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Original Article

Effects of task-specific balance and gait training with external feedback on motor function, balance, and the activities of daily living in subacute stroke survivors: a quasi-experimental study

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Running title: Task-specific training with feedback for stroke

Abstract

Objective: Stroke commonly impairs motor function, balance, gait, and the activities of daily living (ADL). Although task-specific training with external feedback has been proposed to enhance post-stroke motor recovery, evidence in subacute stroke survivors remains limited. This study investigated the effects of task-specific balance and gait training with external feedback on motor function, balance, and ADL in subacute stroke survivors compared with conventional physical therapy.

Methods: This quasi-experimental study included 80 participants with subacute stroke, divided equally into experimental and control groups ($n=40$ each). The experimental group received structured task-specific balance and gait training with external feedback twice weekly for 12 weeks. The control group underwent conventional physical therapy three times/week for eight weeks during inpatient rehabilitation, followed by follow-up care after discharge. Motor function, balance, gait speed, and functional independence were assessed before and after the intervention. Data were analyzed using paired t-tests and analysis of covariance, adjusting for age, body mass index, and stroke onset time.

Results: Both groups showed significant within-group improvements for all outcomes ($P<0.001$). Compared to the control group, the experimental group demonstrated significantly greater improvements in balance ($P<0.001$), both comfortable and fastest gait speeds ($P=0.005$ and 0.013 , respectively), and functional independence ($P<0.001$). No significant between-group differences were observed in motor functions.

Conclusion: Task-specific training with external feedback is more effective than conventional physical therapy in improving balance, gait speed, and functional independence in subacute stroke survivors. These findings support the incorporation of feedback-enhanced, task-oriented interventions during the subacute phase of stroke rehabilitation.

Keywords: rehabilitation, feedback, postural balance, gait, stroke

Introduction

Stroke remains a leading contributor to long-term disability worldwide, with nearly 12 million new cases reported annually¹. A considerable number of survivors experience persistent impairments in motor function, postural control, gait, and the activities of daily living (ADLs), which substantially compromise their independence and quality of life^{2,3}. As such, the restoration of motor function and functional mobility, particularly balance and walking ability, is a central focus of stroke rehabilitation, especially during the subacute phase, when neuroplasticity and functional recovery potential are at their peak⁴⁻⁶.

Task-specific training is a widely used approach to enhance functional outcomes after stroke. It involves the repetitive practice of meaningful, goal-directed activities, such as reaching, grasping, or walking, to facilitate the reacquisition of motor skills and restoration of functional independence⁷. This approach is grounded in the principles of motor learning and neuroplasticity, which posit that the brain can adapt and reorganize neural pathways in response to consistent task-oriented movement practice⁸. Previous studies have demonstrated that task-specific locomotor training can lead to significant improvements in gait velocity and endurance in individuals with stroke⁹. Similarly, the early implementation of task-oriented physical therapy during the subacute phase enhances functional recovery and promotes greater independence¹⁰. Furthermore, a Cochrane review concluded that task-specific practice results in moderate improvements in motor function, especially when delivered with adequate intensity, repetition, and initiation early in the rehabilitation process¹¹.

To further enhance motor learning, the integration of external feedback, such as visual, auditory, or tactile cues, has been increasingly incorporated into rehabilitation programs. External feedback provides real-time sensory information that enhances movement awareness, promotes error correction, and strengthens the connection between intention and execution¹². Several studies have demonstrated the effectiveness of external feedback in stroke rehabilitation. Visual feedback in virtual environments improves reaching accuracy¹³, whereas augmented visual cues during gait training enhance gait symmetry and walking speed¹⁴. Additionally, externally focused feedback promotes better motor skill retention than internally focused instructions¹⁵. When used in conjunction with task-specific training, external feedback facilitates more effective motor relearning and improves balance, gait, and functional mobility in stroke survivors.

Although these findings are promising, evidence regarding the combined effects of task-specific balance, gait training, and external feedback in subacute stroke survivors remains limited. Few studies have examined this combined approach during the subacute phase, which is a critical period for optimizing neuroplasticity and recovery potential. Moreover, there is a lack of research on the effects of such interventions on multiple domains of recovery, namely, motor function, balance, and ADLs in community-based clinical settings. Additionally, most comparisons have focused on either isolated task training or laboratory-based feedback systems, with limited studies directly comparing structured feedback-enhanced locomotor training with conventional physical therapy.

Therefore, this quasi-experimental study investigated the effects of task-specific balance and gait training with external feedback on motor function, balance, and ADLs in subacute stroke survivors, and compared them with those of conventional physical therapy, which involved general strengthening and mobility exercises without structured feedback. We hypothesized that subacute stroke survivors who received task-specific locomotor training with external feedback would demonstrate significantly greater improvements in motor function, balance, and ADLs than those who received conventional physical therapy. By targeting the subacute phase, our results may provide insights into the clinical value of incorporating structured feedback-enhanced locomotor training during the critical window for neuroplasticity and functional recovery.

Methods

Participants and study design

This study employed a quasi-experimental design with two groups, an experimental group and control group. Assessments were conducted at two time points: pre-test and post-test. The study protocol was approved by the Institutional Review Board of XXXXX (REC No. XXXX) and registered under the Thai Clinical Trials Registry (TCTR) No. TCTR20250409003 (<https://www.thaiclinicaltrials.org/show/TCTR20250409003>). This study was conducted in patients with ischemic stroke undergoing physical therapy rehabilitation at two community hospitals (Sadao Hospital and Bang Klam Hospital) in Southern Thailand.

