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Effect of Cross Training Using Progressive Resistive Exercises on Gait and Balance in Patients with Stroke: A Randomized Controlled Trial

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Abstract:
Background: Stroke is a leading cause of long-term disability worldwide, with impaired balance and gait being among the most common functional limitations following stroke. Progressive resistive exercises (PRE) are widely used in stroke rehabilitation; however, the potential benefits of cross training through strengthening of the unaffected limb remain inadequately explored.
Objective: To investigate the effect of cross training using progressive resistive exercises of the unaffected lower limb on balance and gait performance in individuals with subacute stroke.
Methods: A randomized controlled trial was conducted involving 30 individuals with first-ever subacute stroke (30–150 days post-stroke). Participants were randomly allocated using the lottery method into an experimental group ($n = 15$) and a control group ($n = 15$). The experimental group received progressive resistive exercises for both the affected and unaffected lower limbs, whereas the control group received progressive resistive exercises only for the affected lower limb. Both groups received intervention for six weeks, three sessions per week. Outcome measures included the Berg Balance Scale (BBS), walking speed, and cadence, assessed at baseline and after completion of the intervention. Statistical analysis was performed using within-group and between-group comparisons with significance set at $p < 0.05$.
Results: Both groups demonstrated significant improvements in balance and gait parameters following the intervention ($p < 0.001$). The experimental group showed significantly greater improvement in Berg Balance Scale scores (49.66 ± 1.88 vs. 47.20 ± 3.03; $p = 0.027$) and walking speed (0.440 ± 0.030 m/s vs. 0.404 ± 0.025 m/s; $p = 0.001$) compared with the control group. Although cadence improved in both groups, the between-group difference was not statistically significant (67.88 ± 6.81 vs. 63.82 ± 3.91 steps/min; $p = 0.050$).
Conclusion: Cross training using progressive resistive exercises of the unaffected lower limb produced superior improvements in balance and walking speed compared with conventional strengthening of the affected limb alone in individuals with subacute stroke. Cross training may therefore serve as an effective adjunct to conventional stroke rehabilitation programs.

Keywords: Stroke; Subacute Stroke; Cross Training; Progressive Resistive Exercise; Hemiplegia; Balance.

Introduction

Stroke is defined as an acute neurological dysfunction of vascular origin characterized by the sudden or rapid onset of focal neurological signs and symptoms resulting from disturbances in cerebral circulation[1]. It occurs due to interruption of the cerebral blood supply, leading to brain tissue damage as a result of ischemia caused by arterial occlusion, which accounts for nearly 85% of all cases, intracerebral hemorrhage (approximately 10%), or other less common causes[1]. Stroke remains one of the leading causes of mortality and long-term disability worldwide, accounting for approximately 10–20% of all deaths in industrialized countries, with nearly 90% of stroke-related deaths occurring in individuals over 65 years of age. The incidence of first-ever stroke increases markedly with age, rising from approximately 5% among individuals aged 55–59 years to nearly 25% in those aged 80–85 years[2].

Several modifiable and non-modifiable factors contribute to the occurrence of stroke. Hypertension, diabetes mellitus, cardiovascular diseases, and cigarette smoking are considered the major risk factors, whereas alcohol consumption, hypercholesterolemia, drug abuse, and congenital vascular abnormalities also increase susceptibility. Although stroke occurs more frequently in men, women generally experience stroke at an older age and have a higher mortality rate[2].

Stroke results in a wide range of neurological impairments, including motor paralysis, sensory disturbances, pain, cognitive deficits, language disorders, memory impairment, and emotional disturbances, all of which significantly affect functional independence and quality of life[3]. Approximately one-fourth of stroke survivors experience communication disorders involving speech, writing, and language comprehension[3]. Among these deficits, motor impairment is the most common and disabling consequence. Hemiparesis reduces voluntary muscle activation and available muscle mass for contraction, leading to impaired lower limb strength and functional mobility, particularly gait[1]. In addition, muscle weakness has also been reported in the non-paretic limb, resulting in impaired balance, gait asymmetry, reduced mobility, and an increased risk of falls[3].

