

Promoting Sustainable and Inclusive Neuro Rehabilitation Through Neuroplasticity and Motor Engram Based Practice- A Global Scoping Review

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Abstract:

➤ *Background:*

Neurological conditions like stroke, traumatic brain injury, and Parkinson's disease are major causes of long-term disability globally. Neuroplasticity—especially the formation and strengthening of motor memories—plays a key role in recovery from these conditions. However, the consistent use of neuroplasticity principles in everyday neurophysiotherapy practice varies across different clinical and research environments.

➤ *Aim of the Study:*

This scoping review explores how neuroplasticity principles are applied in neurorehabilitation research and treatment. It aims to identify how these principles are implemented and to highlight any gaps in current research and practice.

➤ *Objectives:*

To understand how neuroplasticity principles are put into action in neurophysiotherapy treatments. To identify factors that create challenges in applying these principles in real-world clinical settings.

➤ *Methodology:*

We searched several electronic databases—PubMed, Scopus, Web of Science, and Google Scholar—for articles published between January 2020 and December 2025. The search included terms like “neuroplasticity,” “motor engram,” “neurorehabilitation,” and “inclusive rehabilitation.” We included articles that presented human studies—both interventional and observational—that were clearly based on neuroplasticity concepts in the context of neurorehabilitation. Only peer-reviewed studies published in English during the specified time frame were considered. The review followed PRISMA-ScR guidelines, and data from the selected studies were recorded in a structured manner.

➤ *Results:*

Most of the studies included in this review focused on stroke rehabilitation, with fewer studies addressing other neurological conditions. There was significant variation in how neuroplasticity concepts were defined, how interventions were structured, and how outcomes were measured. Very few studies clearly connected their treatment designs to the underlying mechanisms of neuroplasticity, especially in areas with limited resources.

➤ *Conclusion:*

Although neuroplasticity is a central concept in modern neurophysiotherapy, its systematic and detailed application in both research and clinical settings is still inconsistent.

Keywords: Neuroplasticity, Motor Engram, Neurorehabilitation, Inclusive Rehabilitation.

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I. INTRODUCTION

Neurological diseases such as stroke, traumatic brain injury (TBI), Parkinson's disease and spinal cord injury (SCI) are among the leading causes of long-term disability worldwide and contribute mainly to disability-acclimated life times (DALYs) (Feigin et al., 2019; GBD 2016 Neurology Collaborators, 2019). The global rise in life expectancy and better survival rates following acute neurological events have increased the number of individuals living with habitual motor impairments, thereby enhancing the need for effective, accessible, and sustainable rehabilitation services (Langhorne et al., 2011; Bernhardt et al., 2017).

Motor recovery after neurological injury is unnaturally intermediated by neuroplasticity — the nervous system's capacity for structural and functional reorganization in response to experience, learning, and environmental demands (Cramer et al., 2011; Nudo, 2013). Seminal research on experience-dependent neuroplasticity has identified key principles that facilitate functional recovery, including repetition, intensity, task specificity, salience, appropriate timing, and progressive challenge (Kleim & Jones, 2008). These principles provide the mechanistic foundation for the formation and strengthening of motor engrams, thereby promoting sustained motor learning and skill retention in neurorehabilitation settings (Nielsen et al., 2015; Shumway-Cook & Woollacott, 2017). Clinical guidelines and methodical reviews emphasize that structured, repetitious, and task-aware practice enhances functional issues following stroke and other neurological conditions (Winstein et al., 2016; French et al., 2016). Interventions similar as task-acquainted training, constraint-convinced movement remedy, robotic-supported remedy, and electromechanical bias have demonstrated efficacy in perfecting upper-branch and functional recovery (Laver et al., 2017; Mehrholz et al., 2015; Mehrholz et al., 2018). Virtual reality – grounded recuperation further supports multisensory engagement and motor literacy, easing neuroplastic adaption (Sveistrup, 2004; Laver et al., 2017). Also non-invasive brain stimulation ways have shown pledge in modulating cortical excitability and enhancing malleability-driven motor earnings (O'Brien et al., 2018).

Arising substantiation also highlights the significance of cure – response connections in neurorehabilitation. Meta-logical findings suggest that advanced remedy intensity and lesser reiteration are associated with bettered motor issues, whereas inadequate lozenge may limit neural reorganization (Lohse et al., 2014; Hayward et al., 2017). Resistance and progressive training paradigms further demonstrate the rigidity of neuromuscular systems across age groups, buttressing the part of intensity and load principles in recovery (Peterson et al., 2010). Experimental models have

also underlined the necessity of aligning recuperation protocols with mechanistic perceptivity from neuroscience to optimize functional restoration (Krakauer et al., 2012; Ward, 2017). Despite this expanding substantiation base, restatement of neuroplasticity principles into routine neurophysiotherapy practice remains inconsistent across settings and countries. Variability persists in remedy lozenge, structured protocol perpetration, outgrowth standardization, and unequivocal mechanistic relation between intervention design and neuroplastic processes (Kwakkel et al., 2017; Hayward et al., 2017). Likewise, gaps remain in totally operationalizing neuroplastic constructs within inclusive and sustainable recuperation systems, particularly in resource-constrained surrounds (Bernhardt et al., 2017; Ward, 2017). A scoping review is thus timely to examine the extent, thickness, and global distribution of neuroplasticity-driven practice and to identify crucial translational and perpetration gaps applicable to inclusive and sustainable neurorehabilitation.

