

RESEARCH ARTICLE

Personalised gait training versus standard gait training programme among patients with stroke: A randomised controlled trial



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Abstract

Background: Gait asymmetry after stroke can limit mobility and independence. Standard gait training may improve walking performance but may not address individual biomechanical deficits such as stance-phase asymmetry. This study aimed to compare personalised gait training (PGT) guided by real-time stance-phase analysis with standard gait training (SGT) in adults with subacute stroke.

Methods: This randomised controlled trial included 120 adults aged 45–75 years with first-ever ischaemic stroke and moderate gait impairment. Participants were randomised 1:1 to PGT or SGT and received 45-minute sessions, five days per week for 12 weeks. PGT used instrumented insoles providing real-time feedback, with progression based on stance-phase symmetry. The primary outcome was Functional Independence Measure (FIM) locomotion at 12 weeks. Secondary outcomes included gait speed, Berg Balance Scale, stance-phase symmetry ratio (SPSR), and independent ambulation.

Results: At 12 weeks, mean (standard deviation (SD)) FIM locomotion increased from 4.2 (1.3) to 6.6 (1.1) with PGT and from 4.0 (1.4) to 5.3 (1.4) with SGT, with a between-group difference of 1.3 points (95% CI 0.8–1.7; $P < 0.05$; Cohen's $d = 1.03$). At 12 weeks, PGT also showed higher gait speed (0.94 (0.24) vs 0.68 (0.21) m/s), Berg Balance Scale score (50.2 (5.8) vs 42.8 (7.6)), and SPSR (1.02 (0.1) vs 0.9 (0.1)). Independent ambulation was achieved by 78% participants with PGT compared with 53% with SGT (OR=3.2, 95% CI 1.5–7.2). Time to independent ambulation was 2.3 weeks shorter with PGT (95% CI 1.5–3.1).

Conclusion: Personalised stance-phase-guided gait training can improve functional mobility, gait performance, and independent ambulation compared with standard gait training in adults with subacute stroke.

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Key messages

Personalised gait training using real-time stance-phase feedback produced greater improvements in functional mobility, gait symmetry, balance, and walking speed than standard gait training in adults with subacute stroke. Importantly, more participants achieved independent ambulation and achieved it earlier, supporting objective, data-guided personalisation as a promising approach to improve post-stroke gait rehabilitation.

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Introduction

Stroke is a major cause of long-term disability worldwide, and many survivors experience persistent limitations in mobility and independent walking [1]. Gait dysfunction commonly includes reduced walking speed, impaired propulsion, unequal weight bearing, and temporal and spatial asymmetry between the paretic and non-paretic limbs [2, 3]. These problems can limit daily activities, social participation, and quality of life.

Improved walking speed does not always indicate restoration of normal gait because patients may walk faster by using compensatory movement patterns [3]. Gait symmetry is therefore an important additional target of rehabilitation. Post-stroke gait asymmetry is associated with motor and sensory impairment, muscle weakness, spasticity, and contracture [2].

Conventional rehabilitation includes task-specific walking, balance exercises, treadmill training, strengthening, and functional practice [4–6]. Although these approaches improve mobility, standard progression may not address the main biomechanical deficit of each patient. Wearable sensors and biofeedback systems can now measure gait during walking and provide immediate feedback [7–9]. However, previous interventions have targeted different parameters, including gait speed, cadence, step length, muscle activity, and plantar loading. Evidence remains limited on whether stance-phase asymmetry can be used both as a feedback target and as an objective criterion for treatment progression. This approach is consistent with motor-learning and neuroplasticity principles, which support repeated task-specific practice, error correction, and timely feedback [10].

Therefore, this study aimed to determine whether personalised gait training (PGT) guided by real-time stance-phase analysis improves functional mobility compared with standard gait training (SGT) in adults with subacute stroke. The primary outcome was Functional Independence Measure (FIM) locomotion at 12 weeks. Secondary outcomes included gait speed, balance, gait symmetry, and independent ambulation.

Methods

Trial design and participants

This randomised controlled trial compared PGT with SGT using 1:1 allocation at three rehabilitation centres within the Metropolitan Health Network between June 2025 and January 2026. Reporting followed CONSORT 2025 guidelines (Figure 1) [11].

