RESEARCH PAPER

Assessing the Prevalence of Neuroplasticity and Cortical Reorganization in Neurological Rehabilitation: A Geographically Stratified Systematic Review

[1]Sapna Dagar and [2]Dr. Jaynesh Vandra

[1]*PhD Scholar, Venus Institute of Physiotherapy, Swarrnim Startup & Innovation University*
[2]*MPT Orthopaedic & Sports, PGDHHM, Ph.D., Swarrnim Startup & Innovation University*

Received: 24th May, 2026; Revised: 20th June 2026; Accepted: 30th July, 2026; Available Online: 10th August, 2026

ABSTRACT

Background: Neuroplasticity and cortical reorganization are central mechanisms through which the nervous system adapts to injury, learning and rehabilitation. However, routine rehabilitation assessment is still largely based on impairment, activity and participation outcomes, while direct or indirect measures of neural adaptation are less consistently incorporated into clinical practice. The present review was undertaken as the evidence-synthesis component of Objective 1 of the proposed Neuroplasticity and Cortical Reorganization Assessment Scale (NCRAC) project.

Methods: A focused systematic evidence review was developed around 18 relevant publications, stratified a priori into six Delhi-NCR studies, six studies from other parts of India, and six international studies. The evidence included intervention studies and systematic/scoping reviews that evaluated neuroplasticity or cortical reorganization during neurological rehabilitation using TMS, EEG, fMRI, MRI, fNIRS, or clinically linked neuroplasticity-based interventions. Evidence was synthesized narratively because of substantial heterogeneity in neurological conditions, interventions, neural measures and outcome definitions.

Results: The selected literature consistently indicates that rehabilitation is accompanied by measurable changes in cortical excitability, brain activation, functional connectivity, structural or microstructural brain measures, and neural complexity. Delhi-NCR studies particularly demonstrate the feasibility of measuring cortical change using rTMS, fMRI and robotic or virtual-reality rehabilitation. Indian evidence supports the growing use of neuroplasticity-oriented rehabilitation and non-invasive brain stimulation, but also highlights limited standardization and the scarcity of practical neural outcome measures. International evidence shows similar findings across stroke, multiple sclerosis, Parkinson's disease and spinal cord injury. Across the evidence base, advanced neural measures are informative but remain heterogeneous, resource-intensive, or insufficiently standardized for routine use.

Conclusion: The literature supports a clear clinical and research need for a standardized, accessible and psychometrically sound measure that can complement conventional functional outcomes by capturing patient-relevant domains associated with neural adaptation. Importantly, the reviewed studies do not provide a population prevalence estimate of 'neuroplasticity'; therefore, Objective 1 should be interpreted as determining the evidence and clinical need for assessment rather than estimating disease prevalence. This evidence provides a strong rationale for development and validation of the NCRAC.

Keywords: neuroplasticity; cortical reorganization; neurological rehabilitation; stroke; neurorehabilitation; EEG; TMS; fMRI; neuroplasticity assessment; NCRAC

How to cite this article: Dagar S, Vandra J, Assessing the Prevalence of Neuroplasticity and Cortical Reorganization in Neurological Rehabilitation: A Geographically Stratified Systematic Review Int J Drug Deliv Technol. 2026;16(79s):916-924. DOI: 10.25258/ijddt.16.79s.160
Source of support: Nil.
Conflict of interest: None

1. INTRODUCTION

Neurological disorders are a major cause of long-term disability and frequently result in persistent limitations in movement, sensation, cognition, balance and participation. Rehabilitation is therefore an important component of long-term management. The underlying biological response to rehabilitation is not limited to muscle or peripheral changes; it also involves experience-dependent adaptation within neural networks. The proposal underpinning this review identifies neuroplasticity and cortical reorganization as important processes supporting recovery and emphasizes that routine clinical assessments generally focus on functional recovery rather than the neural mechanisms that contribute to it. [1] Neuroplasticity refers broadly to the nervous system's capacity to modify its structure and function in response to experience, learning, injury and rehabilitation. Cortical reorganization is one expression of this adaptability and may involve altered cortical excitability, recruitment of additional brain regions, changes in interhemispheric relationships, and changes in functional or structural connectivity. These

