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EFFECTS OF HIGH-INTENSITY INTERVAL TRAINING ON MUSCLE STRENGTH, ATROPHY AND AEROBIC CAPACITY IN STROKE PATIENTS

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ABSTRACT

Introduction : Stroke is a major cause of long-term disability and reduced physical functioning. It often leads to muscle weakness, muscle wasting, and decreased cardiovascular fitness, which can affect daily activities. The aim of this study was to determine the effects of high-intensity interval training (HIIT) on muscle strength, atrophy, and aerobic capacity in stroke patients.

Method : It was a single-blinded, randomized controlled trial, including 34 stroke patients. Patients were randomly allocated into two groups. One group received HIIT along with conventional treatment, and the other received conventional treatment alone. To measure muscle strength, calf circumference, and aerobic capacity in stroke patients, MMT, Measuring Tape, 6MWT, and Harvard step test were used, respectively.

Results : Results showed a significant difference between group analysis, as the p-value was less than 0.05, and within the group, both therapies showed effectiveness, but paired differences of group A were more than those of group B.

Conclusion: Both therapies yielded significant outcomes. However, when combined with conventional therapy, the HIIT program improved strength in the muscles and aerobic capacity and reduced atrophy in stroke patients.

Key Words: Aerobic Capacity, High-Intensity Interval Training, Muscle Atrophy, Muscle Strength, Stroke

INTRODUCTION

Stroke is a significant contributor to severe disability, ranking among the top five leading causes of death in the US and the most common severe manifestation of cerebrovascular disease (CVD). Hospitalization for neurological diseases is primarily caused by stroke (1). Some factors, including age, diabetes, heart disease, and stroke type, affect the acute and in-hospital outcomes of patients with stroke. The long-term consequences of a stroke may include altered activity and participation levels, as well as altered body structure and function (2).

Stroke survivors must cope with the consequences of a stroke, such as functional restrictions that restrict their freedom in day-to-day activities. The primary and secondary changes to the acute event determine the degree of motor function impairment that causes long-term disability after a stroke. These shortcomings can become more apparent over time, requiring further modifications and adaptations (3).

To avoid deconditioning due to immobility, early mobilization is advised during acute hospitalization after a stroke (4). In patients who have had a stroke in the past, aerobic capacity shows a substantial inverse relationship with morbidity and mortality. Enhancing aerobic capacity lowers the risk of a second stroke and death, proving that aerobic exercise is crucial for post-stroke care (5).
International clinical exercise recommendations currently identify HIIT as a more effective and alternative strategy than moderate-intensity continuous exercise (MCT), which is the gold standard recommended by multiple guidelines (6). HIIT has been found to be a useful technique for strengthening muscles and enhancing body composition. Additionally, studies have shown that HIIT is both safe and beneficial for older adults with good health (7).

In high-intensity interval training (HIIT), short recovery intervals or no exercise are interspersed with high-intensity aerobic activity at or below peak oxygen uptake (8). HIIT is defined as intervals of high-intensity physical activity (≥90% maximum oxygen consumption or >90–95% HR-max between 6 s and 4 min) separated by active or passive rest intervals (20% to 40% maximum oxygen consumption for 10 s to 5 min) (9, 10). Exercise adherence to HIIT (8).

A sedentary lifestyle is associated with muscle weakening and atrophy, which have a substantial influence on the quality of life of stroke patients, resulting in decreased cardiovascular fitness and diminished aerobic capacity. HIIT addresses these difficulties by improving cardiovascular fitness and increasing peak oxygen consumption (VO2peak). According to certain hypotheses, HIIT protocols that emphasize speed or repeated stepping exercises may selectively improve muscle strength and reduce the risk of degeneration. Protocols that prioritize heart rate are believed to primarily increase aerobic fitness. This study examined the effects of HIIT on muscle strength, degeneration, and aerobic capacity during stroke recovery.
To the best of our knowledge, HIIT has been widely used in various groups, including individuals with medical issues. However, the specific impact on stroke patients, notably in terms of increasing aerobic capacity and muscular strength as well as preventing muscle atrophy, has received little attention. High-quality randomized controlled trials are required to fully investigate HIIT's effects on important clinical outcomes of stroke therapy. Developing an evidence-based strategy through such trials would help researchers and physicians integrate HIIT into treatment methods for stroke patients.

