**Title:** Non-Invasive Brain Stimulation Effects on Post-Stroke Cognitive Impairment: A Structured Review and Network Meta-Analysis

**Running Title**: NIBS in Post-Stroke Cognitive Impairment

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## Abstract:

**Purpose**: Stroke is the second most common cause of death and the third leading factor for disability worldwide. Non-invasive brain stimulation (NIBS) has emerged as an effective option for enhancing cognitive function following stroke. This Network Meta-Analysis attempts to compare the effects of NIBS techniques, including rTMS and tCDS, on post-stroke cognitive function.

**Methods**: Interventional studies published between January 2018 to August 2024 were reviewed in Medline, Scopus, and Psycinfo databases. A total of 220 records were reviewed, and 12studies involving 510 participants met the inclusion criteria. The risk of bias was assessed using Cochrane collaboration tools.

The global cognition severity was quantified using the MMSE and MoCA scales, and the ADL abilities were evaluated using the MBI and FIM scales.

An NMA was performed using the *Netmeta* package in R to compare the efficacy of NIBS modalities and examine their impact across different recovery stages.

**Results**: NIBS significantly improved cognitive function compared with controls. Among modalities, rTMS showed the most substantial effects on global cognition (MoCA: $p < 0.0001$; MMSE: $p = 0.001$), with the greatest benefits observed in the subacute phase ($p < 0.0001$). No significant improvements were observed in ADLs, likely due to variability in measurement scales.

**Conclusion**:Both rTMS and tDCS significantly enhance post-stroke cognitive function, however rTMS demonstrates superior outcomes. The findings highlight the critical role of prompt intervention in optimizing rehabilitation potential.

**Key Words:** Post-stroke cognitive impairment; Non-invasive brain stimulation; Stroke Rehabilitation; Repeated transcranial magnetic stimulation; Transcranial direct current stimulation; Meta-analysis, stroke stages

## Highlights:

- Both rTMS and tDCS significantly improve post-stroke cognitive function.
- The rTMS demonstrates superior outcomes in cognitive rehabilitation, while tDCS remains a safe, effective and practical option.
- The findings highlight the critical role of early intervention in optimizing rehabilitation potential.

**Plain Language Summary:**

stroke is one of the leading causes of death and disability worldwide. Its impact is increasing and it imposes a significant economic burden on healthcare systems. While advances in treatment, such as clot-dissolving therapies, have improved survival, many stroke survivors experience long-term disabilities. One major consequence is cognitive impairment following stroke, which affects up to 60% of patients in the first year.

non-invasive brain stimulation (NIBS) protocols have emerged as an efficient tool to enhance cognitive recovery. This comprehensive analysis attempts to compare the impact of NIBS techniques on post-stroke cognitive functions.

Overall, both magnetic and electrical brain stimulation improve cognitive function after stroke, with magnetic stimulation providing the greatest benefits .It was also found that earlier treatment leads to better therapeutic outcomes

## Introduction

Stroke remains a leading global health challenge. According to the recent World Stroke Organization (WSO) report on non-communicable disorders, stroke ranks as the second most common cause of death, and the third leading factor contributor to combined mortality and disability (measured by disability-adjusted life-years lost, [DALYs]). Notably, the global economic burden of stroke is estimated to account for approximately 0.66% of global GD(Gross domestic product). (Feigin et al., 2025) Furthermore, data from the Global Burden of Disease Study (1990–2019) collected from 204 countries, show a substantial increase in stroke burden, particularly in lower-income countries (including a 70.0% increase in incidence, 43.0% in deaths, 102.0% in prevalence, and 143.0% in DALYs).(Feigin, Stark, & CO, 2021)

the most prevalent type of stroke is Ischemic stroke, which accounts for approximately 80% of all reported cases.(Boehme et al., 2017) intracerebral hemorrhage (ICH) is the second most common subtype and is the most fatal form, contributing nearly 40% of stroke-related deaths.(Huang et al., 2022) The severity of Post-stroke cognitive impairment (PSCI) varies across stroke subtypes, and is generally more severe in hemorrhagic stroke. Overall, PSCI affects up to 60% of stroke survivors within the first year after the stroke onset. (N et al., 2023)

PSCI is influenced by a broad range of risk factors, which can be categorized into four main domains: metabolic, behavioral, dietary, and environmental determinants. Key metabolic risk factors include high systolic blood pressure, elevated body-mass index (BMI), high fasting plasma glucose, dyslipidemia, and reduced glomerular filtration rate. Behavioral factors such as smoking, poor diet, and low levels of physical activity, also play a significant role. In addition, several vulnerability factors have been associated with the development of PSCI, including stroke severity impact, recurrent strokes, baseline cognitive impairment, lesion location, and advanced age. (Feigin et al., 2025; N et al., 2023)

The clinical progression of stroke is typically classified into four phases: the acute stage (0-2 weeks), subacute stage (3-11 weeks), early chronic stage (12–24 weeks), and chronic stage (beyond 24 weeks). Among these phases, the most prominent functional recovery typically occurs during the subacute stage.(Rehme et al., 2011) In terms of cognitive deficits related to lesion location, the left frontotemporal cortex, left thalamus and right parietal lobe, identified as the regions most associated with post-stroke cognitive impairment. This evidence is supported by twelve cohorts of of acute ischemic stroke cases. (Weaver et al., 2021)

Although some medication and cognitive rehabilitation therapy are recommended for individuals with PSCI, concerns remain regarding potential adverse drug reactions and prolonged recovery times.(Urbanova et al., 2018) Consequently, in recent years, non-invasive brain stimulation (NIBS) has attracted increasing attention, as a promising intervention for enhancing cognitive impairment following stroke. Nonetheless, most existing studies have primarily focused on motor dysfunction rather than cognitive outcomes. (Yan et al., 2024)

