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IMPACT OF GAIT TRAINING ON LOWER EXTREMITY MOTOR FUNCTION AND BALANCE PERFORMANCE IN STROKE SURVIVORS

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ABSTRACT

Background: *Stroke is a common cause of long-term disability globally, which frequently follows with impairments in gait, balance, and lower limb motor function. Successful rehabilitation interventions are essential in order to restore mobility and functional independence in stroke survivors.*

Objectives: *To compare the impact of three interventions of physiotherapy gait training with Proprioceptive Neuromuscular Facilitation (PNF), gait training with conventional therapy, and combined PNF-conventional therapy on lower limb motor function, gait ability, balance, and functional independence in stroke patients.*

Methods: *A randomised clinical trial was conducted at Sehat Medical Complex, Lahore, involving 99 post-stroke participants (33 per group). Interventions were delivered three times weekly for six weeks. Standardised outcome measures included the Wisconsin Gait Scale (WGS), Fugl-Meyer Assessment of Lower Extremity (FMA-LE), Berg Balance Scale (BBS), and Functional Independence Measure (FIM). Data were analysed using a repeated-measures ANOVA and non-parametric tests where appropriate.*

Results: *All groups demonstrated statistically significant within-group improvements across all outcome measures ($p < 0.001$). Between-group comparisons revealed that the PNF-gait training group achieved the most pronounced enhancements in gait quality, motor function, and balance, reflected by higher FMA-LE and BBS scores at six weeks.*

Conclusion: *The integration of PNF with structured gait training leads to superior gains in lower limb recovery and postural control compared with conventional physiotherapy alone. These findings emphasise the importance of combining facilitation-based and task-specific interventions in post-stroke rehabilitation, warranting validation in larger, multi-centre trials with long-term follow-up.*

Keywords: *Stroke, Gait, Balance, Mobility, Functional Independence.*

Introduction

Stroke is the second most frequent cause of death and the third most common cause of acquired adult disability in developing countries, occurring in approximately 17 million individuals globally annually (Dos Santos et al., 2018; Mahmoud et al., 2023). Its most disabling consequence is lower-limb motor impairment, which dramatically degrades mobility and independence (Lai et al., 2002). Balance disturbances are observed in over 80% of stroke survivors in the acute phase, and more than 40% have long-term postural instability (Tyson et al., 2006). These impairments, typified by decreased weight-bearing on the paretic side and compromised equilibrium, limit mobility and promote fall risk (Eng & Chu, 2002; Lamb et al., 2003).

Gait impairment is thus one of the key impediments to functional rehabilitation and reintegration into society following stroke (Beyaert et al., 2015; Drużbicki et al., 2018).

Over the course of decades, various rehabilitation methods ranging from traditional gait training through functional electrical stimulation to robotic or surgical approaches have been used in an attempt to achieve normal patterns of walking. However, resumption of symmetrical and coordinated gait is still problematic, especially when patients participate passively in therapy (Pollock et al., 2014; Wolf et al., 2002). Contemporary neurorehabilitation focuses on task-specific, intensive, and active methods that motivate energetic involvement and leverage neuroplasticity to maximise motor recovery (Liang et al., 2024). Since gait and balance impairments severely restrict activity of daily living and quality of life (Hornby et al., 2020; Elameer et al., 2023), the restoration of walking is taken as a pivotal milestone for stroke rehabilitation (Winstein et al., 2016).

Traditional gait training (CGT) such as overground walking, stair walking, and treadmill training has been shown to benefit walking speed, endurance, and functional capacity (Kwakkel et al., 2023). Yet its potential is constrained by therapist burnout, safety risks, and task repetition variability (Winstein et al., 2016; Xue et al., 2023). These constraints have driven the development of complementary or additional methods, like robot-assisted gait therapy, that can facilitate high-intensity, task-specific, and reproducible movement practice (Chang & Kim, 2013).

Among task-specific manual techniques, Proprioceptive Neuromuscular Facilitation (PNF) has become notable for enhancing gait, balance, and postural control in stroke survivors. PNF utilises diagonal and spiral movement patterns that integrate rhythmic initiation, repeated contractions, rhythmic stabilisation, and contract–relax techniques (Moon et al., 2024). The patterned movements increase neuromuscular coordination, muscle activation, and proprioceptive feedback and thus allow for motor relearning (Kim & Kim, 2018; Wang & Xu, 2019). Empirical evidence shows that PNF-based treatments significantly increase stride symmetry, step length, and velocity of walking compared to regular physiotherapy by itself (Wang & Xu, 2019; Kim et al., 2020). The method is believed to activate sensorimotor integration, enhance proper patterns of movement, and enhance postural correction (Sullivan & Hedman, 2018).

Full post-stroke rehabilitation needs multidisciplinary work within the continuum of hospital and community environments to tackle the complex physical, cognitive, and psychosocial demands of survivors and their carers (Lip et al., 2022; Kernan et al., 2021; Kalavina et al., 2019; Lu et al., 2022). In this continuum, gait rehabilitation is still critical to recovering lower-extremity motor function and dynamic balance, both of which are vital for living independently.

