectives emphasize the importance of emotional dysregulation as a significant component of the disorder. Emotional dysregulation encompasses difficulties in monitoring, evaluating, and modifying emotional responses and has been identified as a major contributor to functional impairment among individuals with ADHD (Tharaud & Nikolas, 2025). Evidence indicates that individuals with ADHD frequently experience heightened emotional reactivity, reduced emotional control, and difficulty utilizing adaptive emotion regulation strategies, all of which may exacerbate impulsive behavior and increase vulnerability to psychological distress (Liu et al., 2025). Consequently, emotional processes have become increasingly important targets for intervention in ADHD populations.

The relationship between impulsivity and emotion regulation is particularly noteworthy. Theoretical models suggest that impulsive behaviors often emerge when individuals lack effective cognitive mechanisms for regulating emotional experiences. According to the cognitive emotion regulation framework proposed by Garnefski and colleagues, individuals employ various cognitive strategies to manage emotional responses following stressful or negative events. These strategies can be adaptive, such as positive reappraisal and planning, or maladaptive, such as rumination, self-blame, and catastrophizing (Garnefski et al., 2001). When maladaptive cognitive emotion regulation strategies predominate, emotional distress may intensify, increasing the likelihood of impulsive reactions. In ADHD populations, impairments in cognitive emotion regulation appear particularly pronounced, contributing to both behavioral dyscontrol and emotional instability (Alipour et al., 2023). Therefore, interventions designed to enhance adaptive cognitive emotion regulation strategies may provide a promising approach for reducing impulsivity among adults with ADHD.

Cognitive Emotion Regulation (CER) training has emerged as an intervention aimed at improving individuals' capacity to manage emotional experiences through adaptive cognitive processes. This approach focuses on helping individuals identify maladaptive thought patterns, restructure cognitive appraisals, and employ more constructive strategies when confronted with emotionally challenging situations. Research suggests that strengthening adaptive emotion regulation strategies can reduce emotional distress, improve executive functioning, and decrease



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maladaptive behaviors associated with impulsivity (Garnefski et al., 2001). In individuals with ADHD, difficulties in emotion regulation have been linked not only to symptom severity but also to comorbid conditions such as anxiety and depression, highlighting the potential clinical significance of interventions targeting these processes (Tharaud & Nikolas, 2025). Furthermore, recent behavioral and neurobiological evidence demonstrates that emotion regulation strategies are closely associated with patterns of emotional dysregulation in ADHD, suggesting that modifying these strategies may lead to meaningful improvements in both emotional and behavioral outcomes (Liu et al., 2025).

Alongside psychological interventions, non-pharmacological neurostimulation techniques have attracted increasing interest as potential treatments for ADHD. Among these approaches, transcranial direct current stimulation (tDCS) has emerged as one of the most extensively investigated methods. tDCS is a non-invasive brain stimulation technique that delivers low-intensity electrical currents to specific cortical regions in order to modulate neuronal excitability and facilitate neuroplastic changes. Because many ADHD-related deficits have been linked to dysfunction within prefrontal neural networks, particularly the dorsolateral prefrontal cortex (DLPFC), researchers have proposed that targeted stimulation of these regions may improve executive functioning, attention, and impulse control (Nejati et al., 2024).

The growing body of evidence supporting tDCS in ADHD has generated considerable enthusiasm. Systematic reviews and meta-analyses have reported that non-invasive brain stimulation techniques, including tDCS, can produce improvements in cognitive performance, attentional control, and behavioral functioning among individuals with ADHD (Liang et al., 2025; Wang et al., 2025). Several studies have demonstrated that stimulation of prefrontal cortical regions may enhance inhibitory control and reduce impulsive responding, thereby addressing key deficits associated with ADHD (Wen et al., 2025). Moreover, evidence suggests that tDCS may influence not only cognitive functioning but also emotional processes, potentially improving emotion regulation abilities and reducing emotional dysregulation (Shi et al., 2024). Such findings are particularly relevant given the increasingly recognized role of emotional dysfunction in ADHD symptomatology.

