REVIEW ARTICLE

IJPHY

Exploring the Impact of Stroke on Lower Limb Proprioception: Insights into Physiotherapy Interventions for Rehabilitation: Systematic Review

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ABSTRACT

Background: Stroke often results in significant impairment of proprioception, which is the sensation of body position and movement in space. This impairment can lead to difficulties with motor coordination and balance. The main objective of this review is to provide a concise summary of the significance of proprioception and its relationship with the stroke population from critically published research papers. Specifically, the review aims to determine the influence of lower limb proprioception following a stroke and the efficacy of proprioceptive training in enhancing balance among stroke patients.

Methods: This systematic review explores the effects of stroke on proprioception and delves into the role of physical therapy interventions in enhancing proprioceptive function in the lower limbs post-stroke. It includes studies examining post-stroke proprioceptive impairments in lower limbs and physical therapy interventions, such as sensory re-education and balance training. Eligible studies include RCTs and observational studies with adult participants. Sources include PubMed, Embase, Cochrane Library, and CINAHL, covering publications from 2015 to 2024.

Results: A total of 12 studies involving 236 participants were included in the review. The studies varied in design, with most being randomized controlled trials. Interventions included sensory re-education, balance training, and proprioceptive exercises targeting the lower limbs. Stroke survivors often experience lower limb impairments affecting mobility, including proprioceptive deficits, spasticity, and weakness. Studies advocate proprioceptive training, including robotic-assisted therapy, virtual reality, and exercises, to enhance recovery. Techniques like mirror therapy, motor imagery, and Transcutaneous Electrical Nerve Stimulation (TENS) showed promise in improving gait speed, balance, and neurostimulation outcomes. Coordinating proprioceptive pathways with muscular synergies is crucial for postural control. Emerging therapies, including telerehabilitation and neurostimulation, highlight the potential for innovative approaches in stroke rehabilitation and functional recovery.

Conclusion: This review highlights that targeted physical therapy interventions, such as sensory re-education and balance training, significantly improve stroke survivors' proprioception, balance, and motor function, promoting better functional recovery. These findings emphasize the critical role of proprioceptive-focused rehabilitation in enhancing patient outcomes. However, limitations include methodological variability, small sample sizes, and heterogeneity in intervention approaches, which may limit generalizability. Future research should prioritize standardized protocols, larger participant cohorts, and long-term follow-ups to refine and validate effective rehabilitation strategies.

Keywords: stroke, proprioception, balance, lower limbs, outcome measure, BBS.

Received 29th November 2024, accepted 06th March 2025, published 09th March 2025

www.ijphy.com

10.15621/ijphy/2025/v12i1/1687

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INTRODUCTION

A stroke can damage specific brain areas responsible for the perception of body position and movement [1]. Strokes occur when bleeding in the brain's tissues or the brain's blood supply is cut off because of conditions including diabetes, heart disease, or cerebrovascular disease. In addition to disturbances of awareness, language, and cognition, the majority of stroke patients exhibit symptoms of motor abnormalities and sensory disturbance, as well as paralysis or paresis. Hemiplegic individuals have reduced central nervous system regulation on the afflicted side, as well as antagonistic and protagonist muscular imbalance, excessive muscle tone, and stiffness. Reduced muscular tone and proprioceptive damage are frequently the causes of decreased balancing abilities. Numerous neurological impairments can result from a stroke. One of the most prevalent incapacitating aftereffects of stroke is lower limb motor impairment. Most patients with motor dysfunction are rehabilitated using conventional physical therapy, which includes task-oriented gait training and neurodevelopment approaches [2]. Invasive and noninvasive neurostimulation techniques have recently been developed to modify the human brain. These neurostimulations improve motor function in stroke patients and affect cortical excitability in the brain [3]. As a result, several therapists have used different types of neurostimulation in addition to traditional therapy to address motor dysfunction [4]. The goal of several invasive and noninvasive neurostimulation experiments was to alter the human brain's cortical excitability. Increased cortical excitability may help stroke victims function better. Proprioceptive deficits are common after a stroke and have poorer recovery outcomes. Although there is limited knowledge about the brain regions beyond the primary somatosensory cortex that contribute to proprioception in humans, impairments in proprioception can lead to difficulties in performing daily activities, more extended hospital stays, and poorer post-stroke outcomes. Despite this, proprioceptive impairments receive less attention than motor impairments clinically and in the literature [5]. Compared to the motor system, the anatomy underlying proprioception is less well understood [6]. Fisher G et al. (2020) have found that the primary somatosensory cortex, the supramarginal gyrus, and Heschl's gyrus are essential for proprioception. Absence or reduction in proprioceptive acuity has been directly correlated with falls and reduced functional independence in older individuals [7]. Stroke is a typical condition affecting the central nervous system, which can cause damage to areas of the brain responsible for proprioception. Proprioception impairment can affect individuals after experiencing a stroke. These impairments are associated with poor functional recovery, decreased independence, and disrupted motor learning. Somatosensory impairment is a common occurrence after a stroke, affecting stroke survivors. Stroke survivors with somatosensory impairment have a higher incidence of falls compared to those without impairment. Proprioception and tactile somatosensation are more impaired in the lower limbs than the arm after a stroke, with the frequency increasing with the level of weakness and stroke severity [8]. Following a stroke, proprioception deficiencies can influence movement, balance, and everyday activities. In stroke patients, activation of the affected lower limb can improve movement and balance. Although the Berg Balance Scale (BBS) is a commonly used tool for assessing balance, its ability to predict falls in chronic stroke patients is Innovative. Long-term neurorehabilitation, including strengthening exercises, balance training, and limb coordination training, has significantly improved balance and mobility in chronic stroke survivors. Leg somatosensory impairment has a significant impact on independence in daily activities and activity participation in stroke survivors, and it also predicts more extended hospital stays and lower frequency of home discharges [9]. A highly structured program enriched by proprioceptive exercises is highly effective in helping individuals return to their activities of daily living [10]. The main objective of this review is to provide a concise summary of the significance of proprioception and its relationship with the stroke population from critically published research papers. Specifically, the review aims to determine a) the influence of lower limb proprioception following a stroke and b) the efficacy of proprioceptive training in enhancing balance among stroke patients.

