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REVIEW

Transcranial Magnetic Stimulation Combined with Speech-Language Therapy for Post-Stroke Aphasia Recovery: A Systematic Review and Network Meta-Analysis

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Background: Speech-language therapy (SLT) is standard care for post-stroke aphasia (PSA), and adjunctive transcranial magnetic stimulation (TMS) may further improve language function. Which TMS protocol optimally complements SLT for which language domain at which time point remains unresolved, motivating this network meta-analysis.

Objective: To compare TMS protocols combined with SLT across immediate and long-term language outcomes in post-stroke aphasia.

Methods: Web of Science, EMBASE, PubMed, and the Cochrane Library were searched from inception to 24 January 2026 for randomized trials of TMS plus SLT in post-stroke aphasia. Bayesian network meta-analyses were run in R 4.4.2 with the gemtc and rjags packages, with outcomes grouped into seven immediate and four long-term language domains and effect sizes reported as standardized mean differences (SMDs) with 95% credible intervals (CrIs). Treatments were ranked by the surface under the cumulative ranking curve (SUCRA), and certainty of evidence was rated using GRADE (Grading of Recommendations Assessment, Development and Evaluation).

Results: Across 26 trials enrolling 1,136 patients, three protocols led across the language domains. LF-rTMS+Music+SLT ranked first for immediate aphasia severity (SUCRA = 96.86%), repetition (97.25%), naming (99.69%), and spontaneous speech (95.67%); LF-rTMS+SLT, for writing (87.73%); and Dual-rTMS+SLT, for immediate functional communication (91.49%) and comprehension (97.57%). Dual-rTMS+SLT was also optimal across all four long-term outcomes (overall aphasia severity 95.82%, comprehension 95.06%, naming 99.74%, repetition 97.90%). Heterogeneity was low-to-moderate (moderate-to-high for immediate aphasia severity), and all Bayesian models converged (PSRF < 1.05). Evidence was moderate-to-high for standard comparisons (LF-rTMS+SLT vs SLT) but low to very low for the highest-ranked novel combinations such as LF-rTMS+Music+SLT, driven by imprecision and indirectness.

Conclusion: The optimal TMS-plus-SLT protocol depends on which language domain and which time point matters. LF-rTMS+Music+SLT led the immediate domains, while Dual-rTMS+SLT led the long-term domains. Standard adjunctive comparisons (e.g. LF-rTMS+SLT vs SLT) rest on moderate-to-high certainty evidence, but the highest-ranked novel combinations rest on low-certainty evidence and require head-to-head confirmation.

Keywords: stroke, cerebrovascular accident, aphasia, transcranial magnetic stimulation, network meta-analysis

Introduction

Stroke is the second leading cause of death and disability-adjusted life years (DALYs) lost worldwide and represents a major public health burden.[1,2] Aphasia, defined as partial or complete impairment of language function, affects

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Graphical Abstract

Transcranial Magnetic Stimulation Combined with Speech-Language Therapy for Post-Stroke Aphasia Recovery: A Network Meta-Analysis

Background

Post-stroke aphasia (PSA) affects ~30% stroke survivors
Speech-language therapy (SLT) is standard care
Optimal TMS+SLT protocol remains unclear

Methods

Web of Science, EMBASE, PubMed, and the Cochrane Library were searched from inception to January 24, 2026. Risk of bias was assessed using Cochrane RoB 2.0. A Bayesian NMA was performed using R 4.4.2 and Stata 18.

Conclusion

Optimal TMS+SLT depends on language domain & time point
Short-term: LF-rTMS+Music+SLT is best
Long-term: Dual-rTMS+SLT is best
Head-to-head trials are needed for confirmation

Results

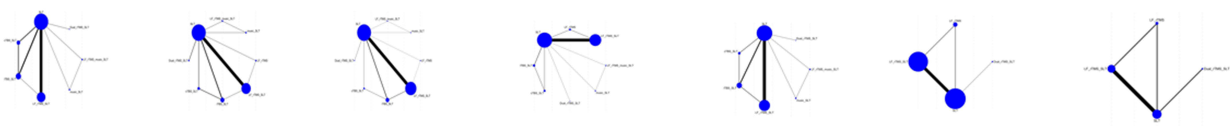
26 RCTs (1,136 patients).

Immediate Outcomes (Post-treatment)

Language Domain	Most Effective Intervention	SUCRA
Aphasia severity	LF-rTMS + Music + SLT	96.86%
Repetition	LF-rTMS + Music + SLT	97.25%
Naming	LF-rTMS + Music + SLT	99.69%
Spontaneous speech	LF-rTMS + Music + SLT	95.67%
Writing	LF-rTMS + SLT	87.73%
Comprehension	Dual-rTMS + SLT	97.57%
Functional communication	Dual-rTMS + SLT	91.49%

Long-term Outcomes (Follow-up)

Language Domain	Most Effective Intervention	SUCRA
Aphasia severity	Dual-rTMS + SLT	95.82%
Repetition	Dual-rTMS + SLT	97.90%
Naming	Dual-rTMS + SLT	99.74%
Comprehension	Dual-rTMS + SLT	95.06%



approximately 30% of stroke survivors.[3] This condition is associated with increased risks of anxiety and depression, reduced social participation, and diminished quality of life.[4–7] Effective therapeutic strategies are therefore urgently needed.

Current rehabilitation approaches for PSA include pharmacological treatments, music therapy, speech-language therapy (SLT), and non-invasive brain stimulation (NIBS).[8] Pharmacological interventions, including conventional drugs and herbal formulations, have shown limited and inconsistent efficacy.[9,10] Their mechanisms remain unclear, and no agent has received regulatory approval specifically for the treatment of aphasia.[11,12] Music therapy has shown potential benefits, but further validation is needed before broad clinical implementation.[13,14] SLT remains the gold-standard behavioral intervention. However, its effectiveness often depends on intensive and sustained practice, which may not be feasible for all patients.[15,16] More effective and individualized strategies are therefore needed.

Non-invasive brain stimulation (NIBS) techniques, particularly transcranial magnetic stimulation (TMS) and transcranial direct current stimulation (tDCS), have emerged as neuromodulatory approaches that enhance cortical neuroplasticity and support language recovery.[8,17,18] TMS comprises repetitive TMS (rTMS) and theta-burst stimulation (TBS); TBS subdivides into excitatory intermittent (iTBS) and inhibitory continuous (cTBS) forms.[19] Combining NIBS with SLT is neurophysiologically motivated: transient modulation of cortical excitability primes the learning and reorganisation triggered by subsequent language training.[20–22]

Several meta-analyses[18,22–24] reported beneficial effects of rTMS on language recovery in PSA, with preliminary evidence that rTMS combined with SLT yields greater improvements than SLT alone, particularly in auditory comprehension, naming, repetition, and spontaneous speech.[25,26] The synthesis base is nonetheless limited. An AMSTAR 2[27] appraisal of existing rTMS reviews[28] found multiple methodological shortcomings: unregistered review protocols, missing justifications for excluded studies, inadequate description of participants and stimulation parameters, neglected risk-of-bias when interpreting results, incomplete reporting of stimulation sites and coil types, and inconsistent data extraction across reviews. Three further constraints persist: (i) some syntheses evaluated rTMS without requiring concurrent SLT,[29,30] however, given that SLT is the cornerstone of aphasia rehabilitation, such a requirement is essential for clinical applicability, and its absence limits the relevance of those syntheses; (ii) recent RCTs of newer protocols such as iTBS and cTBS[31–34] have not been incorporated into existing networks.[18,22–24,35,36] (iii) some reviews included non-randomized studies,[29] provided focused syntheses of specific domains such as action naming[37] rather than a comprehensive multi-domain comparison,or on restricted outcome selection,[36] or omitted detailed stimulation parameters[24] or long-term effects.[38]

This network meta-analysis addresses these gaps by restricting inclusion to randomized trials of TMS combined with concurrent SLT, incorporating recent TBS trials, evaluating 11 outcome measures across 7 language domains, and assessing both immediate and follow-up effects. The certainty of each ranking was rated under the GRADE framework.

Methods

Design and Registration

This network meta-analysis followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Network Meta-Analyses (PRISMA-NMA).[39] The protocol was prospectively registered in PROSPERO (CRD42024602404).

Search Strategy

Two independent reviewers (J.E.L. and Y.J.B.) searched Web of Science, EMBASE, PubMed, and the Cochrane Library from inception to January 24, 2026. No restrictions were applied to date, publication status, or document type. The search strategy combined Medical Subject Headings (MeSH) and free-text terms for keywords such as "stroke," "cerebrovascular accident," "transcranial magnetic stimulation," "rTMS," "cTBS," and "aphasia," along with related variants (see Table S1 for the full search strategies).

Inclusion and Exclusion Criteria

Eligibility followed the Population, Intervention, Comparison, Outcome, and Study Design (PICOS) framework, restricted to English-language randomized controlled trials (RCTs). Eligible participants were adults aged ≥18 years with PSA diagnosed by standardized clinical assessment. Eligible interventions were any TMS protocol (LF-rTMS, high-frequency rTMS (HF-rTMS), iTBS, cTBS, or Dual-rTMS) combined with SLT, provided that identical adjuvant treatments were used in both groups. Comparators were sham or placebo TMS combined with SLT, SLT alone, or other conventional therapies. Outcomes were immediate and long-term language improvement plus adverse events, assessed using validated instruments: the Montreal-Toulouse Protocol,[40] Western Aphasia Battery (WAB),[41] Aachen Aphasia Test (AAT),[42] Concise Chinese Aphasia Test (CCAT),[43] Boston Diagnostic Aphasia Examination (BDAE),[44,45] WAB-Revised,[46] Hemispheric Stroke Scale (HSS),[47] Standard Language Test of Aphasia (SLTA),[48] Boston Naming Test (BNT),[49] semantic verbal fluency tasks,[50–52] 36-item Token Test (TT),[53] Test of Language Assessment in Aphasia (ADD),[54] Picture Naming Test-Turkish (T-RAT),[55] International Picture Naming Database,[56] Functional Independence Measure (FIM),[57] Amsterdam-Nijmegen Everyday Language Test (ANELT),[58] and the Snodgrass-Vanderwart picture inventory.[59] These instruments mapped to seven outcome domains: aphasia severity, naming, repetition, spontaneous speech, comprehension, functional communication, and writing. Immediate and long-term effects were analyzed separately within each domain. Where multidomain scales were used (eg., WAB, AAT, BDAE), subscale scores were assigned to prespecified domains following the original test structure and prior literature.

Because very small studies are susceptible to small-study effects and yield unstable estimates, we excluded those with fewer than 20 participants[60–62] (one study was excluded on this basis). Studies were also excluded for unclear diagnostic or efficacy criteria, non-extractable data, or TMS combined with medications or acupuncture. Non-original studies (reviews, meta-analyses, case reports, animal studies, conference abstracts, guidelines, letters) were also excluded.

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Study Selection

After duplicates were removed in EndNote 21, two reviewers (J.E.L. and Y.J.B.) independently screened titles and abstracts. Full texts of potentially eligible studies were then assessed. Disagreements were resolved through discussion or consultation with a third reviewer (M.F). The selection process is shown in the PRISMA flow diagram (Figure 1).

Data Extraction and Quality Assessment

Data were extracted using standardized Cochrane forms, capturing study characteristics (title, author, year, and country), participant characteristics (sample size, age, sex, handedness, stroke type, aphasia type, and time post-stroke), intervention details (TMS protocol and parameters, stimulation site, content and timing of SLT relative to TMS, treatment duration, and follow-up period), and outcome data (means, standard deviations, numbers of adverse events, and measurement scales). For multi-arm trials with both eligible and ineligible neuromodulation arms, only the arms relevant to the TMS-based network were extracted. One reviewer (J.E.L.) extracted the data, a second (Y.J.B.) verified them, and a third (M.F.) adjudicated discrepancies.