Recent investigations have provided additional support for the potential benefits of tDCS. Experimental and clinical studies indicate that stimulation targeting the DLPFC can improve emotional regulation capacities in individuals with ADHD, suggesting that neural modulation may influence both cognitive and affective mechanisms underlying impulsive behavior (Nejati et al., 2024). Systematic reviews have similarly concluded that non-invasive brain stimulation techniques exert beneficial effects on emotion regulation and executive functioning, although the magnitude and durability of these effects remain subjects of ongoing investigation (Shi et al., 2024). Meta-analytic evidence further suggests that tDCS may yield positive behavioral outcomes immediately following intervention and, in some cases, during follow-up periods, supporting its potential as a clinically meaningful treatment option (Tung et al., 2025).

Despite these encouraging findings, important questions remain regarding the comparative effectiveness of different non-pharmacological interventions for adult ADHD. Recent network meta-analyses have highlighted the growing diversity of available treatment approaches, including neurofeedback, transcranial magnetic stimulation, cognitive interventions, and tDCS, while emphasizing the need for direct comparative studies to determine which approaches are most effective for specific symptom domains (Courrèges et al., 2025; Yang et al., 2025). Although tDCS has demonstrated promise, researchers continue to debate its relative effectiveness compared with interventions that directly target cognitive and emotional processes (Liang et al., 2025; Wang et al., 2025). Consequently, examining the efficacy of tDCS alongside psychologically oriented interventions may provide valuable insights into the mechanisms through which impulsivity can be reduced.

An emerging perspective in ADHD treatment emphasizes the integration of neurobiological and psychological approaches. This perspective recognizes that impulsivity is influenced by both neural dysfunction and maladaptive cognitive-emotional processes. Recent feasibility research has suggested that combining tDCS with neuropsychological interventions may produce synergistic effects on cognitive and emotional outcomes, reflecting the multidimensional nature of ADHD symptomatology (Rodríguez-Prieto et al., 2026). Such findings underscore the importance of evaluating interventions that target distinct but interconnected mechanisms underlying impulsive behavior. Whereas tDCS primarily seeks to modulate neural activity within executive control networks, cognitive emotion regulation training aims to strengthen adaptive cognitive strategies for managing emotional experiences. Comparing these approaches may therefore help clarify whether impulsivity in adult ADHD is more responsive to



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direct neural modulation, cognitive-emotional intervention, or both.

Furthermore, contemporary evidence increasingly supports the view that emotional dysregulation constitutes a critical pathway linking ADHD symptoms to broader psychological difficulties. Studies examining emotional functioning in ADHD populations have demonstrated that deficits in emotion regulation are associated with symptom persistence, functional impairment, and reduced quality of life (Liu et al., 2025; Siqueira et al., 2025). These findings suggest that interventions capable of improving emotion regulation may have broader therapeutic benefits extending beyond symptom reduction alone. At the same time, advances in non-invasive brain stimulation research continue to highlight the potential of tDCS as a practical and accessible treatment strategy for enhancing executive control and behavioral regulation (Courrèges et al., 2025; Wen et al., 2025). Given these parallel developments, comparative investigations of cognitive emotion regulation training and tDCS are both theoretically and clinically warranted.

Although previous studies have examined either cognitive emotion regulation or non-invasive brain stimulation in relation to ADHD, relatively few investigations have directly compared these approaches in adult populations, particularly with respect to impulsivity. Existing literature provides evidence for the effectiveness of both interventions independently, yet uncertainty remains regarding their relative efficacy and the extent to which improvements in impulsivity may differ across intervention modalities (Courrèges et al., 2025; Yang et al., 2025). Addressing this gap may contribute to the development of more targeted and personalized treatment strategies for adults with ADHD.

Therefore, the present study aimed to compare the effectiveness of transcranial direct current stimulation and cognitive emotion regulation training in reducing impulsivity among adults with Attention-Deficit/Hyperactivity Disorder.

