

# Exploring the Therapeutic Potential of Transcranial Direct Current Stimulation (tDCS) Across Psychiatric and Neurocognitive Conditions: Evidence and Future Direction

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## Abstract

**Background:** Transcranial direct current stimulation (tDCS) is a promising neuromodulation approach for psychiatric and neurocognitive disorders, though therapeutic effects vary significantly across conditions and symptom domains.

**Aim:** This narrative review synthesizes recent evidence on the clinical potential of tDCS, focusing on efficacy, limitations, and underlying neurobiological mechanisms.

**Method:** This review synthesizes recent randomized controlled trials and meta-analyses concerning the therapeutic applications of tDCS across major psychiatric and neurocognitive conditions.

**Findings:** Evidence supports tDCS as a safe, well-tolerated adjunctive therapy. Benefits are most consistent in reducing depressive symptoms, improving cognitive and negative symptoms in schizophrenia, decreasing cravings, and enhancing sleep quality. Conversely, effects remain inconsistent in obsessive-compulsive disorder and positive psychotic symptoms, likely reflecting variability in stimulation parameters and individual neurobiological profiles rather than a lack of efficacy.

**Conclusion:** Future clinical utility depends on transitioning to precision neuromodulation. Strengthening tDCS in psychiatric care requires improved methodological rigor, protocol optimization, and integration with computational modeling and biomarker-guided approaches.

**Keywords:** Transcranial Direct Current Stimulation, tDCS, Neuromodulation, Psychiatric Disorders, Neurocognitive Disorders, Precision Psychiatry, Adjunctive Therapy

**Key points:**

1. **Growing Clinical and Practical Interest:** The use of tDCS is expanding because it is relatively low-cost, portable, non-invasive, and generally well tolerated, making it attractive for both clinic-based and home-based applications. However, this growing interest should be interpreted cautiously, as increased adoption does not necessarily imply uniform therapeutic efficacy across disorders or patient populations.
2. **Safety, Accessibility, and Clinical Interest:** tDCS is increasingly utilized in clinical research due to its non-invasive nature, low cost, portability, and established safety profile. However, this growing adoption should be interpreted with caution; practical accessibility and the ease of clinic- or home-based application do not inherently equate to uniform therapeutic efficacy across all psychiatric or neurocognitive populations.
3. **Symptom-Specific vs. Diagnostic Efficacy:** Evidence suggests that tDCS efficacy is more consistent when analyzed by specific symptom domains rather than broad diagnostic categories. It demonstrates distinct utility in targeting affective regulation and cognitive control (e.g., depressive symptoms, negative symptoms in schizophrenia). Conversely, its impact remains limited in conditions characterized by distinct neural circuit pathologies (e.g., positive psychotic symptoms, OCD), highlighting the need for target-specific rather than diagnosis-specific applications.
4. **The Adjunctive Paradigm:** Current evidence indicates that tDCS has limited utility as a standalone monotherapy. Its clinical potential is significantly higher when applied as an adjunctive strategy alongside established pharmacotherapy, other neuromodulation techniques (e.g., rTMS), or psychosocial interventions. This multimodal approach appears essential to maximize therapeutic outcomes in real-world clinical practice.
5. **Methodological Maturity and Future Directions:** The field is transitioning from exploratory pilot findings to the need for definitive, large-scale longitudinal studies. Future clinical utility depends on moving beyond early-phase research toward standardized, biomarker-guided protocols. Establishing long-term durability and predictive response markers is essential to define the precise clinical role of tDCS and to ensure its validity as a scalable therapeutic tool.

## Introduction

Transcranial direct current stimulation (tDCS) is a non-invasive method of brain stimulation, that modulates brain excitability and is potentially effective for various diseases (Brehme et al., 2025). tDCS administers a low-level constant current, typically ranging from 0.5 to 2 milliamps, through surface electrodes on the scalp. These electrodes, known as anodal and cathodal electrodes, are employed either individually or in pairs, with configurations that target specific brain regions unilaterally or bilaterally (Prathum et al, 2025). Normally, anodal stimulation triggers neurone depolarisation, increasing cortical excitability, while cathodal stimulation triggers neurone hyperpolarisation, decreasing cortical excitability (Santarnecchi et al, 2014). Weak constant currents can traverse the cranium, affecting the magnitude and direction of the intracranial electric field, thus causing excitatory changes in the cortex. This regulation of brain discharge activity can lead to various effects, including ion activity, neurotransmitter release, and brain oscillatory activity (Zhou et al, 2024). Studies show that the effect of tDCS depends on multiple factors, such as stimulation intensity, duration, electrode configuration, electrode size, and number of sessions (Prathum et al, 2025).

In this context, there is a growing interest in non-invasive neuromodulation techniques that can complement existing treatments. Among these approaches, transcranial direct current stimulation (tDCS) has received increasing attention as a potential therapeutic tool across a range of psychiatric conditions. Psychological disorders such as major depressive disorder, schizophrenia, bipolar disorder, anxiety disorders, obsessive-compulsive disorder, and post-traumatic stress disorder represent significant global public health challenges due to their high prevalence, chronicity, and frequent resistance to treatment. Recent estimates indicate that over one billion individuals worldwide live with mental health conditions, with depression and anxiety disorders contributing the largest share of disability-adjusted life years (DALYs) globally (World Health Organization, 2025). For instance, despite advances in pharmacotherapy and psychotherapy, many patients with depression or schizophrenia continue to experience residual symptoms, cognitive deficits, and impaired functioning (Mardani et al., 2021; Zheng et al., 2024). For instance, treatment-resistant depression remains a major concern with residual symptoms common despite prolonged interventions (Ren et al., 2025). Similarly, patients with schizophrenia frequently experience enduring positive and negative symptoms alongside cognitive dysfunction that limit quality of life (Stuchlíková & Klířová, 2022). Side effects of medications and high relapse rates further complicate management, challenging long-term adherence and clinical outcomes (Brunoni et al., 2012).

Given these limitations, there remains a substantial unmet need for complementary, safe interventions capable of improving clinical outcomes and cognitive functioning. In this context, transcranial direct current stimulation (tDCS) has emerged as a promising approach, owing to its favorable safety profile, low cost, portability, and ease of administration. Clinical trials and meta-analyses have demonstrated its efficacy in reducing depressive symptoms by modulating prefrontal cortical regions involved in

mood regulation (Ren et al., 2025; Moffa et al., 2018). Additionally, tDCS shows promise in improving cognitive deficits and alleviating positive and negative symptoms in schizophrenia, impacting executive functions such as working memory and attention (Stuchlíková & Klírová, 2022; Shafiee-Kandjani et al., 2024). Its potential extends to treating anxiety symptoms and post-traumatic stress disorder, mechanisms thought to involve modulation of the fear extinction circuitry (Gueserse et al., 2021).

Furthermore, emerging evidence supports the use of tDCS in managing bipolar disorder, borderline personality disorder, and substance use disorders, suggesting broader applicability across psychiatric conditions (Salehinejad et al., 2022; Sahaf et al., 2024). Its effects on neurocognitive disorders, including mild cognitive impairment and dementia, have shown improvements in attention, memory, and executive function, making it a candidate for non-pharmacological cognitive enhancement (Prathum et al., 2025; Lu et al., 2021; Kako Joibari et al., 2020). Studies have also begun exploring combined interventions, such as tDCS paired with mindfulness meditation, cognitive training, or pharmacotherapy, revealing synergistic effects that may optimize outcomes (Momeniyan et al., 2024; Mardani et al., 2021).

Despite promising outcomes, challenges remain regarding the variability in stimulation protocols, including electrode montage, current intensity, session duration, and total number of sessions (Cheng et al., 2020; Schwippel et al., 2025). Patient-related factors such as age, baseline symptom severity, and comorbidities also contribute to heterogeneity in treatment response (Brehme et al., 2025; Zareie et al., 2024). Moreover, the long-term efficacy and durability of tDCS effects necessitate further investigation through large-scale, well-designed longitudinal studies (Ren et al., 2025).

This review aims to provide a comprehensive analysis of the current clinical applications, mechanistic insights, and future directions of tDCS in psychological disorders, emphasizing its potential to enhance existing treatment frameworks and improve patient outcomes.

## Methodology

### Review Design

This study employed a narrative review design with a systematic literature search to synthesize current evidence on the therapeutic potential of transcranial direct current stimulation (tDCS). The review provides an integrative overview of the clinical, emotional, behavioral, and cognitive effects of tDCS across key neuropsychiatric domains. These include major depressive disorder (and its subtypes), obsessive-compulsive disorder, schizophrenia, anxiety, bipolar disorder, substance/medication dependence, and insomnia. Additionally, special emphasis is placed on the impact of tDCS on neurocognitive functions, alongside an evaluation of its safety and tolerability.

### Search Strategy

A comprehensive and systematic search of the literature was undertaken to identify relevant studies published between 2020 and 2025. The electronic databases searched included PubMed/MEDLINE, Scopus, Web of Science, Scientific Information Database (SID), and Magiran.

The search strategy was developed using combinations of free-text terms and, where applicable, controlled vocabulary related to the intervention and clinical conditions of interest. The main search terms included: “*transcranial direct current stimulation*”, “*tDCS*”, “*depression*”, “*major depressive disorder*”, “*anxiety*”, “*generalized anxiety disorder*”, “*schizophrenia*”, “*obsessive-compulsive disorder*”, “*bipolar disorder*”, “*substance dependence*”, “*medication dependence*”, “*insomnia*”, “*sleep disorders*”, “*cognitive impairment*”, and “*neurocognitive function*”. These terms were combined using Boolean operators such as **AND** and **OR**, and the syntax was adjusted for each database. In addition, the reference lists of eligible studies and relevant review articles were manually screened to identify further pertinent records.

### Eligibility Criteria

#### Inclusion Criteria:

- **Population:** Adolescents and adults diagnosed with psychiatric or neurocognitive disorders according to standard diagnostic criteria (e.g., DSM-5, ICD-11).
- **Intervention:** Studies in which tDCS was applied as the primary intervention, either as a standalone treatment or in combination with other therapeutic approaches (e.g., pharmacotherapy, psychotherapy, or cognitive training).
- **Comparators:** Sham/placebo stimulation, active control conditions, treatment-as-usual, or other neuromodulation interventions.
- **Outcomes:** Studies reporting outcomes related to symptom severity, cognitive functioning, emotional or behavioral measures, craving, sleep quality, and/or safety and tolerability.
- **Study design:** Randomized controlled trials, systematic reviews, and meta-analyses were prioritized; however, pilot studies, open-label trials, and selected case series were also considered where higher-level evidence was limited.
- **Time frame:** Studies published between 2020 and 2025 were eligible for inclusion.
- **Accessibility:** Only open-access studies with accessible full text were included.
- **Language:** Only articles published in English were considered.

#### Exclusion Criteria:

- **Population:** Non-human studies.
- **Intervention:** Studies in which tDCS was not the primary intervention of interest.
- **Topical relevance:** Studies not directly relevant to the review topic.
- **Outcomes:** Studies reporting outcomes not aligned with the objectives of the review.
- **Publication type and accessibility:** Conference abstracts, preliminary reports, and studies without accessible full text.
- **Methodological reporting:** Studies with insufficient methodological or reporting detail.

### **Study Selection**

Study selection followed a multistep process. A total of 276 records were initially identified through database searching. Following the removal of 69 duplicate records, 207 unique records were subjected to title and abstract screening. Of these, 35 records were excluded based on title and abstract analysis because they were not directly relevant to the review topic ( $n = 15$ ), did not focus on tDCS as the primary intervention ( $n = 12$ ), or involved non-human samples ( $n = 8$ ). Additionally, 88 records were excluded during the initial retrieval phase due to publication type or accessibility limitations, comprising conference abstracts ( $n = 29$ ), preliminary reports ( $n = 11$ ), and studies for which the full text could not be accessed ( $n = 48$ ). Consequently, the full texts of the remaining 84 articles were assessed for eligibility. Following a detailed evaluation, 54 articles were excluded because their reported outcomes were not aligned with the objectives of the review ( $n = 20$ ) or because they provided insufficient methodological and reporting detail ( $n = 34$ ). Ultimately, 30 studies met all eligibility criteria and were included in the final narrative synthesis.

### **Data extraction**

Data extraction was carried out using a structured and standardized form to ensure methodological consistency across the included studies. The following data were extracted from each article: authors and year of publication, sample size, study design and population characteristics, tDCS protocol, assessed variables and measurement instruments, statistical methods, reported effect sizes (including type and value), and a summary of the main findings. Particular attention was devoted to capturing both methodological features and intervention-related parameters in order to facilitate a systematic comparison of study characteristics, analytical approaches, and outcomes.

### **Data Synthesis**

Due to substantial heterogeneity across the included studies in terms of sample characteristics, stimulation parameters, study design, and reported outcomes, a formal quantitative synthesis was not performed. Instead, the findings were synthesized narratively. Studies were grouped according to major clinical domains, including depression, anxiety-related conditions, schizophrenia spectrum disorders, obsessive-compulsive symptoms, substance use disorders, sleep-related disturbances, emotional processing, and neurocognitive outcomes.

