Review Article

Effectiveness of Intensive Motor Learning Approaches for Stroke: A Systematic Review of Randomized Controlled Trials

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Abstract

Background: Stroke is a major contributor to long-term disability worldwide, presenting significant obstacles to motor function, coordination, and independence. Rehabilitation approaches to those deficits include intensive motor learning strategies aimed at promoting neuroplasticity that will lead to functional recovery. This systematic review examined the effectiveness of different motor learning-based interventions in stroke rehabilitation, including, but not limited to, constraint-induced movement therapy (CIMT), task-specific training (TST), robotics-assisted therapy, virtual reality interventions, and Hand-Arm Bimanual Intensive Therapy Including Lower Extremities (HABIT-ILE).

Methods: A systematic search on PubMed, the Cochrane Library, and Google Scholar identified studies published in the last decade that examined intensive motor learning interventions with respect to stroke rehabilitation. The search yielded 4871 studies, leading to the final selection of ten studies that met strong inclusion criteria. To promote methodological rigor, the PRISMA framework was used. Primary outcome measures were motor function improvements, neuroplasticity changes, and functional independence levels.

Results: The results show HABIT-ILE, TST and virtual reality-based interventions displayed significant and long-lasting improvements in motor function, coordination, and independence. CIMT needs more research and while it has promise, we do not know how it will compare long-term and the evidence is mixed regarding its effectiveness in reducing disability levels. Robotics-assisted therapy improves motor learning and strength, but there are still challenges in applying these improvements to activities of daily living (ADLs).

Conclusion: It is essential to incorporate various intensive motor learning strategies instead of depending only on traditional therapy to maximize stroke rehabilitation. Interventions such as HABIT-ILE and task-specific training show great promise, and new technologies like virtual reality and robotics provide extra advantages. Nonetheless, more research is necessary to improve intervention protocols, create standardized outcome measures, and design personalized rehabilitation strategies to enhance motor recovery for stroke survivors.

Categories: Physical Medicine & Rehabilitation, Therapeutics, Motor Learning, Neurorehabilitation

Keywords: Stroke rehabilitation, motor learning, neuroplasticity, constraint-induced movement therapy (CIMT), hand-arm bimanual intensive therapy (HABIT-ILE)

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Introduction

Stroke remains a major contributor to long-term disability worldwide, with its incidence continuing to rise. It significantly impacts functional independence, limiting daily activities and reducing overall quality of life for affected individuals.[1] It remains a major global health challenge, imposing a substantial burden on mortality and disability rates. Its incidence has increased significantly, rising from 1.1 million cases per year in 2000 to an estimated 1.5 million cases annually by 2025. In the United States alone, stroke risk has grown by 25% since 2010, with projections indicating that more than 4 million people may be affected by 2030. Given its rising prevalence and serious health implications around the world, continued research into effective prevention and management strategies is essential.[2]

Stroke is a neurological condition resulting from an acute focal injury to the central nervous system (CNS) due to a vascular event. It is the third leading cause of mortality in Western countries and a primary contributor to long-term disability. Globally, stroke affects approximately 15 million individuals annually, with an estimated 5 million fatalities and an additional 5 million experiencing permanent disability.[4]

Currently there are limited standardized, intensive efficacious protocols for optimizing motor recovery from stroke rehabilitation. Intensive motor learning approaches have shown promise to improve recovery by enhancing neuroplasticity and functional outcomes; however, this clinical utilization is limited by heterogeneous protocols, inconsistent outcome measures, and a lack of high-quality randomized controlled studies. Additionally, there are no standardized long-term follow-ups, limiting conclusions on sustained efficacy. In this review, we have tried to address these issues by critically reviewing the efficacy of intensive motor learning approaches, and their clinical relevance, as a starting point for evidence-based rehabilitation interventions along with the most effective approach for future research and clinical application.