Common NIBS techniques generally include repetitive transcranial magnetic stimulation (rTMS) and transcranial direct current stimulation (tDCS). NIBS mainly effects three key domains: modulation of cortical excitability, improving neuroplasticity, and promotion of cerebral blood flow. (Pino et al., 2014) Additionally, it may affect neural activity at the molecular level, specifically by modulating membrane potential and altering neurotransmitter dynamics. (Thut & Pascual-Leone, 2010) In contrast to TMS, tDCS does not directly induce action potentials, instead, it alters neuronal membrane polarity. Evidence suggests that tDCS upregulates the presynaptic release of excitatory neurotransmitters. It activates voltage-gated $Na^+$ and $Ca^{2+}$ channels on both pre- and postsynaptic membranes.(Korai et al., 2021; K. P. Li et al., 2023)

Previous studies have demonstrated that rTMS produces clinical improvements in individuals with Alzheimer's disease mild cognitive impairment (MCI), Psychosis management, alleviation of depression, and pain reduction. Moreover, it has shown promising effects on various post-stroke motor dysfunctions. (Lefaucheur et al., 2014) Considering established clinical guidelines, both rTMS and tDCS are considered safe, with rarely reported side effects. However, rTMS may trigger seizures in individuals with a history of seizure or some certain neurological disorders.(Nikolin et al., 2018; Rossi et al., 2021)

Although the existing literature supports the efficacy of NIBS on cognitive enhancement, the ranking of various NIBS modalities has not yet been properly assessed. Consequently, this gap in evidence, hinders the integration of NIBS into approved clinical protocols. This meta-analysis attempts to compare the impact of two NIBS mods, rTMS and tDCS on improving post-stroke cognitive function, and activities of daily living (ADL), in PSCI patients. We applied a network meta-analysis (NMA) to evaluate the domain-specific effects among several cognitive and daily activity domains. This approach offers the most comprehensive evidences.(Rouse et al., 2017)

## Methods:

This study was designed in accordance with the PRISMA guidelines. (Page et al., 2021).

**Search strategy**

Reports published from January 2018 to August 2024 were reviewed.

The search was performed in three electronic databases, including Medline via PubMed, Scopus and Psycinfo (APA), using a combination of free words and subject terms.

Additionally, the Google Scholar were reviewed as a supplementary source. The search formula was (stroke OR Post stroke OR CVA) AND (noninvasive brain stimulation OR transcranial direct current stimulation OR repetitive transcranial magnetic stimulation OR tDCS OR rTMS) AND (cognitive OR cognitive impairment) AND (Intervention OR Clinical trial OR randomized controlled trial OR RCT).

**Inclusion criteria**

- Participants: patients over 18 years old; with clinical diagnosis of hemorrhagic or ischemic stroke, confirmed by approved assessments and neuroimaging techniques, with significant cognitive impairment.

- Intervention: noninvasive brain stimulation modes (NIBS) including Repeated transcranial magnetic stimulation (rTMS) and transcranial direct current stimulation (tCDS)
  Study design: randomized controlled trial (RCT) or non-randomized interventions.

- Outcome: Global cognition severity scales, including Mini Mental State Examination (**MMSE**) and the Montreal Cognitive Assessment (**MoCA**),
  and ADL tasks quantified using Modified Barthel Index (**MBI**) and Functional Independence Measurement (**FIM**)

- Reporting sufficient data to compute the effect size (pre-post mean and standard deviations [SD])

**Exclusion criteria**

- Non- interventional studies
- Invasive interventions or other noninvasive brain stimulation, such as: Transcranial alternating current stimulation (tACS), Transcranial focused ultrasound (tFUS), Transcranial pulse stimulation (TPS), Theta Burst Stimulation (TBS), and Noninvasive Vagus nerve stimulation (nVNS)

- Isolated Interventions on all other types of post-stroke neurologic or mood disorders, such as depression or motor dysfunctions (i.e. Aphasia, Dysphagia, Apraxia, Dyskinesia, upper and lower limb dysfunctions)

- Any previous dementia or cognitive impairment disorders.
- Unavailable full text
- Failure to report the pre-post changes in cognitive functions or activities of daily living.

**Data extraction**

Data were extracted from the literature, including information from the main text, tables and supplementary materials. Contained the sample size, gender, age, disease duration, intervention details, allocation concealment, stimulation target, affected hemisphere, intervention duration, follow up time points, and outcome scales.

**Quality assessment**

The risk of bias in the included studies was independently evaluated using the Cochrane collaboration's tools for assessing the risk of bias in randomized trials (RoB2)("45: RoB 2: A Revised Tool for Assessing Risk of Bias in Randomised Trials," 2019) , and ROBINS-I was applied for non-randomized interventions. (Sterne et al., 2016; *Version 2 of the ROBINS-I Tool, Launched On*, 2024)

Data from studies at high risk of bias (in RoB2 tool) or critical risk of bias (in ROBINS-I tool) excluded from analysis. (shown in Fig2)

**Cognitive and ADL outcome scales**

The pre-post changes in the global cognitive severity were considered as the main outcome. It was quantified using MMSE and MoCa scales; (Arevalo-Rodriguez et al., 2015; Nasreddine et al., 2005)

Activities of daily living (ADL) scores were included as secondary outcomes to assess whether cognitive improvements translated into functional gains. The MBI and FIM scales were used to evaluate ADL abilities. (AW, 2015; T, 2017)

Further details about these scales are provided in Supplementary Appendix 1

Eventually the effectiveness of NIBS across different disease stages, was compared to control groups, using network meta-analysis.