Risk of bias for each included RCT was assessed independently by two reviewers (J.E.L. and Y.J.B.) using the Cochrane Risk of Bias tool for randomized trials (RoB 2.0).[63] Each study was evaluated across five domains and

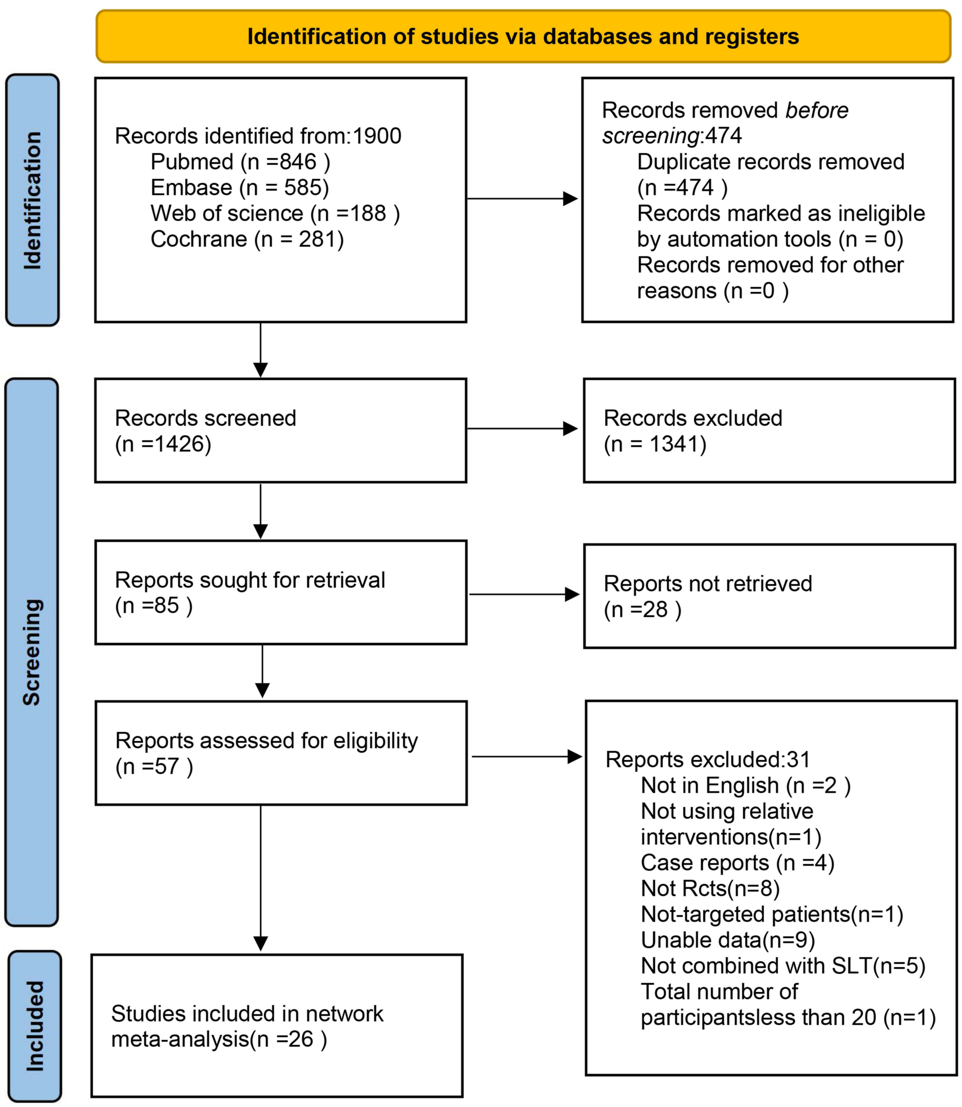

Figure 1 PRISMA flow diagram for search and selection of eligible studies included in the NMA.

assigned a judgment of “low risk,” “some concerns,” or “high risk.” An overall high risk of bias was assigned if any domain was rated as high risk, whereas an overall low risk required all domains to be rated as low risk. Disagreements were resolved through discussion or consultation with a third reviewer (M.F).

Certainty of evidence was assessed using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach.[64,65] For each comparison and outcome, certainty was rated as high, moderate, low, or very low,[66,67] based on risk of bias, inconsistency, indirectness, imprecision, publication bias, intransitivity, and incoherence. Imprecision was rated following GRADE guidance.[68] Where incoherence occurred, the estimate with higher certainty between direct and indirect evidence was adopted.

Statistical Analysis

A Bayesian framework was applied using JAGS through the gemtc (version 0.8–2) and rjags (version 4–10) packages in R (version 4.4.2). Continuous outcomes were expressed as standardized mean differences (SMDs) with 95% credible intervals (CrIs). Random-effects models were used to account for clinical and methodological heterogeneity across studies. The surface under the cumulative ranking curve (SUCRA) and mean ranks were calculated to rank the interventions. Higher SUCRA values, ranging from 0% to 100%, indicated a greater probability that an intervention was the most effective or safest option. Consistency between direct and indirect comparisons was assessed using the deviance information criterion (DIC), with a difference of less than 5 indicating acceptable consistency. Publication bias was assessed visually using comparison-adjusted funnel plots in Stata 18.0.

Prior distributions and model implementation: Non-informative priors were used for all model parameters to let the data dominate the posterior. The relative effect parameters were assigned a normal distribution with mean 0 and SD = 15 x om.scale, where om.scale is a data-derived scale parameter defining the prior range for continuous outcomes. The between-study heterogeneity SD (τ) followed a uniform prior on [0, om.scale] ($\tau \sim$ Uniform(0, om.scale)). Markov chain Monte Carlo (MCMC) simulations used four independent chains with 5,000 burn-in and 20,000 sampling iterations. Heterogeneity, convergence, and visual diagnostics: Heterogeneity was assessed using tau values categorised by established guidelines: low (<0.04), low-to-moderate (0.04–0.16), moderate-to-high (0.16–0.36), and high (>0.36).[69,70] Uncertainty of the heterogeneity estimate was quantified by the 95% credible interval (CrI) for τ^2. Model convergence was assessed by the Brooks-Gelman-Rubin diagnostic, with PSRF < 1.05 indicating adequate convergence for all parameters.[71] Diagnostic plots provided visual validation: trace plots confirmed adequate chain mixing and the absence of trends, and posterior density plots characterised the shape and variability of the posterior distribution.

Results

Search Results

The initial database search identified 1,900 records. After removal of 474 duplicates, 1,426 studies underwent title and abstract screening according to predefined criteria, and 1,341 were excluded. A total of 85 full-text articles were sought for retrieval; 28 could not be obtained, and the remaining 57 were assessed for eligibility. Of these, 31 were excluded because the total number of participants was less than 20 (n=1), the article was not in English (n=2), the intervention was not relevant (n=1), the study was a case report (n=4), the study was not an RCT (n=8), the target population was not eligible (n=1), the data were not extractable (n=9), or the intervention was not combined with SLT (n=5). Ultimately, 26 RCTs were included in the network meta-analysis. The PRISMA flow diagram is shown in Figure 1.

Study Characteristics

Twenty-six RCTs published between 2012 and 2026 were included (Table 1): 2 multinational (Canada/United States/Germany),[72,73] 1 in the United States,[87] 3 in Germany,[78,84,91] 1 in Turkey,[74] 1 in Canada,[86] 15 in China,[25,31–34,75,76,79–82,85,88,89,92] 2 in Poland,[77,90] and 1 in Egypt.[83] The trials enrolled 1,136 patients with PSA; sample sizes ranged from 28 to 96 (mean 43.7, median 41), mean ages from 45.3 to 71.2 years, and follow-up from 1 to 180 days.

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Table 1 Characteristics of the Included Studies

First Author and Year	Country	First Language	Number of Participants	Age (Mean ±SD)	Stroke Type	Aphasia Type	Handedness	Type of Stimulation	Stimulation Procedure	Stimulus Site	Intensity of rTMS	Features of Accompanying Therapy	Duration of Illness (Mean ±SD)	Adverse Effects	Follow Up (After Treatment)	Measurement
			Men (Women)				R/L Handed				*% of Resting Motor Thresholds (RMT)					
Zumbansen, 2022[72]	Canada, the United States, Germany	English, French, or German	9 (5)	66 (9)	Left MCA ischemic stroke	NA	R	Sham LF-rTMS+SLT	/	IHF at the vertex	10%	Immediately post-rTMS SLT (<45min)	33 (84)M	1 headache	30D	1, BNT 2, Semantic Fluency test 3, 36-item Token Test 4, Unified Aphasia Score
			10 (4)	65 (11)				LF-rTMS+SLT	1 Hz,900 pulses (15 min)	Non-affected RH(R IFG pTri), direct the current per pendicular to the target gyrus	90%		33 (82)M	1 dysesthesia (tension in the right shoulder)	30D	
Zumbansen, 2020[73]	Canada/ United States/ Germany	English, French, or German	10 (10)	66.7 (9.8)	Left MCA infarcts	NA	R	LF-rTMS +sham ctDCS +SLT	1 Hz,900 pulses (15 min),10 sessions	Non-affected RH (R IFG pTri)	90%	45min post-real rTMS | during sham ctDCS	21.2 (13.2) D	1 headache,1dysesthesia	30D	1, BNT 2, Semantic Fluency test 3, 36-item Token Test
			14 (10)	65.3 (13.2)				ctDCS+sham LF-rTMS+SLT	2-mA current	The target area (cathode) and the forehead over the right eye (anode)	NA	45 min post-sham rTMS, during real ctDCS	20.4 (14.7) D	1dysesthesia,1 reported several adverse events (mild-moderate neck pain for 10 sessions, mild dysesthesia for 7 sessions, and headache for 1 session	30D	
			12 (7)	67.4 (11.7)				Sham LF-rTMS+sham ctDCS+SLT	Turned on for 30s to elicit a typical skin sensation	IHF at vertex	10%	45min post-sham LF-rTMS	15.9 (11.2) D	1 headache	30D	
Yaşa 2023[74]	Turkey	Turkish	5 (5)	60.00 (5.05)	NA		R	SLT	/	/	/	5×30min sessions/day, Mon-Fri, for 3w	10.4M	NA	1M	1, ADD 2, T-RAT
			5 (5)	59.30 (5.83)		Broca's aphasia		LF-rTMS	1Hz, 1500pulses(20 min), 15 sessions	Right IFG	110%	NA	12.3M	NA	1M	
			6 (4)	59.70 (5.31)				LF-rTMS+ SLT				5×30min sessions/day, Mon-Fri, for 3 w,structured, taken from Shutterstock	10.6M	NA	1M	
			7 (3)	57.70 (3.56)				Sham	Did not receive any of these treatments	/	/	/	10.1M	NA	1M	
Wang,2014[75]	China	NA	14(1)	61.3 (13.2)	First-ever left MCA infarct	Nonfluent aphasia	R	LF-rTMS+SLT (synchronous)	1 Hz, 1200pulses(20min), 10 sessions +synchronous naming training	Broca homologous (ie, contralesional pars triangularis, PTr)	90%	20min,10 sessionsThe training program emphasized verbal expres sive skills, including repetition, phonemic training, semantic training, naming, conversation, picture-description tasks, and phrase-generation tasks	16.8(6.4)M		3M	
			13(2)	62.1 (12.7)				LF-rTMS+SLT (subsequent)	1 Hz+subsequent naming training				15.7(8.5)M	1 reported a dull pain at first when placed under the activated coil, but their discomfort subsided once the stim ulation intensity was reduced by 5%.	3M	1, CCAT 2, Object and Action naming accuracy (%)——selected from the International Picture Naming Database
			13(2)	60.4 (11.9)				LF-rTMSsham +SLT	Sham 1-Hz rTMS +synchronous naming training				16.1(7.3)M		3M	