METHODOLOGY

Trial Design: This parallel group design randomized controlled trial was conducted at the Rehabilitation Center of Riphah International University, Lahore, Pakistan. It had an allocation ratio of 1:1 and was approved by the Research & Ethics Committee of Riphah College of Rehabilitation and Allied Sciences, Riphah International University, Lahore, Pakistan, with the approval number REC/RCR & AHS/23/0237. Prior to participation, all subjects provided written informed consent. This trial was prospectively registered at ClinicalTrials.gov (NCT06292442). This trial followed the Consolidated Standards of Reporting Trials (CONSORT) reporting guidelines. No substantial adjustments were made to the trial design or methodology. To ensure the uniformity and scientific integrity of the research, eligibility criteria were defined in advance and kept constant throughout the investigation.

Participants: Participants were recruited from Jinnah Hospital, Lahore, Pakistan, following a medical history review, physical examination, and Modified Ashworth Scale (MAS) and Mini-Mental Scale Examination (MMSE) screening. Inclusion criteria included: (1) both male and female patients, (2) age 40-60 years, (3) chronic stroke patients (3 months to 5 years post-stroke) (11), (4) first-ever ischemic stroke, (5) stable cardiovascular condition (AHA class B) (12), (6) physician clearance for a 4-week HIIT program, (7) no structured exercise in the previous 3 months, (8) ability to walk 10 meters above ground with or without assistive devices (13), and (9) MMSE score >24/30. The exclusion criteria were recent hospitalization for cardiovascular or pulmonary disease (14), an implanted pacemaker/defibrillator, VO2peak testing contraindications, significant lower limb spasticity, pregnancy, and prior exposure to rapid treadmill walking within the previous year.

Randomization: After screening and obtaining informed consent, a computer-generated randomization program using basic random integers in blocks was used. The sealed envelope approach concealed allocation by splitting participants into control and experimental groups.

Blinding: In order to ensure unbiased outcome evaluation, a single-blind technique was employed, with the assessor being a physiotherapist with 8 years of experience, unaware of the treatment allocations.

Interventions: In both groups, participants received standard medical care. The intervention group received HIIT along with traditional therapy. Pre and post-four-week intervention patients were assessed. The experimental group received HIIT three times a week for 45-50 minutes each time during four weeks. The physical therapist did not physically assist with stepping for safety but provided protection and assistance when needed. Participants exercised on a treadmill without any weight support and used handrails for balance assistance and a fall protection belt. Training HR zones were calculated by HRR method: training HR zones = (HRmax' RHR) percent HRR target + RHR (8, 12) where HRmax is the maximum heart rate during exercise, RHR is the resting heart rate, and percent HRR target is the desired percentage of the Heart Rate reserve to be used for training during treadmill work out. We used the Borg Rating of Perceived Exertion (RPE) scale (15) to validate the heart rate (HR) target zone. That included a three-minute warm-up on the ground at 30-40 percent of the heart rate (HRR) (8, 16). A 20-minute treadmill HIIT session followed by a 10-minute over-the-ground HIIT session (16). 10 mins of over-the-ground HIIT at a 60 percent heart rate and 14 to 16 Perceived Exertion on the Rating of Perceived Exertion (RPE) scale (17). A three-minute cool-down at 30-40% HRR concluded the session (16). Traditional physical therapy consisted of three 20 to 30-minute sessions of range-of-motion (ROM) exercises for the injured hip, knee, and ankle joints, and stretching for tight muscles of the lower limbs. The exertion was adjusted if needed to maintain a moderate effort without pain or discomfort.

HIIT protocol: The short-interval HIIT protocol used by the HIIT group was created especially for post-stroke locomotor exercise (18-22). HIIT was performed at 60% of HRR or 14–16 on the Borg

Rating of Perceived Exertion. A mean aerobic intensity above 60% of HRR was the goal, which was achieved by repeating 3 min of walking at the fastest safe pace, interspersed with 2 min of active recovery moments (walking or jogging at 30–40% of HRR) (16, 17).