Methods

Eligibility Criteria and Reporting Protocols

Articles were selected based on defined inclusion and exclusion criteria. Inclusion criteria comprised studies published in the past 10 years, in English, involving stroke patients undergoing rehabilitation. Eligible studies included randomized controlled trials (RCTs), meta-analyses of RCT's of physiotherapy interventions such as task-specific training, robot-assisted therapy, constraint-induced movement therapy (CIMT), HABIT-ILE and virtual reality-based therapy. Primary outcomes included motor function recovery, functional independence, and neuroplasticity-related changes. Psychological outcomes (e.g., self-efficacy, quality of life) were also considered.Exclusion criteria involved non-English studies, non-human trials, inaccessible full texts, studies unrelated to the review objective, insufficient intervention description, pharmacological or surgical studies lacking a motor learning component, and studies with unreliable outcome measures.

This review followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.The central research question was: Do intensive interventions in motor learning have a significant effect in stroke rehabilitation, and what techniques are considered to be most effective?

Research Strategy and Screening

To synthesize current evidence on the effectiveness of intensive motor learning strategies for stroke rehabilitation, a systematic search was conducted across PubMed, the Cochrane Library, and Google Scholar for studies published between 2015 and January 2025. Where possible, searches were restricted to randomized controlled trials (RCTs) and systematic review and meta-analyses of RCTs. Only English-language, full-text, freely accessible articles were included. Key search terms included stroke rehabilitation, task-specifictraining, constraint-induced movement therapy (CIMT), and Hand-Arm Bimanual Intensive Therapy Including Lower Extremities (HABIT-ILE), incorporating

Medical Subject Headings (MeSH) and Descriptors for Science and Health. Boolean operators "AND" and "OR" were applied, particularly in Cochrane searches. Data extraction included authorship, publication year, study location, participant demographics, and assessment parameters. All selected articles were independently reviewed by multiple investigators. The study design and systematic review framework were verified for methodological rigor.

Data Extraction

Data were extracted from each included study regarding the rationale for topic selection, formulation of the research question, inclusion and exclusion criteria, author details, publication information, sample size (total and per group), intervention intensity and duration for experimental groups, and primary outcome measures. Aims, interventions, outcomes, results, and conclusions were systematically presented. Each study was critically appraised using the PEDro quality assessment scale. The following criteria were evaluated: (a) eligibility criteria specified (not scored), (b) random allocation, (c) concealed allocation, (d) baseline comparability, (e) participant blinding, (f) therapist blinding, (g) assessor blinding for at least one primary outcome, (h) primary outcome data for >85% of participants, (i) intention-to-treat analysis, (j) appropriate statistical reporting, and (k) between-group comparisons with variability estimates. Each fulfilled criterion received a score of 1, yielding a maximum score of 10 (see Table 1).

