A randomised controlled study on the synergistic effects of neuroplasticity-based interventions for trunk control in post-stroke rehabilitation

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ABSTRACT

Introduction: Trunk impairment after a stroke is a common complication in hemiplegic patients. Neuroplasticity-driven interventions, such as trunk rehabilitation exercises (TRE) and transcranial direct current stimulation (tDCS), have shown potential to enhance trunk control, balance, and mobility. This study evaluates the individual and combined effects of TRE and tDCS on trunk function and mobility in post-stroke rehabilitation.

Materials and Methods: A randomised controlled study was conducted among post-ischaemic stroke survivors from a single medical institution. Participants (aged 24–85 years) with first-ever stroke of at least six months' duration, without a history of drug abuse or antidepressant use, with well-controlled comorbidities, and able to stand with minimal support were included. Exclusion criteria included recurrent stroke, fractures, amputations, or other neurological conditions affecting balance. Participants were randomly assigned to four groups: (1) control, (2) TRE, (3) tDCS, and (4) combined intervention (CI). Effectiveness was evaluated using the Trunk Impairment Scale, Postural Assessment Stroke Scale, and Rivermead Mobility Index, measured at baseline and after 8 weeks.

Results: Sixty-nine participants were enrolled and randomly assigned to four groups: control (n=18), TRE (n=17), tDCS (n=17), and CI (n=17). Although no statistically significant differences were observed across groups, the combined intervention group demonstrated higher improvement in Trunk Impairment Scale, Postural Assessment Stroke Scale, and Rivermead Mobility Index scores compared to single interventions or control.

Conclusion: The combination of TRE and tDCS may be a promising approach to enhance trunk control and mobility in post-stroke patients. Further research with larger sample sizes is recommended to confirm these findings.

KEYWORDS:
Neuroplasticity, trunk rehabilitation exercises, transcranial direct current stimulation, stroke rehabilitation, balance training

INTRODUCTION

Stroke, a condition characterised by the rapid onset of focal or global cerebral dysfunction due to vascular causes, remains a leading cause of long-term disability worldwide.[1,2,3] Approximately 70% of stroke survivors face significant dependence, while 30% require assistance with daily activities. Among the most debilitating complications is trunk impairment, which affects multiple systems involved in postural control, including strength, proprioception, range of motion, vision, vestibular function, and endurance.[3,4]

Recovery of trunk function is crucial for restoring balance and functional independence in stroke survivors.[5] Neural pathways from the premotor cortex and supplementary motor area modulate spinal circuitry, enabling anticipatory postural responses.6 However, damage to these areas or hyperexcitability of the premotor regions disrupts normal postural sequencing, leading to impaired coordination.[7,8] Such dysfunction is exacerbated by hyperexcitability of premotor regions, which inhibits normal spinal sequencing and delays postural recovery.[7]

Recent advances in rehabilitation emphasise neuroplasticity-driven interventions, such as task-specific exercises and non-invasive brain stimulation, including transcranial direct current stimulation (tDCS).[9-11] Task-specific exercises, including trunk rehabilitation exercises (TRE), fosters motor learning and neuroplasticity through goal-oriented, repetitive tasks, while tDCS modulates cortical excitability to enhance recovery.[9,12,13] A recent pilot study highlighted the potential of combined task-specific exercises and tDCS interventions in elevating serum brain-derived neurotrophic factor levels, a biomarker for neuroplasticity. The study demonstrated a significant increase in serum brain-derived neurotrophic factor levels in the combined intervention group, underscoring the synergistic effects of these therapies in promoting neuronal recovery.[14]

Despite promising findings in motor rehabilitation, research exploring these interventions' impact on trunk performance remains scarce. Combining tDCS with TRE may amplify therapy-induced recovery through synergistic effects. This study aims to evaluate the individual and combined effects of TRE and tDCS on trunk function, balance, and mobility, in

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post-stroke patients, addressing this critical gap in rehabilitation strategies.