The inclusion criteria were: i) a diagnosis of first episode of ischemic stroke in the subacute phase (within 6 months)¹⁶, ii) age ≥ 60 years, iii) muscle tone graded between 0 and 1+ on the Modified Ashworth Scale (MAS)¹⁷ in the affected lower extremity, assessed in the major muscle

groups, including the hip flexors, extensors, adductors, and abductors; knee flexors and extensors; and ankle dorsiflexors and plantar flexors, iv) quality of movement (QoM) rated from poor to good, assessed by clinical observation of movement quality during functional task performance, in accordance with motor control and stroke rehabilitation principles¹⁸, with the ability to safely maintain supported standing during training, and v) a Mini-Mental State Examination-Thai version (MMSE-Thai) score of 14 or higher¹⁹. The exclusion criteria were as follows: history of Parkinson's disease, lower limb fractures, physical disabilities, unstable vital signs (blood pressure >180/110 mm Hg, body temperature >38°C, heart rate >100 bpm, or respiratory rate >20 bpm), or prior exposure to acupuncture or traditional Thai massage. All eligible participants signed an informed consent form prior to participating in the study.

The sample size estimation was based on data from a previous study that compared balance ability using the Functional Reach Test after motor imagery training in post-stroke patients. In that study, the experimental group had a mean score of 22.5, with a standard deviation (SD) of 3.1, whereas the control group had a mean score of 25.8 with a SD of 4.6²⁰. Calculations were performed using a formula to compare the mean values between two independent populations with a 95% confidence level ($\alpha = 0.05$) and 90% statistical power ($\beta = 0.10$)²¹. To account for potential attrition, the required sample was inflated by $1/(1 - \text{dropout proportion})$. A conservative dropout rate of 30% was applied, consistent with prior rehabilitation studies that planned for similar attrition allowances²². Accordingly, a minimum of 40 participants per group was required.

Procedure

Participants were allocated to groups based on hospital location rather than by random assignment. This allocation approach was adopted for logistical and practical reasons, as Sadao and Bangklam District Hospitals operate under different healthcare teams and follow-up systems, making cross-site intervention implementation impractical. In addition, this method helped minimize contamination between groups, since participants within each hospital were likely to interact during rehabilitation sessions.

Eligible participants residing in the Sadao Hospital area were assigned to the experimental group, which received task-specific balance and gait training with external feedback, whereas eligible participants residing in the Bang Klam Hospital area were assigned to the control group, which received conventional physical therapy. The interventions for each group were conducted

over a 12-week period. Outcome assessments were performed during the week immediately preceding the start of the intervention and during the week immediately following completion of the training period, without a washout interval. Apart from the assigned interventions, no additional rehabilitation therapies beyond the usual hospital care were provided during the study period. A flow diagram of the study participants is shown in Figure 1. The training session was discontinued if the participants experienced dizziness, nausea, abnormal breathing, irregular vital signs, chest pain, fatigue, or reported pain, depending on their exercise capacity.

Interventions

Experimental group

The experimental group underwent a comprehensive task-specific locomotor training program that incorporated balance training with external feedback (BEF) and gait training with external feedback (GEF). The program consisted of sensory integration training, trunk control, balance exercises in both static and dynamic conditions, weight-shifting activities, lower extremity movement training, and gait training targeting both the stance and swing phases. Each session included 45 minutes of BEF and 45 minutes of GEF, delivered twice per week over a period of 12 weeks^{4,5,8,11}. This training frequency and duration were designed to provide sufficient intensity, repetition, and progression in accordance with motor learning and neuroplasticity principles, while remaining feasible for delivery in a community hospital setting during the subacute phase of stroke. All experimental interventions were administered by a single licensed physical therapist with over five years of clinical experience in neurological rehabilitation to minimize treatment bias. This training emphasized body awareness through somatosensory stimulation, vestibular inputs, and visual feedback. The participants were guided through proprioceptive training, which involved sensory perception and organization in both stable (quiet) positions and externally induced perturbations. The intervention protocol was developed and implemented under the guidance of senior physical therapists and a specialist in Physical Medicine and Rehabilitation.

The BEF consists of five progressive exercises: i) standing with feet hip-width apart, ii) standing with feet together, iii) tandem stance (foot-to-foot), iv) single-leg standing, and v) standing on a foam surface with eyes closed. The BEF training lasted 45 minutes per session, with approximately 8 minutes allocated to each exercise and a 1-minute rest between transitions (Table 1 and Figure 2a–e).

The 45-minute GEF training included three main components: i) static standing balance on various surfaces, ii) step standing, and iii) gait cycle training. Each component was performed for 12 minutes, with a 3-minute rest period between activities (Table 1 and Figure 3a–c).

Control group

The control group intervention was delivered by a senior licensed physical therapist who had more than five years of clinical experience in a public hospital setting. This therapist was not involved in outcome assessment.

All participants in the control group received the same core components of the conventional physical therapy program. Minor individual adjustments were made according to each participant's clinical condition, consistent with routine clinical practice. The conventional physical therapy program was delivered for 90 minutes per session, three times per week, over an eight-week period. Each 90-minute session typically consisted of the following components: passive and active range of motion exercises (10–15 minutes), muscle strengthening exercises (10–15 minutes), bed mobility training (5–10 minutes), functional ability training related to activities of daily living (10–15 minutes), standing balance training under static and dynamic conditions focusing on postural control and weight shifting toward the affected lower extremity (10–15 minutes), gait training (10–15 minutes), physical modalities including electrical stimulation combined with hot pack application (approximately 20 minutes), and hand and leg stationary cycling (10–15 minutes). While the exact duration of each component could vary slightly based on individual needs, the overall content and approximate time allocation were consistent across participants. This treatment schedule reflects current inpatient rehabilitation practice, in which conventional physical therapy is typically delivered at a higher weekly frequency during the inpatient phase but over a shorter duration due to service capacity and discharge planning. During weeks 9–12, no additional supervised exercise sessions were provided; however, each participant received one home healthcare visit that included guidance on general mobility and usual activity as part of routine care.

Measurement outcomes

Two physical therapists, each with over five years of clinical experience, conducted the outcome measurements at their respective hospitals. The assessors were not involved in delivering

the interventions. Due to hospital-based group allocation in this quasi-experimental design, assessor blinding was not feasible. All assessments were performed in a fixed, non-randomized sequence at pre- and post-intervention time points, starting from the Stroke Rehabilitation Assessment of Movement (STREAM), followed by the Functional Reach Test (FRT), 10-Meter Walk Test (10MWT), and Barthel Index (BI). This sequence was selected to minimize fatigue and to allow more physically demanding mobility tasks to be performed after basic motor and balance assessments. The details of the measurements are described below.