**Author for Correspondence: Sapna Dagar*

processes can support recovery, compensation or, in some circumstances, maladaptive patterns. The clinical relevance of these changes is increasingly recognized in contemporary neurorehabilitation. The evidence base has expanded rapidly with the use of transcranial magnetic stimulation (TMS), electroencephalography (EEG), functional magnetic resonance imaging (fMRI), diffusion imaging and functional near-infrared spectroscopy (fNIRS). These methods can detect neural changes that may accompany functional improvement. For example, recent reviews report that EEG measures may contribute to assessment, prognosis and monitoring of post-stroke recovery, while MRI studies demonstrate rehabilitation-related changes in functional and structural connectivity. [2] excellent there is an important translational gap. Many neuroplasticity studies are small, use different neural outcomes and apply different analytical methods. A 2026 scoping review found only eight studies of brain entropy or complexity in neurorehabilitation and concluded that these biomarkers are promising but require methodological standardization and longitudinal validation before routine clinical decision-making. [3] Similarly, a recent systematic review of EEG functional connectivity in stroke reported substantial methodological heterogeneity and inconsistent patterns across studies. [4] The proposal therefore identifies a practical gap: advanced neurophysiological techniques provide valuable information but are not always feasible in routine rehabilitation, whereas conventional outcome measures do not specifically target neural adaptability, sensorimotor integration, motor learning, body awareness or cortical reorganization. [5] The NCRAC is intended to address this gap by providing a standardized, clinically applicable questionnaire that complements rather than replaces objective neurophysiological measures.

Prevalence

Neurological conditions represent a substantial global health burden. According to the Global Burden of Disease Study 2021, approximately 3.4 billion people, corresponding to 43.1% of the global population, were affected by neurological conditions in 2021. Neurological conditions collectively represented the leading cause of disability adjusted life years globally. This large and increasing burden highlights the importance of rehabilitation approaches that address not only functional limitations but also the neural adaptations underlying recovery.

2. REVIEW OBJECTIVE

To determine the evidence and clinical need for assessing neuroplasticity and cortical reorganization in individuals undergoing neurological rehabilitation, with specific consideration of evidence from Delhi-NCR, other regions of India, and international settings.

3. METHODS

3.1 Review design

This manuscript was structured according to the principles of PRISMA 2020 for systematic evidence reporting. The review question was developed from Objective 1 of the NCRAC proposal. Because the selected evidence comprises different designs and neural outcomes, a narrative synthesis was considered more appropriate than statistical meta-analysis. The proposed NCRAC study itself is a methodological instrument-development and validation study with phases for item generation, content validation, pilot testing and psychometric evaluation. [6]

3.2 Review question

Among adults undergoing neurological rehabilitation, what evidence demonstrates measurable neuroplasticity or cortical reorganization, which methods are used to assess these changes, and what evidence supports the need for a practical standardized assessment tool?

3.3 Eligibility Criteria:

Eligibility criteria were used to select studies that were directly related to neuroplasticity, cortical reorganization and neurological rehabilitation. The review included adult participants with neurological conditions and studies that investigated neural changes using methods such as TMS, EEG, MRI/fMRI or fNIRS, or used clinically relevant neuroplasticity-based outcomes.

Table 1. Eligibility Criteria for Study Selection

Criterion	Eligibility
Population	Adults with neurological disorders or neurological rehabilitation populations, including stroke, multiple sclerosis, Parkinson’s disease and spinal cord injury.
Concept	Neuroplasticity, cortical reorganization, cortical excitability, neural complexity, functional connectivity, structural brain adaptation, or rehabilitation-related neural change.
Assessment	TMS, EEG, fMRI/MRI, fNIRS or clinically linked neuroplasticity-oriented outcomes.
Study types	Primary intervention/observational studies and systematic/scoping reviews directly relevant to the review question.
Geography	Six Delhi-NCR publications, six publications from other Indian regions, and six international publications.
Exclusion	Studies unrelated to neurological rehabilitation, studies without a neural/neuroplasticity component, and non-relevant non-human research.

3.4 Evidence identification and geographic stratification

The 18-paper evidence set was assembled to provide balanced geographic representation required for Objective 1: six publications affiliated with Delhi-NCR, six from other Indian regions, and six international publications. The geographic grouping is based on the study's reported institutional affiliation or study setting. It is not intended to imply that these 18 papers constitute all literature available from a particular region.

A key methodological point is that the present evidence set is a geographically stratified evidence synthesis rather than a prevalence survey. The reviewed publications assess neural change, rehabilitation response or the feasibility of neural biomarkers; they do not establish the population prevalence of neuroplasticity. Accordingly, claims in this manuscript are framed around the 'need for assessment' and the consistency of evidence for measurable neural adaptation rather than a numerical prevalence of neuroplasticity.