Adults aged 45–75 years were eligible if they had a first-ever CT- or MRI-confirmed ischaemic stroke, were 2–12 weeks post-stroke, had moderate gait impairment defined as comfortable gait speed of 0.2–0.8 m/s with or without an assistive device, Mini-Mental State Examination score ≥ 24 , and medical clearance for intensive rehabilitation. The subacute period was selected because substantial motor recovery may occur during this stage [10, 12].

Exclusion criteria were haemorrhagic or bilateral stroke, severe cardiac or pulmonary disease, severe visual or vestibular impairment, another neurological

condition, mechanical ventilation, or an unstable medical condition preventing intensive rehabilitation. Trained coordinators screened participants using standardised criteria, and eligibility was confirmed before randomisation.

Sample size calculation

The sample size was calculated for the primary outcome: change in FIM locomotion score at 12 weeks. Based on effects reported in comparable technology-assisted and structured gait-training studies [6, 13], a between-group effect size of Cohen's $d=0.55$ was assumed. With a two-sided $\alpha=0.05$ and 80% statistical power, approximately 52 participants were required in each group. Allowing for up to 15% attrition, the target sample was increased to 60 participants per group, giving a total sample of 120. The calculation was performed using G*Power version 3.1.9.7.

Randomisation and blinding

A statistician who was not involved in participant recruitment prepared a computer-generated randomisation sequence using blocks of four and stratification by study site. Allocation was concealed using sequentially numbered, opaque, sealed envelopes, which were opened only after enrolment. Because of the nature of the intervention, participants and treating therapists could not be blinded. Outcome assessors remained blinded to group allocation throughout the study.

Interventions

Participants in the PGT group wore instrumented insoles containing plantar-pressure sensors sampling at 100 Hz and transmitting stance-time and pressure-distribution data to a tablet [14]. Visual feedback was updated after each gait cycle, while an auditory signal indicated when asymmetry exceeded the individual threshold. Therapists used the same information to guide treatment.

Each 45-minute session included 15 minutes of stance-phase-specific exercises, 20 minutes of overground walking with feedback, and 10 minutes of functional activities. Training was provided five days per week for 12 weeks. Progression followed predefined improvements in stance-phase symmetry and functional performance. The initial asymmetry threshold was 20% and was progressively reduced. More difficult tasks were introduced when milestones such as $<10\%$ asymmetry or unassisted 10-m walking were achieved.

The SGT group received the same treatment dose. Training included balance and weight-shifting exercises, single-limb stance, overground and treadmill walking, sit-to-stand, stair negotiation, and obstacle crossing, consistent with task-oriented rehabilitation [5]. Therapists provided verbal and manual cues without instrumented feedback and progressed treatment according to clinical judgement. Attendance and progression were recorded in both groups.

Outcomes and data collection

The primary outcome was FIM locomotion, measured at baseline and 4, 8, and 12 weeks, with week 12 defined as the primary endpoint. Secondary outcomes

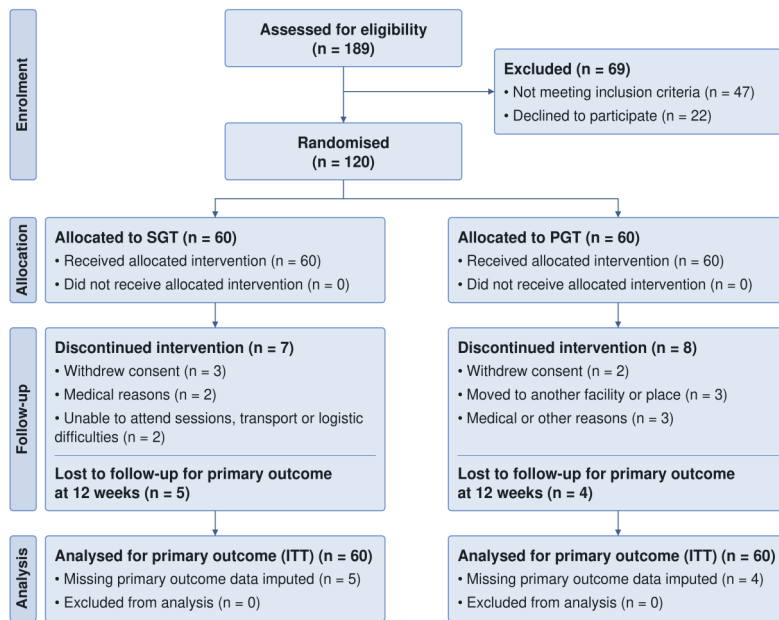


Figure 1 CONSORT flow diagram of participant enrolment, allocation, follow-up, and analysis

