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SYSTEMATIC REVIEW

Effects of Non-Invasive Electrical Stimulation, Transcranial Direct Current Stimulation, and Physical Exercises in Stroke Patients

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Author`s Contribution

[1] [2] Substantial contributions to the conception or design of the work for the acquisition, analysis or interpretation of data for the work, [3] Drafting the work or reviewing it critically for important intellectual content, [1] Final approval of the version to be published, [2] Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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A B S T R A C T

Background: Stroke ranked third in terms related to mortality and impairment worldwide and second common reason of death (11.6%). It greatly affects people quality of life and mobility. For faster recovery different rehabilitation approaches used like Transcranial Direct Current Stimulation (tDCS) device, a small intensity of electrical current is produced that can stimulate specific areas of the brain which are affected due to stroke. The tDCS device can be effective in improving motor skills and aiding in the recovery process after a stroke. Physical exercise is also crucial for stroke rehabilitation. But when we used these approaches together in rehabilitation of stroke patients it enhance recovery effectively.

Objective: The objective of this systematic review is to evaluate the effects of non-invasive transcranial direct current stimulation (tDCS) and physical exercises on the rehabilitation outcomes of stroke patients.

Methodology: This systematic review followed the guidelines of PRISMA. Used several online search engine known as PubMed, Cochrane Library, Google scholar to search eligible data availability. PICO framework used as screening criteria tool. Data relevant to study was extracted using self-developed data table based on previous literature. The Studies on stroke patients from subacute to chronic conditions with age limit 20 to 80 years, using tDCS device as an intervention and physical exercises were included in this review. Studies before 2019, Grey or unreported, not using tDCS device and non-English studies were excluded.

Studies on stroke used tDCS and physical exercises were included in this review. Studies which conducted before the year 2019 and Non-English studies were excluded.

Results: In this systematic review 35 studies were included with 1242 subjects after fulfill the requirements. In which 30 studies revealed significant improvement in stroke patients used noninvasive electrical stimulation tDCS and physical exercises with p value <0.05 but only 5 studies showed no significant improvement after using tDCS.

Conclusion: This systematic review suggests that non-invasive electrical stimulation tDCS and physical exercises are effective for stroke patients. However in comparison to physical exercise alone, tDCS and Physical exercises showed more improvement.

Keywords: Stroke, Physical Exercises, Non-Invasive Electrical Stimulation, Stroke Rehabilitation.

Introduction

Abrupt loss of neurological function brought on by a disruption in the brain's blood supply known as stroke. [1] There are 2 basic types of strokes: hemorrhagic and ischemic. About 80% of stroke survivors experience an ischemic stroke, which is the most frequent type and causes vital oxygen and nutrients to be lost.[2] In terms of causes of mortality worldwide in 2019, stroke ranked second (11.6 %) and third (5.7%) when coupled with other causes of disability.[3] According to World Health Organization 15 million individuals worldwide experience a stroke each year, while the American Heart Association estimates that there are about 70,000 cases reported in the US alone. [4]

Stroke therapy has advanced to the point where the brain's function are directly changed. The goal of neuromodulation techniques is to restore or augment the damaged cortex's lost or compromised functionality. After a stroke, a number of non-invasive brain stimulation methods including motor imaging, action observation, mirror treatment and transcranial stimulation have been studied in post-stroke patients. Among all of these method tDCS (transcranial direct current stimulation) and TMS (transcranial magnetic stimulation) have been thoroughly studied for post-stroke motor problems. Because tDCS is a portable device, it may potentially be used in conjunction with other treatments. When tDCS is used in conjunction with other rehabilitative treatments, including constraint-induced movement therapy, a favorable motor recovery has been noted. Therefore transcranial direct current stimulation may serve as a complementary modality to cortical plasticity in order to enhance the responsiveness of motor treatments.[5] Neurorehabilitation is crucial following a stroke.[6]

A novel technique that shows promise for the future research and treatment of brain disorders is direct current brain stimulation. Relatively fast this new discipline has seen significant advancements in everything from novel stimulation protocols for research to their use for neurological disorders including pain, Parkinson's disease, and Alzheimer's disease.[7] When to successfully transfer this technology from controlled trial settings to public and commercial health systems is one of the major worries of UDCs with limited financial and human resources. Another is the potential returns on investment in this sector. Transcranial direct current stimulation is one inexpensive, painless, and noninvasive method of brain stimulation (tDCS). One noninvasive method of neuromodulation that has showed promise in accelerating rates of motor recovery after stroke is transcranial direct current stimulation (tDCS).[8] The effect of transcranial direct current stimulation (tDCS) is precisely correlated with the electrode polarity; motor cortex excitability is decreased by cathodal stimulation and increased by anodal stimulation. Newer studies by Takano et al. examine changes in corticospinal excitability and motor control during stimulation in healthy persons, offering a more precise and modern knowledge of the therapeutic use of tDCS. [9] With tDCS, two spongy electrodes the cathode and anode that have been soaked in saline provide low voltage currents to the scalp. Low-intensity electric current is sent by a current generator to polarize the membrane potential in the stimulated region. It causes polarity-dependent changes in cortical excitability where anodal electrodes enhance excitability and cathodes reduce excitability. For tDCS surface electrodes dipped in regular saline and a constant current stimulator are needed.[10]

