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Noninvasive Brain Stimulation Techniques for the Recovery of Unilateral Visual Impairment After Stroke: A Systematic Review

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Abstract

According to data from the Global Stroke Report 2025, stroke accounted for 10.72% of all deaths worldwide in 2021. Monocular visual field defects represent one of the most prevalent and severe cognitive impairments following stroke, with a prevalence rate reaching up to 30%. Current conventional treatments for monocular visual field defects yield limited efficacy, whilst non-invasive brain stimulation techniques are advancing rapidly. With the continuous development of these non-invasive brain stimulation technologies, an increasing body of research indicates that they may offer certain restorative effects for post-stroke hemianopia. To synthesize the effects of noninvasive brain stimulation techniques in the recovery of unilateral visual impairment after stroke. A comprehensive search was conducted in six databases, including PubMed, Web of Science, Cochrane Library, CNKI, Wan fang, and VIP, as of January 3, 2026. The articles were screened based on the exclusion criteria. The included articles were analyzed based on their impact on visual function improvement, quality of life, and adverse effects. Sixteen studies were analyzed, demonstrating that noninvasive brain stimulation significantly improved visual function and quality of life for patients. Additionally, adverse effects were minimal. Noninvasive brain stimulation technology shows promise in the recovery of unilateral visual impairment after stroke. However, further multi-center, large-sample, high-quality randomized controlled trials are necessary to verify its efficacy and safety.

Keywords

noninvasive brain stimulation, stroke, unilateral visual impairment

1. Introduction

Stroke is a common neurological disorder. According to the Global Stroke Report 2025, there were 11.946 million new stroke cases worldwide in 2021, resulting in 7.253 million deaths, accounting for 10.7% of all deaths globally. Among these deaths, those caused by ischemic stroke (IS), intracerebral hemorrhage (ICH), and subarachnoid hemorrhage (SAH) accounted for 49.5% (3.591 million), 45.6% (3.308 million), and 4.9% (0.353 million), respectively. Stroke is the second leading cause of death worldwide and ranks third in the global burden of disease [1]. Stroke can lead to unilateral visual impairment, which is one of the most common and severe cognitive deficits following right-hemisphere stroke, with a prevalence of up to

30% [2]. Brain injury affecting the fronto-parietal subcortical cortical network involved in spatial representation and awareness may explain the mechanism underlying hemispatial neglect [3]. Unilateral neglect is characterized by a failure to report, respond to, or orient toward stimuli presented on the side opposite the brain lesion. The presence of unilateral neglect significantly delays recovery from mild hemiparesis, and patients frequently experience more difficulties in activities of daily living [4].

Among the therapeutic approaches for hemispatial neglect, the three most commonly used interventions are visual scanning training, limb activation therapy, and prism adaptation therapy [5]. However, conventional rehabilitation methods often show limited effectiveness, highlighting the need to explore new treatment strategies. In recent years, non-invasive brain stimulation (NIBS) has developed rapidly and has attracted considerable attention because of its non-invasive and safe characteristics. Repetitive transcranial magnetic stimulation (rTMS) can stimulate or inhibit cortical activity by modulating the frequency of the magnetic field, thereby inducing corresponding electrical currents. Theta burst stimulation (TBS) is a patterned form of rTMS with a shorter total stimulation duration [6] and lower stimulation intensity [7]. Its pulses are delivered at a faster rate and can be applied intermittently or continuously. TBS is believed to induce long-lasting changes in cortical excitability that persist beyond the stimulation period [8].

With the continuous development of non-invasive brain stimulation techniques, an increasing number of studies have demonstrated their potential value in the recovery of unilateral visual impairment after stroke [9]. However, systematic evaluations of the role of non-invasive brain stimulation in the recovery of unilateral visual impairment following stroke remain limited. Therefore, this systematic review aims to clarify the role of non-invasive brain stimulation techniques in the recovery of unilateral visual impairment after stroke.