were gait speed measured by the 10-m walk test, Berg Balance Scale score, stance-phase symmetry ratio (SPSR), and independent ambulation. Independent ambulation was defined as walking 50 m without physical assistance. SPSR was calculated as = Shorter limb stance duration/ Longer limb stance duration. A value of 1.0 represented equal stance duration. Percentage asymmetry used during training was calculated as $(1 - \text{SPSR}) \times 100$.

Data collection and quality control

Baseline assessments were completed within 48 hours of randomisation, followed by assessments at 4, 8, and 12 weeks. Trained research assistants who were blinded to treatment allocation completed all outcome assessments using standardised procedures.

Assessors completed training and inter-rater reliability testing before the trial and achieved intraclass correlation coefficients >0.90 for FIM locomotion and gait-speed measures. Identical hardware and software were used across study sites and equipment was calibrated before testing. For quality control, 10% of assessments were independently co-rated by a second blinded assessor.

Statistical analysis

Continuous data were described using mean and standard deviation, and categorical using number and percent. Baseline continuous variables were

compared using independent-samples *t* tests or Mann–Whitney *U* tests, and categorical variables using chi-square tests.

Repeated-measures ANOVA was used for continuous outcomes, including group, time, group×time interaction, and study site. Greenhouse–Geisser correction and Bonferroni-adjusted comparisons were applied when appropriate.

Missing data were handled using multiple imputation by chained equations with 20 datasets. Effect sizes were reported as Cohen's *d*, with between-group effects presented as mean differences and 95% confidence intervals (CI). Statistical significance was set at $P < 0.05$. Analyses were performed using SPSS version 27.0.

Results

Participant flow and baseline characteristics

A total of 189 patients were screened for eligibility. Of these, 47 did not meet the eligibility criteria and 22 declined participations. The remaining 120 participants were randomised equally to PGT or SGT (Figure 1).

Baseline demographic and clinical characteristics were similar between groups. Participants had a mean age of approximately 64 years and entered the study about seven weeks after stroke. Baseline NIHSS scores, gait speed, and FIM locomotion scores indicated moderate neurological and mobility impairment (Table 1).

Primary and secondary outcomes

FIM locomotion improved in both groups, but the improvement was greater with PGT. Mean (standard deviation) scores increased from 4.2 (1.3) at baseline to 6.6 (1.1) at 12 weeks in the PGT group, compared with 4.0 (1.4) to 5.3 (1.4) in the SGT group. The 12-week between-group mean difference was 1.3 points (95% CI 0.8–1.7; $P < 0.05$), representing a large, standardised effect (Cohen's $d = 1.03$) (Table 2).

Gait speed and balance also improved more in the PGT group. At 12 weeks, mean (standard deviation) gait speed was 0.9 (0.2) m/s with PGT compared with 0.7 (0.2) m/s with SGT, while mean Berg Balance Scale scores were 50.2 (5.8) and 42.8 (7.6), respectively (Table 2).

Biomechanical gait measures showed a similar pattern. SPSR improved from 0.7 (0.1) to 1.0 (0.1) with PGT and from 0.7 (0.1) to 0.9 (0.1) with SGT. Affected-limb single-limb support, step-length symmetry, and cadence also improved more with personalised training (Table 3). The small reduction in unaffected-limb single-limb support in both groups occurred alongside increased affected-limb support, suggesting redistribution toward more balanced bilateral loading. At 12 weeks, 47/60 (78%) participants in the PGT group achieved independent ambulation compared with 32/60 (53%) in the SGT group (OR=3.2, 95% CI 1.5–7.2). Mean (standard deviation) time to independent ambulation was also shorter with PGT (5.7 (2.1) versus 8.0 (2.8) weeks; mean difference 2.3 weeks, 95% CI 1.5–3.1; $P < 0.05$).