Since stroke remains a heavy global burden of long-term disability, measuring the effectiveness of gait-training interventions is crucial for maximising recovery performance. Thus, this research seeks to examine the effect of gait training on lower-limb motor function and balance performance in individuals who have survived a stroke. Through the application of evidence-based rehabilitation methods and standardised assessment protocols, the study endeavours to pinpoint therapeutic techniques that maximise functional recovery and enhance quality of life following stroke.

Methodology

Study Design

The study used a randomised clinical trial to determine the comparative effectiveness of three physiotherapy interventions for lower limb motor recovery, balance, and gait function in stroke survivors. The trial was performed in the Department of Physiotherapy, Sehat Medical Complex, Hanjarwal, Lahore, during a period of six months. Ethical approval was received from the Sehat Medical Complex Ethics Committee (IRB-UOL-SMC/001-36/2024). The trial was registered prospectively on ClinicalTrials.gov (Identifier: NCT07066319). All procedures complied with the principles stated in the Declaration of Helsinki, and reporting adhered to the CONSORT (Consolidated Standards of Reporting Trials) guidelines (Figure 1).

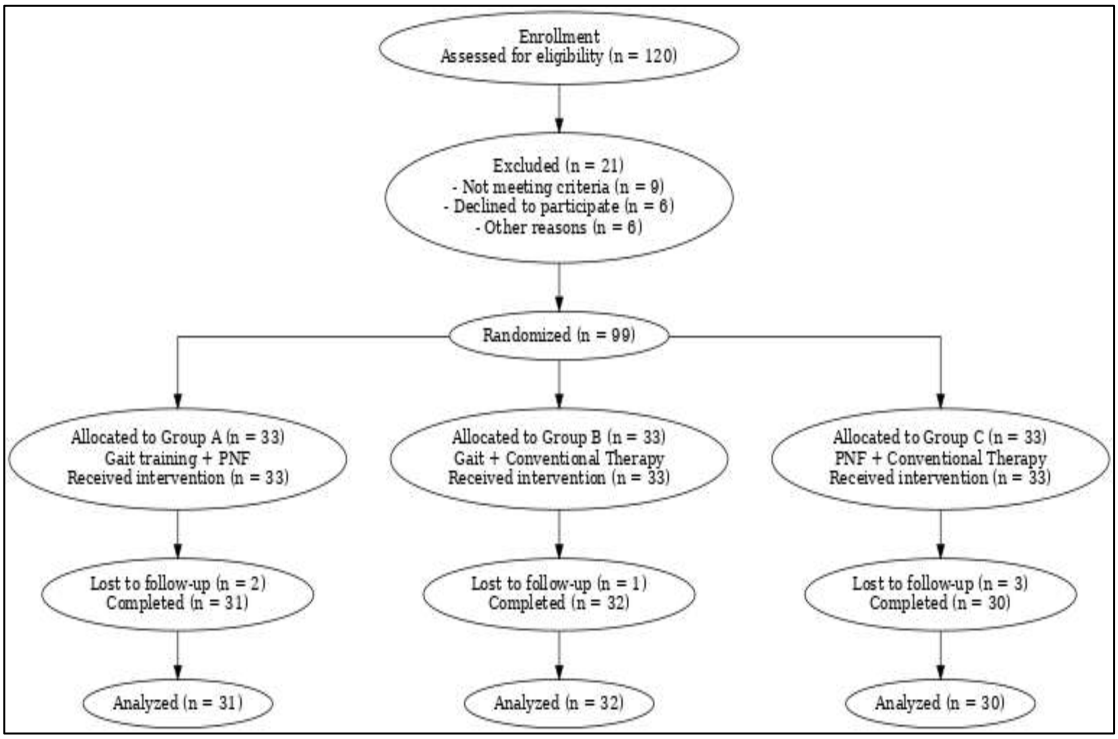

Figure 1 Consort Diagram

Sample Size and Sampling Procedure

The sample size was computed to meet the required sample size using G*Power software based on the effect size from the work of Stephenson et al. (2014). A minimum of 84 participants was estimated to have adequate statistical power. Considering an expected 15% dropout rate, the total sample was predetermined to be 99 participants, divided into three equal groups of 33 participants each. Participants were selected through purposive sampling from the outpatient unit for stroke rehabilitation upon predetermined inclusion and exclusion criteria.

Participants

Adults between 40 and 80 years of both sexes with a confirmed diagnosis of ischaemic or hemorrhagic stroke established by computed tomography (CT) or magnetic resonance imaging (MRI) were eligible participants (Teodoro et al., 2024). The participants were at least three months post-stroke to allow for neurological stabilisation and lived in the community. They showed cognitive and physical capacity to comply with verbal commands, indicated by a Glasgow Coma Scale (GCS) score of ≥9 (Kim et al., 2021), and could perform simple mobility activities, including standing, transferring, and walking short distances without assistance.Patients with other neurological disorders such as Parkinson or multiple sclerosis, multiple strokes or GCS less than 9 were excluded. Patients who have at least one comorbidity and those who have undergone significant surgery within the past three months were also not included (Kim et al., 2022).

Interventions

By applying the simple randomisation technique, the participants were randomly placed into three intervention groups. The experienced physiotherapists were required to administer all interventions and administer them three times a week, each session being 30-45 minutes. Group A: The participants received training of gait with the use of Proprioceptive Neuromuscular Facilitation (PNF) techniques. The protocol was concerned with the patterns of diagonal movements, rhythmic initiation, and facilitation of resistance to enhance muscular coordination and postural controls. Training: Each training session was made up of 10 minutes of warm-up, 30 minutes of PNF gait training using manual resistance and verbal cueing, and a 5 minutes cool-down. The next level was the advancement through resistance and complexity of the movement (Kofotolis and Kellis, 2006).

