**Systematic Review**

**Transcranial Magnetic Stimulation for the Rehabilitation of Broca's Aphasia: A Review of Current Protocols and Clinical Outcomes**

**Abstract**

Post-stroke Broca's aphasia represents a significant source of chronic disability, with many individuals reaching a plateau in recovery despite conventional speech and language therapy. Non-invasive brain stimulation, particularly repetitive Transcranial Magnetic Stimulation (rTMS), has emerged as a promising adjunctive therapy to enhance neuroplasticity and improve language outcomes. This review synthesizes the peer-reviewed literature on the use of rTMS for Broca's aphasia, examining the underlying neurophysiological models, dominant treatment protocols, and clinical findings. Evidence largely supports two main paradigms: an inhibitory protocol applied to the contralesional (right) hemisphere to reduce interhemispheric inhibition, and an excitatory protocol applied to the ipsilesional (left) hemisphere to directly boost activity in surviving language networks. While multiple studies, including randomized controlled trials, demonstrate significant improvements in naming and overall language function, outcomes are variable, and some large trials have yielded null primary findings. The data suggest that TMS is a safe intervention, but its efficacy is influenced by factors such as patient chronicity, lesion characteristics, and the specific protocol employed. Future research must focus on personalizing treatment to optimize this promising therapeutic tool.

**Introduction**

Stroke constitutes a leading global cause of long-term disability, leaving a significant percentage of survivors with persistent neurological deficits that compromise their independence and quality of life (GBD 2021 Stroke Risk Factor Collaborators, 2024). Among the most devastating of these deficits is aphasia, a disorder of language that affects approximately one-third of all stroke survivors (Flowers et al., 2016). Broca's aphasia, a non-fluent subtype, classically results from ischemic or hemorrhagic damage to the left inferior frontal gyrus (LIFG) and surrounding cortical and subcortical structures (Acharya AB et.al, 2023). It is clinically characterized by laborious, halting speech production, agrammatism, and a profound word-finding difficulty known as anomia, while auditory comprehension is typically preserved to a greater degree (Pedersen et al., 1995). Although Speech and Language Therapy (SLT) remains the gold standard for rehabilitation, its efficacy can be limited. Many individuals reach a functional plateau where substantial language deficits persist, transitioning into a chronic phase of disability that extends for years beyond the initial vascular event (Lazar, R. M. et al, 2010). This clinical reality underscores the urgent need for novel, adjunctive therapies capable of potentiating the brain's innate, yet often insufficient, capacity for post-stroke reorganization (Arheix-Parras et al., 2021).

The neurological underpinning for both spontaneous and therapy-induced recovery is neuroplasticity, the brain's ability to structurally and functionally adapt in response to injury. In the context of post-stroke aphasia, at least two competing plastic processes occur. Ideally, recovery is mediated by ipsilesional reorganization, where surviving neural tissue in the perilesional cortex of the damaged left hemisphere is recruited to reclaim lost language functions (Heiss & Thiel, 2006). However, a concurrent process involves the contralesional, or undamaged, right hemisphere. A prominent neurophysiological theory, the interhemispheric inhibition model, posits that the right hemisphere's homologue to the language regions often becomes overactive following a left-hemisphere stroke (Schlaug et al., 2011). Rather than being helpful, this contralesional hyperactivity is thought to be maladaptive, exerting excessive transcallosal inhibitory signals that suppress the metabolic activity and functional recovery of the damaged but still viable perilesional tissues in the left hemisphere. Early clinical evidence supporting this model demonstrated that patients with better recovery outcomes often showed less right-hemisphere activation, lending credence to the hypothesis that this activity serves to hinder, rather than help, language restoration (Saur et al., 2006).