The narrative synthesis focused on identifying common therapeutic patterns, differences in reported efficacy across clinical populations, and the methodological features that may account for variability in outcomes. Greater interpretive emphasis was placed on evidence derived from randomized controlled trials, systematic reviews, and meta-analyses, while findings from conference papers and preprints were considered more cautiously.

### **Methodological Considerations**

Given the focused narrative nature of this review, combined with a systematic search approach, formal risk-of-bias assessment and quantitative meta-analytic procedures were not undertaken. Instead, methodological rigor was considered qualitatively based on key

study features, including design type, sample characteristics, clarity of reporting, appropriateness of outcome measures, and relevance to the review objectives. Greater interpretive weight was assigned to evidence derived from randomized controlled trials, systematic reviews, and meta-analyses, whereas findings from pilot studies, open-label trials, and lower-level designs were interpreted with greater caution. This approach was intended to preserve the clinical and integrative purpose of the review while still allowing for a critical appraisal of the strength and consistency of the available evidence.

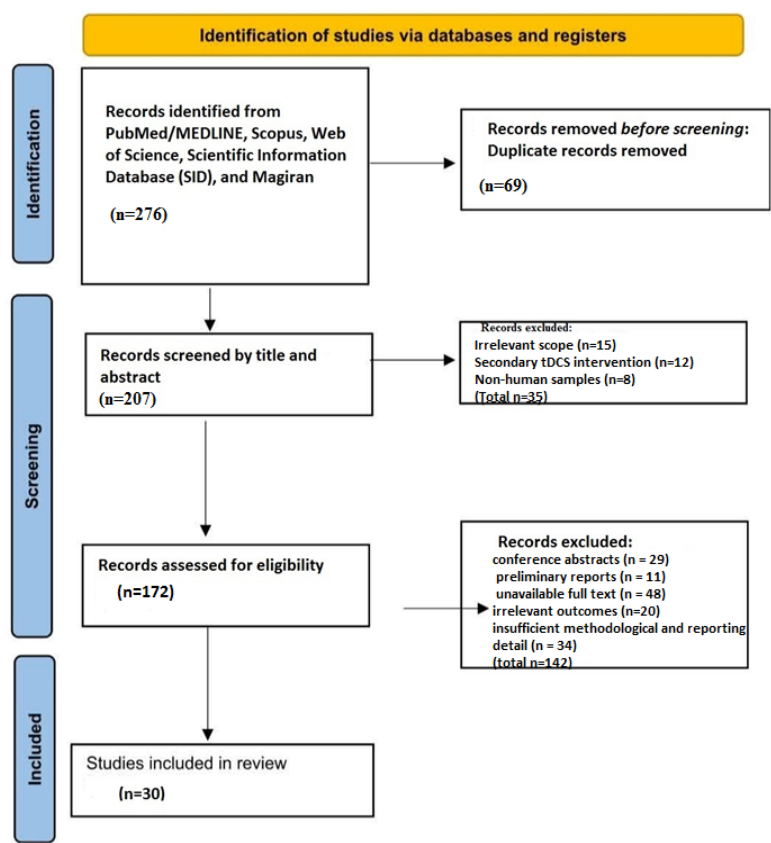


Figure 1. Identification of studies via databases and registers

Results

This narrative review synthesized evidence from 30 studies spanning the period from 2020 to 2025, including randomized controlled trials, meta-analyses, and original clinical

investigations, encompassing several thousand participants across a broad range of psychiatric and neurocognitive disorders. The included studies represented heterogeneous populations, stimulation parameters, and outcome measures, thereby providing a comprehensive and nuanced overview of the clinical application and therapeutic potential of transcranial direct current stimulation (tDCS).

**Table 1.** Overview of Transcranial Direct Current Stimulation (tDCS) Protocols and Applications in Clinical Research

| R<br>o<br>w | Aut<br>hors               | Sampl<br>e Size                                   | Study<br>Design / Po<br>pulation                                                                                                                   | tDCS Proto<br>col                                                                                                                                                                                                 | Variables/To<br>ols                                                                                                                                                                                                                                              | Statistic<br>al Metho<br>d                                                                                                                                                    | Effect Size (Type + Value)                                                                                                                                                                            | Summary<br>of Finding<br>s                                                                                                                                                                                                                                                                 |
|-------------|---------------------------|---------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1           | Afsharipoor et al. (2025) | 24 participants (N=12 experimental; N=12 control) | <b>Pilot study, single-blinded, sham-controlled clinical trial</b> --- Patients (aged 18-40) with moderate to severe Traumatic Brain Injury (TBI). | <b>Protocol:</b> <b>Anode:</b> Left DLPFC; <b>Cathode:</b> Right DLPFC; <b>Intensity:</b> 2mA; <b>Duration:</b> 20min/session; <b>Sessions</b> : 10 sessions (3 times/week) concurrent with occupational therapy. | <ul style="list-style-type: none"> <li>• <b>Working Memory</b> (N-back Test)</li> <li>• <b>Planning</b> (Tower of London)</li> <li>• <b>Problem-Solving</b> (Wisconsin Card Sorting Test - WCST)</li> <li>• <b>Selective Attention</b> (Stroop Test).</li> </ul> | <ul style="list-style-type: none"> <li>• Independent samples t-test</li> <li>• Mann-Whitney U test;</li> <li>• Paired t-test</li> <li>• Wilcoxon signed-rank test.</li> </ul> | Cohen's <i>d</i> : 1.508 (WCST Correct); – 1.508 (WCST Incorrect); – 1.006 (Perseverative Errors); – 1.430 (N-back Time); 1.476 (N-back Result); 1.417 (TOL Total Score); 0.618 (Stroop Speed – n.s.) | Combining tDCS with occupational therapy was <b>significantly more effective than occupational therapy alone</b> in improving <b>working memory, planning, and problem-solving</b> in patients with TBI. <b>No significant between-group difference was found for selective attention.</b> |

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| 2 | Prathum et al. (2025) | 19 studies (945 participants) | <b>Systematic Review &amp; Meta-Analysis</b> — Older adults (mean age ~71.7) with cognitive impairments : Alzheimer's Disease (AD), Mild Cognitive Impairment (MCI), and Dementia. | <b>Various protocols; Intensity:</b> 1-2 mA; <b>Duration:</b> 20-40 min; <b>Electrode size:</b> 2.5-35 cm <sup>2</sup> ; <b>Sessions:</b> 1 to 36; <b>Common targets:</b> Dorsolateral Prefrontal Cortex (DLPFC) and Temporal areas. | <ul style="list-style-type: none"> <li>• <b>Global Cognition</b> (e.g., Mini-Mental State Examination – MMSE; Montreal Cognitive Assessment – MoCA)</li> <li>• <b>Memory abilities</b> (e.g., Auditory Verbal Learning Test – AVLT; California Verbal Learning Test – CVLT)</li> <li>• <b>Executive Function</b> (e.g., Stroop test; Controlled Oral Word Association</li> </ul> | <ul style="list-style-type: none"> <li>• Random-effects meta-analysis</li> <li>• Subgroup and sensitivity analyses</li> <li>• Cochrane Risk of Bias (RoB 2) too</li> <li>• Funnel plots &amp; Egger's test for publication bias.</li> </ul> | <b>Standardized Mean Difference (SMD):</b> Global Cognition post-test <b>SMD = 0.51</b> ; Global Cognition Follow-up: <b>SMD = 2.29</b> ; Global Cognition (Overall, Post-Intervention) : <b>SMD = 0.45</b> ; Subgroup (AD patients): <b>SMD = 0.91</b> . | tDCS significantly improved <b>global cognition</b> , particularly measured by the MMSE, both post-intervention and at follow-up. Benefits were greatest for <b>Alzheimer's Disease</b> patients. Optimal parameters included <b>tDCS alone, current</b> |

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|   |                   |                                 |                                                                                                                                                                                                                         |                                                                                                                                                        | Test COWAT)                                                                                                                                                                                                                                                                                                                                                                                | –                                                                                                                                                                                                                                                                           |                                                                                                                                                                                                             |                                                                                                                                                                                                                                            | <b>density ≤0.06 mA/cm², duration &gt;20 min, ≤15 sessions, and temporal lobe stimulation. No significant improvements</b> were found for memory or executive function. |
| 3 | Ren et al. (2025) | 88 studies (5,522 participants) | <b>Systematic Review &amp; Meta-Analysis</b> — Adults with Major Depressive Disorder ( <b>MDD</b> ), Depression with Psychiatric Comorbidities ( <b>DPC</b> ), or Depression with Medical Comorbidities ( <b>DMC</b> ). | <b>Various protocols:</b> Primarily <b>Anode</b> over Left DLPFC (F3); <b>Intensity:</b> 2 mA; <b>Duration:</b> 20 min/session; Sessions: 10 sessions. | <ul style="list-style-type: none"><li>• <b>Depression severity</b> (e.g., Montgomery–Åsberg Depression Rating Scale – MADRS; Beck Depression Inventory – BDI)</li><li>• <b>Response rates</b> (≥50% reduction in depression scores in baseline)</li><li>• <b>Remission rates</b> (e.g., Hamilton Depression Rating Scale - HDRS≤7)</li><li>• <b>Adverse events of tDCS</b> (AEs)</li></ul> | <ul style="list-style-type: none"><li>• Random-effects meta-analysis (Hartung-Knapp-Sidik-Jonkman)</li><li>• SMD &amp; OR</li><li>• I<sup>2</sup> for heterogeneity</li><li>• Meta-regression</li><li>• Subgroup/sensitivity analyses</li><li>• GRADE for Quality</li></ul> | <b>SMD</b> (tDCS vs. Sham): -0.88 ( <b>DPC</b> ; <b>Large</b> ); -1.05 ( <b>DMC</b> , <b>Large</b> ). <b>SMD</b> (tDCS+Pharmacotherapy vs. Sham+Pharmacotherapy, <b>DMC</b> ): -1.54 ( <b>Very Large</b> ). | tDCS was most effective for depressive symptoms in patients with <b>comorbid conditions (DPC and DMC)</b> , showing large effect sizes, but had a smaller, non-significant benefit in MDD-alone. <b>Combining tDCS with antidepressant</b> |                                                                                                                                                                         |

|   |                       |                                |                                                                                                                      |                                                                                                                                                                                                                              | <div>• <b>Dropout rates</b></div>                                                                                                                                                                                                                                                                                     | <div>of Evidence (QOE).</div>                                                                                                                                                                                                      |                                                                                                                                                                                                                                     | <div><b>medication</b> significantly improved outcomes in MDD.</div>                                                                                                                                                                                                                                                                              |
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| 4 | Yac hou et al. (2025) | 29 studies (1766 participants) | <b>Systematic Review &amp; Electric Field Modeling Meta-Analysis</b> — Patients with unipolar or bipolar depression. | <b>Various protocols:</b> Primarily Bifrontal (F3-F4), Lateral Orbital Wall (F3-F8), Supraorbital (F3-SO), Extra-cephalic (F3-arm); <b>Intensity:</b> 0.5-2.5 mA; <b>Duration:</b> 10-30 min/session; <b>Sessions:</b> 5-30. | <div>• <b>Depression severity</b> (e.g., Montgomery–Åsberg Depression Rating Scale – MADRS; Beck Depression Inventory - BDI)</div> <div>• <b>Electric Field Analysis:</b> Computer-simulated maps of current flow in the brain; Correlation between field strength in specific regions and clinical improvement</div> | <div>• Random-effects meta-analysis (Hedges' *g*)</div> <div>• Finite Element Method (FEM) modeling on 8 head models</div> <div>• Spearman rank correlation for PEC</div> <div>• Kruskal-Wallis test for E-field comparisons</div> | <b>Hedges' *g* (Overall):</b> 0.66 (95% CI: 0.565 to 0.767) — <b>Medium-to-Large effect.</b><br><b>PEC (Correlation):</b> Significant positive correlations found in Brodmann Areas (BA) 10, BA 11, and the anterior part of BA 46. | This innovative meta-analysis combined clinical data with electric field modeling. It found a <b>significant antidepressant effect of tDCS</b> . Crucially, modeling revealed that <b>standard montages do not selectively target the left DLPFC</b> as intended, but produce diffuse frontal fields. Clinical improvement was correlated with E- |