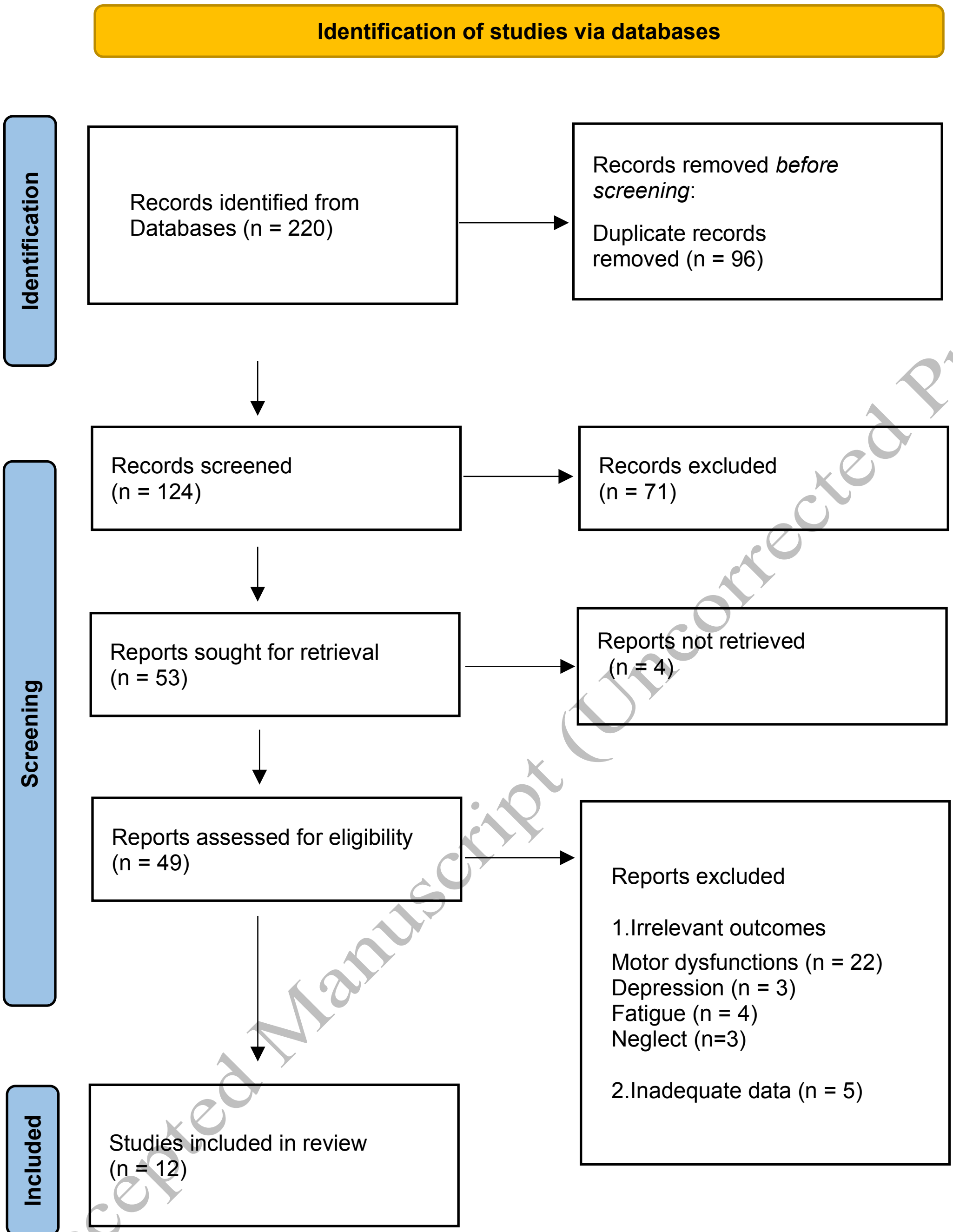
**Statistical analysis**

A network meta-analysis was conducted using R (version 4.4.2, *Netmeta* package 3. 1-1) (Balduzzi et al., 2023), applying a frequentist framework, to evaluate the efficacy of NIBS modalities in enhancing cognitive performance, primarily compared with a sham control Procedures.

Following the recommendations of the Cochrane Handbook for Systematic Reviews of Interventions, to ensure comparability and minimize measurement discrepancies, the standardized mean difference (SMD) was applied to estimate effect size, (Higgins et al., 2024) thereby facilitating a more consistent and interpretable comparison across studies.

Either fixed (common) or random-effects models were utilized depending on the magnitude of heterogeneity, as indicated by Higgins [$I^2$] statistic; when $I^2 \geq 50\%$ the random effects model, and if $I^2 < 50\%$ the fixed effects model was used. (Cumpston et al., 2019)
Results were reported with 95% confidence intervals (CIs) and statistical significance was set at $p \leq 0.05$."

In the network plots the direct comparisons between interventions and controls were represented by straight lines, with the line thickness indicating the number of studies included in each comparison (as shown in fig 3,5). Funnel plots were generated to assess data asymmetry, and the variance of effect size was measured using τ2 (tau2) statistic.
Finally, to rank the efficacy of each intervention, the Surface Under the Cumulative Ranking Curve (SUCRA) was utilized (probability ranging from 0% to 100%), with higher SUCRA values indicating greater effective [(Salanti et al., 2011)]. (Shown in fig 3,5)
There was only one three-arm intervention on cognitive regions, with one group receiving a combined tDCS and rTMS; This group was excluded from the analysis, and only the rTMS group was retained.(Hu et al., 2023b)






Source: Page MJ, et al. BMJ 2021;372:n71. doi:10.1136/bmj.n71.

