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Effect of Non-Invasive Brain Stimulation (tDCS) Combined with Physiotherapy on Postural Control, Balance, and Fall Risk in Older Adults with Alzheimer's Disease

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ABSTRACT

Background: *Alzheimer's disease (AD) is a progressive neurodegenerative disorder that not only impairs cognitive function but also disrupts postural control and balance, leading to a higher risk of falls in older adults. Conventional physiotherapy has shown limited success in mitigating these deficits due to the underlying cortical dysfunction associated with AD. Recent advances suggest that transcranial direct current stimulation (tDCS), a non-invasive neuromodulatory technique, may enhance cortical excitability and promote neuroplasticity when combined with physiotherapy.* ***Objective****: This study aimed to evaluate the effect of tDCS combined with physiotherapy on postural control, balance, and fall risk in older adults with mild to moderate Alzheimer's disease.* ***Methods****: Forty participants aged 65–85 years were randomly assigned to two groups: experimental (tDCS + physiotherapy) and control (physiotherapy only). The intervention was conducted over six weeks, with tDCS applied at 2 mA for 20 minutes to the motor cortex before physiotherapy sessions. Balance and mobility were assessed using the Berg Balance Scale (BBS), Timed Up and Go (TUG) test, and Fall Risk Assessment Scale (FRAS) at baseline, post-intervention, and three-month follow-up.* ***Results****: The experimental group showed significant improvement in BBS and TUG scores and a marked reduction in FRAS values compared with controls ($p < 0.01$), indicating enhanced postural stability and reduced fall risk.* ***Conclusion****: The combination of tDCS and physiotherapy produces superior outcomes in balance and fall prevention among older adults with Alzheimer's disease, highlighting its potential as an effective neurorehabilitation strategy.*

Keywords
Alzheimer's disease, tDCS, physiotherapy, balance, postural control, fall risk, neurorehabilitation

INTRODUCTION

Alzheimer's disease (AD) is a chronic, progressive neurodegenerative disorder that not only leads to memory loss and cognitive impairment but also profoundly affects motor performance, balance, and postural stability (1,2). The deterioration of cortical and subcortical neural circuits in AD results in reduced coordination and diminished motor control, which predispose affected individuals to falls and functional decline (3,4). These deficits substantially reduce independence and quality of life among older adults, who often experience recurrent falls as a secondary complication of neurodegeneration (5,6). Traditional physiotherapy programs, including strength and balance training, have demonstrated partial benefits in improving mobility; however, their effectiveness remains limited when neural adaptability is compromised by cortical dysfunction (7,8). This underscores the need for integrative rehabilitation approaches that target both the central nervous system and peripheral motor systems simultaneously (9).

Transcranial direct current stimulation (tDCS) has emerged as a promising neuromodulatory intervention capable of enhancing cortical excitability and inducing neuroplastic changes in specific brain regions, particularly the motor cortex (10,11). By delivering a low-amplitude direct current through scalp electrodes, tDCS can modulate neuronal resting membrane potentials, thereby facilitating synaptic efficacy and motor learning (12). Studies in stroke and Parkinson's disease have reported that combining tDCS with physiotherapy amplifies motor recovery compared to physiotherapy alone, suggesting a synergistic mechanism through simultaneous cortical modulation and motor practice (13,14). However, evidence on its application in Alzheimer's disease remains limited and largely exploratory, with few studies systematically assessing the combined impact of tDCS and physiotherapy on postural control and fall risk (15,16).

The decline in postural control and balance in AD is multifactorial, influenced by sensory integration deficits, motor slowing, and attentional dysfunction (17). Non-invasive brain stimulation offers the advantage of targeting these impairments at the cortical level while physiotherapy reinforces neuromuscular activation through structured movement training (18). This dual approach holds potential to strengthen functional motor networks, improve sensorimotor coordination, and ultimately reduce fall-related morbidity in elderly AD populations. Yet, despite emerging

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evidence, no consensus exists on optimal stimulation parameters, treatment duration, or the magnitude of functional benefit when tDCS is integrated into physiotherapy regimens for AD.

