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THE EFFECT OF GRADED MOTOR TECHNIQUE VERSUS PROGRESSIVE CIRCUIT TRAINING FOR PAIN AND MOBILITY IN STROKE INDIVIDUALS

Original Research

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ABSTRACT

Background: Stroke is a leading cause of disability and mortality worldwide, significantly impacting functional independence and quality of life. Rehabilitation strategies play a crucial role in post-stroke recovery by enhancing motor function, reducing pain, and improving mobility. Graded Motor Imagery (GMI) and Progressive Circuit Training (PCT) are two distinct therapeutic approaches targeting neuromuscular reorganization and functional rehabilitation. However, comparative evidence regarding their effectiveness remains limited. This study evaluates and compares the efficacy of GMI and PCT in improving pain and mobility among stroke patients, providing insights into their therapeutic impact.

Objective: To determine the comparative effectiveness of Graded Motor Imagery and Progressive Circuit Training in improving pain levels and mobility in stroke patients.

Methods: A randomized clinical trial was conducted at Sehat Medical Complex, Rehab Cure, and the University Institute of Physical Therapy Teaching Hospital. A total of 28 ischemic stroke patients meeting the inclusion criteria were randomly allocated into two groups (14 participants per group). Group A received Graded Motor Imagery (3–5 sessions per week, 20–30 minutes per session, for four weeks), while Group B underwent Progressive Circuit Training (2–4 sessions per week, 30–60 minutes per session, for four weeks). Pain levels were assessed using the Visual Analogue Scale (VAS), and mobility was measured using the Functional Independence Measure (FIM). Assessments were conducted at baseline and after four weeks. Data were analyzed using SPSS 27.0, with independent sample t-tests for between-group comparisons and paired sample t-tests for within-group analysis.

Results: At baseline, no significant differences were observed in pain ($p = .848$) or mobility ($p = .323$) between groups. Post-treatment, both groups showed significant improvements ($p < 0.01$). The GMI group demonstrated a greater reduction in pain (VAS: 7.14 ± 1.03 to 3.21 ± 0.802) compared to the PCT group (VAS: 7.07 ± 0.917 to 4.86 ± 1.23). Mobility improvements were also more pronounced in the GMI group (FIM: 85.50 ± 2.10 to 96.50 ± 2.07) than in the PCT group (FIM: 86.43 ± 2.74 to 91.14 ± 4.42). Statistical analysis confirmed superior effectiveness of GMI in reducing pain and enhancing mobility compared to PCT ($p < 0.01$).

Conclusion: Both Graded Motor Imagery and Progressive Circuit Training proved effective in reducing pain and improving mobility in stroke patients. However, Graded Motor Imagery demonstrated superior outcomes, highlighting its potential as a more effective rehabilitation technique for stroke recovery. The findings suggest that cognitive-motor rehabilitation strategies like GMI may play a crucial role in optimizing neuroplasticity and functional independence in stroke survivors.

Keywords: Cerebrovascular accident, Functional Independence Measure, Graded Motor Imagery, Pain management, Progressive Circuit Training, Stroke rehabilitation, Visual Analogue Scale

INTRODUCTION

Stroke is a leading cause of disability and mortality worldwide, ranking as the second most common cause of death and a major contributor to long-term functional impairment (1). Medically referred to as a cerebrovascular accident (CVA), stroke occurs when cerebral function is disrupted due to vascular compromise, leading to irreversible neuronal damage if not promptly managed. The World Health Organization (WHO) defines stroke as a neurological event characterized by sudden-onset focal brain dysfunction persisting beyond 24 hours, often resulting from ischemic infarction, intracerebral hemorrhage, or subarachnoid hemorrhage (2). Stroke may present with or without overt symptoms, yet its consequences can be devastating, affecting not only survival but also long-term quality of life. It is categorized into early hyperacute (0–6 hours), late hyperacute (6–24 hours), acute (1–7 days), subacute (1–3 weeks), and chronic stages (beyond three weeks) (3,4). While acute stroke is sometimes described as an "accident," experts argue that the term "brain attack" is more appropriate, emphasizing its resemblance to acute cardiac events requiring immediate medical intervention (5).