**Figure 1.** Flow diagram illustrating the selection of studies for inclusion in the network meta-analysis

| Study | Study design | Groups | N | Disease duration | Stimulation target | Cognitive & ADL outcomes |
|---|---|---|---|---|---|---|
| **rTMS** | | | | | | |
| Yamei Li et al.(Y. Li et al., 2020) | Double blind RCT | rTMS | 15 | 22.73 ± 8.05 d | Left DLPFC | MMSE MoCA |
| | | sham | 15 | 19.13 ± 7.95 d | | |
| An-Ming Hu et al.(Hu et al., 2023a) | Double blind RCT | rTMS | 12 | 96.25 ± 29.11 d | Left DLPFC | MoCA |
| | | sham | 12 | 105.83 ± 44.20 d | | |
| Mingyu Yin et al. (Yin et al., 2020) | Double blind RCT | rTMS | 16 | 52(38.25–98.75) d | Left DLPFC | MoCA MBI |
| | | sham | 18 | 55 (39.75–94.75) d | | |
| Yuanwen Liu et al. (Liu et al., 2020) | Double blind RCT | rTMS | 29 | 8.79 (1.84) m | Left DLPFC | MMSE FIM |
| | | sham | 29 | 8.62 (1.84) m | | |
| Hong Li et al. (H. Li et al., 2021) | Single blind RCT | rTMS | 33 | 28.64±12.60 d | DLPFC | MoCA |
| | | sham | 32 | 27.78±11.01 d | | |
| Zhang et al(Zhang et al., 2023) | Retrospect intervention analysis | rTMS + rehab | 61 | 23.8 ± 2.6 d | DLPFC | MoCA MBI |
| | | rehab | 58 | 23.3 ± 3.0 d | | |
| Byoungwoo Cha et al.(Cha et al., 2022) | Before & after | rTMS | 10 | 29.5 ± 49.5 m (6–169) | Left DLPFC | MoCA MMSE MBI |
| **tDCS** | | | | | | |
| Ahmed Shaker et al.(Shaker et al., 2018) | Double blind RCT | tDCS + rehab | 20 | 14.05 ± 1.53 m | DLPFC | FIM |
| | | Sham + rehab | 20 | 16.55 ± 2.78 m | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Zhengtao Wang et al.(Z. Wang et al., 2022) | single-blind RCT | tDCS | 12 | 13.33(10.66) w | Left DLPFC | MoCA ADL |
| | | sham | 12 | 16.00 (8.82) w | | |
| Myoung-Hwan Ko et al.(Ko et al., 2022) | Double blind RCT | RS-tDCS + rehab | 12 | ≥6 month | Left DLPFC | MoCA |
| | | Sham + rehab | 14 | ≥6 month | | |
| Caihong Yang et al.(Yang et al., 2022) | Openlable RCT | tDCS | 22 | 2-25 w | Left DLPFC | MMSE MoCA |
| | | Healthy no IV | 14 | none | | |
| Zafran Ahmad et al.(Ahmad et al., 2022) | Double blind RCT | tDCS | 22 | 17.63 ± 13.75 nm | Cerebellum | MMSE MoCA |
| | | sham | 22 | 18.18 ± 13.1 nm | | |

**Table 1.** Demographic and clinical characteristics of the included studies

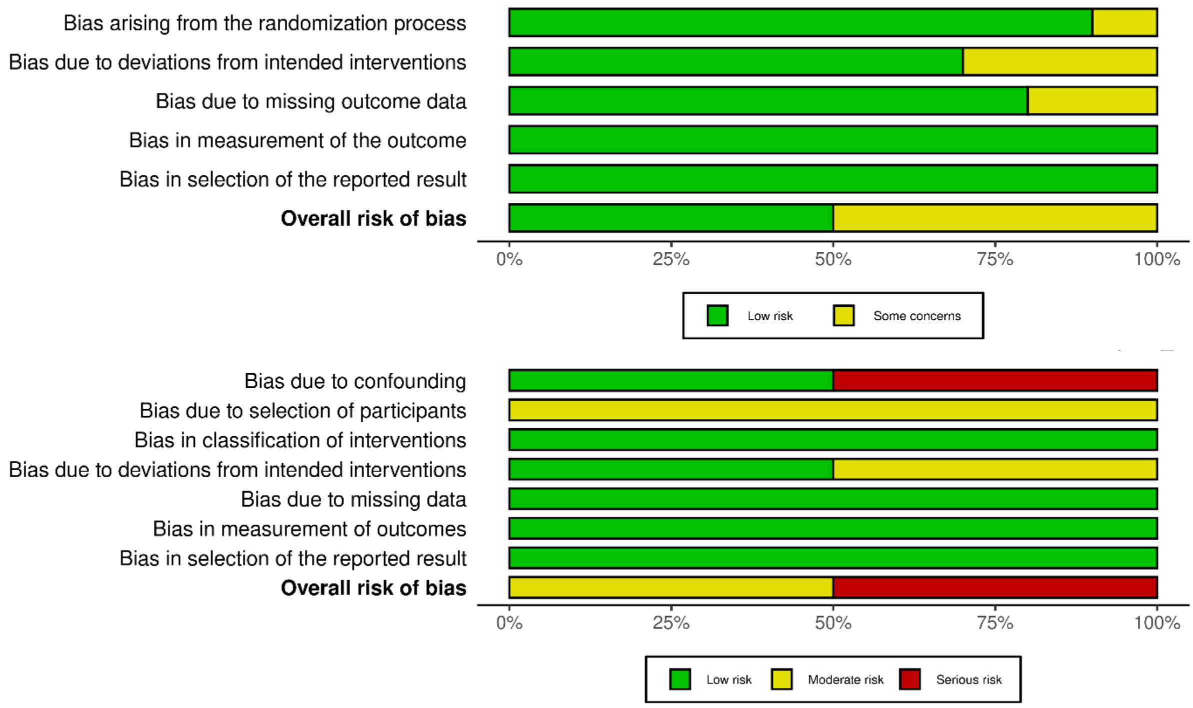



**Figure 2.** Risk of bias, ROB and ROBVIS Summary plots:

## Results:

### Study characteristics

The study selection process is presented in Fig.1; And Table 1 provides the detailed characteristics of the included studies.