2. Materials and Methods

2.1 Search Strategy

This systematic review was conducted in accordance with the PRISMA 2020 Statement. Relevant literature was retrieved from six databases, including PubMed, Web of Science, Cochrane Library, CNKI, Wanfang Data, and VIP Database. The search period extended from database inception to January 3, 2026. The following keywords were used for the literature search: “stroke”, “cerebrovascular accident”, “unilateral spatial neglect”, “spatial neglect”, “unilateral neglect”, “transcranial magnetic stimulation”, “TMS”, “repetitive transcranial magnetic stimulation”, “rTMS”, “theta burst stimulation”, and “TBS”.

2.2 Inclusion and Exclusion Criteria

Inclusion Criteria:

1) Original studies published in peer-reviewed journals.
2) Participants were adult patients diagnosed with visuospatial neglect after stroke (ischemic or hemorrhagic).
3) The included studies were randomized controlled trials (RCTs).
4) The control group received sham stimulation or conventional stroke rehabilitation, while the experimental group received non-invasive brain stimulation interventions in addition to the treatments given to the control group, including but not limited to tDCS, rTMS, TBS, iTBS, tACS, and PAS.

Exclusion Criteria:

1) Study types including meta-analyses, reviews, conference papers, or case reports.
2) Studies with insufficient data, and complete data could not be obtained even after contacting the authors.
3) Participants with visual impairment, abnormal vision, or corrected vision problems unrelated to stroke.
4) Patients with metal implants, cardiac pacemakers, or cochlear implants.

5) Patients with comorbidities that are contraindications to non-invasive brain stimulation, such as malignant tumors, open wounds, a history of epilepsy, or a family history of epilepsy.

2.3 Study Selection

All retrieved records were imported into EndNote 9.0 reference management software. After removing duplicates, the studies were screened. The titles, abstracts, and full texts were independently reviewed according to the predefined inclusion and exclusion criteria, and the reasons for exclusion were documented for each excluded article.

2.4 Quality Assessment

Since the included studies were randomized controlled trials, the Cochrane Risk of Bias (ROB) assessment tool was used to evaluate methodological quality. Evidence quality was assessed from several aspects, including research objectives, study design, study population, observation or measurement methods, outcome analysis, quality control, and result reporting. After completing the quality assessment, Review Manager 5.3 software was used to generate the risk-of-bias summary figures and individual quality assessment results.

2.5 Data Extraction and Analysis

Information extraction and analysis were conducted for studies that passed the quality assessment. The extracted study characteristics included: Clinical characteristics, including the first author and year of publication, sample size (experimental group/control group), and treatment conclusions; Spatial neglect-related outcome measures, including the Star Cancellation Test, Line Bisection Test, Line Cancellation Test, and Albert Test, among others. Due to the substantial heterogeneity among the included studies, performing a meta-analysis might introduce bias. Therefore, a systematic review approach was adopted to comprehensively analyze the role of non-invasive brain stimulation techniques in the functional recovery of patients with unilateral visuospatial impairment after stroke.

3. Results

3.1 Study Selection Results and Characteristics of Included Studies

A total of 16 relevant studies were included, comprising 15 English-language articles and 1 Chinese-language article. The studies involved a total sample size of 375 patients, among whom 209 received non-invasive brain stimulation treatment, while 160 received conventional therapy or sham stimulation as placebo treatment. The literature screening process is shown in Figure 1.

3.2 Quality Assessment Results

Among the 16 included studies [10–25], the participants were randomly assigned using methods such as random number tables or computer-generated randomization. In 11 studies, the method of allocation concealment was not clearly described, and one study did not employ allocation concealment, which may have introduced a certain degree of selection bias. Six studies explicitly reported a double-blind experimental design, and most studies did not present other sources of bias. Overall, the methodological quality of the included studies was moderate. The results of the methodological quality assessment are presented in Figure 2 and Figure 3.

