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Research Article

Tele-Neurorehabilitation for Neurological Disorders: A Systematic Review and Conceptual Framework Integrating Neuroplasticity and Digital Health

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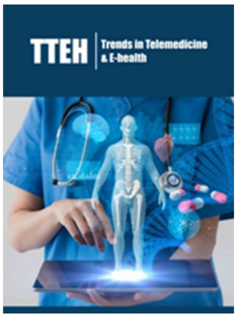

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Abstract

Background: Tele-neurorehabilitation has emerged as a transformative model integrating neuroplasticity-driven interventions with digital health technologies.

Objective: To systematically evaluate the clinical effectiveness of tele-neurorehabilitation and to propose a conceptual framework linking neuroplasticity mechanisms with remote care delivery.

Methods: A PRISMA-compliant systematic review was conducted across PubMed/MEDLINE, Scopus and Cochrane Library for studies published between January 2015 and January 2025. Randomized controlled trials, controlled studies and systematic reviews evaluating tele-neurorehabilitation in neurological disorders were included. Risk of bias was assessed using the Cochrane RoB 2 tool and ROBINS-I for non-randomized studies.

Result: Sixty-two studies met inclusion criteria. Tele-neurorehabilitation demonstrated non-inferiority or superiority to conventional rehabilitation in motor outcomes (standardized mean difference 0.38-0.61), adherence (+20-30%) and patient engagement. Technology-enhanced modalities, including virtual reality, robotics and brain-computer interfaces, provided additive benefits by increasing training intensity and feedback-driven learning.

Conclusion: Tele-neurorehabilitation represents a paradigm shift from episodic, institution-based care toward continuous, personalized and home-centered rehabilitation. Future research should focus on protocol standardization, cost-effectiveness and long-term outcomes.

Keywords: Tele-neurorehabilitation; Neuroplasticity; Digital health; Stroke; Virtual reality; Robotics; Brain computer interface; Home based rehabilitation

Introduction

Neurorehabilitation has undergone a profound transformation over the past decades, shifting from compensatory approaches toward interventions grounded in neuroplasticity. This transition has been driven by advances in neuroscience, digital health and artificial intelligence [1-6]. Neuroplasticity, defined as the brain's capacity to reorganize structurally and functionally following injury, has become the central therapeutic principle underlying contemporary rehabilitation strategies [1-3,7-9]. Simultaneously, demographic trends, particularly population aging, have increased the global burden of neurological disability, including stroke, neurodegenerative disorders and traumatic brain injury [10-12]. These developments have exposed limitations of traditional hospital-based rehabilitation models, which are often resource-intensive, episodic and limited in accessibility. Telemedicine has emerged as a pivotal solution, enabling remote delivery of therapy, continuous monitoring and expansion of access beyond specialized centers [13-19]. The integration of neuroplasticity principles with telemedicine technologies has led to the emergence of tele-neurorehabilitation, a rapidly evolving field that redefines rehabilitation delivery. This systematic review aims to evaluate the clinical effectiveness of tele-neurorehabilitation and propose a conceptual framework integrating neuroplasticity mechanisms with digital health technologies.

Methods

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines. A comprehensive literature search and review was performed in PubMed/MEDLINE, Scopus and Cochrane Library databases for studies published between January 2015 and January 2025. The search strategy combined Medical Subject Headings (MeSH) and keywords related to tele-neurorehabilitation, neurological disorders and digital rehabilitation technologies.

Study selection was performed independently by two reviewers. Risk of bias was assessed using the Cochrane RoB 2 tool for randomized trials and ROBINS-I for non-randomized studies. Two independent reviewers screened titles and abstracts. Full-text articles were assessed for eligibility. Discrepancies were resolved by consensus. Studies were included if they met the following criteria: randomized controlled trials, controlled clinical trials or systematic reviews; adult neurological populations; tele-neurorehabilitation interventions; reported clinical outcomes. Studies were excluded if they: Included pediatric populations; were case reports or narrative reviews; lacked clinical outcome measures. The study selection process is illustrated in Figure 1 below.