MATERIALS AND METHODS

Study Design and Participants

The randomised controlled study was conducted at Imamu Wali General Hospital, Kano, Nigeria. Recruitment of participants was made from this single institution among post-ischaemic stroke survivors after ethical approval was obtained from the Health Research Ethics Committee of the Ministry of Health, Kano State of Nigeria (NHREC Approval No.: NHREC/17/03/2018). The health research ethics committee approval was issued on the 12th of April 2024. The trial protocol was also registered with the Pan African Clinical Trial Registry (Reg. ID: PACTR202408592508053) prior to commencement. Participants were eligible if they were aged 25–85 years, had experienced a first-ever stroke at least six months prior, and were able to stand with minimal or without support. Additional criteria included the absence of drug abuse, antidepressant use, or significant visual/auditory deficits, and well-controlled hypertension or diabetes. Exclusion criteria included recurrent stroke, fractures, amputations, or other neurological conditions affecting balance.

Recurrent stroke patients were excluded to ensure homogeneity of the study population and to reduce confounding factors. Individuals with multiple strokes often present with more complex neurological impairments, varying lesion locations, and different recovery trajectories, which may affect the outcome measures. Including only first-ever stroke survivors allowed for a more accurate assessment of the effects of the interventions on trunk control and mobility.

Sample Size Calculation

The sample size was determined using G*Power software version 3.1, based on an alpha level (α) of 0.05, statistical power of 0.80, and an effect size of 0.426, which yielded a minimum required sample of 68 participants. To account for a potential dropout rate of 10%, an additional seven participants were added (10% of 68 = 6.8, rounded to 7), resulting in a total estimated sample size of 75 participants.

Randomisation and Blinding

After providing written informed consent, participants were randomly assigned into four groups using Microsoft Excel's random number function: the control intervention group (control), the trunk rehabilitation exercises group (TRE), the transcranial direct current stimulation group (tDCS), and the combined TRE + tDCS intervention group (CI). Both the treating physiotherapists and laboratory scientists conducting assessments were blinded to the group allocations.

Procedure and Interventions

All participants received a standard 20-minute control intervention consisting of 5 minutes of infrared radiation therapy, followed by 15 minutes of proprioceptive neuromuscular facilitation exercises. These exercises were designed to target the neck, trunk, and scapular regions, following a cephalo-caudal sequence.

In the tDCS group, participants underwent the control intervention and received tDCS. The stimulation was delivered using the International 10-20% electroencephalography montage, applying a constant current for 20 minutes with anodal stimulation targeting the primary motor cortex. In the TRE group, participants performed selective trunk movements in supine and sitting positions for 30 minutes, as outlined by Karthikbabu et al.,[15] in addition to receiving the control intervention. These exercises were designed to improve trunk coordination and balance through goal-directed practice. The CI group received a sequential combination of therapies. This included 30 minutes of TRE, followed by 20 minutes of tDCS, and 20 minutes of the control intervention. A 5-minute rest period was observed between the TRE and tDCS sessions to prevent fatigue and ensure participant comfort.

The sequence of the combined intervention (CI group) was based on prior studies supporting the priming effect of task-specific movement on cortical excitability.[5,14] Initiating with TRE was intended to activate motor pathways and enhance cortical responsiveness to subsequent tDCS. The session concluded with proprioceptive-based control therapy to reinforce functional integration and consolidate motor learning.

All interventions were administered three times weekly over eight weeks. Baseline assessments of trunk control and functional mobility were conducted three days prior to the first intervention using the Postural Assessment Stroke Scale, Rivermead Mobility Index, and Trunk Impairment Scale. Procedures were explained to participants and caregivers, and clinical deficits were evaluated. Post-intervention assessments were conducted using the same standardised tools to monitor changes and assess improvements. All outcome assessments were conducted by two trained physiotherapists who were blinded to group allocation. To ensure consistency, each participant was assessed by the same physiotherapist for both pre- and post-intervention evaluations.

Statistical Analysis

Data were analysed using IBM SPSS version 23.0. Descriptive statistics, including frequencies, means, standard deviations (SD), and percentages, were used to summarize patient characteristics. The Shapiro-Wilk test was applied to assess the normality of continuous variables. Factorial ANOVA was conducted to evaluate the effects of the interventions on trunk control measures. If ANOVA indicated statistically significant differences among group means, Tukey's post hoc test was performed to identify specific group differences. The level of statistical significance for all analyses was set at $p < 0.05$.