3.3 Improvement in Visual Function

Among the included studies, 14 used the Line Bisection Test, and 9 used the Star Cancellation Test as outcome measures for evaluating unilateral neglect function. The results of multiple studies indicated that visual spatial bias improved after intervention with non-invasive brain stimulation techniques. One study reported that after 10 sessions of rTMS treatment administered daily, the Line Bisection Test showed that the mean improvement in leftward deviation of line bisection in the rTMS experimental group was greater than that in the control group. Studies conducted by Kim Yong-Kyun et al. [11] and Lim et al. [23] both

confirmed and recommended the use of low-frequency rTMS at a frequency of 10 sessions per day for non-invasive brain stimulation rehabilitation training. The basic characteristics of the included studies are summarized in Table 1.

Figure 1: Flow diagram of the literature selection process

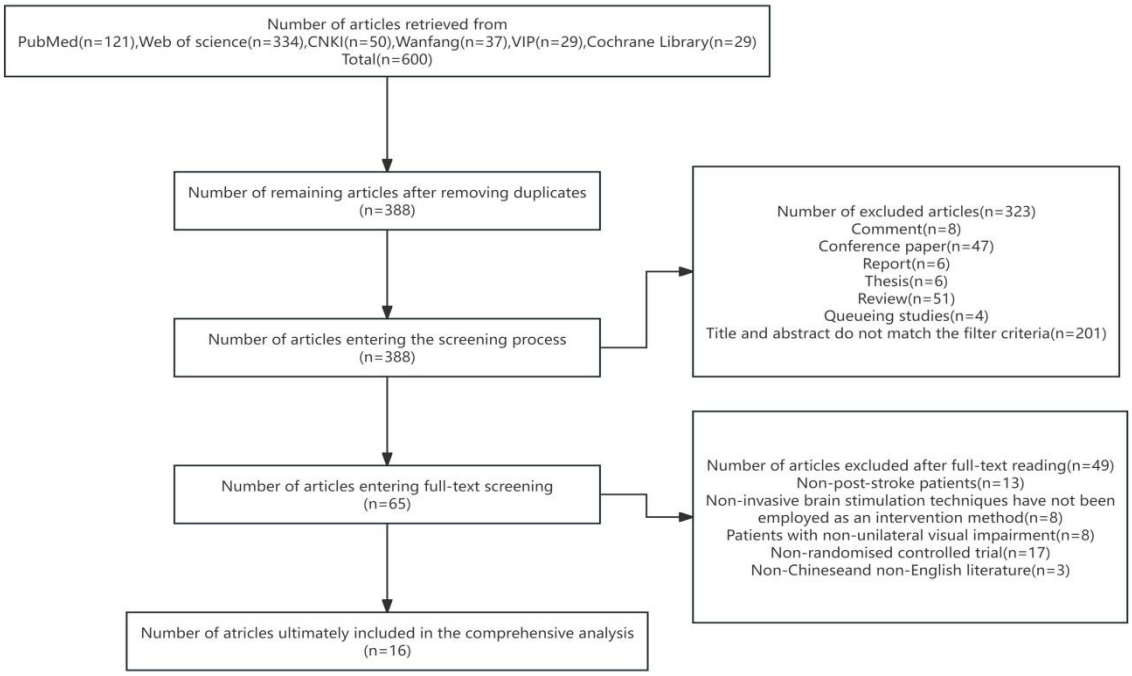

Figure 2: Risk-of-bias graph

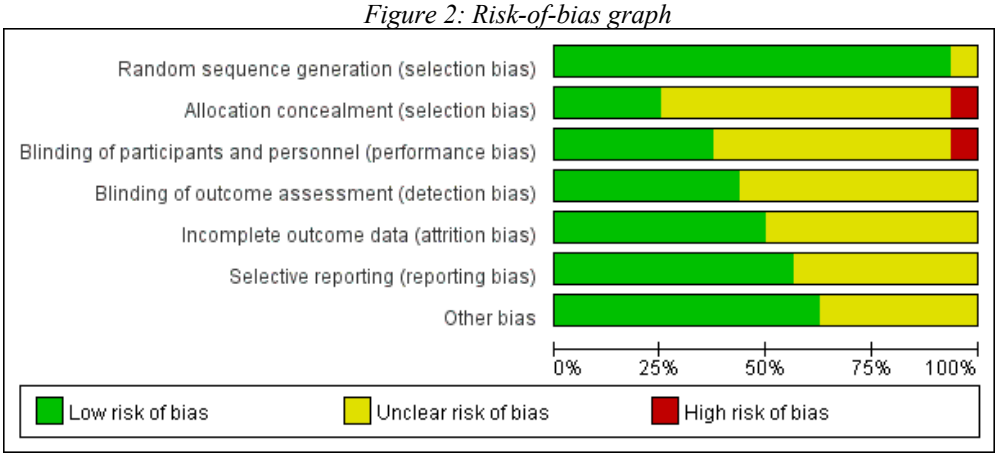

Figure 3: Risk-of-bias graph

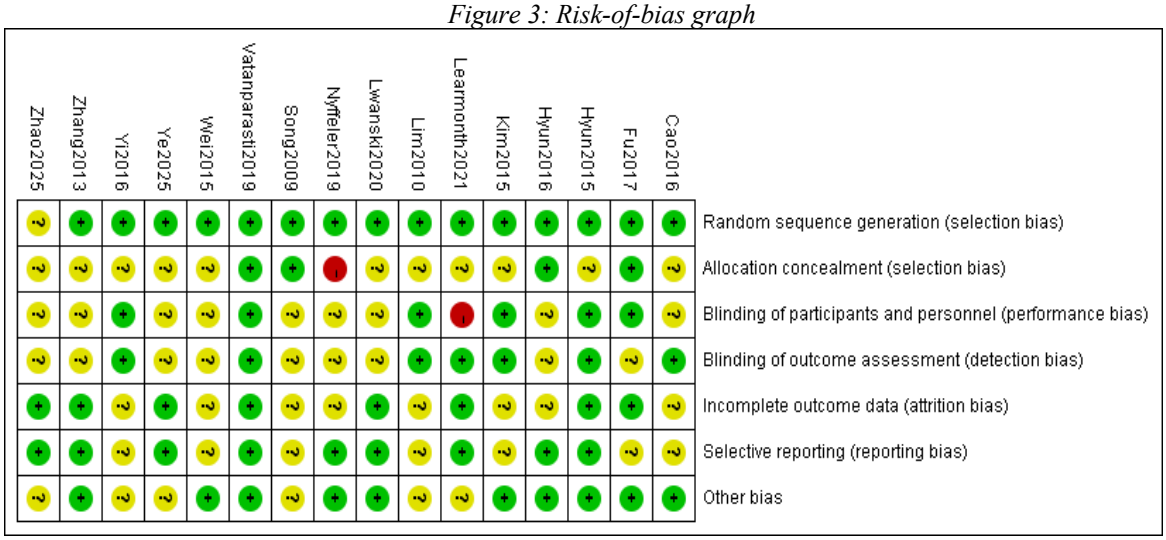

Table 1: Characteristics of the Included Studies

First Author / Year	Sample Size (Experimental / Control)	Study Type	Outcome Measures	Study Conclusions
Kim Yong·Kyun/2015	19/15	RCT	Letter cancelation test, Line bisection test, Ota's task	Compared with a single daily session of rTMS, ten sessions of low-frequency rTMS per day applied to the left parietal cortex had a more positive effect on spatial neglect. Therefore, low-frequency rTMS administered 10 times per day may be used for the treatment of left hemispatial neglect after stroke.
Wei Yang/2015	28/10	RCT	Star cancelation test, Line bisection test	The study provided strong evidence that rTMS significantly improved the neurocognitive function of VSN, with continuous TBS showing the best therapeutic effect. According to DTI assessment, enhanced connectivity within white-matter tract networks related to visual attention may represent a potential mechanism underlying the recovery of VSN observed with continuous TBS.