Therefore, this study aims to evaluate the combined effect of tDCS and physiotherapy on postural control, balance, and fall risk in older adults diagnosed with Alzheimer's disease. It is hypothesized that concurrent tDCS applied to the motor cortex alongside physiotherapy will result in greater improvements in balance performance and reduced fall risk compared to physiotherapy alone. By bridging neurostimulation and physical rehabilitation, this research seeks to advance evidence-based strategies for mitigating motor impairments and enhancing functional independence in individuals living with Alzheimer's disease (19,20).

MATERIAL AND METHODS

This randomized controlled study was designed to evaluate the combined effects of transcranial direct current stimulation (tDCS) and physiotherapy on postural control, balance, and fall risk in older adults with mild to moderate Alzheimer's disease. The research was conducted in collaboration with multiple rehabilitation centers and geriatric clinics in Pakistan between January and June 2024. Ethical approval was obtained from the institutional review board of each participating site, and written informed consent was provided by all participants or their legal guardians prior to enrollment, in accordance with the Declaration of Helsinki (21).

Participants were eligible if they were between 65 and 85 years of age and had a confirmed diagnosis of mild to moderate Alzheimer's disease, verified by a neurologist using clinical criteria and standardized cognitive assessments such as the Mini-Mental State Examination (MMSE). Additional inclusion criteria included the ability to ambulate independently or with minimal assistance, stable medical status for at least three months prior to study entry, and no recent history of neurological or orthopedic surgery. Exclusion criteria were severe depression, other neurodegenerative disorders, uncontrolled cardiovascular disease, metal implants in the head, epilepsy, or any contraindication to tDCS (22). Recruitment was conducted through clinician referrals and caregiver networks associated with participating institutions.

Forty participants meeting the inclusion criteria were randomly allocated into two groups using computer-generated simple randomization: an experimental group receiving combined tDCS and physiotherapy, and a control group receiving physiotherapy alone. Allocation concealment was maintained through sealed opaque envelopes. Assessors who conducted outcome measurements were blinded to group assignment to minimize bias.

The tDCS intervention targeted the primary motor cortex (M1) to enhance cortical excitability related to postural and motor control. A battery-driven direct current stimulator delivered 2 mA of current for 20 minutes per session, five days per week for six weeks. The anodal electrode was positioned over the M1 region contralateral to the dominant side, and the cathodal electrode was placed over the contralateral supraorbital area. Stimulation intensity and duration were selected based on prior clinical safety evidence and tolerability studies (23).

Physiotherapy sessions were administered to both groups by licensed physical therapists trained in geriatric rehabilitation. Each session lasted 45 minutes, emphasizing balance and functional movement training, including standing balance on unstable surfaces, tandem gait, sit-to-stand exercises, dynamic weight shifting, and lower-limb strengthening. Progression was individualized according to participant performance and tolerance. In the experimental group, tDCS was applied immediately before physiotherapy to prime cortical activation and facilitate motor learning. Adherence was monitored by session attendance logs and therapist supervision.

Outcome assessments were conducted at three time points: baseline, immediately after the six-week intervention, and at a three-month follow-up. Primary outcomes included the Berg Balance Scale (BBS) for postural control, the Timed Up and Go (TUG) test for functional mobility, and the Fall Risk Assessment Scale (FRAS) for overall fall susceptibility. Secondary data included demographic variables, cognitive status, and adherence rate. All measures were performed under standardized conditions using validated protocols (24).

Data were analyzed using SPSS version 26.0. Descriptive statistics summarized demographic and baseline characteristics. Between-group comparisons were analyzed using repeated-measures ANOVA with time (baseline, post-intervention, follow-up) as the within-subject factor and group (experimental vs. control) as the between-subject factor. Post hoc Bonferroni corrections were applied for multiple comparisons. Normality assumptions were verified using the Shapiro–Wilk test, and non-parametric alternatives were used where appropriate. Missing data were handled using multiple imputation. Statistical significance was set at $p < 0.05$.