Stroke Rehabilitation Assessment of Movement

STREAM is a standardized tool used to evaluate voluntary movement and basic mobility in individuals with stroke. This tool has demonstrated high inter- and intra-rater reliability, along with strong construct and criterion validity, making it appropriate for use in both clinical and research settings to monitor post-stroke motor recovery^{23,24}. The STREAM consists of 30 items divided into three subscales: upper extremity movements (10 items), lower extremity movements (10 items), and basic mobility tasks (10 items). The tasks are assessed in various positions, including supine, sitting, standing, and walking. This study assessed the lower extremity and mobility subscales of STREAM. The lower extremity subscale has a maximum score of 20 points, with each item rated on a 3-point ordinal scale. In contrast, the mobility subscale has a maximum score of 30 points, with each item rated on a 4-point ordinal scale. Higher scores on both subscales indicate better motor function and mobility performance²⁴. The participants were allowed up to three attempts per item, and the highest score was recorded.

Functional Reach Test

FRT is a clinical measure used to assess an individual's stability and static balance by evaluating the maximal distance one can reach forward beyond the arm's length while maintaining a fixed base of support in the standing position. The FRT has demonstrated good test-retest reliability in adults and stroke populations, with intraclass correlation coefficients (ICC) of 0.81 and 0.89, respectively^{25,26}. The participants were asked to stand sideways against the wall and raise their non-affected arm against the wall, 90° parallel to the floor. They then leaned forward as far as possible without falling or stepping on their feet, and tried to keep their arms at the same level.

The distance (cm) between the starting and reaching points of the third fingertip was measured. Three trials were performed, and the average distance was used for the analysis²⁵.

10-Meter Walk Test

10MWT, a key indicator of functional mobility and community ambulation potential, is widely used to assess the walking speed in patients with stroke. The 10MWT has demonstrated high reliability and validity in stroke populations and is sensitive to changes in walking ability during rehabilitation²⁷. The participants were instructed to walk at their comfortable and fastest speeds along a 10-meter walkway, with or without the use of a walking aid. The timing was recorded over the central 6 m to allow for acceleration and deceleration phases at the beginning and end. Walking speed was calculated using the following formula: walking speed=distance/time. Each condition (comfortable and fastest pace) was assessed three times, and the average walking speed (m/s) was used for the analysis.

Barthel Index

BI is widely used to assess functional independence in individuals with neurological conditions, particularly stroke. This assessment has demonstrated high reliability, sensitivity to change, and strong clinical utility for stroke rehabilitation²⁸. The BI consists of 10 items evaluating performance in ADLs, such as feeding, bathing, grooming, dressing, toileting, mobility, and stair climbing. Each item is scored based on the level of assistance required, with the total score ranging from 0 to 100. The scores were interpreted as follows: 0–20 = very severely disabled; 21–60 = severely disabled; 61–90 = moderately disabled; 91–99 = mildly disabled; and 100 = fully independent in physical function, although not necessarily socially independent²⁹.

Prior to data collection, the assessors participated in a standardized preparation process, which included a joint review of all outcome measures (STREAM, FRT, 10MWT, and BI), clarification of scoring criteria, and practice sessions to ensure consistency in assessment procedures. A pilot assessment involving 10 stroke patients at the control hospital was also conducted to harmonize scoring and assessment techniques before the formal study began.

Statistical analyses

All statistical analyses were performed using SPSS version 25 statistical software (IBM Corp., Armonk, NY, USA). Descriptive statistics were used to present the baseline demographics of the participants and study findings. The Shapiro-Wilk test was used to estimate data normality. To compare baseline demographic characteristics between the experimental and control groups, the Chi-square test was used for categorical variables. For continuous variables, either the independent t-test or Mann-Whitney U test was used, depending on the normality of the data distribution. The paired t-test was used to compare the pre-test and post-test scores within each group. To compare changes in outcomes between the experimental and control groups, an analysis of covariance (ANCOVA) was performed using the difference in scores (post-test minus pre-test), while adjusting for baseline values and relevant covariates, including age, body mass index (BMI), and stroke onset time. The level of significance was set at $P < 0.05$.

Results

A total of 227 individuals were assessed for eligibility across both hospitals during the same recruitment period. Of these, 147 were excluded: 126 did not meet the inclusion criteria, 19 declined to participate, and two were excluded for other reasons. The remaining 80 eligible participants were enrolled in the study and allocated to two groups ($n = 40$ each) based on their residential area. No dropouts were observed in either group during the 12-week study period. All participants completed both the pre- and post-test assessments, resulting in a final sample size of 80 (Figure 1). No training sessions were discontinued due to safety concerns, and no adverse events were reported during the intervention period.

Table 2 presents the general characteristics of the participants. No significant differences were found between the experimental and control groups in terms of sex, affected side, or cognitive function (MMSE-Thai scores). However, significant differences were observed in age, height, weight, BMI, and stroke onset time between the two groups.

After the 12-week intervention, both the experimental and control groups showed significant improvements in all outcome measures: lower extremity function and basic mobility (STREAM), balance (FRT), walking speed (10MWT), and functional independence, as reflected by ADL performance, assessed using the BI scores ($P < 0.001$ within groups; Table 3).

On comparing the magnitude of improvement between the groups with age, BMI, and onset time included as the covariates, the experimental group demonstrated significantly greater gains than the control group in the FRT ($P < 0.001$), both comfortable and fastest walking speeds in the 10MWT ($P = 0.005$ and 0.013 , respectively), and BI scores ($P < 0.001$). However, between-group differences in the STREAM subscales (lower extremity and basic mobility) were not statistically significant (Table 3).

Discussion

This study investigated the effects of task-specific balance and gait training with external feedback on the motor function, balance, and ADLs in subacute stroke survivors. The results demonstrated significant improvements in all outcome measures, including motor function, balance, walking speed, and ADL performance, after 12 weeks of intervention in both the experimental and control groups. Notably, compared to the control group, the experimental group showed significantly greater improvements in balance, gait speed, and ADL performance. However, no significant between-group differences were found in the motor function scores.