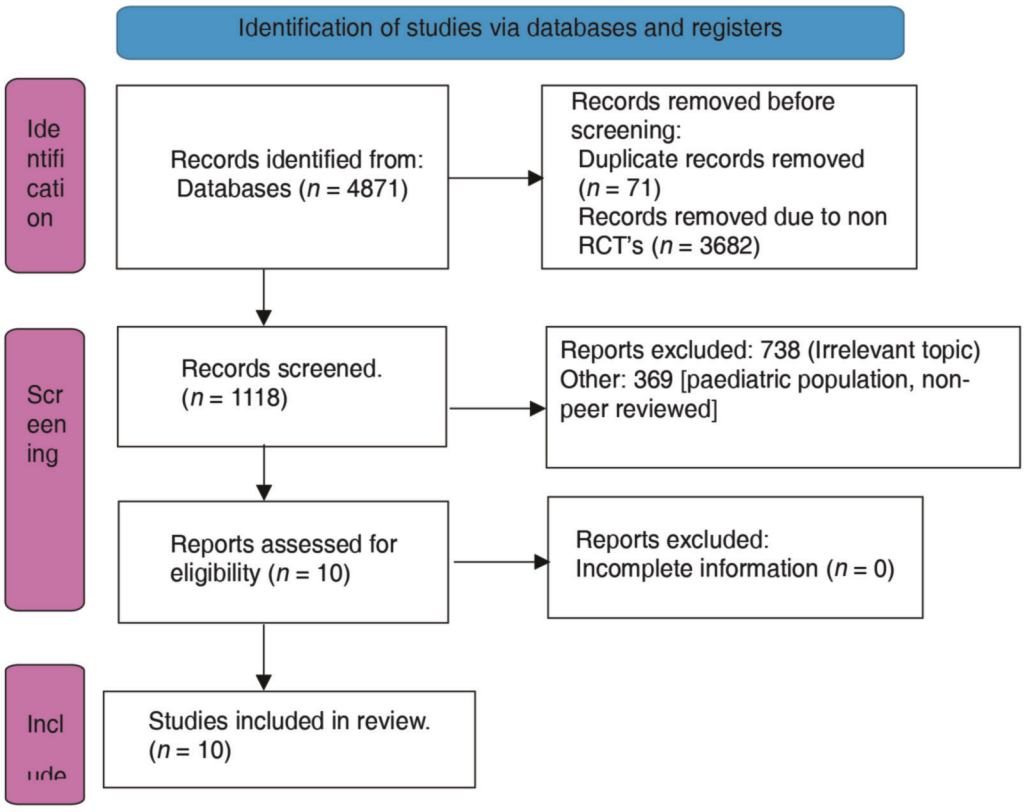

Figure 1: PRISMA Chart

Table 1. Methodological Quality assessment of included studies for review via PEDro scale.

Author\year	A	B	C	D	E	F	G	H	I	J	K	Total
Liu G et al. (2022)	1	1	0	1	0	0	0	1	1	0	1	5
Corbetta D et al. (2015)	1	1	1	1	0	0	1	1	1	1	1	8
Kim et al. (2021)	1	1	0	1	0	0	1	1	0	1	1	6
Reddy et al. (2022)	1	1	0	1	0	0	1	1	1	1	1	7
Ebner-Karestinos, et al. (2023)	1	1	1	1	0	0	1	1	1	1	1	8
Abdollahi et al. (2018)	1	1	0	1	1	0	1	1	0	1	1	7
Tedla et al. (2022)	1	1	0	1	0	0	1	1	0	1	1	6
French et al. (2016)	1	1	1	1	0	0	1	1	1	1	1	8
Alsubiheen et al. (2022)	1	1	1	1	0	0	1	1	0	1	1	7
Chengpeng et al.	1	1	1	1	1	0	1	1	1	1	1	9

Task-specific training [TST], Constraint-Induced Movement Therapy (CIMT), Hand-Arm Bimanual Intensive Therapy Including Lower Extremities (HABIT-ILE), Repetitive task Training [RTT], Robotic-assisted motor training. Virtual reality-based motor training

Table 2. Literature Matrix

Sr. No	Author	Study Type	Study Sample	Intervention	Results	Conclusion	Analysis
1.	Liu G, Cai H, Leelayuwat N (2022)	RCT	Stroke patients with hemiplegia	Rehabilitation robotic bed under machine learning combined with intensive motor training	Significant improvement in motor function recovery compared to conventional therapy	Machine learning-assisted robotic rehabilitation can enhance motor recovery in stroke patients	The research underlines the adoption of intensive motor learning in technology-enabled rehabilitation and focuses on machine learning to optimize stroke recovery.

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2	Corbetta D, Sirtori V, Castellini G, Moja L, Gatti R (2015)	Systematic Review	42 studies, 1453 stroke patients	CIMT for upper extremities in stroke patients	Limited improvements in motor impairment and function, but no significant reduction in disability	CIMT may improve motor function but does not convincingly reduce disability in stroke patients	Indicates that while CIMT is an intensive motor learning approach, its effectiveness in reducing disability remains uncertain, necessitating further investigation.
3	Kim K-H, Jang S-H (2021)	RCT	37 stroke patients, divided into three groups	TST combined with Cognitive Sensorimotor Exercise (CSE)	Significant improvements in proprioception, spasticity, and gait speed, especially in the experimental group	TST combined with CSE enhances proprioception and gait function in stroke patients better than conventional therapy	It recommends that while CIMT is a intensive motor learning approach, its effectiveness in lessening disability is not yet clear and more studies are needed to arrive at final conclusions.
4	Reddy RS, Gular K, Dixit S, et al. (2022)	Systematic Review & Meta-Analysis	10 studies, 329 stroke patients	CIMT for lower extremities	No significant improvements in gait speed and balance compared to control	CIMT for lower limbs may not significantly enhance ambulation, requiring further study on its effectiveness	It proves that intensive motor learning via task-specific practice and cognitive sensorimotor training produces favourable rehabilitation outcomes in patients with stroke.