MATERIALS AND METHODS

Search strategy: To gain a comprehensive understanding of the impact of stroke on lower limb proprioception and physical therapy efficiency in improving, a systematic search of articles published on or after 2015 was conducted. This research involved an exhaustive examination of studies retrieved from PubMed, Cochrane Library, Science Direct, Web of Science, and Scopus databases using medical subject headings terms and free text keywords such as Proprioception, stroke, balance, elderly, rehabilitation, training, BBS, and CVA. A descriptive, analytical approach was used to summarize the data. During the title and abstract reviews, 236 potentially relevant articles were identified. However, 224 studies were excluded as they did not meet the inclusion criteria, were duplicated, had improper study design, had insufficient information, etc. 12 articles were selected for in-depth review for this study.

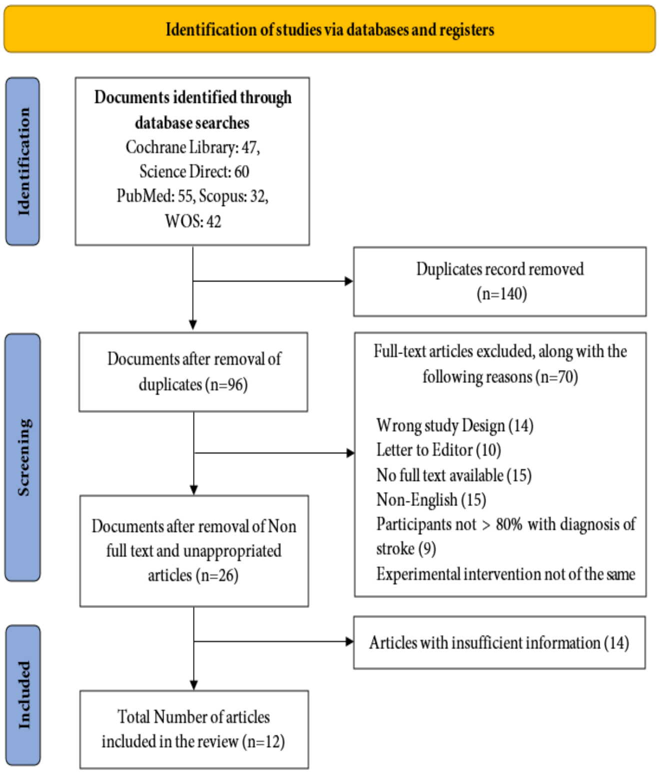

Figure 1: Flowchart depicting the methodology

Inclusion Criteria:

Studies from 2015 to 2024 focusing on adult patients (≥18 years of age) with chronic stroke, evaluating lower limb proprioception, balance, or gait. Randomized controlled trials, cohort studies, systematic reviews, and meta-analyses that assess physical therapy interventions, including proprioceptive neuromuscular facilitation (PNF), are included. Only English-language articles are considered.

Exclusion Criteria

Non-chronic stroke studies, non-peer-reviewed literature, case studies, quasi-randomized trials, qualitative studies, and articles unrelated to stroke rehabilitation or proprioception.

Identification of Studies

Research was rated as either irrelevant, likely relevant, or relevant. The abstract and title were considered, and the papers judged either relevant or likely relevant were filtered [11]. This review covered the studies that satisfied the qualifying inclusion requirements.

Potential Risk of Bias

The Downs and Black technique were utilized to evaluate the possible risk of bias because most of the included research had observational designs. Only the criteria relevant to the possible risk of bias in observational study designs were used to modify the tool [12,13], for instance, eliminating questions about group allocation, randomization, and group concealment.

Data Extraction

The systematic review paper provides a comprehensive overview of the conventional and adjunct therapies that can improve stroke patients' lower limb proprioception. The title, authors' main findings, outcome measures, and year of publication have been summarized in the Tables**.** Data extracted from the articles includes outcome measures covered in this systematic review.

RESULTS

Table 1: Study design

Study	Study Design	Country/setting	Groups	Number of participants	Gender
Min Cheol Chang, Dae Yul Kim and Dae Hwan Park (2015). [14]	The study was a randomized controlled trial with 24 stroke patients, comparing anodal tDCS and sham stimulation, assessing motor function through various evaluations before and after intervention	University Hospital in South Korea, specifically within the Department of Physical Medicine and Rehabilitation.	tDCS group: 12 patients Sham group: 12 patients	24 participants	15 men and 9 women.
H. Lee, Heesoo Kim, Myung-Hwan Ahn, Y. You 2015 [15]	The study employed a two-phase proprioception training program for 18 stroke patients, comparing the effects of proprioception training with motor imagery over 8 weeks, measuring outcomes like K-BBS and TUG.	The study was conducted in the Republic of Korea.	Motor Imagery Training Group (MTG): 18 participants Proprioceptive Training Group (PTG): 18 participants	Total: 36 participants (18 in each group)	MTG: Male: 9 (50%) Female: 9 (50%) PTG: Male: 11 (61.1%) Female: 7 (38.9%)
Gera, G., McGlade, K. E., Reisman, D. S., & Scholz, J. P. (2016) [16]	Experimental research focusing on trunk muscle coordination during reaching tasks.	The study is conducted at the University of Delaware, USA.	Stroke survivors and Control subjects (healthy individuals)	19 (10 stroke survivors and 9 control subjects).	Stroke Survivors: 8 men, 2 women. Control Subjects: 7 men, 2 women.
Emília Márcia Gomes de Souza E Silva, T. Ribeiro, Tállyta Camyla Chaves da Silva, M. F. P. Costa, F. Cavalcanti & A. Lindquist 2017 [17]	Following CONSORT recommendations, the study utilized a randomized trial with two arms conducted at a university movement analysis laboratory.	Study was conducted at Federal University of Rio Grande do Norte (Natal, Brazil).	Experimental Group: 19 participants Control Group: 19 participants	Total participants assessed for eligibility: 43 Randomized participants: 38 (19 in each group)	The gender distribution is not explicitly mentioned in the excerpts provided.