Tsai, 2014[76]	China	NA	24(9)	62.3 (12.1)	Secondary to first-ever Left MCA territory infarction (cortical)	Nonfluent aphasia	R	LF-rTMS+SLT	1-Hz,600pulses(10min),10 sessions	Contralesional PTr	90%	1H speech therapy, emphasized on the expressive production including semantic training, phonemic training, repetition,naming, conversation, picture-description tasks, and phrase generation tasks	17.8(7.2)M	0	3M	1, CCAT 2, Object and Action naming accuracy (%)-selected from the International Picture Naming Database 3, Object Naming and Action naming reaction time averaged for each testing picture.
			17(6)	62.8 (14.5)				Sham LF-rTMS+SLT	Sham 1-Hz,(less than 5% of the magnetic output with audible click-on discharge)		/		18.3(8.2)M	0	3M	
Seniów, 2013[77]	Poland	Polish	8(12)	61.8 (11.8)	First-ever ischemic stroke (subacute phase, Left-dominant hemisphere)	NA	R	LF-rTMS+SLT	1 Hz,1800 pulses(30min),interstimulus interval=1 second,15 sessions	Anterior portion of the right Broca's area homologue (pTri)	90%	45min	33.5 (24.1) D	0	106.7 (7.92) D	1, BDAE
			10(10)	59.7 (10.7)				Sham LF-rTMS+SLT	Air-cooled sham coil (visual/auditory matched)		/		39.9 (28.9) D	0	106.5 (7.30) D	
Rubi-Fessen, 2015[78]	Germany	German	5(10)	67.9 (8.12)	First-ever Left MCA stroke (subacute phase) with aphasia	NA	R	LF-rTMS+SLT	1-Hz(20min),10 sessions	Right IFG (Brodmann area 45)	90%	45 min,focused on reactivation of word retrieval as required in tasks such as oral and written picture naming, picture description, and writing from memory	41.47 (21.51)D	NA	2W	1, AAT 2, FIM 3, Naming screening-selected from the Snodgrass and Vanderwart picture naming inventory 4, ANELT
			9(6)	69.60 (6.67)				Sham LF-rTMS+SLT	Sham 1-Hz(20mi),10 sessions	Vertex			48.73 (21.57)D			
Ren, 2023[31]	China	NA	5 (10)	52.53 (11.84)	First stroke in the LH	NA	R	iTBS +SLT	1200 pulses/day, 2 sessions/day, 200 s/ session (50 Hz triplets, 5 Hz repetition, 2 s on/8 s off), 15 min interval between sessions, 30 sessions total.	Personalized target in the ipsilesional SFG	80%	30min/d, 5d/w×3w,focused primarily on language comprehension and expression	2.57 (2.50) M	1Seizure,1Pain at stimulation site,1 seizure 3 days after intervention	3W	1, WAB-R
			7 (8)	)53.13 (12.19)				cTBS+SLT	2 sessions/day, 1200 pulses/day, 200 s/ session (50 Hz triplets, 5 Hz repetition, 40s)	Contralesional SFG			2.65 (1.38) M	1Pain at stimulation site,1 other discomfort,1 involuntary movement 2 weeks after intervention		
			5(9)	51.93 (12.80)				Sham iTBS +SLT	Sham iTBS (matched pad + sound mimicry)	Left SFG	/		1.79 (1.52) M	1 headache		
								Sham cTBS +SLT	Mimicking the cTBS procedure(visual/ auditory matched)	Right SFG						
Ren, 2019[79]	China	Chinese	7 (6)	65.95 (8.53)	Subacute poststroke,a frst-ever lef sided MCA)stroke with the lesion site	Global aphasia	R	LF-rTMS+SLT (Broca)	1HZ(20min),1200Pulses	Right pTri of the pIFG (the homolog of the lef Broca's area)	80%	30min/d, Mon-Fri×3w,focused on the comprehension and expression of spoken language	55.90 (19.41)D	NA	3W(15D)	1, WAB
			12 (6)	62.46 (10.95)				LF-rTMS+SLT (Wernicke)		Right pSTG(the homolog of the lef Wernicke's area)			50.58 (23.80)D		3W(15D)	
			6 (6)	63.60 (16.71)				Sham LF-rTMS +SLT	1HZ(20min),1200Pulses,used the same coil	Over the vertex			61.20 (22.66)D		3W(15D)	
Liu, 2024[80]	China	Chinese	16(4)	55.40 (14.56)	First-ever Left-hemisphere stroke	Non-fluent aphasia	R	SLT	/	/	/	Schuell training method,30min/d, 5d/w×3w	45.00 (62.50)D	0	3W	1, WAB

(*Continued*)

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Table 1 (Continued).

First Author and Year	Country	First Language	Number of Participants Men (Women)	Age (Mean ±SD)	Stroke Type	Aphasia Type	Handedness R/L Handed	Type of Stimulation	Stimulation Procedure	Stimulus Site	Intensity of rTMS *% of Resting Motor Thresholds (RMT)	Features of Accompanying Therapy	Duration of Illness (Mean ±SD)	Adverse Effects	Follow Up (After Treatment)	Measurement
			14(6)	49.50 (35.25)				music+SLT				Sing along with the music,read lyrics,ask questions,30min/d, 5d/w×3w	54.50 (54.75)D	0	3W	
			15(5)	54.90 (16.81)				LF-rTMS +Music+SLT	1HZ(20 min), 5 days a week, for 3 weeks.1000Pulses	The right pTri of the right Broca's homologue (right Brodmann area 45)	90%	Schuell training method,sing along with the music,read lyrics,ask questions,30min/d, 5d/w×3w	27.00 (59.50) D	2 dizziness,improved after rest	3W	
Lin, 2022[81]	China	Chinese	11 (6)	54.71 (12.03)	First-ever Left MCA stroke (chronic phase)	Nonfluent aphasia	R	LF-rTMS+SLT	1-Hz(15 min),900 pulses,10 sessions	Contralesional pTri,right posterior pTri	90%	training program emphasized verbal expressive skills, including repetition, phonemic training, semantic training, naming, conversation, picture description tasks, and phrase generation tasks,(once a week,40min	9.41(7.27) M	NA	2W	I, CCAT
			11 (5)	62.94 (14.59)				Sham rTMS +SLT	Sham stimulation (<5% output + matched click/size)				12.63 (12.90)M	NA		
Lin, 2023[82]	China, Taipei	Chinese	10(6)	54.06 (12.12)	A first ischaemic infarction in the left territory of the MCA	Nonfluent aphasia	R	LF-rTMS+SLT	1HZ(15 min),900 pulses,10 sessions	Contralesional pTri	90%	40min,once a week	9.00(7.30) M	NA	NA	I, CCAT
			12(5)	62.24 (14.42)				Sham LF-rTMS+SLT	Sham coil (<5% output)				12.18 (12.63)M			
Khedr,2014[83]	Egypt	NA	8(11)	61.0 (9.8)	Subacute solitary MCA infarct (thromboembolic etiology)	Nonfluent aphasia	R	Dual-rTMS +SLT	LF-rTMS:1 Hz, 1000 pulses (500 pTri + 500 pOp) → HF-rTMS:10 trains of 20 Hz, 5s each, 30s interval (5 trains pTri + 5 trains pOp)	LF-rTMS:unaffected right Broca's area HF-rTMS:left Broca's area of the affected hemisphere	LF-rTMS :110%,HF-rTMS:80%	30min,operant learning	5.8(4.08) W	0	2M	I, HSS
			5(5)	57.4 (9.6)				Sham rTMS +SLT	Same parameters, subthreshold intensity	Edge contact + 90° sagittal tilt (sound mimicry)			4.0(2.6)W	0	2M	
Heiss, 2013[84]	Germany	German	14(Total)	69.0 (6.33)	First-ever MCA ischemic stroke	NA	R	Sham rTMS +SLT	Matched cutaneous sensation at reduced intensity	Over the midline at the vertex	90%	45min, focused on the individual lin guistic symptoms by a blinded certified therapist	50.1 (23.96)D	NA	NA	I, AAT
			15(Total)	68.5 (8.19)				LF-rTMS+SLT	1 Hz (20 min)	Triangular part of the right IFG			39.7 (18.43)D			
Chou, 2021[34]	China, Taipei	NA	15(14)	62.7 (12.7)	First-ever left hemispheric stroke (ischemic or hemorrhagic)			iTBS+SLT	3 pulses of 50-Hz bursts repeated at 5 Hz (2 s on and 8 s off) for a total of 190s,10sessions	Ipsilesional Brodmann area 45 (BA45)	80%	1h,twice a week,forcing patients to use verbal language and intensive practice	17.6 (20.8) M	0	2W	I, CCAT
			19(8)	56.9 (13.2)		NA	NA	LF-rTMS+SLT	1 Hz	Contralesional PTr	90%		13.2 (21)M	2 dizziness at first, but their discomfort subsided once the stimulation intensity was reduced by 2%.		
			20(9)	61.6 (14.7)				Sham TMS +SLT	<5% output + click sham	Ipsilesional PTr	NA		16.5 (24.6) M	0		

Bai, 2022[85]	China	Chinese	17(13)	63.47 (7.81)	First LH stroke	Non-fluent aphasia	R	LF-rTMS+SLT	1 Hz, 10 pulses per sequence, sequence interval 2 s, 100 sequences per day (total 1,000 pulses),5 days a week*4W	Stimulation coil placed tangentially on the scalp surface, centered at the mark, handle pointing vertically to the back occiput,non-dominant hemisphere (right hemisphere)at the back of the IFG	80%	30 min, Schuell training method, blocking removal method, de-inhibition method, program training method combine computer picture naming training	3.27(1.50) M	0	NA	1, WAB 2, Short-form Token Test
			14(16)	59.91 (8.58)				Sham LF-rTMS+SLT		The stimulation coil was perpendicular to the surface of the skull			3.75(1.67) M	0		
Low, 2025[86]	Canada	English	15(7)	64.9 (10.5)	LH Ischemic strokes, not involving the right frontal lobe	Nonfluent aphasia	NA	Sham LF-rTMS+SLT	Looks, feels, and sounds the same as the active coil but does not deliver active stimulation	NA	NA	3.5H,5 days a week for 2 weeks (35 hours)M-MAT, with an additional 15 minutes of daily home practice tasks. M-MAT involved structured communication activities such as requesting items, recalling items from memory, and naming items	4.5 (4.1)Y	Im total 27/216 sessions,10 mild headaches after stimulation;9tingling sensations near the target site or in the right upper extremity after stimulation	15W	1, WAB 2, Scenario Test 3, CETI
			14 (7)	61.8 (14.0)				LF-rTMS+SLT	1 Hz(20 min),1200 pulses,10 sessions	The pars triangularis of the right IFG	100%		3.5 (3.2)Y	Im total 21/206 sessions,10 mild headaches after stimulation;tingling 4 sensations near the target site or in the right upper extremity after stimulation	15W	
Dresang, 2025[87]	United States	English	13(6)	60 (10.57)	A single LH ischemic stroke	NA	NA	LF-rTMS+SLT	1 Hz(20 min),10 sessions	45 degree angle tangential to the right PTr	90%	60min,CILT, comprised 72 cards, where 36 depicted agent nouns with high spoken lexical frequency and 36 depicted agent nouns with low spoken lexical frequency	4.5 (4.51)Y	NA	6m	1, PNT
			10(1)	61 (12.05)				Sham LF-rTMS+SLT			NA		6.25 (6.35) Y	NA	6m	
Dang, 2025[25]	China	Chinese	25(23)	67.50 (11.67)	LH strok,Ischemic +Hemorrhagic	Motor aphasia	NA	Sham rTMS +SLT	NA	Perpendicular to the surface of the patient's stimulation site	NA	60min,5 days per week*4weeks,muscle movement training, pronunciation training, and word and sentence training	52.50 (22.22)D	NA	NA	1, CRRCAE 2, CADL
			29(19)	68.50 (15)				Dual-rTMS +SLT	LF:1HZ,20min,6 sequences,200 pulses per sequence,15 seconds between sequences,20 sessions HF:5HZ,5min,25 sequences,40 pulses per sequence,15 seconds between sequences,20 sessions	Tangent to the surface of the patient's stimulation site,IFG of the patient's undamaged hemisphere (RH) IFG of the patient's damaged hemisphere (LH)			56.00 (24.81)D	NA	NA	

(*Continued*)

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Table 1 (Continued).

First Author and Year	Country	First Language	Number of Participants	Age (Mean ±SD)	Stroke Type	Aphasia Type	Handedness	Type of Stimulation	Stimulation Procedure	Stimulus Site	Intensity of rTMS	Features of Accompanying Therapy	Duration of Illness (Mean ±SD)	Adverse Effects	Follow Up (After Treatment)	Measurement
			Men (Women)				R/L Handed				*% of Resting Motor Thresholds (RMT)					
Dai, 2025[32]	China	Chinese	10(6)	52.89 (7.83)	LH lesions, Ischemic +Hemorrhagic	Global/ Broca's/ Mixed transcortical	NA	Sham rTMS +SLT	The same appearance and parameters as the real stimulation	Oriented perpendicularly,R IFG	NA	40min,oral expression, response, gesture, language communication, naming, and reading rehabilitation	4.94(1.35) M	0	10D	I, WAB
			10(6)	54.88 (8.49)				iTBS+SLT	Intra-cluster frequency:50HZ,3 pulses per cluster; inter-cluster frequency:5 Hz with 10 clusters;This sequence was repeated 20 times, delivering 600 stimuli in 3 min and 20s	A 45-degree angle,R IFG	80%		5.09(1.67) M	0		
			12(4)	53.38 (8.28)				cTBS+SLT	Intra-cluster frequency:50HZ,3 pulses per cluster; inter-cluster frequency:5 Hz with 200 clusters;The protocol was repeated once, delivering 600 stimuli in 48s				5.25(1.72) M	0		
Dai, 2026[33]	China	Chinese	12(7)	54.47 (8.09)	First-time LH stroke,Ischemic/ Hemorrhage	Global/Broca 's/Wernicke's aphasia/ Mixed transcortical/ Transcortical Sensory	R	cTBS+SLT	Three-pulse clusters at 50 Hz with 200ms intervals between clusters for a duration of 40 seconds	Right cerebellar hemisphere	80%	60min,five days per week,10 sessions,Standardized Therapeutic Framework: errorless learning methodology, hierarchical cueing systems (semantic → phonological → combined → direct modeling), and adaptive difficulty adjustment targeting 70–80% accuracy	3.92(1.65) M	0	2W	I, WAB
			11(7)	54.3 (9.08)				iTBS+SLT	2-second trains repeated 20 times at 10-second intervals, totaling 190 seconds	Right cerebellar hemisphere			3.92(1.95) M	0		
			10(8)	54.50 (8.59)				Sham rTMS +SLT	NA	Coil positioned tangentially and perpendicular to the scalp	NA		4.00(1.63) M	0		
Bai, 2021[88]	China	Chinese	13(17)	45.3 (6.8)	First LH (dominant hemisphere)	Nonfluent aphasia	R	Sham rTMS +SLT	The same as the stimulation group,5 days a week for 4 weeks	Coil is perpendicular to the stimulation site RH IFG,coil is tangent to the surface of the patient's skull	80%	20 minutes per time, 1 time per day, 5 times per week* 4 weeks:reading, oral expression, reading, retelling training, restoration and improvement of articulation function, improvement of articulation clarity and other training.	3.0(1.5M) M	NA	4W	I, WAB
								LF-rTMS+SLT	1 Hz,10 pulses,sequence interval time is 2S,100 sequences,a total of 1000 pulses for 1 treatment, 20 minutes,5 days a week for 4 weeks							
								2rTMS+SLT	2 times a day LF-rTMS							
Bai, 2025[89]	China	Chinese	11(9)	61.59 (8.13)	First stroke in the LH (dominant hemisphere)	NA	R	iTBS +SLT	Three 50 Hz pulses per cluster, each cluster was repeated at 5 Hz,Continuous stimulation was stopped for 8 seconds after continuous stimulation for 2 seconds, with a total duration of 191.84 seconds, a total pulse number of 600 pulses, and treatment 5 days per week for a total duration of 4 weeks	Close to the surface of the patient's skull, posterior IFG of the LH	80%	30 min,the Schuell training method, blocking removal method, deinhibition method, and program training method combined with computer picture naming training	3.41(1.25) M	NA	NA	I, WAB
			12(8)	58.95 (7.18)				Sham iTBS +SLT	The same as the treatment group	A sham stimulation coil			3.82(1.53) M			