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5	Ebner-Karestinos D, Gathy E, Carton de Tournai A, et al. (2023)	RCT	48 chronic stroke patients	HABIT-ILE	Improved motor function and bimanual coordination compared to conventional therapy	HABIT-ILE is an effective intensive motor learning approach for stroke patients targeting both upper and lower extremities	It highlights the effectiveness of whole-body motor learning, emphasizing goal-directed and task-specific training using HABIT-ILE in stroke rehabilitation.
6	Abdollahi F, Corrigan M, Lazzaro EDC, Kenyon RV, Patton JL (2018)	RCT	26 chronic stroke patients	Error-Augmented Bimanual Therapy (EABT) using robotic feedback and self-rehabilitation system	Modest gains in motor function, with significant improvement detected after removing an outlier	Error augmentation in bimanual training may enhance motor recovery, but further studies are needed to confirm clinical significance	This research introduces robotic-assisted error augmentation as an encouraging intensive motor learning strategy, especially for self-rehabilitation.
7	Tedla JS, Gular K, Reddy RS, et al. (2022)	Systematic Review & Meta-Analysis	8 RCTs, 208 stroke patients	CIMT for balance and functional mobility	Significant improvement in balance (effect size 0.51, p=0.01) but no significant improvement in functional mobility (effect size -4.18, p=0.16)	CIMT is effective in improving balance in stroke patients, but its impact on functional mobility remains uncertain	Supports CIMT for balance improvement but underscores the need for further research on its impact on functional mobility.
8	French B, Thomas LH, Coupe J, et al. (2016)	Systematic Review	33 trials, 1853 stroke patients	RTT for improving functional ability	Low- to moderate-quality evidence supporting RTT for improving upper/lower limb function, but benefits diminish after six months	RTT can enhance motor function post-stroke, but long-term benefits are unclear	This emphasizes the value of task-specific intensive motor learning but calls for further study of duration and intensity.

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9	Alsubiheen AM, Choi W, Yu W, Lee H (2022)	RCT	33 chronic stroke patients	Task-Oriented Activities of Daily Living (T-ADL) training vs. conventional occupational therapy	T-ADL improved upper limb function and manual dexterity significantly, but ADL and QoL improvements were similar in both groups	T-ADL training is effective in improving upper limb function and dexterity but does not significantly outperform conventional therapy in ADL and QoL improvements	Supports the use of task-oriented training in stroke rehabilitation but recommends its combination with other methods for more general functional gains.
10	Chengpeng Hu, Chun Hang Eden Ti, et al.	Pilot RCT	18 chronic stroke survivors	HD-tDCS targeting individual motor hotspot with EMG-driven robotic hand training	HDtDCS-group showed significant improvement in FMAUE scores and MASf scores compared to Sham-group	Personalized HD-tDCS enhances brain activation in motor-related regions and improves motor recovery	The study highlights the benefits of combining HD-tDCS with EMG-controlled robotic training, supporting intensive motor learning by enhancing neuroplasticity, hand dexterity, and grip strength post-stroke.

Results

Selection of Studies

The initial search yielded 4871 records. After screening titles and abstracts, 3682 non-RCTs and 71 duplicates were excluded. Full-text screening was performed on 1118 articles, of which 738 were excluded due to non-intensive motor training protocols, different populations, or non-RCT designs. Ten studies met the eligibility criteria and were included in the final analysis [Table 1].

Summary of Identified Studies

Of the 4871 studies screened, 10 experimental studies were included in the data extraction process. These were conducted in China, the USA, Taiwan, India, Turkey, Belgium, and Brazil—countries actively contributing to stroke rehabilitation research. The included studies also incorporated robot-assisted and virtual reality-based interventions.