Outcome Assessment: Blinded raters evaluated the results both prior to randomization (baseline) and after four weeks of training. The primary outcome measures were the Harvard step test, the 6-minute walk test, muscle atrophy measured by the calf circumference measured by the measuring tape, and muscle strength measured by manual muscle testing (MMT). The 10-meter walk test was used as a secondary measure to determine the fastest gait speed.

Statistical Analysis: SPSS (Statistical Package for Social Science) version 23 was used to analyze the data. The statistical significance level was set at $p < 0.05$. Shapiro-Wilk test was used to assess the normality of data, and a non-normal distribution was indicated by a p-value of less than 0.05. Parametric tests were used for the analysis of data after the confirmation of normal distribution. Independent sample t-test was used for between-group differences, and within-group differences were investigated employing paired sample t-tests.

RESULTS

Recruitment and Retention

Initially 42 stroke patients were screened, identifying 38 eligible patients for randomization (Figure 1). Participant enrollment occurred in December 2023. The trial ended when the desired sample size was achieved. After checking the normality of the data using the Shapiro-Wilk test, the results indicated that the data for all variables was normally distributed (p value < 0.05), allowing parametric tests to be applied in subsequent analyses.

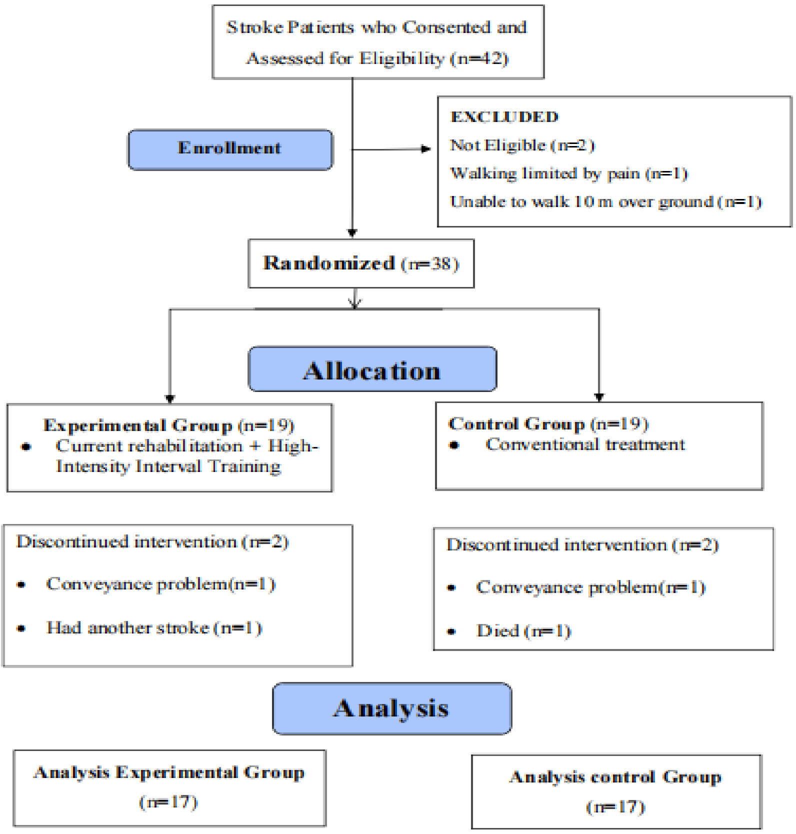

Figure 1: Study Flow Diagram

Table 1 presents the participants' baseline demographic data of 34 participants, 17 were randomly assigned to the experimental group and 17 to the control group. The experimental group had a mean age of 48.23 ± 4.94 years, while the control group had a mean age of 50.52 ± 4.30 years. There were 18 male (52.9%) and 16 female participants (47.1%) in the study. Height and sex distributions were documented for both groups. The experimental group showed a higher mean weight (96.94 ± 9.41 kg) than the control group (70.70 ± 7.85 kg).