The primary objective of stroke rehabilitation is to restore functional independence by improving motor performance and enabling patients to perform activities of daily living. Recovery of gait and balance is considered a major rehabilitation goal because independent ambulation is closely associated with improved participation and quality of life. Conventional rehabilitation approaches such as the Bobath concept, Proprioceptive Neuromuscular Facilitation (PNF), Brunnstrom movement therapy, and the Motor Relearning Programme have been widely used to improve motor recovery following stroke[4]-[7]. Although these interventions have demonstrated clinical benefits, many patients continue to exhibit persistent gait deficits and balance impairments, highlighting the need for additional evidence-based rehabilitation strategies.

Cross education, also known as cross transfer of strength, is a neurophysiological phenomenon in which unilateral strength training produces improvements in strength and motor performance of the contralateral untrained limb. This phenomenon is believed to result primarily from neural adaptations rather than

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peripheral muscular changes. Cortical mechanisms, including increased motor cortex excitability and interhemispheric interactions, together with spinal neural adaptations, have been proposed to facilitate motor output in the untrained limb. Previous studies have demonstrated that motor skills and strength acquired by one limb can be transferred to the opposite limb, suggesting that cross education may be an effective rehabilitation strategy for individuals with unilateral impairments such as stroke, amputation, and prolonged limb immobilization.

Following stroke, weakness is observed not only in the affected limb but also, to a lesser extent, in the ipsilateral or unaffected limb because of bilateral cortical involvement[1]. Conventional rehabilitation protocols primarily emphasize strengthening of the affected lower limb to improve gait and balance, whereas strengthening exercises for the unaffected limb are generally not included. Previous studies have demonstrated cross-transfer effects in both upper and lower extremities of healthy individuals; however, evidence supporting the effectiveness of lower limb cross training in stroke rehabilitation remains limited. Consequently, it is unclear whether unilateral progressive resistive exercises performed by the unaffected lower limb can improve gait and balance of the affected limb in individuals with stroke.

Therefore, the present study aimed to determine the effect of cross training using progressive resistive exercises of the unaffected lower limb on gait and balance in individuals with stroke. It was hypothesized that cross training combined with conventional rehabilitation would produce greater improvements in gait and balance than progressive resistive exercises performed only by the affected lower limb. If proven effective, this intervention could provide physiotherapists with a simple, evidence-based approach to enhance functional recovery following stroke.

Methodology

Study Design

The present study employed a pre-test and post-test experimental design to evaluate the effectiveness of cross training using progressive resistive exercises (PRE) on gait and balance in individuals with subacute stroke. Participants were randomly allocated into an experimental group and a control group, and outcome measures were assessed before and after the intervention period.

Study Setting and Participants

The study was conducted on patients diagnosed with subacute stroke who were referred for physiotherapy rehabilitation. A total of 30 participants meeting the eligibility criteria were recruited after obtaining written informed consent. Ethical principles outlined in the Declaration of Helsinki were followed throughout the study, and confidentiality of participant information was maintained.

Sample Size and Sampling Technique

A total sample of 30 participants was included in the study. Participants were selected based on predefined inclusion and exclusion criteria. Following baseline assessment, participants were randomly allocated into two equal groups using multiple block randomization, with 15 participants in the experimental group (Group A) and 15 participants in the control group (Group B). Random allocation ensured equal distribution of participants between groups and minimized selection bias.

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Eligibility Criteria
Inclusion Criteria
Participants were included if they met the following criteria:
- Diagnosed with a first episode of subacute stroke resulting in hemiplegia within 30–150 days of onset.
- Age between 40 and 70 years.
- Mini-Mental State Examination (MMSE) score of 24 or above, indicating adequate cognitive ability to understand and follow instructions.
- Spasticity of Grade 1+ or less on the Modified Ashworth Scale.
- Ability to stand independently for at least 30 seconds and walk independently without physical assistance.
- Right lower limb dominance.

Exclusion Criteria
Participants were excluded if they had:
- Other neurological disorders such as multiple sclerosis, Parkinson's disease, cerebellar disorders, or dementia.
- Inability to understand verbal instructions.
- Uncontrolled hypertension.
- Orthopaedic conditions such as fractures, dislocations, or musculoskeletal disorders affecting gait and balance.