Waldowski, 2012[90]	Poland	Polish	6 (7)	62.31 (11.03)	First-ever left-sided MCA	Varying type	R	LF-rTMS+SLT	1HZ,15 minutes over the PTr and 15 minutes over the Pop	Coil was placed tangentially to the scalp over the right IFG	90%	Specific language training,focus on the expression and comprehension of spoken language,45 minutes*3 w	28.92 (19.39)D	NA	15W	1, CPNT
			7 (6)	60.15 (10.58)				Sham LF-rTMS+SLT	n air-cooled sham coil that looks and sounds similar to the discharge of real TMS coil				48.54 (32.33)D		15W	
Thiel, 2013[91]	Germany	German	13(Total)	69.8 (7.96)	First ischemic infarct within the left MCA	Varying type	R	LF-rTMS+SLT	1 Hz,20 min	Triangular part of the R posterior IFG	90%	45min,eficit-specific aphasia therapy focused on the individual linguistic symptoms	37.5 (18.52)D	0	37.5(18.52)D	1, AAT
			11(Total)	71.2 (7.78)				Sham LF-rTMS+SLT	NA	Over the midline at the vertex			50.6 (22.63)D	0	50.6(22.63)D	
Lee, 2022[92]	China, Taipei	Chinese	9(4)	56.61 (12.66)	First-ever ischemic stroke affecting the left region of the MCA	Nonfluent aphasia	R	LF-rTMS+SLT	1-Hz,20min,10 sessions	R PTr	90%	1h language training program, two training sessions,including semantic training, phonemic training, oral motor training, picture naming, conversation tasks, complex picture description, and phrase generation	9.38(8.13) M	NA	1D	1, CCAT
			9(4)	62(14.4)				Sham LF-rTMS+SLT	a placebo coil, which delivered <5% of the magnetic output received by the experimental group but produced an audible click on discharge				14.46 (13.68)M		1D	

Notes: For multi-arm studies that included both eligible TMS-based arms and ineligible non-TMS neuromodulation arms, only the TMS-relevant comparisons were included in the quantitative synthesis.

Abbreviations: PTr, posterior pars triangularis; MCA, middle cerebral artery; IHF, inter-hemispheric fissure; IFG, inferior frontal gyrus; pTri, pars triangularis; RH, right hemisphere; pOp, pars opercularis; pSTG, posterior superior temporal gyrus; SFG, superior frontal gyrus; min, minutes; D, Day; W, week; M, month; H, hour SD, standard deviation; R, right-handed; L, left-handed; LF-rTMS, low-frequency repetitive transcranial magnetic stimulation; rTMS, repetitive transcranial magnetic stimulation; HF-rTMS, High-frequency repetitive Transcranial Magnetic Stimulation; ctDCS, cathodal transcranial direct current stimulation; iTBS, intermittent theta burst stimulation; cTBS, continuous theta burst stimulation; SLT, speech-language therapy; CILT, constraint-induced language therapy; BNT, Boston Naming Test; AMT, active motor threshold; BDAE, Boston Diagnostic Aphasia Examination; WAB(-R), Western Aphasia Battery (Revised); AAT, Aachen Aphasia Test; CCAT, Concise Chinese Aphasia Test; PNT, Philadelphia Naming Test; CADL, Communicative Abilities in Daily Living; CRRCAE, Chinese Rehabilitation Research Center Aphasia Examination; CETI, Communicative Effectiveness Index; ANELT, Amsterdam-Nijmegen Everyday Language Test; FIM, Functional Independence Measure; HSS,Hemispheric Stroke Scale; CPNT, Computerized Picture Naming Test; PNT, Philadelphia Naming Test; T-RAT, Picture Naming Test Turkish; ADD, Test of Language Assessment in Aphasia; ASRS, Aphasia Severity Rating Scale;NA, Not Available/not Applicable.

Across the included trials, the network comprised the following nodes: LF-rTMS alone;[74] LF-rTMS with SLT (n=19);[34,72–79,81,82,84–88,90–92] LF-rTMS with SLT and music (n=1);[80] dual-hemisphere rTMS with SLT (n=2)[25,83] iTBS with SLT (n=5);[31–34,89] and cTBS with SLT (n=3).[31–33] The intensity of rTMS ranged from 80% to 110% of resting motor threshold (RMT), and the mean duration of illness from 15.9 days to 6.25 years. A detailed breakdown of stimulation parameters (intensity, frequency, and total pulses per session) is provided in Table 1.

Risk of Bias and GRADE Evidence Grading

Overall, 18 studies (69.2%) were low risk, 5 (19.2%) had some concerns, and 3 (11.5%) were high risk (Figure 2).

Most studies showed a low risk of bias across domains: outcome reporting (100%), missing data (88.5%), outcome measurement (96.2%), randomization (76.9%), and protocol deviations (88.5%). Unclear risk was noted for inadequate reporting of missing data (7.7%), protocol deviations (11.5%), and randomization methods (19.2%). High risk was identified for poorly described randomization (3.8%), missing outcome data (3.8%), and outcome measurement (3.8%). Studies failing to report relevant information were classified as unclear risk. Three trials were rated high risk for specific reasons: Yaşa et al[74] for insufficient randomization description allowing prediction of group assignment; Bai et al[85] for not reporting outcome-assessor blinding (possible detection bias); and Dresang et al[87] for missing outcome data with evidence that missingness depended on the true value (attrition bias).

The certainty of evidence varied substantially across comparisons. Conventional protocols, notably LF-rTMS+SLT versus SLT alone, had moderate-to-high certainty across several domains (eg., immediate naming, comprehension, and writing), reflecting narrow credible intervals and direct robust comparisons. However, network estimates involving novel or multi-component interventions (eg., LF-rTMS+Music+SLT) had predominantly low to very low certainty. Downgrades were driven by inconsistency (larger upper bound of tau-squared), indirectness (sparse network connections), and imprecision (wide credible intervals crossing the null). Risk of bias was generally not downgraded, as approximately 70% of studies showed low overall risk per the Cochrane RoB 2.0 assessment. A detailed GRADE summary for all network estimates is provided in Table S2.

Heterogeneity and Model Convergence Assessment

The between-study heterogeneity variance (τ^2) varied across outcomes, with posterior medians ranging from 0.0033 (95% CrI: 0.00001 to 0.0404) for immediate comprehension to 0.1728 (95% CrI: 0.0057 to 0.6349) for immediate aphasia severity. Most τ^2 estimates were small, although long-term repetition showed greater uncertainty ($\tau^2 = 0.0673$, 95% CrI: 0.00013 to 1.7868). Overall model convergence was satisfactory, with all PSRF values < 1.05 (Table S3). Trace plots showed adequate mixing without drift, and posterior density plots were generally unimodal and stable, supporting model convergence and stability (Figure S1). These findings were consistent with the Brooks-Gelman-Rubin diagnostic plots (Figure S2).

NMA

Immediate Improvement in Aphasia Severity

Twenty studies[31–34,72,75,76,78–86,88,89,91,92] Involving seven interventions reported immediate aphasia severity outcomes (Figure 3A). LF-rTMS+Music+SLT was significantly more effective than several alternatives (Figure 3B): compared with LF-rTMS+SLT (SMD =1.48, 95% CrI [0.21, 2.73]); music+SLT (SMD = 1.77, 95% CrI [0.43, 3.14]); iTBS+SLT (SMD = 1.51, 95% CrI [0.18, 2.82]); and SLT alone (SMD = 2.05, 95% CrI [0.84, 3.29]). SUCRA ranked LF-rTMS +Music+SLT highest (96.86%) (Figure 3C).

The certainty of evidence for this outcome is shown in Table S2; heterogeneity and convergence diagnostics are summarized in Table S3.

Immediate Improvement in Repetition

Twenty studies[25,32–34,74,76–86,88,89,91,92] involving eight protocols assessed immediate repetition improvement (Figure 4A). LF-rTMS+Music+SLT was superior to cTBS+SLT (SMD = 1.07, 95% CrI [0.12, 1.98]), iTBS+SLT (SMD = 1.38, 95% CrI [0.53, 2.21]), LF-rTMS (SMD = 1.68, 95% CrI [0.49, 2.86]), LF-rTMS+SLT (SMD = 1.29,

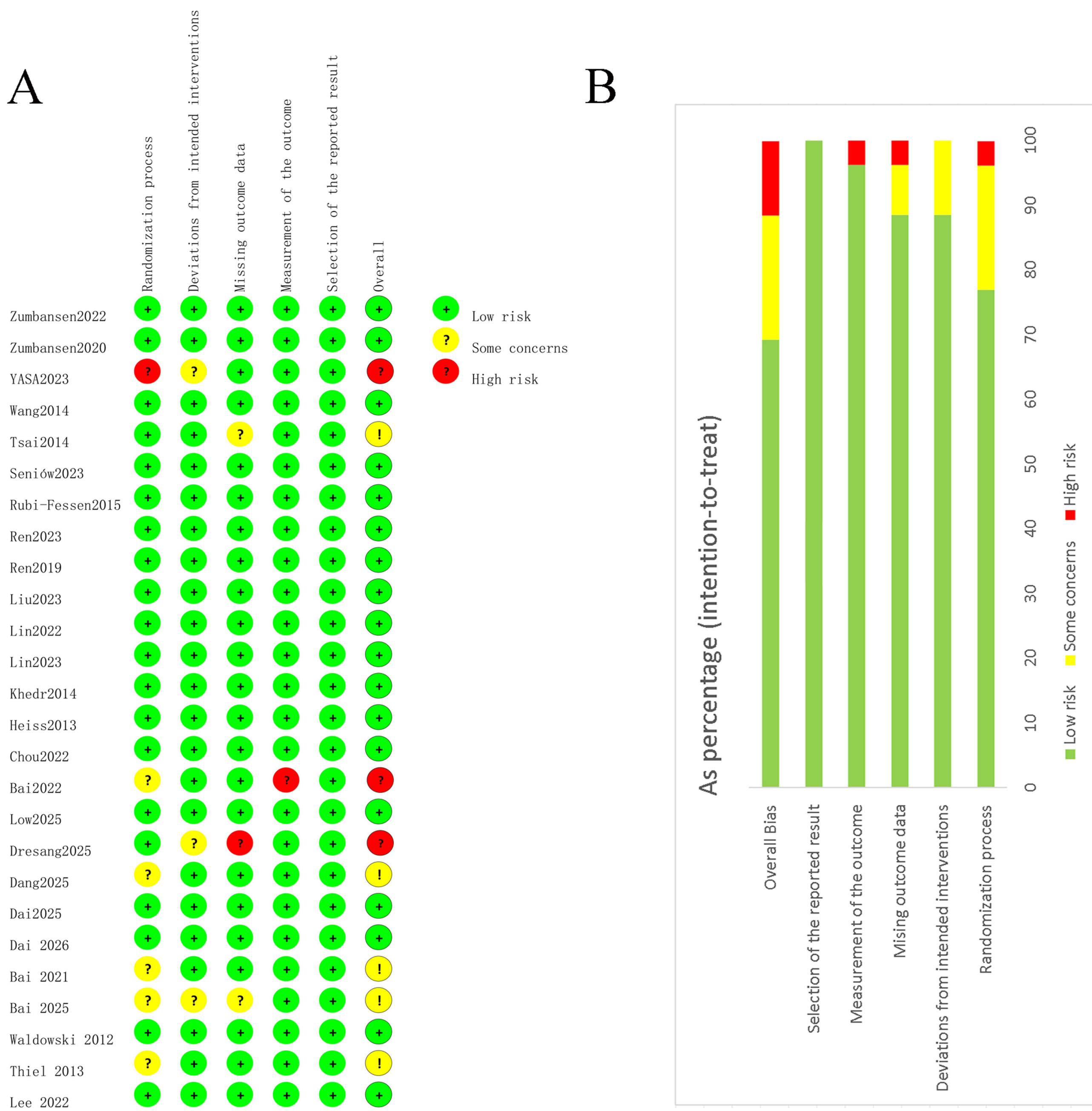


Figure 2 Summary of risk of bias for the included studies.