II. METHODOLOGY

➤ *Study Design:*

A scoping review methodology was espoused to explore how neuroplasticity and motor engram – grounded principles are operationalized in contemporary neurophysiotherapy and to identify global operation gaps. The review followed the frame of (Arksey and O'Malley 2005), meliorated by Levac et al. (2010), and was reported in agreement with PRISMA-ScR guidelines (Tricco et al., 2018). Methodological considerations were described narratively to enhance interpretive rigor.

➤ *Search Strategy:*

A comprehensive literature hunt was conducted using PubMed, Scopus, and Web of Science. The hunt was confined to studies published between January 2020 and December 2025 to prisoner contemporary substantiation in neurorehabilitation. Keywords were developed in English and combined using Boolean drivers (AND, OR), including “neuroplasticity,” “motor engram,” “neurorehabilitation,” “activity,” “stroke,” “motor literacy,” “cortical reorganization,” “virtual reality,” and “robotics.” Eligible studies included randomized controlled trials, quasi-experimental, non-randomized, and experimental designs that explicitly applied neuroplasticity-grounded intervention principles.

➤ *Eligibility for the Research Question:*

The review question was developed in accordance with the Population-Concept-Context (PCC) framework proposed by Arksey and O'Malley (2005) for conducting scoping reviews.

Table 1 Framework for Determining Eligibility of the Research Question.

Population	Adults (≥ 18 years) with neurological conditions, including but not limited to stroke, traumatic brain injury, Parkinson’s disease, and spinal cord injury.
Concept	Physiotherapy-led or integrated interventions explicitly based on neuroplasticity principles, including intensity, repetition, task specificity, salience, multisensory engagement, and motor engram formation.
Context	Clinical, community, and technology-assisted neurorehabilitation settings globally, with attention to implementation variability and resource contexts.

➤ *Eligibility Criteria and Study Selection*

Study selection was conducted in accordance with predefined inclusion and exclusion criteria.

• *Inclusion Criteria:*

- ✓ Studies involving adults with neurological conditions
- ✓ Physiotherapy-led or interdisciplinary rehabilitation interventions
- ✓ Explicit reference to neuroplasticity or motor learning principles in intervention design
- ✓ Randomized controlled trials, quasi-experimental studies, or observational studies

✓ Published in English

✓ Published between January 2020 and December 2025

• *Exclusion Criteria:*

- ✓ Pediatric populations
- ✓ Non-neurological conditions
- ✓ Abstract-only publications
- ✓ Review articles (systematic, narrative, scoping, meta-analyses)
- ✓ Editorials, commentaries, and opinion papers