Variables
Independent Variable
The independent variable was progressive resistive exercise (PRE) administered either to both lower limbs (experimental group) or only to the affected lower limb (control group).
Dependent Variables
The dependent variables included:
- Balance
- Walking speed
- Cadence

Outcome Measures
Berg Balance Scale (BBS)
Balance was assessed using the Berg Balance Scale (BBS), a reliable and valid clinical measure for evaluating functional balance in individuals with stroke. The scale consists of 14 functional tasks, each scored on a five-point ordinal scale ranging from 0 to 4, with a maximum score of 56 points. Higher scores indicate better balance performance. Participants were evaluated according to standardized testing procedures before and after completion of the intervention.
Walking Speed
Walking speed was assessed using the 10-Meter Walk Test (10MWT). Participants were instructed to walk at their self-selected comfortable speed over a 10-metre walkway. To eliminate the effects of

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acceleration and deceleration, only the middle 6 metres were timed using a stopwatch. Walking speed was calculated by dividing the distance covered (6 metres) by the time taken (seconds), and expressed in metres per second (m/s).

Cadence

Cadence was measured simultaneously during the 10-Meter Walk Test. The number of steps taken over the middle 6-metre distance was counted manually. Cadence was calculated as the number of steps per minute using the following equation:

$$\frac{\text{Steps}}{\text{Seconds}} \times \frac{60\ \text{seconds}}{1\ \text{minute}}$$

This measure provided an objective assessment of temporal gait performance.

Equipment and Materials

The following equipment was used during the study:

- Adjustable ankle exerciser
- Weight cuffs of varying resistance
- Standard stopwatch
- 10-metre paper walkway
- Measuring tape
- Standard chair

These instruments were used for administering exercises and measuring functional outcomes.

Intervention Protocol

Following baseline assessment, participants were randomly assigned to one of two intervention groups.

Experimental Group (Group A)

Participants in the experimental group received progressive resistive exercises for both the affected and unaffected lower limbs in addition to conventional physiotherapy.

Resistance training targeted the following muscle groups:

- Hip flexors
- Hip extensors
- Quadriceps
- Hamstrings
- Ankle dorsiflexors
- Ankle plantarflexors

Training intensity was individualized using the One Repetition Maximum (1RM) principle. Initially, participants performed each movement using a weight that could be comfortably lifted through the full range of motion. The estimated 1RM was calculated using the equation:

1RM=load/(1.0278-0.0278×reps).

Exercise intensity was initiated at 50% of the calculated 1RM. By the second week, the resistance was progressively increased to 80% of the 1RM, provided participants tolerated the progression without adverse effects. The 1RM was reassessed every two weeks, and exercise loads were adjusted accordingly to maintain training intensity.

Each treatment session lasted 30 minutes, and participants attended three sessions per week for six

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consecutive weeks.

Control Group (Group B)

Participants in the control group received the same progressive resistive exercise programme only for the affected lower limb, while the unaffected lower limb was not trained. The duration, exercise intensity, progression, and treatment frequency were identical to those of the experimental group to ensure consistency between groups.

Conventional Physiotherapy

In addition to the assigned interventions, participants in both groups received conventional physiotherapy for the affected upper limb throughout the intervention period. This ensured that both groups received similar routine rehabilitation apart from the cross-training component.

Study Procedure

After obtaining informed consent, demographic details and baseline clinical characteristics were recorded. Pre-intervention assessment of balance, walking speed, and cadence was performed for all participants by the investigator using standardized assessment protocols.

Participants then underwent the allocated intervention programme for six weeks. Exercise progression was monitored throughout the intervention period, and adherence to the protocol was ensured during supervised treatment sessions.

At the end of the six-week intervention, all outcome measures were reassessed using the same testing procedures. Pre- and post-intervention scores were compared within each group as well as between the experimental and control groups to determine the effectiveness of cross training.

Statistical Analysis

Statistical analysis was performed using appropriate statistical software. Descriptive statistics were used to summarize demographic and baseline characteristics, and data were expressed as mean ± standard deviation (SD). Within-group comparisons of Berg Balance Scale (BBS), walking speed (WS), and cadence were performed using paired statistical tests, whereas between-group comparisons were carried out using independent statistical tests. The choice of parametric or non-parametric tests was based on the distribution of the data. A p-value of less than 0.05 was considered statistically significant.

RESULT

A total of 30 participants with subacute stroke were enrolled and completed the study. Participants were randomly allocated into the experimental group (Group A, n = 15) and the control group (Group B, n = 15). No participant was lost to follow-up during the intervention period, and all participants were included in the final analysis.