## 2. Methods and Materials

### *2.1. Study Design and Participants*

The present study was applied in terms of purpose and quasi-experimental in terms of data collection, utilizing a pretest–posttest design with a control group. In this design, three groups (two experimental groups and one control group) were assessed at two stages: pretest and posttest. The first experimental group received the transcranial direct current stimulation (tDCS) intervention, and the second experimental group received the cognitive emotion regulation (CER) training intervention, whereas the control group received no intervention and was placed on a waiting list. The statistical population consisted of all adults diagnosed with Attention-Deficit/Hyperactivity Disorder (ADHD) who attended counseling centers and psychiatric clinics in Tehran in 2025. The study sample included 45 adults with ADHD who were selected through convenience sampling based on the inclusion and exclusion criteria. Participants were then randomly assigned to three groups of 15 individuals each (two experimental groups and one control group). The sample size was determined based on previous similar studies that reported the effectiveness of tDCS and emotion regulation interventions with sample sizes of 15–20 participants per group.

**Inclusion Criteria:**

1. Confirmation of ADHD diagnosis by a psychiatrist based on DSM-5 criteria.
2. Age range between 18 and 45 years.
3. Minimum educational attainment of a high school diploma.
4. Obtaining a score above the cutoff point on the impulsivity scale (a score higher than 72 on the Barratt Impulsiveness Scale).
5. No concurrent participation in regular psychotherapy interventions during the previous three months.
6. No regular use of psychiatric medications other than prescribed medications maintained at a stable dosage for at least two months.
7. Provision of informed consent for participation in the study.

**Exclusion Criteria:**

1. Absence from more than two intervention sessions.
2. Occurrence of acute psychiatric crises (e.g., active suicidal ideation or psychosis) during the study.
3. Initiation of new psychiatric medications or changes in the dosage of existing medications during the study.
4. History of seizures or use of anticonvulsant medications (for the tDCS group).
5. Presence of cranial lesions or metallic implants in the head region (for the tDCS group).



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### 2.2. Measures

**Barratt Impulsiveness Scale–11 (BIS-11).** This questionnaire was developed by Patton, Stanford, and Barratt (1995). The instrument is a 30-item self-report measure designed to assess impulsivity in individuals aged 18 to 80 years. Each item is rated on a 4-point Likert scale (1 = Never/Rarely, 2 = Sometimes, 3 = Often, 4 = Almost Always/Always), yielding a total score ranging from 30 to 120. The scale comprises three primary subscales: motor impulsivity (acting without thinking), cognitive/attentional impulsivity (rapid decision-making and inattentiveness), and non-planning impulsivity (lack of future orientation). The questionnaire is self-administered, and respondents are instructed to select the option that best describes their condition during the previous week. The Persian version of the instrument was translated and standardized by Mohammadi et al. (2007). In their study of 226 Iranian university students, satisfactory internal consistency (Cronbach's α = .82), acceptable test–retest reliability (.89), and significant convergent validity with an ADHD impulsivity measure were reported. In the present study, Cronbach's alpha for the BIS-11 was .86, indicating satisfactory internal consistency.

**Adult ADHD Impulsivity Scale (AIS).** This scale was developed by Kooij et al. (2020) based on DSM-5 criteria. The instrument is a 10-item self-report measure specifically designed to assess behavioral and emotional impulsivity in adults with ADHD. Each item is rated on a 4-point Likert scale (1 = Never to 4 = Always), resulting in total scores ranging from 10 to 40, with higher scores indicating greater levels of impulsivity. The Persian version was translated and standardized by Sadeghi et al. (2022). Their study involving 154 adults with ADHD reported satisfactory internal consistency (Cronbach's α = .84), acceptable test–retest reliability (.85), and significant concurrent validity with the BIS-11 (r = .71). In the present study, Cronbach's alpha for the AIS was .88, indicating satisfactory internal consistency.