Risk of Bias

When the concealed allocations were employed, there was nearly never any bias in the process of

creating the randomly allocated item sequences. Due to the participants' and professionals' blinding of items, there was a considerable possibility of bias. This occurs because of the public availability of important study methodologies and findings.

The risk of bias was evaluated using the RoB 2.0 tool and visualized with the Risk of Bias Visualization (RobVis) tool. Each study was independently assessed as shown in figure 2 and 3.

Main Findings

The study reported that CIMT moderately improved upper limb function, though its long-term impact on disability remains unclear. Despite its frequent use, CIMT lacks consistent evidence when compared to other intensive motor training techniques. In contrast, task-specific training (TST) with cognitive-sensorimotor components significantly enhanced proprioception and gait. Robotics-assisted therapy promoted motor recovery via error augmentation and feedback-based learning. Virtual reality interventions enhanced patient engagement and improved functional outcomes, whereas HABIT-ILE demonstrated high efficacy by targeting motor control recovery in both the upper and lower limbs.

Table 3. Study assessment criteria

Author/ Year	Type of study	Place	Demographic details	Assessment
Liu et al., 2022	Randomized Controlled Trial (RCT)	Ganzhou Hospital, China	80 stroke patients (40 per group), Mean Age: 48.52 ± 11.46 years, 38 males, 42 females, Course of disease <6 months	Fugl-Meyer Assessment of Lower Extremity (FMA-LE), Rivermead Mobility Index (RMI), Modified Barthel Index (MBI)
Corbetta et al., 2015	Systematic Review and meta-analysis	Multicenter (42 RCTs across USA, Europe, Asia)	42 studies, 1453 stroke patients, Mean Age: 37–87 years, 64% male, Various global locations	Fugl-Meyer Assessment (FMA), Wolf Motor Function Test (WMFT), Motor Activity Log (MAL), Nine-Hole Peg Test (9HPT), Stroke Impact Scale (SIS)
Kim & Jang, 2021	Randomized Controlled Trial (RCT)	Bundang Jesaeng Hospital, Gyeonggi-do, South Korea	37 stroke patients (13 in Experimental I, 12 in Experimental II, 12 in Control Group); Mean age: 50.23 ± 14.89 years	Electro-goniometer (Proprioception), Composite Spasticity Score (CSS), MyotonPRO (Muscle Tone), 10-Meter Walk Test (10MWT)
Ebner-Karestinos D et al., 2023	Randomized Controlled Trial (RCT)	Belgium (UCLouvain, CHU UCL Namur, Saint-Luc University Hospital)	48 adults with chronic stroke (≥40 years old), able to walk independently, functional upper limb movement	Ad-AHA Stroke, Fugl-Meyer UE, Box and Block Test, Wolf Motor Function Test, 6MWT, ACTIVLIM-Stroke, ABILHAND, SIS, COPM, neuroimaging

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Abdollahi et al., 2018	Double-Blinded Randomized Controlled Trial (RCT)	University of Illinois at Chicago, Rehabilitation Institute of Chicago, USA	26 chronic stroke patients (Age: 26–77, Mean: 53.86 years, 8 Female), hemiparetic arm function recovery	Fugl-Meyer Assessment (UE), Wolf Motor Function Test, Motor Activity Log (Quantity & Quality), Box and Blocks Test, Intrinsic Motivation Inventory
Tedla et al., 2022	Systematic Review & Meta-Analysis	Brazil	208 stroke patients (127 males, 81 females), Mean Age: 59.3 ± 8.6 years, Height: 1.69 ± 0.08 m, Mass: 74.2 ± 10.3 kg	Berg Balance Scale (BBS), Timed Up and Go Test (TUG), Functional Reach Test (FRT), Trunk Impairment Scale (TIS), Limits of Stability (LOS)
French B et al., 2016	Systematic Review & Meta-Analysis	Cochrane Collaboration	33 trials, 1853 stroke patients, Mixed age groups, Mean Age: ~59 years (range: 26–85), Height & Mass not consistently reported	Arm Function, Hand Function, Walking Distance, Functional Ambulation, Lower Limb Functional Measures (6MWT, TUG, BBS, FIM, SIS, ARAT, Box & Blocks, etc.)
Alsubiheen et al., 2022	Randomized Controlled Trial (RCT)	Saudi Arabia & South Korea (King Saud University, Gachon University, Eulji University)	30 chronic stroke patients (15 per group), Mean Age: 54.4 ± 12.7 (T-ADL group), 59.8 ± 8.3 (OT group), BMI: 22.9 ± 1.8 (T-ADL), 23.4 ± 2.6 (OT)	Manual Function Test (MFT), Box and Block Test (BBT), Grip Strength Test, Modified Barthel Index (K-MBI), Stroke-Specific Quality of Life (SS-QoL)
Hu et al., 2024	Pilot Randomized Controlled Trial (RCT)	Hong Kong	19 chronic stroke patients (HDtDCS-group: n=9, Sham-group: n=10), Mean Age: 56.0 ± 9.7 years (HDtDCS), 62.1 ± 10.8 years (Sham), No height/mass data	Fugl-Meyer Assessment UE (FMAUE), Modified Ashworth Scale (MAS), Action Research Arm Test (ARAT), fMRI, EEG-EMG, EMG assessments