Table 1: Baseline demographic data

Variable	**Experimental group (n=17)**	**Control group (n=17)**
Age (years)	48.23 ± 4.94	50.52 ± 4.30
Weight (Kg)	96.94 ± 9.41	70.70 ± 7.85
Height (cm)	160.52 ± 4.81	161.11 ± 5.36
Gender, n (%)		
• Male	8(47.1)	10(58.8)
• Female	9 (52.9)	7 (41.2)

The baseline clinical characteristics of all participants are shown in Table 2 for all variables, including MMT, Calf circumference, 6-minute walk test, Harvard step test, and 10-meter walk test as mean ± SD. The difference between the control and experimental groups was calculated by applying an independent sample t-test and is represented as a p-value.

Table 2: Baseline clinical characteristics for each group

Variable	**Experimental group (n=17)**	**Control group (n=17)**	**P-value**
MMT hip flexion right side	2.58 ± 0.50	2.24 ± 0.65	.12
MMT hip extension right side	2.17 ± 0.63	1.88 ± 0.66	.17
MMT knee flexion right side	2.11 ± 0.60	2.10 ± 0.60	1.00
MMT knee extension right side	2.00 ± 0.70	1.83 ± 0.63	.45
MMT ankle dorsiflexion right side	2.29 ± 0.77	1.94 ± 0.65	.16
MMT ankle plantar flexion right side	2.17 ± 0.72	1.88 ± 0.60	.20
MMT hip flexion left side	2.41 ± 0.79	1.88 ± 0.60	.06
MMT hip extension left side	1.76 ± 0.66	1.82 ± 0.63	.79
MMT knee flexion left side	2.17± 0.72	1.94 ± 0.74	.35
MMT knee extension left side	2.70 ± 0.68	2.93 ± 0.82	.07
MMT ankle dorsiflexion left side	2.17 ± 0.72	1.92 ± 0.42	.25
MMT ankle plantar flexion left side	2.05 ± 0.74	1.70 ± 0.68	.16
Calf circumference measurement	33.58 ± 1.17	32.35 ± 1.11	.40
6-Minute walk test	49.94 ± 5.15	46.00 ± 5.06	.08
Harvard step test	23.47 ± 6.05	22.00 ± 5.32	.45
10-Meter walk test	0.64 ± 0.07	0.66 ± 0.77	.34

MMT= Manual Muscle Testing

Outcomes:
After four weeks, substantial differences were observed between primary and secondary outcomes. Table 3 compares between-group muscular strength (MMT), calf circumference, and aerobic capacity (6 MWT and Harvard step test), as well as the secondary objective of highest gait speed (10 MWT). Independent sample t-tests revealed significant changes between the groups for all variables ($P < 0.05$), highlighting the effectiveness of high-intensity interval training. No adverse events were seen in either group.

Table 3: Post-Treatment Between Group Comparison of Both Groups

Variable	Experimental group (n=17)	Control group (n=17)	P-value
MMT hip flexion right side	4.58 ± 0.61	2.94 ± 0.55	.00
MMT hip extension right side	4.47± 0.62	2.88 ± 0.69	.00
MMT knee flexion right side	4.46 ± 0.61	2.11 ± 0.85	.00
MMT knee extension right side	4.52 ± 0.51	2.41 ± 0.71	.00
MMT ankle dorsiflexion right side	4.41 ± 0.50	2.70 ± 0.68	.00
MMT ankle plantar flexion right side	4.58 ± 0.61	2.47 ± 0.79	.00
MMT hip flexion left side	4.64 ± 0.49	2.76 ± 0.83	.00
MMT hip extension left side	4.52 ± 0.62	3.11 ± 1.11	.00
MMT knee flexion left side	4.47 ± 0.63	3.17 ± 0.72	.00
MMT knee extension left side	4.52 ± 0.62	3.17 ± 0.72	.00
MMT ankle dorsiflexion left side	4.29 ± 0.68	2.94 ± 0.65	.00
MMT ankle plantar flexion left side	4.41 ± 0.71	3.29 ± 0.77	.00
Calf circumference measurement	35.41 ± 1.66	32.47 ± 1.32	.00
6-Minute walk test	81.88 ± 4.79	57.88 ± 5.03	.00
Harvard step test	47.76 ± 10.59	25.00 ± 6.72	.00
10-Meter walk test	0.59 ± 0.72	0.69 ± 0.74	.01