Table 1 Baseline characteristics of the study participants (n=120)

Characteristic	PGT Group (n=60)	SGT Group (n=60)
Age (years), mean (SD) ^a	63.4 (10.2)	64.1 (9.8)
Male sex, n (%)	32 (53.3)	29 (48.3)
Time since stroke (weeks), mean (SD)	6.8 (3.1)	7.2 (3.4)
NIHSS score, mean (SD)	8.4 (2.7)	8.9 (2.9)
Baseline FIM locomotion score	4.2 (1.3)	4.0 (1.4)
Baseline gait speed (m/s)	0.41 (0.2)	0.38 (0.2)
Stroke type (ischemic), n (%) ^b	60 (100.0)	60 (100.0)

^aStandard deviation; ^bAll enrolled participants had radiologically confirmed ischemic stroke, consistent with the eligibility criteria (haemorrhagic stroke was an exclusion criterion); FIM indicates functional independence measure; NIHSS, National Institutes of Health Stroke Scale; SGT, standard gait training; PGT, personalised gait training

Table 2 Primary and secondary outcome measures of study participants (n=120)

Outcome measure	Baseline	4 Weeks	8 Weeks	12 Weeks	Cohen's d
FIM locomotion score					
PGT Group	4.2 (1.3)	5.3 (1.1) ^a	6.4 (1.2) ^a	6.6 (1.1) ^a	1.03
SGT Group	4.0 (1.4)	4.6 (1.3)	5.1 (1.5)	5.3 (1.4)	
Gait speed (m/s)					
PGT Group	0.41 (0.18)	0.67 (0.22) ^a	0.89 (0.26) ^a	0.94 (0.24) ^a	1.00
SGT Group	0.38 (0.16)	0.52 (0.19)	0.64 (0.23)	0.68 (0.21)	
Berg balance scale					
PGT Group	32.1 (8.4)	42.3 (7.2) ^a	48.7 (6.1) ^a	50.2 (5.8) ^a	1.06
SGT Group	31.8 (8.7)	37.4 (8.1)	41.2 (7.9)	42.8 (7.6)	

^aP <0.05 compared to SGT group at each time point. Effect sizes (Cohen's d) are for between-group differences at 12 weeks; FIM indicates functional independence measure; SGT, standard gait training; PGT, personalised gait training

Discussion

This trial found that PGT guided by real-time stance-phase information produced greater improvement in functional mobility than SGT in adults with subacute stroke. The primary FIM locomotion result was supported by consistent improvements in gait speed, balance, gait symmetry, and independent ambulation. This pattern suggests that the intervention influenced both functional performance and the underlying quality of gait.

The findings are consistent with recent evidence supporting technology-assisted and biofeedback-based gait rehabilitation. Meta-analyses have shown that wearable biofeedback can improve gait speed, balance, and functional mobility after stroke, although the effects are usually small to moderate and vary between studies [7, 8, 15]. The larger effect observed here may therefore relate not only to the technology but also to the way it was used.

A key feature of the present intervention was that stance-phase information was used for both immediate feedback and treatment progression. Participants received information about asymmetry during walking, while task difficulty was adjusted according to measured performance. This differs from interventions in which biofeedback is used only to inform the patient without changing progression criteria. The combination of feedback and structured individualisation may therefore be an important explanation for the observed benefit.

The biomechanical findings support this interpretation. Post-stroke gait asymmetry can arise from weakness, sensory impairment, reduced motor control, spasticity, fear of loading the affected limb, or compensatory strategies [2, 3]. Standard training may improve walking capacity without fully correcting

these problems. In contrast, repeated feedback about stance time may increase awareness of unequal loading and encourage greater use of the affected limb.

This mechanism is consistent with motor-learning principles. Motor recovery is supported by repetitive task-specific practice, feedback about performance, correction of movement error, and progressive challenge [9, 10]. Real-time feedback reduces the delay between an error and its correction, while individualised progression allows task difficulty to remain close to the participant's current ability.

The improvement in gait speed should also be interpreted together with the biomechanical findings. Faster walking after stroke can sometimes result from compensation rather than restoration of normal movement [3]. In this study, increased speed occurred together with improved stance-phase and step-length symmetry. This suggests that participants did not simply walk faster but also developed a more balanced gait pattern.