Fu Wei/2017	6/6	RCT	Star cancelation test, Line bisection test	The present study indicated that continuous theta stimulation combined with visual scanning training and motor function training can regulate RSFC within the attention network, thereby promoting recovery from behavioral deficits in patients with post-stroke VSN. The stimulation parameters used in this study may provide valuable references for clinical treatment strategies for VSN and functional recovery after stroke.
Hyun Gyu Cha/2015	12/12	RCT	Motor Free Visual Perception Test, Star cancelation test, Line bisection test, Albert test	The findings suggest that repetitive transcranial magnetic stimulation may help reduce unilateral neglect in patients with stroke.
Hyun Gyu·Cha/2016	15/15	RCT	Line bisection test, Albert test	The study suggests that rTMS may be effective in improving unilateral neglect and motor function.
Cao Lei/2016	7/6	RCT	Star cancelation test, Line	The results support the critical role of the left dorsolateral prefrontal cortex (LDLPFC) in regulating the attention network involved in neglect,

First Author / Year	Sample Size (Experimental / Control)	Study Type	Outcome Measures	Study Conclusions
			bisection test	and enhancing LDLPFC activity through intermittent theta burst stimulation may facilitate recovery of VSN in stroke patients.
Yi You Gyoung/2016	20/10	RCT	Motor Free Visual Perception Test, Star cancelation test, Line bisection test, Catherine Bergego Scale	The results showed that anodal tDCS facilitated the right cortex while cathodal tDCS inhibited the left cortex, thereby improving symptoms of visuospatial neglect. Therefore, tDCS may serve as an effective adjunctive therapy for the recovery of neglect symptoms.
Vatanparasti, S./2019	7/7	RCT	Star cancelation test, Line bisection test, Figure Copying Test, Clock Drawing, Modified Rankin Scale	The study indicated that transcranial magnetic stimulation did not enhance the effect of prism adaptation training on neglect symptoms in stroke patients.