D. Rand 2018 [18]	The study utilized a secondary analysis of chronic stroke participants, focusing on mobility and balance.	The study was conducted in a rehabilitation center in the United States, although the specific location is not explicitly mentioned.	Participants with Intact Proprioception (N = 45) Participants with Mild Proprioception Deficits (N = 19)	The total number of participants in the study is 64.	All Participants: 39 males and 25 females (61% male, 39% female) Proprioception Intact: 27 males and 18 females (60% male, 40% female) Proprioception Deficits: 12 males and 7 females (63% male, 37% female)
Ko EJ, Chun MH, Kim DY, Kang Y, Lee SJ, Yi JH, Chang MC, Lee SY 2018 [19]	The study was a retrospective cohort study that enrolled 14 patients with subacute ischemic stroke.	The study was conducted in Korea, specifically at the Asan Medical Center in Seoul.	Intervention group: 7 participants Control group: 7 participants Total: 14 participants	Intervention group: 7 Control group: 7 Total: 14	Total Gender Distribution: 8 Male (57.1%) : 6 Female (42.9%) Intervention group Gender Distribution: 3 Male (42.9%) : 4 Female (57.1%) Control group Gender Distribution: 5 Male (71.4%) : 2 Female (28.6%)
Li, S., Zhuang, C., Niu, C. M., Bao, Y., Xie, Q., & Lan, N. (2017) [20]	The study utilized a comparative design to evaluate task-specific muscle synergies in stroke patients versus age-matched control subjects.	The research was conducted in a clinical setting, although the specific country is not explicitly mentioned.	Stroke patients (10 subjects) Age-matched healthy control subjects (9 subjects)	Total participants: 19 (10 stroke patients and 9 control subjects)	NR
Zakharov, V. Bulanov, E. Khivintseva, A. Kolsanov, Y. Bushkova, G. Ivanova 2020 [21]	Comparison study between control and experimental groups to evaluate VR and robotics in rehabilitation.	The study was conducted in Russia, specifically at the Samara State Medical University.	Control(N = 27) vs. Experimental (N = 35) groups,	The study included a total of 62 participants, with 27 in the Control group and 35 in the Experimental group	Control group: 14 males and 13 females Experimental group: 18 males and 17 females
Neha Ramchandra Tambe, S. Pazare 2020 [22]	The study design involved a comparative analysis of two sequencing combinations for balance improvement.	The study was conducted in India, as indicated by the address for correspondence provided in the article, which is from Pune, Maharashtra, India.	Group A: Participants: 15 Male: 11 Female: 4 Group B: Participants: 15 Male: 12 Female: 3	Total Participants: 30 (15 in Group A and 15 in Group B)	Group A: Male: 11 Female: 4 Group B: Male: 12 Female: 3
Izhar Uddin, Mirza Obaid Baig, Aruba Iram 2021 [23]	The study design involves a randomized controlled trial with a parallel-group design and double-blind methodology.	The study was conducted in Pakistan, specifically at Bibi Zahida Memorial Teaching Hospital in Peshawar.	Control and Experimental group	A total of 20 participants were randomly allocated to the two groups equally.	A total of n=10 participants were male and remaining 6 were female.
Yajun Mao, Zhenzhen Gao, Hang Yang, Caiping Song 2022 [24]	The study design involves selecting participants, collecting data, and analyzing results to answer research questions.	The study was conducted in China, as indicated by the affiliation of the authors with the First Affiliated Hospital of Zhejiang Chinese Medical University, which is located in Zhejiang Province, China.	SG group (Sensory Training Group) RG (Control Group)	SG group: 30 participants (20 males, 10 females) RG: 30 participants (18 males, 12 females)	SG group: 20 males, 10 females RG: 18 males, 12 females
Jie Shen, Lianjie Ma, X. Gu, Jianming Fu, Yun-hai Yao, Jia Liu, Yan Li 2023[25]	The study design involves a randomized controlled trial with a parallel-group design and a 11 allocation ratio.	The study referenced in the document appears to have been conducted in China, as indicated by the mention of the "Second Hospital of Jiaxing" and the research context.	DMIST Group (Group 1): Dynamic motion instability system training (DMIST). Control Group (Group 2): General balance training.	40	29 men, 11 women.

transcranial direct current stimulation (tDCS)

Study design

This compilation of studies spans from 2015 to 2023 and includes various research designs related to stroke rehabilitation and motor function. Min Cheol Chang et al. (2015) [14] conducted a randomized controlled trial with 24 stroke patients, comparing anodal tDCS and sham stimulation, while Lee et al. (2015) [15] employed a two-phase proprioception training program with 18 stroke patients over eight weeks, comparing proprioception training with motor imagery. Gera et al. (2016) [16] focused on trunk muscle coordination during reaching tasks, and e Silva et al. (2017) [17] followed CONSORT recommendations in their randomized trial at a movement analysis laboratory. D. Rand (2018) [18] performed a secondary analysis of chronic stroke participants, evaluating mobility and balance, while Ko et al. (2018) [19] conducted a retrospective cohort study on 14 patients with subacute ischemic stroke. Li et al. (2017) [20] utilized a comparative design to evaluate task-specific muscle synergies in stroke patients and age-matched control subjects. Zakharov et al. (2020) [21] compared control and experimental groups to assess the role of VR and robotics in rehabilitation, while Tambe et al. (2020) performed a comparative analysis of two sequencing combinations for balance improvement. Izhar Uddin et al. (2021) [23] conducted a randomized controlled trial with a double-blind, parallel-group design, while Yajun Mao et al. (2022) [24] designed a study to select participants, collect data, and analyze results for research questions. Finally, Jie Shen et al. (2023) [25] conducted a randomized controlled trial with a parallel-group design and a 1:1 allocation ratio.