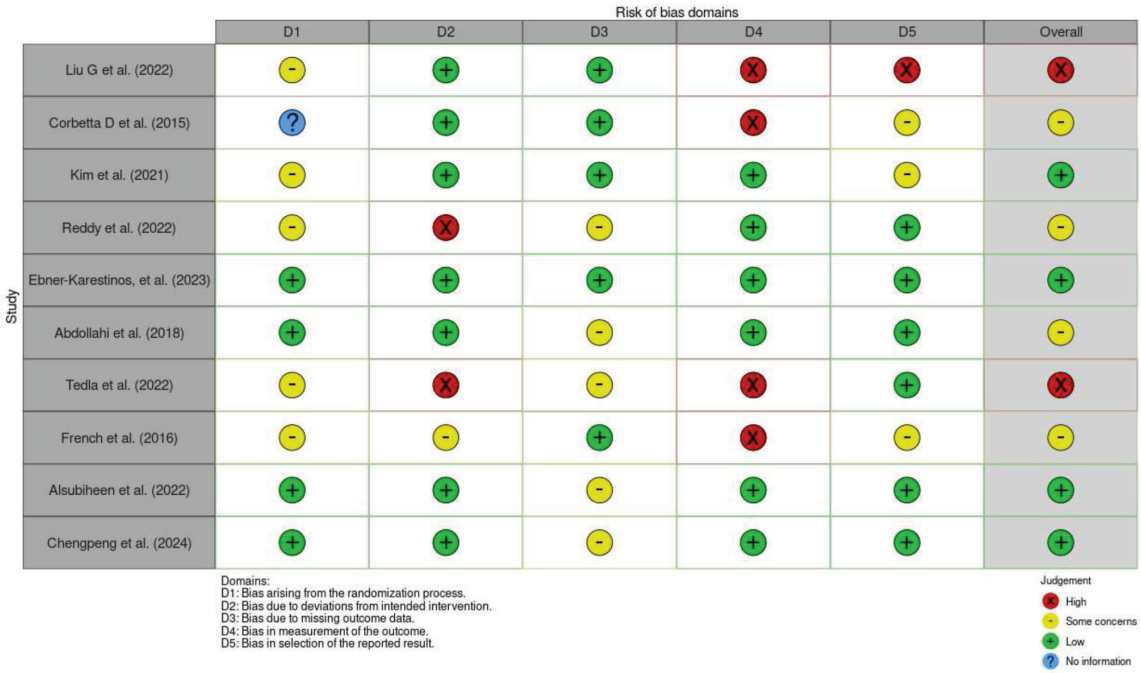

Figure 2: Risk of bias assessment

It appears to be Further high-quality research with larger samples focused on other instead of CIMT to evaluate a successful intensive technique for motor recovery in patients with stroke to confirm these results.