In this network meta-analysis, a total of 510 participants were included across three groups: rTMS (176 participants), tDCS (88 participants), and control (246 participants). The demographic breakdown of participants within each group shows a higher proportion of male participants; rTMS (106 males, 70 females), tDCS (62 males, 26 females), and control (163 males, 83 females). Overall, the analysis included 331 male and 179 female participants. Additionally, 248 participants were in the subacute phase, whereas 138 participants were in the chronic phase. The pooled mean age of the participants across all groups was 59.38 ±7.67 years.

Table 2. The Pre-Post Changes in each outcome Measurement.

| **Cognitive and ADL outcome scores** | | | | | |
|---|---|---|---|---|---|
| | intervention | SMD | 95%-CI | z | p |
| **MoCA** | tDCS | 1.52 | [0.66; 2.38] | 3.48 | 0.0005 |
| | rTMS | 2.66 | [1.93; 3.39] | 7.16 | < 0.0001 |
| **MMSE** | tDCS | 1.91 | [-0.19; 4.00] | 1.79 | 0.0741 |
| | rTMS | 2.43 | [0.96; 3.89] | 3.25 | 0.0012 |
| **ADL** | tDCS | 6.13 | [-2.19; 14.45] | 1.44 | 0.149 |
| | rTMS | 5.07 | [-1.40; 11.55] | 1.54 | 0.124 |
| **Various stages of recovery** | | | | | |
| | intervention | SMD | 95%-CI | z | p |
| **Subacute** | tDCS | 5.11 | [2.81; 7.41] | 4.35 | < 0.0001 |
| | rTMS | 2.81 | [2.03; 3.59] | 7.03 | < 0.0001 |
| **Chronic** | tDCS | 0.91 | [-0.66; 2.49] | 1.14 | 0.254 |
| | rTMS | 1.89 | [0.20; 3.57] | 2.19 | 0.029 |

## Cognitive outcomes:

**MoCA**

The network connections for the different NIBS, using MoCA as the outcome indicator, are shown in Fig 3. The results indicated that both interventions improved MoCA compared with control. rTMS showed a larger effect (SMD = 2.66, 95% CI [1.93, 3.39], $p < 0.0001$) than tDCS (SMD = 1.52, 95% CI [0.66, 2.38], $p = 0.0005$). Heterogeneity was moderate ($\tau^2 = 0.898$, $I^2 = 41.1\%$), with no significant within-design heterogeneity (Q = 13.59, df = 8, $p = 0.093$) and no detected between-design inconsistency (Q = 0.00, df = 0). SUCRA values were rTMS = 86% and tDCS = 85%.

**MMSE**

Next plot in Fig. 3 illustrates the network connections among the various NIBS, with MMSE serving as the outcome measure. The rTMS significantly improved MMSE versus control (SMD = 2.43, 95% CI [0.96, 3.89], $p = 0.001$), while tDCS was not significant (SMD = 1.91, 95% CI [-0.19, 4.00], $p = 0.074$). Heterogeneity was low ($\tau^2 = 0.252$, $I^2 = 10.6\%$), with no significant within-design heterogeneity (Q = 3.36, df = 3, $p = 0.340$) and no detected between-design inconsistency (Q = 0.00, df = 0). These results support the assumptions of homogeneity and consistency across the network. SUCRA values were rTMS = 66% and tDCS = 62%.

**ADL**

Neither rTMS nor tDCS significantly improved ADL versus control (rTMS: SMD = 5.07, 95% CI [-1.40, 11.55], $p = 0.124$; tDCS: SMD = 6.13, 95% CI [-2.19, 14.45], $p = 0.140$). Heterogeneity was substantial ($\tau^2 = 30.67$, $I^2 = 81.8\%$), with significant within-design heterogeneity (Q = 21.96, df = 4, $p = 0.0002$) and no detected between-design inconsistency (Q = 0.00, df = 0).