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|   |                   |                               |                                                                 |                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                   | field strength in <b>frontopolar (BA10) and orbitofrontal (BA11) cortices</b> , suggesting these may be more critical targets than the DLPFC itself. Highlights the need for personalized, simulation-guided tDCS protocols. |
| 5 | Yao et al. (2025) | 11 Studies (468 participants) | Systematic Review & Meta-Analysis — Patients with schizophrenia | <b>Various protocols</b> Primarily <b>Anode</b> over left DLPFC, <b>Cathode</b> over right DLPFC/supraorbital; <b>Intensity:</b> 2 mA; <b>Duration:</b> 20–30 min/session; <b>Sessions:</b> 10–15 sessions; | <ul style="list-style-type: none"> <li>• <b>Cognitive functions</b> (Paced Auditory Serial Addition Task – PASTA)</li> <li>• <b>Positive/Negative symptoms of schizophrenia</b></li> <li>• <b>a:</b> Positive and Negative Syndrome Scale (PANSS); Scale for the</li> </ul> | <ul style="list-style-type: none"> <li>• Random-effects meta-analysis: Used due to expected variation between studies</li> <li>• Subgroup analysis: Analyzed effects by session count (10 vs 15)</li> </ul> | <ul style="list-style-type: none"> <li>• PASAT: SMD = 1.72 (95% CI: 1.17 to 2.28) — <b>Very large</b></li> <li>• CGI (15 sessions): SMD = -0.56 (95% CI: -0.87 to -0.25) — <b>Medium</b></li> <li>• CGI (twice daily): SMD = -0.85 (95% CI: -1.67 to -</li> </ul> | tDCS showed <b>significant benefits for cognitive function</b> (PASAT) with a very large effect size. Disease severity (CGI) improved significantly with 15 sessions (medium                                                 |

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|   |                     |                                                     |                                                                                               |                                                                                                 | Assessment of Negative Symptoms (SANS); Auditory Hallucinations Rating Scale (AHRs); Calgary Depression Scale for Schizophrenia (CDSS) Clinical Global Impression-Schizophrenia scale (CGI) | and frequency (once vs twice daily) <ul style="list-style-type: none"> <li>Sensitivity analysis: "Leave one out" method to test result stability</li> <li>Publishing bias: Assessed via funnel plot symmetry</li> </ul> | 0.03) —<br><b>Large</b><br>•Other outcomes:<br><b>Non-significant</b>                                                                                                                        | effect) or twice-daily stimulation (large effect). <b>No significant effects</b> were found for general symptoms (PANSS), negative symptoms (SANS), auditory hallucinations (AHRs), or depression (CDSS). The analysis noted high heterogeneity between studies and potential publication bias, suggesting cautious interpretation of results. |
| ٦ | Joshi et al. (2025) | 149 participants (N=75 active tDCS, N=74 sham tDCS) | <b>Randomized, single-blind, sham-controlled trial</b> — Male adults (aged 18-55) with severe | <b>Protocol:</b> Anode over Left DLPFC (F3), Cathode over Right DLPFC (F4); <b>Intensity:</b> 2 | <ul style="list-style-type: none"> <li>•<b>Craving</b> (Obsessive Compulsive Drinking Scale, OCDS).</li> <li>•<b>Time to relapse</b> (Timeline</li> </ul>                                   | <ul style="list-style-type: none"> <li>• Intention-to-treat analysis</li> <li>• Mixed-model ANOVA</li> <li>• Independent</li> </ul>                                                                                     | <b>Cohen's d:</b> <ul style="list-style-type: none"> <li>• Craving (3-month): 0.45 (<b>Small</b>)</li> <li>• Time to First Drink: 0.35 (<b>Small</b>)</li> <li>• Time to Relapse:</li> </ul> | <b>Active tDCS was superior to sham</b> in reducing alcohol craving and delaying                                                                                                                                                                                                                                                               |

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|   |                         |                                                   | Alcohol Use Disorder (AUD), abstinent for $\geq 3$ days and exhibiting active craving. | mA; <b>Duration:</b> 20 min/session; <b>Sessions:</b> 10 sessions (2 sessions/day for 5 consecutive days).  | Follow-Back - TLFB)<br>• <b>Time to first drink</b><br>• <b>Reverse events of tDCS</b> (tDCS Side-Effect Checklist) | samples t-test<br>•Chi-square test<br>•Kaplan-Meier survival analysis. | 0.42 ( <b>Small</b> ) <b>Partial <math>\eta^2</math></b> (Time effect on craving): 0.58 ( <b>Large</b> ) <b>Partial <math>\eta^2</math></b> (Group $\times$ Time on craving): 0.04 ( <b>Small</b> ) | the time to first drink and relapse over a 3-month period. The active tDCS group had a <b>significantly lower relapse rate</b> (44%) compared to the sham group (63.5%). The intervention was safe, with no reported adverse events. While statistically significant, the between-group effect sizes on craving and relapse outcomes were small. |
| Y | Gholipour et al. (2025) | 24 participants (N=12 experimental, N=12 control) | <b>Randomized Controlled Trial, single-blind</b> — Individuals aged 18-50 diagnosed    | <b>Protocol:</b> Anode over Fp1; Cathode over Fp2; <b>Intensity:</b> 2 mA; <b>Duration:</b> 23 min/session; | •Absolute power of Alpha (8-12 Hz) and Theta (4-8 Hz) brain waves (QEEG).<br>•Visual and auditory                   | •Kolmogorov-Smirnov (normality)<br>•Levene's Test                      | <b>Partial <math>\eta^2</math>:</b> •0.831 (Alpha Power — <b>Large</b> )<br>•0.794 (Theta Power— <b>Large</b> )                                                                                     | Active tDCS over Fp1/Fp2 significantly <b>increased Alpha power</b> and <b>decreased Theta</b>                                                                                                                                                                                                                                                   |

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|   |                                 |                                     | with Generalized Anxiety Disorder (GAD) according to DSM-5 criteria                                        | <b>Sessions:</b> 15 sessions (3 times/week for 5 weeks).                                                                  | attention (Integrated Visual and Auditory Continuous Performance Test IVA-2 test).                                            | (homogeneity of variance)<br>• Box's M Test (homogeneity of covariance)<br>• Repeated-Measures ANOVA (RM-ANOVA)<br>• Multivariate Analysis of Covariance (MANCOVA). | • 0.770 (Visual Attention– <b>Large</b> )<br>• 0.889 (Auditory Attention – <b>Large</b> )<br>• <b>Cohen's d</b> for within-group improvements in attention subcomponents ranged from 0.48 to 1.27. | <b>power</b> , indicating a shift towards a less anxious neural state. This was accompanied by significant, large improvements in all measured subcomponents of <b>visual and auditory attention</b> . The intervention was particularly beneficial for participants with higher baseline anxiety. |
| 8 | Rodriguez-Manrique et al., 2025 | 47 participants (patients with OCD) | <b>Double-blind, randomized, sham-controlled, cross-over design</b> — Patients with a primary diagnosis of | <b>Protocol:</b> Anode over right pre-supplementary motor area (pre-SMA); <b>Intensity:</b> 2 mA; <b>Duration:</b> 20 min | • <b>Inhibition performance</b> (Stroop task: % correct responses and response time)<br>• <b>Neural activation</b> (fMRI BOLD | • Paired Wilcoxon signed-rank test<br>• Multivariate Partial Least Squares (PLS)                                                                                    | Cohen's <i>d</i> * (approx. from reported z-score and n): ~0.35 ( <b>small-to-moderate</b> )                                                                                                       | A single session of anodal tDCS over the right pre-SMA <b>significantly improved inhibition</b>                                                                                                                                                                                                    |

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|  |  |  | Obsessive-Compulsive Disorder (OCD). | (1200 s for real, 30 s for sham);<br><b>Session:</b> 1 session | signal during task). |  | for accuracy). | <b>accuracy</b> in patients with OCD compared to sham stimulation . This behavioral improvement was associated with <b>increased neural activation</b> in a fronto-parieto-cerebellar network, including key areas for inhibitory control. The study provides the first concurrent tDCS-fMRI evidence in OCD, suggesting tDCS can modulate the core neural deficit of inhibition, making it a promising intervention. |
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| 9  | Sch wipp el et al. (2025) | 26 rando mized studies              | Double-blind, sham-controlled randomized clinical trial in adults with <b>schizophrenia or schizo affective disorder</b> | <b>Protocol:</b> Anodal over right DLPFC (F4), cathode on left deltoid; <b>Intensity:</b> 2 mA; <b>Duration:</b> 25.5 min per session; <b>Sessions:</b> 10 sessions over 2 weeks | <b>•Working memory</b> (response time, d')<br><b>• Transfer cognition</b> (BACS, TMT-B, Tower of London)<br><b>•Clinical symptoms/Q uality of Life</b> (PANSS, SANS, CDSS, GAF, WHOQOL-BREF) | <b>•2×3 ANOVA</b><br><b>•RM-ANCOV A</b><br><b>•linear mixed-effects models</b><br><b>•Tukey's post-hoc,</b><br><b>•ITT</b> | <b>•<math>\eta^2</math>:</b> response time = 0.267<br><b>•BACS digit sequencing</b> = 0.226<br><b>•BACS symbol coding</b> = 0.153<br><b>•Tower of London</b> = 0.130 | Anodal tDCS combined with working memory training <b>significantly improved response times and d' during training</b> , with transfer effects observed in BACS digit sequencing and symbol coding. No significant differences were found for clinical symptoms, depression, or quality of life, and benefits were not fully sustained at long-term follow-ups. |
| 10 | Zho u et al. (2024)       | 157 partici pants (N=56 active tDCS | Randomized , double-blind , parallel-grou p controlled                                                                   | <b>Protocol:</b> Combined tDCS+rTMS ;<br><b>•Protocol of tDCS:</b>                                                                                                               | <b>•Sleep quality</b> (Pittsburgh Sleep Quality Index-PSQI);<br><b>•Depression</b> (Hamilton                                                                                                 | <b>•Repeate d-measures ANOVA</b><br><b>•Random -effects</b>                                                                | <b>Cohen's d</b> (tDCS+rTMS vs. tDCS+sham rTMS): Sleep                                                                                                               | <b>Combined tDCS+rTMS was significantly superior to both</b>                                                                                                                                                                                                                                                                                                   |

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|    |                  | + rTMS; N=50 sham tDCS + rTMS; N=51 active tDCS + sham Rtms) | trial -- Adults with chronic primary insomnia (measured by ICD-11) on stable zopiclone medication.                                | Anode = Left DLPFC (F3), Cathode = Right DLPFC (F4); <b>Duration/Intensity:</b> 2 mA × 20 min. <b>•Protocol of rTMS:</b> 1 Hz over right DLPFC; <b>Sessions:</b> 20 sessions over 4 weeks.        | Depression Scale-HAMD); <b>•Anxiety</b> (Hamilton Anxiety Scale-HAMA), response/remission rates, adverse events of tDCS.                                                                                                                             | mixed-model analysis <b>•Post-hoc tests</b> (Bonferroni) <b>•Chi-square test</b> <b>•Intention-to-treat analysis;</b> SPSS v25.                              | Quality = -0.66; Sleep Duration = -0.72; Sleep Efficiency = -1.30; Sleep Medication = -0.32; Daytime Dysfunction = -0.16. | monotherapies in improving sleep quality (PSQI), with benefits evident at 2 weeks and sustained at 3-month follow-up. Also led to greater reductions in depression (HAMD) scores. The therapy was safe and well-tolerated. |
| 11 | Li et al. (2025) | 196 patients (N=98 active tDCS N=98 sham tDCS)               | <b>Randomized Clinical Trial (RCT)</b> — Patients undergoing elective laparoscopic radical resection for Colorectal Cancer (CRC). | <b>Protocol:</b> Anode over Left DLPFC; Cathode over Right DLPFC; <b>Intensity:</b> 2 mA; <b>Duration:</b> 20 min/session; <b>Sessions:</b> 2 sessions (afternoon before and morning of surgery). | <b>•Perioperative Anxiety</b> (Hospital Anxiety and Depression Scale-Anxiety - HADS-A) <b>•Postoperative Delirium</b> (Confusion Assessment Method - CAM) <b>•Pain</b> (Numeric Rating Scale - NRS), <b>•Sleep quality</b> (Pittsburgh Sleep Quality | <b>•</b> Intention-to-treat analysis <b>•</b> Chi-square test; <b>•Fisher's exact test;</b> <b>•Linear mixed-effects models</b> <b>•Logistic regression.</b> | <b>Relative Risk</b> (RR) for incidence of perioperative anxiety: 0.55 (95% CI, 0.42-0.73).                               | Two preoperative sessions of active tDCS significantly <b>reduced the incidence of perioperative anxiety</b> compared to sham. The active tDCS group also showed significant                                               |