Group B: The participants were provided with the standard gait training and the standard physiotherapy practices targeted at the flexibility, strength, and balance. The activities included stretching, over-ground walking, sit-to-stand, and active-assisted joint mobilisation. Exercising was advanced slowly with regard to the tolerance and capability of the participants (Sullivan et al., 2012). Group C: The group members were provided with a combination of PNF and standard physiotherapy intervention. Ethical considerations were taken into consideration as every 45 minutes session was accompanied by a 10-minute PNF-based warm-up, 25 minutes of gait and balance training, and a 10-minute cool-down. This was a combined approach meant to improve neuromuscular re-education and functional mobility (Yang et al., 2014).

Outcome Measures

Outcomes were measured with the help of four standardised measurements tools: the Wisconsin Gait Scale (WGS) to measure the gait quality, the Fugl-Meyer Assessment of Lower Extremity (FMA-LE) to measure motor recovery, the Berg Balance Scale (BBS) to measure balance, and the Functional Independence Measure (FIM) to measure functional mobility (Pohl et al., 2019). The data were collected at the baseline, three and six weeks after the intervention (Haeussler et al., 2023).

Data Analysis

IBM SPSS Statistics (Version 24) was used to analyse data. Continuous data were expressed as mean ± standard deviation (SD), and categorical data as frequency and percentage. The Kolmogorov–Smirnov test was used to confirm data normality. For normally distributed data, paired t-tests and one-way ANOVA were used; for non-parametric data, Mann–Whitney U and Wilcoxon tests were used for between-group and within-group comparisons, respectively. A significance level of $p < 0.05$ was applied to all analyses. MATLAB (Version 2024a) was employed to create line graphs showing trends in mean scores over time points.

Results

Table 1: Common and clinical characteristics of the subjects (N = 99)

Variables	Group A (n = 33)	Group B (n = 33)	Group C (n = 33)
Gender (male/female)	14/15[b]	11/22[b]	11/22[b]
Age (Years)	61.34 ± 10.58[a]	60.33 ± 13.16[a]	60.32 ± 10.32[a]
MMSE	26.76 ± 1.75[a]	27.18 ± 1.74[a]	26.09 ± 1.76[a]
TUG	20.22 ± 6.54[a]	19.00 ± 5.24[a]	19.13 ± 5.31[a]
MAS	1.62 ± 1.18[a]	1.58 ± 1.03[a]	1.70 ± 1.24[a]

a Mean ± standard deviation, b Frequency

The table 1 shows the common and clinical features of the study participants (N = 99) in the three intervention groups (Group A, Group B, and Group C). Each group had 33 subjects, and gender distortion was a slight difference between them. Group A consisted of 14 and 15 males and females respectively and Group B and C had the same number of 11 and 22 males respectively. The average age of the participants was similar in all the groups with Group A reporting 61.34 ± 10.58 years, Group B reporting 60.33 ± 13.16 years and Group C reporting 60.32 ± 10.32 years and there was no significant difference in terms of the age distribution. The score of the Mini-Mental State Examination (MMSE), which is a measure of cognitive functioning, was also comparable as Group A scored 26.76 ± 1.75, Group B scored 27.18 ± 1.74, and Group C scored 26.09 ± 1.76. These values imply that there were comparatively similar cognitive functions across the participants of each group. The Timed Up and Go (TUG) test, which was a functional mobility test, had a slight variation of the mean values between groups with Group A measuring 20.22 ± 6.54 seconds, Group B measuring 19.00 ± 5.24 seconds, and Group C measuring 19.13 ± 5.31 seconds. The Modified Ashworth Scale (MAS), which was used to measure the spasticity, showed similar scores in the groups with Group A having 1.62 ± 1.18, Group B having 1.58 ± 1.03, and Group C having 1.70 ± 1.24.