Among the various types of stroke, ischemic stroke is the most prevalent, accounting for approximately 85% of all acute cases (6). It results from an obstruction in cerebral blood flow due to thrombotic or embolic events, leading to neuronal ischemia and infarction (7). Hemorrhagic strokes, which constitute the remaining 15%, occur due to the rupture of cerebral blood vessels, further classified into intracerebral hemorrhage (ICH) and subarachnoid hemorrhage (8,9). Regardless of etiology, stroke remains a global health crisis, with an estimated 2 million deaths annually (10). According to WHO statistics, approximately 15 million individuals suffer from stroke each year, with 5 million fatalities and an equal number of survivors left with permanent disabilities (11). The Global Burden of Disease Study (GBDS) identifies stroke as the second leading cause of mortality, whereas the Disability-Adjusted Life Years (DALY) framework ranks it as the third most significant contributor to global disability (12). The disease burden is further amplified by modifiable risk factors, including hypertension, obesity, smoking, diabetes mellitus, and physical inactivity, as well as non-modifiable factors such as age, genetic predisposition, and underlying cardiovascular abnormalities (13,14).

The neuropathophysiology of stroke is closely linked to the cerebrovascular supply. The brain is perfused by the anterior cerebral artery (ACA), middle cerebral artery (MCA), and posterior cerebral artery (PCA), with ischemic events occurring when blood supply is disrupted in any of these major vessels (15,16). Pathophysiological changes associated with stroke include hematoma formation due to vascular rupture, intracranial pressure elevation, and secondary neuronal injury, leading to motor, sensory, and cognitive impairments (17,18). Hemorrhagic stroke, in particular, results in hematoma formation, increasing intracranial pressure and impairing cerebral autoregulation, thus exacerbating neuronal injury (19,20). Stroke-induced neurological deficits vary based on the affected brain region and the severity of ischemic insult. In ischemic stroke, the extent of infarcted tissue dictates functional impairment, ranging from mild motor weakness to complete hemiplegia and cognitive dysfunction (21,22). The global impact of stroke is evident in epidemiological data, with an estimated prevalence of 2 million new cases annually in China, 4.12% prevalence among individuals aged over 44 years in Turkey, and 95 per 100,000 individuals annually in Pakistan between 2000 and 2016 (23,24,25). Furthermore, approximately 400,000 stroke survivors in Pakistan experience long-term disability, underscoring the urgent need for effective rehabilitation strategies (26).

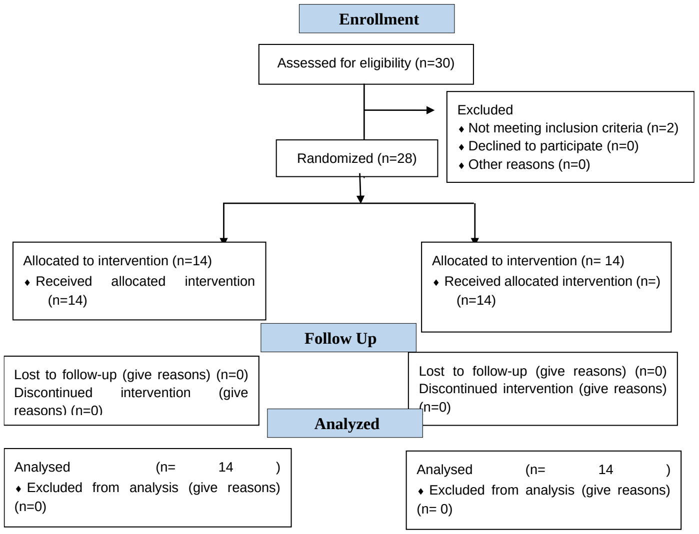
Stroke survivors often experience profound motor deficits, sensory impairments, and functional disability, significantly affecting their ability to perform activities of daily living (27). Among these impairments, hemiplegia is the most common motor dysfunction, typically manifesting as unilateral weakness or paralysis (28). Sensorimotor deficits include diminished proprioception, loss of thermal sensation, bladder and bowel dysfunction, hypersensitivity, and paresthesia, further complicating functional recovery (29). Stroke rehabilitation aims to mitigate these disabilities through targeted interventions that enhance neuroplasticity and promote functional restoration. The acute stage, which lasts for approximately two weeks post-lesion, is critical for initiating early rehabilitation to prevent complications such as contractures, spasticity, and secondary musculoskeletal disorders (30). The complex interplay between pain and mobility restrictions further limits patient participation in rehabilitation, necessitating multifaceted therapeutic approaches (31). Innovative techniques such as Graded Motor Imagery (GMI) and Progressive Circuit Training (PCT) have emerged as promising rehabilitation strategies for enhancing motor function and reducing stroke-related pain (32). This study aims to determine the comparative efficacy of Graded Motor Imagery (GMI) versus Progressive Circuit Training (PCT) in improving pain management and mobility in stroke survivors. By evaluating these two rehabilitation approaches, this study seeks to provide clinicians with evidence-based strategies to optimize functional recovery and enhance the quality of life in post-stroke individuals.