MMT= Manual Muscle Testing

Table 4 shows the within-group comparisons of the pre-and post-intervention evaluations for both the experimental and control groups. Both groups showed significant within-group differences ($P < 0.05$) using paired t-tests. Notably, the experimental group showed more significant gains, with a greater mean difference than the control group.

Table 4: Within-group comparison of pre- and post-intervention assessments.

Variables	Groups	Paired difference Mean +S.D	P-value (within groups)
MMT hip flexion right side	Experimental	-2.00 ± 0.70	< 0.001*
	Control	-1.00 ± 0.70	< 0.001*
MMT hip extension right side	Experimental	-2.29 ± 6.85	< 0.001*
	Control	-1.00 ± 0.93	< 0.001*
MMT knee flexion right side	Experimental	-2.35 ± 0.60	< 0.001*
	Control	0.01 ± 0.79	< 0.001*
MMT knee extension right side	Experimental	-2.52 ± 1.06	< 0.001*
	Control	-0.5 ± 0.79	< 0.001*
MMT ankle dorsiflexion right side	Experimental	-2.11 ± 0.85	< 0.001*
	Control	-0.75 ± 0.97	< 0.001*
MMT ankle plantar flexion right side	Experimental	-2.41 ± 0.93	< 0.001*
	Control	-0.58 ± 0.87	< 0.001*
MMT hip flexion left side	Experimental	-2.23 ± 0.83	< 0.001*
	Control	-0.88 ± 0.78	< 0.001*
MMT hip extension left side	Experimental	-2.76 ± 0.75	< 0.001*
	Control	-1.29 ± 0.98	< 0.001*
MMT knee flexion left side	Experimental	-2.29 ± 0.84	< 0.001*
	Control	-1.05 ± 0.74	< 0.001*
MMT knee extension left side	Experimental	-1.82 ± 0.63	< 0.001*
	Control	-1.23 ± 0.66	< 0.001*

MMT ankle dorsiflexion left side	Experimental	-2.11 ± 0.60	< 0.001*
	Control	-1.00 ± 0.70	< 0.001*
MMT ankle plantar flexion left side	Experimental	-2.35 ± 0.60	< 0.001*
	Control	-1.58 ± 0.71	< 0.001*
Calf circumference measurement	Experimental	-1.82 ± 1.13	< 0.001*
	Control	-0.11 ± 0.33	< 0.001*
6-minute walk test	Experimental	-31.96 ± 4.36	< 0.001*
	Control	-1.88 ± 1.76	< 0.001*
Harvard step test	Experimental	-24.29 ± 7.03	< 0.001*
	Control	-3.00 ± 5.50	< 0.001*
10-meter walk test	Experimental	0.04 ± 0.02	< 0.001*

MMT, Manual Muscle Testing, SD = Standard Deviation, *Significant difference between groups, P < 0.05.

DISCUSSION

HIIT is gaining popularity in stroke therapy, with an emphasis on muscle strength, atrophy, and aerobic capacity. The experimental group received both HIIT and traditional physiotherapy, while the control group received only conventional treatment. Baseline screening, which included Manual Muscle Testing (MMT), the 6-Minute Walk Test (6MWT), the 10-Meter Walk Test (10MWT), and the Harvard Step Test, found no significant differences between groups. However, after the intervention, the HIIT group showed significant gains, outperforming the control group.

Capparos et al. discovered that HIIT increases lean mass in healthy people, motivating research into its effect on muscular strength and atrophy in patients with stroke (23). Research on robot-assisted gait training (RAGT) has shown that HIIT can enhance dynamic balance and aerobic capacity, which is worth comparing to our findings, particularly in terms of aerobic improvements (24). Our analysis of alterations in limb strength and velocity among patients with stroke is consistent with previous research on limb power and speed (25). A meta-analysis implied that high-intensity exercise increases aerobic capacity after stroke, prompting a critical review of our contradictory findings (26).