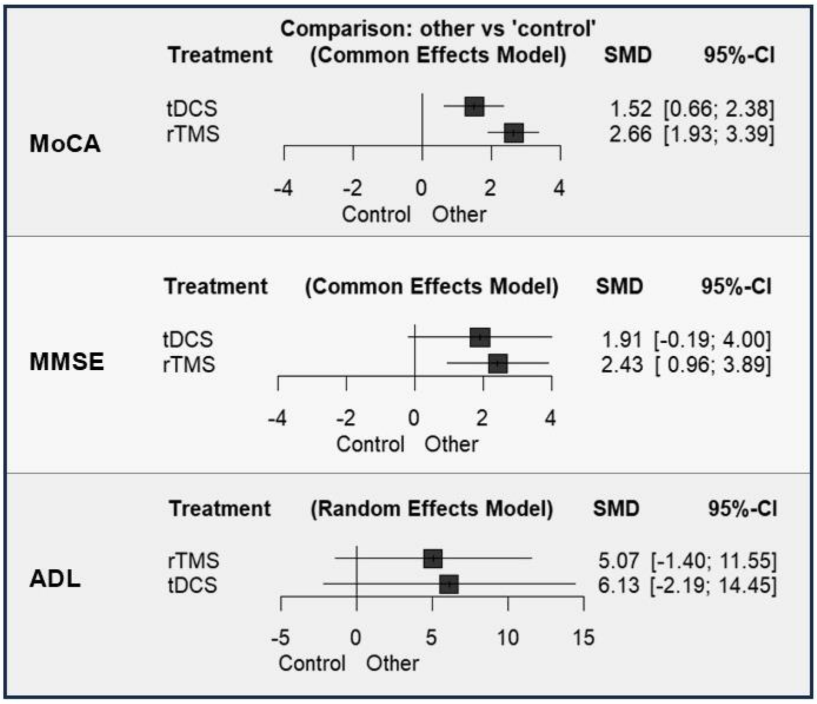



Figure 3

**Figure 3.** Forest Plots of Cognitive Function and ADL Scores in NIBS Protocols vs. Control Groups.

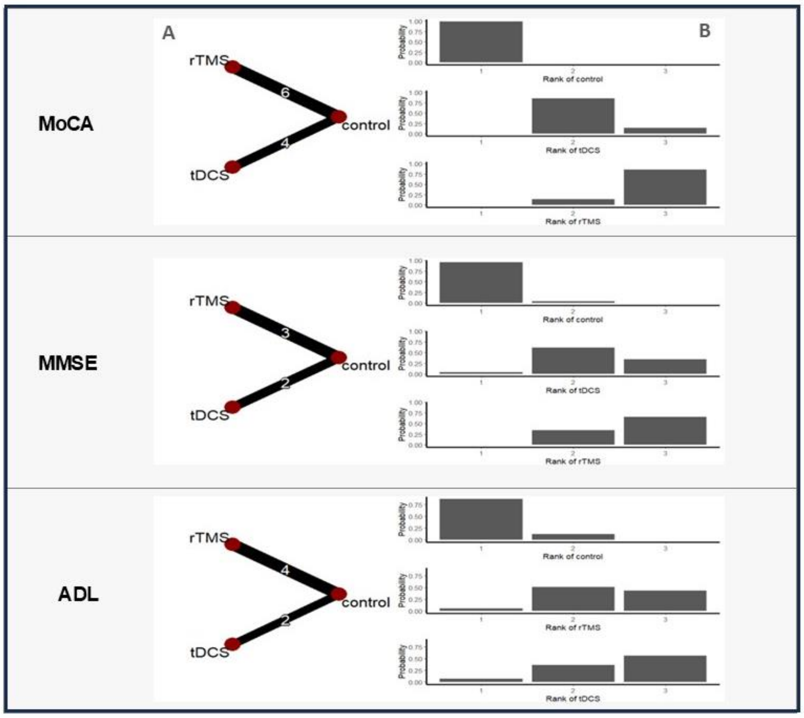



Figure 4

**Figure 4.** The network plots(A) and SUCRA plots(B), in NIBS Protocols vs. Control Groups.

## Phase-specific Effects:

### Subacute stag

Using a random-effects NMA (Fig. 5–6), both interventions significantly improved outcomes versus control in the subacute phase: rTMS (SMD = 2.75, 95% CI [2.03, 3.47], $p < 0.0001$) and tDCS (SMD = 5.11, 95% CI [2.83, 7.39], $p < 0.0001$). Heterogeneity was minimal ($\tau^2 = 0.0559$; $I^2 = 4.7\%$), with no significant within-design heterogeneity (Q = 5.25, df = 5, p = 0.387) and no detected between-design inconsistency (Q = 0.00, df = 0).

### Chronic stage

In the chronic phase (Fig. 5–6), rTMS showed a significant benefit versus control (SMD = 1.89, 95% CI [0.20, 3.57], p = 0.029), whereas tDCS was not significant (SMD = 0.92, 95% CI [-0.66, 2.49], p = 0.254). No heterogeneity was detected ($\tau^2 = 0$; $I^2 = 0\%$), with no significant within-design heterogeneity (Q = 0.45, df = 4, p = 0.978) and no detected between-design inconsistency (Q = 0.00, df = 0).