METHODS

The study was conducted at Sehat Medical Complex, Rehab Cure, and the University Institute of Physical Therapy Teaching Hospital. A randomized clinical trial (RCT) design was employed to compare the efficacy of Graded Motor Imagery (GMI) and Progressive Circuit Training (PCT) in improving pain management and mobility in stroke survivors. The sample size was determined using the Functional Independence Measure (FIM) outcome scale, and after incorporating a 10% attrition rate, the final sample size was 28 participants (14 per group) (39). Participants were selected through simple random sampling. The study was completed over six months following the approval of the research synopsis. Participants were included if they were aged 18 to 75 years (40), diagnosed with ischemic stroke, had experienced a stroke within the past year, and achieved a score greater than 23 on the Mini-Mental State Examination (MMSE) (41). Both male and female participants were eligible. Exclusion criteria included individuals with neurological or orthopedic conditions affecting upper limb function (e.g., Parkinson's disease) (42), history of severe aphasia or apraxia (43), systemic disorders such as rheumatoid arthritis (42), unstable angina (40), and coexisting physical impairments, including limb amputation (40).

Participants who met the eligibility criteria were recruited after obtaining written informed consent. Randomization was conducted using the fishbowl method (lottery method), and participants were assigned to Group A (GMI) or Group B (PCT). The study followed a single-blinded approach, where participants were unaware of their treatment allocation, but assessors conducting the outcome evaluations remained blinded to minimize bias. Baseline demographic and clinical characteristics, including age, stroke onset, MMSE score, and initial motor function, were recorded before intervention to ensure group comparability. A second assessment was conducted after four weeks of intervention.

Participants in Group A received Graded Motor Imagery (GMI), a structured neurocognitive rehabilitation technique designed to enhance motor recovery and pain modulation. Sessions followed the Frequency, Intensity, Time, and Type (FITT) principle, ensuring structured progression. Sessions were conducted three to five times per week for four weeks, each lasting 20 to 30 minutes. The intervention was divided into three progressive phases: laterality recognition, motor imagery, and mirror therapy. Initially, participants engaged in left-right discrimination tasks, followed by mental practice of specific movements, and finally, mirror therapy, where movements of the unaffected limb were used to create a visual illusion of movement in the affected limb. This systematic approach aimed to promote neuroplasticity, enhance motor relearning, and facilitate pain-free movement (44).



Participants in Group B received Progressive Circuit Training (PCT), a structured regimen focusing on progressive resistance training and cardiovascular endurance. Sessions were scheduled two to four times per week for four weeks, with each session lasting 30 to 60 minutes. Each PCT session comprised multiple 5- to 10-minute circuits, incorporating exercises that targeted strength, endurance, flexibility, and balance. The intensity was progressively increased by modifying resistance loads, repetitions, and aerobic intensity, ensuring participants operated within their target heart rate range (50–70% of maximum heart rate) for cardiovascular conditioning. Circuit progression included bodyweight squats for lower limb strength, advancing to jump squats for explosive power, transitioning to mountain climbers for endurance, and concluding with yoga-based postures to enhance flexibility and neuromuscular control (45). This approach was designed to improve functional mobility, motor coordination, and overall cardiovascular fitness. Pain intensity was assessed using the Visual Analogue Scale (VAS), while mobility and functional independence were measured using the Functional Independence Measure (FIM). Outcome assessments were performed at baseline and post-intervention (week 4) by a blinded assessor to ensure objective evaluation.

Data analysis was conducted using SPSS version 27.0 (Statistical Package for the Social Sciences). Categorical variables were represented as frequencies and percentages, visualized using bar charts and pie charts, while continuous variables were summarized using means and standard deviations, depicted through histograms. Data normality was evaluated using the Kolmogorov-Smirnov and

Shapiro-Wilk tests. Since the data followed a normal distribution, independent sample t-tests were applied for between-group comparisons, and paired sample t-tests were used for within-group analysis.