The former continuously checks the resistance in the system and provides a consistent flow of 0–4 mA direct current. The methods that give 1-2 mA current are within the boundaries of a prior study that showed current density up to 25 mA/cm2 did not harm brain tissue. Previous research has suggested that tDCS delivers enough currents to the underlying cortex to cause neuronal excitability alterations, even if only a small portion of the direct current is shunted via the scalp. [11] Direct currents delivered transcranial have the potential to modify both tissue excitability and regional blood flow, which may function as a proxy for alterations in regional tissue excitability. Another study that also examined changes in cerebral blood flow measurements in brain areas exposed to transcranial anodal direct current supports this.[10] Stroke and tDCS Different regions of the world employ tDCS in stroke rehabilitation. Although several researcher have presented differing findings, the general effect has been favorable.[12] Improvement was observed in patients with subcortical, upper limb, post-stroke dysphagia, left hemisphere, post-stroke nonfluent aphasia, and sub-acute stroke.[13] According to clinical research, tDCS improves limb dysfunction by modifying physiological activity in a number of brain regions. Therefore, it shows great potential as a non-invasive and effective method for controlling brain activity that may be used to manage chronic pain as well as neurological, psychiatric, and other associated problems.

According to earlier research, tDCS is superior than FES in the stroke recuperation stage and can greatly accelerate a patient's return of leg motor function.[14] One of the most prevalent medical diseases for which brain stimulation is used is stroke. The effectiveness and safety of transcranial direct current stimulation (tDCS) for restoring motor function in stroke patients have been extensively studied over the years. tDCS is safe and successful in restoring motor and cognitive function in stroke patients, according to a number of studies. Furthermore, He et al. and Huang et al. stress the lack of information needed to fully understand this modality's safety and effectiveness. The most recent study on the topic, which observed alterations in cognitive performance following stimulation of schizophrenia patients, mirrored similar comments regarding data constraint.[15]

The idea that tDCS can modify a patient's neural activity has not yet undergone a thorough analysis. Nonetheless, a number of investigations have shown that the electric current produced by the stimulation severely disrupts the resting membrane potential of neuronal cells, changing the voluntary movements in brain circuits. Some researchers believe that tDCS may modify the strength of synaptic connections between neurons, which in turn modifies the activation of NMDA and GABA receptors.[16] In the end, this procedure could trigger long-term depression and potentiation as well as the plasticity process. Applying a stimulus causes the brain's electro field to change over time, which may cause cortical neurons to fire action potentials. Chen and Liu provide an overview of neural activity and action potentials generated in neurons. They highlight how transcranial direct current stimulation (tDCS) may alter neural cells' electrical potential and, as a result control their voluntary movements in brain circuits.[17]

Physical exercise is a cornerstone of stroke rehabilitation, aiming to improve motor function, balance, coordination, and overall mobility. Engaging in regular physical activity can enhance neuroplasticity, promote cardiovascular health, and reduce the risk of recurrent strokes.[18]

The rationale of the study was giving the way to improve quality of life, better recovery of stroke patients, to reduce the burden on our society because of these patients, lesser hospital stays ,faster recovery and helping to set or change patient's protocol if obvious treatment related significant differences exist from our systematic review results. The objective of this systematic review is to evaluate the effects of non-invasive transcranial direct current stimulation (tDCS) and physical exercises on the rehabilitation outcomes of stroke patients.

Methodology

Study design was systematic review. This systematic review followed the guidelines of PRISMA. Used several online search engine known as Google Scholar PubMed and Cochrane Library to search eligible data availability. PICO framework used as screening criteria tool. Data relevant to study was extracted using self-developed data table based on previous literature. Studies on stroke non-invasive electrical stimulation tDCS and physical exercises were covered in this review. The researches which conducted before 2019 and Non-English studies were excluded. From the year 2019 to July 2024 these studies were included.

Search Strategy: Appropriate search strategy was developed by substantial and extensive reading of background literature that is related to the concept of current review. Pub Med, Google scholar, Cochrane library and Web of Science were searched for relevant articles. Article searching was carried out during March and April 2024. The search string used for Pub Med advanced search was the following: All Fields = ("Stroke Rehabilitation" or "Stroke Management" or “Noninvasive electrical stimulation”) AND ("Physical exercise" or "Exercises") AND ("Electrical Stimulation" or “Stroke”) AND (“Noninvasive electrical stimulation" or "Physical exercise”).

The search string used for Web of Science advanced search was the following: ((("Stroke treatment" or "Stroke Rehab" or "tDCS") AND ("Stroke patients" or "elderly")) AND ("Physical exercise" or "Exercise management" or "tDCS") AND (“Noninvasive electrical stimulation techniques” or “types of stroke management” or "Physical exercise”) AND (“Rehabilitation" or "Stroke” or "tDCS”)). Searches were limited to paper published in English, but time 2019-2024 interval was set for the year of publication.

1-Quality Assessment of the Included Studies: To guarantee that only high-caliber research were featured in this review, all of the included papers underwent screening. The Physiotherapy Evidence-Based Database was utilized for the evaluation of the included rcts. Pedro is regarded as a reliable instrument with strong psychometric qualities for evaluating the methodological rig our of research. Research has indicated that in physiotherapy research, pedro is thought to have good inter-rater reliability (ICC = 0.80 to 0.89). The 11-item pedro measure is used to evaluate the research' internal and external validity.

Data Extraction: The study features were gathered and put into a self-designed table after rigorous eligibility criteria and quality evaluation. To make sure it permits the extraction of all pertinent data, this data extraction table has been utilized previously. According to published research, the research question should guide the design of the data extraction table. When creating this extraction table, the Centre for Review and Dissemination (CRD) established instructions for the extraction of data form, which were adhered to.