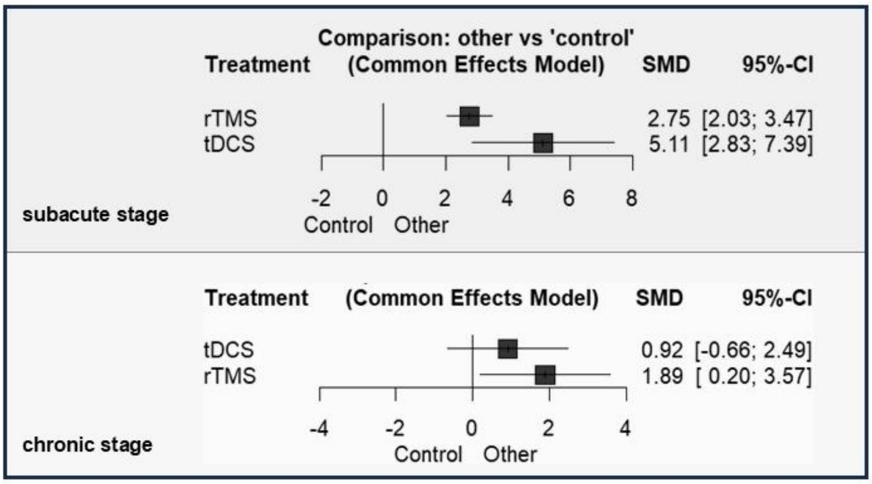



Figure 5

**Figure 5.** Forest Plots of Cognitive enhancement in stroke stages vs. Control Groups.

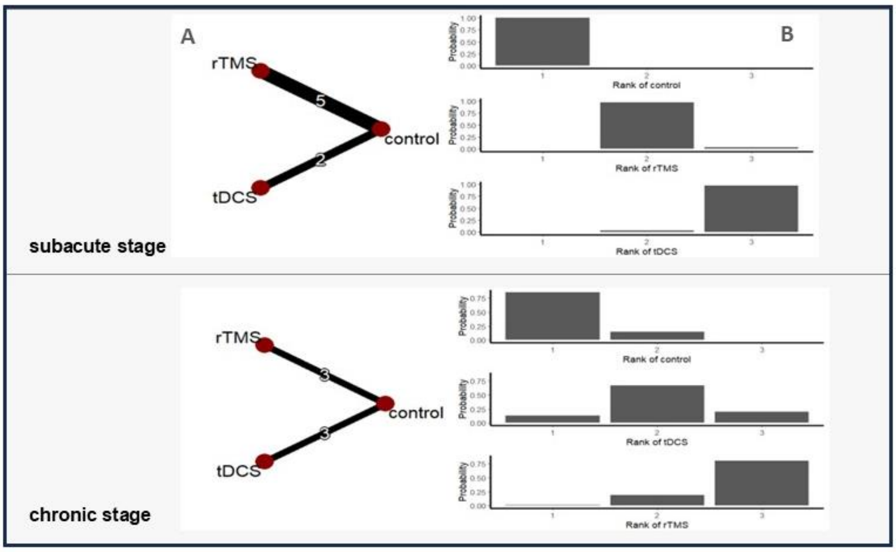



Figure 6

**Figure 6.** The network plots(A) and SUCRA plots(B), in stroke stages vs. Control Groups.

The funnel plots of the included literature showed that the data scatter was generally symmetrical, and the Meta-analysis results were reliable (Fig 7).

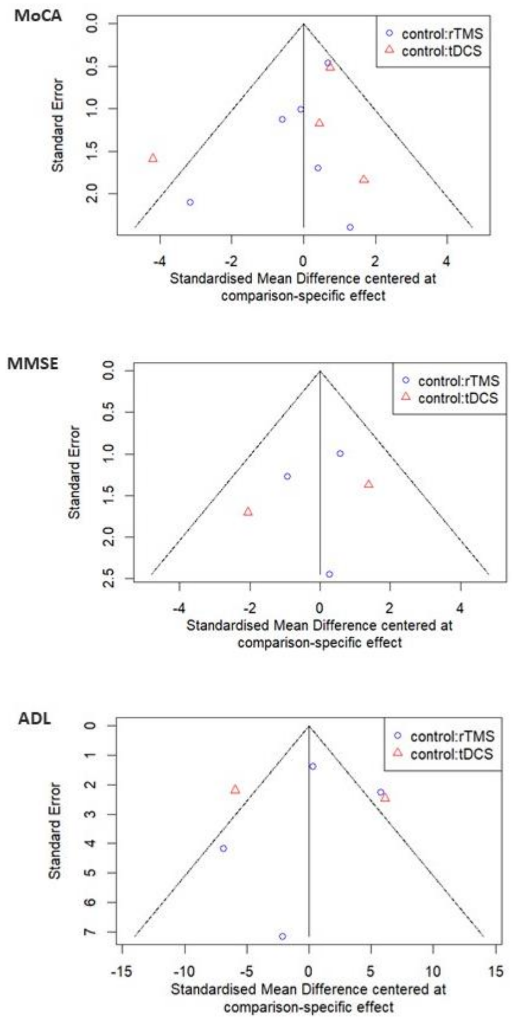



**Figure 7.** The funnel plots of the included studies

## Discussion:

### Main findings:

The present network meta-analysis evaluated the efficacy of rTMS and tDCS in 510 patients with post-stroke cognitive impairment. Most participants were at the subacute stage, a phase typically associated with substantial neurological and cognitive changes following a stroke. The results of the NMA indicated that both tDCS and rTMS significantly improve cognitive function in PSCI patients; With rTMS showing a greater effect on global cognition performance.

- The baseline variables, such as age, disease recovery stage, and treatment duration, could influence how patients respond to neuromodulatory interventions.

Although no significant statistical heterogeneity was observed according to Higgins' $I^2$ and Cochran's Q statistics, potential clinical heterogeneity related to baseline characteristics, intervention intensity, and treatment duration was considered in result interpretation.

The absence of ADL improvement could be attributed to high heterogeneity in measurement tools; In six studies that assessed ADL, three different scales were used, and despite applying the Standardized Mean Difference, the heterogeneity was not fully resolved, which may have reduced the statistical power of the meta-analysis.
Nevertheless, individual studies have generally reported improvement in ADL abilities, suggesting that the interventions may still be effective despite challenges in pooling the data.

- Our findings are largely consistent with previous studies. Several meta-analyses, including those by Mengyu et al.(Yan et al., 2024) and HRA (Hara et al., 2021), have reported a greater effect of rTMS on cognitive function compared with tDCS.
  Conversely, a smaller number of studies, such as Wang,(Y. Wang et al., 2022) have suggested that tDCS may have a greater effect on cognitive improvement. This variability may be due to differences in patients' baseline characteristics, methodological approaches, and other contextual factors across the studies.

