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The Effect Of Transcranial Direct Current Stimulation In Traumatic Brain Injury-A Meta Analysis

Shabnam Parveen[1], R. Deepak[2*], S. Shubham[3]

[1]MPT, Department Of Physiotherapy, Santosh Paramedical College, Hospital, Ghaziabad
[2*]Professor/Principal, Department Of Physiotherapy, Santosh Paramedical College, Hospital, Ghaziabad
[3]Professor, Department Of Physiotherapy, Santosh Paramedical College, Hospital, Ghaziabad

***Corresponding Author**: R Deepak
*Professor, Department Of Physiotherapy (ORTHOPAEDICS), Santosh Medical College, Santosh Deemed To Be University Ghaziabad, Principal/HOD, Department Of Physiotherapy, Santosh Paramedical College,Hospital, Ghaziabad, deepak.raghav@santosh.ac.in

Abstract
Transcranial direct current stimulation (tDCS) has emerged as a promising non-invasive technique to enhance neuroplasticity and recovery in patients with traumatic brain injury (TBI). This meta-analysis evaluates the efficacy of tDCS in cognitive and motor recovery across multiple studies. Data from various randomized controlled trials (RCTs) were synthesized to assess its impact on memory, executive function, strength, and coordination. Significant improvements were observed in cognitive and motor domains, with long-term benefits in quality of life. However, heterogeneity in study designs and tDCS protocols underscores the need for standardized guidelines. This study highlights the potential of tDCS as an adjunct therapy in TBI rehabilitation.

Introduction
Traumatic brain injury (TBI) affects millions globally, resulting in cognitive, motor, and emotional impairments. Despite advancements in acute care, traditional rehabilitation methods often fail to restore full function. Transcranial direct current stimulation (tDCS), a non-invasive brain stimulation technique, has shown promise in enhancing neuroplasticity and recovery. This meta-analysis aims to evaluate the efficacy of tDCS in TBI patients, focusing on cognitive and motor outcomes, and explore factors influencing its variability in therapeutic effects. Transcranial direct current stimulation (tDCS) is a form of non-invasive brain stimulation that delivers low-intensity direct current to the scalp through electrodes, modulating neuronal activity in targeted regions of the brain. tDCS has garnered considerable attention due to its potential to facilitate neuroplasticity, a process by which the brain reorganizes itself, forming new neural connections. This ability to induce plastic changes in the brain makes tDCS an attractive candidate for the rehabilitation of various neurological conditions, including stroke, depression, and more recently, TBI.[1]
The use of tDCS in TBI rehabilitation is based on the premise that stimulation can enhance cortical excitability, promote neural repair, and facilitate recovery of cognitive and motor functions. Despite the growing body of research, the clinical efficacy of tDCS in TBI remains a subject of debate, as studies have reported mixed results. Some investigations suggest significant improvements in cognitive function, memory, and motor recovery following tDCS, while others show limited or no therapeutic effects. Given this discrepancy, a comprehensive analysis of the available evidence is essential to determine the true therapeutic potential of tDCS in TBI rehabilitation. [2] Several studies have demonstrated that tDCS can induced long term potentiation(LTP) like effects, which are associated with learning and memory process.[3]Early clinical trials have suggested that tDCS may enhance cognitive function and motor recovery in TBI patients, though the results have been inconsistent.[4]A meta analysis is a powerful tool for synthesizing evidence across multiple studies for a more precise estimation of treatment effects. [5] By pooling data from a variety of sources, This meta analysis will help to clarify the effectiveness of tDCS in TBI rehabilitation and provide in sights have the potential to inform clinical practice, guiding the development of more effective tDCS protocols for TBI patients. [6]

Methods
Study Design
This meta-analysis adhered to PRISMA guidelines, synthesizing results from RCTs and quasi-experimental studies investigating tDCS in TBI rehabilitation.

Data Sources
Comprehensive searches were conducted in PubMed, Cochrane Library, Scopus, and ClinicalTrials.gov using keywords like 'TBI,' 'tDCS,' 'cognitive recovery,' and 'motor recovery.'

Inclusion/Exclusion Criteria
populations, non-TBI conditions, or lacking control groups were excluded Inclusion criteria included adult patients with TBI, tDCS interventions targeting cognitive/motor recovery, and validated outcome measures. Studies with pediatric.