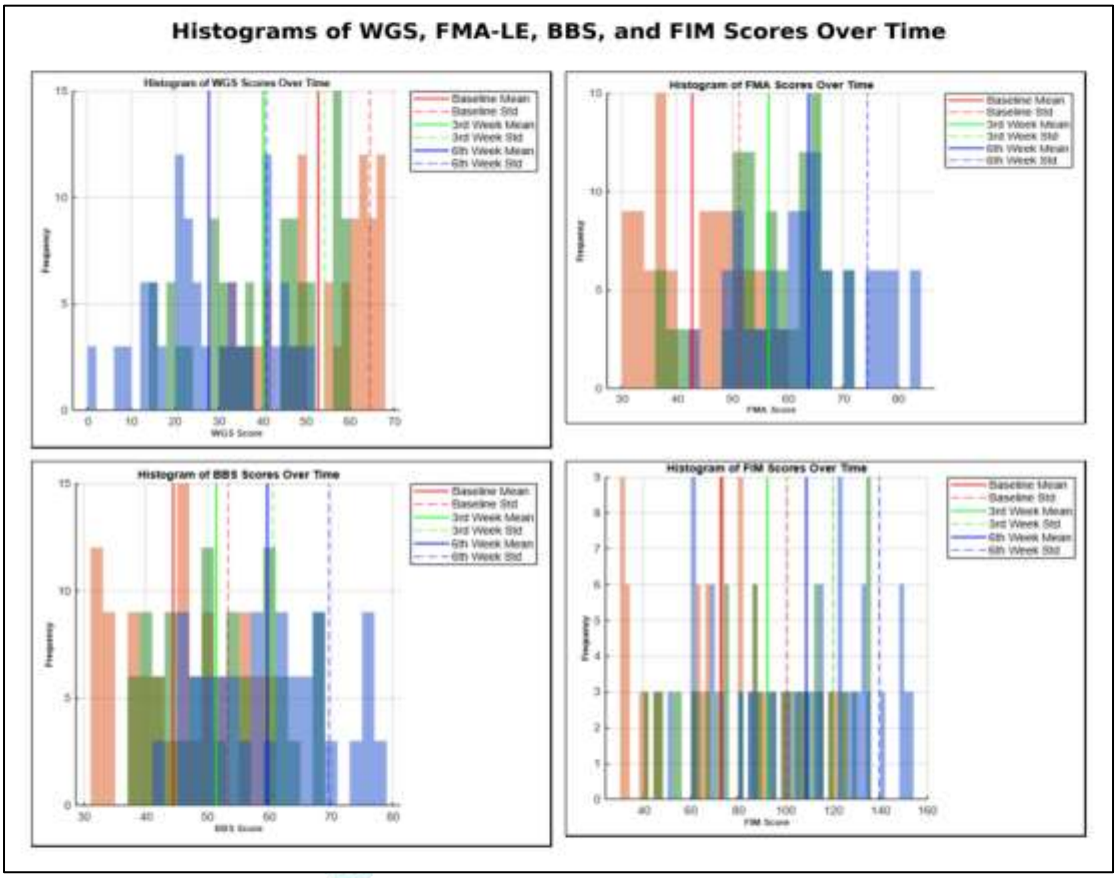

Figure 2 Histograms of subject scores baseline, 3rd and 6th week interventions

Figure 1 gives the baseline, 3 rd week and 6 th week score of Weight-Bearing Symmetry (WGS), Fugl-Meyer Assessment of Lower Extremity (FMA-LE), Berg Balance Scale (BBS) and Functional Independence Measure (FIM) of the three intervention groups (A, B and C). The four measures showed similar scores at the baseline of all groups. Throughout the time, considerable changes were noted in FMA-LE, BBS, and FIM scores, whereas the values of WGS were lower, which implies increased weight-bearing symmetry. At the 6 th week, Group A exhibited the most improvement and specifically in FMA-LE (71.83 ± 9.16) and BBS (65.62 ± 9.63), then Group B and C. The Repeated Measures ANOVA outcomes indicate that the time effect (p = 0.001) and group effect (p = 0.001) are statistically significant in all the measures, which proves that the interventions had a significant effect on the functional recovery and mobility in the long run.

Table 2: Pairwise Comparisons of Scores between Time Points

Variable	Baseline vs. 3rd Week	Baseline vs. 6th Week	3rd Week vs. 6th Week
WGS Score	0.001(20.21)	0.001(17.51)	0.001(15.46)
FMA-LE Score	0.001(14.25)	0.001(13.56)	0.001(11.80)
BBS Score	0.001(13.36)	0.001(13.15)	0.001(12.11)
FIM Score	0.001(39.54)	0.001(50.42)	0.001(45.80)

P-value (Effect Size)

Table 2 shows the pair-wise comparisons of the scores on the various time points (Baseline vs. 3 rd Week, Baseline vs. 6 th Week, 3 rd Week vs. 6 th Week) on the scales of Weight-Bearing Symmetry (WGS) Fugl-Meyer Assessment of Lower Extremity (FMA-LE), Berg Balance Scale (BBS) and Functional Independence Measure (FIM). The findings show that there is statistically significant improvement (p = 0.001) in all comparisons, which demonstrates the effectiveness of the interventions in the long term. These findings are further supported by the effect sizes with the largest effect size (50.42) of FIM at the 6th week is significant as the functional independence has improved significantly. On the same note, WGS, FMA-LE, and BBS scores increased in a significant way, which then intensified between the 3rd and 6th week, implying ongoing improvement in balance, motor functioning, and weight-bearing symmetry. On the whole, these results validate that the interventions resulted in considerable and long-term functional recovery enhancement.

Table 3: Pairwise Comparisons between Groups

(I) Groups	(J) Groups	Mean Difference (I-J)	Std. Error	Sig	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
Group A	Group B	-4.411	3.069	.462	-11.896	3.074
	Group C	3.033	3.069	.977	-4.452	10.518
Group B	Group A	4.411	3.069	.462	-3.074	11.896
	Group C	7.444*	2.969	.042	.205	14.684
Group C	Group A	-3.033	3.069	.977	-10.518	4.452
	Group B	-7.444*	2.969	.042	-14.684	-.205

Table 3 presents the pairwise comparisons between the three intervention groups (A, B, and C) using mean differences, standard errors, significance values, and confidence intervals. The results indicate that there were no significant differences between Group A and Group B (p = .462) or Group A and Group C (p = .977), suggesting similar outcomes in these groups. However, a statistically significant difference (p = .042) was observed between Group B and Group C, with Group B showing better outcomes (Mean Difference = 7.444), indicating that Group B's intervention was more effective than Group C. These findings suggest that while Groups A and C showed comparable results, Group B demonstrated a greater improvement in functional recovery, highlighting its potential as a more effective intervention strategy.