- In terms of the importance of timing for treatment initiation, understanding intervention efficacy across disease stages helps clinicians optimize treatment strategies. Neurological and functional recovery primarily occur in the acute and subacute stages, emphasizing the important role of prompt intervention in optimizing rehabilitation potential.(Jung, 2017)
  Our study identified the most significant effects during the subacute stage, which is consistent with previous literature.
  However, some therapeutic effects were also noted during the chronic phase, but they were more limited; in line with the findings of Maggio et.al.(Maggio et al., 2024)

**Stroke clinical neuroscience insights:**

- Post-stroke interventions have undergone significant developments over the past two decades. In 1995, the National Institute of Neurological Disorders and Stroke (NINDS) presented the tissue-type plasminogen activator (tPA) trial, which started a paradigm shift in the management of ischemic stroke(Campbell et al., 2015)consequently, as stroke survival rates have improved with reperfusion medication, post-stroke disabilities have become more prevalent.(Feigin, Stark, Johnson, et al., 2021)
  Early thrombolytic therapy, such as Alteplase, has demonstrated a favorable safety profile, with cognitive improvement effects. (J. Wang et al., 2021)

- In the context of stimulation location in PSCI patients, the Dorsolateral Prefrontal Cortex (DLPFC) is the most frequently targeted region for cognitive recovery in non-invasive brain stimulation procedures. It plays a crucial role in cold executive functions, differentiating it from regions involved in emotional and reward-related processing (hot executive functions). (Dedoncker et al., 2016; Nejati et al., 2018)
  The DLPFC was primary stimulation target in the majority of our included studies.

- According to the interhemispheric competition theory, following a stroke, the healthy hemisphere may compensate for some functions of the lesioned hemisphere. This interhemispheric imbalance can lead to overactivity in the unaffected hemisphere and excessive inhibition of the damaged one; which may potentially prevent optimal recovery. the rTMS has been shown to modulate this imbalance and promote functional reorganization.(Boddington & Reynolds, 2017)
  Only a limited number of studies included in our analysis, examined the dual approach of simultaneously inhibiting the contralesional hemisphere while stimulating the ipsilesional hemisphere.

- With respect to excitatory and inhibitory effects, rTMS coils generate a pulsating magnetic field, with high-frequency (≥5 Hz) that associated with excitatory effects and low-frequency (≤1 Hz), associated with inhibition.(Lefaucheur et al., 2014) Similarly, anodal tDCS polarization known to enhance cortical excitability, whereas cathodal stimulation tends to induce inhibitory effects.(Nitsche et al., 2003)

- In the context of stimulation focality, rTMS particularly with figure-8 coils, provides more localized stimulation. While tDCS is more cost-effective and convenient than rTMS, it typically produces broader and less focal stimulation. the HD-tDCS configurations appear to improve focality compared to traditional setups.(M et al., 2020); however, none of the studies included in our analysis, employed this method.

- post stroke cerebral vascular occlusion, contributes to tissue infarction resulting in an ischemic semi-dark zone (ischemic penumbra) between the ischemic and normal tissue; it may cause an ischemic white matter lesions and cognitive impairment. NIBS has been proven to modulate cerebral blood flow, which improves cognitive performance. (Nabs et al., 2019) As evaluated in the study by D. Knoch, which assessed cerebral perfusion using PET scan (positron emission tomography); the TMS exerts differential effects on cerebral blood flow, dependent on the stimulation frequency and targets. (Knoch et al., 2006)

**Strengths, limitations and future prospects**

The included studies involved patients at different stages; Acknowledging that recovery responses may vary based on disease duration, we conducted a comparative analysis across these different stages.

The main limitation of our study was the non-systematic search strategy. Despite this limitation, a structured literature screening process was performed.
Moreover, network meta-analysis employed in this synthesis is considered as the most effective method for determining the optimal treatment approach in clinical contexts, providing the most comprehensive and robust evidence currently available. (Rouse et al., 2017)

The prefrontal cortex, as the most recently evolved region of the brain, has relatively limited structural support from the skull, and is the most vulnerable brain part; This region performs an essential role in higher-order cognitive functions.

If non-invasive brain stimulation is shown to be effective in enhancing cognitive performance, it may hold potential for widespread application across various forms of cognitive decline.

## Conclusion:

The available evidence indicates that both rTMS and tDCS, significantly improve cognitive function in post-stroke patients; however, the rTMS demonstrated greater effects on cognitive outcomes. Furthermore, the most substantial impacts were observed at the subacute stage of recovery.
In contrast, neither rTMS nor tDCS showed statistically significant improvements in activities of daily living (ADL), likely due to the limited number of included studies and substantial heterogeneity across ADL-related outcome indicators.

Overall, NIBS could be considered as a recommended approach for improving global cognitive function in PSCI patients.

Future clinical trials are warranted to clarify optimal stimulation parameters, including stimulation target, intervention duration and inter-individual factors such as cognitive reserve variability.
Moreover, integrating advanced neurophysiological and neuroimaging tools, would be essential to develop a personalized patient-dependent neueomodulation approach; Ultimately lead to more efficient rehabilitation strategy for PSCI.

**Declarations:**

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**Appendix 1**

- ✓ **MoCA.** The Montreal Cognitive Assessment is a 30-point scale that covers multiple cognitive domains including spatiotemporal orientation, sustained attention, visuospatial function, executive function, verbal memory, language, naming, and abstract thinking.

- ✓ (**MMSE**). The Mini-Mental State Examination was used for the assessment of the overall cognitive function. The higher the score, the better the cognitive function. 27 points or more are considered as normal.

- ✓ **FIM** Functional Independence Measure; was used to evaluate the functional independence of the activities of daily living. The higher the score, the better the independence.

- ✓ **MBI**. Modified Barthel ADL index, Measure of physical disability used widely to assess behaviour relating to activities of daily living for stroke patients or patients with other disabling conditions.

**Appendix 2**

The study protocol has been registered in non-public format and can be provided to researchers upon reasonable request.

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