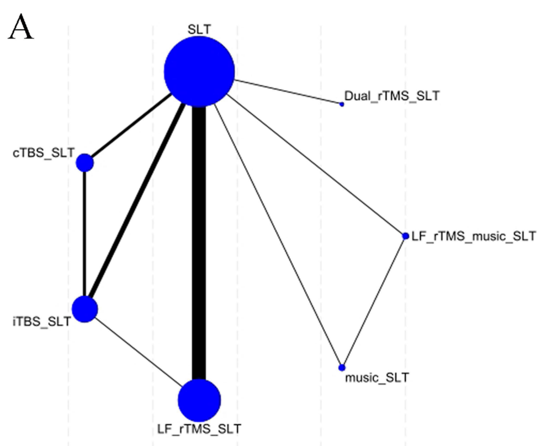
95% CrI [0.49, 2.08]), music+SLT (SMD = 1.06, 95% CrI [0.05, 2.05]), and SLT (SMD = 1.63, 95% CrI [0.86, 2.39]) (Figure 4B). SUCRA ranked LF-rTMS+Music+SLT highest (97.25%) (Figure 4C).

The certainty of evidence for this outcome is shown in Table S2; heterogeneity and convergence diagnostics are summarized in Table S3.

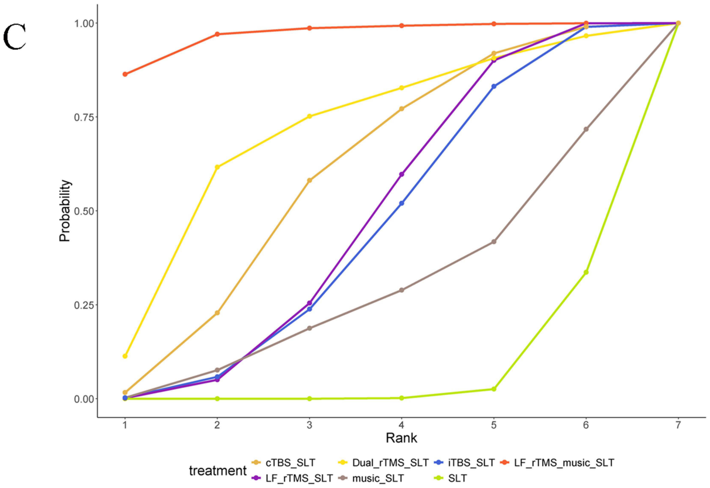
Immediate Improvement in Comprehension

Twenty[25,32–34,72–74,77–86,89,91,92] studies involving eight interventions evaluated immediate comprehension outcomes (Figure 5A). Dual-rTMS+SLT was superior to iTBS+SLT (SMD = 0.84, 95% CrI [0.35, 1.30]), LF-rTMS (SMD = 1.38, 95% CrI [0.39, 2.37]), LF-rTMS+SLT (SMD = 0.91, 95% CrI [0.48, 1.33]), music+SLT (SMD = 1.1, 95% CrI

A



C

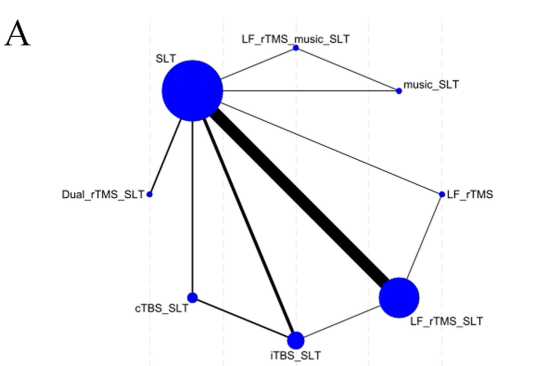


B

SLT						
-0.28 (-1.38, 0.82)	music_SLT					
-0.58 (-0.9, -0.29)	-0.3 (-1.46, 0.83)	LF_rTMS_SLT				
-2.05 (-3.29, -0.84)	**-1.77 (-3.14, -0.43)**	**-1.48 (-2.73, -0.21)**	LF_rTMS_music_SLT			
-0.54 (-1.06, -0.06)	-0.27 (-1.49, 0.93)	0.03 (-0.53, 0.6)	**1.51 (0.18, 2.82)**	iTBS_SLT		
-1.07 (-2.29, 0.17)	-0.79 (-2.43, 0.86)	-0.49 (-1.74, 0.79)	0.99 (-0.74, 2.73)	-0.52 (-1.83, 0.82)	Dual_rTMS_SLT	
-0.74 (-1.43, -0.09)	-0.47 (-1.78, 0.8)	-0.17 (-0.9, 0.56)	1.31 (-0.11, 2.69)	-0.19 (-0.94, 0.54)	0.32 (-1.09, 1.7)	cTBS_SLT

Figure 3 NMA of immediate improvement in aphasia severity: (**A**) network plot; (**B**) comparative effectiveness; (**C**) SUCRA rankings. SMDs with 95% CrIs; significant results are shown in bold.

A



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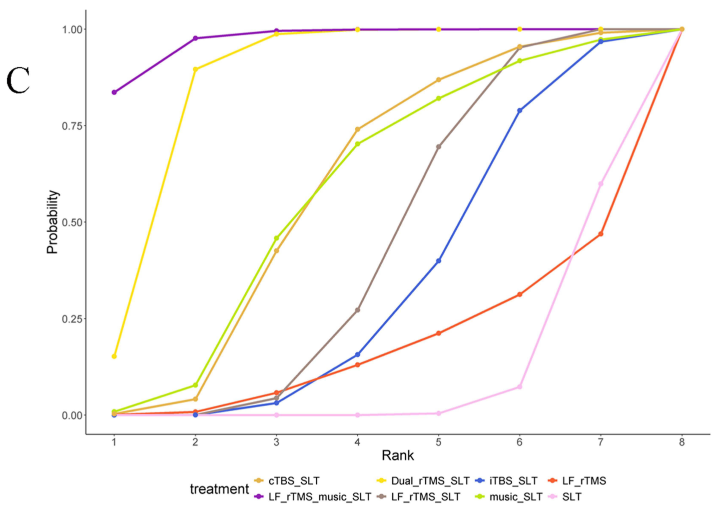


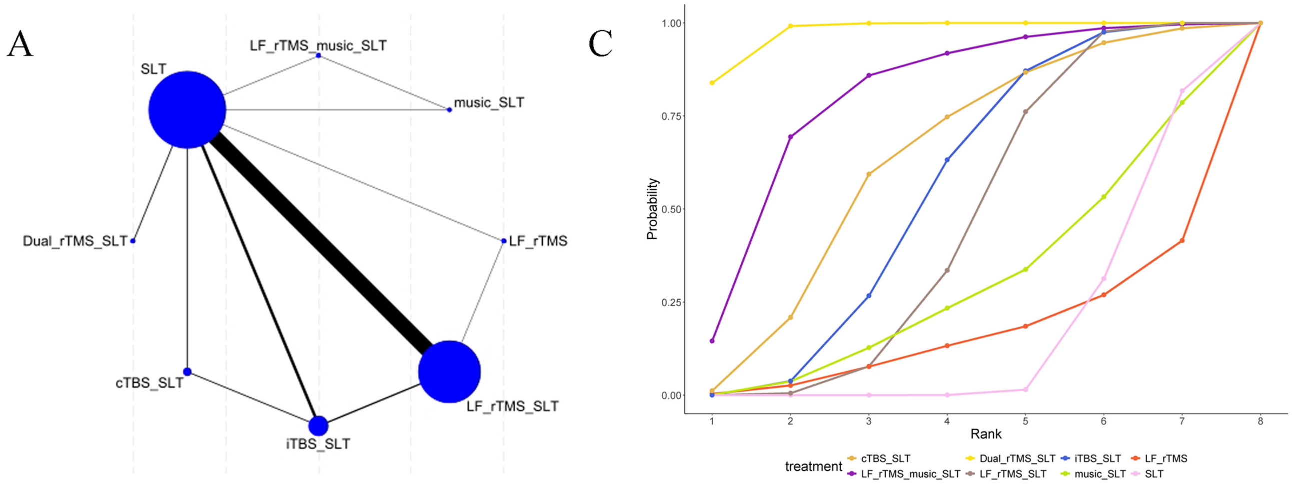
B

SLT							
-0.57 (-1.25, 0.11)	music_SLT						
-0.34 (-0.53, -0.16)	0.23 (-0.47, 0.93)	LF_rTMS_SLT					
-1.63 (-2.39, -0.86)	**-1.06 (-2.05, -0.05)**	**-1.29 (-2.08, -0.49)**	LF_rTMS_music_SLT				
0.05 (-0.84, 0.95)	0.63 (-0.5, 1.73)	0.39 (-0.51, 1.31)	**1.68 (0.49, 2.86)**	LF_rTMS			
-0.25 (-0.59, 0.08)	0.32 (-0.44, 1.07)	0.09 (-0.29, 0.46)	**1.38 (0.53, 2.21)**	-0.3 (-1.27, 0.67)	iTBS_SLT		
-1.18 (-1.61, -0.73)	-0.61 (-1.41, 0.21)	**-0.84 (-1.31, -0.35)**	0.45 (-0.44, 1.33)	**-1.22 (-2.24, -0.24)**	**-0.93 (-1.47, -0.37)**	Dual_rTMS_SLT	
-0.57 (-1.09, -0.03)	0.01 (-0.86, 0.87)	-0.23 (-0.78, 0.34)	**1.07 (0.12, 1.98)**	-0.61 (-1.66, 0.43)	-0.31 (-0.91, 0.29)	0.61 (-0.08, 1.3)	cTBS_SLT

Figure 4 NMA of immediate repetition: (**A**) Network plot; (**B**) Comparative effects; (**C**) SUCRA rankings. SMD with 95% CrI; significant results in bold.

[0.34, 1.859]), cTBS+SLT (SMD = 0.72, 95% CrI [0.06, 1.37]), and SLT (SMD = 1.18, 95% CrI [0.77, 1.57]) (Figure 5B). Dual-rTMS+SLT had the highest SUCRA (97.57%) (Figure 5C).

The certainty of evidence for this outcome is shown in Table S2; heterogeneity and convergence diagnostics are summarized in Table S3.



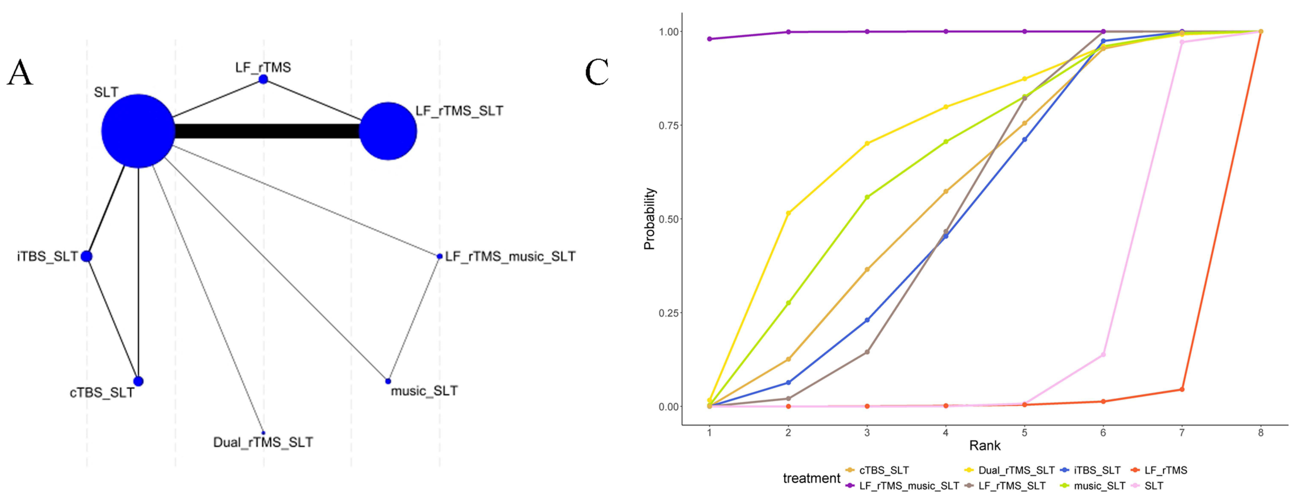
B

SLT							
-0.07 (-0.72, 0.59)	music_SLT						
-0.26 (-0.39, -0.14)	-0.19 (-0.87, 0.48)	LF_rTMS_SLT					
-0.75 (-1.41, -0.09)	-0.68 (-1.61, 0.25)	-0.49 (-1.15, 0.19)	LF_rTMS_music_SLT				
0.21 (-0.71, 1.1)	0.29 (-0.86, 1.34)	0.47 (-0.46, 1.36)	0.95 (-0.16, 2.06)	LF_rTMS			
-0.33 (-0.58, -0.08)	-0.26 (-0.98, 0.45)	-0.08 (-0.34, 0.21)	0.42 (-0.29, 1.12)	-0.53 (-1.5, 0.43)	iTBS_SLT		
-1.18 (-1.57, -0.77)	**-1.1 (-1.89, -0.34)**	**-0.91 (-1.33, -0.48)**	-0.42 (-1.2, 0.35)	**-1.38 (-2.37, -0.39)**	**-0.84 (-1.3, -0.35)**	Dual_rTMS_SLT	
-0.46 (-0.97, 0.06)	-0.4 (-1.23, 0.48)	-0.2 (-0.72, 0.34)	0.29 (-0.53, 1.12)	-0.67 (-1.72, 0.43)	-0.13 (-0.68, 0.43)	**0.72 (0.06, 1.37)**	cTBS_SLT

Figure 5 NMA of immediate comprehension: (**A**) Network plot; (**B**) Comparative effectiveness; (**C**) SUCRA rankings. SMD with 95% CrI; significant results in bold.