3.5 Data extraction and synthesis

The following information was extracted: author and year, location, neurological condition, study design, rehabilitation or exposure, neural assessment method, clinical outcome measures, principal findings, and implications for routine assessment. Findings were grouped into four themes: (1) evidence of measurable neural change, (2) relationship between neural change and functional recovery, (3) feasibility and limitations of existing assessment approaches, and (4) implications for development of NCRAC.

4. RESULTS

Eighteen publications were included in the geographically stratified evidence set. Six were from Delhi-NCR, six from other parts of India, and six from international settings. The evidence was dominated by stroke rehabilitation, with additional evidence from multiple sclerosis, Parkinson’s disease and spinal cord injury. The neural assessment approaches included TMS, fMRI, EEG, MRI/diffusion imaging, fNIRS and neural complexity measures.

Table 2. Geographic distribution of the selected evidence

No.	Study	Region	Population	Rehabilitation/Focus	Neural assessment	Key finding
1	Kuthiala et al., 2019	Delhi-NCR	Chronic stroke	rTMS + rehabilitation	fMRI/BOLD	Cortical reorganization was investigated after high-frequency rTMS with rehabilitation. [7]
2	Boardsworth K et al., 2021	Delhi-NCR	Chronic stroke	Robotic upper-limb therapy	fMRI + RMT	Cortical remapping and clinical change were assessed before/after robotic therapy. [8]
3	Singh et al., 2023	Delhi-NCR	Stroke	Robotic exoskeleton	TMS (MEP/RMT)	Robotic therapy improved motor outcomes and ipsilesional cortical excitability. [9]
4	Nath et al., 2024	Delhi-NCR	Chronic stroke	Targeted VR	Clinical + neuroplasticity measures	Pilot study evaluated clinical potential and neuroplastic effects of targeted VR. [10]
5	Sharma et al., 2020	Delhi-NCR	Ischemic stroke	Low-frequency rTMS	Clinical recovery; neuromodulation	RCT evaluated rTMS combined with rehabilitation for stroke recovery. [11]
6	Bhasin et al., 2025	Delhi-NCR	Post-stroke	Bicephalic tDCS + physiotherapy	fMRI/BOLD	Cortical neural plastic changes were assessed alongside functional outcomes. [12]
7	Shetty et al., 2026	Other India	Neurological rehabilitation	Multiple rehabilitation approaches	EEG/neural complexity	Brain entropy/complexity may sensitively reflect neural adaptation but require standardization. [13]
8	Ravichandran et al., 2026	Other India	Post-stroke	NIBS + physiotherapy	NIBS/neurophysiological outcomes	Combined NIBS and physiotherapy showed generally favorable but heterogeneous effects. [14]

9	Gupta et al., 2026	Other India	Subacute stroke	EEG neurofeedback/brain wave entrainment	EEG + clinical outcomes	Pilot evidence supports feasibility of EEG-linked neurorehabilitation approaches. [15]
10	Kashoo et al., 2022	Other India	Chronic stroke	tDCS + motor imagery + training	Clinical proxy for cortical modulation	64-participant RCT found greater upper-limb gains with real tDCS plus training. [16]
11	Bhaskare, 2025	Other India	Stroke	Neuroplasticity-based physiotherapy	Clinical outcomes	Review of 23 RCTs found positive effects of CIMT/task-specific training, with heterogeneity [17]
12	Juhi et al., 2026	Other India	Stroke	rTMS + rehabilitation	Neuromodulation /neurophysiology	Systematic review examined rTMS protocols targeting supplementary motor areas. [18]
13	Calabrò et al., 2026	International	Stroke	Robot-assisted upper-limb rehabilitation	TMS/EEG/MRI/fNIRS	55 studies were included; biomarker evidence was heterogeneous and certainty was low/very low for pooled endpoints. [19]
14	Lin et al., 2026	International	Stroke	Natural recovery/rehabilitation	EEG connectivity	42 studies showed potential assessment, prognostic and monitoring roles for EEG biomarkers. [20]
15	Tavazzi et al., 2021	International	Multiple sclerosis	Motor rehabilitation	MRI/DTI/fMRI	17 studies showed adaptive brain changes accompanying rehabilitation, but small samples and heterogeneity limited conclusions. [21]
16	Emmenegger et al., 2026	International	Chronic SCI	Motor rehabilitation training	Microstructural MRI/diffusion MRI	Training-related gray/white matter changes accompanied performance improvement. [22]
17	Péran P et al., 2020	International	Progressive MS	Multidisciplinary rehabilitation	fMRI	Rehabilitation was associated with altered task-related and network brain activity. [23]
18	Pei et al., 2025	International	Parkinson's disease	Multidisciplinary intensive rehabilitation	EEG + fMRI	Responders showed network-level neural reorganization associated with motor improvement. [24]

Table 3. Characteristics of the Included Studies

Region	No. of studies	Main conditions	Common assessment approaches	Overall evidence signals
Delhi-NCR	6	Stroke	TMS, fMRI, rTMS/tDCS, robotic/VR rehabilitation	Consistent feasibility of measuring rehabilitation-related cortical change; mostly small/single-centre studies.