Discussion

Gait impairment is one of the most disabling complications of stroke, and it greatly adds to functional dependence as well as reduced quality of life. This study compared three rehabilitation approaches robotic-assisted gait training with proprioceptive neuromuscular facilitation (PNF) (Group A), task-oriented training with PNF (Group B), and conventional physiotherapy (Group C) to assess their impacts on lower-limb motor recovery, balance, and functional mobility. Statistically significant within-group improvements were observed across all outcome measures, including the Fugl-Meyer Assessment for Lower Extremity (FMA-LE), Berg Balance Scale (BBS), Functional Independence Measure (FIM), and Weight-Bearing Symmetry (WGS). Compared between groups, the combined robotic-assisted and PNF protocol (Group A) elicited greater gains, especially in motor control and balance recovery, suggesting that multimodal therapies combining neurofacilitation with technology-enabled practice are more effective than standard protocols alone.

These findings are consistent with the reports of Yoon et al. (2025), who found that incorporating robotic-assisted gait training with PNF irradiation improved muscle activation and ankle kinematics in hemiparetic gait. The considerably better outcomes observed in Group A can be attributed to the synergy between the precision of robotics and the neuromuscular facilitation principles of PNF, which together enhance repetitive, task-specific motor learning. The irradiation mechanism in PNF is believed to stimulate additional motor units through overflow stimulation, while robotic devices offer consistent and precise lower-limb mobility. These mechanisms, coupled together, maximise sensorimotor feedback and facilitate cortical reorganisation important factors in neuroplastic rehabilitation. Group B participants, who underwent task-oriented training with the addition of PNF, also showed significant improvement, especially in functional independence as scored by FIM at the sixth week. This corresponds with Priya et al. (2024), who concluded that task-specific training was a key predictor of balance and postural gain in stroke survivors. Likewise, Han and Park (2025) showed that apparatus-based Pilates, a type of organised task-oriented therapy, enhanced hip abductor strength and static balance, ultimately leading to gait efficiency. These results support the hypothesis that repetitive, goal-orientated activities integrated with proprioceptive stimulation enhance functional outcomes through the augmentation of proximal stability and neuromuscular control.

While Group B did not exceed Group A across all measures, its elevated FIM outcomes underscore the essential role of functional significance in the design of rehabilitation protocols. Functional activities that simulate natural movement might elicit enhanced confidence and autonomy in daily living activities, reinforcing the connection between ecological validity and rehabilitation efficacy. The concordance of our results with previous work indicates that hybrid models integrating motor control retraining with goal-directed movement can serve as efficacious interventions for both biomechanical and psychological aspects of post-stroke recovery.

Balance and gait symmetry improvement between Groups A and B supports prior evidence highlighting proprioceptive stimulation as a basis for postural control. Lee et al. (2025) proved that sensorimotor system-based balance interventions employing feedback mechanisms like the SBT-330 highly improved the postural stability of chronic stroke patients. Our experiment didn't utilise feedback devices, yet the proprioceptive augmentation inherent in PNF presumably triggered the same type of adaptations. These improvements were also reflected in statistically significant decreases in WGS scores, reflecting better weight-bearing distribution between the paretic and non-paretic sides.

The results are consistent with Moon et al. (2024), who found that PNF Kinesio Taping benefited gait symmetry through greater neuromuscular activation, and TM (2024), who observed that PNF had better outcomes than conventional exercise in balance and quality of life in acute stroke survivors. These studies show a consistent gain across the literature which emphasizes the critical role of neuromuscular facilitation in the restoration of the postural control. Besides, Neupane (2024) demonstrated that bilateral upper-limb training has a positive influence on trunk stability and results in its further implication on gait. The given route may also explain the trunk-mediated improvements of our PNF-based groups, as trunk and pelvic control are the cornerstones of the lower-limb coordinated activity during a walking process.

Further evidence is provided by Asghar et al. (2023), who reported a much better balance and mobility in the conditions of the combined use of PNF and gait training in contrast to gait training alone. This is consistent with our finding that the performance of Groups A and B both containing PNF was better than normal therapy (Group C) performance. Saklecha et al. (2023) also established that scapular and pelvic PNF facilitation enhanced global neuromuscular outcomes through cross-irradiation effects, which supplemented systemic motor outcome beyond that which was local to the area. The positive transfer effect of such neuromuscular activation is capable of explaining the multidimensional functional improvements within our population.

Our observations are also consistent with general evidence. Nguyen et al. (2022) meta-analysed 14 randomised trials and concluded that PNF significantly enhanced balance (BBS, FRT) and gait speed (10MWT) in stroke rehabilitation. The effect sizes shown in their meta-analysis are closely in line with the improvements we made from baseline to the sixth week, supporting the external validity of our findings. Similarly, Boob et al. (2022) highlighted the role of pelvic PNF on gait and balance, while Moreno-Segura et al. (2022) underscored that core stabilisation training has the effect of increasing trunk control and gait performance. Combining robotic precision with PNF facilitation in this study very likely yielded a cumulative effect by addressing distal mobility and proximal stability at the same time.