Immediate Improvement in Naming

Twenty-two studies[32,33,72–91] involving eight interventions evaluated immediate naming outcomes (Figure 6A). LF-rTMS +Music+SLT was superior to cTBS+SLT (SMD = 1.51, 95% CrI [0.53, 2.46]), Dual-rTMS+SLT (SMD = 1.21, 95% CrI [0.10, 2.41]), iTBS+SLT (SMD = 1.56, 95% CrI [0.65, 2.47]), LF-rTMS (SMD = 2.59, 95% CrI [1.53, 3.61]), LF-rTMS



B

SLT							
-0.58 (-1.25, 0.07)	music_SLT						
-0.41 (-0.54, -0.27)	0.18 (-0.49, 0.86)	LF_rTMS_SLT					
-1.96 (-2.76, -1.15)	**-1.38 (-2.38, -0.36)**	**-1.55 (-2.36, -0.72)**	LF_rTMS_music_SLT				
0.62 (-0.05, 1.26)	**1.21 (0.26, 2.11)**	**1.03 (0.36, 1.69)**	**2.59 (1.53, 3.61)**	LF_rTMS			
-0.4 (-0.81, 0)	0.18 (-0.59, 0.97)	0.01 (-0.43, 0.43)	**1.56 (0.65, 2.47)**	**-1.02 (-1.8, -0.25)**	iTBS_SLT		
-0.75 (-1.57, 0.11)	-0.16 (-1.22, 0.91)	-0.34 (-1.17, 0.53)	**1.21 (0.1, 2.41)**	**-1.36 (-2.44, -0.28)**	-0.34 (-1.27, 0.62)	Dual_rTMS_SLT	
-0.46 (-0.96, 0.08)	0.12 (-0.71, 0.98)	-0.05 (-0.57, 0.5)	**1.51 (0.53, 2.46)**	**-1.09 (-1.88, -0.23)**	-0.06 (-0.68, 0.59)	0.29 (-0.7, 1.25)	cTBS_SLT

Figure 6 NMA of immediate naming: (**A**) Network plot; (**B**) Comparative effects; (**C**) SUCRA rankings. SMD with 95% CrI; significant results in bold.

+SLT (SMD = 1.55, 95% CrI [0.72, 2.36]), music+SLT (SMD = 1.38, 95% CrI [0.36, 2.38]), and SLT (SMD = 1.96, 95% CrI [1.15, 2.76]) (Figure 6B). LF-rTMS+Music+SLT ranked first by SUCRA (99.69%) (Figure 6C)..

The certainty of evidence for this outcome is shown in Table S2; heterogeneity and convergence diagnostics are summarized in Table S3.

Immediate Improvement in Spontaneous Speech

Sixteen studies[25,32–34,75,76,78–82,85,86,88,89,92] involving seven interventions reported immediate spontaneous speech outcomes (Figure 7A). LF-rTMS+Music+SLT significantly outperformed cTBS+SLT (SMD = 2.53, 95% CrI [1.4, 3.7]), iTBS+SLT (SMD = 1.23, 95% CrI [0.24, 2.21]), LF-rTMS+SLT (SMD = 1.05, 95% CrI [0.1, 1.99]), music+SLT (SMD = 1.27, 95% CrI [0.17, 2.36]), and SLT (SMD = 1.48, 95% CrI [0.57, 2.4]) (Figure 7B). SUCRA for LF-rTMS+Music+SLT was 95.67% (Figure 7C).

The certainty of evidence for this outcome is shown in Table S2; heterogeneity and convergence diagnostics are summarized in Table S3.

Immediate Improvement in Functional Communication

Seven studies[25,34,75,76,78,86,92] involving four interventions assessed immediate improvement in functional communication (Figure 8A). Dual-rTMS+SLT was significantly more effective than SLT alone (SMD = 0.62, 95% CrI [0.06, 1.17]) (Figure 8B). SUCRA ranked Dual-rTMS+SLT highest (91.49%) (Figure 8C).

The certainty of evidence for this outcome is shown in Table S2; heterogeneity and convergence diagnostics are summarized in Table S3.

Immediate Improvement in Writing

Seven studies[34,78,81,82,84,91,92] involving three interventions evaluated immediate writing outcomes (Figure 9A). LF-rTMS+SLT was significantly more effective than SLT (SMD = 0.34, 95% CrI [0.10, 0.58]) (Figure 9B). SUCRA for LF-rTMS+SLT was 87.73% (Figure 9C).

The certainty of evidence for this outcome is shown in Table S2; heterogeneity and convergence diagnostics are summarized in Table S3.

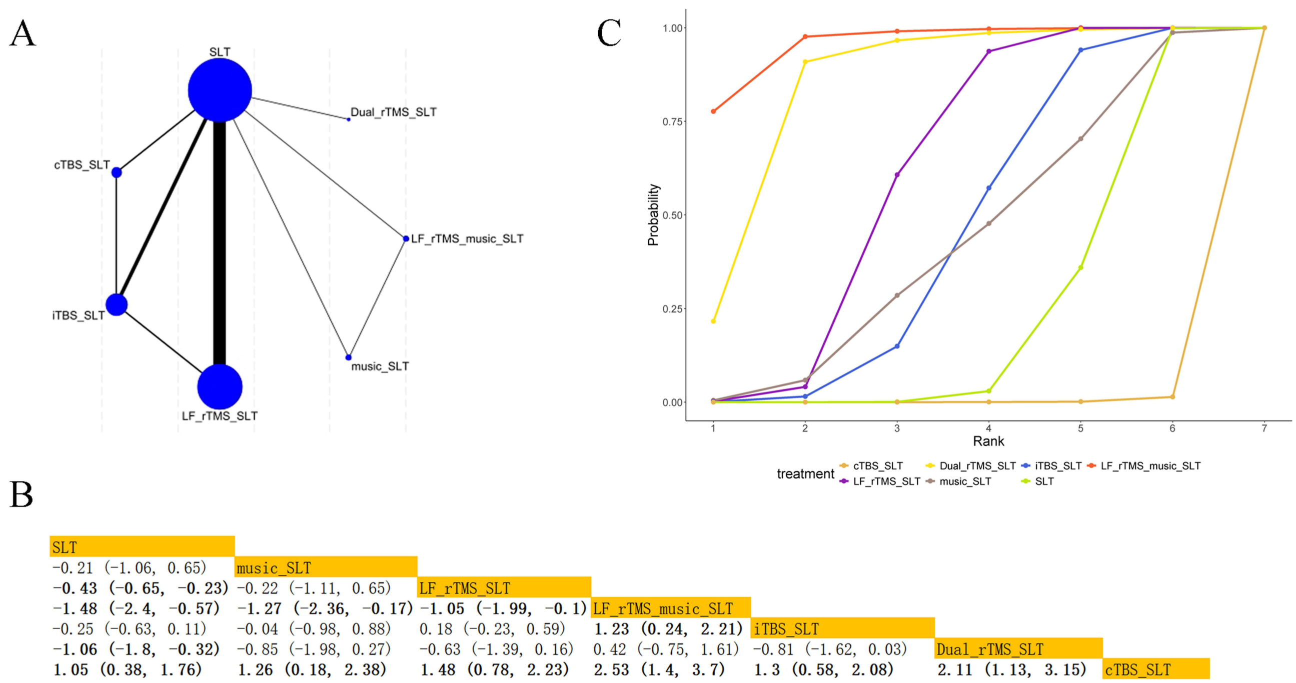


Figure 7 NMA of immediate spontaneous speech: (**A**) Network plot; (**B**) Comparative effectiveness; (**C**) SUCRA rankings. SMD with 95% CrI; significant results in bold.

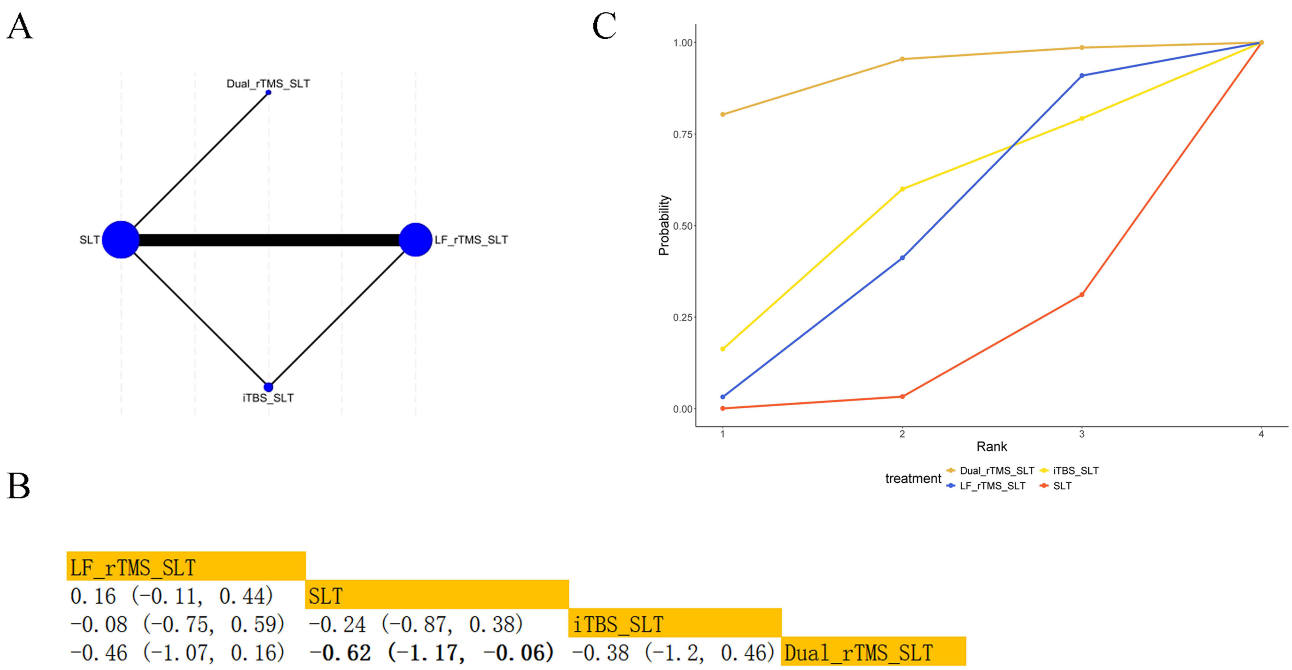


Figure 8 NMA of immediate functional communication: (**A**) Network plot; (**B**) Comparative effectiveness; (**C**) SUCRA rankings. SMD with 95% CrI; significant results in bold.