Baseline Characteristics

The baseline demographic characteristics of both groups are presented in Table 1. The experimental group consisted of 8 males and 7 females, while the control group comprised 9 males and 6 females. The mean age of participants was 53.93 ± 6.36 years in Group A and 54.13 ± 6.20 years in Group B. The mean MMSE scores were 29.06 ± 0.96 and 29.26 ± 0.96, respectively. There were no significant differences between the groups at baseline, indicating that both groups were comparable before the intervention.

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Variable	Group A (Mean ± S.D)	Group B (Mean ± S.D)
Age (yrs)	53.93 ± 6.36	54.13 ± 6.20
MMSE	29.06± 0.96	29.26 ± 0.96

Table 1 : Comparison of characteristics (Age, MMSE) of patients between the groups.

Balance (Berg Balance Scale)

Within-group analysis demonstrated a significant improvement in Berg Balance Scale (BBS) scores following six weeks of intervention in both groups. In the experimental group, the mean BBS score increased significantly from 38.73 ± 3.83 at baseline to 49.66 ± 1.88 post-intervention, representing a 28.2% improvement (p = 0.001). Similarly, the control group showed a significant increase in BBS score from 38.40 ± 4.40 to 47.20 ± 3.03, corresponding to a 22.9% improvement (p = 0.001), indicating that both intervention protocols were effective in improving functional balance following stroke.

Group	Pre-interventionMean ± SD	Post-interventionMean ± SD	% Improve-ment	*p*-value
Experimental (n = 15)	38.73 ± 3.83	49.66 ± 1.88	28.2	0.001*
Control (n = 15)	38.40 ± 4.40	47.20 ± 3.03	22.9	0.001*

Table 2 : Within group comparison of Berg Balance Scale before and after intervention

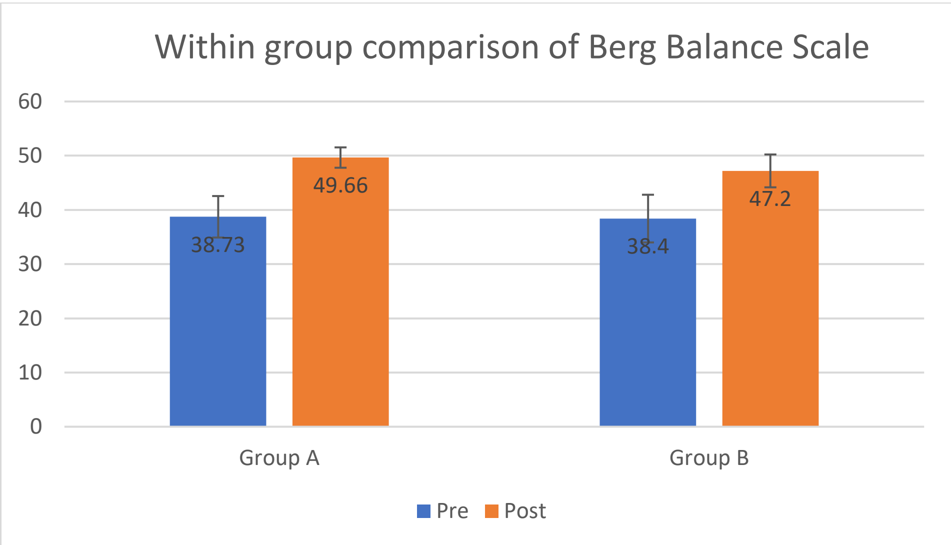

Figure 1 : Within group comparison of Berg Balance Scale before and after intervention

Between-group analysis showed that there was no significant difference in Berg Balance Scale (BBS) scores between the experimental and control groups at baseline (38.73 ± 3.83 vs. 38.40 ± 4.40; p = 0.884), indicating that both groups were comparable before the intervention. Following six weeks of treatment, both groups demonstrated improved BBS scores. However, the experimental group achieved a

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significantly higher post-intervention BBS score than the control group (49.66 ± 1.88 vs. 47.20 ± 3.03; *p* = 0.027), suggesting that progressive resistive exercises performed on both the affected and unaffected lower limbs resulted in greater improvement in balance than exercises performed only on the affected lower limb.