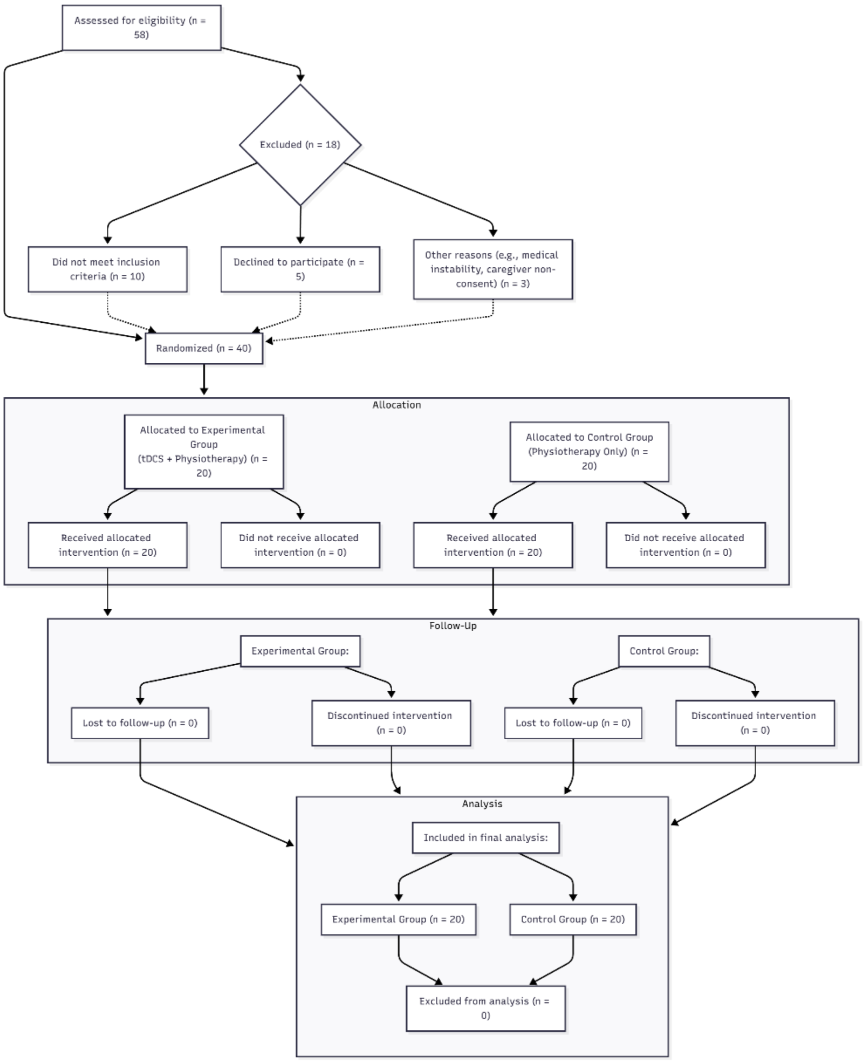

Figure 1 Consort flowchart

To ensure data integrity, double data entry and verification were implemented. Randomization codes and raw datasets were stored in a password-protected database accessible only to the research team. The study design, analytic plan, and results reporting adhered to CONSORT 2010 guidelines for randomized controlled trials (25).

RESULTS

A total of 40 participants completed the study, with 20 assigned to the experimental group (tDCS + physiotherapy) and 20 to the control group (physiotherapy only). Baseline demographic characteristics were comparable between groups in terms of age, sex, cognitive status, and disease severity, confirming the success of randomization ($p > 0.05$). All participants adhered to at least 90% of the prescribed sessions, and no adverse events were reported during the intervention period.