Other India	6	Stroke; neurological rehabilitation	EEG, NIBS, clinical neuroplasticity-oriented rehabilitation	Growing evidence and clinical interest, but limited standardization and relatively few mechanistic biomarkers.
International	6	Stroke, MS, SCI, PD	EEG, TMS, MRI/fMRI, diffusion MRI	Broad and increasingly multimodal evidence; heterogeneity remains a major barrier to routine translation.

4.1 Evidence of measurable neuroplastic change

The Delhi-NCR evidence provides direct examples of measurable neural adaptation during rehabilitation. A New Delhi study of robotic hand-exoskeleton rehabilitation used TMS-derived resting motor threshold and motor-evoked potential measures alongside clinical scales. The robotic group demonstrated greater improvement in several motor outcomes and increased ipsilesional cortical excitability, supporting the presence of measurable neurophysiological change during rehabilitation. [9] Another Delhi-NCR study evaluated cortical remapping following upper-limb robotic rehabilitation using fMRI and resting motor threshold. The study illustrates how clinical improvement can be examined together with cortical changes, but the very small sample demonstrates one of the limitations of the existing evidence base. [25] Targeted virtual-reality rehabilitation has also been investigated by the IIT Delhi–AIIMS group, extending the assessment of neuroplastic effects to technology-supported rehabilitation. [10] The 2025 AIIMS New Delhi prospective study of bicephalic tDCS combined with conventional physiotherapy further demonstrates the feasibility of pairing clinical recovery measures with fMRI-derived measures such as BOLD mapping and motor-cortex laterality. [12] Together, these studies show that neural change can be detected in rehabilitation research, but they also demonstrate the dependence on specialized laboratory facilities.

4.2 Evidence from other parts of India

Indian evidence outside Delhi-NCR shows a rapidly developing interest in neuroplasticity-oriented rehabilitation. A 2026 scoping review from Karnataka synthesized eight studies of brain entropy and complexity and reported that increases in entropy or complexity often accompanied functional improvement after task-oriented, robotic or brain-computer-interface rehabilitation. The review nevertheless concluded that standardization and longitudinal validation are needed before these biomarkers can routinely guide clinical decisions. [26] A 2026 systematic review from Karnataka examining non-invasive brain stimulation combined with physiotherapy included 15 RCTs involving 440 participants. The authors reported generally favorable but heterogeneous outcomes and emphasized the importance of standardized protocols and mechanistic biomarkers. [14]A Jaipur-based randomized trial similarly demonstrated greater upper-limb improvement when anodal tDCS was combined with motor imagery and functional training, although the primary outcomes were functional measures rather than a direct neural biomarker. [16] The Indian literature therefore supports the biological plausibility and clinical relevance of neuroplasticity-based rehabilitation, but it does not yet provide a standardized, widely applicable instrument for assessing neuroplasticity across neurological diagnoses. This aligns with the research gap identified in the NCRAC proposal. [27]

4.3 International evidence

International evidence strengthens the argument that neuroplasticity is relevant across neurological conditions rather than only stroke. In multiple sclerosis, a systematic review identified 17 studies using structural and functional MRI markers and concluded that motor rehabilitation was associated with adaptive brain changes, while emphasizing small sample sizes and substantial heterogeneity. [28] A study of progressive MS also demonstrated changes in brain activity following multidisciplinary rehabilitation, providing evidence that functional recovery may be accompanied by reorganization of task-related and broader network activity. [28] In chronic spinal cord injury, a 2026 longitudinal MRI study found training-related changes in gray and white matter alongside performance improvements, demonstrating that plastic adaptation can remain detectable despite chronic neurological injury. [22] In Parkinson's disease, multimodal EEG-fMRI analysis has similarly been used to characterize network reorganization associated with response to intensive rehabilitation. [24] Stroke remains the largest component of the evidence base. A 2026 systematic review of EEG biomarkers included 42 studies and classified EEG measures into assessment, prognostic and monitoring roles. This suggests that neural measures may provide information beyond conventional clinical scales, although the authors noted that clinical translation remains fragmented. [20]A 2026 meta-analysis of robot-assisted upper-limb rehabilitation included 55 studies and grouped biomarkers into TMS, electrophysiological and neuroimaging families, but concluded that measurement heterogeneity limits comparability and certainty. [19]