Strength and Limitations

One of the key strengths of this study is its clinical significance and value in post-stroke rehabilitation research in a resource-scarce setting. It is one of the few locally conducted randomised clinical trials to investigate the comparative impact of gait training, proprioceptive neuromuscular facilitation (PNF), and their combined use with standard physiotherapy on lower-limb motor recovery, balance, and functional independence. Use of well-validated and well-established outcome measures the Wisconsin Gait Scale (WGS), Fugl-Meyer Assessment for Lower Extremity (FMA-LE), Functional Independence Measure (FIM), and Berg Balance Scale (BBS) allowed detailed measurement of gait quality, balance performance, and independence. The repeated-measures design at baseline, three weeks, and six weeks enhanced internal validity by measuring temporal change and short-term responsiveness to intervention. The standardised and protocol intervention approaches between groups also promoted consistency and replication.

Along with these strengths, a number of limitations must be considered. The trial was conducted in a single centre with an overall small sample size (n = 99), which might limit the generalisability of results to stroke populations outside of a single centre or different rehabilitation settings. Participants were community-living adults with mild to moderate levels of functional abilities, with the exclusion of individuals in acute or severely impaired phases of recovery; thus, findings may not generalise to all severity levels. The six weeks' intervention time, while adequate to show short-term effects, may not sufficiently measure long-term retention of motor and balance gains. Furthermore, the lack of follow-up evaluation restricts knowledge about whether the observed gains were maintained in the longer term. Participants' and therapists' blinding was not possible because physiotherapy interventions are manual in nature, potentially introducing some performance bias. However, objective and standardised measures were used to help control measurement bias. In general, the research lays a solid groundwork for future multi-centre, long-term studies to validate and generalise these results to various clinical populations and extended rehabilitation periods.

Conclusion

This randomised clinical experiment demonstrates that gait training combined with proprioceptive neuromuscular facilitation (PNF) yields significantly greater enhancements in lower limb motor recovery, balance, and functional mobility in stroke survivors compared to standard physiotherapy alone. All three interventions showed significant improvements within the group on important outcome measures like the Wisconsin Gait Scale, the Fugl-Meyer Assessment of Lower Extremity, the Berg Balance Scale, and the Functional Independence Measure. This result shows that structured physiotherapy programmes are generally effective for people who have had a stroke. Nevertheless, those who underwent combined gait and PNF training attained superior functional results, indicating a synergistic impact of neuromuscular facilitation and task-specific movement retraining. These results support the therapeutic significance of including PNF in gait rehabilitation procedures to enhance post-stroke recovery. Subsequent investigations employing multi-centre frameworks, extended follow-up periods, and varied patient demographics are essential to corroborate and enhance the generalisability of these findings in broader clinical settings.

Author Contribution: Hamna Sarfraz contributed to the study conceptualization, literature review, methodology development, data collection, and manuscript writing. Hafiz Muhammad Waseem Javaid supervised the research process, contributed to study design refinement, critical review, and final approval of the manuscript. Nida Razzak served as the statistician and was responsible for data analysis planning, statistical interpretation, and validation of results.

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References

Asghar, M., Fatima, A., Ahmed, U., Ahmad, A., & Hanif, K. (2023). Effects of gait training with and without proprioceptive neuromuscular facilitation on balance and gait in chronic stroke patients. Physiother Q, 31(2), 39–44.

Beyaert, C., Vasa, R., & Frykberg, G. E. (2015). Gait post-stroke: Pathophysiology and rehabilitation strategies. Neurophysiol Clin, 45(4–5), 335–355. https://doi.org/10.1016/j.neucli.2015.09.005

Boob, M. A., Kovela, R. K., & Kovela Sr, R. K. (2022). Effectiveness of pelvic proprioceptive neuromuscular facilitation techniques on balance and gait parameters in chronic stroke patients: A randomized clinical trial. Cureus, 14(10).

Chang, W. H., & Kim, Y. H. (2013). Robot-assisted therapy in stroke rehabilitation. J Stroke, 15(3), 174–181. https://doi.org/10.5853/jos.2013.15.3.174

Collaborators GBDS. (2021). Global, regional, and national burden of stroke and its risk factors, 1990–2019. Lancet Neurol, 20(10), 795–820. https://doi.org/10.1016/S1474-4422(21)00252-0

Dos Santos, B. M., de Oliveira, C. B., dos Santos, A., Pires, C. G., Dylewski, V., & Arida, R. M. (2018). A comparative study of conventional physiotherapy versus robot-assisted gait training associated to physiotherapy in individuals with ataxia after stroke. Behav Neurol, 2018, 2892065. https://doi.org/10.1155/2018/2892065

Drużbicki, M., Przysada, G., Guzik, A., Brzozowska-Magoń, A., Kołodziej, K., Wolan-Nieroda, A., Majewska, J., & Kwolek, A. J. (2018). The efficacy of gait training using a body weight support treadmill and visual biofeedback in patients with subacute stroke: A randomized controlled trial. Biomed Res Int, 2018, 3812602. https://doi.org/10.1155/2018/3812602