### 2.3. Interventions

Transcranial Direct Current Stimulation Intervention: The first experimental group received tDCS for 10 sessions (two sessions per week over five weeks). The anodal (active) electrode was positioned over the left dorsolateral prefrontal cortex (DLPFC) according to the international 10–20 EEG system (F3 position), while the cathodal (reference) electrode was placed over the right supraorbital area (Fp2 position). Stimulation was delivered at an intensity of 2 mA for 20 minutes per session. The current was gradually increased during the first 30 seconds and gradually decreased during the final 30 seconds of each session (ramp-up and ramp-down procedure). All sessions were administered by a trained specialist under the supervision of a psychiatrist.

Cognitive Emotion Regulation Training Intervention: The second experimental group participated in cognitive emotion regulation training delivered in 10 group sessions of 90 minutes each (two sessions per week over five weeks). Sessions were conducted in small groups of four to five participants. The intervention protocol was developed based on the cognitive emotion regulation strategies model proposed by Garnefski et al. (2001). The session content was as follows: Session 1—introduction to emotions, the role of emotion regulation in impulsive behavior, and participant introductions; Session 2—identification and introduction of the nine cognitive emotion regulation strategies (adaptive and maladaptive); Session 3—training in acceptance and positive reappraisal strategies; Session 4—training in refocus on planning and perspective-taking strategies; Session 5—training in positive refocusing; Session 6—identification and reduction of the maladaptive catastrophizing strategy; Session 7—identification and reduction of the maladaptive self-blame strategy; Session 8—identification and reduction of the maladaptive rumination strategy; Session 9—identification and reduction of other-blame and catastrophizing strategies; Session 10—review, integration of strategies, and planning for maintenance. Each session included psychoeducation, group discussion, practical exercises, and homework assignments. The sessions were led by a clinical psychologist experienced in the treatment of ADHD.

### 2.4. Data Analysis

Data were analyzed using SPSS version 26. At the descriptive level, means and standard deviations of impulsivity scores (total score and subscales) were calculated for the three groups at both the pretest and posttest stages. At the inferential level, statistical assumptions were evaluated using the Kolmogorov–Smirnov test (normality of score distributions), Levene's test (homogeneity of variances), and Box's M test (equality of covariance matrices). Subsequently, one-way analysis of covariance (ANCOVA) was employed to compare the effectiveness of the interventions at posttest while controlling for pretest scores. When significant between-group differences were



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observed, Bonferroni post hoc tests were conducted to perform pairwise comparisons (each experimental group versus the control group and the two experimental groups versus each other). The level of statistical significance was set at .05.

## 3. Findings and Results

The study sample consisted of 45 participants allocated to three groups of 15 individuals each (tDCS group, CER group, and control group). The mean age of the participants was 32.47 years (SD = 7.82), with an age range of 19 to 44 years. Of the total participants, 26 (57.8%) were male and 19 (42.2%) were female. Gender distribution was relatively balanced across the three groups. Chi-square and analysis of variance tests indicated no significant differences among the three groups in terms of age ($\chi^2 = 0.60$, $p = .74$) or gender ($F = 0.23$, $p = .86$), indicating demographic homogeneity across groups.

**Table 1**

*Means and Standard Deviations of Impulsivity Scores at Pretest and Posttest by Group*

| Group | Variable | Pretest Mean | Pretest SD | Posttest Mean | Posttest SD |
|---|---|---|---|---|---|
| tDCS | Total Impulsivity | 88.42 | 6.35 | 73.18 | 5.91 |
| tDCS | Motor Impulsivity | 32.15 | 3.42 | 26.83 | 3.08 |
| tDCS | Cognitive Impulsivity | 30.87 | 3.18 | 25.42 | 2.95 |
| tDCS | Non-Planning Impulsivity | 25.40 | 2.96 | 20.93 | 2.74 |
| CER | Total Impulsivity | 89.07 | 5.98 | 68.40 | 5.23 |
| CER | Motor Impulsivity | 32.33 | 3.28 | 24.93 | 2.88 |
| CER | Cognitive Impulsivity | 31.20 | 3.05 | 23.00 | 2.65 |
| CER | Non-Planning Impulsivity | 25.54 | 2.85 | 20.47 | 2.59 |
| Control | Total Impulsivity | 88.73 | 6.18 | 87.87 | 6.02 |
| Control | Motor Impulsivity | 32.00 | 3.35 | 31.80 | 3.28 |
| Control | Cognitive Impulsivity | 30.93 | 3.12 | 30.87 | 3.08 |
| Control | Non-Planning Impulsivity | 25.80 | 2.89 | 25.20 | 2.80 |