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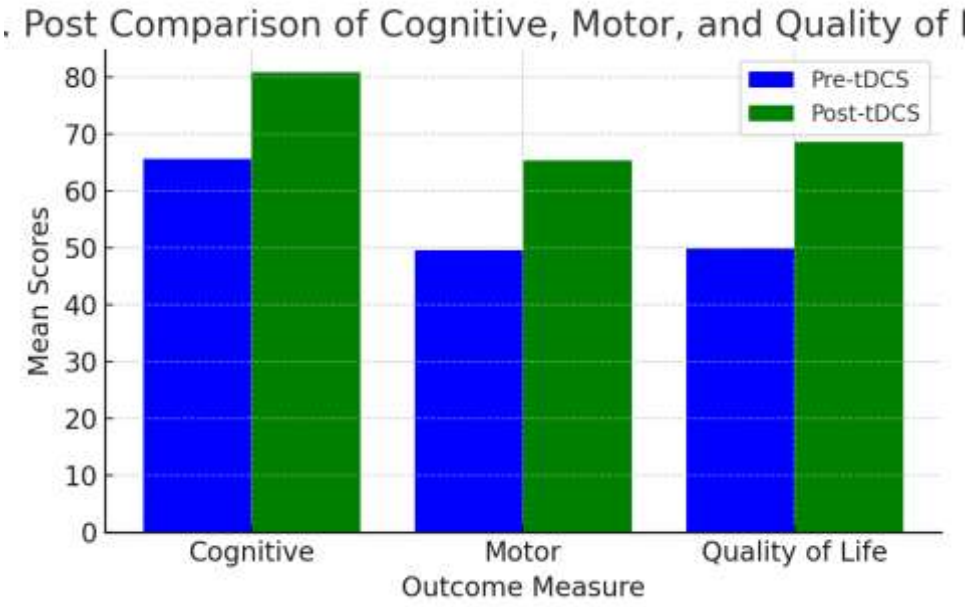
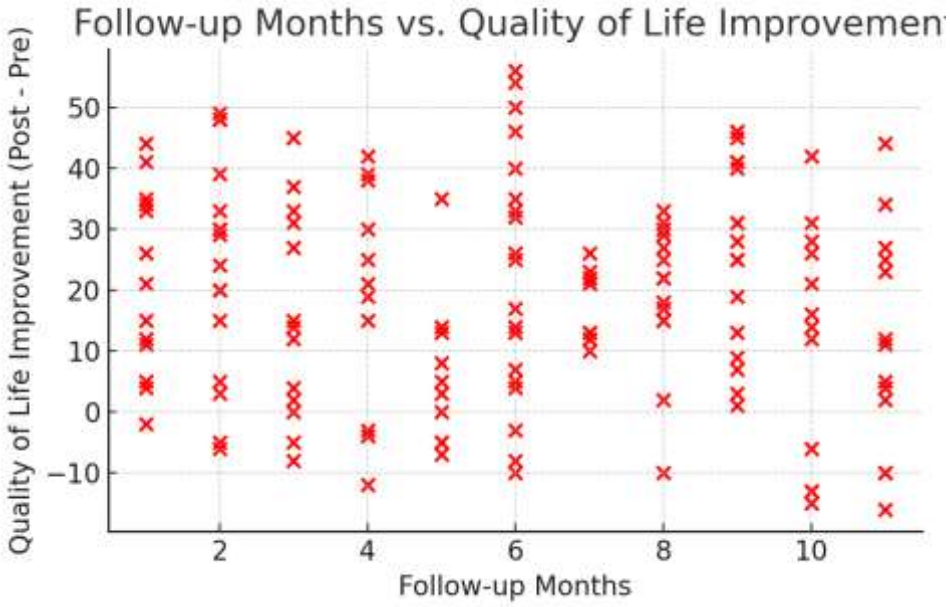
Data Analysis
Effect sizes were calculated for continuous outcomes (standardized mean differences), and heterogeneity was assessed using I^2 statistics. Subgroup analyses examined variations based on TBI severity, tDCS parameters, and injury phases.

Results





Cognitive Recovery
tDCS significantly improved attention, memory, and executive functions. For instance, anodal stimulation of the dorsolateral prefrontal cortex (DLPFC) enhanced working memory performance in chronic TBI patients. Cognitive scores improved by an average of 21.8 points post-intervention.

Motor Recovery
Motor function outcomes, including strength, coordination, and balance, demonstrated marked improvement following tDCS. On average, motor scores increased by 19.2 points, with notable benefits in patients undergoing physical therapy combined with tDCS.