The higher rate of independent ambulation is clinically important. Evidence from robotic and electromechanical gait rehabilitation indicates that structured intensive walking practice can increase the chance of regaining independent walking after stroke [13, 16]. In the present study, PGT participants achieved independence about 2.3 weeks earlier. Earlier walking independence may reduce caregiver assistance and allow greater participation in daily activities, although these outcomes were not directly measured.

The findings should nevertheless be interpreted cautiously. Participants and therapists could not be blinded, so motivation, expectations, or greater therapist attention may have contributed to the effect. The trial also combined real-time biofeedback with individualised progression, making it impossible to determine their separate contributions. Spontaneous recovery is another consideration because all participants were in the subacute phase [10, 12]. Randomisation should have distributed this effect between groups, and both groups improved over time. However, the findings may not apply to chronic stroke, where recovery patterns differ.

Generalisability is also limited because participants had first-ever ischaemic stroke, moderate gait impairment, adequate cognitive function, and medical stability. Patients with severe stroke, haemorrhagic stroke, major cognitive impairment, or substantial comorbidity were not represented. The technology also requires equipment and staff able to interpret gait information, which may limit immediate implementation in resource-constrained settings [17–20].

Table 3 Biomechanical gait parameters of the study participants (n=120)

Parameter	PGT Group (n=60)			SGT Group (n=60)		
	Baseline	8 Weeks	12 weeks	Baseline	8 Weeks	12 weeks
Stance-Phase Symmetry Ratio	0.72 (0.14)	0.91 (0.09) ^a	1.02 (0.08)	0.73 (0.13)	0.82 (0.12) ^a	0.88 (0.10)
Single Limb Support Time (% gait cycle)						
Affected limb	28.4 (4.2)	35.1 (3.1) ^a	38.8 (2.7)	28.9 (4.5)	31.2 (3.8) ^a	32.7 (3.3)
Unaffected limb	39.2 (3.8)	38.4 (2.9)	37.9 (2.5)	39.8 (4.1)	38.1 (3.2)	37.3 (2.8)
Step Length Symmetry Ratio	0.68 (0.12)	0.87 (0.08) ^a	0.97 (0.07)	0.69 (0.11)	0.79 (0.10) ^a	0.84 (0.09)
Cadence (steps/min)	78.3 (12.4)	96.2 (9.8) ^a	106 (8.5)	76.8 (13.1)	87.4 (11.2) ^a	94 (9.7)

^aP <0.05 for between-group difference at 12 weeks; SGT indicates standard gait training; PGT, personalised gait training

Important strengths include random allocation, concealed assignment, blinded outcome assessment, equal treatment dose, objective biomechanical measures, standardised therapist procedures, repeated assessment, and intention-to-treat analysis. The main limitations were the absence of participant and therapist blinding, follow-up limited to 12 weeks, lack of predefined safety outcomes such as falls, and absence of cost-effectiveness analysis. Future trials should include longer follow-up, formal safety monitoring, broader patient groups, and economic evaluation. Multi-arm trials comparing standard treatment, biofeedback alone, personalised progression alone, and their combination would also help identify the most effective component.

Conclusion

Personalised gait training guided by real-time stance-phase analysis produced greater improvements in locomotor function, gait speed, balance, gait symmetry, and independent ambulation than standard gait training in adults with subacute stroke. These findings support objective, data-guided individualisation of gait rehabilitation. Larger multicentre studies with longer follow-up are needed to confirm effectiveness, safety, sustainability, and cost-effectiveness.

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Author contributions

Concept or design of the work; or the acquisition, analysis, or interpretation of data for the work: JM. *Drafting the work or reviewing it critically for important intellectual content:* BJ, VV. *Final approval of the version to be published:* BJ, VV. *Accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved:* JM, BJ, VV, MPG, PR.

Conflict of interest

We do not have any conflict of interest.

Data availability statement

We confirm that the data supporting the findings of the study will be shared upon reasonable request.

AI disclosure

Artificial intelligence tools were used to improve the language, clarity, and structure of this manuscript. The authors reviewed and verified all AI-assisted content and take full responsibility for the accuracy, interpretation, and conclusions of the manuscript.

Supplementary file

None

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