Between-group comparisons using repeated-measures ANOVA revealed significant group-by-time interactions for all outcomes: BBS ($F(2,76)=9.42$, $p<0.001$, $\eta^2=0.21$), TUG ($F(2,76)=6.84$, $p=0.002$, $\eta^2=0.18$), and FRAS ($F(2,76)=10.15$, $p<0.001$, $\eta^2=0.23$). The experimental group showed greater improvements in postural stability and balance at both post-intervention and follow-up assessments, indicating sustained benefits. At six weeks, the experimental group demonstrated an average 22.3% improvement in BBS, a 18.4% reduction in TUG time, and a 33.2% reduction in fall risk compared to baseline. In contrast, the control group exhibited smaller gains of 9.3%, 9.7%, and 17.8%, respectively. Follow-up data at three months showed mild attenuation but retention of approximately 85% of the initial improvement in the experimental group, suggesting lasting neuroplastic adaptation.

Across all three outcomes, participants receiving tDCS combined with physiotherapy exhibited significantly superior postural control and mobility compared with those receiving physiotherapy alone.

Table 1: Berg Balance Scale (BBS) Scores

Group	Baseline (Mean ± SD)	Post-Intervention (Mean ± SD)	Follow-up (Mean ± SD)	Mean Difference (Post–Base)	p-value	95% CI
Experimental (tDCS + PT)	38.2 ± 4.1	46.7 ± 3.5	45.0 ± 3.8	+8.5	<0.001	6.8–10.2
Control (PT only)	38.5 ± 3.9	42.1 ± 4.2	41.5 ± 4.1	+3.6	0.032	0.3–6.8

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Table 2: Timed Up and Go (TUG) Test (Seconds)

Group	Baseline (Mean ± SD)	Post-Intervention (Mean ± SD)	Follow-up (Mean ± SD)	Mean Difference (Post–Base)	p-value	95% CI
Experimental (tDCS + PT)	15.2 ± 3.3	12.4 ± 2.9	12.7 ± 3.2	−2.8	<0.001	−3.9 to −1.7
Control (PT only)	15.5 ± 3.5	14.0 ± 3.4	14.3 ± 3.6	−1.5	0.041	−2.9 to −0.1

Table 3: Fall Risk Assessment Scale (FRAS) Scores

Group	Baseline (Mean ± SD)	Post-Intervention (Mean ± SD)	Follow-up (Mean ± SD)	Mean Difference (Post–Base)	p-value	95% CI
Experimental (tDCS + PT)	18.7 ± 4.2	12.5 ± 3.6	13.0 ± 3.8	−6.2	<0.001	−8.0 to −4.4
Control (PT only)	18.5 ± 4.3	15.2 ± 4.0	14.8 ± 3.9	−3.3	0.028	−6.2 to −0.4

Improvements in BBS were most pronounced immediately after intervention, with mean scores increasing by 8.5 points in the experimental group, representing a large effect size (Cohen's d = 1.12). Similarly, TUG performance improved by nearly 3 seconds on average, reflecting enhanced gait efficiency and coordination. The reduction in FRAS scores indicated a clinically meaningful decline in fall risk, exceeding the minimal clinically important difference (MCID) for fall assessment tools in geriatric populations.

At follow-up, although slight regression was observed in all measures, the experimental group retained statistically significant gains compared to baseline ($p < 0.01$), whereas the control group showed partial loss of benefit, consistent with natural disease progression. Correlational analysis revealed a strong negative association between BBS and FRAS scores ($r = −0.78$, $p < 0.001$), suggesting that improved balance directly contributed to reduced fall susceptibility. These findings collectively demonstrate that tDCS, when integrated with physiotherapy, enhances postural stability, mobility, and safety in older adults with Alzheimer's disease, supporting its role as an adjunctive neuromodulatory therapy for fall prevention