Table 2: Interventions and outcome measures

Study authors	Stroke types	Kinematic measures	Physiotherapy interventions	Outcome measures
Min Cheol Chang, Dae Yul Kim, Dae Hwan Park 2015 [14]	The study included patients with first unilateral ischemic stroke in the cortical or subcortical area, diagnosed within 7-30 days.	The document mentions performance-based gait tests and evaluations such as the Berg Balance Scale for assessing motor function after stroke.	The patients received conventional physical therapy for 6 days/week, primarily aimed at improving postural control, motor function, and movement patterns.	Fugl-Meyer Assessment, Motricity Index, Functional Ambulatory Category, Berg Balance Scale, and gait analysis.
H. Lee, Heesoo Kim, Myung-Hwan Ahn, Y. You 2015 [15]	Strokes are categorized into ischemic and hemorrhagic types, with ischemic strokes accounting for 87% and hemorrhagic strokes causing bleeding.	K-BBS (Korean version of Berg Balance Scale) TUG (Timed Up and Go test) AUWBR (Affected side/Unaffected side weight bearing ratio) AAPWBR (Affected side anterior/posterior weight bearing ratio) UAPWBR (Unaffected side anterior/posterior weight bearing ratio) JPSE (Joint Position Sense Error)	The physiotherapy interventions included proprioception training with exercise imagery and motor imagery training to improve the balance ability of stroke patients	the Korean version of the Berg Balance Scale (K-BBS), Timed Up and Go test (TUG), weight bearing ratio, and joint position sense error.
Gera, G., McGlade, K. E., Reisman, D. S., & Scholz, J. P. (2016) [16]	Participants had either left cerebrovascular accident (LCVA) or right cerebrovascular accident (RCVA).	Kinematic analysis of trunk, head, and pelvis movements during reaching tasks.	Not explicitly detailed in the provided text, but the study likely involved task-related training based on the context of stroke rehabilitation.	Trunk Impairment Scale (TIS) Modified Fugl-Meyer (MFM) scale Kinematic performance during reaching tasks.
Emília Márcia Gomes de Souza E Silva, T. Ribeiro, Tállyta Camyla Chaves da Silva, M. F. P. Costa, F. Cavalcanti, A. Lindquist (2017) [17]	The main types of stroke include ischemic stroke, hemorrhagic stroke, transient ischemic attack (TIA), lacunar stroke, and cryptogenic stroke.	The specific motor functioning tests used in the study are not detailed in the excerpts provided. However, the study likely included assessments related to functional mobility and postural balance, as indicated in the abstract.	Treadmill training, harness support, posture monitoring, verbal corrections, and constraint-induced movement therapy (CIMT).	Berg Balance Scale, Timed Up and Go Test, Functional Ambulatory Category, NIHSS, and MMSE.
D. Rand (2018) [18]	The study does not specify stroke types; it focuses on individuals post-stroke with proprioception deficits.	The document mentions the Timed Up and Go Test (TUG) and the Functional Reach Test (FRT) for assessing motor functioning.	The study did not detail specific physiotherapy interventions; it primarily assessed mobility and balance outcomes.	TUG, FRT, ABC scale, FIM, and IADL questionnaire for assessing functionality.
Ko EJ, Chun MH, Kim DY, Kang Y, Lee SJ, Yi JH, Chang MC, Lee SY (2018) [19]	The stroke types included subacute ischemic stroke in patients with reduced proprioception in the lower limbs.	The document measures stroke recovery using mNIHSS, MMSE, NSA kinesthetic/tactile subscales, K-BBS, MI, FAC, and K-MBI.	The physiotherapy interventions included Frenkel's exercises to improve lower limb sensation and balance.	kinesthetic and light touch sensation, balance, motor function, ambulation, and ADL.
Li, S., Zhuang, C., Niu, C. M., Bao, Y., Xie, Q., & Lan, N. (2017) [20]	The specific types of strokes experienced by the participants are not detailed in the study.	Peak velocities of arm movements Movement durations during reaching tasks	The study focused on task-specific training, particularly reaching tasks, but specific physiotherapy interventions are not detailed in the provided text.	Kinematic performance (peak velocities and movement durations) Similarity indices of muscle synergies Clinical scores, such as the Fugl-Meyer score for the arm
Zakharov, V. Bulanov, E. Khivintseva, A. Kolsanov, Y. Bushkova, G. Ivanova (2020) [21]	The study focused on acute ischemic cerebral circulation disorder in the carotid pool.	NIHSS (National Institutes of Health Stroke Scale) - assesses stroke severity. RMI (Rivermead Mobility Index) - evaluates functional mobility. FMA-LE (Fugl–Meyer Assessment Lower Extremity scale) - measures motor impairment. BBS (Berg Balance Scale) - determines balance ability.	The physiotherapy interventions involved using a ReviVR walk simulator with visual and tactile biofeedback	NIHSS, RMI, FMA-LE, and BBS scales to assess rehabilitation progress.
Tambe NR, Pazare SW (2020) [22]	The study focused on subacute stroke patients with lower limb weakness and balance impairments.	Tests mentioned in the document include: BESTest (Balance Evaluation Systems Test) ABC (Activities-Specific Balance Confidence Scale)	The physiotherapy interventions included upper and lower extremity exercises, stretching, and mental practice.	The BESTest scale and the Activities-Specific Balance Confidence Scale (ABC scale).
Izhar Uddin, Mirza Obaid Baig, Aruba Iram(2021) [23]	Ischemic stroke, hemorrhagic stroke, and transient ischemic attack are common types of strokes.	The tests included observations for knee flexion and extension range of motion (ROM), as well as sitting to standing ability and stepping.	Physiotherapy interventions may include exercise, manual therapy, electrotherapy, and education to promote healing and function.	Functional Independence Measure, Modified Rankin Scale, and Barthel Index are commonly used outcome measures in stroke rehabilitation.
Yajun Mao, Zhenzhen Gao, Hang Yang, Caiping Song (2022) [24]	The two main types of stroke are ischemic stroke, caused by a blockage in a blood vessel, and hemorrhagic stroke, caused by a ruptured blood vessel.	10 Meter Walk Test (10MWT) Berg Balance Scale (BBS) Fugl-Meyer Assessment of Lower Extremity (FMA-LE)	Physiotherapy interventions may include exercise, manual therapy, electrotherapy, and education to improve physical function and well-being.	Range of motion, strength, balance, gait speed, and functional independence.
Jie Shen, Lianjie Ma, X. Gu, Jianming Fu, Yun-hai Yao, Jia Liu, Yan Li (2023) [25]	The stroke types included ischemic stroke, hemorrhagic stroke, and transient ischemic attack (TIA) in the study.	Fugl-Meyer Assessment, Berg balance scale, Gait analysis.	The physiotherapy interventions included exercises, manual therapy, electrotherapy, and patient education to improve functional outcomes	Lower-extremity Fugl-Meyer Assessment, Berg balance scale, and gait function.