RESULTS

A total of 72 post-ischaemic stroke patients were initially assessed for eligibility, but only 69 were recruited; three were excluded due to recurrent stroke. The mean age of the participants was 57.2 ± 11.83 years, with no significant differences across groups. Participants were randomly assigned to four groups, as described earlier (Figure 1). Table I summarises the demographic distribution across groups.

Table I: Socio-demographic characteristics of study participants (n = 69)

Characteristics	Intervention Groups				p-value
	Control (n = 18) n (%)	tDCS (n = 17) n (%)	TRE (n = 17) n (%)	CI (n = 17) n (%)	
Age (years)					0.785
25-44	0 (0)	0 (0)	0 (0)	0 (0)	
45-64	15 (83.3)	15 (88.2)	15 (88.2)	16 (94.1)	
65-85	3 (16.7)	2 (11.8)	2 (11.8)	1 (5.9)	
Mean ± SD	57.94 ± 5.84	58.94 ± 5.99	58.12 ± 5.81	56.94 ± 5.29	
Gender					0.689
Male	10 (55.6)	10 (58.8)	11 (64.7)	11 (64.7)	
Female	8 (44.4)	7 (41.2)	6 (35.3)	6 (35.3)	
Marital status					0.934
Single	5 (27.8)	4 (23.5)	5 (29.4)	5 (29.4)	
Married	11 (66.1)	11 (64.7)	9 (52.9)	9 (52.9)	
Divorced	0 (0)	0 (0)	0 (0)	0 (0)	
Widow	2 (11.1)	2 (11.8)	3 (17.6)	3 (17.6)	
Residence					0.377
Rural	13 (72.2)	9 (58.8)	10 (58.8)	10 (58.8)	
Urban					
5 (27.8)	8 (41.2)	7 (41.2)	7 (41.2)		
SBP (mmHg)					0.974
< 140	14 (77.8)	12 (70.6)	12 (70.6)	12 (70.6)	
≥ 140	4 (22.2)	5 (29.4)	5 (29.4)	5 (29.4)	
Mean ± SD	135.0 ± 11.8	134.35 ± 11.0	135.72 ± 5.9	134.35 ± 9.1	
DBP (mmHg)					0.704
< 90	15 (83.3)	14 (82.4)	13 (76.5)	12 (70.6)	
≥ 90	3 (16.7)	3 (17.6)	4 (23.5)	5 (29.4)	
Mean ± SD	80.47 ± 8.6	83.2 ± 6.1	81.0 ± 10.43	81.1 ± 8.2	

CI: combined intervention, DBP: diastolic blood pressure, SBP: systolic blood pressure, tDCS: transcranial direct current stimulation, TRE: trunk rehabilitation exercises.

Table II: Pre- and post-intervention assessments and the mean differences of outcome measures in the study groups

Outcomes measures	Control (Mean ± SD)	tDCS (Mean ± SD)	TRE (Mean ± SD)	CI (Mean ± SD)
Pre-intervention (baseline) assessment				
PASS	18.94 ± 1.71	18.94 ± 1.82	19.06 ± 1.85	19.17 ± 1.47
RMI	8.71 ± 1.31	8.88 ± 1.05	9.05 ± 0.89	9.12 ± 0.93
TIS	14.41 ± 2.00	15.59 ± 1.69	15.06 ± 1.54	15.65 ± 1.62
Post-intervention assessment				
PASS	24.76 ± 0.74	20.77 ± 2.28	26.06 ± 2.11	28.24 ± 1.72
RMI	11.06 ± 1.03	9.94 ± 1.14	12.06 ± 0.89	12.88 ± 0.61
TIS	18.41 ± 1.28	17.12 ± 2.03	18.24 ± 1.25	20.17 ± 1.55
Pre- and post-assessment mean differences				
PASS	5.82 ± 1.54	1.83 ± 1.62	7.00 ± 1.43	9.07 ± 1.13
RMI	2.35 ± 0.87	1.06 ± 0.92	3.01 ± 0.93	3.76 ± 1.23
TIS	4.00 ± 2.20	1.53 ± 0.69	3.18 ± 1.41	4.52 ± 1.03

CI: combined intervention, PASS: Postural Assessment Stroke Scale, RMI: Rivermead Mobility Index, SD: standard deviation, tDCS: transcranial direct current stimulation, TIS: Trunk Impairment Scale, TRE: trunk rehabilitation exercises.

interventions, which consistently outperformed other groups in all outcome measures (Table II).