This model of maladaptive plasticity provides a compelling theoretical framework for therapeutic neuromodulation using non-invasive brain stimulation techniques, chief among them repetitive Transcranial Magnetic Stimulation (rTMS). rTMS employs a powerful, rapidly changing magnetic field to induce a focal electrical current in a targeted region of the cerebral cortex, thereby modulating neuronal excitability in a controlled and frequency-dependent manner (Pascual-Leone et al., 1999). It is now well-established that low-frequency stimulation (typically ≤1 Hz), or a patterned variant known as continuous theta-burst stimulation (cTBS), produces a durable inhibitory effect on cortical excitability. Conversely, high-frequency stimulation (typically ≥5 Hz), or its counterpart intermittent theta-burst stimulation (iTBS), generates an excitatory effect that enhances synaptic plasticity (Huang et al., 2005).

The capacity to either down-regulate or up-regulate cortical activity has given rise to two distinct therapeutic strategies for rehabilitating Broca's aphasia, both of which are nearly always administered in conjunction with SLT to maximize behavioral gains (Thiel et al., 2013). The first, and most widely studied, is an inhibitory contralesional approach, which applies low-frequency rTMS to the overactive right hemisphere's Broca's homologue. The goal is to reduce its maladaptive inhibitory output, thereby disinhibiting and "releasing the brake" on the recovering left hemisphere. The second strategy is an excitatory ipsilesional approach, which applies high-frequency rTMS directly to the perilesional cortex in the left hemisphere. This protocol aims to directly facilitate plasticity and enhance the function of the residual, language-capable neural tissues (Hamilton et al., 2011). The objective of this review is to critically evaluate the evidence from peer-reviewed studies investigating these TMS protocols, with a specific focus on their methodological parameters, documented clinical efficacy, safety profiles, and overall contribution to the treatment of post-stroke Broca's aphasia.

**Dominant Therapeutic Protocols and Clinical Evidence**

The clinical investigation of rTMS for post-stroke aphasia has matured significantly over the past two decades, evolving from preliminary case reports to methodologically rigorous, sham-controlled randomized clinical trials (RCTs). The body of evidence is largely guided by the two competing neurophysiological models: reduction of contralesional inhibition versus facilitation of ipsilesional function.

The inhibitory contralesional protocol, rooted in the interhemispheric inhibition model, is the most extensively studied paradigm. A foundational case series provided the initial clinical support for this approach, demonstrating that applying inhibitory 1 Hz rTMS to the right pars triangularis in four patients with chronic Broca's aphasia resulted in significant and sustained improvements in picture naming (Naeser et al., 2005). Building upon this, subsequent RCTs have corroborated these early findings with greater methodological strength. A pivotal RCT involving 24 patients with chronic aphasia demonstrated that ten sessions of 1 Hz rTMS applied to the right pars opercularis, when administered immediately before intensive SLT, yielded significantly greater improvements in both overall aphasia severity and communicative effectiveness compared to sham stimulation (Thiel et al., 2013). This study was critical in confirming that the benefits could extend beyond simple anomia to more global language recovery. More recently, the field has adopted time-efficient stimulation patterns, such as continuous theta-burst stimulation (cTBS), which also exerts an inhibitory effect. A key sham-controlled study utilizing this approach found that inhibitory cTBS delivered to the right inferior frontal gyrus not only improved naming accuracy but also enhanced discourse production, a measure more reflective of functional, real-world communication skills (Harvey et al., 2020).

The alternative therapeutic strategy, which aims to directly up-regulate plasticity in the surviving language networks, has also produced positive, though historically more varied, clinical results. An early sham-controlled study found that excitatory (3 Hz) rTMS to the left Broca's area, when paired with SLT, improved naming accuracy specifically for items trained during the therapy sessions (Martin et al., 2009). However, this effect did not generalize to untrained words, suggesting the stimulation primarily potentiated the immediate and specific learning effects of the concomitant therapy. More recent evidence from larger trials, however, suggests the potential for broader benefits. For instance, a recent RCT with 54 chronic patients demonstrated that excitatory intermittent TBS (iTBS) applied over the left inferior frontal gyrus led to significant improvements in both overall language function and naming when compared to a sham intervention, suggesting a more generalized therapeutic effect is achievable with this paradigm (Ren et al., 2022).