Elameer, M., Lumley, H., Moore, S. A., Marshall, K., Alton, A., Smith, F. E., et al. (2023). MRI biomarkers for prediction of lower-limb motor recovery after stroke. Front Neurol, 14, 1229681. https://doi.org/10.3389/fneur.2023.1229681

Eng, J. J., & Chu, K. S. (2002). Reliability and comparison of weight-bearing ability during standing tasks for individuals with chronic stroke. Arch Phys Med Rehabil, 83(8), 1138–1144. https://doi.org/10.1053/apmr.2002.33641

Haeussler, A. S., et al. (2023). Robot-assisted gait training and virtual reality for balance and gait in stroke survivors: A RCT. Front Neurol. https://pubmed.ncbi.nlm.nih.gov/37262976/

Han, S. Y., & Park, D. H. (2025). Effects of apparatus-based Pilates on hip abductor strength, static balance, and gait in chronic stroke patients: A RCT. PNF Mov, 23(1), 173–183.

Hesse, S. (2008). Treadmill training with partial body weight support after stroke: A review. Neurorehabil Neural Repair, 22(1), 5–12. https://doi.org/10.1177/1545968307304053

Hornby, T. G., Reisman, D. S., Ward, I. G., Scheets, P. L., Miller, A., Haddad, D., et al. (2020). Clinical practice guideline to improve locomotor function following chronic stroke. J Neurol Phys Ther, 44(1), 49–100. https://doi.org/10.1097/NPT.0000000000000303

Kalavina, R., Chisati, E., Mlenzana, N., & Wazakili, M. (2019). Experiences of stroke patients and spouses in Blantyre, Malawi. Malawi Med J, 31(2), 112–117. https://doi.org/10.4314/mmj.v31i2.7

Kernan, W. N., et al. (2021). Primary care of adult patients after stroke: A scientific statement from AHA/ASA. Stroke, 52(7), e558–e571. https://doi.org/10.1161/STR.0000000000000355

Kim, C. H., Chu, H., Kang, G. H., Kim, K. H., Lee, Y. U., Lim, H. S., Sung, K. K., & Lee, S. (2021). Comparison of gait recovery patterns according to paralyzed side in stroke patients. Medicine (Baltimore), 100(16), e25212. https://doi.org/10.1097/MD.0000000000025212

Kim, K. H., Lee, J. H., & Kim, Y. J. (2022). Hybrid robot-assisted gait training for motor function in subacute stroke. J Neuroeng Rehabil, 19(1), 1–12. https://doi.org/10.1186/s12984-022-01076-6

Kim, T. H., & Kim, J. H. (2018). Effects of proprioceptive neuromuscular facilitation therapy on balance and gait in stroke patients: A systematic review. J Phys Ther Sci, 30(8), 1022–1030. https://doi.org/10.1589/jpts.30.1022

Kim, T., Lee, H. S., & Park, D. S. (2020). PNF-based gait training on walking performance and mobility in stroke survivors. J Stroke Cerebrovasc Dis, 29(5), 104586. https://doi.org/10.1016/j.jstrokecerebrovasdis.2020.104586

Kofotolis, N. D., & Kellis, E. (2006). Effects of proprioceptive neuromuscular facilitation on muscle strength and functional performance in women with chronic low back pain. J Strength Cond Res, 20(2), 361–367.

Kwakkel, G., et al. (2023). Motor rehabilitation after stroke: ESO consensus definition and framework. Eur Stroke J, 8(4), 880–894. https://doi.org/10.1177/23969873231193751

Lai, S. M., Studenski, S., Duncan, P. W., & Perera, S. (2002). Persisting consequences of stroke measured by the Stroke Impact Scale. Stroke, 33(7), 1840–1844. https://doi.org/10.1161/01.STR.0000019289.15440.F2

Lamb, S. E., Ferrucci, L., Volapto, S., Fried, L. P., & Guralnik, J. M. (2003). Risk factors for falling in older women with stroke. Stroke, 34(2), 494–501. https://doi.org/10.1161/01.STR.0000048742.03933.BF

Lee, J. L., Min, J. H., Ko, S. H., Hwang, H., Baik, J. S., Park, I. J., Lee, Y. C., et al. (2025). Effectiveness of balance training using the Balance Pro (SBT-330) device in stroke. J Bodyw Mov Ther, 42, 381–386.

Liang, S., Hong, Z. Q., Cai, Q., Gao, H. G., Ren, Y. J., Zheng, H. Q., & Hu, X. Q. (2024). Robot-assisted gait training on motor performance of lower limb in post-stroke survivors: Meta-analysis. Eur Rev Med Pharmacol Sci, 28(3).