lwarski, S./2020	14/14	RCT	BIT-c, BIT-b, Visuospatial Scale	No statistically significant differences were found in outcome measures between the rTMS group and the sham stimulation group. The magnitude of stimulation effects was not related to lesion volume, lesion location, or baseline motor threshold. The study did not confirm the effectiveness of 1 Hz rTMS as an adjunct to visual scanning training in patients with subacute stroke and VSN.
Nyffeler T/2019	20/10	RCT	Catherine Bergego Scale, Fluff test, Two-Part-Picture Test, bird cancellation task	The study showed that cTBS applied to the contralesional posterior parietal cortex significantly improved and accelerated recovery from neglect, as well as related overall functional outcomes, in patients with intact interhemispheric connections.
Song W./2009	7/7	RCT	Line bisection test, Line cancelation test	This study suggested that low-frequency rTMS applied to the unaffected hemisphere may improve visuospatial neglect after stroke, supporting the interhemispheric competition theory of the attention network, and highlighting the need for further research.
Lim, J. Y./2010	7/7	RCT	Line bisection test, Albert test	The study demonstrated that low-frequency rTMS applied to the unaffected left parietal region was safe and improved performance on the Line Bisection Test, suggesting that non-invasive cortical stimulation may serve as an adjunctive strategy for cognitive rehabilitation in patients with hemispatial neglect. Further prospective randomized sham-controlled trials are required to confirm the beneficial effects.
Zhao, W. Y./2025	10/10	RCT	Line bisection test, Line cancelation test, Star	The study showed that iTBS not only alleviated symptoms of unilateral neglect (UN) but also significantly enhanced cortical excitability at the stimulation site, contributing to reconstruction of