5. EVIDENCE GAPS AND NEED FOR STANDARDIZED ASSESSMENT

The 18-paper evidence set supports five main conclusions. First, neuroplastic changes are measurable during neurological rehabilitation. Across TMS, EEG, fMRI, MRI and fNIRS, studies have demonstrated changes in cortical excitability, activation, connectivity, neural complexity or structural markers. Second, these changes frequently occur alongside improvements in motor, cognitive or functional outcomes, suggesting that neural assessment may add mechanistic information to conventional outcome measurement. Third, the current methods are difficult to standardize. The recent international evidence shows substantial variation in neural variables, acquisition protocols, analysis strategies, intervention doses and timing of assessment. This heterogeneity makes it difficult to compare findings across studies and limits routine clinical implementation. [29]

Fourth, advanced techniques are not universally accessible. MRI, fMRI, TMS, EEG and fNIRS require equipment, technical expertise, dedicated space and, in many settings, substantial financial resources. EEG is relatively accessible compared with fMRI and has advantages for bedside acquisition, but even EEG-based biomarkers currently lack a universally accepted standardized set for clinical use. [30] Fifth, conventional rehabilitation scales remain essential but are not designed to measure neuroplasticity itself. The NCRAC proposal specifically identifies this gap and lists neural adaptability, sensorimotor integration, motor learning, body awareness, functional brain adaptation, recovery-related changes and cognitive-motor interaction as candidate domains. [31]A standardized patient-oriented measure could therefore complement objective laboratory measures and functional scales by capturing clinically meaningful experiences related to neural adaptation.

Table 4. Evidence Supporting Neuroplasticity Assessment in Neurological Rehabilitation

Evidence domain	Findings across studies	Clinical implication
Cortical excitability	Changes observed with rehabilitation	Neural adaptation can be measured
Brain activation	Altered activation patterns reported	Recovery may involve cortical reorganization
Functional connectivity	Changes reported after rehabilitation	Network-level adaptation may accompany recovery
Structural adaptation	MRI/diffusion changes reported	Plasticity may involve structural changes
Neural complexity	Promising changes reported	Potential future biomarker
Functional recovery	Neural changes often accompanied functional improvement	Neural assessment may complement conventional outcomes

6. IMPLICATIONS FOR DEVELOPMENT OF NCRAC

The evidence synthesis provides direct support for the development phase of NCRAC. The reviewed literature suggests that a useful instrument should not attempt to reproduce TMS, EEG or MRI findings. Instead, it should capture clinically observable and patient-reported manifestations of neural adaptation that can be assessed without specialized equipment. The domains proposed in the research protocol—neural adaptability, sensorimotor integration, motor learning and skill acquisition, body awareness, functional brain adaptation, recovery-related changes and cognitive-motor interaction—are therefore appropriate starting domains for item generation. [32] The instrument should be condition-independent where possible so that it can be used across common neurological rehabilitation populations. This is consistent with the proposal's intention to include stroke, traumatic brain injury, spinal cord injury, Parkinson’s disease and multiple sclerosis. [33] It should also be brief enough for routine clinical use, understandable to adults with neurological conditions, and supported by evidence of content validity, face validity, construct validity, reliability and responsiveness. The proposed methodological pathway is consistent with established scale-development principles: literature-based item generation, expert review, pilot testing, factor analysis, reliability testing and responsiveness assessment. [34] Thus, the systematic evidence review can serve as the scientific foundation for the content domains and item pool of NCRAC.

7. STRENGTHS AND LIMITATIONS

A strength of this review is its deliberate geographic stratification, allowing comparison of evidence emerging from Delhi-NCR, other Indian settings and international research. It also integrates direct neural measures with rehabilitation outcomes and includes several neurological conditions. This is particularly relevant to a condition-independent instrument intended for neurological rehabilitation. The main limitation is that the 18-study set was intentionally constructed to satisfy the geographic distribution specified in the research proposal and should not be interpreted as an exhaustive census of all published studies. In addition, the included evidence is highly heterogeneous in design, sample size, neurological diagnosis, rehabilitation intervention and neural measurement. The review therefore uses narrative synthesis and does not provide a pooled effect estimate. Most importantly, the literature does not report a conventional prevalence of neuroplasticity; therefore, a numerical 'prevalence of neuroplasticity' should not be claimed from these studies. A formal database-based PRISMA review with a prospectively registered protocol would be required before journal submission if the target journal requires a full systematic review with reproducible search counts.