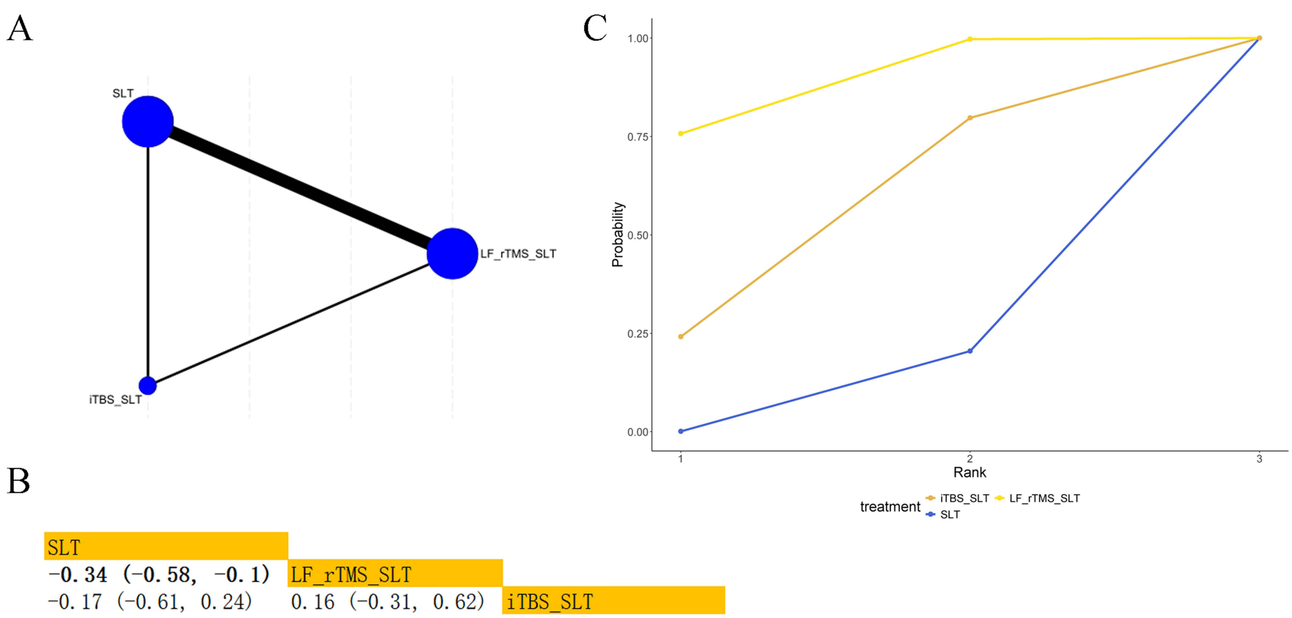
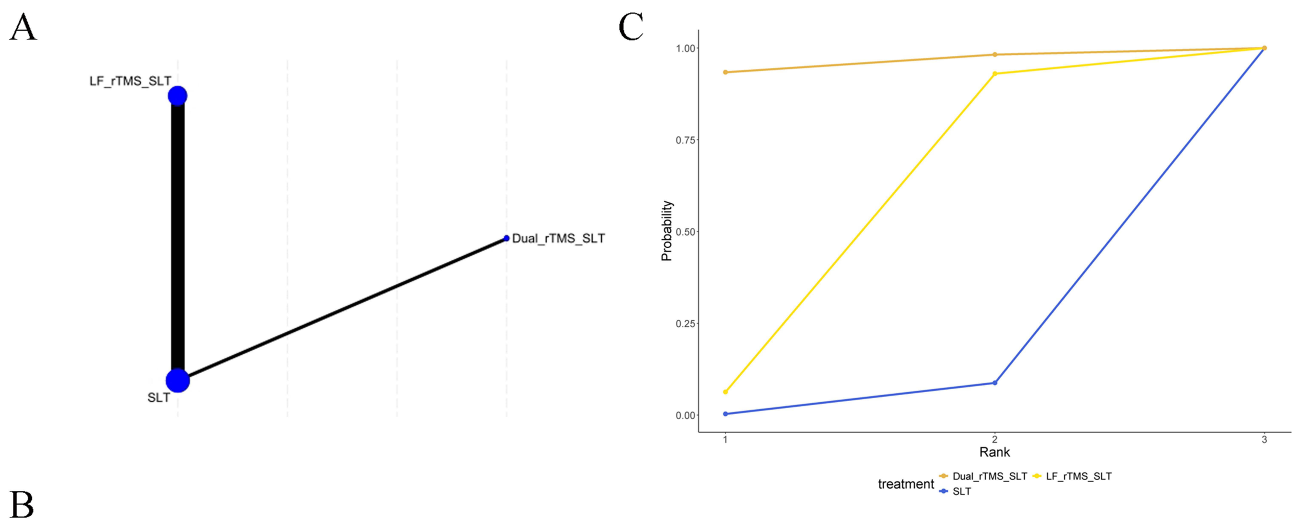


Figure 9 NMA of immediate writing: (**A**) Network plot; (**B**) Comparative effectiveness; (**C**) SUCRA rankings. SMD with 95% CrI; significant results in bold.

Long-Term Improvement in Aphasia Severity

Five studies[72,75,76,83,86] involving three interventions reported long-term aphasia severity outcomes (Figure 10A). Dual-rTMS+SLT showed a larger improvement than SLT (SMD = 1.23, 95% CrI [0.10, 2.36]) (Figure 10B). Although the credible interval did not cross the null, the lower bound was close to zero and the interval was wide. This imprecision, largely attributable to the limited number of studies informing this comparison, contributed to the evidence being rated low certainty in the GRADE assessment. SUCRA ranked Dual-rTMS+SLT highest (95.82%) (Figure 10C).



B

SLT		
−0.34 (−0.83, 0.17)	LF_rTMS_SLT	
−1.23 (−2.36, −0.1)	−0.89 (−2.12, 0.35)	Dual_rTMS_SLT

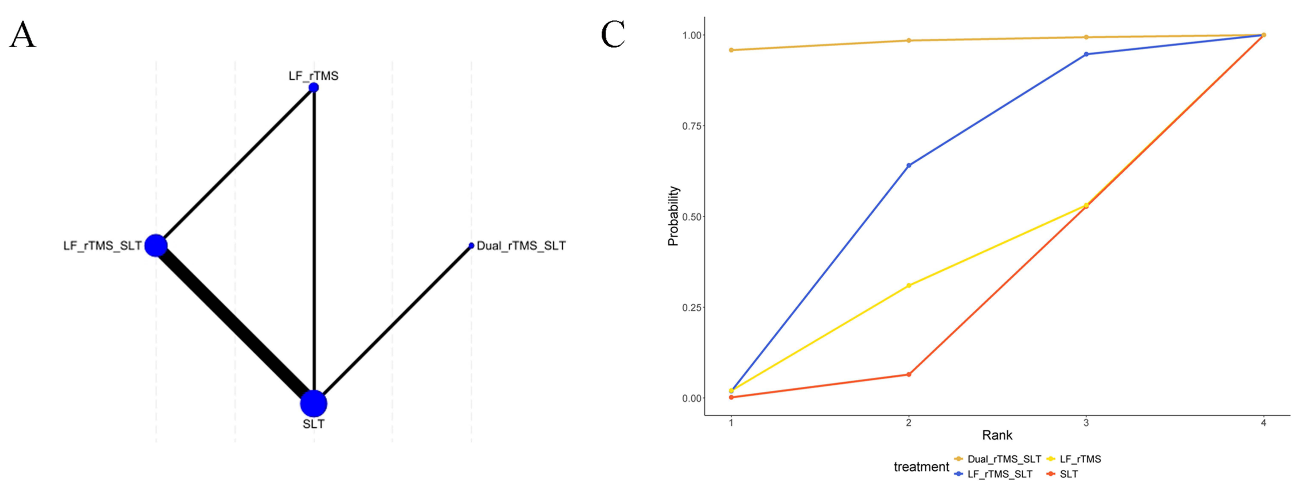
Figure 10 NMA of long-term severity of aphasia: (**A**) Network plot; (**B**) Comparative effectiveness; (**C**) SUCRA rankings. SMD with 95% CrI; significant results in bold.

The certainty of evidence for this outcome is shown in Table S2; heterogeneity and convergence diagnostics are summarized in Table S3.

Long-Term Improvement in Repetition

Five studies[74,76,83,86,91] involving four interventions assessed long-term repetition improvement (Figure 11A). Dual-rTMS+SLT was superior to SLT (SMD = 1.82, 95% CrI [0.44, 3.17]) (Figure 11B). Dual-rTMS+SLT had the highest SUCRA (97.90%) (Figure 11C).

The certainty of evidence for this outcome is shown in Table S2; heterogeneity and convergence diagnostics are summarized in Table S3.



B

SLT			
−0.31 (−0.97, 0.27)	LF_rTMS_SLT		
−0.03 (−1.25, 1.34)	0.28 (−0.98, 1.73)	LF_rTMS	
−1.82 (−3.17, −0.44)	−1.51 (−2.96, 0.03)	−1.78 (−3.72, 0.02)	Dual_rTMS_SLT

Figure 11 NMA of long-term repetition: (**A**) Network plot; (**B**) Comparative effects; (**C**) SUCRA rankings. SMD with 95% CrI; significant results in bold.

 https://doi.org/10.2147/TCRM.S597978

Long-Term Improvement in Comprehension

Six studies[72–74,77,83,86] involving four interventions assessed long-term comprehension outcomes (Figure 12A). Pairwise comparisons showed no statistically significant differences among the interventions, as all 95% credible intervals crossed the null value (Figure 12B). Although Dual-rTMS+SLT had the highest SUCRA value (95.06%) (Figure 12C), this ranking reflects relative probability rather than statistically confirmed superiority. Therefore, these long-term comprehension results should be interpreted cautiously.

The certainty of evidence for this outcome is shown in Table S2; heterogeneity and convergence diagnostics are summarized in Table S3.

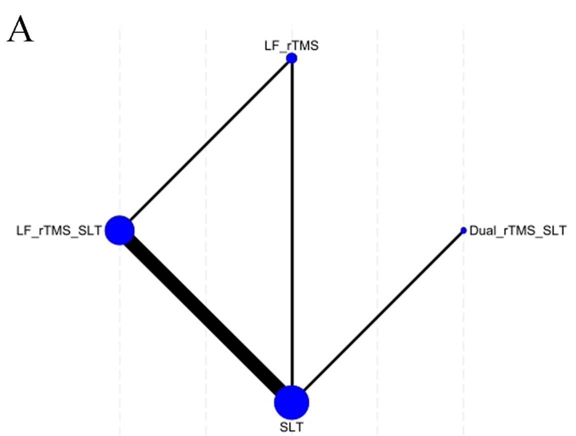
Long-Term Improvement in Naming

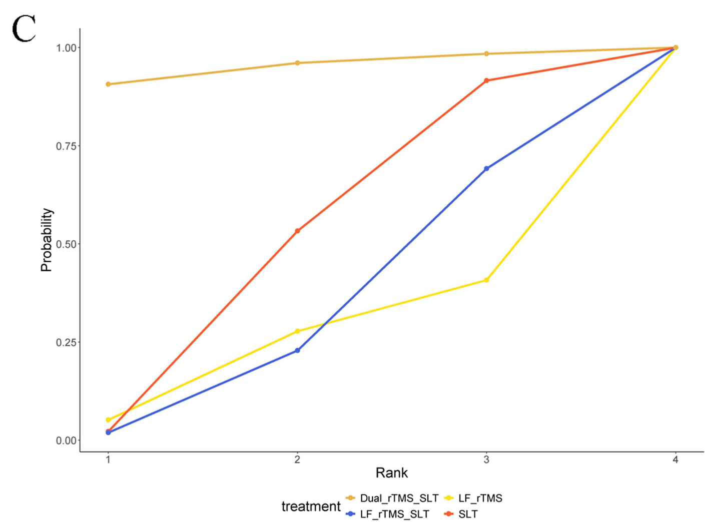
Ten studies[72–77,83,86,87,90] involving four interventions assessed long-term naming outcomes (Figure 13A). Dual-rTMS +SLT was significantly more effective than LF-rTMS (SMD = 1.99, 95% CrI [0.82, 3.07]), LF-rTMS+SLT (SMD = 1.23, 95% CrI [0.29, 2.15]), and SLT (SMD = 1.47, 95% CrI [0.55, 2.37]) (Figure 13B). SUCRA ranked Dual-rTMS+SLT highest (99.74%) (Figure 13C).

The certainty of evidence for this outcome is shown in Table S2; heterogeneity and convergence diagnostics are summarized in Table S3.

Adverse Events

The reporting of adverse events was inconsistent across studies: some trials reported the number of affected participants, while others reported the total number of events or sessions during which events occurred. We therefore present the data as originally described, without pooling, and highlight relevant limitations. Among the 26 included studies, seven studies[31,34,72,73,75,80,86] documented at least one treatment-related adverse event, all occurring during or shortly after the TMS procedure. Headache was reported in four studies: Ren et al[31] (1 participant), Zumbansen et al[72] (1 participant), Zumbansen et al[73] (1 participant), and Low et al[86] (10 episodes across sessions; affected participants not specified).