Before conducting the analysis of covariance, statistical assumptions were examined. The results of the Kolmogorov–Smirnov test indicated that score distributions were normal in all three groups ($p > .05$ for all variables). Levene's test confirmed the homogeneity of error variances ($p > .05$). In addition, Box's M test supported the equality of covariance matrices ($F = 1.28$, $p = .69$). The assumption of homogeneity of regression slopes was also confirmed by examining the interaction effect of pretest × group. Therefore, all assumptions required for ANCOVA were met.

**Table 2**

*Results of Analysis of Covariance Comparing Posttest Total Impulsivity Scores Across Groups*

| Source | Sum of Squares | df | Mean Square | F | p | η² |
|---|---|---|---|---|---|---|
| Pretest | 680.42 | 1 | 680.42 | 32.84 | .001 | .45 |
| Group | 2890.53 | 2 | 1445.27 | 69.72 | .001 | .78 |
| Error | 849.38 | 41 | 20.72 | — | — | — |
| Total | 34260.00 | 45 | — | — | — | — |

The results presented in Table 2 indicate that, after controlling for pretest scores, a significant difference existed among the three groups in posttest total impulsivity scores, $F(2, 41) = 69.72$, $p < .001$, $\eta^2 = .78$. This finding suggests that at least one of the interventions was effective in reducing impulsivity.

**Table 3**

*Bonferroni Post Hoc Test Results for Pairwise Comparisons of Total Impulsivity Scores*

| Group Comparison | Mean Difference | Standard Error | p | 95% CI Lower Bound | 95% CI Upper Bound |
|---|---|---|---|---|---|
| tDCS − Control | -14.69 | 1.66 | .001 | -18.86 | -10.52 |
| CER − Control | -19.47 | 1.66 | .001 | -23.64 | -15.30 |
| CER − tDCS | -4.78 | 1.66 | .018 | -8.95 | -0.61 |


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The results shown in Table 3 indicate that both the tDCS and CER groups had significantly lower total impulsivity scores than the control group. Furthermore, the CER group demonstrated a significantly greater reduction in total impulsivity compared with the tDCS group.

**Table 4**

*Pairwise Group Comparisons on Impulsivity Subscales (Bonferroni Test)*

| Subscale | Group Comparison | Mean Difference | Standard Error | p |
|---|---|---|---|---|
| Motor Impulsivity | tDCS − Control | -4.97 | 1.04 | .001 |
| Motor Impulsivity | CER − Control | -6.87 | 1.04 | .001 |
| Motor Impulsivity | CER − tDCS | -1.90 | 1.04 | .235 |
| Cognitive Impulsivity | tDCS − Control | -5.45 | 0.93 | .001 |
| Cognitive Impulsivity | CER − Control | -7.87 | 0.93 | .001 |
| Cognitive Impulsivity | CER − tDCS | -2.42 | 0.93 | .041 |
| Non-Planning Impulsivity | tDCS − Control | -4.27 | 0.88 | .001 |
| Non-Planning Impulsivity | CER − Control | -4.73 | 0.88 | .001 |
| Non-Planning Impulsivity | CER − tDCS | -0.46 | 0.88 | 1.000 |

The results presented in Table 4 indicate that both transcranial direct current stimulation and cognitive emotion regulation training significantly reduced motor impulsivity scores compared with the control group. However, no significant difference was observed between the effectiveness of these two interventions on motor impulsivity, suggesting comparable efficacy in improving this component.