8. CONCLUSION

The available evidence demonstrates that neuroplasticity and cortical reorganization are measurable components of neurological recovery and can be influenced by rehabilitation. Evidence from Delhi-NCR, other Indian regions and international settings consistently supports the relevance of neural adaptation to rehabilitation, while also revealing major limitations in accessibility, standardization and clinical translation of current neurophysiological assessment methods. The literature therefore supports a clear need for a practical assessment approach that can complement conventional measures of function and disability.

The most defensible conclusion is that there is a substantial evidence-based need to assess neuroplasticity and cortical reorganization, but insufficient evidence to assign a population prevalence percentage to neuroplasticity itself. This distinction strengthens the rationale for developing NCRAC as a standardized, reliable, valid and clinically applicable instrument for neurological rehabilitation. The proposed scale can bridge the gap between advanced neurophysiological research and routine clinical assessment.

REFERENCES

1. Baricich A, Spitoni GF, Morone G. Editorial: Long term disability in neurological disease: A rehabilitation perspective. Front Neurol. 2022 Aug 17;13:964664. doi: 10.3389/fneur.2022.964664. PMID: 36062020; PMCID: PMC9430660.
2. Margetis K, Vadakekut ES. Neuroplasticity. [Updated 2026 May 24]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2026 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK557811/
3. Chen Y, Jiang Y, Wang X, Zeng M and Cui J (2026) Advances in mechanisms of neuroplasticity induced by multimodal closed-loop brain–computer interfaces after stroke. Front. Hum. Neurosci. 20:1828191. doi: 10.3389/fnhum.2026.1828191
4. Napoli E, Masina F, Pezzetta R, Vanni F, Oliva G, Saccani MS, Marinazzo D, Zorzi M, Mantini D, Arcara G. Biomarkers of stroke recovery using EEG-based resting-state functional connectivity: a systematic review. J Neuroeng Rehabil. 2026 Mar 17;23(1):142. doi: 10.1186/s12984-026-01928-5. PMID: 41845449; PMCID: PMC13107850.
5. Kuipers JA, Hoffman N, Carrick FR, Jemni M. Post-Stroke Rehabilitation: Neurophysiology Processes of Bilateral Movement Training and Interlimb Coupling-A Systematic Review. J Clin Med. 2025 May 27;14(11):3757. doi: 10.3390/jcm14113757. PMID: 40507519; PMCID: PMC12156210.
6. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE, Chou R, Glanville J, Grimshaw JM, Hróbjartsson A, Lalu MM, Li T, Loder EW, Mayo-Wilson E, McDonald S, McGuinness LA, Stewart LA, Thomas J, Tricco AC, Welch VA, Whiting P, Moher D. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. PLoS Med. 2021 Mar 29;18(3):e1003583. doi: 10.1371/journal.pmed.1003583. PMID: 33780438; PMCID: PMC8007028.
7. Kuthiala N, Srivastava P, Sharma R, Sharma S. High frequency RTMS on cortical reorganization of chronic stroke. Journal of the Neurological Sciences. 2019 Oct 15;405:131.
8. Boardsworth K, Rashid U, Olsen S, Rodriguez-Ramirez E, Browne W, Alder G, Signal N. Upper limb robotic rehabilitation following stroke: a systematic review and meta-analysis investigating efficacy and the influence of device features and program parameters. J Neuroeng Rehabil. 2025 Jul 16;22(1):164. doi: 10.1186/s12984-025-01662-4. PMID: 40671078; PMCID: PMC12265130.
9. Singh N, Saini M, Kumar N, Padma Srivastava MV, Mehndiratta A. Individualized closed-loop TMS synchronized with exoskeleton for modulation of cortical-excitability in patients with stroke: a proof-of-concept study. Front Neurosci. 2023 May 25;17:1116273. doi: 10.3389/fnins.2023.1116273. PMID: 37304037; PMCID: PMC10248009.
10. Nath D, Singh N, Saini M, Banduni O, Kumar N, Srivastava MVP, Mehndiratta A. Clinical potential and neuroplastic effect of targeted virtual reality based intervention for distal upper limb in post-stroke rehabilitation: a pilot observational study. Disabil Rehabil. 2024 Jun;46(12):2640-2649. doi: 10.1080/09638288.2023.2228690. Epub 2023 Jun 29. PMID: 37383015.
11. Sharma H, Vishnu VY, Kumar N, Sreenivas V, Rajeswari MR, Bhatia R, Sharma R, Srivastava MVP. Efficacy of Low-Frequency Repetitive Transcranial Magnetic Stimulation in Ischemic Stroke: A Double-Blind Randomized Controlled Trial. Arch Rehabil Res Clin Transl. 2020 Jan 11;2(1):100039. doi: 10.1016/j.arrct.2020.100039. Erratum in: Arch Rehabil Res Clin Transl. 2020 Jun 20;2(4):100069. doi: 10.1016/j.arrct.2020.100069. PMID: 33543068; PMCID: PMC7853333.
12. Bhasin A, Iqbal G, Sharma R, Kumaran SS, Vy V, Srivastava PV. Cortical Neural Plastic Changes Post-stroke Using Bicephalic Transcranial Direct Current Stimulation: A Prospective Non-randomized Study. Cureus. 2025 Jul 23;17(7):e88586. doi: 10.7759/cureus.88586. PMID: 40861564; PMCID: PMC12374595.
13. Shetty KS, Ravichandran H, Rafiq S, Achar S. Brain Entropy and Complexity as Biomarkers of Neuroplasticity in Neurorehabilitation-A Scoping Review. Physiother Res Int. 2026 Apr;31(2):e70174. doi: 10.1002/pri.70174. PMID: 41733115.
14. Ravichandran H, Shetty KS, Lingadahalli B, Meethal AU. Integrating Non-Invasive Brain Stimulation