Interventions and Outcome Measures

Interventions and outcome measures in stroke rehabilitation are crucial for optimizing recovery and enhancing patients' quality of life. Various studies emphasize the effectiveness of specialized rehabilitation strategies, such as balance training and proprioceptive exercises, essential for addressing sensory deficits, particularly in the lower limbs (Emília et al., 2017; D. Rand, 2018). These interventions are designed to improve motor control and reduce fall risk among stroke survivors, as highlighted by Zakharov et al. (2020) [21]. Additionally, studies by Min Cheol Chang et al. (2015) [14] and Li et al. (2017)[20] stress the importance of early interventions in the subacute phase, where tailored rehabilitation programs can significantly influence motor and cognitive outcomes, particularly in patients with unilateral ischemic strokes. Neuroplasticity is a key focus in these interventions, as Jie Shen et al. (2023) [25] noted, which aims to leverage the brain's ability to reorganize and adapt after injury. Standardized outcome measures, such as the Fugl-Meyer Assessment for motor recovery and the Berg Balance Scale for balance assessment, are commonly used to quantify improvements and guide treatment planning (Yajun Mao et al., 2022) [24]. Using these measures allows for the comparison of intervention effectiveness across studies and helps establish evidence-based practices in stroke rehabilitation. Furthermore, the inclusion of cognitive assessments in rehabilitation programs, as suggested by studies like those of Izhar Uddin et al. (2021) [23], highlights the need to address both motor and cognitive deficits to achieve comprehensive recovery outcomes. Overall, these interventions and outcome measures illustrate the multidimensional approach required in stroke rehabilitation, ensuring that both physical and cognitive aspects of recovery are adequately addressed.

Table 3: Main Findings and Recommendation of the Studies

Study	Main findings	Recommendations	Challenges and Gaps
Min Cheol Chang, Dae Yul Kim, Dae Hwan Park (2015) [14]	Anodal tDCS improved cortical excitability and lower limb motor function in subacute stroke patients.	Integrating innovative neurostimulation techniques like tDCS into rehabilitation practices could enhance recovery outcomes for stroke patients, particularly in improving motor function in the lower limbs.	The study's limitations include a small sample size, lack of long-term effect evaluation, and potential statistical reliability issues due to multiple intergroup comparisons.
H. Lee, Heesoo Kim, Myung-Hwan Ahn, Y. You (2015) [15]	Motor imagery training significantly improved balance ability in stroke patients compared to conventional training.	The study recommends using motor imagery training alongside conventional proprioception training to enhance balance abilities in stroke patients. This method is effective, poses minimal risk, and can be performed without time constraints, making it a valuable addition to rehabilitation programs for improving mobility and balance outcomes	The study's limitations include a small sample size and uncontrolled activities outside training, highlighting the need for more controlled and comprehensive research.
Gera, G., McGlade, K. E., Reisman, D. S., & Scholz, J. P. (2016) [16]	Stroke survivors exhibited different trunk muscle coordination patterns compared to healthy controls, indicating challenges in stabilizing the trunk during reaching movements. The study highlighted the importance of trunk control as a predictor of functional outcomes in stroke rehabilitation.	Emphasize trunk control training in rehabilitation programs for stroke survivors to improve reaching performance and overall functional outcomes.	The study may face limitations in generalizability due to the small sample size and specific demographic characteristics of participants. Further research is needed to explore the long-term effects of trunk control interventions and their impact on daily activities in stroke survivors.
Emília Márcia Gomes de Souza E Silva, T. Ribeiro, Tállyta Camyla Chaves da Silva, M. F. P. Costa, F. Cavalcanti, A. Lindquist (2017) [17]	Both groups showed improved postural balance and functional mobility after treadmill training, with maintained improvements in follow-up.	The recommendations from the study emphasize the importance of consistent gait training and home exercises for stroke rehabilitation, while suggesting that the addition of load may not be necessary for achieving improvements in the targeted outcomes	The study's limitations suggest that the added load and intervention time may not have been adequate, necessitating further testing of various load percentages and intervention times.
D. Rand (2018) [18]	Participants with chronic stroke and mild proprioception deficits showed significant differences in mobility, balance, and independence in daily living.	The study recommends proprioception screening and further research to include participants with moderate and severe proprioception deficits.	The study's limitations include a single proprioception test, uneven group sizes, exclusion of moderate and severe deficits, and inconsistent correlation findings, suggesting future research requires separate participant recruitment.
Ko EJ, Chun MH, Kim DY, Kang Y, Lee SJ, Yi JH, Chang MC, Lee SY (2018) [19]	Frenkel's exercise improved sensory and balance recovery in subacute ischemic stroke patients with impaired proprioception and minimal motor weakness	Recommends future studies should include larger sample sizes, longer follow-up periods, and imaging methods to assess recovery.	The study faces limitations due to its small sample size, retrospective nature, lack of long-term follow-up, and lack of information on somatosensory evoked potential.
Li, S., Zhuang, C., Niu, C. M., Bao, Y., Xie, Q., & Lan, N. (2017) [20]	Three and four components were necessary to account for forward and lateral reaching movements, respectively. There was a positive correlation between task-specific similarity indices and motor performance in stroke patients. Pathological synergies in patients differed from baseline synergies observed in healthy controls, indicating deficits in motor function.	The authors suggest that task-specific muscle synergy analysis can provide valuable insights into motor deficits in stroke patients and that the developed similarity indices could serve as useful neurophysiological metrics for clinical evaluation.	The study acknowledges the complexity of motor rehabilitation in stroke patients and the need for a better understanding of the neurophysiological mechanisms underlying recovery. Limitations regarding the sample size and the lack of detailed information on the types of strokes and gender distribution were noted, indicating areas for further research.
Zakharov, V. Bulanov, E. Khivintseva, A. Kolsanov, Y. Bushkova, G. Ivanova (2020) [21]	The study showed significant progress in post-stroke lower limb rehabilitation using virtual reality and tactile feedback. VR-based rehabilitation with tactile feedback significantly improved post-stroke lower limb function.	Recommendations further research with larger sample sizes and long-term follow-up to validate the effectiveness of VR-based rehabilitation	The study faces limitations including a small sample size, lack of long-term follow-up, and potential bias due to the study design.
Neha Ramchandra Tambe, Pune Maharashtra India Mpt Physiotherapist, S. Pazare (2020) [22]	The main findings indicate that both sequences of mental and physical practice are equally effective in improving balance in stroke patients	The study would benefit from a larger sample size and a longer-term follow-up to assess sustained effects.	The study found challenges like physical fatigue, limited improvement, individual responses, and assessment limitations in stroke rehabilitation strategies, highlighting the need for larger studies for generalizability.