Our findings are consistent with previous studies on regaining cardiovascular fitness after stroke (27). Comparing HIIT with other treatments is critical, given its ability to stand out. Research on the effects of HIIT on lean mass and strength in healthy persons enhances our comparison, while insights into muscle size changes provide context for the observed improvements in stroke patients (27). HIIT's favorable effects on lean mass and maximum strength are consistent with our findings, although variations between dominant and non-dominant limbs require further investigation (23). Cardiovascular exercise after a cerebrovascular accident has been extensively studied, with a focus on its benefits (28).

Comparisons between mixed activity training and remote coaching indicate potential body composition benefits, adding to our lean mass and strength-focused study (29). Considering the advantages of aerobic exercises for mild-to-moderate stroke patients, including aerobic capacity aspects in our discussion, improves our knowledge of exercise outcomes in stroke therapy (30). Making links with cancer-related studies may shed light on the common functional ability implications, allowing for a more complete explanation of our results (31). Comparisons between High-Intensity Power Training (HIPT) and HIIT demonstrate program uniqueness and efficacy, which influenced our choice of HIIT routine (30).

Our inquiry into the influence of HIIT on muscular strength and functional gain is consistent with previous research, validating the ongoing trend in the literature (32). Research on the effects of HIIT and integrated exercise (CT) on physical function and body composition complexity adds to our

understanding of various exercise strategies (33). Despite HIIT's ability to change muscle growth in overweight people, changes in participant characteristics may explain variances in fitness objectives, emphasizing the necessity for nuanced methods in HIIT research (27, 34). Exploring the factors of improved aerobic capacity post-stroke and comparing workout frequencies in HIIT highlights the range of programs, emphasizing the importance of individualized exercise routines (35, 36).
HIIT's effects on lean mass, maximal strength, and lower limb muscular power in healthy persons are consistent with our findings, emphasizing the complex character of HIIT effects (23). The findings of Fajrin et al. on power limbs and speed, which contradict the focus of Stankovic et al. on numerous performance parameters, underscore the need for comprehensive measurements to evaluate the impact of HIIT on physical capabilities (24, 34).

Limitations: A major limitation of this study was the large variation in the time interval from stroke onset among the participants included. This heterogeneity poses a twin problem: it can confuse the interpretation of our results while also being a possible confounding factor. Another limitation is the absence of studies on underlying systems, which prevents a detailed understanding of the physiological justification of current data. The lack of variation in training regimens raises questions about ignoring the possible benefits of a more diverse approach. In addition, the external validity of our study may be restricted to stroke patients and not relevant to other neurological diseases directly.

Conclusion:
In conclusion, this randomized controlled trial evaluating the efficacy of HIIT in combination with conventional treatment versus conventional treatment alone in chronic stroke patients found promising results. Both therapies yielded significant outcomes, but when combined with conventional therapy, the high-intensity interval training program improved muscle strength and aerobic capacity and reduced atrophy in stroke patients. It is worth mentioning that these positive findings are consistent across demographic differences.

Generalizability:
Our study implies that including high-intensity interval training in traditional treatment regimens offers promising results in improving patient outcomes in chronic stroke rehabilitation.

Recommendations:
To validate our findings and draw clearer guidelines for clinical practice, we need a larger, more diverse population. This gives an overview of intervention efficiency across different demographic groups. We also advocate HIIT as part of stroke rehabilitation programs for both muscular strength and aerobic capacity. With possible benefits observed, more work on the long-term impact of HIIT on stroke prevention is needed. This will enrich the information base and allow optimization of stroke rehabilitation procedures.

Registration: This trial was prospectively registered at ClinicalTrials.gov (NCT06292442).

Protocol:
Currently, the full trial protocol is unavailable for public access. For inquiries or additional information regarding the trial protocol, please contact the principal investigator at tayyabadhillon@gmail.com

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Declaration of Interests:
The authors declare that they have no conflicts of interest related to this study.

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