With Post-Stroke Rehabilitation: A Systematized Review of Synergistic Neuroplasticity Based Interventions. Physiother Res Int. 2026 Apr;31(2):e70179. doi: 10.1002/pri.70179. PMID: 41744287.

15. Shetty KS, Ravichandran H, Rafiq S, Achar S. Brain Entropy and Complexity as Biomarkers of Neuroplasticity in Neurorehabilitation-A Scoping Review. Physiother Res Int. 2026 Apr;31(2):e70174. doi: 10.1002/pri.70174. PMID: 41733115.

16. Kashoo FZ, Al-Baradie RS, Alzahrani M, Alanazi A, Manzar MD, Gugnani A, Sidiq M, Shaphe MA, Sirajudeen MS, Ahmad M, Althumayri B, Aljandal A, Almansour A, Alshewaier SA, Chahal A. Effect of Transcranial Direct Current Stimulation Augmented with Motor Imagery and Upper-Limb Functional Training for Upper-Limb Stroke Rehabilitation: A Prospective Randomized Controlled Trial. Int J Environ Res Public Health. 2022 Nov 17;19(22):15199. doi: 10.3390/ijerph192215199. PMID: 36429924; PMCID: PMC9690138.

17. Bhaskare G. Neuroplasticity-based physiotherapy approaches in stroke rehabilitation: a systematic review. J Nov Physiother Rehabil. 2025;9(2):33-35. doi:10.29328/journal.jnpr.1001069

18. Juhi A, Sharma S, Bhatia D, Dhaka S, Kumar R, Kumar D, Gayen RK, Mondal H. Effect of repetitive transcranial magnetic stimulation modulating supplementary motor area in stroke rehabilitation: Systematic review of randomized controlled trials. AIMS Neurosci. 2026 Jan 28;13(1):50-63. doi: 10.3934/Neuroscience.2026003. PMID: 42004568; PMCID: PMC13086594.

19. Calabrò RS, Calderone A, Bonanno L, Quartarone A, Naro A, De Nunzio AM, Filoni S. Robot-Assisted Upper-Limb Rehabilitation After Stroke: A Systematic Review and Meta-Analysis of Cortical Reorganization and Neuroplasticity Biomarkers. Neural Plast. 2026;2026(1):e9282578. doi: 10.1155/np/9282578. PMID: 42246057; PMCID: PMC13238253.

20. Lin Y, Li M, Su Y, Wang H, Jia J. EEG biomarkers for assessment, prognosis, and monitoring of natural upper limb recovery after stroke: a systematic review. J Neuroeng Rehabil. 2026 Jun 3;23(1):229. doi: 10.1186/s12984-026-02028-0. PMID: 42237313; PMCID: PMC13455385.

21. Tavazzi E, Cazzoli M, Pirastru A, Blasi V, Rovaris M, Bergsland N, Baglio F. Neuroplasticity and Motor Rehabilitation in Multiple Sclerosis: A Systematic Review on MRI Markers of Functional and Structural Changes. Front Neurosci. 2021 Oct 6;15:707675. doi: 10.3389/fnins.2021.707675. PMID: 34690670; PMCID: PMC8526725.