Izhar Uddin, Mirza Obaid Baig, Aruba Iram (2021) [23]	Motor imagery technique combined with conventional therapy significantly improved lower extremity function, gait, and quality of life in stroke patients.	Further research should focus on determining the optimal dose and procedure for motor imagery technique to enhance its effectiveness in stroke rehabilitation.	The study's limitations included the incapacity to determine the optimal dose and procedure for motor imagery technique.
Yajun Mao, Zhenzhen Gao, Hang Yang, Caiping Song (2022) [24]	Proprioceptive training with an ankle-foot robot significantly improved walking speed, balance, and motor function in stroke patients.	The study suggests optimizing the standardized rehabilitation training program through long-term follow-up of data and using gait analysis equipment for more objective balance assessment.	The study acknowledges limitations like small sample size and lack of long-term follow-up data, and emphasizes the subjective nature of BBS assessment and the need for objective methods like gait analysis equipment.
Jie Shen, Lianjie Ma, X. Gu, Jianming Fu, Yun-hai Yao, Jia Liu, Yan Li (2023) [25]	DMIST significantly improved lower-extremity motor function and gait speed in post-stroke patients.	Optimize the follow-up protocol and extend the follow-up period for future studies. Conduct more double-blind, multicenter research to corroborate the findings. Explore the treatment strategy and onset mechanism of multisensory integrated dynamic movement in stroke patients.	The study has limitations including a small sample size, limited treatment time (8 weeks), potential bias, variations between animal and human studies, limited resources for long-term clinical trials, and lack of published literature on balance exercise.

Broader Analysis and Emerging Themes of the Studies

The Dominance of Ischemic Stroke Research across these 12 studies, ischemic stroke consistently emerges as the primary focus due to its overwhelming prevalence accounting for around 85-87% of all strokes. Many studies, such as those by Min Cheol Chang et al. (2015) [14] and Yajun Mao et al. (2022) [24], emphasize ischemic strokes and their recovery pathways. The blockage of blood flow leading to ischemia is most often caused by thrombosis or embolism, making rapid diagnosis and intervention critical. Hemorrhagic strokes, though less common, are featured as well (e.g., in studies by Neha Ramchandra Tambe et al. (2020) [22] and Izhar Uddin et al. (2021) [23]. These studies illustrate the severity of hemorrhagic strokes, which involve ruptured blood vessels and bleeding in or around the brain, often necessitating immediate surgical intervention. The distinct pathophysiologies of these two major stroke types demand different approaches to treatment and rehabilitation. Ischemic stroke recovery efforts are typically focused on early interventions to restore blood flow, such as thrombolysis or mechanical thrombectomy. In contrast, hemorrhagic stroke treatments revolve around managing intracranial pressure and bleeding. The focus on these two stroke types reflects their significant burden on healthcare systems and the importance of developing targeted recovery protocols for each. Transient Ischemic Attack (TIA) as a Stroke Predictor. Multiple studies, including those by Yajun Mao et al. (2022) [24] and Neha Ramchandra Tambe et al. (2020) [22], include TIA in their analysis. Often referred to as a "mini-stroke," TIA involves temporary disruptions in blood flow to the brain, causing brief symptoms similar to a stroke but without lasting damage. The inclusion of TIA reflects its significance as a warning sign for full-blown strokes, as 1 in 3 people who experience a TIA will later suffer a more severe stroke. The presence of TIA in these studies suggests a growing emphasis on preventive care and early diagnosis in stroke management. Recognizing and treating TIA as a medical emergency can provide an opportunity to address underlying risk factors, such as hypertension, atrial fibrillation, or high cholesterol, potentially preventing larger, more debilitating strokes in the future [26]. Timing in Stroke Recovery A common theme across these studies is the importance of timing in stroke treatment and rehabilitation. Several studies, like those by Li et al. (2017) [20] and Gera et al. (2016) [16], focus on the acute phase of stroke, which refers to the first few hours to days after the event. In this critical period, rapid interventions such as clot-dissolving drugs for ischemic stroke or surgical procedures for hemorrhagic stroke—are essential for reducing long-term damage. On the other hand, studies like those by Rand (2018) [18] and Zakharov et al. (2020) [21] highlight the importance of the subacute phase, which typically spans several days to a few months post-stroke. This phase is crucial for rehabilitation as the brain undergoes neuroplasticity, the process by which it reorganizes itself to compensate for lost functions. Studies focusing on the subacute phase often stress the need for intensive physical, cognitive, and speech therapy to maximize recovery potential. Proprioception and Motor Recovery, a crucial Role of Sensory proprioception deficits, particularly in the lower limbs, appear prominently in studies such as those by Rand (2018) [18] and Zakharov et al. (2020) [21]. Proprioception, the body's ability to sense its position and movement, is essential for balance and coordinated motor function. Stroke patients, especially those in the subacute phase, frequently suffer from proprioception impairments, which contribute to balance issues, increased fall risk, and difficulties in walking. The focus on proprioceptive deficits underscores the broader theme of motor-sensory integration in stroke recovery. While many rehabilitation efforts target motor recovery (e.g., strengthening muscles, improving gait), sensory recovery is equally important. Techniques like balance training, sensory feedback exercises, and, in some cases, robotic-assisted rehabilitation aim to restore proprioceptive function, helping stroke survivors regain independence in daily activities. In Left vs. Right Hemispheric Strokes differential outcomes, the distinction between left cerebrovascular accident (LCVA) and right cerebrovascular accident (RCVA) is highlighted in Lee et al. (2015) [15]. Strokes in different brain hemispheres lead to varying outcomes and require tailored rehabilitation approaches. LCVA commonly affects the language centers in the brain (such as Broca's and Wernicke's areas), leading to aphasia (language impairment). At the same time, RCVA often results in spatial neglect and difficulties in perceiving the environment [27]. Understanding the deficits caused by left vs. right hemispheric strokes is crucial for designing effective rehabilitation programs. For example, patients with LCVA may benefit more from speech therapy, while those with RCVA might require training in spatial awareness and perceptual tasks. This differential approach to stroke rehabilitation underscores the complexity of stroke recovery and the need for individualized care. In Subacute Stroke Rehabilitation, several studies, including those by Rand (2018) [18] and Zakharov et al. (2020) [21], emphasize the importance of rehabilitation in the subacute phase, particularly targeting lower limb weakness and balance impairments. Post-stroke patients often experience motor control and balance deficits, especially after strokes affecting the brain regions responsible for movement (e.g., the motor cortex, basal ganglia). These studies highlight the significance of balance training and strengthening exercises for improving mobility and reducing the risk of falls. Subacute rehabilitation strategies often include physical therapy, occupational therapy, and, increasingly, technological interventions like robotic-assisted gait training or virtual reality (VR) systems designed to enhance proprioceptive feedback and motor control. The more recent studies, such as those by Jie Shen et al. (2023) [25] and Yajun Mao et al. (2022) [24], reflect a growing trend toward individualized rehabilitation rather than focusing solely on stroke type. The growing understanding of neuroplasticity and stroke outcomes emphasizes the need for personalized stroke recovery. This involves addressing the individual deficits, such as motor, cognitive, sensory, or speech, and integrating various therapies like physical therapy, cognitive therapy, speech-language therapy, and newer approaches like constraint-induced movement therapy, robotic-assisted rehabilitation, and neurofeedback training.