The improvements observed in both the experimental and control groups after the 12-week intervention may be attributed to several key factors. First, both groups received consistent and structured rehabilitation programs over a sustained period. The control group underwent conventional physical therapy consisting of general exercises, whereas the experimental group received task-specific balance and gait training with external feedback. Second, both interventions involved repetitive task practice with adequate intensity and frequency, which are recognized as the two key principles of motor learning^{4,8}. Specifically, repetitive practice with adequate intensity promotes experience-dependent neuroplasticity, whereas task-specific, goal-directed training facilitates motor adaptation and functional skill transfer. These principles were reinforced in the experimental group through balance and gait tasks combined with external feedback. Additionally, all participants were in the subacute phase of stroke, typically within the first three to six months after stroke onset, which is a period associated with heightened neuroplasticity and responsiveness to rehabilitation^{5,6}. These factors likely contributed to the within-group improvements observed in both groups, reflecting the combined effects of consistent therapeutic engagement, training-induced neuroplasticity, and time-dependent biological recovery during the subacute phase of stroke.

When interpreting the magnitude of improvement, it is important to consider the minimal clinically important difference (MCID) for each outcome measure to contextualize the clinical significance beyond statistical findings. For motor function, both groups showed improvements in STREAM scores exceeding the MCID thresholds of 1.9 points for the lower extremity and 4.8 points for the mobility subscales³⁰, indicating meaningful recovery. Balance performance also improved substantially, with FRT gains of 18 cm and 12.8 cm in the experimental and control groups, respectively, surpassing the minimal detectable change of 6.79 cm for subacute stroke²⁵. Gait speed increased by 0.46 m/s (comfortable) and 0.73 m/s (fastest) in the experimental group, well above the MCID of 0.16 m/s³¹, demonstrating clinically significant improvement in walking ability. Likewise, BI scores rose by 20.88 and 14.88 points in the experimental and control groups, far exceeding the MCID range of 1.45–1.85 points³². Overall, these outcomes demonstrate that the improvements observed in the present study reflect not only statistical significance but also tangible functional benefits with strong clinical implications for stroke rehabilitation.

On comparing the differences in the scores between the experimental and control groups, the experimental group showed significantly greater improvements in balance, gait speed, and ADL performance. This may be because of the structured, task-specific nature of the intervention, which directly targeted functional mobility through repetitive goal-directed walking and balance tasks. The integration of external feedback likely enhanced motor control by reinforcing accurate movement patterns and enabling real-time error correction¹². Unlike conventional therapy, the experimental program incorporated progressive task difficulty and variability, including perturbation-based balance and gait-phase-specific training, which better reflect real-life mobility demands. These elements probably contributed to the superior improvements in walking performance, balance, and functional independence in daily activities. These findings are consistent with those of previous studies demonstrating that task-specific and feedback-enhanced training improves gait velocity, balance, and endurance^{9,10}. A Cochrane review also reported moderate improvements in motor function through early, intensive, and repetitive task-specific interventions¹¹. Recent studies have further reinforced these findings; for example, Phonthee et al. (2020) showed that step training with external feedback improved lower limb support and complex motor activity in stroke survivors³³. Okonkwo et al. (2018) found that task-specific balance training enhanced balance even in stroke survivors with cognitive impairment³⁴. Similarly, Chung et al. (2019) reported gait and balance gains following lower extremity task-specific training³⁵.

Taken together, these studies support the effectiveness of structured, feedback-informed rehabilitation in promoting functional recovery post-stroke.

Beyond these findings, comparative evidence from other countries indicates that task-specific balance and gait training with external feedback can be successfully adapted across diverse rehabilitation contexts. In high-resource settings, such as university hospitals in high-income countries, virtual or technology-assisted feedback systems have been implemented to enhance motor learning and functional recovery^{36–38}. Meanwhile, in low- and middle-income countries, simplified and low-cost feedback approaches, such as visual or verbal cues, have been effectively applied in community-based programs to achieve similar functional improvements^{33,39,40}. These observations suggest that structured feedback-enhanced locomotor training is flexible and scalable, and can be tailored to local healthcare infrastructure, available resources, and patient needs. Our study reinforces the potential for implementing such interventions in community hospital settings, highlighting their applicability in real-world, resource-limited rehabilitation contexts.

No significant between-group differences were found in motor function scores as measured by STREAM (lower extremity and mobility). One possible explanation is that STREAM primarily evaluates isolated voluntary movements of the limbs and basic mobility rather than complex functional activities^{23,24}. While both groups received interventions promoting general motor activation, the task-specific locomotor training in the experimental group targeted dynamic balance, postural control, and coordinated gait components that were not fully captured by STREAM. Although STREAM has been widely used to assess poststroke recovery, few studies have specifically focused on balance and gait training using STREAM as an outcome measure. Nevertheless, Kılınç et al. (2016) reported similar findings in a randomized controlled trial investigating the effects of Bobath-based trunk exercises on trunk control, balance, functional mobility, and gait in patients with stroke, with STREAM as one of the outcome measures. In that study, both the intervention and control groups demonstrated significant within-group improvements in motor function and mobility, while no significant between-group differences were observed⁴¹. Importantly, these findings suggest that STREAM is sensitive to clinically meaningful motor recovery within groups, even when between-group differences are not detected. Similarly, in the present study, improvements in STREAM scores in both groups exceeded established MCID thresholds, indicating meaningful motor recovery rather than a lack of treatment effect.

This study has several limitations. First, the quasi-experimental design with area-based allocation may have introduced a selection bias. Second, full participant blinding was not feasible; however, the allocation of participants from separate hospital areas likely reduced the risk of treatment contamination and minimized performance bias. Third, baseline characteristics differed between the experimental and control groups in terms of age, height, weight, BMI, and onset time. Although ANCOVA was performed using the difference in scores while adjusting for baseline values and relevant covariates, residual confounding factors cannot be entirely excluded. Fourth, although STREAM was used to assess motor function, it primarily evaluates basic voluntary movements and may not fully capture complex functional changes, particularly in dynamic balance and gait performance. Fifth, the relatively modest sample size and inclusion of only subacute stroke survivors limit the generalizability of the findings to broader stroke populations. Sixth, because task-specific training and external feedback were delivered as a combined intervention, the present design does not allow the independent effects of each component to be distinguished. Lastly, this study did not directly assess clinically important outcomes, such as fall risk, discharge readiness, or long-term independence, which are highly relevant for post-stroke rehabilitation.