Fugl-Meyer Assessment scale: It is meant to assess motor function, balance, joint functioning, and sensitivity in those who have experienced a stroke-related hemiplegia. It is used to define motor recovery, gauge the severity of the ailment, and

Table I: Eligibility Criteria for Studies

Population (P)	AND	Intervention (I)	AND	Comparator (C)	AND	Outcome Measure (O)	AND	Study (S)
Stroke male/female patients Subacute to chronic conditions.		Non-invasive electrical stimulation tDCS OR Physical Exercises (Strengthening Exercises OR Balance exercises)		Conventional treatment or no treatment		Fugl-Meyer Assessment Scale		Randomized controlled trial case studies, pilot studies and experimental studies

create and assess therapy regimens in both clinical and research contexts.[19]

Criteria for Choosing Studies: Types of Participants Studies with (a) individuals aged 20 to 80 years or older were considered in this review. From subacute to chronic stroke. Patients with a high degree of cognitive were among them. Research with participants' poor cognitive function who were not underwent physical exercise or TDCS treatments were not included in this analysis. **Types of Intervention**: This review includes studies that employed physical exercises or targeted non-invasive electrical stimulation (TDCS).

Table II: Inclusion and Exclusion Criteria.

Inclusion Criteria	Exclusion Criteria
Article included stroke male/female patients with age 20 to 80 years subacute to chronic conditions. Studies using non-invasive electrical stimulation tDCS and physical exercises as an intervention.	Grey or unreported studies. Before to 2019 Articles were excluded. Non-English Studies. Studies did not included noninvasive electrical stimulation or physical exercises among stroke patients.

Types of Comparator: Research that employed sham treatment or other methods as a comparator, such as a control group receiving conventional treatment without intervention, or alternative therapies such Virtual therapy and Mirror therapy, were included in this study. By using these comparators, the intervention's robust efficacy and bias will be reduced.

Types of Outcome Measure: The FUGL-MEYER ASSESSMENT was the research assessment tool in this review to employ validated outcome measures, and it was developed as the first quantitative evaluation tool for quantifying sensorimotor stroke recovery. As a clinical and research tool, it comes highly recommended for evaluating changes in motor disability after stroke.

Types of Studies: Pilot studies, case studies, and randomized controlled trials (RCTs) were all included in the review. RCTs were emphasized since they are seen to be the gold standard for determining the effectiveness of therapy on condition. A further search was conducted, but it was restricted to 2019–2024 in order to include current research. Peer-reviewed English-language papers were comprised. Peer review makes guarantee that only reliable and high-quality research is released. The English language was used to be easily understood by the general audience.

Results

Following a thorough search utilizing internet databases including Cochrane Library, Google scholar, Web of science and PUBMED, 1600 papers were found using the MeSh and the key phrases listed in Table 2. Following the removal of 600 duplicates, 1000 studies underwent further screening. After additional examination, 800 excluded reports were not included in the evaluation. After screening the remaining 200 titles and abstracts for complete reports, 140 more were disqualified. After evaluating 60 research for eligibility, this evaluation only included 35 of them.

Discussion

The purpose of this systematic review's objective was to look at the effects of physical activity and non-invasive electrical stimulation therapy on stroke patients. In this analysis, 35 research with 1246 persons altogether were considered. Quality assessment of studies showed mostly studies were high quality 8,7 and 6Non-invasive electrical stimulation (tDCS) and physical workouts can be a useful and clinically meaningful means of decreasing disability for stroke patients, according to included studies ($p < 0.05$). Review findings indicate that, however, physical exercise plus non-invasive electrical stimulation therapy (tDCS) is superior to physical exercise alone ($p > 0.05$).

Alashram et al. conducted a systematic review using 1204 records, finding that seven studies with 320 participants (mean age = 60.3), 31.1% of whom were female, satisfied the inclusion criteria. Of the overall patients, 77.2% had an ischemic stroke, while 42.2% had a right hemisphere stroke. One study had "moderate" quality, while six had "high" quality. These results were consistent with the current review, which reviewed 30 studies and found that all included studies revealed significant improvement after tDCS. Additionally, current SLR includes physical exercises, which previous literature lacks. Five of the selected studies that combined the tDCS intervention and other traditional interventions showed a significant reduction in upper extremity spasticity after stroke following tDCS intervention. [55]

Toktas et al. carried out randomized controlled trial to find anodal tDCS vs task oriented physiotherapy effect on stroke subjects FMA were used as assessment tool study revealed both intervention had significant improvement on stroke subjects but anodal TDCS showed more significant improvement with significant p value 0.03.[20] these results were accordance to current systematic review study showed tDCS showed more improvement among stroke with p value 0.05.