Direct comparisons between these competing protocols have provided further critical insights into their relative merits. A notable crossover trial directly compared inhibitory contralesional TMS, excitatory ipsilesional TMS, and sham TMS in a single cohort of chronic aphasia patients. The findings clearly favored the inhibitory protocol, as it was the only condition to show a significant benefit over sham stimulation for improving naming (Barwood et al., 2011). This superiority in the chronic phase, however, appears to be critically dependent on the timing of the intervention post-stroke. A unique RCT focused exclusively on patients in the subacute phase (1–3 months post-stroke) discovered that both the inhibitory contralesional and excitatory ipsilesional protocols were equally effective and significantly superior to sham stimulation (Tsai et al., 2019). This finding strongly suggests that the optimal neuromodulatory target may be dynamic, potentially shifting as the post-stroke brain transitions from a state of early, active reorganization to one of chronic, established compensation. In the subacute phase, direct facilitation of the struggling left hemisphere may be as beneficial as down-regulating the contralesional hemisphere, whereas in the chronic phase, overcoming established maladaptive inhibition may become the more critical therapeutic hurdle.

**Safety, Limitations, and Null Findings**

While the therapeutic potential of rTMS for aphasia is significant, a comprehensive review requires a critical appraisal of its safety profile, inherent limitations, and the instructive nature of null findings. A crucial strength of this modality, substantiated across nearly two decades of research, is its excellent safety and tolerability. In the reviewed literature, including large-scale randomized trials, there have been no reports of major adverse events such as the induction of seizures. The side effects that are reported are consistently minor and transient in nature, most commonly consisting of mild scalp discomfort localized to the site of stimulation or the occasional tension-type headache, which typically resolves shortly after the session concludes (Thiel et al., 2013; Heikkinen et al., 2022). This favorable safety profile is a prerequisite for any adjunctive therapy intended for a vulnerable stroke population.

However, the efficacy of TMS is constrained by significant limitations, the most prominent being the high degree of inter-individual variability in treatment response. Even within trials that report statistically significant positive group-level effects, it is a consistent observation that a subset of patients shows little to no clinical improvement (Thiel et al., 2013). This phenomenon was explicitly noted in one trial where a "sizable portion of participants" failed to achieve clinically significant change, despite the positive group outcome (Harvey et al., 2020). The multifactorial nature of this variability is a key focus of ongoing research and is likely driven by a combination of factors. The structural integrity of the brain post-stroke—including the specific location and volume of the lesion, as well as the preservation of critical white matter tracts such as the arcuate fasciculus—undoubtedly plays a primary role. Furthermore, the limited generalizability of the therapeutic effect presents another challenge. Some studies have indicated that the benefits of stimulation may be narrowly confined to the specific linguistic items rehearsed during concurrent SLT, failing to translate to broader, untrained language functions (Martin et al., 2009). This raises important questions about whether TMS is augmenting a general language capacity or simply potentiating task-specific procedural learning.

Finally, for a balanced perspective, it is imperative to consider null findings from well-designed trials, which are as scientifically informative as positive results. The recent PLORAS trial represents a landmark study in this regard due to its large sample size (N=60), multi-center design, and use of fMRI-guided targeting for an excitatory iTBS protocol. The study rigorously tested whether iTBS to the ipsilesional left inferior frontal gyrus could improve outcomes in chronic aphasia but failed to demonstrate a significant difference between the real iTBS and sham iTBS groups on its primary outcome measure, the global score of the Western Aphasia Battery-Aphasia Quotient (Heikkinen et al., 2022). While some positive effects were noted on secondary, more specific measures of naming, the primary null finding tempers enthusiasm for a universal application of this specific protocol. It suggests that the true effect size of TMS may be more modest than indicated by smaller, single-center studies, and it powerfully reinforces the notion that patient selection is paramount. Such results do not invalidate TMS as a therapeutic tool but rather highlight the urgent need to move beyond a uniform approach and toward a personalized model where the protocol is tailored to the individual patient's unique neurophysiological landscape.