Despite these limitations, this study has several strengths. It focuses on the subacute phase of stroke, a critical period for promoting neuroplasticity and functional recovery. The intervention combined task-specific balance and gait training with external feedback and applied motor learning principles in a structured and clinically feasible manner. Importantly, no participants dropped out during the 12-week intervention, reflecting good feasibility, safety, and acceptability, and reducing the risk of attrition bias. Additionally, multiple validated outcome measures were employed to capture improvements in motor function, balance, gait, and ADLs, providing a comprehensive evaluation of the rehabilitation effects. These strengths enhance the clinical relevance and applicability of the findings in real-world rehabilitation settings. Future studies should employ randomized controlled trial designs with blinded assessors to enhance internal validity, recruit a larger and more diverse stroke population, and incorporate long-term follow-up, as well as use a multi-arm design to disentangle the independent effects of task-specific training and external feedback. Additionally, using sensitive measures of dynamic balance and complex gait performance, and directly assessing outcomes such as fall risk, discharge readiness, and long-term independence, would provide stronger evidence for the clinical effectiveness and real-world applicability of feedback-based task-specific rehabilitation programs.

In conclusion, task-specific balance and gait training with external feedback significantly enhanced balance, gait speed, and daily functional abilities in subacute stroke survivors. These findings support the clinical application of structured feedback-enhanced rehabilitation programs for promoting effective motor recovery and greater independence during the subacute phase of stroke rehabilitation. Furthermore, the program has potential for implementation and scaling in community hospital settings, highlighting its relevance and feasibility in resource-limited healthcare systems.

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Conflict of Interest

The authors declare that there are no conflicts of interest regarding the research, authorship, or publication of this article.

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Ethical Considerations and Consent to Participate

The study protocol was approved by the Institutional Review Board of Thaksin University (REC No.0391), 14 November 2022, in accordance with the Declaration of Helsinki. The study was registered under the Thai Clinical Trials Registry (TCTR) No. TCTR20250409003, <https://www.thaiclinicaltrials.org/show/TCTR20250409003>. Prior to participation, all

participants received information on the purpose and procedures of the study, were assured that their personal data would be treated confidentially, and were informed of their right to withdraw at any time without consequence. Written informed consent was obtained from each participant.

Data availability

The data associated with the paper are not publicly available but are available from the corresponding author upon reasonable request.

Author Contributions

Patchariya Khunjan – Conception, study design, study management, data collection and assembly, provision of study materials or patients, administrative and logistic support, drafting of the article, and finalizing study documentation.

Lalita Khuna – Analysis and interpretation of data, critical revision of the manuscript for important intellectual content, and final approval of the article.

Tum Boonrod – Conception and study design, analysis and interpretation of data, statistical expertise, and critical revision of the manuscript for important intellectual content.

Vallop Ditsuwat – Conception and study design, and critical revision of the manuscript for important intellectual content.

Chamnan Chinnasee – Conception and study design, and critical revision of the manuscript for important intellectual content.

Aseed Yaprachan – Provision of study materials or patients, and collection and assembly of data.

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Table 1. Balance training with external feedback program and gait training with external feedback program

Program	Training posture
Balance training with external feedback (BEF)	
1. Standing with feet hip-width apart (8 min) (Figure 2a)	1.1 Static standing balance Stand upright with feet hip-width or stride width apart, maintaining a still posture while counting from 1 to 30, without responding to any sound or light sensor signals. This was repeated for 3 minutes, followed by a 1-minute rest. 1.2 Dynamic standing balance Stand in a balanced position with feet at stride width, shift weight left and right until the doorbell rings, then move forward and backward until the light sensor activates. Return to the starting position and repeat for 3 minutes, followed by a 1-minute rest.
2. Standing with feet together (8 min) (Figure 2b)	2.1 Static standing balance Stand upright with feet together, maintaining balance without swaying, and count from 1 to 30. Repeat this process for 3 minutes, followed by a 1-minute rest. 2.2 Dynamic standing balance Stand upright with feet together, shift weight left and right until the doorbell rings, then shift forward until the light sensor activates. Return to the starting position and repeat for 3 minutes, followed by a 1-minute rest.
3. Foot-to-foot (8 min) (Figure 2c)	3.1 Static standing balance Stand in a foot-to-foot position, maintaining balance without swaying, and count from 1 to 30. Repeat for 3 minutes, followed by a 1-minute rest.

Program	Training posture
	3.2 Dynamic standing balance Stand in a foot-to-foot position, shift your weight left and right until you hear a sound, then shift forward until the light turns on. Return to the starting position and repeat for 3 minutes, followed by a 1-minute rest.
4. Single-leg standing (8 min) (Figure 2d)	4.1. Static standing balance Stand on one leg, maintaining balance without falling, and count from 1 to 30. Repeat for 3 minutes, followed by a 1-minute rest, and then repeat the task on the opposite leg.
5. Standing on foam with eyes closed (8 min) (Figure 2e)	5.1 Static standing balance Stand on foam with eyes closed, feet at stride width, and maintain balance without swaying. Count from 1 to 30. Repeat for 3 minutes, followed by a 1-minute rest. 5.2 Dynamic standing balance Stand on a foam surface with eyes closed and feet positioned at stride width. Shift body weight laterally (left and right) and then in the anterior–posterior direction until an auditory signal is heard, indicating that the target weight shift has been reached. Return to the starting position and repeat for 3 minutes, followed by a 1-minute rest.
Gait training with external feedback (GEF)	
1. Static standing balance (12 min) (Figure 3a)	Stand on a simulated walking base with the feet positioned at step-width distance. Maintain static standing while shifting body weight alternately between the left and right legs as well as in the anterior–posterior direction within the base of support. The exercise was performed bilaterally, with equal time allocated to each side. A mirror placed in front provides visual feedback to enhance body alignment, weight-shifting control, and postural awareness during the task.