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|    |                       |                                        |                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                         | Index - PSQI)<br>• <b>Frailty</b><br>(Fatigue, Resistance, Ambulation, Illness and Loss of Weight - FRAIL Index). |                                                                                                                                                                                  |                                                                                                                                                             | improvements in secondary outcomes, including <b>lower rates of postoperative delirium, reduced pain, better sleep quality, and less frailty.</b>                                                                                                             |
| 12 | Moameni et al. (2024) | 60 participants (assigned to 4 groups) | <b>Quasi-experimental, 2x2 factorial design</b> — Healthy university students. The 4 groups were:<br>1. Active tDCS + Active Mindfulness (Body Scan)<br>2. Sham tDCS + Active Mindfulness<br>3. Active tDCS + Sham Mindfulness (Mind Wandering)<br>4. Sham tDCS + | <b>Protocol:</b><br>• <b>Single session of Active tDCS:</b> Anode over left DLPFC (F3) <b>OR</b> Cathode over right IPL (P4).<br>• <b>Sham tDCS:</b> Applied to the same locations.<br><b>Intensity:</b> 2 mA; <b>Duration:</b> 20 min. | • <b>State anxiety</b> (Spielberger State-Anxiety Inventory - STAI-S) — Assessed at 5 time points.                | •Descriptive statistics (Mean, SD)<br>•Mixed-model Analysis of Variance (ANOVA)<br>•Mauchly's Test of Sphericity<br>•Greenhouse-Geisser correction<br>•Bonferroni post-hoc test. | <b>Partial <math>\eta^2</math> Time</b> (Within-Subject): $\eta^2 = 0.66$ ( <b>Large</b> ); <b>Group</b> (Between-Group): $\eta^2 = 0.06$ ( <b>Small</b> ). | A single concurrent session of active tDCS (targeting DLPFC or IPL) and mindfulness meditation <b>did not yield a significant between-group effect</b> on state anxiety levels in response to induced rumination. However, a <b>statistically significant</b> |

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|  |  |  | Sham Mindfulness (Control). |  |  |  |  | <b>and large main effect of time</b> was observed, indicating that the experimental manipulation (breathing meditation and rumination induction) was effective in modulating anxiety within subjects. The findings suggest that the synergistic impact of a single-session, combined neuromodulatory and mindfulness-based intervention may be insufficient to produce differential anxiolytic effects beyond the control |
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|    |                                 |                                                     |                                                                                                                              |                                                                                                                                                                                                |                                                                                                        |                                                                                                                                                                           |                                                                                                                                                                                                                                                                                                            | conditions in a non-clinical population.                                                                                                                                                                                                                                                                                                                      |
| 13 | Shafiee-Kandjani et al . (2024) | 30 participants (N=15 experimental ; N=15 control ) | <b>Randomized Controlled Trial</b> — Inpatients with schizophrenia (based on DSM-5 criteria) from Razi Psychiatric Hospital. | <b>Protocol:</b> Anode over left DLPFC (F3); <b>Cathode</b> over right supraorbital area; <b>Intensity:</b> 1.2–2 mA; <b>Duration:</b> 20 min/session; <b>Sessions:</b> 10 sessions (3x/week). | <b>•Positive and negative symptoms of schizophrenia</b> (Positive and Negative Syndrome Scale - PANSS) | <ul style="list-style-type: none"> <li>•Multivariate Analysis of Covariance (MANCOVA)</li> <li>•Assumption checks (Kolmogorov-Smirnov, Shapiro-Wilk, Box's M).</li> </ul> | <b>Partial Eta-Squared (<math>\eta^2</math>):</b> <ul style="list-style-type: none"> <li>•Negative Symptoms: <math>\eta^2 = 0.568</math> (<b>Large</b>)</li> <li>• General Symptoms: <math>\eta^2 = 0.516</math> (Large)</li> <li>• Positive Symptoms: <math>\eta^2 = 0.011</math> (Negligible)</li> </ul> | A 10-session regimen of anodal tDCS over the left DLPFC led to a <b>significant and large improvement in negative symptoms and general psychopathology</b> in patients with schizophrenia. However, it <b>did not have a significant effect on positive symptoms</b> . The intervention was found to be a suitable adjunct therapeutic tool for targeting the |

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| 14 | Wang et al. (2024) | 12 Studies (371 patients) | <b>Systematic Review &amp; Meta-Analysis</b> — Patients with Major Depressive Disorder (MDD). | <b>Various protocols:</b> Primarily <b>Anode</b> over Left DLPFC (F3); <b>Cathode</b> over right DLPFC (F4) or supraorbital; <b>Intensity:</b> 1-2 mA; <b>Duration:</b> 20-30 min/session; <b>Sessions:</b> 5 to 22. | <ul style="list-style-type: none"> <li>• <b>Depression severity</b> (e.g., Hamilton Depression Rating Scale - HDRS).</li> <li>• <b>Global cognition</b> (e.g., Montreal Cognitive Assessment - MoCA),</li> <li>• <b>Verbal memory</b> (e.g., Rey Auditory Visual Learning Test - RAVLT)</li> <li>• <b>Executive function</b> (e.g., N-back, Stroop test)</li> <li>• <b>Attention</b> (e.g., Digit Span; Symbol Digit Modalities Test - SDMT)</li> <li>• <b>Safety:</b> Adverse events of tDCS.</li> </ul> | <ul style="list-style-type: none"> <li>• Random-effects meta-analysis</li> <li>• Standardized Mean Difference (SMD) for continuous outcomes</li> <li>• Odds Ratio (OR) for adverse events; <math>I^2</math> for heterogeneity</li> </ul> | <b>SMD (Antidepressant Effect):</b> -0.77 (95% CI: -1.44, -0.11) — <b>Large SMD</b> (Verbal Memory): 0.30 (95% CI: -0.02, 0.62) — <b>Small-to-medium</b> effect, trend towards significance. SMD (Global Cognition): -0.01 — <b>No effect.</b> <b>OR (Adverse Events):</b> 1.19 — <b>No significant difference</b> from sham. | This meta-analysis provides crucial evidence that tDCS has a <b>significant and large antidepressant effect</b> in MDD. It also shows a <b>promising, though not fully significant, trend for improving verbal memory</b> , suggesting dimension-specific cognitive benefits. No significant effects were found for global cognition, other cognitive domains, or adverse event rates compared to sham. |

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| 15 | Ibrahim et al. (2024) | 6 Studies (147 participants) | <b>Systematic Review &amp; Meta-Analysis</b> — Patients with Obsessive-Compulsive Disorder (OCD). | <b>Various protocol:</b> Primarily <b>Anode</b> over Left DLPFC; Other montages targeted the Orbitofrontal Cortex (OFC) and Supplementary Motor Area (SMA); <b>Intensity:</b> 1.5-2 mA; <b>Duration:</b> 20-30 min/session; <b>Sessions:</b> varied. | <b>•OCD symptom severity</b> (Yale-Brown Obsessive Compulsive Scale - Y-BOCS). | <ul style="list-style-type: none"><li>• Random-effects and fixed-effect models</li><li>• Mean Difference (MD)</li><li>• I<sup>2</sup> for heterogeneity</li><li>• Sensitivity analysis</li></ul> | <b>Mean Difference (MD):</b> Active vs. Sham tDCS: MD = -1.13, 95% CI [-5.35, 3.10] ( <b>not significant</b> ). <b>Pre-Post tDCS:</b> MD = 7.89, 95% CI [4.40, 11.38] ( <b>large</b> ). <b>Heterogeneity:</b> I <sup>2</sup> = 70% for active vs. sham comparison ( <b>large</b> ). | This meta-analysis <b>did not demonstrate a significant superiority of active tDCS over sham tDCS</b> for reducing OCD symptoms. While symptoms improved significantly from baseline after tDCS, the change was not significantly different from the sham intervention. Findings were limited by <b>significant heterogeneity</b> and <b>small number of included studies</b> , indicating that the evidence for tDCS |
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|    |                    |                                                                   |                                                                                                     |                                                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                                 |                                                                                                                                     | as an effective treatment for OCD is currently inconclusive.                                                                                                                                                                                                                                                                          |
| 16 | Saha et al. (2024) | 23 studies (495 participants; N=284 active tDCS; N=211 sham tDCS) | <b>Systematic Review &amp; Meta-Analysis</b> — Individuals with Methamphetamine Use Disorder (MUD). | <b>Various protocols:</b> Primarily <b>Anode</b> over Left DLPFC (F3) or Right DLPFC (F4); <b>Cathode</b> over contralateral DLPFC or supraorbital region; <b>Intensity:</b> 2 mA; <b>Duration:</b> 20 min; <b>Sessions:</b> 1 to 20 sessions | <ul style="list-style-type: none"> <li>•<b>Craving</b> (momentary and cue-induced)</li> <li>•<b>Cognitive functions</b> (working memory, cognitive flexibility, decision-making, inhibition)</li> <li>•<b>Affective states</b> (anxiety, depression).</li> </ul> | <ul style="list-style-type: none"> <li>• Random-effects meta-analysis</li> <li>• Standardized Mean Difference (SMD; Hedge's <math>g^*</math>)</li> <li>• <math>I^2</math> statistic for heterogeneity</li> <li>• Cochrane Risk-of-Bias Tool (RoB-2)</li> <li>• Comprehensive Meta-Analysis Software.</li> </ul> | <b>SMD (Hedges' <math>g^*</math>) = -0.64</b> (95% CI: -0.85 to -0.30) — A <b>medium to large</b> effect size for reducing craving. | tDCS demonstrated a significant, medium-to-large effect in <b>reducing craving</b> in individuals with MUD. Stimulation of the <b>right DLPFC</b> may be more effective than the left. Effects on cognitive functions were inconsistent across studies due to methodological heterogeneity, varied protocols, and small sample sizes. |

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| 17 | Asadipour et al. (2024) | 30 participants (N=15 active tDCS; N=15 sham tDCS) | <b>Semi-experimental, pre-test/post-test with 2-week follow-up</b> / Patients (aged 18-50) diagnosed with migraine by a neurologist. | <b>Protocol:</b> <b>Anode</b> over Central lobe (Cz); <b>Cathode</b> over Visual Cortex (Oz); <b>Intensity:</b> 2 mA; <b>Duration:</b> 20 min/session; <b>Sessions:</b> 5 sessions (with 48-hour intervals). | <b>•Headache Signs</b> (Ahvaz Migraine Questionnaire -AMQ); <b>•Sleep Quality</b> (Pittsburgh Sleep Quality Index-PSQI) | <ul style="list-style-type: none"> <li>• Analysis of Covariance (ANCOVA)</li> <li>• Paired t-test</li> </ul> | <b>Partial Eta Squared (<math>\eta^2</math>):</b> Headache Signs: 0.851 ( <b>Large</b> ); Sleep Quality Total: 0.502 ( <b>Large</b> ); Mental Sleep Quality: 0.328 ( <b>Large</b> ); Sleep Delay: 0.241 ( <b>Large</b> ); Sleep Duration: 0.229 ( <b>Large</b> ); Enough Sleep: 0.196 ( <b>Large</b> ); Sleep Disturbance: 0.235 ( <b>Large</b> ); Use of sleeping pills: 0.132 ( <b>Medium</b> ); Daily dysfunction: 0.095 ( <b>Medium</b> ). | <b>Active tDCS was significantly more effective than sham stimulation</b> in reducing headache signs and improving overall sleep quality in migraine patients. The treatment effects were large and <b>maintained at the 2-week follow-up</b> . Significant improvements were also seen in specific sleep components (subjective quality, sleep latency, duration, adequacy, and disturbances). <b>No significant effect</b> was |
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|    |                             |                                                     |                                                                                                                                               |                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                   |                                                                                                                                                                                                                                                            | found for the use of sleeping pills or daily dysfunction, which showed medium effect sizes.                                                                                                                                                                                                         |
| 18 | Mohajeri Aval et al. (2024) | 45 participants (N=15 MCT; N=15 Tdcs; N=15 control) | <b>Semi-experimental</b> , pre-test/post-test with control group** — Patients (aged 18-50) diagnosed with Generalized Anxiety Disorder (GAD). | <b>Protocol:</b> Anode over Left DLPFC (F3); <b>Cathode</b> over Right DLPFC (F4); <b>Intensity:</b> 2 mA; <b>Duration:</b> 20 min/session; <b>Sessions:</b> 15 sessions (3 times/week). | <ul style="list-style-type: none"> <li>• <b>Experiential Avoidance</b> (Acceptance and Action Questionnaire -II - AAQ-II);</li> <li>• <b>Negative Strategies of Cognitive Emotion Regulation</b> (Cognitive Emotion Regulation Questionnaire -- CERQ)</li> <li>• <b>Emotional Processing</b> (Emotional Processing Scale – EPS)</li> </ul> | <ul style="list-style-type: none"> <li>• Multivariate Analysis of Covariance (MANCOVA)</li> <li>• Post-hoc Tukey test.</li> </ul> | <b>Partial Eta Squared (<math>\eta^2</math>):</b> Experiential Avoidance ( $\eta^2=0.744$ ; <b>Large</b> ); Negative Strategies of Cognitive Emotion Regulation ( $\eta^2=0.824$ ; <b>Large</b> ); Emotional Processing ( $\eta^2=0.931$ ; <b>Large</b> ). | <b>Both tDCS (anodal left DLPFC/cathodal right DLPFC) and Mindfulness Meta-Cognitive Therapy (MCT) were effective</b> in improving experiential avoidance, negative cognitive emotion regulation strategies, and emotional processing in patients with GAD compared to the control group. <b>Ho</b> |