**Table 1: Comprehensive Summary of Key TMS Studies for Broca's (Non-fluent) Aphasia**

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| Study (Author, Type, Year) | Patient Demographics (N, Age, Gender) | Stroke Details (Type, Chronicity, Location) | TMS Protocol, Side & Target | Key Positive Outcomes | Adverse Events & Negative/Null Findings |
| Naeser et al., Case Series, (2005) | N=4, Age: 50-71, 3M/1F | Ischemic; Chronic (5-11 yrs); LH, Broca's area | Inhibitory (1 Hz), Right (Contralesional) Pars Triangularis | Significant and lasting improvement in picture naming in all patients. | Adverse Events: None reported. Negative: No control group. |
| Martin et al., Sham-Controlled Study, (2009) | N=7, Avg. Age: 58, 4M/3F | Ischemic; Chronic (Avg. 4.8 yrs); LH, Frontal/Parietal | Excitatory (3 Hz) + SLT, Left (Ipsilesional) Broca's Area | Improved naming accuracy for trained items only. | Adverse Events: None. Negative: Effect did not generalize to untrained words. |
| Barwood et al., Sham-Controlled Crossover Trial, (2011) | N=13, Avg. Age: 61, 9M/4F | Ischemic; Chronic (Avg. 4.7 yrs); LH, MCA territory | Inhibitory (1 Hz) on R-IFG vs. Excitatory (10 Hz) on L-IFG | Inhibitory TMS on the right hemisphere was significantly more effective for naming than both sham and excitatory TMS. | Adverse Events: None serious. Null Finding: Excitatory left-sided TMS was not superior to sham. |
| Thiel et al., RCT. (2013) | N=24, Avg. Age: 58, 16M/8F | Ischemic; Chronic (Avg. 3.2 yrs); LH, Frontal cortex | Inhibitory (1 Hz) + SLT, Right (Contralesional) Pars Opercularis | Significantly greater improvement in overall aphasia severity and naming compared to sham group. | Adverse Events: One transient headache. Negative: Not all patients responded to treatment. |
| Tsai et al., RCT. (2019) | N=21, Avg. Age: 64, 18M/3F | Ischemic; Subacute (1-3 mos); LH, MCA territory | Inhibitory (1 Hz) on R-IFG vs. Excitatory (10 Hz) on L-IFG | Both active TMS protocols were significantly better than sham; no difference was found between the two active protocols. | Adverse Events: None major. Null Finding: Neither active protocol was superior to the other in the subacute stage. |
| Harvey et al., RCT, (2020) | N=17, Avg. Age: 60, 10M/7F | Ischemic; Chronic (Avg. 4.2 yrs); LH, MCA territory | Inhibitory (cTBS) + SLT, Right (Contralesional) IFG | Significant improvements in picture naming and discourse production compared to sham. | Adverse Events: None reported. Negative: A 'sizable portion' of participants did not show clinically significant change. |
| Heikkinen et al., RCT, (2022) | N=60, Avg. Age: 61, 42M/18F | Ischemic; Chronic (Avg. 3.1 yrs); LH, MCA territory | Excitatory (iTBS) + SLT, Left (Ipsilesional) IFG | Positive trends on some secondary naming measures. | Adverse Events: Minor scalp discomfort. Primary Null Finding: No significant difference between real and sham iTBS on the primary outcome measure (Aphasia Quotient). |