Program	Training posture
2. Step standing (12 min) (Figure 3b)	Stand with the feet positioned at a step-length distance, allowing the heel of the leading foot to contact the surface first. Step forward by alternately leading with each leg while shifting body weight in the anterior–posterior direction and maintaining a heel strike position (placing the heel of the leading foot on the ground first, followed by controlled forefoot contact). After completing the task on one side, the leading leg was alternated so that both lower extremities were trained equally. A mirror placed in front provides visual feedback to facilitate correct body alignment, weight transfer, and step coordination during the task.
3. Gait cycle training (12 min) (Figure 3c)	Step over a 20-centimeter barrier while maintaining approximately 25 degrees of hip flexion and 65 degrees of knee flexion; replicate the maximum angles observed during the gait cycle. A mirror placed in front provides visual feedback to enhance step accuracy, postural alignment, and movement control.

Table 2. General characteristics of the participants

Variables	Experimental Group (n = 40)	Control Group (n = 40)	P-value
Age (years): mean $\pm$ SD (95%CI)	67.98 $\pm$ 6.53 (65.89–70.06)	71.50 $\pm$ 5.71 (69.67–73.33)	0.010 ^a
Height (cm): mean $\pm$ SD (95%CI)	160.43 $\pm$ 7.40 (158.06–162.79)	165.55 $\pm$ 6.84 (163.36–167.74)	0.002 ^b
Weight (kg): mean $\pm$ SD (95%CI)	64.21 $\pm$ 12.98 (60.05–68.36)	76.18 $\pm$ 10.51 (72.81–79.54)	<0.001 ^b
BMI (kg/m ²): mean $\pm$ SD (95%CI)	25.02 $\pm$ 4.25 (23.66–24.87)	27.84 $\pm$ 3.72 (26.64–29.03)	0.001 ^a
Time post stroke (months): mean $\pm$ SD (95%CI)	2.88 $\pm$ 1.04 (2.54–3.21)	3.73 $\pm$ 0.91 (3.44–4.01)	<0.001 ^a
MMSE-Thai (score): mean $\pm$ SD (95%CI)	18.88 $\pm$ 4.21 (17.53–20.22)	18.93 $\pm$ 4.24 (17.57–20.28)	0.942 ^a
Sex: n (%)			
Male	28 (70)	28 (70)	1.000 ^c
Female	12 (30)	12 (30)	
Affected side: n (%)			
Left	23 (42.5)	26 (35)	0.49 ^c
Right	17 (57.5)	14 (65)	

Note: BMI = body mass index; MMSE-Thai = Mini-Mental State Examination-Thai version; SD = standard deviation, CI = confidence intervals.

^a Data between the groups were compared using the Mann-Whitney U test.

^b Data between the groups were compared using the independent t-test.

^c Data between the groups were compared using the Chi-square test.

Table 3. Comparison of outcome measures within and between the groups after the intervention

Variable	Experimental Group (n = 40)				Control Group (n = 40)				Between groups
	Pre-test, Mean±SD (95% CI)	Post-test, Mean±SD (95% CI)	<i>P</i> -value ^a	Change score	Pre-test, Mean±SD (95% CI)	Post-test, Mean±SD (95% CI)	<i>P</i> -value ^a	Change score	<i>P</i> -value ^b
STREAM (score)									
Lower extremity	9.80±2.81 (8.90– 10.70)	18.70±1.16 (18.33– 19.07)	<0.001	8.90±2.60 (8.07–9.73)	6.95±2.04 (6.30–7.60)	17.10±1.30 (16.69– 17.51)	<0.001	10.15± 2.18 (9.45– 10.85)	0.173
Basic mobility	15.45±3.76 (14.25– 16.65)	24.98±2.01 (24.33– 25.62)	<0.001	9.53±3.49 (8.41– 10.64)	13.70±2.19 (13.00– 14.00)	22.73±1.55 (22.23– 23.22)	<0.001	9.03±2.07 (8.36–9.69)	0.124
FRT (cm)	19.19±4.47 (17.76– 20.61)	37.29±2.51 (36.49– 38.10)	<0.001	18.11±4.96 (16.52– 19.69)	20.10±5.29 (18.41– 21.79)	32.93±3.81 (31.71– 34.15)	<0.001	12.83±5.83 (10.70– 14.69)	<0.001
10MWT (m/s)									
Comfortable speed	0.40±0.10 (0.36–0.43)	0.86±0.28 (0.77–0.94)	<0.001	0.46±0.30 (0.37–0.55)	0.25±0.08 (0.23–0.28)	0.57±0.14 (0.53–0.61)	<0.001	0.32±0.14 (0.27–0.36)	0.005
Fastest speed	0.67±0.16	1.39±0.44	<0.001	0.73±0.50	0.39±0.14	0.89±0.28	<0.001	0.50±0.27	0.013

	(0.62–0.72)	(1.25–1.53)		(0.56–0.89)	(0.35–0.44)	(0.80–0.98)		(0.41–0.58)	
BI (score)	60.00±9.27 (57.04– 62.96)	80.88±6.97 (78.65– 83.10)	<0.001	20.88±8.23 (18.24– 23.51)	55.50±6.28 (53.49– 57.51)	70.38±7.11 (68.10– 72.65)	<0.001	14.88±8.28 (12.23– 17.52)	<0.001

Note: STREAM = Stroke Rehabilitation Assessment of Movement; FRT = Functional Reach Test; 10 MWT = 10-Meter Walk Test;

BI = Barthel Index

Change of score represents the difference between post-test and pre-test values (post-test minus pre-test), presented as mean difference ± standard deviation (95% confidence intervals).

^a Paired t-tests were used to compare the pre-test and post-test outcomes within each group.

^b ANCOVA was used to compare the differences in scores between the groups, with age, BMI, and time post-stroke included as the covariates.