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|    |                      |                              |                                           |                                           |                                      |                              |                                              | <p>wever, only MCT showed a significant advantage over tDCS in reducing rumination, a specific negative cognitive strategy. For other variables, no significant difference was found between the two active treatments. The study concludes that MCT may be superior for specifically targeting maladaptive cognitive regulation strategies like rumination.</p> |
| 19 | Hervik et al. (2024) | 40 participants (N=20 active | Randomized, double-blind, sham-controlled | Protocol: Anode over Primary Motor Cortex | •Daily function (Migraine Disability | • Linear mixed-effects model | Mean Difference (Active - Sham): MIDAS Post- | Active tDCS over the primary motor                                                                                                                                                                                                                                                                                                                               |

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|    |                               | tDCS, N=20 sham tDCS)  | <b>trial</b> — Patients (aged 18-70) diagnosed with primary chronic headache. | (M1); <b>Cathode</b> over Contralateral supraorbital area; <b>Intensity</b> : 2 mA; <b>Duration</b> : 30 min/session; <b>Sessions</b> : 8 sessions over 4 weeks. | Assessment-MIDAS)<br>• <b>Pain severity</b> (Visual Analog Scale-VAS)<br>• <b>Medication Use</b> | • Intention-to-treat analysis. | Treatment: - 3.24; MIDAS 3-Month: - 3.83; VAS Post-Treatment: - 2.76; VAS 3-Month: - 2.27. <b>Calculated Cohen's *d* (approx.):</b> MIDAS Post-Treatment: ~0.64 ( <b>Medium</b> ); VAS Post-Treatment: ~1.17 ( <b>Large</b> ). | <b>cortex was significantly more effective than sham stimulation</b> in improving daily function and reducing pain levels in patients with chronic headaches. The therapeutic effects were <b>sustained at the 3-month follow-up</b> . <b>No significant changes in medication use</b> were observed in either group. The intervention was safe, with only mild and transient adverse effects reported. |
| 20 | Erfa<br>nma<br>nesh<br>et al. | 30 participants (N=15) | <b>Quasi-experimental</b> , pretest-posttest                                  | <b>Protocol:</b> Anode over Left DLPFC (F3); <b>Cathode</b>                                                                                                      | • <b>Impulsivity</b> (Barratt Impulsiveness Scale-BIS)                                           | • Analysis of Covarian         | <b>Partial Eta-Squared (<math>\eta^2</math>)</b> Impulsivity:                                                                                                                                                                  | tDCS was <b>significantly effective</b> in                                                                                                                                                                                                                                                                                                                                                              |

|    |                       |                                        |                                                                                            |                                                                                                                           |                                                                                            |                                                                             |                                                                                         |                                                                                                                                                                                                                                                                                                                       |
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|    | (2024)                | active tDCS; N=15 control)             | control group design-<br>- Patients (aged 30-50) with Paranoid Personality Disorder (PPD). | <b>de</b> over Right DLPFC (F4); <b>Intensity:</b> 1-2 mA; <b>Duration:</b> 20 min/session; <b>Sessions:</b> 10 sessions. | • <b>Anxiety</b> (Beck Anxiety Inventory-BAI).                                             | ce (ANCOVA)<br>• Shapiro-Wilk test<br>• Paired t-test<br>• Chi-square test. | $\eta^2 = 0.96$ ( <b>Very Large</b> )<br>Anxiety: $\eta^2 = 0.92$ ( <b>Very Large</b> ) | improving impulsivity and reducing anxiety in patients with Paranoid Personality Disorder (PPD) at the posttest stage. The intervention accounted for a very high proportion of the variance in the outcomes. It is recommended as a <b>complementary therapy</b> for addressing these psychological problems in PPD. |
| 21 | Mastari et al. (2023) | 4 studies (241 participants; N=18 TMS, | <b>Meta-analysis</b> of studies comparing tDCS and TMS in Patients with insomnia           | <b>Protocol:</b><br><b>Anode</b> over Left DLPFC (F3); <b>Cathode</b> over Right DLPFC                                    | • <b>Sleep quality</b> (Pittsburgh Sleep Quality Index-PSQI)<br><b>Lab-Measured Sleep:</b> | • Meta-analysis (WMD).<br>• Heterogeneity ( $I^2$ ).<br>• Risk of Bias      | TMS (PSQI): WMD = 2.29 ( <b>Large</b> )<br>tDCS (PSQI): WMD = 1.05                      | Both <b>TMS and tDCS</b> are effective for insomnia with depression                                                                                                                                                                                                                                                   |

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|    |                   | N=127<br>tDCS)                 | ia comorbid<br>with<br>depression.                                                                                      | (F4).<br><b>Duration:</b> 2<br>mA,<br><b>Sessions:</b> 10-<br>20 sessions<br>over 2-4<br>weeks.                                                                                                           | <ul style="list-style-type: none"> <li>• Time to fall asleep</li> <li>• Total time asleep</li> <li>• Light sleep stage</li> <li>• Dreaming sleep stage</li> <li>• Time until first dreaming sleep</li> </ul>                                                 | (RoB 2).<br>• Mann-Whitney U test (for group comparison).                                                                                                                 | ( <b>Medium</b> )                                                                                                                                                                                                                                                                                | vs. sham. But <b>no significant difference</b> in efficacy between TMS and tDCS was found. <b>tDCS</b> showed additional benefits in <b>objective sleep measures</b> (e.g., faster sleep onset, more deep sleep).          |
| 22 | Qiu et al. (2023) | 27 studies (1650 participants) | <b>Systematic Review &amp; Meta-Analysis</b> --- Healthy human adults from studies using emotion regulation (ER) tasks. | <b>Various protocols:</b> Primarily <b>Anode</b> over prefrontal regions (e.g., DLPFC, VLPFC); <b>Intensity:</b> 1-2.5 mA; <b>Duration:</b> 20-34 min/session; <b>Sessions:</b> Primarily single-session. | <ul style="list-style-type: none"> <li>• <b>Explicit ER</b> (down-regulation, up-regulation)</li> <li>• <b>Implicit ER;</b> measured via subjective experience (self-report) and Physiological response (e.g., skin conductance, pupil dilation).</li> </ul> | <ul style="list-style-type: none"> <li>• Random-effects meta-analysis (Hedges' g)</li> <li>• Moderator analysis</li> <li>• Cochrane Risk of Bias (ROB 2.0) too</li> </ul> | <b>Hedges' g:</b> <ul style="list-style-type: none"> <li>• Explicit ER (Subjective, Down-regulation): -0.20 (<b>Small</b>)</li> <li>• Explicit ER (Physiological, Down-regulation): -0.65 (<b>Medium to Large</b>)</li> <li>• Implicit ER (Physiological): -0.04 (<b>Negligible</b>).</li> </ul> | Excitatory tDCS over the PFC had a <b>significant positive effect on explicit emotion regulation</b> (especially down-regulation), but <b>no significant effect on implicit emotion regulation</b> . Effects were stronger |

|    |                               |                                                    |                                                                                                                                                      |                                                                                                                                                                                                               |                                                                                                                                             |                                                                                                     |                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                 |
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|    |                               |                                                    |                                                                                                                                                      |                                                                                                                                                                                                               |                                                                                                                                             |                                                                                                     |                                                                                                                                                                                                                                             | for <b>physiological responses</b> than subjective experience. The <b>right ventrolateral PFC (rVLPFC)</b> was identified as a particularly effective stimulation target. The findings support the use of neuromodulation for voluntary, but not automatic, emotion regulation. |
| 23 | Mot evali zadeh et al. (2022) | 32 participants (N=16 active tDCS; N=16 sham tDCS) | <b>Randomized, single-blind, sham-controlled trial</b> — Female patients (aged 18-55) with chronic insomnia recruited from a sleep disorders clinic. | <b>Protocol:</b><br>• <b>Active tDCS:</b> <b>Anode</b> over left primary motor cortex (M1); <b>Cathode</b> over right dorsolateral prefrontal cortex (rDLPFC); <b>Intensity:</b> 2 mA; <b>Duration:</b> 20-30 | • <b>Insomnia</b> (Insomnia Severity Index - ISI);<br>• <b>Positive and Negative Affect</b> (Positive and Negative Affect Schedule - PANAS) | • Descriptive Statistics<br>• Univariate Analysis of Covariance (ANCOVA)<br>• Multivariate Analysis | <b>Partial Eta-Squared (<math>\eta^2</math>):</b><br>• MANCOVA (Overall): $\eta^2 = 0.63$ ( <b>Large</b> )<br>• ANCOVA (ISI): $\eta^2 = 0.62$ ( <b>Large</b> )<br>• ANCOVA (Negative Affect): $\eta^2 = 0.42$ ( <b>Large</b> ).<br>• ANCOVA | A 12-session tDCS protocol with anodal stimulation of the left M1 and concurrent cathodal stimulation of the right DLPFC <b>significantly reduced insomnia</b>                                                                                                                  |

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|  |  |  |  | <p>min/session;<br/><b>Sessions:</b> 12 sessions in 3 weeks<br/>•<b>Sham tDCS:</b> Identical electrode placement and duration.</p> |  | <p>of<br/>Covariance (MANCOVA)<br/>• Levene's Test<br/>• Shapiro-Wilk Test<br/>• Box's M Test</p> | <p>(Positive Affect): <math>\eta^2 = 0.41</math> (<b>Large</b>).</p> | <p><b>severity and improved affective states</b> (decreased negative affect, increased positive affect) in women with chronic insomnia compared to the sham stimulation group. The results suggest that this novel dual-site montage, designed to simultaneously increase motor cortex excitability and inhibit right prefrontal hyperarousal, is <b>an effective therapeutic intervention for chronic insomnia and its</b></p> |
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|    |                        |                                                                       |                                                                                                                                   |                                                                                                                                                                                                                 |                                                                                                                                                                                                                                 |                                                                                                                                                                                                                           |                                                                                                                                                                                                                                   | comorbid affective symptoms.                                                                                                                                                                                |
| 24 | Guesse et al. (2021)   | 60 participants (N=30 active tDCS; N=30 control with no intervention) | <b>Semi-experimental</b> with pre-test, post-test, control group, and 2-month follow-up — Adults (30-60 years) with chronic pain. | <b>Protocol:</b> <b>Anode</b> over Left DLPFC (F3); <b>Cathode</b> over Right DLPFC (F4); <b>Intensity:</b> 1 mA; <b>Duration:</b> 20 min/session; <b>Sessions:</b> 12 sessions over 6 weeks.                   | <ul style="list-style-type: none"> <li>• <b>Depression</b> (Beck Depression Inventory-II; BDI-II);</li> <li>• <b>Anxiety</b> (Beck Anxiety Inventory – BAI)</li> <li>• <b>Pain</b> (McGill Pain Questionnaire – MPQ)</li> </ul> | <ul style="list-style-type: none"> <li>• Repeated Measures Analysis of Variance (ANOVA)</li> <li>• Bonferroni post-hoc test</li> <li>• Tests for homogeneity of variance (Levene's) and sphericity (Mauchly's)</li> </ul> | <b>Partial Eta Squared (<math>\eta^2</math>):</b> <ul style="list-style-type: none"> <li>• Depression: 0.16 (<b>medium</b>)</li> <li>• Anxiety: 0.24 (<b>large</b>)</li> <li>• Physical Symptoms: 0.13 (<b>medium</b>)</li> </ul> | <b>tDCS significantly reduced depression, anxiety, and physical symptoms</b> in patients with chronic pain compared to the control group. The therapeutic effects were maintained at the 2-month follow-up. |
| 25 | Mar dani et al. (2021) | 30 participants (N=15 tDCS + medication; N=15 medication)             | <b>Double-blinded randomized clinical trial</b> — Patients with Bipolar Disorder Type I (depressive phase).                       | <b>Protocol:</b> <b>Anode</b> over Right DLPFC (F4); <b>Cathode</b> over Left DLPFC (F3); <b>Intensity:</b> 2 mA; <b>Duration:</b> 20 min/session; <b>Sessions:</b> 2 sessions for 10 days (20 total sessions); | <ul style="list-style-type: none"> <li>• <b>Depression</b> (Hamilton Depression Rating Scale - HDRS)</li> <li>• <b>Response Inhibition</b> (Go/No-Go test: Commission Error, Omission Error, Response Time).</li> </ul>         | <ul style="list-style-type: none"> <li>• Univariate Analysis of Covariance (ANCOVA)</li> <li>• Repeated Measures Analysis of Variance (ANOVA)</li> </ul>                                                                  | <b>Partial <math>\eta^2</math>: 0.65</b> (for HDRS post-test between groups) — <b>Large.</b>                                                                                                                                      | <b>Combined tDCS + medication led to significantly greater reductions</b> in depressive symptoms and improvement in response inhibition (reduced commission errors)                                         |