RESULTS

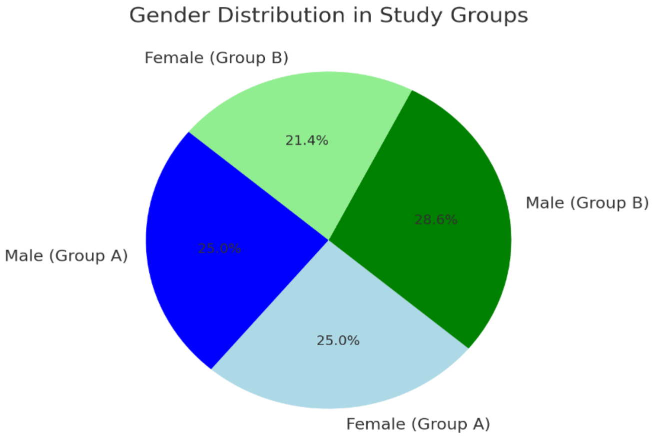


Figure 1 Gender Distribution in Study Group

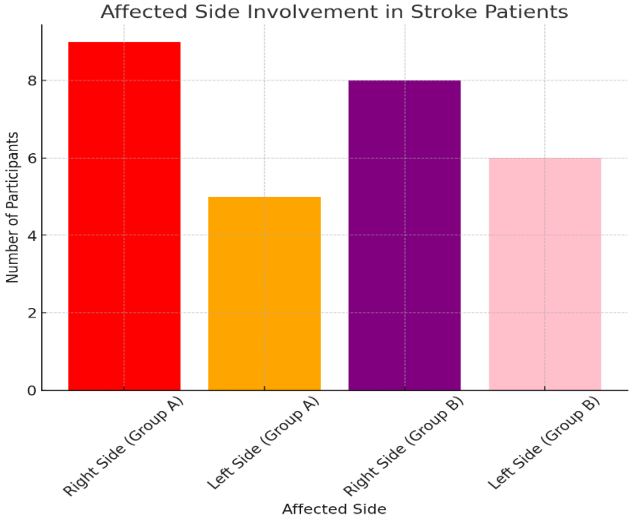


Figure 2 Affected Side Involvement In Stroke Patients

In Group A (graded motor imagery group) 9 (64.3%) had the right side involved, 5 (35.7) had left side involved. Whereas 6 (42.9) had left sided stroke and 8 (57.1) had right sided stroke. Displayed bar chart of sides involved of both groups. It presented that in Group A, 9 participants (64.3%) had right side participation, 5 participants (35.7%) had left side involvement, and 0 participants (0.0%) had engagement on both sides. Out of the total number of cases, 6 (42.9%) individuals experienced a stroke on the left side, 0 (0%) individuals had strokes on both sides, and 8 (57.1%) individuals had strokes on the right side.

Table 1: Age

Groups	Age of Participants
Group A (Graded Motor Imagery)	50.71 ± 5.93
Group B (Progressive circuit training)	50.57 ± 5.85

Table of both age groups (group A & Group B). It presented mean age of graded motor imagery group 50.71 ± 5.93 and mean age of 50.57 ± 5.85 of Progressive circuit training group 14 participants in each group recruited in the study.

Table 2: Independent Sample T test for Mobility (Functional Independence Measure) Pre and Post Treatment

Sr. No	Treatment	Groups	Mean± SD	Mean Difference	p-value
1	FIM Pre-Treatment	Group A (Graded Motor Imagery)	85.50±2.10	-.9286	.323
		Group B (Progressive circuit training)	86.43±2.74		
2	FIM post-treatment	Group A (Graded Motor Imagery)	96.50±2.07	5.357	<0.01
		Group B (Progressive circuit training)	91.14±4.42		

To determine the significant differences for Mobility (FIM) between the Graded Motor Imagery Group A and Progressive circuit training group B Independent sample t test was applied, the results depicts that there is a significant difference between the group for the applied intervention as P-value less than 0.05 with respect to post treatment. It was also seen that both groups were seen to show no difference at the level of baseline/ before the intervention was applied (P=.323)

Table 3: Independent Sample T test for Pain (Visual Analogue Scale) Pre and Post Treatment

Sr. No	Treatment	Groups	Mean± SD	Mean Difference	p-value
1	VAS Pre-Treatment	Group A (Graded Motor Imagery)	7.14±1.03	.0714	.848
		Group B (Progressive circuit training)	7.07±.917		
2	VAS post-treatment	Group A (Graded Motor Imagery)	3.21±.802	-1643	<0.01
		Group B (Progressive circuit training)	4.86±1.23		

The table presents the comparison of pain levels (VAS scores) between the Graded Motor Imagery (GMI) group and the Progressive Circuit Training (PCT) group before and after treatment. At baseline, the mean VAS score for the GMI group was 7.14 ± 1.03, while the PCT group had a mean VAS score of 7.07 ± 0.917, with a mean difference of 0.0714 and a p-value of 0.848, indicating no statistically significant difference in pain levels between the groups prior to intervention.

Following four weeks of intervention, the post-treatment mean VAS score significantly reduced to 3.21 ± 0.802 in the GMI group, whereas the PCT group showed a post-treatment VAS score of 4.86 ± 1.23. The mean difference in pain reduction between the groups was -1.643, with a statistically significant p-value of <0.01, suggesting that both interventions were effective in reducing pain, but Graded Motor Imagery demonstrated a greater reduction in pain levels compared to Progressive Circuit Training.