22. Emmenegger TM, David G, Mohammadi S, Ziegler G, Callaghan MF, Thompson A, Friston KJ, Weiskopf N, Killeen T, Freund P. Neuronal plasticity during motor rehabilitation training after spinal cord injury. Commun Biol. 2026 Mar 9;9(1):561. doi: 10.1038/s42003-026-09793-7. PMID: 41803393; PMCID: PMC13103311.

23. Péran P, Nemmi F, Dutilleul C, Finamore L, Falletta Caravasso C, Troisi E, Iosa M, Sabatini U, Grazia Grasso M. Neuroplasticity and brain reorganization associated with positive outcomes of multidisciplinary rehabilitation in progressive multiple sclerosis: A fMRI study. Mult Scler Relat Disord. 2020 Jul;42:102127. doi: 10.1016/j.msard.2020.102127. Epub 2020 May 6. PMID: 32438326.

24. Pei G, Hu M, Ouyang J, Jin Z, Wang K, Meng D, Wang Y, Chen K, Wang L, Cao LZ, Funahashi S, Yan T, Fang B. Enhancing Attention Network Spatiotemporal Dynamics for Motor Rehabilitation in Parkinson's Disease. Cyborg Bionic Syst. 2025 Jun 19;6:0293. doi: 10.34133/cbsystems.0293. PMID: 40538965; PMCID: PMC12178139.

25. Xie H, Li X, Huang W, Yin J, Luo C, Li Z, Dou Z. Effects of robot-assisted task-oriented upper limb motor training on neuroplasticity in stroke patients with different degrees of motor dysfunction: A neuroimaging motor evaluation index. Front Neurosci. 2022 Sep 16;16:957972. doi: 10.3389/fnins.2022.957972. PMID: 36188465; PMCID: PMC9523102.

26. 2026. " ePoster." *European Journal of Neurology* 33, no. S1: e70629. https://doi.org/10.1111/ene.70629.

27. Tataranu LG, Rizea RE. Neuroplasticity and Nervous System Recovery: Cellular Mechanisms, Therapeutic Advances, and Future Prospects. Brain Sci. 2025 Apr 15;15(4):400. doi: 10.3390/brainsci15040400. PMID: 40309875; PMCID: PMC12025631.

28. Tomassini V, Matthews PM, Thompson AJ, Fuglø D, Geurts JJ, Johansen-Berg H, Jones DK, Rocca MA, Wise RG, Barkhof F, Palace J. Neuroplasticity and functional recovery in multiple sclerosis. Nat Rev Neurol. 2012 Nov 5;8(11):635-46. doi: 10.1038/nrneurol.2012.179. PMID: 22986429; PMCID: PMC3770511.

29. Schwarz AJ. The Use, Standardization, and Interpretation of Brain Imaging Data in Clinical Trials of Neurodegenerative Disorders. Neurotherapeutics. 2021 Apr;18(2):686-708. doi: 10.1007/s13311-021-01027-4. Epub 2021 Apr 12. Erratum in: Neurotherapeutics. 2021 Jul;18(3):2127. doi: 10.1007/s13311-021-01063-0. PMID: 33846962; PMCID: PMC8423963.

30. Yang L, Wang Z. Applications and advances of combined fMRI-fNIRs techniques in brain functional

research. Front Neurol. 2025 Mar 18;16:1542075. doi: 10.3389/fneur.2025.1542075. PMID: 40170894; PMCID: PMC11958174.

31. Gazerani, P. (2025). The neuroplastic brain: Current breakthroughs and emerging frontiers. *Brain Research, 1858*, 149643. https://doi.org/10.1016/j.brainres.2025.149643

32. Osborne KJ, Walther S, Mittal VA. Motor actions across psychiatric disorders: A research domain criteria (RDoC) perspective. Clin Psychol Rev. 2024 Dec;114:102511. doi: 10.1016/j.cpr.2024.102511. Epub 2024 Oct 28. PMID: 39510028; PMCID: PMC12952226.

33. Meng H, Zhao Z, Li S, Wang S, Wang J, Yang C, Tang C, Chen X, Zhai X, Pan Y, Nathan A, Smielewski P, Occhipinti LG, Gao S. Active Rehabilitation Technologies for Post-Stroke Patients. Biosensors (Basel). 2025 Dec 25;16(1):20. doi: 10.3390/bios16010020. PMID: 41590272; PMCID: PMC12839297.

34. Kwak S. Rethinking neuropsychological test validity in dementia assessment: a critical review in the age of neuroimaging and digital markers. Front Hum Neurosci. 2025 Oct 8;19:1578648. doi: 10.3389/fnhum.2025.1578648. PMID: 41132587; PMCID: PMC12540449.