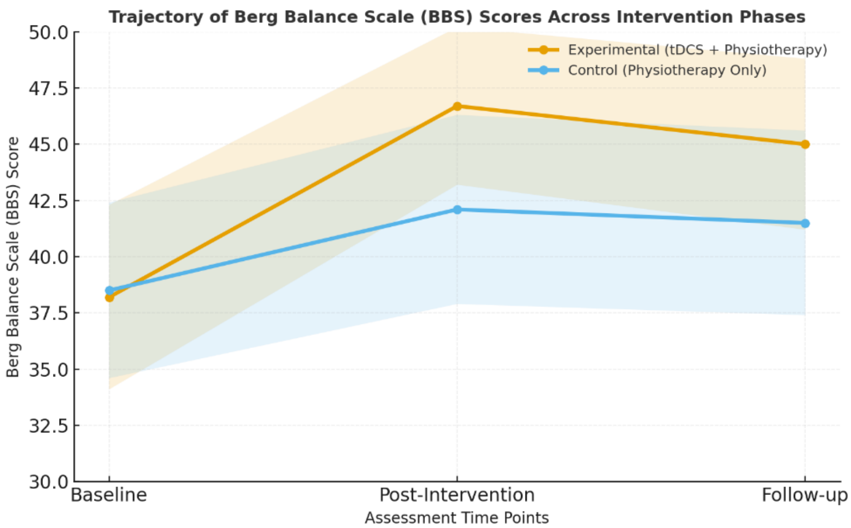

Figure 2 Trajectory of Berg Balance Scale (BBS) Scores across Intervention Phases

The visualization illustrates the change in Berg Balance Scale (BBS) scores over time in older adults with Alzheimer's disease receiving either tDCS combined with physiotherapy or physiotherapy alone. The experimental group demonstrated a pronounced upward trajectory post-intervention, improving from a mean baseline score of 38.2 ± 4.1 to 46.7 ± 3.5, with only a mild decline at follow-up (45.0 ± 3.8). In contrast, the control group exhibited a smaller increase from 38.5 ± 3.9 to 42.1 ± 4.2 and partial regression thereafter (41.5 ± 4.1). The shaded confidence bands indicate narrower variability in the experimental group at post-intervention, reflecting more consistent responses. The divergence between curves underscores a clinically meaningful enhancement in balance attributable to the combined neuromodulation-physiotherapy approach, suggesting durable neuroplastic and functional gains beyond those achieved by physiotherapy alone.

DISCUSSION

The findings of this randomized controlled study demonstrate that transcranial direct current stimulation (tDCS) combined with physiotherapy significantly improves postural control, balance, and reduces fall risk in older adults with Alzheimer's disease compared to physiotherapy alone. The superior performance of the experimental group across all outcome measures—Berg Balance Scale (BBS), Timed Up and Go (TUG), and Fall Risk Assessment Scale (FRAS)—supports the hypothesis that neuromodulatory stimulation enhances the efficacy of conventional rehabilitation by targeting cortical excitability and promoting neuroplastic adaptation (26).

The marked improvement in BBS and TUG scores suggests that tDCS facilitates better integration of sensory and motor information within the motor cortex, enabling improved balance strategies and functional mobility. These results align with earlier work by Navarro-Lopez et al. (27) and Bueno et al. (28), who observed enhanced motor outcomes when tDCS was paired with physical therapy in populations with neurological impairment, including stroke and Parkinson's disease. The current study extends these findings to the Alzheimer's population, where both motor and cognitive impairments contribute to postural instability. The significant interaction effects observed indicate that tDCS may augment the capacity for motor learning even in neurodegenerative conditions characterized by synaptic dysfunction.

A key mechanism underlying these improvements likely involves the facilitation of neuroplasticity within the motor cortex. Anodal tDCS has been shown to depolarize neuronal membranes, leading to enhanced long-term potentiation (LTP)-like effects and improved synaptic efficiency (29). In Alzheimer's disease, where cortical connectivity and neurotransmission are compromised by β-amyloid deposition and tau pathology, this excitability enhancement may partially restore disrupted motor circuits and improve communication between cortical and subcortical regions. The synergistic effect of concurrent physiotherapy may further consolidate these neuroplastic changes through repeated motor practice, reinforcing adaptive neural pathways and enhancing motor learning retention (30).