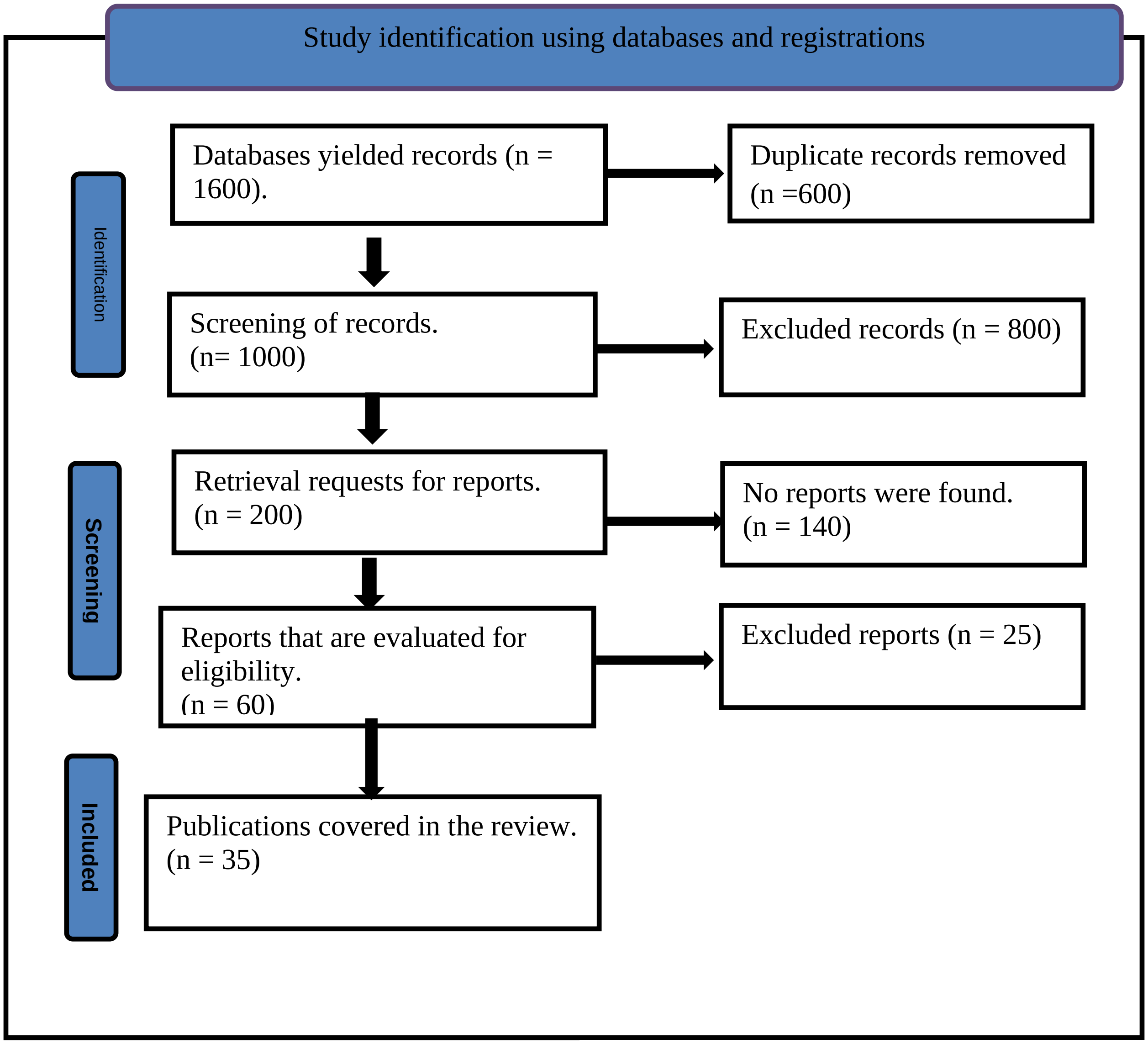

Figure 1: Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Flow Chart

Serkan u et al. conducted a study on 40 stroke survivors 3 groups were made; first group received sham neuromuscular electrical stimulation (NMES) and tDCS; second group received tDCS and sham NMES; third group received NMES and sham tDCS; and fourth group received all therapeutic procedures. Fugl-Meyer scale of evaluation Dysphagia Severity Rating Scale (DSRS), Functional Oral Intake Scale (FOIS), and Penetration Aspiration Scale (PAS) were the assessment tools results revealed DSRS (p = 0.005), GUSS (p = 0.005), FOIS (p = 0.004), PAS IDDSI-4 (p = 0.027), and PAS IDDSI-0 (p = 0.004) FMA is 0.05.(21) these results were compatible to current review showed tDCS has significant effect on stroke subjects

Lai MH et al. conducted RCT on 39 stroke patients 3 distinct groups, including the sham tDCS group (SS group), the single-target tDCS group (ST group), and the multi-target tDCS group (MT group) FMA,box and block test were assessment tools results revealed FMA: TDCS.SS group 4.86±2.41 to 1.67±1.9 ,ST group 5.74±2.60 to 4.05±2.24 and MT group 5.56 ±2.50 to 4.00±2.31.(22) these results were in lined to current review showed tDCS has significant effect on stroke subjects.

Massaferri et al. Investigated multimodal physical training and cortical tDCS affected the motor function of chronic stroke patients as measured by strength, motor performance, and cardiorespiratory capacity. The results demonstrated that the combination of tDCS and MPT produced significant differences ($p < 0.05$) when compared to MPT alone ([56]). These results were accordance to current study showed tDCS showed more improvement among stroke with p value 0.05.

RCT by Milot et al. conducted to determine effects of an Individualized upper limb strength training program coupled