DISCUSSION

Trunk performance plays a crucial role in postural control, balance, and overall stabilization, allowing stroke patients to perform activities independently. It also serves as a predictive factor for independence and good rehabilitation prognosis.[3,4,6,16] In this study, we observed modest improvements in trunk control across all outcome measures, including the Postural Assessment Stroke Scale, Rivermead Mobility Index, and Trunk Impairment Scale. While no statistically significant differences were detected among the intervention groups, patients receiving combined interventions (CI group) tended to demonstrate greater improvements compared to those receiving individual interventions or control treatments.

The three outcome measures were selected to comprehensively evaluate the multidimensional aspects of trunk function, balance, and functional mobility in stroke patients. Each tool offered distinct advantages in capturing specific components of trunk performance, making them collectively suitable for achieving the study's objectives.

Table III: The effects of studied interventions on trunk control and performance of participants

Interventions	Mean ± SE	df	F-value	p-value
Postural Assessment Stroke Scale (PASS)				
Control	5.656 ± 0.731	3	2.109	0.111
tDCS	6.825 ± 0.789			
TRE	7.631 ± 0.767			
CI	8.661 ± 0.789			
Rivermead Mobility Index (RMI)				
Control	2.250 ± 0.375	3	2.217	0.098
tDCS	2.530 ± 0.405			
TRE	3.012 ± 0.394			
CI	3.774 ± 0.405			
Trunk Impairment Scale (TIS)				
Control	3.854 ± 0.484	3	2.195	0.101
tDCS	3.077 ± 0.523			
TRE	3.509 ± 0.509			
CI	4.893 ± 0.523			

CI: combined intervention, SE: standard error, tDCS: transcranial direct current stimulation, TRE: trunk rehabilitation exercise