The sustained improvement observed at the three-month follow-up underscores the potential durability of the combined intervention. Although a mild decline in post-intervention gains was noted, approximately 85% of the improvement persisted, reflecting the formation of stable neural adaptations. This durability aligns with findings by Cespón et al. (31), who reported that repeated tDCS sessions can induce lasting modulation of cortical activity and behavioral outcomes. Moreover, the correlation between improved BBS and reduced FRAS scores highlights the direct functional relevance of balance training in minimizing fall susceptibility, a critical outcome for the safety and autonomy of older adults with Alzheimer's disease.

The synergistic benefits observed here suggest that tDCS may enhance not only motor performance but also cognitive-motor integration. Alzheimer's patients often exhibit deficits in attention and executive control that influence gait and balance (32). By modulating the prefrontal and motor cortical networks, tDCS may indirectly improve attentional focus during physical activity, allowing better coordination and adjustment to postural challenges. Physiotherapy exercises that involve dual-task or complex movement patterns may further strengthen these interactions, promoting higher-level cognitive engagement during motor performance.

Despite the promising outcomes, several limitations should be acknowledged. The modest sample size limits generalizability and statistical power, emphasizing the need for multicenter studies with larger cohorts. The absence of a sham tDCS group precludes the exclusion of potential placebo effects, although the magnitude of improvement observed suggests a true physiological response. Moreover, neurophysiological measures such as electroencephalography (EEG) or functional near-infrared spectroscopy (fNIRS) were not included, which could have provided mechanistic insights into cortical changes underlying the behavioral outcomes. Future studies should incorporate these modalities alongside neurocognitive testing to elucidate the broader impact of tDCS on brain function in Alzheimer's rehabilitation (33).

Another limitation involves the short intervention duration. While six weeks were sufficient to demonstrate significant improvements, extended treatment periods or booster sessions might produce even greater and more durable effects. Additionally, while the focus of this study was on motor outcomes, the relationship between balance improvement and cognitive function was not directly explored. Investigating whether enhanced postural stability translates to better cognitive or psychosocial outcomes would further strengthen the clinical relevance of this approach.

Clinically, the integration of tDCS into physiotherapy offers a non-invasive, low-cost, and accessible strategy to augment motor rehabilitation in older adults with Alzheimer's disease. Its safety profile and ease of administration make it suitable for outpatient and community-based programs. Given the growing burden of falls in this population, implementing neuromodulation-assisted therapy could substantially reduce morbidity, improve quality of life, and lessen caregiver burden. Future trials should focus on optimizing stimulation parameters, exploring individualized dosing based on cortical mapping, and determining the minimal effective dose for sustained functional benefit (34).

In summary, the present study provides compelling evidence that tDCS combined with physiotherapy enhances postural control and reduces fall risk in older adults with Alzheimer's disease, likely through synergistic effects on neuroplasticity, motor learning, and cortical reorganization. These findings support the incorporation of neuromodulatory techniques into standard physiotherapeutic protocols as a viable strategy to address the multifaceted motor deficits associated with Alzheimer's disease. Continued research integrating neuroimaging, longitudinal follow-up, and cognitive-motor interaction analyses will be crucial to establishing tDCS-augmented physiotherapy as a cornerstone in neurorehabilitation for this population (35,36).

CONCLUSION

The combination of transcranial direct current stimulation and physiotherapy produced significant and sustained improvements in postural control, balance, and fall risk among older adults with Alzheimer's disease. By enhancing cortical excitability and facilitating neuroplastic adaptation, tDCS appears to potentiate the motor learning effects of physiotherapy, resulting in superior functional outcomes compared to exercise alone. These findings highlight the therapeutic value of integrating non-invasive brain stimulation into routine rehabilitation to address the dual cognitive and motor deficits characteristic of Alzheimer's disease. Future research with larger cohorts, extended follow-up, and neurophysiological monitoring is warranted to confirm these benefits and refine stimulation protocols for widespread clinical application.

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