First Author / Year	Sample Size (Experimental / Control)	Study Type	Outcome Measures	Study Conclusions
			cancelation test	brain networks, particularly functional connectivity between the hemispheres.
Ye, L. L./2025	10/10	RCT	Line bisection test, Line cancelation test, Star cancelation test	The findings indicated that iTBS significantly improved symptoms of UN and enhanced excitability at the stimulation site. Moreover, iTBS promoted early enhancement of connectivity within the fronto-parietal network, demonstrating potential therapeutic value for restoring neural network balance.
Learmonth, G./2021	18/6	RCT	BIT, Line bisection test, The Balloons test, The Broken Hearts test, Visual field testing	The results showed that patients receiving tDCS alone or tDCS combined with behavioral training exhibited varying degrees of improvement in core unilateral neglect assessment indicators such as the Line Bisection Test and Balloon Test. The findings also suggest that future studies may explore the feasibility of home-based tDCS interventions for post-stroke unilateral spatial neglect.
Zhang/2013	15/15	RCT	Line bisection test, Line cancelation test, Clock Drawing	The study showed that rTMS inhibited excessive cortical excitability in the unaffected hemisphere, promoted restoration of excitatory balance between the bilateral hemispheres, improved neglect symptoms, and also contributed to recovery of motor function.

Notes:
RCT = randomized controlled trial
TBS / rTMS / tDCS = transcranial magnetic stimulation techniques
DTI = diffusion tensor imaging
VSN / UN = visuospatial neglect / unilateral neglect
iTBS = intermittent theta burst stimulation
BIT = Behavioural Inattention Test
BIT-C = conventional subtests of the BIT
BIT-B = selected behavioral subtests of the BIT

3.4 Quality of Life and Adverse Effects

The results indicated that patients receiving non-invasive brain stimulation (NIBS) showed significant improvements in visual function and quality of life. Specifically, patients exhibited improvements in visual spatial bias after treatment, and their quality of life was also significantly enhanced. In addition, most patients did not experience obvious adverse reactions. Only a small number of patients reported mild symptoms such as headache and localized skin itching.

4. Discussion

This study included 16 randomized controlled trials and comprehensively evaluated the effectiveness of non-invasive brain stimulation techniques in the recovery of unilateral visual impairment after stroke. The results suggest that non-invasive brain stimulation has a certain therapeutic effect on the recovery of unilateral visual impairment after stroke. The underlying mechanisms may be related to regulation of neurotransmitter secretion, improvement of neural conduction pathways, and promotion of neural regeneration.

Non-invasive brain stimulation techniques directly act on damaged brain regions through external stimulation, particularly for behavioral and cognitive disorders such as unilateral neglect, enabling targeted improvement of related symptoms. This approach can better meet patients' rehabilitation needs and achieve optimal therapeutic outcomes. Moreover, NIBS may not only improve symptoms in the short term, but also promote recovery and reorganization of brain function through modulation of neuroplasticity, thereby providing sustained long-term therapeutic effects [26].

With the development of neuromodulation techniques and multimodal neuroimaging, the mechanisms underlying the effects of NIBS on post-stroke unilateral neglect have been increasingly explored. Mechanistic research has gradually shifted from focusing on local changes in cortical excitability to investigating reorganization of brain network topology. Previous studies have suggested that relative hyperexcitability of the contralesional hemisphere and functional suppression of the lesioned hemisphere after stroke, together with interhemispheric inhibition imbalance via the corpus callosum, constitute an important mechanism underlying unilateral spatial neglect (USN). In recent years, evidence from TMS-EEG, functional connectivity analysis, and structural connectivity studies has provided more refined neurophysiological support for this theory.