➤ *Study Selection Process:*

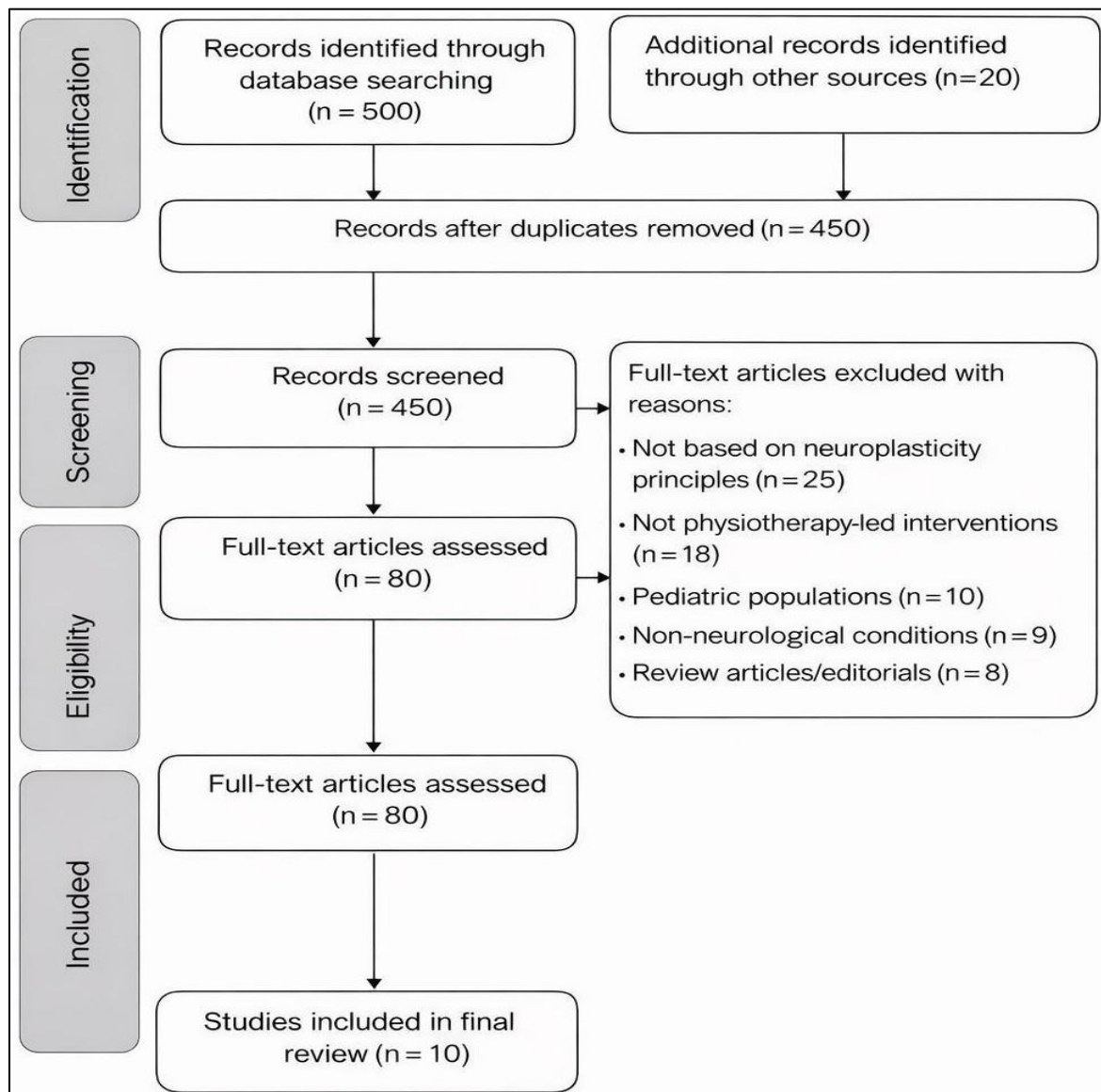


Fig 1 Prisma Flowchart

➤ *Data Interpretation:*

Table 2 Data Interpretation

No	Author & Year	Neurological Condition	Intervention	Sample Size	Neuroplasticity Principle applied	Key findings
1.	Laver et al., 2020	Stroke	Virtual reality–based physiotherapy	60	Task -specific training, repetition,	VR improved upper limb motor recovery
2.	Mehrholz et al., 2020	Stroke	Electro mechanical assisted Gait Training	75	Task-oriented practice, motor relearning	Significant improvement in gait speed and walking independence
3.	Veerbeek et al., 2020	Stroke	Intensive task-oriented therapy	90	Use dependent plasticity ,salience	Better functional recovery
4.	Calabrò et al., 2021	Stroke	Robotic-assisted upper limb therapy	40	feedback, motor engram activation	Improved cortical reorganization
5.	Gandolfi et al.,2020	Parkinson's	Virtual reality Gait Training	46	Sensory motor integration	Improved gait parameters
6.	Cho & Lee, 2021	Stroke	Mirror therapy with physiotherapy	52	Hebbian plasticity, motor imagery	Enhanced upper limb motor outcomes
7.	Aprile et al., 2022	Multiple Sclerosis	Task-oriented circuit training	38	Specificity, intensity	Improved walking endurance
8.	Li et al., 2022	Stroke	Non-invasive brain stimulation + physiotherapy	64	Cortical excitability modulation, timing	Greater motor gains
9.	Morone et al., 2023	Stroke	Body-weight supported treadmill training 50 Improved gait symmetry and speed	50	Repetition, task specificity,	Improved gait symmetry and speed
10.	da Silva Cameirão et al., 2023	Traumatic Brain Injury	VR-based motor retraining	30	Salience, engagement	Functional independence

III. RESULTS

Ten studies published between 2020 and 2025 met the inclusion criteria, involving adults with stroke, Parkinson’s disease, multiple sclerosis, and traumatic brain injury (sample sizes: 30–90). Most studies focused on stroke rehabilitation, emphasizing post-stroke neuroplastic recovery. Technology-assisted interventions such as virtual reality, robotics, and electromechanical gait training demonstrated improvements in motor function, gait performance, and functional independence (Laver et al., 2020; Mehrholz et al., 2020; Calabrò et al., 2021; Morone et al., 2023). Mirror therapy and non-invasive brain stimulation enhanced cortical activation and motor recovery, supporting motor engram reinforcement (Cho & Lee, 2021; Li et al., 2022). In Parkinson’s disease and multiple sclerosis, task-oriented and VR-based training improved balance and walking endurance (Gandolfi et al., 2021; Aprile et al., 2022). Across studies, repetition, intensity, task specificity, salience, and feedback were consistently applied neuroplasticity principles. However, variability in dosage reporting and accessibility of advanced technologies were noted. Overall, findings support structured, neuroplasticity-informed physiotherapy to enhance functional recovery in neurological populations.