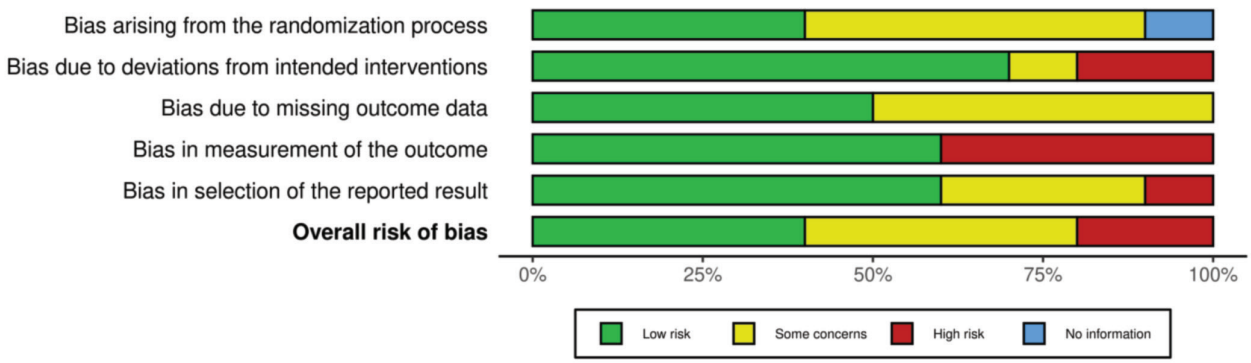

Figure 3: Risk of bias summary of included articles for review

Discussion

This systematic review highlights the effectiveness of intensive motor learning strategies in stroke rehabilitation. These methods promote neuroplasticity through repetitive, task-specific training and sensorimotor integration, leading to notable improvements in motor function and independence. Constraint-Induced Movement Therapy (CIMT) has demonstrated positive short-term effects by restricting the unaffected limb and promoting use of the affected one; however, its long-term functional benefits remain uncertain, with some studies reporting limited transfer to daily activities.[16] Task-Specific Training (TST), focused on functional task repetition, consistently improves

motor outcomes, particularly when combined with cognitive and sensorimotor tasks.[18,19]

Technology-assisted interventions, including robotics and virtual reality (VR), offer promising enhancements. Robotics delivers high-intensity and interactive movement training, improving upper limb strength, though its translation to activities of daily living (ADL) is still limited.[17] VR promotes engagement and motivation, aiding motor learning and recovery, but its long-term efficacy and standardization require further exploration.[18]

Hand-Arm Bimanual Intensive Therapy Including Lower Extremities (HABIT-ILE) improves both upper and lower limb coordination, balance, and mobility. Early findings suggest strong outcomes in independence and quality of life.[20] Despite these advancements, factors such as individual patient differences, the chronicity of the stroke, and adherence to rehabilitation programs play a crucial role in recovery outcomes. Future studies should focus on hybrid models that merge various motor learning strategies, combining HABIT-ILE, robotics, and virtual reality to develop personalized rehabilitation plans for the best possible stroke recovery

Study Limitations

The exclusion of non-English studies may have introduced language bias, potentially overlooking relevant data. Limited availability of high-quality RCTs weakened the evidence base. Heterogeneity in intervention protocols, outcome measures, participant profiles, stroke severity, and rehabilitation settings hinders comparability and generalizability. Despite a comprehensive search strategy, some pertinent studies may have been missed. Furthermore, the lack of standardized long-term follow-up limits conclusions on the sustained efficacy of intensive motor learning interventions

Conclusion

The systematic review demonstrated the benefits of employing intensive motor learning approaches in stroke rehabilitation. It was emphasized that CIMT, task-focused training, robotics-assisted rehabilitation, HABIT-ILE and virtual interventions can be effective at improving motor recovery through neuroplasticity. More research on CIMT is warranted as the evidence regarding its effectiveness is unclear, also HABITILE, Task specific approach and newer approaches such as Virtual or augmented reality applies promise in results although more research is warranted to optimize the interventions protocols, determine industry standard measures of outcomes, and consider personalized clinical interventions for stroke rehabilitation outcomes. Further high-quality research is still required to confirm these results, especially RCTs.

Ethical Statement: Ethics approval was not required for this.

Financial Support and Sponsorship: No funding was received for this study.

Conflicts of Interest: There are no conflicts of interest.

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