Recommendations

Early Intervention

Across multiple studies, such as those by Min Cheol Chang et al. (2015)[14] and Li et al. (2017)[20], early intervention in both ischemic and hemorrhagic stroke management is emphasized. The first few weeks' post-stroke (particularly the first 7-30 days) are crucial for maximizing neuroplasticity and recovery. Thrombolytic therapy and mechanical thrombectomy should be administered as soon as possible for ischemic stroke patients to restore cerebral blood flow and prevent further brain damage. Early mobilization and physical therapy are also recommended to reduce complications and promote motor recovery.

Personalized and Targeted Rehabilitation

Personalized rehabilitation approaches, as emphasized by Jie Shen et al. (2023) [25], are critical for addressing the unique deficits each stroke survivor faces. Lee et al. (2015) [15] suggests that left and right cerebrovascular accidents (LCVA and RCVA) require different rehabilitation strategies. LCVA patients often benefit from speech therapy due to aphasia, while RCVA patients need more focus on motor coordination and spatial awareness. Neuroimaging, as recommended by Yajun Mao et al. (2022), can guide clinicians in tailoring rehabilitation strategies to individual patients' needs.

Balance, Mobility, and Proprioception

Studies by e Silva et al. (2017)[17] and Rand (2018) [18] emphasize the importance of balance and proprioception training for stroke survivors, particularly those with lower limb weakness or proprioceptive deficits. Incorporating gait training, proprioceptive exercises, and sensory re-education into rehabilitation programs can significantly improve mobility and reduce the risk of falls. Additionally, Zakharov et al. (2020)[21] advocate for the use of assistive technologies such as robotic therapy or virtual reality-based interventions to enhance proprioceptive recovery.

Comprehensive Post-Stroke Care

Rehabilitation programs must address both physical and cognitive impairments. Gera et al. (2016) [16] and Izhar Uddin et al. (2021) [23] highlight the need for comprehensive rehabilitation that includes physical therapy, cognitive training, and lifestyle modifications to prevent recurrent strokes. Managing risk factors like hypertension, diabetes, and hyperlipidemia through community awareness programs is critical for reducing stroke incidence and recurrence.

Subacute and Chronic Phase Rehabilitation

For patients in the subacute phase (weeks to months' post-stroke), studies such as Zakharov et al. (2020)[21] and Rand (2018) [18] recommend intensive rehabilitation focused on balance, strength, and proprioception. The subacute phase is crucial for regaining functional independence, and early intervention during this period can accelerate recovery. Long-term rehabilitation should involve ongoing physical therapy to manage chronic impairments and prevent deterioration.

Challenges and Gaps of the studies

These studies reveal several key challenges and gaps that limit the robustness and generalizability of their findings. Small sample sizes are a consistent issue, as highlighted in studies by Min Cheol Chang et al. (2015) [14], Lee et al. (2015) [15], and Gera et al. (2016) [16], which raises concerns about the statistical power and the reliability of the results. Uncontrolled variables—such as participants' activities outside the training protocols—limit the ability to isolate the effects of the interventions, as noted in the study by Lee et al. (2015) [15]. Several studies, including those by Zakharov et al. (2020) [21] and Jie Shen et al. (2023) [25], lacked long-term follow-up data, which is critical for assessing the sustained impact of rehabilitation strategies over time. e Silva et al. (2017) [17] faced limitations with the use of a single proprioception test, making it difficult to draw comprehensive conclusions about sensory recovery. Furthermore, studies like Rand (2018) [18] and Ko et al. (2018) [19] dealt with issues such as uneven group sizes, exclusion of more severe cases, and retrospective study designs, which limit the generalizability of the results. The complexity of stroke rehabilitation is further compounded by inconsistent intervention times and the variability in individual responses to treatment, as seen in the work of Neha Ramchandra Tambe et al. (2020) and Izhar Uddin et al. (2021) [23]. These factors suggest a need for larger, more controlled studies with standardized protocols to ensure consistency across patient groups. Lastly, studies like

Yajun Mao et al. (2022) [24] emphasized the limitations of subjective assessments, calling for more objective evaluation methods, such as gait analysis, to accurately measure improvements in motor function.