Outcome	Time Point	Experimental Group (n = 15)Mean ± SD	Control Group (n = 15)Mean ± SD	*p*-value
Berg Balance Scale (Score)	Baseline	38.73 ± 3.83	38.40 ± 4.40	0.884
	Post-inter-vention	49.66 ± 1.88	47.20 ± 3.03	0.027*

Table 3 : Between-group comparison of Berg Balance Scale before and after intervention

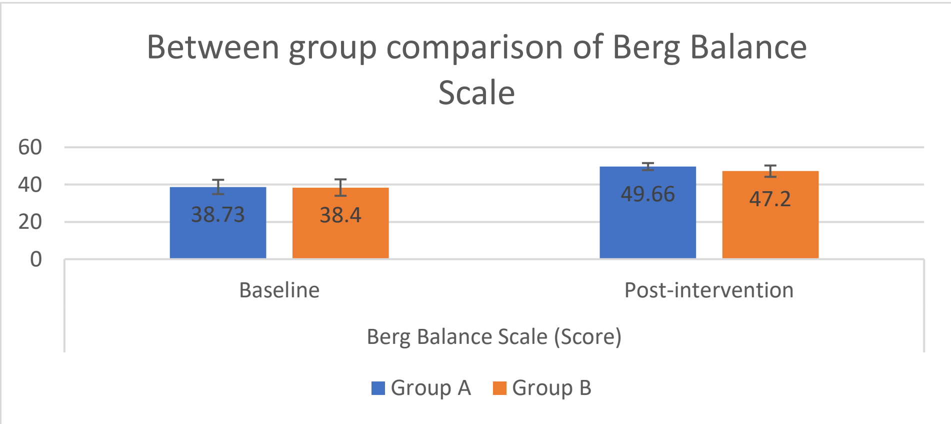

Figure 2 : Between-group comparison of Berg Balance Scale (steps/min) before and after intervention

Walking Speed

Within-group analysis demonstrated a significant improvement in walking speed (WS) following six weeks of intervention in both groups. In the experimental group, the mean walking speed increased from 0.327 ± 0.024 m/s at baseline to 0.440 ± 0.030 m/s after the intervention, representing a 37.5% improvement (*p* < 0.001). Similarly, the control group showed a significant increase in walking speed from 0.334 ± 0.015 m/s to 0.404 ± 0.025 m/s, corresponding to a 21.2% improvement (*p* < 0.001). These findings indicate that progressive resistive exercise significantly improved walking speed in both groups over the six-week intervention period.

Group	Pre (m/s)	Post (m/s)	% Improvement	p-value
Experimental	0.327 ± 0.024	0.440 ± 0.030	34.6%	< 0.001*
Control	0.334 ± 0.015	0.404 ± 0.025	21.0%	< 0.001*

Table 4 : Within group comparison of Walking speed before and after intervention

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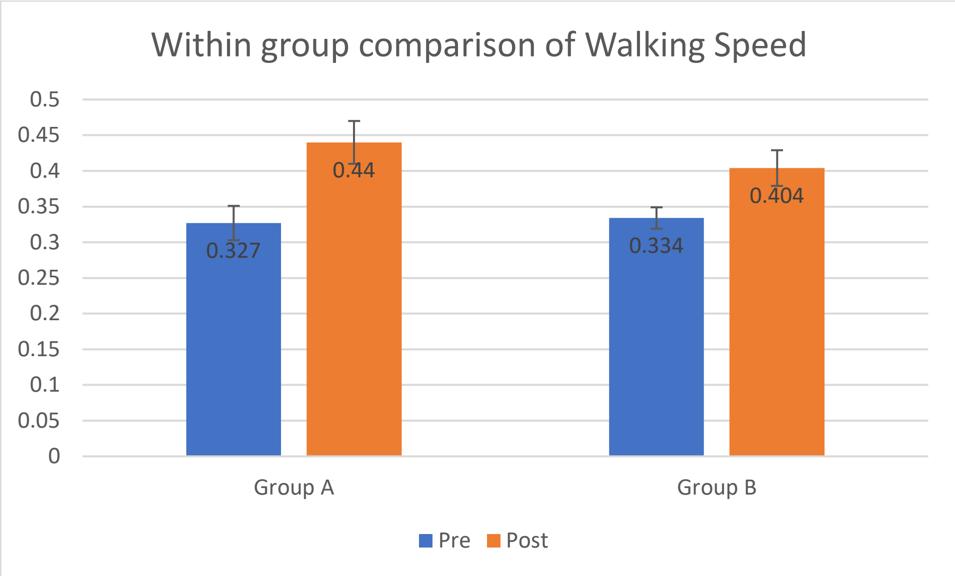