These findings indicate that although both rehabilitation techniques contributed to pain relief, the GMI group experienced a more pronounced improvement in pain reduction. The statistically significant post-treatment difference highlights Graded Motor Imagery as a potentially more effective intervention for pain management in stroke patients.

Table 4: Paired sample t test of Pain (VAS) and Mobility (FIM)

Tools	**Group A (Graded Motor Imagery)**	**t-value**	**p-value**	**Group B (Progressive circuit training)**	**p-value**

	Pre-Treatment	Post-Treatment			Pre-Treatment	Post-Treatment	
	Mean ± S.D	Mean ± S.D			Mean ± S.D	Mean ± S.D	
FIM	85.50±2.10	96.50±2.07	-12.725	<0.01	86.43±2.74	91.14±4.42	<0.01
VAS	7.14±1.03	3.21±.802	16.032	<0.01	7.07±.917	4.86± 1.23	<0.01

The table presents the within-group comparison of mobility (Functional Independence Measure - FIM) and pain (Visual Analogue Scale - VAS) scores in the Graded Motor Imagery (GMI) and Progressive Circuit Training (PCT) groups before and after treatment. For mobility (FIM scores), the GMI group had a pre-treatment mean score of 85.50 ± 2.10, which significantly improved to 96.50 ± 2.07 post-treatment, with a t-value of -12.725 and a p-value of <0.01, indicating a statistically significant improvement. Similarly, the PCT group had a pre-treatment mean FIM score of 86.43 ± 2.74, which increased to 91.14 ± 4.42 post-treatment, also showing significant improvement with a p-value of <0.01. These results suggest that both interventions effectively enhanced functional mobility, with the GMI group demonstrating a greater increase in post-treatment functional independence.

For pain levels (VAS scores), the GMI group had a pre-treatment mean VAS score of 7.14 ± 1.03, which significantly decreased to 3.21 ± 0.802 post-treatment, with a t-value of 16.032 and a p-value of <0.01, confirming a substantial reduction in pain. Likewise, the PCT group showed a reduction in mean VAS scores from 7.07 ± 0.917 pre-treatment to 4.86 ± 1.23 post-treatment, with a p-value of <0.01, indicating a statistically significant improvement. However, the greater reduction in pain in the GMI group suggests that Graded Motor Imagery was more effective in pain management compared to Progressive Circuit Training. Overall, both rehabilitation techniques resulted in significant improvements in mobility and pain reduction. However, the GMI group exhibited superior outcomes in both domains, suggesting that Graded Motor Imagery may provide greater benefits for functional recovery and pain relief in stroke patients compared to Progressive Circuit Training.

DISCUSSION

The findings of this study demonstrated significant improvements in pain reduction and mobility enhancement following the application of Graded Motor Imagery (GMI) and Progressive Circuit Training (PCT) in stroke rehabilitation. Both interventions led to statistically significant improvements, confirming their effectiveness in post-stroke recovery. However, the results indicated that GMI was superior to PCT in both pain reduction and mobility enhancement, suggesting its greater potential in optimizing neuroplasticity and functional independence. Previous research has provided evidence supporting these interventions, with findings consistently reporting their role in enhancing motor function, mobility, and pain modulation. A study by Sashikala Bhandaru et al. (2021) demonstrated that progressive circuit training effectively improved gross motor function and mobility in stroke patients when compared to conventional aerobic and resistance training (46). These findings align with the current study, where PCT significantly improved mobility, though GMI yielded even greater functional gains. The observed differences between the two interventions could be attributed to the structured cognitive engagement in GMI, which fosters motor reorganization at the cortical level.

The superior outcomes of GMI observed in this study align with prior research by Breera Amjad et al. (2019), which demonstrated the effectiveness of GMI in improving balance, motor function, and mobility in stroke patients (47). While balance and gross motor function were not the primary focus of the current study, the improvement in mobility corroborates previous findings. Furthermore, Deisiane Oliveira Souto et al. (2020) reported that GMI effectively enhanced upper limb function and pain relief in stroke survivors, providing further support for its efficacy in neurorehabilitation (48). However, unlike previous studies that focused on upper limb function, the present study emphasized mobility and pain reduction, highlighting GMI's impact beyond isolated limb rehabilitation. The mechanism underlying GMI's superiority over PCT may be attributed to its ability to activate sensorimotor pathways through mental imagery, facilitating cortical reorganization and improved movement execution. Despite these benefits, the study did not evaluate the long-term retention of improvements, which remains an important consideration in stroke rehabilitation.