IV. DISCUSSION

This scoping review gathered evidence published between 2020 and 2025 on how neuroplasticity principles are applied in adult neurophysiotherapy. Following models of experience-dependent brain adaptability (Kleim & Jones, 2008; Nudo, 2013), therapeutic approaches that focused on repetition, appropriate intensity, task-specific practice, attention, and feedback were linked to improved functional outcomes. Most of the studies reviewed were focused on stroke recovery, highlighting its major impact on global health (Feigin et al., 2019). Technology-assisted methods, such as virtual reality and robotics, facilitated high-intensity, task-specific training and provided multisensory feedback, which supported motor learning and changes in brain organization (Laver et al., 2020; Mehrholz et al., 2020; Calabrò et al., 2021).

Combining neuromodulation with physical activity further improved motor recovery by increasing brain excitability (Li et al., 2022). The concept of motor engrams is particularly relevant to the interpretation of these findings. Motor engrams are considered neural representations of learned movement patterns that are stored within distributed

neural networks. Repeated execution of meaningful tasks strengthens these neural representations and improves movement efficiency. Interventions such as mirror therapy, virtual reality, and robotic rehabilitation may facilitate motor engram activation by repeatedly exposing individuals to task-specific movement experiences combined with sensory feedback. This process supports motor learning and retention, ultimately contributing to long-term functional recovery.

Emerging evidence from conditions like Parkinson's disease and multiple sclerosis suggests that neuroplasticity-based strategies may have broader applications (Gandolfi et al., 2021; Aprile et al., 2022). However, inconsistencies in the way results are reported and a lack of clear understanding of underlying mechanisms continue to create gaps in the evidence (Winstein et al., 2016). Additionally, the use of advanced technologies raises concerns about their accessibility and sustainability in low-resource areas.

The findings also highlight the need for improved translation of neuroscience concepts into routine clinical practice. Although many interventions appear to utilize neuroplasticity principles implicitly, explicit reporting and justification of these principles remain inconsistent. Future research should clearly describe how intervention components relate to mechanisms such as repetition, intensity, specificity, salience, and motor engram formation. Standardized reporting would strengthen evidence synthesis and improve clinical implementation.

Overall, the evidence suggests that neuroplasticity-based rehabilitation can improve functional outcomes across neurological populations. However, greater methodological consistency, stronger mechanistic validation, and increased attention to accessibility are required to support the widespread adoption of neuroplasticity-driven rehabilitation strategies.

➤ *Implications:*

Physiotherapy should be explicitly aligned with core neuroplasticity principles such as intensity and task specificity. Standardized dosage reporting and adoption of low-cost, high-repetition models are essential for sustainable practice. Future studies should include neurophysiological measures to strengthen mechanistic validation.

➤ *Strengths & Limitations:*

The review followed PRISMA-ScR guidelines and focused on recent evidence (2020–2025), enhancing methodological transparency and clinical relevance. Inclusion of diverse neurological conditions improved applicability. Restriction to English-language studies and limited representation from low-resource settings may affect generalizability. Heterogeneity in outcome measures and inconsistent dosage reporting limited comparative synthesis.

V. CONCLUSION

Neuroplasticity underpins modern neurophysiotherapy, yet its structured application remains inconsistent across clinical and research settings. Evidence from this review

supports the use of high-intensity, task-specific, repetitive, and feedback-driven interventions to facilitate motor recovery and functional improvement in individuals with neurological conditions.

The findings also highlight the important role of motor engram formation in promoting motor learning, skill retention, and long-term functional gains. While technology-assisted interventions such as virtual reality, robotics, and neuromodulation demonstrate promising outcomes, challenges related to accessibility, affordability, and implementation persist, particularly in resource-limited settings.

Therefore, future neurorehabilitation should focus on the systematic integration of neuroplasticity principles within sustainable and inclusive rehabilitation frameworks. Standardized reporting, greater mechanistic validation, and wider adoption of accessible neuroplasticity-based interventions may enhance the quality, effectiveness, and global reach of neurorehabilitation services.

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➤ *Ethics approval and Consent to Participate*

- Not applicable.

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