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|    |                         |                                                    |                                                                                                                 | <b>Concurrent medication:</b> mood stabilizers (lithium, sodium valproate, carbamazepine).                                                                                                                            |                                                                                                                          | <ul style="list-style-type: none"> <li>• Independent t-test</li> <li>• Chi-square test</li> </ul>                                                          |                                                                                                                                                                                                                             | compared to medication alone post-treatment. However, these therapeutic gains were not maintained at the 3-month follow-up.                                                                                                                                        |
| 26 | Azmooodeh et al. (2021) | 30 participants (N=15 active tDCS; N=15 sham tDCS) | <b>Randomized clinical trial, pretest-posttest control group design</b> – Patients with temporal lobe epilepsy. | <b>Protocol:</b> Anode over F3 (left DLPFC); <b>Cathode</b> over F4 (right DLPFC); <b>Intensity:</b> 1.5 mA; <b>Duration:</b> 20 min/session; <b>Sessions:</b> 10 (5 daily sessions, and 5 every-other-day sessions). | <ul style="list-style-type: none"> <li>• <b>Psychological Profile:</b> Depression, Anxiety, Stress (DASS-21).</li> </ul> | <ul style="list-style-type: none"> <li>• Univariate Analysis of Covariance (ANCOVA)</li> <li>• Levene's test</li> <li>• Kolmogorov-Smirnov test</li> </ul> | <b>Partial Eta-squared (<math>\eta^2</math>):</b> <ul style="list-style-type: none"> <li>• Depression = 0.867 (<b>Large</b>)</li> <li>• Anxiety = 0.775 (<b>Large</b>)</li> <li>• Stress = 0.868 (<b>Large</b>).</li> </ul> | Active tDCS over the left DLPFC (anodal) and right DLPFC (cathodal) was <b>significantly more effective than the sham/control condition</b> in reducing scores of <b>depression, anxiety, and stress</b> in patients with temporal lobe epilepsy. The intervention |

|    |                  |                                                  |                                                                                                                                   |                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                  |                                                                                                                      |                                                                                                                                                                                                                                                |                                                                                                                                                                                                                |
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|    |                  |                                                  |                                                                                                                                   |                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                  |                                                                                                                      |                                                                                                                                                                                                                                                | n resulted in <b>large effect sizes</b> for all three outcome variables. The study concludes that tDCS is a useful and practical intervention to improve the psychological profile in this patient population. |
| 27 | Lu et al. (2021) | 43 participants (22 active tDCS; N=21 sham tDCS) | <b>Pilot study</b> , single-blinded, sham-controlled, randomized trial** --- Healthy undergraduates (mean age ~21), right-handed. | <b>Protocol:</b><br>• <b>Active tDCS:</b> Anode over F3 (left DLPFC); <b>Cathode</b> over 4 electrodes (AF3, F1, F5, FC3); <b>Intensity:</b> 1.5 mA; <b>Duration:</b> 20 min/session; <b>Sessions:</b> 9 sessions over 18 days.<br>• <b>Sham tDCS:</b> Identical | • <b>Executive functions:</b> Inhibitory Control (Stroop Test), Cognitive Flexibility (Shifting Attention Test - SAT), Working Memory (2-back Test).<br>• <b>Neural Correlate:</b> HbO concentration in bilateral DLPFC during Stroop test (measured via fNIRS). | • Independent samples t-test<br>• Repeated Measures Analysis of Variance (ANOVA)<br>• Bonferroni-adjusted contrasts. | <b>Partial Eta Squared (<math>\eta^2</math>):</b><br>• SAT (Group x Time interaction): 0.08 ( <b>Medium</b> )<br>• Right DLPFC HbO (Group x Time interaction): 0.10 ( <b>Medium</b> )<br>• 2-back (Main effect of Time): 0.56 ( <b>large</b> ) | Repeated anodal HD-tDCS over the left DLPFC was <b>significantly more effective than sham stimulation</b> in improving <b>cognitive flexibility</b> , with benefits emerging earlier (after the 5th            |

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|  |  |  |  | electrode placement and duration. |  |  |  | session). No significant between-group difference was found for working memory or behavioral measures of inhibitory control. f NIRS data indicated a significant reduction in Stroop-related neural effort (HbO) in the right DLPFC for the anodal group, suggesting improved neural efficiency. The study concludes that multiple HD-tDCS sessions are a promising intervention for enhancing |
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| 28 | Schroeder et al. (2020) | 45 studies (2668 participants) | <b>Meta-analysis</b> — Healthy adults and clinical populations (e.g., ADHD, depression, obesity) from single-session tDCS studies. | <b>Various protocols:</b> Primarily stimulating Right Inferior Frontal Gyrus (rIFG), right DLPFC (rDLPFC), pre-SMA.<br><b>Intensity:</b> 0.5–2.0 mA;<br><b>Electrode size:</b> 9–35 cm <sup>2</sup> ;<br><b>Sessions:</b> 1 session. | <ul style="list-style-type: none"> <li>• <b>Inhibitory control performance:</b> (Stop-Signal Task - SST); Go/No-Go Task - GNG)</li> </ul> | <ul style="list-style-type: none"> <li>• Random-effects meta-analysis (Hedges' <math>g^*</math>)</li> <li>• Moderator analysis (meta-regression)</li> <li>• Sensitivity analyses for publication bias (trim-and-fill, PET-PEESE)</li> <li>• Cochran's <math>Q</math> and <math>I^2</math> for heterogeneity</li> </ul> | <ul style="list-style-type: none"> <li>• <b>Primary Overall Effect:</b> Hedges' <math>g^* = 0.21</math> (SE = 0.046, 95% CI [0.14, 0.32]) (<b>Small but significant</b>)</li> <li>• <b>Subgroup by Task:</b> SST: <math>g^* = -0.33</math> (<b>Small and significant</b>); GNG: <math>g^* = 0.10</math> (n.s.) (<b>No overall effect</b>)</li> <li>• <b>After Bias Correction:</b> Trim-and-fill: <math>g^* = 0.11</math>; PET-PEESE: <math>g^* = 0.02</math> (n.s.), indicating the true effect is likely smaller.</li> </ul> | Single-session tDCS has a <b>small, significant overall effect</b> on improving inhibitory control, but this effect is highly dependent on protocol and task. Stimulation of the rIFG was more effective than rDLPFC. Effects were significant for the <b>Stop-Signal Task</b> but not the Go/No-Go Task. The overall effect was <b>not robust to correction</b> . |

|    |                   |                                                                            |                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                    |                                                                       |                                                                                  |                                                                                                                                                                                  | for publication bias, indicating that the true effect is likely smaller.                                                                                                                                                                                                                                                 |
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| 29 | Yoo et al. (2020) | 60 participants N=30 active tDCS + medication N=30 sham tDCS + medication) | <b>Randomized, double-blind, sham-controlled trial</b> — Patients (aged 18-60) with moderate to severe Obsessive-Compulsive Disorder (OCD) based on DSM-5 criteria. | <b>Protocol:</b><br>• <b>Active tDCS:</b> Anode over Left DLPFC Fp3); Cathode over Right Orbitofrontal Cortex (F8); <b>Intensity:</b> 2 mA; <b>Duration:</b> 20 min/session; <b>Sessions:</b> 24 sessions (3 times/week for 8 weeks)<br>• <b>Sham tDCS:</b> Identical electrode placement and duration.<br>• <b>Concurrent medication:</b> Fluoxetine (40 mg/day). | • <b>OCD severity</b> (Yale-Brown Obsessive Compulsive Scale, Y-BOCS) | • Mixed-design Repeated Measures Analysis of Variance (ANOVA)<br>• Cohen's $d^*$ | <b>Cohen's <math>d^*</math> (at final follow-up):</b><br>• Y-BOCS Total: 0.079 (Negligible)<br>• Y-BOCS Obsession: 0.029 (Negligible)<br>• Y-BOCS Compulsion: 0.119 (Negligible) | <b>Active tDCS as an add-on to fluoxetine was not superior to sham tDCS + fluoxetine</b> in reducing OCD symptoms. Both groups showed significant improvement over time, but there was no significant between-group difference. The tDCS protocol was safe and well-tolerated, with only minor, transient adverse events |

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|    |                              |                                         |                                                                                                                            |                                                                                                                                                  |                                                                                                                                                                                                                                                                                              |                                                                                                                                                                                                                                                                      |                                                          | (e.g., skin redness, irritation) reported in the active group.                                                                                                                                                                                                                                                                 |
| 30 | Kak o Joib ari et al. (2020) | 11 studies (not specified participants) | <b>Meta-analysis</b> — Systematic review and meta-analysis of studies on individuals with Mild Cognitive Impairment (MCI). | <b>Various protocols:</b> Primarily <b>Anode</b> over the left DLPFC. <b>Intensity:</b> 1-2 mA; <b>Duration</b> ~20 min; <b>Sessions:</b> varied | <ul style="list-style-type: none"> <li>• <b>Neurocognitive functions</b> (various cognitive domains including memory, attention, executive function measured by standard tools like Mini-Mental State Examination – MMSE; Clock Drawing Test – CDT; Word List Memory Test – WLMT)</li> </ul> | <ul style="list-style-type: none"> <li>• Funnel plots</li> <li>• Duval &amp; Tweedie trim-and-fill method</li> <li>• Q-test and <math>I^2</math> for heterogeneity</li> <li>• Hedges' g for overall effect size</li> <li>• Chi-square test for hypotheses</li> </ul> | Hedges' g = 0.26 (Random Effects Model) ( <b>Large</b> ) | The meta-analysis found a <b>large and significant overall effect</b> of tDCS on improving neurocognitive functions in people with MCI, confirming its effectiveness. Significant heterogeneity and publication bias were present and adjusted for. The result suggests tDCS is an effective intervention for this population. |

### Major Depressive Disorder and Depression Subtypes

Recent research into transcranial direct current stimulation (tDCS) has advanced our understanding of its application for major depressive disorder (MDD). Yachou et al. (2025) reviewed 29 studies with 1766 participants and reported significant antidepressant effects of tDCS. They reported that targeting the left dorsolateral prefrontal cortex (particularly Brodmann area 46) and frontopolar prefrontal and orbitofrontal cortices could be ideal for tDCS in treating depression. Another important finding was that individual differences in skull and brain anatomy may significantly change the electrical current in patients, leading to inconsistent results. Therefore, the authors recommend using personalized computer simulations to plan tDCS treatments for each patient, which could make the therapy more reliable and effective.

Wang et al. (2024) meta-analyzed 12 studies (with 371 participants) to see the effect of tDCS in patients with MDD. This meta-analysis found that active tDCS, compared to sham treatment, could significantly reduce depressive symptoms. However, no significant improvement was observed in overall global cognitive function following tDCS therapy. A marginal, near-significant benefit specifically in verbal memory performance, suggested a potential cognitive effect in that domain. No significant enhancements were detected in other cognitive areas, including executive function, attention, or working memory. The treatment was also shown to be safe, with no significant difference in adverse events between active and sham groups. The authors conclude that while tDCS is an effective antidepressant, its cognitive benefits appear limited and require further investigation through larger, more targeted trials.

Ren et al. (2025) examined 88 studies involving a total of 5,522 participants to assess the efficacy of various brain stimulation techniques in the treatment of depression subtypes. The findings showed that effectiveness differed across depression subtypes and stimulation methods. For major depression disorder (MDD), tES (transcranial electrical stimulation) was clearly effective. Also, tDCS (transcranial direct current stimulation) worked best for MDD when it was added to antidepressant medication. However, tDCS alone appeared to be more effective in patients whose depression co-occurred with other conditions, such as chronic pain or anxiety. Stronger benefits were observed in cases of depression accompanied by medical illnesses or other psychiatric disorders. In addition, combining tDCS with pharmacotherapy further improved outcomes in patients with depression comorbid with medical conditions (DMC) as well as those with comorbid psychiatric disorders (DPC). In contrast, a third method, tRNS (transcranial random noise stimulation) did not show clear benefits for reducing depressive symptoms. Current evidence suggests that tRNS may have limited effectiveness in targeting the underlying pathophysiological mechanisms of depression.

In a randomized clinical trial, Azmoodeh et al. (2021) compared the effects of active and sham tDCS on depression in 30 patients with temporal lobe epilepsy. The findings indicated that active tDCS was associated with a statistically significant reduction in depressive symptom severity compared to sham stimulation. Overall, the results support the potential efficacy of tDCS in alleviating depressive symptoms within this clinical population. Nevertheless, the lack of a follow-up assessment limits inferences regarding the persistence of the therapeutic effects.

Overall, these treatments were safe for most people. Side effects were usually mild (e.g., itching or headache), and very few people had to stop treatment, though there was a small risk of triggering overly energetic or manic feelings.

### **Obsessive-Compulsive Disorder**

Obsessive-compulsive disorder (OCD) is a common and disabling psychiatric condition that often shows partial resistance to pharmacological and psychotherapeutic treatments, leading researchers to explore novel neuromodulation approaches such as transcranial direct current stimulation (tDCS) as potential therapeutic alternatives. Rodriguez-Manrique et al. (2025) investigated how tDCS affects brain inhibition mechanisms in OCD. In a double-blind, randomized, sham-controlled design, tDCS was performed for 47 OCD patients while performing an inhibition task. Results showed that real stimulation, compared with sham, significantly improved inhibition performance, marked by more correct responses and faster reaction times. However, electric field strength and cortical thickness did not significantly mediate the performance enhancements.