Regarding cognitive impulsivity, both interventions produced significant reductions relative to the control group. Nevertheless, cognitive emotion regulation training resulted in a significantly greater reduction than transcranial direct current stimulation, indicating the superiority of this intervention in improving cognitive impulsivity.

Similarly, for the non-planning impulsivity component, both intervention groups demonstrated significantly lower scores than the control group. However, no significant difference was found between the effectiveness of the two interventions, suggesting comparable effects on reducing non-planning impulsivity.

## 4. Discussion

The present study aimed to compare the effectiveness of transcranial direct current stimulation (tDCS) and cognitive emotion regulation (CER) training in reducing impulsivity among adults with Attention-Deficit/Hyperactivity Disorder (ADHD). The findings demonstrated that both interventions significantly reduced total impulsivity and its dimensions, including motor impulsivity, cognitive impulsivity, and non-planning impulsivity, compared with the control group. Furthermore, although both interventions were effective, CER training produced significantly greater reductions in overall impulsivity and particularly in cognitive impulsivity than tDCS. These findings suggest that both neurobiological and cognitive-emotional interventions can improve self-regulatory functioning in adults with ADHD, but interventions directly targeting cognitive-emotional mechanisms may exert stronger effects on higher-order impulsive processes.

The finding that tDCS significantly reduced overall impulsivity is consistent with a growing body of literature emphasizing the role of non-invasive brain stimulation in improving executive functioning and behavioral regulation among individuals with ADHD. Recent meta-analyses have reported that stimulation of prefrontal cortical regions, particularly the dorsolateral prefrontal cortex (DLPFC), is associated with improvements in attention, inhibitory control, and behavioral regulation (Wang et al., 2025; Wen et al., 2025). The DLPFC is a critical component of the executive control network responsible for planning, decision-making, working memory, and inhibitory processes. Dysfunction within this region has been repeatedly implicated in the pathophysiology of ADHD, particularly in relation to impulsive behavior and deficient self-control (Cortese et al., 2025). By increasing cortical excitability and enhancing neural efficiency within the DLPFC, tDCS may facilitate top-down control mechanisms that suppress impulsive responses and improve behavioral regulation. Therefore, the reduction in impulsivity observed among participants receiving tDCS is theoretically consistent with contemporary neurocognitive models of ADHD.



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The present findings also align with previous evidence suggesting that tDCS may improve emotional and self-regulatory capacities in ADHD populations. Nejati and colleagues demonstrated that tDCS contributes to improvements in emotion regulation among individuals with ADHD, indicating that its effects extend beyond purely cognitive domains and may influence broader self-regulatory processes (Nejati et al., 2024). Similarly, Shi and colleagues concluded in their systematic review that non-invasive brain stimulation interventions can positively affect emotional regulation capacities in ADHD populations (Shi et al., 2024). Because impulsive behavior often emerges from failures in both cognitive control and emotional regulation, enhancement of these processes through tDCS may explain the reductions observed in motor, cognitive, and non-planning impulsivity in the current study.

The results further support previous meta-analytic evidence indicating that tDCS produces meaningful behavioral improvements following intervention. Tung and colleagues reported that tDCS interventions can generate significant behavioral benefits immediately after treatment and, in some cases, maintain these improvements during follow-up periods (Tung et al., 2025). Likewise, Liang and colleagues identified tDCS as one of the more promising non-invasive interventions for reducing ADHD symptoms and improving executive functioning (Liang et al., 2025). The present findings extend these observations by demonstrating that such improvements are also reflected in reductions in impulsivity among adults with ADHD, a population that has historically received less attention than children and adolescents in intervention research.