The effectiveness of PCT in pain and mobility enhancement was evident, though its impact was relatively less pronounced than that of GMI. Findings from Mansoor Rahman et al. (2015) supported the role of PCT in improving motor function and pain management in stroke patients, particularly when compared to conventional therapy (49). While the current study also observed significant pain reduction with PCT, the greater effectiveness of GMI suggests that cognitive-motor training may provide additional benefits beyond physical exercise alone. A study by Jose Fierro Marrero et al. (2024) further demonstrated the impact of GMI on hand recognition in stroke patients, highlighting its role in sensorimotor integration and cognitive rehabilitation (50). Although the present study did not assess hand recognition, the improved mobility outcomes support the broader application of GMI in stroke recovery. While both interventions proved beneficial, GMI appeared to offer a more holistic approach by engaging neurocognitive pathways that contribute to functional recovery.

The strengths of this study include its randomized controlled design, well-defined inclusion criteria, and use of validated outcome measures. The study provides direct evidence comparing two promising stroke rehabilitation techniques, contributing to clinical decision-making regarding optimal post-stroke therapy. However, several limitations must be acknowledged. The sample size was relatively small, which may limit the generalizability of the findings. Additionally, the study duration was short, making it unclear whether improvements were sustained over the long term. Future research should investigate the durability of these effects and explore whether a combination of GMI and PCT could yield even greater functional outcomes. Despite these limitations, the results strongly suggest that Graded Motor Imagery is a superior intervention for enhancing mobility and reducing pain in stroke patients. Based on previous evidence and the current study's findings, GMI emerges as a more effective approach in post-stroke rehabilitation, offering a greater degree of neuroplastic adaptation and functional recovery.

CONCLUSION

The findings of this study concluded that both Graded Motor Imagery (GMI) and Progressive Circuit Training (PCT) were effective in improving pain management and mobility in stroke patients. However, GMI demonstrated superior outcomes, suggesting its greater potential in enhancing neuroplasticity, functional independence, and pain reduction compared to PCT. These results highlight the importance of integrating cognitive-motor rehabilitation techniques in stroke recovery, as GMI not only facilitated movement but also contributed to neural reorganization and motor skill refinement. While both interventions proved beneficial, GMI emerged as a more effective approach, offering enhanced therapeutic benefits in post-stroke rehabilitation.

AUTHOR CONTRIBUTIONS

Author	Contribution
Khizer Mehmood Qadri*	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Muhammad Naveed Babur	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Muhammad Saleh Shah	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Javairya Amjad Peerzadi	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Ayesha Sadiqua	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Gulzar Ahmad	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published

REFERENCES

1. Lindsay MP, Norrving B, Sacco RL, Brainin M, Hacke W, Martins S, et al. World Stroke Organization (WSO): Global Stroke Fact Sheet 2019. Int J Stroke. 2019;14(8):806–17.

2. Jia F, Zhao Y, Wang Z, Chen J, Lu S, Zhang M. Effect of graded motor imagery combined with repetitive transcranial magnetic stimulation on upper extremity motor function in stroke patients: A randomized controlled trial. Arch Phys Med Rehabil. 2024;105(5):819–25.

3. Lindsay MP, Norrving B, Sacco RL, Brainin M, Hacke W, Martins S, et al. World Stroke Organization (WSO): Global Stroke Fact Sheet 2019. SAGE Publ Sage UK: London, England; 2019.

4. Sirsat MS, Fermé E, Câmara J. Machine learning for brain stroke: a review. J Stroke Cerebrovasc Dis. 2020;29(10):105162.

5. Huang S, Joshi A, Shi Z, Wei J, Tran H, Zheng SL, et al. Combined polygenic scores for ischemic stroke risk factors aid risk assessment of ischemic stroke. Int J Cardiol. 2024;404:131990.

6. Aiyejusunle C, Olawale O, Umeaku G, Onuegbu N. Development and use of a new tool for assessing upper and lower limb synergies in people with stroke. Rom J Neurol. 2019;18(1).

7. Diener H-C, Hankey GJ. Primary and secondary prevention of ischemic stroke and cerebral hemorrhage: JACC focus seminar. J Am Coll Cardiol. 2020;75(15):1804–18.

8. Krishnamurthi RV, Barker-Collo S, Parag V, Parmar P, Witt E, Jones A, et al. Stroke incidence by major pathological type and ischemic subtypes in the Auckland regional community stroke studies: changes between 2002 and 2011. Stroke. 2018;49(1):3–10.

9. Krishnamurthi RV, Ikeda T, Feigin VL. Global, regional and country-specific burden of ischemic stroke, intracerebral hemorrhage and subarachnoid hemorrhage: a systematic analysis of the Global Burden of Disease Study 2017. Neuroepidemiology. 2020;54(2):171–9.

10. Johnson W, Onuma O, Owolabi M, Sachdev S. Stroke: a global response is needed. Bull World Health Organ. 2016;94(9):634.