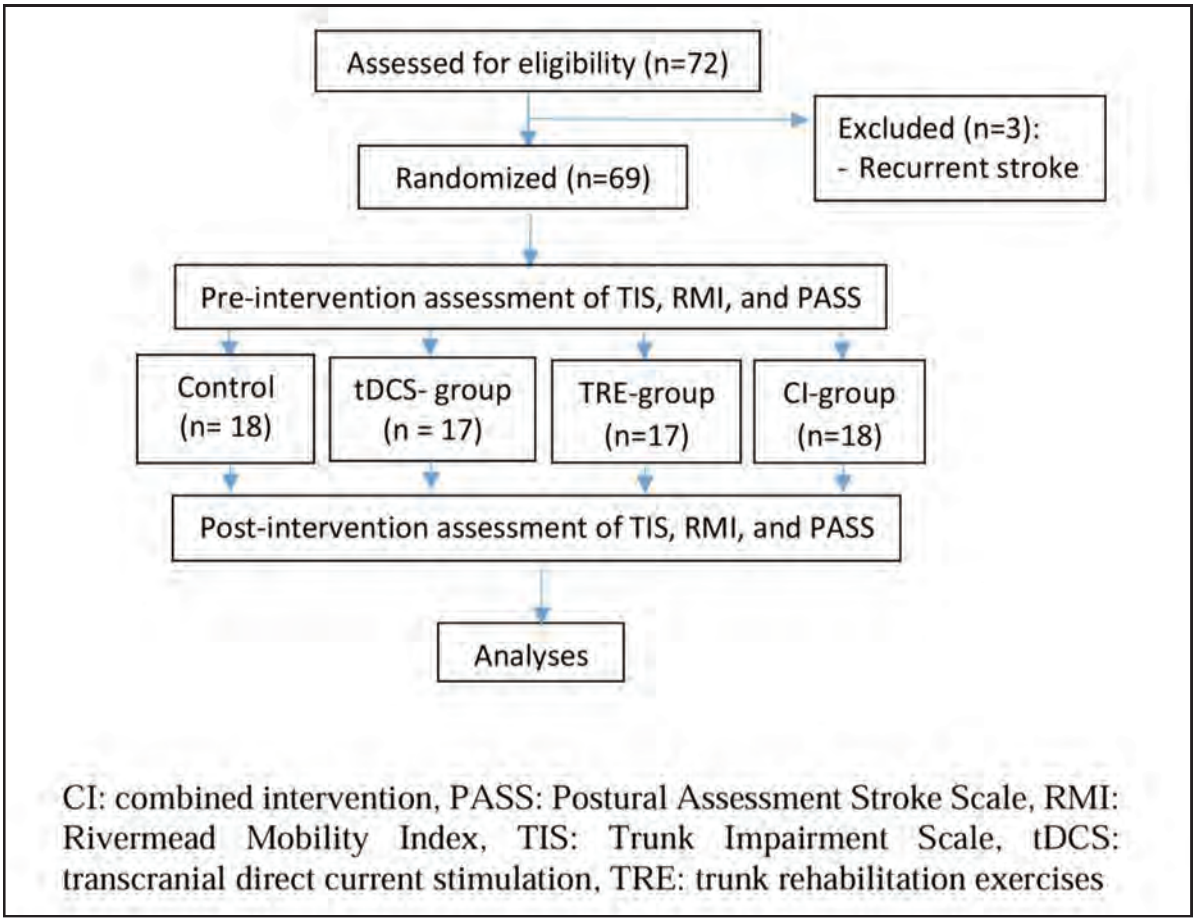

Fig. 1: Flow chart of the study

There was a modest improvement in trunk control and performance levels across all groups following eight weeks of intervention, as shown in Table II. Participants who received the combined interventions demonstrated the greatest improvements. Despite these observed trends, factorial ANOVA revealed no statistically significant differences in the effects of the interventions on trunk control and performance outcomes, including Postural Assessment Stroke Scale ($F=2.109$, $p=0.111$), Rivermead Mobility Index ($F=2.217$, $p=0.098$), and Trunk Impairment Scale ($F=2.195$, $p=0.101$) (Table III). As the ANOVA results did not indicate significant differences between groups, Tukey post hoc tests were not performed.

However, the pre-test to post-test differences in trunk control and performance measures were highest in the CI group, suggesting a potential synergistic effect. The mean differences in post-test scores indicated a trend favouring the combined

The Postural Assessment Stroke Scale was used to assess both static and dynamic balance, which are crucial for maintaining postural control in stroke patients. The scale comprises 12 items that evaluate the ability to maintain or change lying, sitting, or standing postures, providing a comprehensive assessment of functional equilibrium. PASS has demonstrated excellent reliability, with high internal consistency (Cronbach's alpha: 0.95) and inter- and intra-rater reliability (0.88 and 0.72, respectively). Its strong correlation with the Functional Independence Measure (FIM) underscores its validity as a balance assessment tool.[17,18]

The Rivermead Mobility Index was selected to evaluate functional mobility, encompassing gait, balance, and transfers. This 15-item scale provides a simple yet effective measure of mobility, with higher scores indicating better functional performance. RMI demonstrates strong psychometric properties, including excellent test-retest reliability (ICC: 0.98), inter-rater reliability (ICC: 0.93), and internal consistency (Cronbach's alpha: 0.93–0.96). Its predictive and content validity for stroke patients further establish its suitability for this study.[19,20]

The Trunk Impairment Scale was chosen to assess motor coordination and selective trunk movements, which are critical for core functionality in stroke rehabilitation. Its robust psychometric properties, including high reliability (ICC: 0.85–0.99) and internal consistency (Cronbach's alpha: 0.89), make it a reliable measure for both clinical and research applications. The scale evaluates static and dynamic sitting balance and trunk coordination, offering a detailed understanding of trunk motor impairment. Its strong correlations with the Barthel Index (Spearman rank: 0.86) and Trunk Control Test (Spearman rank: 0.83) further establish its validity.[11]

Together, these measures provided a comprehensive framework for evaluating the impact of the interventions on trunk control and functional recovery. By capturing complementary dimensions of trunk performance, the tools facilitated a multidimensional understanding of rehabilitation outcomes, aligning with the study's objectives to explore the effects of neuroplasticity-driven interventions.