Lip, G. Y. H., Lane, D. A., Lenarczyk, R., Boriani, G., Doehner, W., Benjamin, L. A., et al. (2022). Integrated care for stroke and associated heart disease: ESC Council on Stroke position paper. Eur Heart J, 43(26), 2442–2460. https://doi.org/10.1093/eurheartj/ehab649

Lu, Q., Mårtensson, J., Zhao, Y., & Johansson, L. (2022). Needs of family members caring for stroke survivors in China. BMC Geriatr, 22, 96. https://doi.org/10.1186/s12877-022-02802-z

Mahmoud, H., et al. (2023). AI machine learning and conventional PT for upper limb outcome in stroke: A meta-analysis. Eur Rev Med Pharmacol Sci, 27, 4812–4827. https://doi.org/10.26355/eurrev_202308_33311

Mohan, D. M., Khandoker, A. H., Wasti, S. A., Ismail I. I. I. A., Jelinek, H. F., & Khalaf, K. (2021). Assessment methods of post-stroke gait: Technology-driven approaches. Front Neurol, 12, 650024. https://doi.org/10.3389/fneur.2021.650024

Moon, S. J., Han, S. Y., & Park, D. H. (2024). Effects of PNF pattern Kinesio taping on arm swing, balance, and gait in chronic stroke. Life (Basel), 14(2), 242.

Moreno-Segura, N., Martín-San Agustín, R., García-Bafalluy, S., & Escriche-Escuder, A. (2022). Core training on trunk function, balance, and gait in stroke patients: Meta-analysis. Clin Rehabil, 36(12), 1635–1654.

Neupane, R. (2024). Bilateral upper extremity exercise training on trunk performance, posture and gait in subacute stroke. Indian J Physiother Occup Ther, 18(4).

Nguyen, P. T., Chou, L. W., & Hsieh, Y. L. (2022). PNF-based physical therapy on balance and gait in chronic stroke: Meta-analysis. Life (Basel), 12(6), 882.

Pohl, M. A., et al. (2019). RCT of gait training using GEAR in stroke patients with hemiplegia. Front Neurol. https://pubmed.ncbi.nlm.nih.gov/31307899/

Pollock, A., Farmer, S. E., Brady, M. C., Langhorne, P., Mead, G. E., Mehrholz, J., & van Wijck, F. (2014). Interventions for improving upper limb function after stroke. Cochrane Database Syst Rev, 2014(11), CD010820. https://doi.org/10.1002/14651858.CD010820.pub2

Priya, S., Kumar, P., Kumaresan, A., Kumar, S. S., & Suriya, N. (n.d.). Comparative analysis of PNF and task-oriented training to improve balance in stroke survivors. (Details unavailable).

Roth, G. A., Mensah, G. A., Johnson, C. O., Addolorato, G., Ammirati, E., Baddour, L. M., et al. (2020). Global burden of cardiovascular diseases and risk factors, 1990–2019. J Am Coll Cardiol, 76(25), 2982–3021. https://doi.org/10.1016/j.jacc.2020.11.010

Saklecha, A., Quershi, M. D. I., Raghuveer, R., & Harjpal, P. (2023). Efficacy of scapular and upper limb PNF techniques on gait in subacute stroke. F1000Res, 12, 1305.

Sullivan, K. J., & Hedman, L. D. (2018). Motor control and recovery in stroke rehabilitation: The role of PNF. Phys Ther, 101(4), 322–338. https://doi.org/10.1093/ptj/pzy001

Sullivan, K. J., Knowlton, B. J., & Dobkin, B. H. (2012). Step training with body weight support and treadmill speed on post-stroke locomotor recovery. Arch Phys Med Rehabil, 83(5), 683–691.

Teodoro, J., Fernandes, S., Castro, C., & Fernandes, J. B. (2024). Current trends in gait rehabilitation for stroke survivors. J Clin Med, 13(5), 1358. https://www.mdpi.com/2077-0383/13/5/1358

TM, S. N. K. (2024). Comparing PNF exercise and focused regimen program to assess balance and QoL in acute stroke. Indian J Physiother Occup Ther, 18.

Tyson, S. F., Hanley, M., Chillala, J., Selley, A., & Tallis, R. C. (2006). Balance disability after stroke. Phys Ther, 86(1), 30–38. https://doi.org/10.1093/ptj/86.1.30

Vincent-Onabajo, G., & Shaphant, N. D. (2019). Functional independence and psychosocial QoL of stroke survivors in rehabilitation. J Patient Rep Outcomes, 3, 18. https://doi.org/10.1186/s41687-019-0103-7

Wang, J., & Xu, Y. (2019). Comparative analysis of PNF and conventional therapy in post-stroke recovery. Neurorehabil Neural Repair, 33(6), 517–526. https://doi.org/10.1177/1545968319846122

Winstein, C. J., Stein, J., Arena, R., Bates, B., Cherney, L. R., Cramer, S. C., et al. (2016). Guidelines for adult stroke rehabilitation and recovery: AHA/ASA guideline. Stroke, 47(6), e98–e169. https://doi.org/10.1161/STR.0000000000000098

Wolf, S. L., Blanton, S., Baer, H., Breshears, J., & Butler, A. J. (2002). Repetitive task practice: A critical review of constraint-induced movement therapy in stroke. Neurologist, 8(6), 325–338. https://doi.org/10.1097/00127893-200211000-00006

Xue, X., Yang, X., & Deng, Z. (2023). Efficacy of robot-assisted gait training on lower extremity dyskinesia in Parkinson's disease: A meta-analysis. Ageing Res Rev, 85, 101837. https://doi.org/10.1016/j.arr.2023.101837

Yoon, B., Park, S., Oh, S., & You, J. S. H. (2025). Augmented effect of combined robotic assisted gait training and PNF-irradiation technique on muscle activation and ankle kinematics in hemiparetic gait. NeuroRehabilitation, 56(2), 196–206.