11. Hui C, Tadi P, Suheb MZK, Patti L. Ischemic stroke. StatPearls [Internet]. StatPearls Publ; 2024.

12. Pega F, Náfrádi B, Momen NC, Ujita Y, Streicher KN, Prüss-Üstün AM, et al. Global, regional, and national burdens of ischemic heart disease and stroke attributable to exposure to long working hours for 194 countries, 2000–2016: A systematic analysis from the WHO/ILO Joint Estimates of the Work-related Burden of Disease and Injury. Environ Int. 2021;154:106595.

13. Werring D, Adams M, Benjamin L, Brown M, Chandratheva A, Cowley P, et al. Stroke and cerebrovascular diseases. Neurology: A Queen Square Textbook. 2024:107–98.

14. van Sloten TT, Sedaghat S, Carnethon MR, Launer LJ, Stehouwer CD. Cerebral microvascular complications of type 2 diabetes: stroke, cognitive dysfunction, and depression. Lancet Diabetes Endocrinol. 2020;8(4):325–36.

15. Gialanella B, Santoro R. Prediction of functional outcomes in stroke patients: the role of motor patterns according to limb synergies. Aging Clin Exp Res. 2015;27(5):637–45.

16. Yoon H, Park C, editors. Effectiveness of proprioceptive body vibration rehabilitation on motor function and activities of daily living in stroke patients with impaired sensory function. Healthcare. 2023.

17. Serlin Y, Shelef I, Knyazer B, Friedman A, editors. Anatomy and physiology of the blood–brain barrier. Semin Cell Dev Biol. 2015.

18. Zhao LJ, Jiang LH, Zhang H, Li Y, Sun P, Liu Y, et al. Effects of motor imagery training for lower limb dysfunction in patients with stroke: A systematic review and meta-analysis of randomized controlled trials. Am J Phys Med Rehabil. 2023;102(5):409–18.

19. Zulu O, Lupenga J, Simpamba MM, Banda MC. Efficacy of constraint-induced movement therapy and mirror therapy in improving upper extremity function in late subacute and chronic stroke patients: A randomized crossover trial. J Prev Rehabil Med. 2023;5(2):136–45.

20. Braga MAF, Faria-Fortini Id, Dutra TMdFV, Silva EAdM, Sant'Anna RV, Faria CDCdM. Functional independence measured in the acute phase of stroke predicts both generic and specific health-related quality of life: a 3-month prospective study in a middle-income country. Disabil Rehabil. 2023;45(25):4245–51.

21. Kaji R. Global burden of neurological diseases highlights stroke. Nat Rev Neurol. 2019;15(7):371–2.

22. Zafar F, Tariq W, Shoaib RF, Shah A, Siddique M, Zaki A, et al. Frequency of ischemic stroke subtypes based on TOAST classification at a tertiary care center in Pakistan. Asian J Neurosurg. 2018;13(4):984.

23. Sedova P, Brown RD, Zvolsky M, Belaskova S, Volna M, Baluchova J, et al. Incidence of stroke and ischemic stroke subtypes: a community-based study in Brno, Czech Republic. Cerebrovasc Dis. 2021;50(1):54–61.

24. Maistrello L, Rimini D, Cheung VC, Pregnolato G, Turolla A. Muscle synergies and clinical outcome measures describe different factors of upper limb motor function in stroke survivors undergoing rehabilitation in a virtual reality environment. Sensors. 2021;21(23):8002.

25. Frisoli A, Barsotti M, Sotgiu E, Lamola G, Procopio C, Chisari C. A randomized clinical control study on the efficacy of three-dimensional upper limb robotic exoskeleton training in chronic stroke. J Neuroeng Rehabil. 2022;19(1):1–14.

26. Balkaya M, Cho S. Optimizing functional outcome endpoints for stroke recovery studies. J Cereb Blood Flow Metab. 2019;39(12):2323–42.

27. Jokinen H, Laakso HM, Ahlström M, Arola A, Lempiäinen J, Pitkänen J, et al. Synergistic associations of cognitive and motor impairments with functional outcome in covert cerebral small vessel disease. Eur J Neurol. 2022;29(1):158–67.

28. Katan M, Luft A, editors. Global burden of stroke. Semin Neurol. 2018;38(2):208–11.

29. Wu S, Wu B, Liu M, Chen Z, Wang W, Anderson CS, et al. Stroke in China: advances and challenges in epidemiology, prevention, and management. Lancet Neurol. 2019;18(4):394–405.

30. Padir Şensöz N, Türk Börü Ü, Bölük C, Bilgiç A, Öztop Çakmak Ö, Duman A, et al. Stroke epidemiology in Karabük city Turkey: Community-based study. eNeurolSci. 2018;10:12–5.