The combined intervention appeared to leverage complementary mechanisms, potentially explaining the observed trends of improvement. TRE likely promoted neuroplasticity through repetitive, goal-directed movements that enhanced motor learning and neuromuscular re-education.[13] Stroke patients often experience postural disturbances, but recovery is achievable to some extent through intensive rehabilitation practices.10 Exercises like TRE, rooted in movement science and motor learning principles, emphasise goal-directed practice and repetition, making them effective for improving motor function in the arm, hand, and lower limb after a stroke.[13,21] These exercises are believed to induce behavioural changes that lead to structural neuronal adaptations, promoting neuroplasticity through processes such as neurogenesis, angiogenesis, and axonal sprouting.[22] Furthermore, increased physical activity enhances brain function, stimulates biochemical activity, and facilitates motor recovery after stroke.[23]

On the other hand, tDCS facilitates neuroplasticity by modulating cortical excitability, particularly in motor regions.[9,10,12,14] Animal studies further support this mechanism, showing that neurons in the subcortical ponto-medullary reticular formation are essential for anticipatory postural adjustments, transmitting signals from higher cortical levels before movement initiation.[6] However, in chronic stroke patients, abnormal hyperexcitability in the premotor areas may excessively inhibit the ponto-medullary reticular formation and spinal cord, disrupting the normal sequencing needed for coordinated posture and movement.[7,24] Previous research has shown that tDCS is effective in enhancing neuroplasticity even in the chronic phase of stroke rehabilitation.[25-28] Studies involving healthy controls revealed that tDCS could induce sustained cortical excitability in the primary motor cortex for up to 90 days following stimulation.[12,29] Moreover, several studies have demonstrated the benefits of tDCS applied over the primary motor cortex region in improving arm, leg, and hand performance in stroke patients, highlighting its potential for motor recovery.[30,31]

The synergistic effects of these interventions could be attributed to their capacity to reinforce bilateral trunk muscle activation and facilitate motor recovery through neural pathways that innervate both paretic and non-paretic muscles.[32] Researchers have postulated that changes in the musculoskeletal system may indirectly influence the formation and function of the brain-derived neurotrophic factor, a key marker of neuroplasticity.[14,21] The observed improvements in our study may also align with this hypothesis, as enhanced trunk control and stabilization could support neural recovery. However, the anatomical bilateral innervation of trunk muscles, which rarely contract unilaterally, may also explain the improvements in both the study and control groups. Axial muscle contraction on the paretic side may have been facilitated through irradiation during interventions, further contributing to functional gains.[32]

TRE, unlike tDCS, offers a practical and accessible approach that can be continued at home under caregiver supervision. Once properly instructed by a rehabilitation professional, caregivers can safely assist patients in performing TRE, which involves structured, goal-directed trunk movements in supported positions. This makes TRE a cost-effective and sustainable method for improving trunk control, postural stability, and overall functional independence in stroke survivors, particularly in settings with limited access to continuous physiotherapy. In contrast, tDCS requires trained personnel and clinical supervision due to its technical and safety considerations.

While the present study yielded encouraging findings, it is not without limitations. The small sample size might have reduced the statistical power, potentially obscuring meaningful differences between groups. Furthermore, the study exclusively focused on participants in the chronic phase of stroke recovery, which limits the generalisability of the results to those in the acute or subacute phases. The relatively short intervention duration and absence of long-term follow-up further constrained assessment of sustained improvements and the potential cumulative benefits of the interventions. Additionally, the intervention sequence in the CI group was structured to maximise neuroplastic effects based on theoretical and prior research foundations. However, the influence of different sequencing strategies remains unclear and warrants further investigation in future research.

Future studies should aim to address these limitations by recruiting larger and more diverse cohorts that include acute and subacute stroke populations. Extending the duration of interventions and incorporating long-term follow-up assessments will provide greater insights into the durability of the observed improvements. Furthermore, exploring biomarkers such as brain-derived neurotrophic factor levels with trunk control interventions may offer a deeper understanding of the mechanisms driving neuroplasticity and recovery. Optimising intervention protocols and identifying patient-specific factors that enhance responsiveness to combined interventions should also be prioritized in future research.

CONCLUSION

This study suggests that combining TRE and tDCS may offer a promising neuroplasticity-driven approach to improving trunk control and performance in post-stroke patients. Although no statistically significant differences were found, the trends favouring the CI group indicate it could leverage neuroplasticity to improve outcomes. Larger-scale studies are needed to validate these preliminary findings and refine the intervention protocols for broader clinical application.

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