Table IV: Using non-invasive electrical stimulation tDCS and physical exercises in stroke patients				
Authors	**Year**	**No. of Subjects**	**Disease Investigated**	**Results**
Toktas N et al.(20)	2024	28	Stroke	Improved
Serkan Bengisu et al.(21)	2024	40	Post Stroke dysphagia	Improved
Lai MH et al.(22)	2024	39	Stroke	Improved
Jayan J et al.(23)	2024	33	Ischemic Stroke	Improved
Wong, P. L. et al.(24)	2023	45	Chronic stroke	Improved
Li et al. (25)	2023	30	Stroke	Improved
Zhou et al. (26)	2023	40	Stroke	Not Improved
Da Silva et al.(27)	2022	34	Unilateral spatial neglect after	Improved
Qurat Ul, Ain et al.(28)	2022	66	Stroke	Improved
Dumont AJL et al.(29)	2022	28	Stroke	Improved
Ohnishi, S et al.(30)	2022	1	lower limb motor function in a stroke	Improved
Divya M, Narkeesh A et al.(31)	2022	60	Subacute Stroke	Improved
Sharma R et al.(32)	2022	40	Stroke	Improved
Wanalee Klomjai et al.(33)	2022	19	Lower limb function of stroke	Improved
Haq et al. (34)	2022	136	Stroke	Improved
Kaviannejad R et al.(35)	2022	32	Ischemic stroke	Not Improved
Thatchaya Prathum et al.(36)	2022	24	Chronic stroke	Improved
Kesikburun S et al.(37)	2022	20	Stroke rehab	Improved
Tereshin AE et al.(38)	2022	62	ischemic stroke	Improved
Ahmad et al. (39)	2022	66	Hemorrhagic stroke	Not Improved
Zhang et al. (14)	2021	122	Lower limb function of stroke	Improved
Mitsutake et al.(40)	2021	34	Subacute stroke	Improved
Learmonth et al. (41)	2021	40	Hemispatial neglect stroke	Improved
Bornheim S et al.(42)	2020	50	Acute stroke	Improved
Pavlova E et al.(43)	2020	20	Chronic stroke	Improved
Ojardias, E et al.(44)	2020	18	Chronic stroke	Improved
Shibata T et al.(45)	2020	5	Acute stroke	Improved
Abualait TS et al.(46)	2020	1	Chronic stroke	Improved
Belopasova AV et al.(47)	2020	20	Chronic stroke	Improved
Elsner et al.(48)	2020	20	Chronic stroke	Not improved
Wang et al. (49)	2020	20	Sub cute stroke	Not improved
Beaulieu L-D et al.(50)	2019	14	Chronic stroke	Improved
Milot M-H et al(51)	2019	84	Chronic stroke	Improved
Picelli A et al.(52)	2019	40	Chronic stroke	Improved
Schjetnan AG etal.(53)	2019	20	Stroke	Improved

with transcranial direct current stimulation (tDCS) in patients with stroke recruited 84 patients results revealed Individualized upper limb strength training regimen paired with transcranial direct current stimulation showed improvement with ($p < 0.05$) value [51] these results were consistent to current study but first of all, the lack of demographic information in the study, such as age and gender, restricts the applicability among the results. Because there was no control group in the second research that's why it restricts the study's generalizability.

Klomjai et al. conducted study on stroke subjects results showed subjects received tDCS showed significant improvement wth significant p value 0.05 these fndngs were accordance to current review Firstly, the study's absence of demographic data, including age and gender, limits how broadly the conclusions may be applied. The second research study's limited generalizability stems from the absence of a control group. [33] A majority of the participants in the study were female, which limited how broadly the study's conclusions could be applied.

Esht et al. examined the effects of transcranial direct current stimulation on living standards parameters, as well as behavioral, physical, and cognitive abilities in stroke survivors. It also sought to understand the mechanisms underlying the effects of different domains associated with improvements in health-related quality of life (HRQoL). The findings demonstrated that stroke survivors who received direct current stimulation (tDCS) saw improvements in lifestyle indices as well as in their physical, behavioral, and cognitive abilities ($p = 0.05$). [57] These outcomes were consistent with the latest findings that stroke patients responded better to transcranial magnetic stimulation (tDCS) but the lack of demographic information in the research, such as age and gender, restricts how broadly the results may be applied. Second, there is no non-intervention group in the study. As a result, it is challenging to ascertain if the change in the outcome measure was exclusively brought about by the intervention techniques used.

You Yi et al. conducted RCT on 32 consecutive individuals Consequently, tDCS may be an effective adjuvant treatment to enhance visuospatial attention in individuals who have had a subacute stroke.[58] These findings aligned with recent research on reducing stroke symptoms; however, the study's focus was limited to enhancing visuospatial attention, which may restrict the generalizability of the findings.

Table V: Characteristics of Included Studied						
Author and year	**Sample size**	**Intervention vs control**	**Duration**	**Outcomes**	**Results**	**Conclusion**
Toktas N et al.(20)	28	Group A:anodal tDCS Group B: task oriented physiotherapy	5sessions per week for 4 weeks	Timed Up and Go Test Fugl Meyer Lower Extremity Scale	FMLES: Group A: $p < 0.05$ Group B: $p < 0.07$ TUGS A: $p < 0.056$ B: $p < 0.09$	Group A tDCS showed more improvement as compare to Group B
Serkan Bengisu et al.2024 (21)	40	Group A: Received tDCS Group B: tDCS and sham NMES Control group : Traditional therapy	4 sessions per week for 8 weeks	Fugl-Meyer scale of evaluation	FMA Group A: is p< 0.05 Group B: p< 0.05 Control group : p more than 0.05	Additionally integrating several treatment modalities like NMES and TDCS was more successful than relying just on traditional therapy.
Lai MH et al.2024 (22)	39	Group A:TDCS for 40 min Group B: Traditional therapy	8 session 2 week	FMA, box and block test	FMA: tDCS Group A 4.86±2.41 to 1.67±1.9 Group B 5.74±2.60 to 4.05±2.24	Results showed tDCS group showed more improvement as compare to traditional therapy.
Jayan J et al.2024(23)	N=33	Group A: tDCS Group B. Just ROM and stretching	24 Session for 8 week	FMA	Group A: P value 0.005 Group B: p value 0.98	Group A tDCS enhanced the amplitude of cortical somatosensory potentials among stroke.
Li et al. 2023 (25)	N = 30 Screening criteria present	Transcranial direct stimulation(TDCS and exercises) VS Exercise	3 sessions for 8 week	Fugl–Meyer assessment scale	FMA: TDCS. 5.96±2.30 to 1.73±2.16 Exercise group 5.74±2.30 to 2.05±2.24	There was a noteworthy increase in improvement (p < 0.005) in the group that had exercises and transcranial direct stimulation.
Zhou et al. (26)	40	Group A:Received TDCS Group B: Received gait therapy	5 session for 2 week	FMA scale	Group A:P <0.05 Group B:P >0.05	TDCS Showed not significant improvement after 2 week session.
Wong, P. L. et al.2023(24)	45	Group A receives treadmill training and a fictitious transcranial DC stimulation. Group B is exposed to 30 minutes of treadmill exercise after cathodal transcranial direct current stimulation. Group under control: receiving training on a treadmill and tDCS	5 sessions up to 6 week	Fugl–Meyer assessment scale	Group A p value 0.005 Group B P value 0.007 Group C 0.008	The group that received treadmill training in addition to cathodal transcranial direct current stimulation had a much higher increase in cognitive dual-task walking speed.
Da Silva et al.2022 (27)	N = 34 Screening criteria present	Group A anodal and cathodal tDCS VS Group B Physical exercises	5 session a week for 6 weeks	Fugl–Meyer assessment scale Catherine Bergego Scale (CBS)	FMA Group A (2.69 p <.001) Group B (3.04 , p <001) CBS Group A: (-36.92, p <0.001) Group B: (-34.59, p <001)	Group A experienced a more notable improvement.