31. Khan MI, Khan JI, Ahmed SI, Ali S. The epidemiology of stroke in a developing country (Pakistan). Pak J Neurol Sci (PJNS). 2019;13(3):30–44.

32. Singh V, Dhamoon MS, Alladi S. Stroke risk and vascular dementia in South Asians. Curr Atheroscler Rep. 2018;20(9):1–7.

33. Bae S-H, Kim T-G, Lee Y-S, Hwang J-A, Jeon B-H, Kim K-Y. The effects of median nerve mobilization therapy on stroke patients with carpal tunnel syndrome: A pilot study. Int Inf Inst (Tokyo) Inf. 2018;21(2):831–42.

34. Al Baradie RS. Neurodynamics and mobilization in stroke rehabilitation–A systematic review. Majmaah J Health Sci. 2017;5(2):99–112.

35. Salvalaggio A, De Filippo De Grazia M, Zorzi M, Thiebaut de Schotten M, Corbetta M. Post-stroke deficit prediction from lesion and indirect structural and functional disconnection. Brain. 2020;143(7):2173–88.

36. Murphy SJ, Werring DJ. Stroke: causes and clinical features. Medicine. 2020;48(9):561–6.

37. Gonzalez-Hoelling S, Bertran-Noguer C, Reig-Garcia G, Suñer-Soler R. Effects of a music-based rhythmic auditory stimulation on gait and balance in subacute stroke. Int J Environ Res Public Health. 2021;18(4):2032.

38. Cao M, Li X. Effectiveness of modified constraint-induced movement therapy for upper limb function intervention following stroke: A brief review. Sports Med Health Sci. 2021;3(3):134–7.

39. Choi J-U, Kang S-H. The effects of patient-centered task-oriented training on balance, activities of daily living, and self-efficacy following stroke. J Phys Ther Sci. 2015;27(9):2985–8.

40. Kerr A, Dawson J, Robertson C, Rowe P, Quinn TJ. Sit-to-stand activity during stroke rehabilitation. Top Stroke Rehabil. 2017;24(8):562–6.

41. Mahmood W, Ahmed Burq HSI, Ehsan S, Sagheer B, Mahmood T. Effect of core stabilization exercises in addition to conventional therapy in improving trunk mobility, function, ambulation, and quality of life in stroke patients: A randomized controlled trial. BMC Sports Sci Med Rehabil. 2022;14(1):62.

42. Simeon L. The effect of rhythmic auditory stimulation on gait performance in individuals with neurological disorders: An integrative review [dissertation]. Florida State University; 2022.

43. Kerr A, Clark A, Cooke EV, Rowe P, Pomeroy V. Functional strength training and movement performance therapy produce analogous improvement in sit-to-stand early after stroke: early-phase randomized controlled trial. Physiotherapy. 2017;103(3):259–65.

44. Monteiro KB, dos Santos Cardoso M, da Costa Cabral VR, Dos Santos AOB, da Silva PS, de Castro JBP, et al. Effects of motor imagery as a complementary resource on the rehabilitation of stroke patients: A meta-analysis of randomized trials. J Stroke Cerebrovasc Dis. 2021;30(8):105876.

45. Martins JC, Nadeau S, Aguiar LT, Scianni AA, Teixeira-Salmela LF, De Morais Faria CDC. Efficacy of task-specific circuit training on physical activity levels and mobility of stroke patients: A randomized controlled trial. NeuroRehabilitation. 2020;47(4):451–62.

46. Bhandaru S, Neelima D, Neelam S, Swathi S, Senthil P. Efficacy of task-oriented training vs group circuit training programme to improve functional mobility in children with cerebral palsy. J Pharm Res Int. 2021;33:154–60.

47. Amjad B, Asif M, Tanveer E, Rashad A, Haider H, Hassan MF, et al. Effects of motor imagery techniques in children with spastic cerebral palsy. J Phy Fit Treat Sports. 2019;6(5):555696.

48. Souto DO, Cruz TKF, Coutinho K, Julio-Costa A, Fontes PLB, Haase VG. Effect of motor imagery combined with physical practice on upper limb rehabilitation in children with hemiplegic cerebral palsy. NeuroRehabilitation. 2020;46(1):53–63.

49. Rahman M, Chandrasekaran B, Venugopalan M, Arumugam A. The effect of a circuit training program on functional performance in children with spastic cerebral palsy: A quasi-experimental pilot study. Int J Health Rehabil Sci. 2015;4(4):227–37.

50. Fierro-Marrero J, Corujo-Merino A, La Touche R, Lerma-Lara S. Motor imagery ability in children and adolescents with cerebral palsy: A systematic review and evidence map. Front Neurol. 2024;15:1325548.