Figure 3 : Within group comparison of Walking speed before and after intervention

Between-group analysis showed that there was no significant difference in walking speed (WS) between the experimental and control groups at baseline (0.327 ± 0.024 m/s vs. 0.334 ± 0.015 m/s; $p = 0.342$), indicating that both groups were comparable before the intervention. Following six weeks of treatment, walking speed improved in both groups. However, the experimental group demonstrated a significantly greater post-intervention walking speed than the control group (0.440 ± 0.030 m/s vs. 0.404 ± 0.025 m/s; $p = 0.001$), indicating that progressive resistive exercises performed on both the affected and unaffected lower limbs resulted in superior improvement in gait velocity compared with exercises performed only on the affected lower limb.

Outcome	**Time Point**	**Experimental Group (n = 15)Mean ± SD**	**Control Group (n = 15)Mean ± SD**	***p*-value**
Walking Speed (m/s)	Baseline	0.327 ± 0.024	0.334 ± 0.015	0.342
	Post-inter-vention	0.440 ± 0.030	0.404 ± 0.025	0.001*

Table 5 : Between-group comparison of Walking Speed before and after intervention

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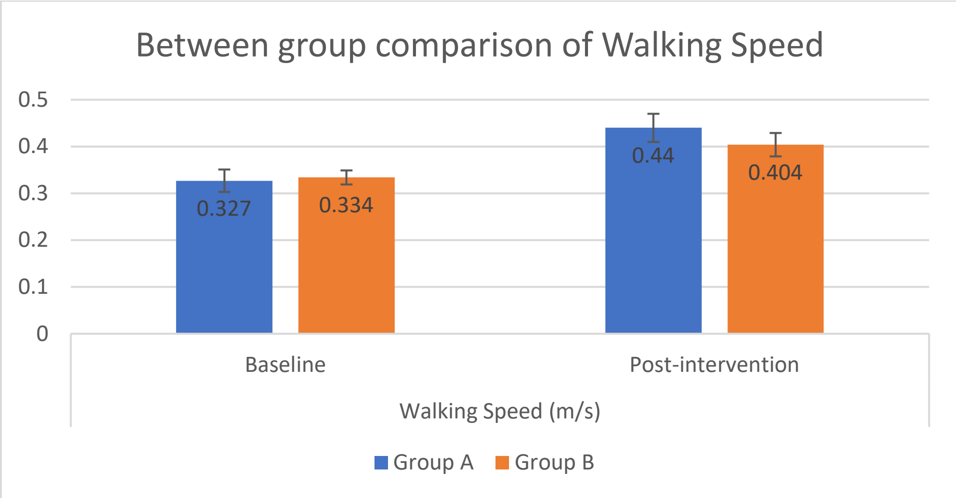

Figure 4 : Between-group comparison of Walking Speed before and after intervention

Cadence

Within-group analysis demonstrated a significant improvement in cadence following six weeks of intervention in both groups. In the experimental group, the mean cadence increased from 48.58 ± 4.01 steps/min at baseline to 67.88 ± 6.81 steps/min after treatment, representing a 39.7% improvement ($p < 0.001$). Similarly, the control group showed a significant increase in cadence from 49.05 ± 3.58 steps/min to 63.82 ± 3.90 steps/min, corresponding to a 30.1% improvement ($p < 0.001$) (Table X).

Group	**Pre (Mean ± SD)**	**Post (Mean ± SD)**	**% Improvement**	**p-value**
Experimental	48.58 ± 4.01	67.88 ± 6.81	**39.7%**	**< 0.001***
Control	49.05 ± 3.58	63.82 ± 3.90	**30.1%**	**< 0.001***