Ting et al. reported that rTMS improves unilateral neglect primarily by suppressing attentional bias toward the contralesional side and restoring orienting balance between the two hemispheres [27]. With further research, studies by Zhao et al. and Ye et al., using TMS-EEG techniques, demonstrated that NIBS improves post-stroke unilateral neglect by enhancing cortical excitability at the stimulation target and reshaping functional connectivity within brain networks [17,22]. These findings suggest that the effects of NIBS are not limited to simply "activating the lesioned hemisphere" or "inhibiting the contralesional hemisphere," but rather involve reconstruction of cross-regional network synchronization to restore the dynamic balance of the attention system. From the perspective of structural connectivity, Yang et al. provided complementary evidence, indicating that enhanced connectivity of white matter tract networks associated with visual attention may represent a potential mechanism underlying the therapeutic effects of continuous TBS (cTBS) in USN [10]. This finding extends the effects of NIBS from functional connectivity modulation to structural connectivity remodeling, suggesting that stimulation may improve spatial attention deficits by promoting compensatory strengthening of residual white matter pathways or enhancing network integration efficiency. Therefore, the therapeutic mechanism of NIBS in post-stroke unilateral neglect has evolved from the early "single-region excitation/inhibition hypothesis" to a "brain network plasticity-based systemic regulation model." This theoretical advancement not only provides neurophysiological evidence for optimizing stimulation parameters, but also lays the foundation for developing individualized neurorehabilitation strategies.

However, there is considerable heterogeneity in stimulation parameters used in NIBS for the treatment of post-stroke unilateral neglect, mainly due to the lack of uniform standards and consensus. Taking transcranial direct current stimulation (tDCS) as an example, the effects of parameters such as stimulation intensity, duration, and frequency remain unclear. Some studies have suggested that high-intensity tDCS may more effectively improve symptoms of unilateral neglect, whereas other studies indicate that low-intensity tDCS may be safer and equally effective [23]. In addition, there are differing views regarding stimulation duration and frequency [28,29].

Furthermore, repetitive transcranial magnetic stimulation (rTMS) and other non-invasive brain stimulation techniques, such as transcranial ultrasound stimulation, also exhibit heterogeneity in stimulation parameters when used to treat post-stroke unilateral neglect [7]. The selection of stimulation parameters in these techniques is often based on researchers' experience and experimental design, rather than standardized guidelines.

Therefore, to facilitate the clinical application of NIBS in the treatment of post-stroke unilateral neglect, further research is required to determine optimal stimulation parameters and establish standardized protocols. In addition, greater attention should be paid to individual differences among patients and heterogeneity in treatment outcomes.

5. Conclusion

This study updates the current evidence regarding the role of non-invasive brain stimulation in post-stroke unilateral visual impairment. The results indicate that non-invasive brain stimulation has certain benefits in promoting recovery from unilateral visual impairment after stroke and can be used as an adjunctive technique in routine rehabilitation training. Low-frequency rTMS administered 10 sessions per day is recommended as a training protocol. Moreover, in recent years, randomization, blinding, and allocation concealment in randomized controlled trials have been implemented more rigorously, resulting in higher methodological quality compared with earlier studies.

However, several limitations should be acknowledged. First, the number of included studies was relatively small, and the sample sizes were limited, which may affect the stability and reliability of the results. Second, treatment protocols and outcome measures varied across studies, which may have influenced the results of the overall analysis. In addition, some studies had relatively low methodological quality or small sample sizes, which may have introduced bias. Therefore, further high-quality randomized controlled trials are needed to verify the effectiveness and mechanisms of non-invasive brain stimulation in the recovery of unilateral visual impairment after stroke.

Future research should focus on the mechanisms of action of non-invasive brain stimulation and the upstream and downstream regulatory targets involved. Large-scale, multicenter randomized controlled trials are also needed to validate the efficacy and safety of non-invasive brain stimulation techniques. Moreover, exploring the combined application of non-invasive brain stimulation with other therapeutic approaches may be more suitable for clinical implementation. In addition, the current stimulation parameter settings for non-invasive brain stimulation lack standardized protocols, which warrants further investigation in future studies.

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Conflicts of Interest

The authors declare no conflict of interest.

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