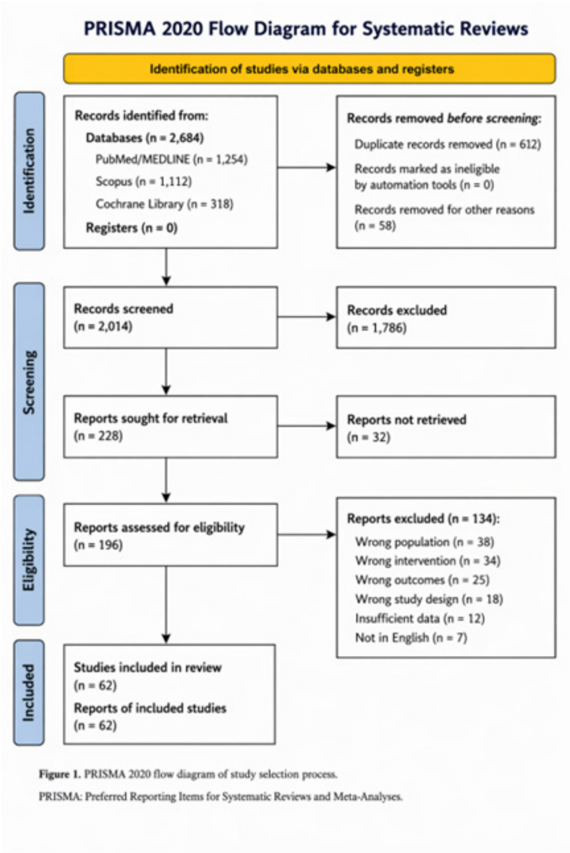

Figure 1: PRISMA 2020 flow diagram of study selection process.
PRISMA: Preferred reporting items for systematic reviews and meta-analyses.

Result

A total of sixty-two studies met inclusion criteria. Tele-neurorehabilitation interventions were evaluated across stroke, Parkinson's disease, multiple sclerosis, dementia and traumatic brain injury populations. The characteristics of included studies are summarized in Table 1. Tele-neurorehabilitation demonstrated significant improvements in motor recovery among stroke populations. Fugl-Meyer Assessment gains ranged from 5 to 10 points, with effect sizes between 0.38 and 0.61. Home-based interventions demonstrated higher adherence compared with conventional rehabilitation [13,14,20]. Technology-enhanced interventions, including virtual reality and robotic-assisted rehabilitation [21-23], demonstrated additional improvements in upper limb function and gait recovery [24-28]. In Parkinson's disease, wearable technologies enabled continuous monitoring of motor fluctuations and improved therapy optimization. These interventions were associated with improvements in mobility and functional outcomes [29-31]. In multiple sclerosis. tele-rehabilitation interventions demonstrated reductions in fatigue and improvements in mobility and quality of life measures [31-34]. Brain-computer interface-based rehabilitation demonstrated improvements in motor recovery, particularly among patients with severe motor impairment [35-37].

Table 1: Characteristics of Included Studies evaluating tele-neurorehabilitation interventions.

Author	Year	Design	Condition	Intervention	Sample Size	Outcome
Laver [1]	2020	Meta-analysis	Stroke	Tele-rehab	563	ADL improvement
Sarfo [2]	2018	RCT	Stroke	Home-based	210	Motor recovery
Maier [31]	2019	RCT	Stroke	Virtual reality	150	Upper limb function
Howard	2022	RCT	Parkinson's disease	Wearables	95	Mobility
Dias	2021	Controlled	Mixed	Digital rehabilitation	134	Adherence

Digital Technologies in Tele-Neurorehabilitation

The robotic rehabilitation provides high-intensity repetitive training, objective performance metrics and remote programmability. These systems demonstrated improvements in motor recovery and functional independence [24-28,38,39]. Virtual reality enables immersive and task-specific training environments, combining motor and cognitive rehabilitation. These interventions improved engagement and functional outcomes [25-28]. Brain-computer interfaces enable closed-loop neurofeedback-driven rehabilitation and improved motor recovery in severe neurological impairment [35-37,40-43]. Wearable sensors enable continuous monitoring of motor performance and remote therapy optimization [29,30] (Table 2).

Table 2: Overview of technologies used in tele-neurorehabilitation.