Table 6 : Within group comparison of Cadence before and after intervention

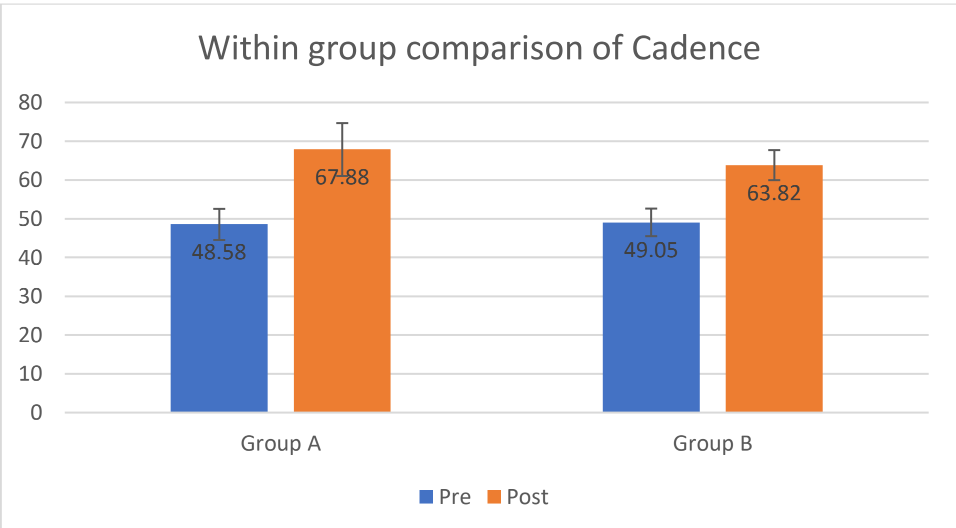

Figure 5 : Within group comparison of Cadence before and after intervention

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Between-group analysis showed that there was no significant difference in cadence between the experimental and control groups at baseline (48.58 ± 4.01 vs. 49.05 ± 3.58 steps/min; $p = 0.736$), indicating that both groups were comparable before the intervention. Following six weeks of treatment, cadence improved in both groups. The experimental group demonstrated a higher post-intervention cadence than the control group (67.88 ± 6.81 vs. 63.82 ± 3.91 steps/min). However, the between-group difference at post-intervention was not statistically significant ($p = 0.050$), suggesting that although cross training produced greater improvement in cadence, the difference between the two interventions did not reach the predetermined level of statistical significance.

Outcome	Time Point	Experimental Group (n = 15)Mean ± SD	Control Group (n = 15)Mean ± SD	*p*-value
Cadence (steps/min)	Baseline	48.58 ± 4.01	49.05 ± 3.58	0.736
	Post-inter-vention	67.88 ± 6.81	63.82 ± 3.91	0.050

Table 7 : Between-group comparison of Cadence (steps/min) before and after intervention

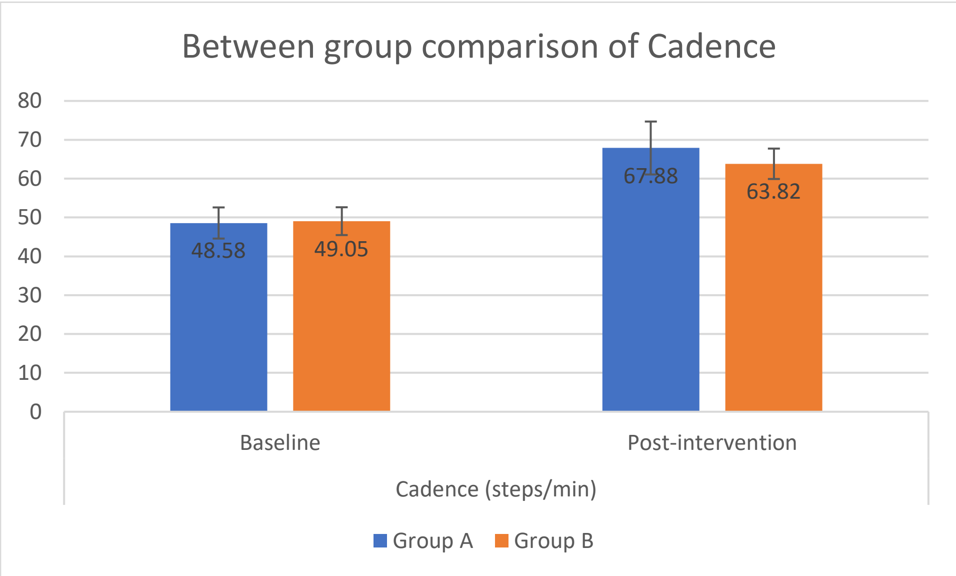

Figure 6 : Between-group comparison of Cadence (steps/min) before and after intervention

DISCUSSION

The present study investigated the effect of cross training using progressive resistive exercises (PRE) of the unaffected lower limb on balance and gait performance in individuals with subacute stroke. The findings demonstrated that both the experimental group, which received PRE to both lower limbs, and the control group, which received PRE only to the affected limb, showed significant improvements in Berg Balance Scale (BBS), walking speed, and cadence after six weeks of intervention. However, the

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experimental group demonstrated significantly greater improvements in balance and walking speed, indicating an additional therapeutic benefit of cross training in stroke rehabilitation.