Another important finding was the significant effectiveness of cognitive emotion regulation training in reducing total impulsivity and all impulsivity subscales. This result is highly consistent with theoretical and empirical literature emphasizing the central role of emotional regulation processes in ADHD. According to the cognitive emotion regulation model proposed by Garnefski and colleagues, individuals regulate emotional experiences through a range of cognitive strategies that influence emotional and behavioral outcomes (Garnefski et al., 2001). Adaptive strategies such as positive reappraisal, acceptance, planning, and perspective-taking facilitate emotional control and thoughtful decision-making, whereas maladaptive strategies such as catastrophizing, rumination, self-blame, and other-blame increase emotional distress and behavioral dysregulation. The CER intervention employed in the present study focused on strengthening adaptive strategies while reducing reliance on maladaptive cognitive processes, thereby improving participants' capacity to regulate emotions before they translated into impulsive actions.

The effectiveness of CER training is also supported by recent ADHD research highlighting emotional dysregulation as a core mechanism underlying symptom expression and functional impairment. Tharaud and Nikolas identified emotion regulation difficulties as a key transdiagnostic mechanism connecting ADHD symptoms with broader psychological difficulties, particularly internalizing symptoms such as depression (Tharaud & Nikolas, 2025). Similarly, Liu and colleagues demonstrated significant associations between emotion regulation strategies and emotional dysregulation in individuals with ADHD, supported by both behavioral and neurobiological evidence (Liu et al., 2025). These findings suggest that interventions improving emotion regulation may have broad therapeutic effects by addressing one of the fundamental mechanisms underlying impulsive behavior. Therefore, the substantial reductions in impulsivity observed in the CER group likely reflect improvements in participants' ability to monitor emotional states, reinterpret emotionally provocative situations, and inhibit impulsive responses.

The current findings are further consistent with research showing that adults with ADHD exhibit deficits in cognitive emotion regulation compared with individuals without ADHD. Alipour and colleagues reported significant differences between adults with and without ADHD regarding emotion regulation strategies, decision-making styles, and behavioral systems, suggesting that emotional self-regulation deficits constitute a meaningful aspect of ADHD-related dysfunction (Alipour et al., 2023). Because impulsive behavior is frequently triggered by poorly regulated emotional reactions, enhancing emotion regulation capacities may directly reduce impulsivity. The present study provides empirical support for this proposition by demonstrating that participants receiving CER training experienced substantial improvements across all impulsivity domains.

One of the most noteworthy findings of the present study was the superiority of CER training over tDCS in reducing total impulsivity and cognitive impulsivity. This result may reflect fundamental differences in the mechanisms targeted by these interventions. Whereas tDCS primarily modifies neural excitability within executive control networks, CER training directly targets the cognitive and emotional processes responsible for generating impulsive thoughts and behaviors. Cognitive impulsivity is particularly associated



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with rapid decision-making, insufficient deliberation, attentional instability, and difficulty evaluating long-term consequences. Because CER training explicitly teaches individuals to pause, evaluate emotional triggers, engage in perspective-taking, and employ planning-oriented cognitive strategies, it may exert a more direct influence on cognitive impulsivity than neural stimulation alone.

The superiority of CER training in cognitive impulsivity also aligns with contemporary perspectives emphasizing the importance of emotional and cognitive integration in ADHD treatment. Recent evidence indicates that emotional dysregulation is not merely a secondary consequence of ADHD but rather a central feature influencing symptom severity, functional outcomes, and quality of life (Cortese et al., 2025; Siqueira et al., 2025). Consequently, interventions that simultaneously address emotional experiences and cognitive processing may produce stronger and more comprehensive improvements than interventions focusing exclusively on neural modulation. The current findings support this interpretation by demonstrating that although tDCS improved impulsivity, CER training generated larger effects in domains most closely associated with cognitive-emotional processing.

Another possible explanation for the greater effectiveness of CER training is that participants actively practiced and generalized adaptive strategies throughout the intervention period. Unlike tDCS, which exerts its effects primarily through neurophysiological mechanisms during stimulation sessions, CER training provides participants with enduring cognitive tools that can be applied across diverse contexts. Skills such as positive reappraisal, planning, emotional awareness, and perspective-taking may continue to influence behavior long after formal training has ended. This active learning process may facilitate greater transfer of treatment gains into daily life and contribute to stronger reductions in impulsive behavior.