In a systematic review and meta-analysis, Ibrahim et al. (2024) assessed the effectiveness of tDCS for treating obsessive-compulsive symptoms non-pharmacologically. Analyzing 6 empirical studies with 147 OCD patients of various ages, the pooled data indicated that active tDCS significantly ameliorated both symptoms severity. The greatest improvements were associated with anodal stimulation over the prefrontal or supplementary motor areas and cathodal placement over the orbitofrontal cortex, targeting circuits involved in inhibitory control. Effects were maintained for several weeks post-intervention, suggesting neuroplastic changes rather than transient modulation. The study concluded that tDCS is a safe, well-tolerated, and potentially effective adjunctive therapy for treatment-resistant OCD. However, the need for larger randomized controlled trials to confirm durability and optimal electrode parameters was emphasized.

In a double-blind, sham-controlled trial, Yoosefee et al. (2020) investigated tDCS as an add-on therapy to fluoxetine in 60 patients with moderate-to-severe OCD. Over an 8-week course of 24 sessions, both the active tDCS group and the sham control group showed a significant reduction in OCD symptoms. However, no significant difference was revealed in symptom improvement between the group receiving real tDCS plus fluoxetine, and the group receiving sham stimulation plus fluoxetine. The lack of a significant group effect or time-by-group interaction indicates that the added tDCS did not provide a clinical advantage over standard pharmacotherapy alone.

### **Schizophrenia**

Regarding schizophrenia, multiple studies have demonstrated promising therapeutic effects of transcranial direct current stimulation (tDCS) on cognitive functioning and symptomatology. Yao et al. (2025) performed a systematic review and meta-analysis on 11 randomized controlled trials involving 468 individuals with schizophrenia. It was manifested that tDCS significantly improved attention and working memory of schizophrenic patients. Furthermore, treatment regimens consisting of 15 sessions or administration twice daily were effective in reducing the overall severity of the disease. However, tDCS did not show a significant advantage over sham treatment for other

symptoms including general psychopathology, negative symptoms, and auditory hallucinations. The authors note that the evidence is still exploratory due to factors like high heterogeneity and potential publication bias among the included studies. They conclude that while tDCS is a promising non-pharmacological intervention, more standardized and larger trials are needed to confirm its efficacy.

In a double-blind, sham-controlled randomized trial, Schwippel et al. (2025) examined 28 participants with schizophrenia or schizoaffective disorder and found that anodal tDCS applied to the right dorsolateral prefrontal cortex (DLPFC) during adaptive working memory training significantly enhanced working memory performance during the training period, with some benefits persisting at follow-up assessments. The intervention was also associated with short-term transfer effects on broader cognitive performance; however, it did not produce significant improvements in clinical symptoms, depression, or quality of life. Overall, the findings suggest that tDCS may serve as a promising adjunct to cognitive training for ameliorating cognitive deficits in schizophrenia, particularly in the domain of working memory.

Shafiee-Kandjani et al. (2024) found significant reductions in negative and general symptoms of schizophrenia after 10 sessions of tDCS, although positive symptoms showed less consistent improvement. This experimental study investigated the effects tDCS on 30 patients with schizophrenia. While the authors suggest that the lack of effect on positive symptoms could be attributed to the low number of treatment sessions, they concluded that tDCS is a suitable therapeutic tool for treating the pathological symptoms of schizophrenia, particularly for negative symptoms.

### **Neurocognitive Functions**

Transcranial direct current stimulation (tDCS) has shown benefits in ameliorating neurocognitive impairments. In a meta-analysis on 19 studies with totally 945 participants, Prathum et al. (2025) reported that tDCS could improve global cognition in older adults with cognitive impairments, especially those with Alzheimer's disease. Optimal results were achieved with specific parameters, including a lower current density and stimulation targeting the temporal area. However, tDCS did not significantly enhance memory or executive function. The treatment was found to be safe, causing only minor side effects like tingling.

Afsharipoor et al. (2025) investigated the adjunctive effects of tDCS in 12 patients with traumatic brain injury (TBI), assessing working memory, planning, problem-solving, and selective attention. Their findings indicated that tDCS combined with occupational therapy was significantly more effective than occupational therapy alone in improving working memory, planning, and problem-solving while no significant between-group difference was observed for selective attention.

In a randomized, single-blind, sham-controlled pilot trial, Lu et al. (2021) evaluated the cognitive and neurofunctional effects of tDCS in 43 healthy undergraduates. This program lasted for 18 sessions and manifested significant enhancement in cognitive flexibility, with improvements emerging as early as the fifth session. However, no significant behavioral differences were observed for working memory or inhibitory control. These neuroimaging findings suggest that multiple sessions of tDCS can enhance specific executive functions by improving neural efficiency during cognitive tasks.

Kako Joibari et al. (2020) performed a meta-analysis on 11 studies and found that tDCS was an effective intervention for cognitive deficits. These deficits, which span key neurocognitive domains such as memory, executive function, complex attention, and language, were significantly improved following tDCS sessions. The effectiveness was particularly noted in enhancing episodic verbal memory and was influenced by stimulation region, treatment duration, and the number of sessions.

### **Anxiety**

Growing clinical interest has focused on the therapeutic efficacy of transcranial direct current stimulation (tDCS) in modulating neural circuits associated with anxiety. Gholipour Fallahy et al. (2025) studied 25 participants with generalized anxiety disorder (GAD) and found enhanced attention and auditory performance.

Mohajeri Aval et al., (2024) also confirmed the efficacy of tDCS for helping GAD patients. By studying 45 individuals with GAD, the authors found that both Mindfulness Meta-Cognitive Therapy (MCT) and tDCS were effective in reducing core symptoms. Specifically, both treatments significantly improved experiential avoidance and emotional processing in patients. However, a key difference emerged in managing rumination, a negative cognitive strategy, where only MCT demonstrated a significant effect. The results indicate that while both are viable treatments for GAD, MCT may be superior for specifically targeting persistent, repetitive negative thinking.

In a quasi-experimental study, Erfanmanesh et al. (2024) investigated the clinical efficacy tDCS for anxiety reduction in 15 patients diagnosed with Paranoid Personality Disorder (PPD). The therapeutic regimen consisted of 10 sessions of bilateral stimulation (anode over F3, cathode over F4). Following the intervention, a highly significant reduction in anxiety levels was revealed. These findings underscore the clinical utility of tDCS as a viable, high-impact neuromodulatory tool to alleviate anxiety in patients with PPD.

Qiu et al. (2023), in a systematic review and meta-analysis of 27 studies involving 1,650 healthy adults, reported that excitatory transcranial direct current stimulation (tDCS) over prefrontal cortical regions exerted a significant beneficial effect on explicit emotion regulation, particularly during the down-regulation of negative emotional responses. However, no significant effect was identified for implicit emotion regulation, suggesting that tDCS may be more effective in enhancing voluntary rather than automatic regulatory processes. The authors noted that since impaired emotion regulation is a central mechanism in the development and maintenance of anxiety symptoms, these findings provide meaningful support for the therapeutic potential of prefrontal tDCS in anxiety-related condition.

Based on a study of 30 patients with chronic pain, Gueserse et al., (2021) reported that brain stimulation by tDCS was effective for reducing anxiety. The intervention, which involved stimulating the posterior-lateral regions of both the left and right prefrontal cortex over 12 sessions, resulted in a statistically significant decrease in anxiety scores. This therapeutic effect was maintained at a two-month follow-up, indicating a sustained benefit.

### **Bipolar Disorder**

Accumulating evidence supports the clinical utility of transcranial direct current stimulation (tDCS) as an effective non-invasive intervention for helping people with

bipolar disorder (BD). Alizadehgoradel et al. (2024) reported as an effective and safe method for reducing depressive symptoms in BD patients. The treatment was shown to be effective both as a standalone therapy and as an add-on to medication, with benefits including not only mood improvement but also enhanced cognitive functions like attention and working memory. The main limitations identified across the literature were small sample sizes and a lack of long-term follow-up to assess the durability of the treatment effects.

In a clinical trial, Mardani et al. (2021) examined the effects of combining tDCS with medication therapy in patients with bipolar disorder type I. The results demonstrated that while both medication alone and combined therapy (medication + tDCS) reduced depressive symptoms, the combined approach led to significantly greater short-term improvement in depression and response inhibition. However, these benefits were not sustained at the three-month follow-up, suggesting the effects were not long-lasting. The study also found that medication alone did not significantly improve response inhibition. Limitations included a small sample size and the absence of a sham tDCS control group. Overall, the findings support tDCS as a potentially useful adjunctive short-term treatment for enhancing mood and cognitive control in bipolar disorder.

### **Substance/Medication Dependence**

Preliminary evidence suggests that transcranial direct current stimulation (tDCS) may have potential as a non-invasive adjunctive intervention for reducing craving in individuals with substance/medication dependence. In treating severe alcohol use disorder, Joshi et al. (2025) compared the effectiveness of active and sham transcranial direct current stimulation (tDCS). 75 participants of the active group who received 10 sessions of active bilateral tDCS (anode F3/cathode F4) over 5 days showed significantly greater reductions in alcohol craving compared to the sham group at both 1-month and 3-month follow-ups. The active tDCS group also had a substantially lower relapse rate, and took a longer time to their first drink post-treatment. Survival analysis confirmed a higher probability of sustained abstinence in the active treatment group. The intervention was well-tolerated with no reported side effects. The authors conclude that tDCS is a promising, safe adjunctive therapy for reducing craving and preventing relapse in severe alcohol dependence.

Hervik et al. (2024) conducted a randomized, double-blind, sham-controlled trial involving 40 patients with primary chronic headache to evaluate the efficacy of tDCS. Although the intervention yielded significant and sustained improvements in pain severity and daily functioning with medium-to-large effect sizes, the results indicated no significant reduction in medication use at the post-treatment or 3-month follow-up stages. These findings suggest that while tDCS is highly effective in alleviating clinical symptoms, its capacity to acutely disrupt established patterns of medication dependency in chronic headache populations may require more intensive or prolonged stimulation protocols.

Based on a systematic review and meta-analysis of 23 studies involving nearly 500 individuals with Methamphetamine Use Disorder (MUD), Sahaf et al., (2024) reported tDCS as an effective intervention for reducing cravings, demonstrating a medium to large effect size compared to sham treatments. However, the overall evidence was limited by

generally low-quality studies, small sample sizes, significant variability in tDCS protocols, and the use of inconsistent measurement scales for assessing cravings and cognitive functions. Consequently, while tDCS presented a promising non-pharmacological treatment for mitigating craving symptoms in MUD, the review underscored the critical need for larger, more standardized randomized controlled trials to firmly establish its efficacy and optimize protocol parameters.

### **Insomnia and Sleep Disorders**

The persistent challenges in managing insomnia and various sleep disorders have spurred the exploration of novel treatment modalities, with transcranial direct current stimulation (tDCS) showing promise as a non-invasive neuromodulatory technique to address the underlying neural mechanisms contributing to sleep disturbances. By performing a randomized controlled trial, Li et al. (2025) showed that targeting the dorsomedial prefrontal cortex (DMPFC) over 10 sessions through tDCS could effectively improve sleep quality and reduce sleep onset latency in patients with chronic insomnia.

Zhou et al. (2024) conducted a randomized double-blind controlled trial with 157 participants. They compared combined tDCS and repetitive transcranial magnetic stimulation (rTMS) against each treatment alone. The combined tDCS + rTMS therapy resulted in significant improvements of sleep quality, insomnia symptoms, and depression symptoms after 2 weeks of intervention, with these benefits persisting through 3 months of follow-up. No serious adverse events were reported, indicating a safe and promising augmentation strategy for chronic insomnia.

Complementing these findings, Motevalizadeh et al. (2024) conducted a 12-session tDCS protocol with 32 female participants experiencing chronic insomnia. In a comparison between active and sham conditions, the active tDCS group demonstrated a significant reduction in insomnia severity and improvements in affective states (decreased negative affect, increased positive affect), suggesting tDCS as a potentially effective intervention. In a meta-analysis, Mastari et al. (2023) synthesized data from 4 randomized controlled trials involving a total of 245 participants with insomnia comorbid with depression. The study concluded that both transcranial magnetic stimulation (TMS) and transcranial direct current stimulation (tDCS) were effective, non-invasive therapies that could significantly improve patients' subjective sleep quality compared to sham treatments. Furthermore, analysis of objective polysomnography data revealed that tDCS provided concrete benefits to sleep architecture, including reducing the time it took to fall asleep, increasing total sleep time, and boosting dreaming sleep stage. Albeit, the authors noted that these promising results were tempered by high variability between the individual studies and the small overall sample size, underscoring the need for more standardized, large-scale trials to confirm and refine the protocol.