Muscle weakness is one of the major impairments following stroke and contributes substantially to reduced mobility, impaired balance, and decreased functional independence. Previous studies have demonstrated that progressive resistive exercises improve muscle strength, gait performance, and participation in daily activities without increasing spasticity or abnormal movement patterns. J. Lexell and Ulla-Britt Flansbjer reported significant improvements in gait performance following strength training after stroke. Similarly, therapeutic exercise programmes have been shown to improve functional mobility and physical performance in subacute stroke survivors[1],[10]-[12],[8],[9].

The experimental group demonstrated a significantly greater improvement in balance compared with the control group, with BBS scores improving by 28.2% and 22.9%, respectively. Balance impairment following stroke results from muscle weakness, sensory deficits, impaired postural reactions, and altered motor control. Previous studies have identified balance dysfunction as one of the major contributors to disability after stroke and have demonstrated a strong relationship between postural stability and walking performance[13],[14]. Furthermore, the Berg Balance Scale has been shown to be a valid and reliable outcome measure for assessing balance in stroke rehabilitation[15],[16]. The superior improvement observed in the experimental group suggests that strengthening the unaffected limb may enhance postural control through neural adaptations associated with cross education.

Walking speed improved significantly in both groups, with the experimental group demonstrating a significantly greater increase than the control group (34.6% versus 21.0%). Walking speed is considered an important indicator of functional mobility and community ambulation following stroke. Previous investigations have shown strong associations between lower limb muscle strength and gait velocity in hemiparetic individuals [17],[18]. Similar improvements in gait performance following strengthening interventions have been reported in stroke rehabilitation studies using progressive resistance exercises[11],[8],[19]. The greater improvement observed in the experimental group suggests that cross training may enhance motor recovery beyond the effects of conventional strengthening alone.

The additional benefits observed in the experimental group can be explained by the phenomenon of cross education or cross transfer, whereby unilateral training produces improvements in strength and motor performance in the contralateral untrained limb. Several studies have demonstrated significant contralateral strength gains following unilateral resistance training[20]-[23]. Proposed mechanisms include increased excitability of the ipsilateral motor cortex, reduced interhemispheric inhibition, activation of uncrossed corticospinal pathways, and improved interhemispheric communication[24]-[28]. In addition, spinal mechanisms involving modulation of interneuronal circuits and reflex pathways may contribute to improved motor output in the contralateral limb[24]-[28]. These neurophysiological adaptations may explain the superior improvements in balance and walking speed observed in the experimental group.

Cadence improved significantly within both groups, with improvements of 39.7% in the experimental group and 30.1% in the control group. Although the experimental group demonstrated higher post-treatment cadence values, the between-group difference did not reach statistical significance ($p = 0.050$). Previous studies have shown that cadence is influenced by multiple factors including strength, balance, coordination, and motor control, and may require longer intervention periods to demonstrate significant between-group differences[29]-[32]. Nevertheless, the greater percentage improvement observed in the experimental group suggests a positive clinical trend favouring cross training.

The findings of this study have important implications for physiotherapy practice. Cross training of the unaffected lower limb may serve as an effective adjunct to conventional rehabilitation, particularly in patients with severe weakness or limited voluntary activation of the affected limb during the early stages of recovery.

The present study was limited by its relatively small sample size, short intervention duration, and absence of long-term follow-up. Future randomized controlled trials with larger samples and neurophysiological assessments are recommended to further investigate the mechanisms and long-term effects of cross training after stroke.

Conclusion

The present study demonstrated that progressive resistive exercises significantly improved balance, walking speed, and cadence in individuals with subacute stroke. However, participants who received cross training involving both the affected and unaffected lower limbs achieved significantly greater improvements in Berg Balance Scale scores and walking speed compared with those receiving exercises only for the affected limb. Although improvements in cadence were greater in the experimental group, the between-group difference was not statistically significant. These findings suggest that cross training is an effective adjunct to conventional stroke rehabilitation and may enhance functional recovery through mechanisms of cross education and neural adaptation.

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