***Footnote:*** *Avg., Average; cTBS, Continuous Theta-Burst Stimulation (an inhibitory rTMS protocol); F, Female; Hz, Hertz; iTBS, Intermittent Theta-Burst Stimulation (an excitatory rTMS protocol); L-IFG, Left Inferior Frontal Gyrus; LH, Left Hemisphere; M, Male; MCA, Middle Cerebral Artery; mos, Months; N, Number of participants; RCT, Randomized Controlled Trial; R-IFG, Right Inferior Frontal Gyrus; rTMS, Repetitive Transcranial Magnetic Stimulation; SLT, Speech and Language Therapy; TMS, Transcranial Magnetic Stimulation; yrs, Years.*

**Future Directions**

To translate these promising findings into robust clinical practice, the field must now pivot towards a more nuanced and evidence-driven approach to protocol design and patient selection. A primary focus of future research must be the personalization of treatment through the use of advanced neuroimaging as a predictive and targeting tool. Rather than relying solely on anatomical landmarks, multimodal imaging can serve to stratify patients and guide interventions. For instance, functional MRI (fMRI) can be used to objectively identify the degree of maladaptive contralesional hyperactivity in a given individual, providing a clear target for inhibitory rTMS, or to pinpoint areas of residual function in the perilesional cortex, offering a precise target for excitatory stimulation. Concurrently, diffusion tensor imaging (DTI) can assess the structural integrity of critical language-related white matter tracts, such as the arcuate fasciculus, potentially providing a biomarker to identify patients who possess the necessary neural infrastructure to benefit from stimulation.

In addition, the influence of stroke chronicity on treatment efficacy requires systematic investigation. The provocative finding that both ipsilesional and contralesional protocols may be equally effective in the subacute phase suggests the optimal therapeutic target may evolve as the brain reorganizes over time (Tsai et al., 2019). Large-scale, longitudinal RCTs are therefore necessary to directly compare these therapeutic strategies at different time points post-stroke, which will help elucidate whether there is an optimal window for specific interventions. It may be that a dynamic treatment paradigm is needed, perhaps beginning with ipsilesional facilitation early on, with a subsequent shift to contralesional inhibition should maladaptive plasticity become established. Beyond personalizing who and where to stimulate, the field must also refine the specific parameters of the intervention itself. Key questions remain regarding the optimal "dose"—including the total number of sessions, the utility of extended or maintenance treatment schedules, and the comparative efficacy of different stimulation patterns. Finally, the synergy between TMS and SLT must be more deeply interrogated. Future studies should move beyond generic pairings and systematically investigate which specific evidence-based therapies, such as Constraint-Induced Aphasia Therapy or Melodic Intonation Therapy, combine most effectively with neuromodulation to yield the greatest and most durable therapeutic gains.

**Conclusion**

The collective body of peer-reviewed literature positions rTMS as a safe, well-tolerated, and compelling adjunctive therapy for the rehabilitation of post-stroke Broca's aphasia. There is now substantial evidence, supported by multiple randomized controlled trials, demonstrating that TMS can be used to meaningfully modulate the neuroplastic processes that underpin language recovery. The inhibitory contralesional protocol, in particular, stands out as a well-supported strategy for improving naming and overall language function in chronic patients (Thiel et al., 2013; Harvey et al., 2020). At the same time, the excitatory ipsilesional approach has also shown clear efficacy, affirming that multiple pathways to enhancing recovery are viable (Ren et al., 2022).

This promising outlook, however, must be tempered by a clear-eyed acknowledgment of the modality's current limitations. The high degree of inter-individual variability in treatment response, with the consistent presence of non-responder subgroups, remains the single greatest challenge to its widespread clinical implementation. Moreover, the null primary finding of a large, methodologically rigorous trial such as the PLORAS study serves as an essential scientific benchmark, cautioning against a uniform application of any single protocol and suggesting that the true therapeutic effect size may be more modest or more specific than initially anticipated (Heikkinen et al., 2022). In its entirety, the current research landscape provides a solid foundation and a clear mandate: the era of generalized TMS application is ending, and the era of personalized, biomarker-guided neuromodulation for aphasia must now begin.

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