Wanalee Klomjai et al.2022(33)	N=19	Active Group (n=10) During the first twenty minutes of physical therapy, single session of dual-tDCS, and the session last for an hour. Group of Shams: Sham group (n=9) After sham dual-tDCS during the first twenty minutes of physical therapy, the session continued for an hour.	2 session for 2 weeks	The Timed Up and Go test	TUG: 22.38 ± 2.67 s for PRE, 22.15 ± 2.70 s for POST, and 19.00 ± 2.58 s Sham group's scores were 21.66 ± 3.33 s at PRE and 21.21 ± 3.16 s at POST. The FTSTS: PRE–POST score for the "before" group was 3.06 ± 0.64, whereas the scores for the "during" and sham groups were 0.35 ± 0.72 and 0.06 ± 0.38.	Although the stimulation paradigms did not vary in terms of their aftereffects, it is probable that applying tDCS "before" would be more advantageous in terms of instant results.
Haq et al.2022 (34)	N =136 Screening criteria present	Group A transcranial direct current stimulation Vs Group B virtual reality physical exercises	3 sessions per week for three weeks	Fugl–Meyer assessment scale	Cluster A (2.82 to 0.25) Team B (2.89 through 1.79) Group A's FMA improvement was greater (scores) .	tDCS showed improved stroke survivors condition, according to Group A ($p < 0.001$).
Qurat Ul, Ain et al.2022(28)	66	Active group: Cerebellar Anodal tdcs Sham group:with no intervention	4 week treatment 3 session per week	TUG test berg balance scale used	TUG,tdcs vs sham $p = 0.001$ BBS: sham $p \leq 0.001$	Anodal tDCS showed improvement on balance , gait and fall risk in stroke survivors
Dumont AJL et al2022(29)	28	Experimental group: treadmill training paired with anodal tDCS control group : underwent treadmill training	4 week treatment 3 session per week	FMA scale	FMA $P > 0.05$ in spatiotemporal variables experimental group demonstrated improvements in ($p < 0.05$)	Combining treadmill training with anodal tDCS injured hemisphere improved post effects of stroke.
Ohnishi, S et al.2022(30)	1	Only period A involved aided gait training, while period B involved tDCS	Thrice a week for 4 weeks.	Six-meter walk test	tDCS 0.05 assisted gait training only 0.09	tDCS has the potential to assist stroke patients in regaining motor function in their lower limbs.
Thatchaya Prathum et al.2022 (36)	N=24	Active group: 1 hour of at-home activity following 20 minutes of dual-tDCS at 2 mA Sham group: alone exercise	Thrice a week for 4 weeks.	Fugl-Meyer Assessment (54)	Active group p=0.005 Sham group =0.007	The sham group's FMA ratings were lower than those of the active group. And these improvements persisted for at least a month. The results of the functional tasks did not differ across the groups.
Sharma R et al. 2022(32)	40	Group A:tDCS for 30 min Group B: Modified Constraint Induced Movement Therapy	4 time a week upto 4 weeks	FMA scale	Group A; P Value 0.006 Group B: 0.007	Group A showed significant improvement stroke survivors after using tDCS stimulation.
Kaviannejad R et al.(35)	32	Group A: tDCS for 15 min Group B: Walk training	5 session up to 4 week	FMA scale	Group A: P Value 0.009 Group B: 0.007	tDCS stimulation showed non-significant improvement
Divya Met al. 2022(31)	60	Group A: Dual-tDCS 20 min then physiotherapy Group B: physiotherapy then 20 min Dual-tDCS	2 session after 1 Week	FMA	Group A: P value 0.005 Group B : p value was 0.009	Lower limb performance was not substantially improved by dual-tDCS "after PT Performance in the "before" group was considerably better at post-intervention than in the "during" and sham groups, according to a comparison with the prior data.