DISCUSSION

This review aims to provide a comprehensive understanding of proprioception's significance and its connection to stroke patients, highlighting the importance of coordination between multiple senses, including vision and vestibular sense, in maintaining balance and postural control. Stroke survivors often experience impairments in lower limb proprioception, which can significantly impact their gait, balance, and overall motor function (Chu 2015) [28]. Several studies highlight the importance of lower limb somatosensory impairments in stroke survivors. Rand (2018) [18] and Zakharov et al. (2020) [21] emphasize the need for proprioceptive training to improve balance and mobility. Ko et al. (2018) [19] and e Silva et al. (2017) [17] suggest that interventions like proprioceptive exercises and ankle-foot robotics can enhance lower limb function, improving recovery outcomes for stroke survivors with sensory deficits. The prevalence and distribution of lower limb somatosensory impairments in chronic stroke survivors are also important considerations (Gorst 2019) [29]. Proprioceptive training, such as using an ankle-foot robot, has improved lower limb function in patients with stroke (Zheng 2024) [30]. e Silva et al. (2017) [17] and Rand (2018) [18] emphasize the need for proprioceptive training to improve gait, while Zakharov et al. (2020) [21] and Ko et al. (2018) [19] link balance restoration to improved Functional Ambulation Categories (FAC). These studies suggest that targeting proprioceptive pathways and balance could enhance gait speed, stride length, and neurostimulation-based recovery. Resting-state functional connectivity associated with impaired proprioception post-stroke has been identified, providing potential targets for therapeutic neurostimulation (Kenzie, 2023) [31]. According to Functional Ambulation Categories (FAC), which include gait speed and stride length, increased balance is the most essential factor in restoring gait ability (Buvarp et al. 2020) [32]. Proprioceptive strength training should be emphasized in patients' regular therapy following a stroke. Proprioceptive information must be coordinated with muscular synergies to maintain postural control. Even in healthy people, women are more likely to fall, with the hip joint being the most prone to proprioceptive deficits [33]. Zakharov et al. (2020) [21] support using proprioceptive exercises to coordinate muscular synergies for postural control. Additionally, Lee et al. (2015) [15] suggest that women, even in healthy populations, are more prone to falls, particularly due to hip proprioceptive deficits. Motor impairment in the lower limbs is a typical complication in stroke patients, and the lower extremities in approximately 88% of stroke patients show persistent impairment. Lower limb weakness accounts for 48.6% of the common deficits observed in stroke survivors [34]. Lower extremity impairments, including motor weakness, somatosensory deficits, and spasticity, can significantly affect walking ability and require effective therapy programs (Li, 2019) [35]. Constraint-induced movement therapy for the lower extremities effectively improves balance and ambulation in stroke patients. Zakharov et al. (2020) [21] highlight using virtual reality and robotic-assisted therapy to improve proprioception and motor recovery in stroke patients with lower limb impairments. Additionally, Gera et al. (2016) [16] suggest mirror therapy for the lower extremities, which effectively enhances gait speed, mobility, and motor function. In early reported studies, telerehabilitation and virtual reality interventions have been proposed as potential strategies for post-stroke lower extremity recovery (Park, 2022; Luque-Moreno, 2015) [36]. Mirror therapy for the lower extremity effectively improves gait speed, mobility, and motor recovery in stroke patients (Louie, 2019) [37]. Most patients with motor dysfunction are rehabilitated using conventional physical therapy, which includes neurodevelopmental approaches and task-oriented gait training. Recently, invasive and noninvasive neurostimulation techniques have been developed to alter the human brain. These neurostimulations affect brain cortical excitability and improve stroke patients' motor performance [38]. Rand (2018) [18] suggested combining sensory re-education with motor imagery to enhance recovery in patients with proprioceptive deficits. Motor imagery, often known as mental practice, is a dynamic state in which an individual mentally replicates a certain action; it is also defined as the covert cognitive process of visualizing the movement of one's own body (body part) without actually moving it [39]. Treatments such as Transcutaneous Electrical Nerve Stimulation (TENS) can improve spasticity and proprioception when applied to specific muscles, such as the calf muscles. This treatment method can be beneficial in reducing muscle stiffness and enhancing the sense of body awareness in individuals.

CONCLUSION

The review of the twelve studies provides a comprehensive understanding of stroke types, rehabilitation strategies, and the critical role of sensory input and motor imagery in recovery. Common themes include the significance of early intervention and personalized rehabilitation approaches tailored to the individual needs of stroke survivors. The studies collectively highlight that effective rehabilitation should address motor and sensory impairments, as these factors are intricately linked to overall functional recovery. However, several challenges and gaps persist in the existing literature, including small sample sizes, lack of long-term follow-up, and inconsistent methodologies. Future research should focus on larger, multicentric trials to enhance the statistical power and generalizability of findings. Additionally, incorporating advanced technologies, such as virtual reality and robotic-assisted therapies, can provide innovative avenues for enhancing sensory input and motor imagery practices. Furthermore, more studies are needed to explore the neurophysiological mechanisms underlying motor imagery and its impact on sensory recovery, particularly in patients with significant proprioceptive deficits. Addressing the variability in individual responses to interventions and the subjective nature of current assessment methods is also crucial. By embracing a multidisciplinary approach and leveraging emerging technologies, future research can better equip clinicians with practical strategies to optimize recovery for stroke survivors, ultimately improving their quality of life and functional independence. This review lays the groundwork for future inquiries into enhancing rehabilitation practices and addressing the complex needs of this population.

Acknowledgement

We sincerely thank Assam Down Town University (ADTU) for their steadfast support.

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