Figure legend

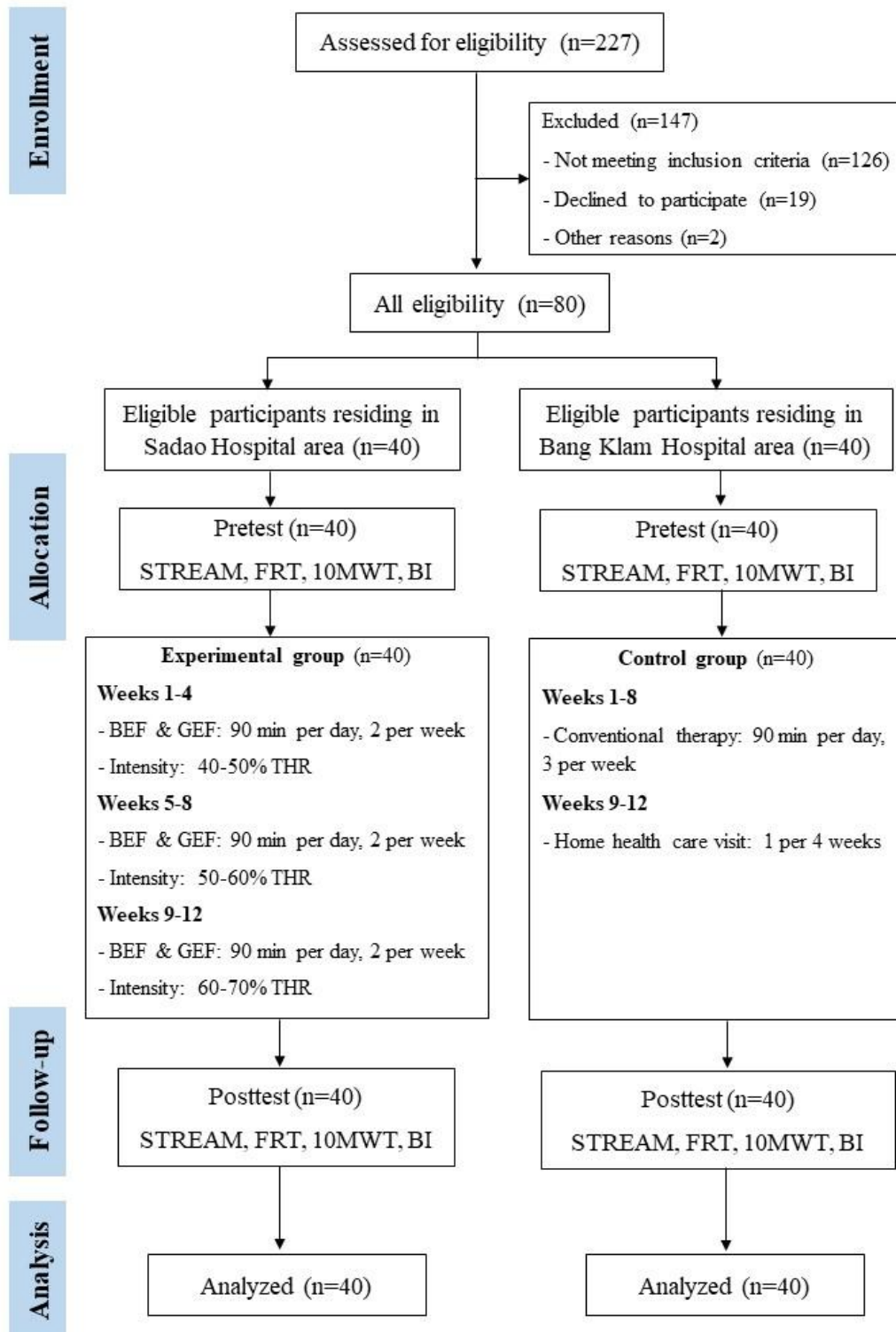


Figure 1. Participant flow diagram

STREAM, Stroke Rehabilitation Assessment of Movement, FRT: Functional Reach Test; 10 MWT: 10-Meter Walk Test, BI: Barthel Index; BEF, Balance training with external feedback; GEF, Gait training with external feedback; THR, target heart rate.