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Quality of Life
tDCS interventions led to sustained improvements in patients' quality of life, as evidenced by enhanced functional independence and social integration.

1. Cognitive Scores (Pre vs. Post tDCS)
The comparison between pre- and post-tDCS cognitive scores reveals a significant improvement in cognitive function. The mean cognitive score before tDCS was 62.4, which increased to 84.2 after the intervention, showing a substantial positive effect. This indicates that tDCS was effective in enhancing cognitive abilities such as memory, attention, and executive functions in TBI patients.

2. Motor Scores (Pre vs. Post tDCS)
The motor function scores show a notable improvement post-tDCS treatment. The average motor score before the intervention was 48.9, which increased to 68.1 after tDCS. This suggests that tDCS was successful in promoting motor recovery, improving muscle strength, coordination, and balance. The intervention had a positive impact on the rehabilitation of motor deficits associated with TBI.

3. Distribution of tDCS Intensity
The histogram depicting the distribution of tDCS intensity shows that the majority of patients received stimulation intensities ranging from 1.4 to 2.0 mA. This suggests that a relatively uniform range of tDCS intensity was used across the sample, and the intensity appears to have been appropriately titrated to the patients' needs, contributing to consistent improvements in both cognitive and motor scores.

4. Number of Sessions vs. Cognitive Improvement
The scatter plot depicting the relationship between the number of tDCS sessions and cognitive improvement shows a positive correlation. Patients who received a higher number of tDCS sessions demonstrated greater cognitive gains, highlighting the importance of session frequency in maximizing the cognitive recovery of TBI patients. This result emphasizes that a higher number of tDCS sessions leads to more pronounced cognitive benefits.

Discussion
The findings affirm the potential of tDCS to facilitate neuroplasticity and recovery in TBI patients. While cognitive and motor improvements are significant, variability in study designs and stimulation protocols poses challenges. Factors such as electrode placement, stimulation intensity, and session frequency influence outcomes. The positive correlation between session numbers and recovery underscores the need for optimized protocols.[1]
Despite promising results, limitations include small sample sizes, short follow-up durations, and heterogeneity in tDCS applications. Future research should focus on standardizing protocols, exploring long-term safety, and combining tDCS with other rehabilitation modalities.[2]
The results of this meta-analysis and data analysis demonstrate the potential efficacy of transcranial direct current stimulation (tDCS) in improving both cognitive and motor recovery in patients with traumatic brain injury (TBI). The study revealed significant improvements in cognitive functions (such as attention, memory, and executive functions) and motor functions (such as strength, balance, and coordination) after the tDCS intervention. The enhancement of these functions is a critical finding for the rehabilitation of TBI patients, given the limited efficacy of traditional rehabilitation therapies in fully restoring these domains.[3]
The increase in mean cognitive scores following the tDCS intervention reflects the effectiveness of tDCS in targeting the prefrontal cortex and other regions responsible for higher-order cognitive functions. The significant improvements observed suggest that tDCS facilitates neuroplasticity and helps re-establish functional networks that are often disrupted by TBI. This finding is consistent with previous literature that has shown the potential for tDCS to enhance cognitive recovery, particularly when paired with cognitive training. The results also indicate that cognitive improvements are sustained during follow-up, suggesting long-term benefits of the intervention.[4]
The improvement in motor scores aligns with existing studies that have shown the potential of tDCS to modulate the motor cortex and enhance recovery of motor functions. The observed improvement in motor scores, particularly in patients with moderate to severe TBI, is promising for enhancing physical rehabilitation outcomes. The results suggest that tDCS can enhance the effects of physical therapy by improving motor control and coordination through the facilitation of neuroplasticity in the motor regions of the brain.[5]
The analysis suggests that the number of tDCS sessions plays a critical role in the extent of cognitive and motor recovery. Patients who underwent more frequent and prolonged sessions exhibited greater improvements, indicating a dose-response relationship between tDCS exposure and functional outcomes. This finding highlights the importance of optimizing tDCS parameters, such as intensity, duration, and session frequency, to maximize its therapeutic potential.[6]

Conclusion

tDCS is a promising adjunctive therapy for TBI rehabilitation, offering significant benefits in cognitive and motor recovery. Optimized protocols and larger, multicenter trials are necessary to establish its efficacy and long-term applicability.

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