At the same time, the absence of significant differences between CER and tDCS in motor impulsivity and non-planning impulsivity suggests that both interventions may effectively target certain dimensions of impulsive behavior through distinct pathways. Motor impulsivity is closely related to inhibitory control and response suppression, functions strongly associated with prefrontal cortical activity. Therefore, tDCS-induced enhancement of DLPFC functioning may be sufficient to produce improvements comparable to those achieved through cognitive-emotional training. Similarly, reductions in non-planning impulsivity may result from improvements in executive functioning and self-regulation generated by both interventions, albeit through different mechanisms.

The present findings also contribute to the broader literature concerning non-pharmacological treatments for adult ADHD. Recent systematic reviews have highlighted increasing interest in interventions that complement or serve as alternatives to pharmacotherapy, including neurostimulation techniques and psychological interventions (Yang et al., 2025). While stimulant medications remain effective for many individuals, concerns regarding side effects, treatment adherence, and individual variability in response have encouraged the exploration of alternative approaches (Cortese et al., 2025). The current results support this trend by demonstrating that both tDCS and CER training can significantly reduce impulsivity, one of the most functionally impairing symptoms of adult ADHD.

Furthermore, these findings are compatible with recent proposals advocating integrated intervention models. Rodríguez-Prieto and colleagues reported promising outcomes when tDCS was combined with neuropsychological treatment, suggesting that interventions targeting both neural and cognitive-emotional mechanisms may produce synergistic benefits (Rodríguez-Prieto et al., 2026). Although the present study did not evaluate a combined intervention, the effectiveness of both approaches independently suggests that future integrated models may offer even greater therapeutic potential.

## 5. Conclusion

Overall, the findings indicate that impulsivity in adults with ADHD is influenced by both neurocognitive and emotional-regulatory mechanisms. While modulation of prefrontal neural activity through tDCS can improve inhibitory control and behavioral regulation, direct enhancement of cognitive emotion regulation skills appears particularly effective in reducing cognitively mediated forms of impulsivity. These results support multidimensional conceptualizations of ADHD that emphasize the interaction between executive dysfunction and emotional dysregulation in the maintenance of impulsive behavior.

One limitation of the present study was the relatively small sample size, which may limit the generalizability of the findings. In addition, participants were recruited using convenience sampling from counseling centers and psychiatric clinics in a single city, which may reduce the



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representativeness of the sample. Another limitation was the reliance on self-report measures of impulsivity, which may be influenced by response biases. Furthermore, the absence of a long-term follow-up assessment prevented evaluation of the durability of treatment effects over time.

Future research should employ larger and more diverse samples to enhance the generalizability of findings. Longitudinal studies incorporating multiple follow-up assessments are needed to determine the long-term effectiveness and stability of treatment outcomes. Future investigations may also examine combined intervention protocols integrating tDCS with cognitive emotion regulation training to evaluate potential synergistic effects. Additionally, the inclusion of neuropsychological assessments, behavioral tasks, and neurophysiological measures could provide a more comprehensive understanding of the mechanisms underlying treatment-related improvements.

From a practical perspective, mental health professionals working with adults diagnosed with ADHD may consider incorporating cognitive emotion regulation training into treatment programs aimed at reducing impulsive behavior. Given the effectiveness of tDCS, this intervention may also serve as a useful adjunctive treatment, particularly for individuals who prefer non-pharmacological approaches or experience limited benefits from medication. Clinical centers may benefit from adopting multidisciplinary treatment models that combine cognitive, emotional, and neurobiological interventions. Such approaches have the potential to improve self-regulation, decision-making, emotional functioning, and overall quality of life among adults with ADHD.

## Authors' Contributions

Authors equally contributed to this article.

## Declaration

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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