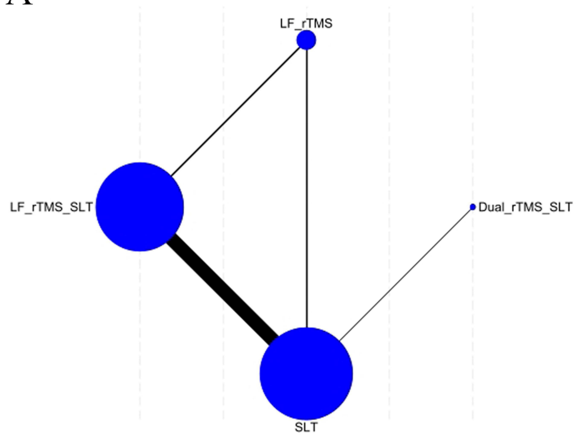


B

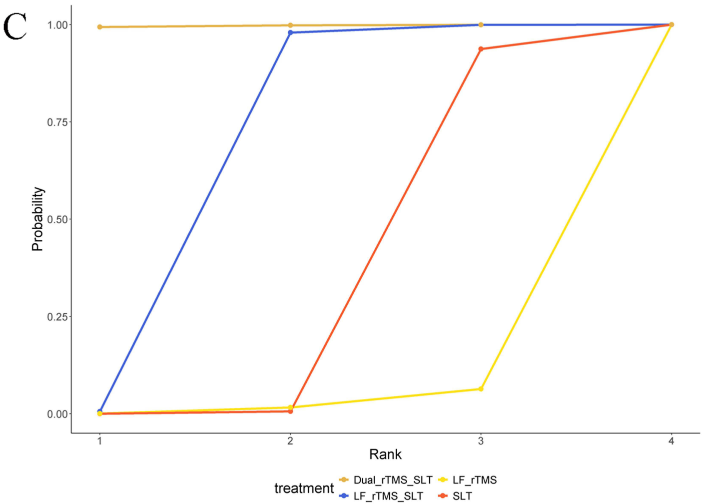
SLT			
0.11 (−0.3, 0.51)	LF_rTMS_SLT		
0.28 (−0.74, 1.35)	0.17 (−0.9, 1.29)	LF_rTMS	
−0.83 (−1.83, 0.16)	−0.94 (−2.02, 0.14)	−1.1 (−2.59, 0.32)	Dual_rTMS_SLT

Figure 12 NMA of long-term comprehension: (**A**) Network plot; (**B**) Comparative effects; (**C**) SUCRA rankings. SMD with 95% CrI; significant results in bold.

A



C



B

SLT			
−0.24 (−0.41, −0.06)	LF_rTMS_SLT		
0.51 (−0.17, 1.17)	**0.75 (0.07, 1.43)**	LF_rTMS	
−1.47 (−2.37, −0.55)	**−1.23 (−2.15, −0.29)**	**−1.99 (−3.07, −0.82)**	Dual_rTMS_SLT

Figure 13 NMA of long-term naming: (**A**) Network plot; (**B**) Comparative effects; (**C**) SUCRA rankings. SMD with 95% CrI; significant results in bold.

Dysesthesia was reported in Zumbansen et al[72] (1 participant) and Zumbansen et al[73] (1 participant). Dizziness was reported in Chou et al[34] (2 participants) and Liu et al[80] (2 participants). Ren et al[31] also reported seizure (2 participants) and involuntary movement (1 participant), and Wang et al[75] reported dull pain (1 participant). No serious adverse events were reported. Because reporting formats were heterogeneous, the true number of participants experiencing adverse events may differ from the figures above.

Consistency and Publication Bias

Model consistency was assessed using DIC, with all closed-loop models showing differences <5, indicating adequate consistency. Node-splitting analysis was conducted for outcomes with available closed loops in the network. Only four outcomes (immediate aphasia severity, immediate repetition, immediate comprehension, and immediate spontaneous speech) had sufficient closed loops for this assessment; the remaining outcomes lacked closed loops and were therefore not amenable to node-splitting (Table 2). No significant inconsistency was detected in any of the assessable comparisons (all $P > 0.05$). Comparison-adjusted funnel plots detected potential publication bias (Figure S3).

Table 2 Local Inconsistency Assessment for Outcomes with Available Closed Loops

Outcomes	Comparison	Direct	Indirect	Network	P.Value CrI
Aphasia severity improvement-Immediate	iTBS+SLT vs LF-rTMS+SLT	0.12 (−1.3, 1.6)	−0.027(−0.76, 0.69)	−0.033 (−0.61, 0.54)	0.845125
Repetition-immediate	iTBS+SLT vs LF-rTMS+SLT	0.054(−0.98,1.1)	−0.065(−0.51,0.40)	−0.099(−0.49,0.30)	0.84615
Comprehension-immediate	iTBS+SLT vs LF-rTMS+SLT	0.21 (−0.32, 0.80)	−0.0090(−0.44, 0.42)	0.071 (−0.21, 0.35)	0.5423
Spontaneous language- immediate	iTBS+SLT vs LF-rTMS+SLT	0.086(−0.85, 1.0)	−0.31 (−1.0, 0.36)	−0.18 (−0.59, 0.23)	0.466875

Discussion

Across 26 randomized trials, no single TMS protocol led every language domain. Three protocols partitioned the leadership: LF-rTMS+Music+SLT produced the largest immediate gains in aphasia severity, repetition, naming, and spontaneous speech; Dual-rTMS+SLT led short- and long-term comprehension and the long-term outcomes for aphasia severity, naming, and repetition plus immediate functional communication; LF-rTMS+SLT topped immediate writing. Whether these domain-specific advantages survive critical appraisal of the underlying evidence is the focus of the remainder of this Discussion.

The ranking hierarchy carries an interpretive ceiling. Trials varied in aphasia subtype, time since stroke, lesion characteristics, stimulation targets, and co-intervention details, so apparently direct protocol contrasts often draw on quite different study settings. The ceiling tightens further for nodes informed by a single trial or only by indirect comparisons; those rankings should be read as hypothesis-generating, not confirmatory.

LF-rTMS+Music+SLT ranked first for immediate aphasia severity, This finding is broadly consistent with prior studies supporting LF-rTMS-based approaches in post-stroke aphasia.[30,80,93] However, this estimate rests on a single trial and should be treated as hypothesis-generating. The mechanism is plausible, with neuromodulation likely facilitating transient cortical reorganization while structured language therapy plus music-based input reinforces engagement and language processing,[14,94–96] yet head-to-head replication is needed before this protocol can be positioned ahead of established LF-rTMS+SLT for severity recovery.

LF-rTMS+Music+SLT led immediate repetition, contradicting Li et al[38] who identified iTBS as the optimal protocol. Two non-exclusive explanations apply. Mechanistically, repetition draws primarily on frontal language regions including Broca's, Wernicke's, and Geschwind's territories and their associated pathways,[97,98] and although iTBS spreads dynamic neurophysiological effects from the stimulation site to distributed fronto-limbic circuits,[99] pairing LF-rTMS+SLT with music input may amplify repetition recovery through synergistic neuromodulation and intensive language engagement. Methodologically, Li et al[38] did not require concurrent SLT as an inclusion criterion, whereas the present network restricted comparators to TMS+SLT, which can shift the relative ranking. Head-to-head trials are needed to clarify the comparative efficacy of LF-rTMS– and iTBS-based combinations.

Dual-rTMS combined with SLT was the most effective intervention, not only for short- and long-term improvement in comprehension, but also for long-term improvement in aphasia severity, naming, and repetition. This finding is consistent with Li et al[38] Khedr et al[83] Dang et al[25] and supports the relevance of bilateral neuromodulation for auditory–semantic processing. Comprehension is largely mediated by a ventral neural pathway.[100,101] In the dual-hemisphere protocol, low-frequency stimulation is applied to the right Broca's homologue to reduce transcallosal inhibition, while high-frequency stimulation is delivered to the left Broca's area to enhance connectivity in metabolically compromised regions. Sequential bilateral stimulation, first targeting the unaffected hemisphere and then the affected hemisphere, may reduce pathological right-hemisphere hyperactivity. This approach restores interhemispheric balance and creates favorable conditions for excitatory stimulation.[83] The dependence of comprehension on coordinated bilateral networks may explain the pronounced benefit of Dual-rTMS+SLT.

Immediate naming improved most with LF-rTMS, SLT, and music therapy. This contrasts with Ding et al[30] who identified Dual-rTMS as optimal and cTBS as ineffective, and with Li et al[38] who reported cTBS as superior. Variability in adjunctive interventions may partly explain these differences. Naming outcomes are also influenced by the duration of therapy and the first language of participants,[30] and environmental factors such as background noise may affect performance.[101] The phase of stroke recovery represents a critical moderator. During the subacute phase, contralesional hyperexcitability may increase transcallosal inhibition of perilesional networks. Inhibitory LF-rTMS targeting the right inferior frontal gyrus may mitigate this maladaptive effect.[102] In the chronic phase, when structural reserve in the left hemisphere is diminished, compensatory recruitment of right-hemisphere homologues may become the primary recovery pathway. In such cases, facilitatory stimulation, including HF-rTMS within dual-mode protocols or iTBS, may provide greater benefit.[103] Differences in cohort composition across trials likely influenced pooled estimates and may explain why studies with a higher proportion of chronic patients[30] reported stronger effects for bilateral stimulation.

For immediate spontaneous speech, LF-rTMS+Music+SLT demonstrated the most favorable outcomes, consistent with Ding et al[30] Beyond direct modulation at the stimulation site, LF-rTMS may suppress maladaptive activation in frontal and temporal regions of the right hemisphere while facilitating functional engagement of corresponding areas in the left dominant hemisphere. This coordinated modulation promotes restoration of interhemispheric balance and supports functional reorganization within preserved language networks.[81]

Dual-rTMS combined with SLT was most effective for long-term naming. This finding agrees with Ding et al[30] but differs from Li et al[38] who reported cTBS as optimal. Differences in adjunctive therapy and follow-up duration may account for the discrepancy. Importantly, SLT remains the essential behavioral component across all protocols. Structured and goal-directed language practice is necessary to guide and consolidate neuroplastic changes.[104] The failure of some studies[38] to distinguish between immediate and long-term outcomes may further contribute to inconsistent conclusions. Future trials should analyze short- and long-term effects separately across language domains.

Consistent with the findings of Lee et al[92] LF-rTMS+SLT produced the greatest immediate improvement in writing. One possible explanation is that LF-rTMS promotes language recovery by modulating neural activity in the right hemisphere, particularly in the right frontotemporal cortex, caudate nucleus, and insular cortex.[102] These neuroadaptive changes have been linked to enhanced language production.

Strengths and Limitations

This network's principal strength is comparing multiple TMS protocols head-to-head while holding SLT as a concurrent co-intervention, which keeps the clinical question intact. Separating language domains and distinguishing immediate from follow-up outcomes further yielded a treatment-effect picture that conventional pairwise meta-analysis cannot produce.

Five limitations bound the inferences. First, included trials varied in patient characteristics, stroke chronicity, stimulation targets, treatment intensity, and SLT content, which limits cross-study comparability and likely shaped the rankings. Second, several nodes (particularly newer or combined protocols) rested on sparse or single-trial evidence, so any node-level claim is provisional. Third, the top-ranked combinations (notably LF-rTMS+Music+SLT) carry low to very low certainty driven by imprecision and indirectness, even though standard TMS-vs-SLT-alone comparisons reached moderate-to-high certainty. Fourth, long-term outcomes drew on fewer studies than immediate outcomes, making follow-up estimates less stable Fifth, inconsistent adverse-event reporting precluded reliable cross-protocol safety comparison. Together, these constraints place the protocol hierarchy on hypothesis-generating rather than confirmatory footing, with adequately powered head-to-head trials of the top three combinations as the most informative next step.

Conclusions

This NMA suggests that the optimal TMS protocol depends on the rehabilitation goal in post-stroke aphasia. LF-rTMS combined with music therapy and SLT showed the most favorable short-term pattern across several language outcomes, whereas Dual-rTMS+SLT ranked highest for most follow-up outcomes. LF-rTMS+SLT appeared to offer the clearest short-term benefit for writing. These findings may guide targeted rehabilitation strategies, but remain uncertain because most comparisons rest on low-certainty, largely indirect evidence. Direct comparative trials are needed to inform firm clinical recommendations.

Abbreviations

DALYs, disability-adjusted life years; SLT, speech-language therapy; NIBS, non-invasive brain stimulation; TMS, transcranial magnetic stimulation; tDCS, transcranial direct current stimulation; rTMS, repetitive TMS; TBS, theta-burst stimulation; iTBS, intermittent TBS; cTBS, continuous TBS; PSA, post-stroke aphasia; PICOS, Population/ Patients, Intervention, Comparison, Outcome, and Study Design; WAB, Western Aphasia Battery; AAT, Aachen Aphasia Test; CCAT, Concise Chinese Aphasia Test; BDAE, Boston Diagnostic Aphasia Examination; HSS, Hemispheric Stroke Scale; SLTA, Standard Language Test of Aphasia; BNT, Boston Naming Test; TT, Token Test; T-RAT, Picture Naming Test-Turkish; FIM, Functional Independence Measure; ANELT, Amsterdam-Nijmegen Everyday

Language Test; RCTs, randomized controlled trials; SMD, Standardized mean differences; RR, risk ratios; SUCRA, surface under the cumulative ranking curve; DIC, deviance information criterion.

Data Sharing Statement

Data available from corresponding author upon reasonable request.

Ethics Approval and Informed Consent

This article does not contain any studies with human or animal participants.

Consent for Publication

There are no human participants in this article and informed consent is not required.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors declare that they have no competing interests in this work.

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