Tereshin AE et al. 2022(38)	62	Group A : transcranial direct current stimulation VS Group B : no intervention	4 session per week upto 6 week	Fugl–Meyer assessment scale	FMA: Group A P 0.002 Group B 0.007 More improvement in Group A	Transcranial direct current stimulation Showed improvement on stroke rehab
Kesikburun S et al.2022 (37)	32	Group A tDCS Group B: no intervention	3 sessions per week for 2 weeks	Fugl–Meyer assessment scale	Group A:0.005 Group B:0.0093	tDCS showed positive effect on stroke rehab
Ahmad et al. (39)	66	Group A: tDCS Group B:no intervention	6 session 4 week	Fugl–Meyer assessment scale	Group A:0.009 Group B: 0.005	tDCS and no intervention group showed same post reading showed tDCS showed no improvement
Zhang et al. 2021 (14)	N = 122 Screening criteria present	Group A tDCS VS Group B Functional electrical stimulation	4 session in a week up to 8 week	Fugl–Meyer assessment scale functional ambulatory category (FAC),	FMA A (7.76±2.3 to 4.68±3.38) B (8.12±1.77 to 4.76±3.41) FAC A (40.00±16.48 to 55.96±19.45) B(48.16±17.06 to 57.88±18.03)	Reported no discernible variation across the treatments. FMA and FAC significantly decreased after therapy. FAC p = 0.001, FMA p < 0.001)
Mitsutake et al.2021(40)	N = 34 Screening criteria present	Group A: gait training along (tDCS) VS Group B: Gait training along FES	5 session per week for 8 week	Fugl-Meyer assessment scale walking speed,	Group A: FMA (-7.4 <±2.1) Section B (-3.9±1.8) WS: -298±24.4B: -59.1±22.0 Additional progress in Group A	Both groups showed improvement (p < 0.01). 8 weeks (Group A, p < 0.05)
Learmonth et al.2021 (41)	N = 40 Screening criteria present	Group A: transcranial direct current stimulation (tDCS) VS GroupB: Behavioural rehabilitation programme	5 session per week for 6 week	Fugl-Meyer assessment scale QOL scale	FMA: Group A (-7.3±2.1) Group B (-3.9±2.7) QOL scale : Group A: -69.1±23.0 Group B: -38±21.4 More improvement in Group A	There were more improvement groups in both Group A (p < 0.05) after improvement. After six weeks (p < 0.07) in Group B
Shibata T et al.2020 (45)	5	Seven to fourteen days following the beginning of the stroke, d-tDCS (1 mA, 20 min per day) was administered vs traditional therapy.	Patients had 40 treatments overall for 2 weeks	FMA	d-TDCS showed improvement with significant p value 0.001	These data imply that d-tDCS administered over a three-month period may be advantageous for acute stroke patients in the acute to subacute phases, safe, and practicable. It may also have therapeutic potential to aid in the restoration of upper limb function.
Belopasova AV et al.2020 (47)	20	Group A: tDCS Group B:No intervention	4 session per week for 4 months	FMA	FMA showed significant improvement in acute stage with Group A :p=0.001 Group B: p=0.009	tDCS showed positive effect on stroke rehab.

Pavlova E, et al.2020(43)	20	Group 1: anodal tDCS Group 2:No intervention	3 session per week for 6 months	The Jebsen-Taylor hand function test was employed.	Jebsen-Taylor hand showed significant improvement in subacute stage with p=0.005	Anodal tDCS can enhance recovery of stroke
Bornheim S et al.2020(42)	N=50	GROUP 1: tDCS GROUP 2: No intervention	5 times a week for 8 week	Fugl Meyer assessment scale Wolf Motor Function Test,	WMFT (p = 0.04) FMA p= 0.02	Variations between the two groups' major results showed improvements in all functional motor outcomes and somatosensory capabilities following tDCS that were clinically significant.
Ojardias et al.2020 (44)	18	Group A: Every subject had a single session of pseudostimulation Group B: -tDCS (2 mA, 20 min).	2 session ion of 11 days interval	6-minute walk test (6MWT)	6MWT group A(p = 0.360) Group B (p = 0.001)	tDCS Showed significant improvement using tDCS
Elsner et al.(48)	20	Group A: simple ROM exercises Group B: -tDCS (2 mA, 20 min).	3 session for 3 week	FMA Scale	Group A:p<0.05 Group B: p>0.05	tDCS showed no improvement on stroke outcomes
Wang et al. (49)	20	Group A: tDCS pseudostimulation Group B: - no intervention	4 session for 10 week	FMA scale	Group A: p value >0.05 Group B:p<0.05	tDCS showed no improvement on stroke outcomes regarding enhancing upper limb function
Abualait TS et al.2020(46)	N=1 case study	30 Active stimulation sessions across both M1 cortices	The patient had thirty sessions with Two-mA stimulation was used for 20 minutes per session.	Action Research Arm Test, grooved pegboard test	Action Research Arm Test p 0.001 grooved pegboard test p 0.005	Better recovery of fine motor abilities was positively linked with higher regional grey matter density and fractional anisotropy of the corticospinal tract. This stroke patient had both structural and functional improvements as a result of the tDCS treatments.
Schjetnan AG etal. 2019(53)	N=20	Group A:Anodal tDCS Group B: Strengthening exercises.	5 times a week up to 8 week	Fugl Meyer scale	Anodal tDCS: FMA p= 0.000 strengthening exercises FMA p value 0.001	Following tDCS, improvements were more proficient
Picelli A et al.2019 (52)	40	Group A: tDCS Group B: gait training	5 times a week for 8weeks	Fugl Meyer scale	Group A:0.005 Group B:0.007	Both groups showed significant improvement but tDCS showed more improvement
Milot M-H et al.2019 (51)	N=84	Two tDCS groups (real vs. sham)	12 session 4 session a week	Fugl-Meyer Stroke Assessment-FMA	Group difference was detected for I Real group (p 0.005), as well as for sham and real-tDCS. Sham group: 0.009	According to a research that applied tDCS repeatedly to chronic stroke patients, the tDCS real group saw an 8-point increase in FMA.
Louis-David Beaulieu et al.2019 (50)	N=14	Group 1: tDCS + resistance training Group 2: Sham tDCS + resistance training.	3 times a week up to 6 week	Box Block Test, Fugl-Meyer Assessment, modified Ashworth scale	There was no discernible group difference in the frequency or intensity of either group 1 or sham-tDCS (p > 0.38).	Comparing the use of tDCS to sham-tDCS, however, did not yield any extra sensorimotor benefits.