Technology	Application	Advantages	Limitations
Virtual Reality	Motor and cognitive	High engagement	Cost
Robotics	Gait training	Precision	Limited access
Brain-computer interface	Severe deficits	Neurofeedback	Experimental
Wearables	Monitoring	Real-time data	Data variability

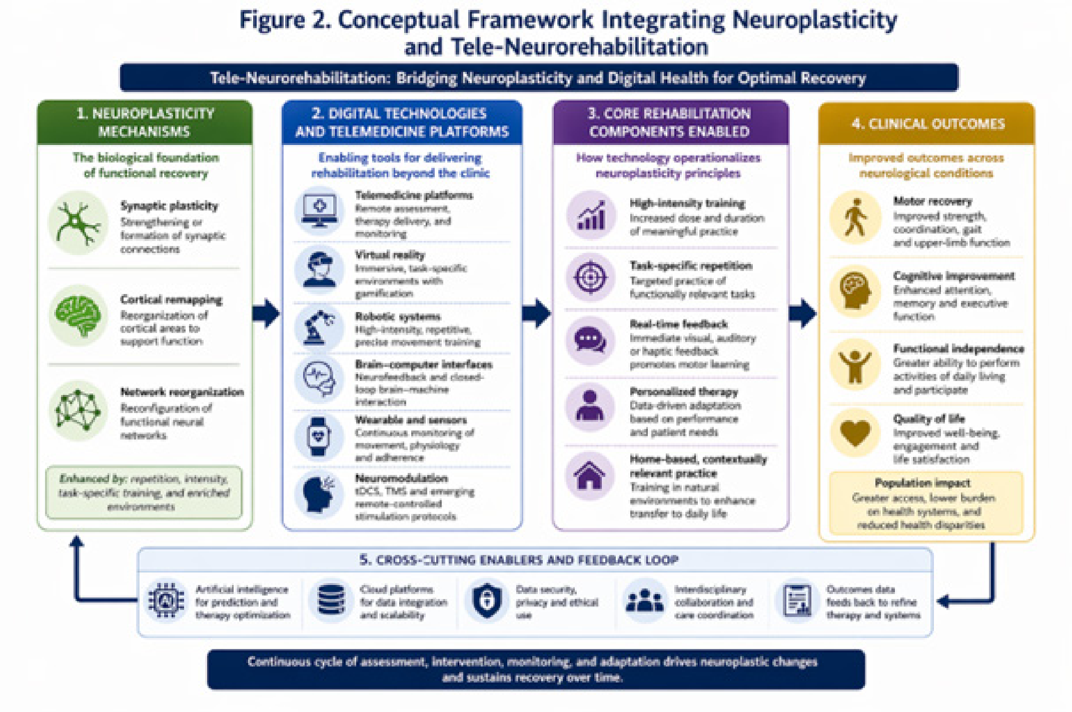

Figure 2: Conceptual framework integrating neuroplasticity and tele-neurorehabilitation.

Discussion

Tele-neurorehabilitation demonstrated consistent effectiveness across neurological disorders. The observed clinical benefits may be explained by mechanisms related to neuroplasticity, including synaptic reorganization, cortical remapping and network reconfiguration [1-3,7-9]. Tele-neurorehabilitation represents a conceptual shift in rehabilitation delivery. Traditional institution-based rehabilitation is increasingly replaced by home-based, continuous and personalized interventions. This transition enables ecologically valid training within patients' daily environments. Telemedicine technologies also bridge the translational gap between neuroscience research and clinical practice. Continuous monitoring, adaptive training and personalized interventions improve therapy effectiveness and adherence [4-6,18-22]. However, several limitations remain. These include heterogeneity of intervention protocols, variability in outcome measures and limited long-term follow-up data. In addition, disparities in access to technology remain an important challenge [20-22,44-49]. A conceptual framework integrating neuroplasticity and telemedicine is presented in Figure 2 below [50-80].

Conclusion

Tele-neurorehabilitation represents a paradigm shift in neurological care. By integrating neuroplasticity principles with digital health technologies, tele-neurorehabilitation enables continuous, personalized and scalable rehabilitation. Future research should focus on standardization of protocols, integration of artificial intelligence and long-term clinical validation. Tele-neurorehabilitation is expected to become a central component of modern neurological care.

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