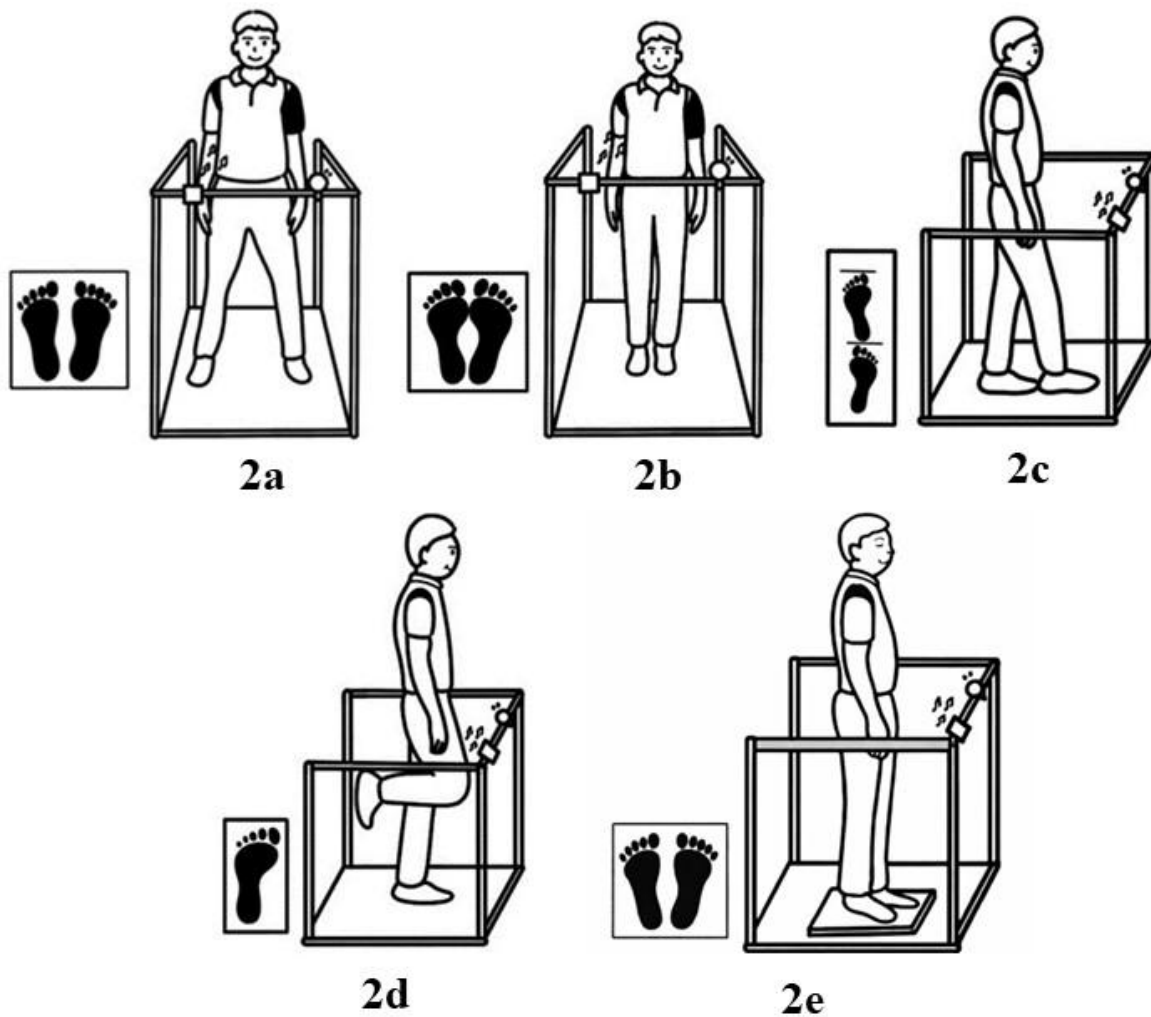


Figure 2. Balance training with external feedback

- a) Standing with feet hip-width apart
- b) Standing with feet together
- c) Foot-to-foot
- d) Single-leg standing
- e) Standing on foam with eyes closed

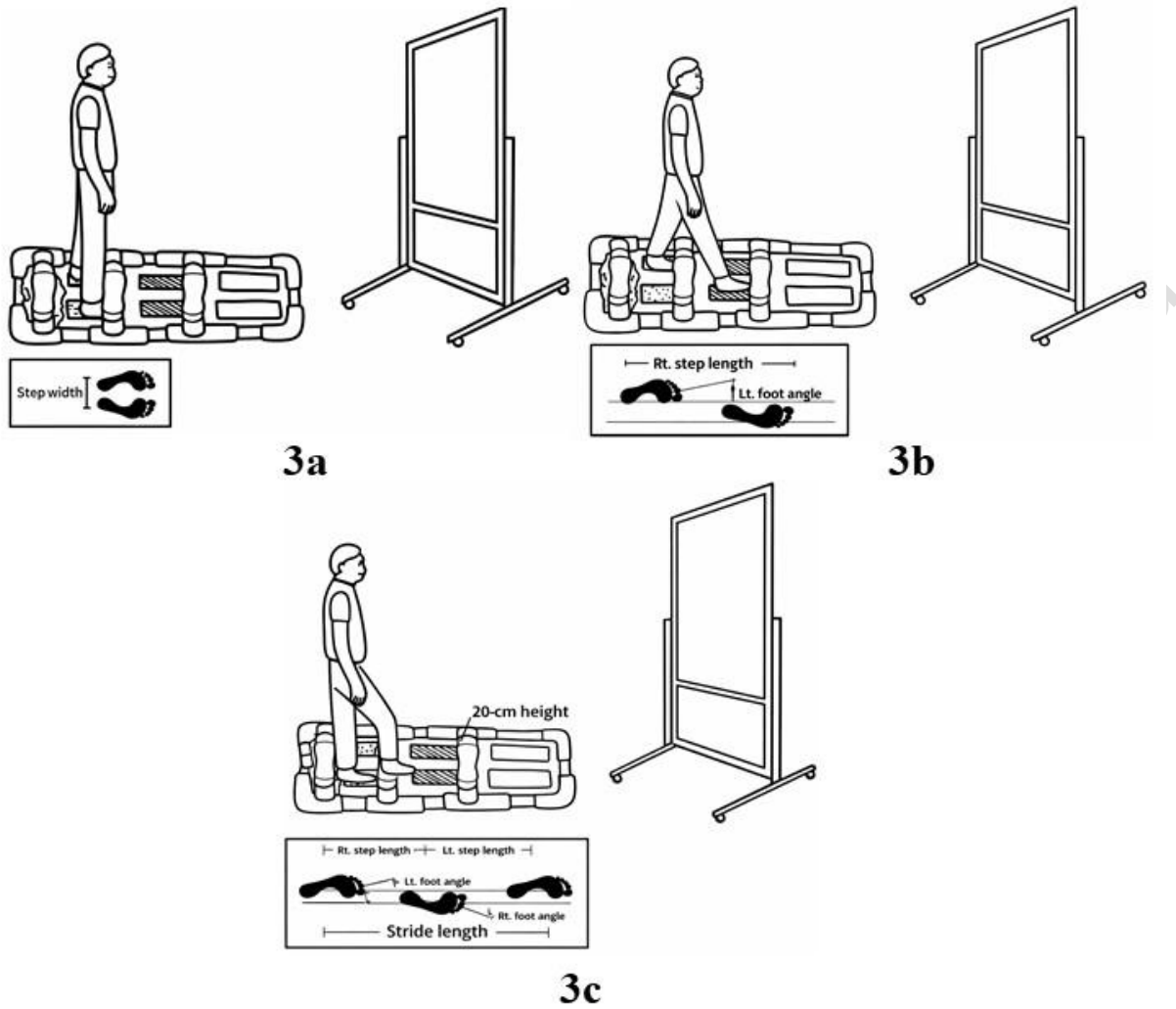


Figure 3. Gait training with external feedback

- a) Static standing balance
- b) Step standing
- c) Gait cycle training