Table VI: Quality Assessment of Included Studies

Quality Metrics	Eligibility criteria	Random allocation	Concealed allocation	Baseline compatibility	Blinded subjects	Blinded therapist	Blinded assessors	Measurement of outcome measure	ITT	B/w group analysis	Point estimates & variability	Total scores & quality
Toktas N et al.2024(20)	1	1	0	1	0	1	1	1	0	1	1	8
Serkan Bengisu et al.2024(21)	1	0	0	1	0	1	1	1	1	1	1	8
Lai MH et al.2024(22)	1	1	0	0	0	1	1	1	0	1	1	7
Jayan J et al.2024(23)	1	1	1	1	0	0	1	1	0	1	0	7
Li et al. 2023 (25)	1	1	0	1	0	1	1	1	1	1	0	8
Wong, P. L. et al.2023(24)	1	1	1	1	0	1	1	1	0	1	0	8
Zhou et al. (26)	1	1	1	1	0	1	1	1	0	1	0	8
Da Silva et al.2022(31)	1	1	1	1	0	0	1	0	0	1	1	7
Haq et al.2022 (34)	1	1	0	1	0	1	1	1	0	1	0	7
Wanalee et al.2022(66)	1	1	0	1	0	1	1	1	0	1	0	7
Qurat Ul, Ain et al.2022(28)	1	1	0	1	0	1	1	1	0	1	1	8
Dumont AJL et al2022(29)	1	1	0	0	0	1	1	1	0	0	1	6
Ohnishi, S et al.2022(30)	1	1	0	1	0	1	1	1	0	1	1	5
Thatchaya Prathum et al.2022(36)	1	1	0	1	0	1	1	1	0	1	1	8
Sharma R et al. 2022(32)	1	1	0	1	1	1	0	0	0	1	1	6
Wanalee Klomjai et al. 2022(33)	1	1	0	1	0	1	1	1	1	1	0	8
Kaviannejad R et al.2022(35)	1	1	0	1	0	1	1	1	0	1	1	8
Ahmed et al2022(39)	1	1	0	1	1	1	0	0	0	1	1	6
LD,Beaulieu et al.(50)	1	1	0	1	0	1	1	1	0	1	1	8
Tereshin AE et al. 2022(38)	1	1	0	1	0	1	0	0	1	1	1	7
Kesikburun S et al.2022 (37)	1	1	0	1	0	1	1	1	0	0	1	7
Zhang et al. 2021 (14)	1	1	0	1	0	1	1	1	0	0	0	6
Mitsutake et al.2021(40)	1	1	0	1	0	1	1	1	1	1	1	9
Learmonth et al.2021 (41)	1	1	0	1	0	1	1	1	1	1	0	8
Shibata T et al.2020(45)	1	1	0	1	0	1	1	1	0	1	1	8
Belopasova AV et al.2020(47)	1	1	0	1	0	1	1	1	0	1	1	8
Pavlova E, et al.2020(43)	1	1	0	1	0	1	1	1	0	1	1	8
Bornheim S et al.2020(42)	1	0	0	1	0	1	1	1	0	1	1	7
Ojardias et al.2020(44)	1	1	0	1	0	1	1	1	0	1	1	8
Abualait TS et al.2020(46)	1	1	0	1	0	1	1	1	0	1	1	8
Elsner et al.(48)	1	1	0	1	1	1	0	0	0	1	1	6
Wang et al.(49)	1	1	0	1	1	1	0	0	0	1	1	6
Schjetnan AG etal. 2019(53)	1	1	0	1	0	1	1	1	0	0	1	7
Picelli A et al.2019 (52)	1	1	0	1	0	1	1	1	0	1	0	7
Milot M-H et al.2019 (51)	1	1	0	1	0	1	1	1	0	1	1	8

Seong and Hyun conducted a research to find out how patients with chronic strokes' gait was affected by transcranial direct current stimulation during task-related training. There were twenty-four patients involved. individuals who underwent TRT for general showed useful rehabilitation technique for improving gait is the administration of transcranial magnetic stimulation (tDCS), which modifies excitatory regulation in the cortical motor region.[59] These findings aligned with the present analysis, as tDCS was found to enhance outcomes for stroke patients; however, the specific focus of this study was gait improvement.

A variety of parameters, including outcome variables, outcome measuring instruments and time frames, demographic traits (age, gender), and methodological evaluation of the research, were compared and contrasted across the included studies in the review. Five of the six research that made up the review had sizable sample sizes, which improved the findings' relevance from a wider standpoint.

Conclusion

This systematic review suggests that non-invasive electrical stimulation tDCS and physical exercises in stroke individuals are effective for stroke patients. However, in comparison to physical exercise alone tDCS with physical exercises showed more improvement.

RECOMMENDATIONS

- Standardizing outcome measures across studies to enable more consistent comparisons and meta-analyses.
- Investigating the optimal timing, frequency of tDCS, locations of electrodes and exercise sessions for maximizing therapeutic benefits.
- Exploring the impact of patient-specific factors, such as age, stroke severity, and comorbidities, on the efficacy of these combined interventions.
- Assessing the long-term sustainability of functional improvements and quality of life enhancements resulting from these combined therapies.
- Enhancing reporting transparency by adhering to established guidelines, such as PRISMA, to improve the reproducibility and reliability of findings in future research.

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