### **Safety and Tolerability**

Increasing evidence suggests that transcranial direct current stimulation (tDCS) is a well-tolerated and safe neuromodulatory technique, with a favorable profile for long-term clinical application. Ren et al. (2025) reinforced this claim in their large-scale synthesis involving more than 5,500 participants; they reported favorable safety profiles across diverse applications, including in populations with medical and psychiatric comorbidities.

In a large dataset of home-administered tDCS sessions analyzed by Maravic da Silva et al. (2025), no severe adverse effects were reported despite the high frequency and prolonged use (up to 10 weeks), highlighting the feasibility and safety of remote, self-administered tDCS interventions. By analysis of 5 studies with 415 depressed patients, Moshfeghinia et al (2025) described tDCS as a noninvasive brain stimulation technique that offers a promising alternative for neuromodulation. The adverse effects were restricted to tolerable skin lesions, pain, burning sensations, increased sensitivity, redness, and mild headaches. This robust evidence was echoed in bipolar depression studies by Alizadehgoradel et al. (2024), where repeated tDCS treatments were well tolerated without serious adverse events, supporting its use as a safe adjunct to pharmacotherapy. Motevalizadeh et al. (2024) similarly reported no serious safety concerns among chronic insomnia patients undergoing up to 12 sessions of 2 mA tDCS, underscoring favorable tolerability in this population.

Collectively, these studies demonstrate that tDCS, when applied within standardized safety parameters, maintains an excellent safety profile characterized by minimal, transient side effects and no reports of lasting harm. This strong safety record enhances its appeal as a non-pharmacological neuromodulation modality suitable for adjunctive or standalone therapeutic use in insomnia, depression, migraine, and schizophrenia, among other conditions. The availability of home-based tDCS devices further expands access while maintaining safety under appropriate protocols and monitoring.

## Discussion

The synthesized evidence from this narrative review positions transcranial direct current stimulation (tDCS) as a versatile, low-risk, and clinically viable neuromodulatory tool. However, the transition of tDCS from a promising experimental intervention to a standardized clinical staple is hindered by a persistent dichotomy: high safety and mechanistic plausibility versus high inter-individual variability and clinical heterogeneity. Rather than viewing this variability as a failure of the technology, a critical appraisal of the literature suggests it is a predictable consequence of interactions between clinical phenotypes, stimulation parameters, and baseline neurophysiological states. To contextualize these interactions, this discussion will first critically evaluate the transdiagnostic and domain-specific efficacy of tDCS across affective, psychotic, and sleep disorders, as well as its boundary conditions in anxiety and obsessive-compulsive pathologies. Finally, it will address the clinical implications of home-based protocols and outline a strategic transition from standardized to personalized, model-guided neuromodulation.

### Synergistic and Transdiagnostic Efficacy in Affective Disorders

A key theme emerging from the literature is that tDCS rarely operates at peak efficacy as a standalone treatment; rather, its true clinical value lies in its adjunctive and synergistic potential. The meta-analytic findings of Ren et al. (2025) and Wang et al. (2024) demonstrate that co-administering tDCS alongside pharmacotherapy yields superior antidepressant outcomes compared to monotherapy. Mechanistically, this synergy is likely driven by activity-dependent neuroplasticity. While pharmacotherapy elevates synaptic monoamine levels or modulates receptor sensitivity, concurrent anodal tDCS depolarizes resting membrane potentials, lowering the threshold for long-term

potentiation (LTP) and upregulating brain-derived neurotrophic factor (BDNF) expression.

Furthermore, the transdiagnostic utility of tDCS in ameliorating depressive symptoms across distinct comorbid pathologies—ranging from neurological conditions like temporal lobe epilepsy (Azmoodeh et al., 2021) to acute perioperative distress (Li et al., 2025) and chronic somatic pain (Gueserse et al., 2021)—implies that left dorsolateral prefrontal cortex (DLPFC) stimulation modulates a core transdiagnostic node. The left DLPFC acts as a critical hub in the central executive network (CEN); restoring its activity likely enhances top-down cognitive control over hyperactive limbic structures (e.g., the amygdala), thereby alleviating affective dysregulation regardless of the primary diagnosis.

### **Dissociation of Cognitive, Negative, and Positive Symptoms in Psychosis**

The application of tDCS in schizophrenia highlights a critical dissociation between symptom domains, challenging the notion of tDCS as a broad-spectrum intervention. The meta-analysis by Yao et al. (2025) and the trial by Shafiee-Kandjani et al. (2024) consistently demonstrate that while prefrontal anodal tDCS yields large effect sizes in improving cognitive subdomains (specifically working memory and processing speed via tasks like the PASAT) and negative symptoms, it exerts negligible influence on positive symptoms or general psychopathology.

This selective efficacy can be explained by how different symptoms are mapped in the brain:

- **Cognitive and Negative Symptoms:** These symptoms (such as social withdrawal, lack of motivation, and attention deficits) are closely linked to underactivity in the front part of the brain (the prefrontal cortex). Anodal tDCS directly target this area, delivering a stimulating current that helps “wake up” these underactive brain networks.
- **Positive Symptoms:** Symptoms like hallucinations and delusions are driven by hyperactivity in deeper, subcortical regions of the brain that rely heavily on dopamine. Because these target networks are located deep beneath the surface, standard tDCS electrodes placed on the scalp cannot easily reach or influence them.

Furthermore, the dose-dependent response identified by Yao et al. (2025) (e.g., 15 sessions or twice-daily protocols) implies that repairing and reorganizing these highly disrupted brain networks in schizophrenia requires a much higher volume of stimulation than the standard, shorter protocols typically used for depression.

### **Sleep Architecture and Excitability Regulation**

The therapeutic reach of tDCS extends to sleep and circadian regulation, where it demonstrates both subjective and objective efficacy. The objective polysomnography data from Mastari et al. (2023) showing altered sleep architecture (reduced sleep onset latency and increased total sleep time) suggests that tDCS does not merely induce a placebo-mediated relaxation effect. Instead, frontal or sensorimotor cortex stimulation likely modulates slow-wave activity and stabilizes thalamocortical loops, which are critical for sleep initiation and maintenance. The finding by Asadipour et al. (2024) that visual cortex stimulation in migraineurs concurrently improves sleep quality supports a

network-level normalization model: by reducing cortical hyperexcitability and restoring sensory gating, tDCS mitigates the sensory overload that frequently disrupts sleep architecture.

### **Methodological Discrepancies and Boundary Conditions (Anxiety, Substance/medication dependency, and Obsessive-Compulsive Disorder)**

When moving beyond depression and schizophrenia, the literature reveals clear boundary conditions for tDCS efficacy, driven primarily by treatment dosage, network targets, and state-dependency.

- **Dose and Duration:** In anxiety disorders, the contrast between the positive neurophysiological outcomes observed in multi-session designs (Gholipour Fallahy et al., 2025) and the null findings of a single-session combined tDCS-mindfulness protocol (Momeniyan et al., 2024) highlights the limitations of acute stimulation. A single session may transiently alter cortical excitability, but it is insufficient to induce the structural synaptic changes necessary to sustain clinical anxiety reduction.
- **Cognitive Control vs. Circuit Pathology:** The consistent reduction in cravings observed in substance/medication dependency studies (Sahaf et al., 2024; Joshi et al., 2025) confirms that stimulating the DLPFC successfully strengthens the brain's voluntary control systems, helping patients suppress automated urges and cravings. Essentially, tDCS acts as an external boost to the prefrontal cortex, enhancing the patient's conscious ability to override subcortical reward-seeking signals. However, the clinical failure of standard tDCS to outperform sham in obsessive-compulsive disorder (OCD; Ibrahim et al., 2024) suggests that this conscious control pathway is not the primary issue in obsession-compulsion loops. Instead of a general control problem, OCD is caused by overactive, locked-in communication loops between the deep brain and the surface. Therefore, future treatments need to stimulate different areas—like the pre-supplementary motor area (pre-SMA) or the orbitofrontal cortex (OFC) —to directly calm down the specific brain pathways (CSTC circuits) that keep patients stuck in obsessive thoughts and behaviors.

### **Safety, Accessibility, and the Paradigm Shift to Home-Based Care**

A major strength of tDCS, corroborated across all reviewed trials, is its benign safety profile. The absence of serious adverse events—even during extended home-use applications (Maravic da Silva et al., 2025)—is a crucial clinical differentiator from other somatic treatments like Electroconvulsive Therapy (ECT) or Repetitive Transcranial Magnetic Stimulation (rTMS). This safety profile, combined with the low cost of the equipment, facilitates a paradigm shift toward remotely supervised, home-based tDCS. Transitioning to home-use protocols addresses one of the primary logistical barriers in neuromodulation: the patient burden of daily clinic visits. By facilitating high-adherence, multi-week protocols in the patient's natural environment, home-based tDCS increases the likelihood of achieving sustained clinical remission.

### **Conclusion**

Overall, the evidence reviewed in this article supports transcranial direct current stimulation (tDCS) as a safe, accessible, and clinically promising neuromodulation

technique across a range of psychiatric and neurocognitive conditions. Its therapeutic value appears to be most consistent not as a universal standalone intervention, but as a flexible adjunctive approach whose benefits depend on the specific disorder, symptom domain, and treatment context. The most robust findings were observed in depressive symptoms, negative and cognitive symptoms in schizophrenia, craving reduction in substance/medication dependency, and sleep-related outcomes, whereas effects remained less consistent in conditions such as obsessive-compulsive disorder and in positive psychotic symptoms. Evidence for bipolar disorder remains preliminary and should be interpreted with caution.

Importantly, the variability in outcomes across studies should not be understood simply as inconsistency, but as a reflection of the fact that tDCS effects are strongly shaped by stimulation parameters, cortical targets, and inter-individual neurobiological differences. In this sense, the current literature suggests that the future clinical value of tDCS will depend less on applying standardized protocols uniformly and more on refining targeted, mechanism-informed, and personalized treatment strategies. With continued methodological improvement, stronger protocol optimization, and integration into multimodal care models, tDCS holds meaningful potential to become a more precise and scalable therapeutic tool in psychiatric practice.

### **Limitations and the Path to Personalized Neuromodulation**

Despite the clinical efficacy, high safety profile, and accessibility of transcranial direct current stimulation (tDCS), the literature is heavily limited by methodological fragmentation and a lack of mechanistic personalization.

1. **Methodological Heterogeneity:** The wide variation in electrode size, current density, session timing, and sham parameters makes cross-study comparisons difficult and impedes the formulation of consensus clinical guidelines.
2. **Anatomical and Physiological Variability:** Standardized “one-size-fits-all” montages ignore critical individual differences. Variations in skull thickness, subcutaneous fat, cerebrospinal fluid distribution, and cortical folding dictate that the same externally applied current (e.g., 2 mA) yields vastly different electric field strengths at the cortical target in different patients.
3. **State-Dependency:** The baseline neural state during stimulation acts as a gatekeeper for tDCS effects. Stimulating a quiescent network versus an actively engaged network can lead to opposite plastic outcomes due to homeostatic plasticity mechanisms.

To address these limitations, the next generation of tDCS research must move away from trial-and-error clinical applications and transition toward:

- **Computational Electric Field Modeling:** Utilizing individualized MRI-based head models (e.g., SimNIBS) to adjust externally applied current intensity, ensuring a consistent electric field dose reaches the target pathology in every patient.
- **Biomarker-Guided Target Selection:** Integrating baseline EEG, functional connectivity (fMRI), or genetic profiling (such as BDNF Val66Met

polymorphism) to predict responders and match patients with optimal target sites.

- **Closed-Loop and Concurrent Paradigms:** Combining tDCS with active cognitive-behavioral tasks to steer neural plasticity toward specific, task-relevant networks rather than stimulating the brain in a resting state.

Finally, the scope of this review was restricted to English-language, peer-reviewed publications, which may introduce a degree of language and publication bias. By excluding unpublished findings (e.g., conference abstracts or grey literature) and non-English studies, the potential for an incomplete evidentiary landscape exists. Consequently, it is recommended that future research initiatives strive to incorporate more diverse linguistic sources and grey literature to broaden the evidentiary scope and provide an even more robust synthesis of the existing literature.

### Implications for Clinical Practice and Future Research

Transcranial direct current stimulation (tDCS) is a valuable, accessible adjunctive treatment for various psychiatric and cognitive conditions. Its ease of use and safety profile support wider adoption in clinical settings, especially when combined with medications or therapy to enhance patient outcomes. To maximize its benefits, future research should focus on standardizing stimulation protocols and personalizing treatments based on patient factors. Large, well-controlled trials are needed to establish long-term efficacy and understand response mechanisms. Additionally, expanding home-based and remotely supervised tDCS could improve treatment accessibility and adherence. Continued research and clinical integration of tDCS hold promise for advancing mental health care and cognitive rehabilitation.

### Conflict of interest

This study did not have any conflict of interest for the authors

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