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EFFECTIVENESS OF RHYTHMIC AUDITORY STIMULATION COMBINED WITH TREADMILL TRAINING ON GAIT SYMMETRY IN PATIENTS WITH PARKINSON'S DISEASE: A RANDOMIZED CONTROLLED TRIAL

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Abstract

Background: *Parkinson's disease (PD) is a progressive neurodegenerative disorder commonly associated with gait abnormalities, including reduced step length, decreased walking speed, impaired cadence, and gait asymmetry. Rhythmic auditory stimulation (RAS) provides external rhythmic cues that may facilitate auditory-motor synchronization and improve gait performance. Combining RAS with treadmill training may provide additional benefits in improving gait symmetry and functional walking ability.*
Objective: *To determine the effectiveness of rhythmic auditory stimulation combined with treadmill training on gait symmetry in patients with Parkinson's disease and compare its effects with treadmill training alone.*
Methods: *A two-arm, parallel-group randomized controlled trial was conducted at IIMCT – Railway General Hospital, Rawalpindi, Pakistan. A total of 54 patients with Parkinson's disease were enrolled and randomly allocated into two equal groups. Group A (n = 27) received rhythmic auditory stimulation combined with treadmill training, whereas Group B (n = 27) received treadmill training alone. The primary outcome was gait symmetry, assessed using the Symmetry Index (SI). Secondary outcomes included step length, stride length, cadence, and walking speed. Assessments were*

performed at baseline and immediately after completion of the intervention. Data was analyzed using IBM SPSS Statistics version 27, with statistical significance set at $p < 0.05$.

Results: *Both groups demonstrated improvements in gait-related outcomes following their respective interventions. In Group A, the mean Symmetry Index decreased from 18.25 ± 5.05 to 10.45 ± 4.25, representing a mean reduction of 7.80 points ($p < 0.001$). In Group B, the SI decreased from 18.35 ± 4.90 to 15.40 ± 4.55, representing a mean reduction of 2.95 points ($p = 0.012$). The between-group difference in gait symmetry was statistically significant ($p < 0.001$), favoring Group A. Significant between-group differences were also observed in step length ($p = 0.003$), stride length ($p = 0.001$), cadence ($p = 0.021$), and walking speed ($p = 0.005$), with greater improvements in the experimental group.*

Conclusion: *Rhythmic auditory stimulation combined with treadmill training was more effective than treadmill training alone in improving gait symmetry, step length, stride length, cadence, and walking speed in patients with Parkinson's disease. Incorporating rhythmic auditory stimulation into treadmill-based rehabilitation may provide additional benefits for improving gait performance and bilateral coordination.*

INTRODUCTION

Parkinson's disease (PD) is a progressive neurodegenerative disorder characterized by the degeneration of dopaminergic neurons in the substantia nigra pars compacta, resulting in impaired dopamine transmission within the basal ganglia circuits. It is one of the most common neurodegenerative disorders worldwide and represents a major cause of neurological disability, particularly among older adults. The clinical manifestations of PD extend beyond its classical motor symptoms of bradykinesia, rigidity, resting tremor, and postural instability, frequently involving disturbances in gait, balance, coordination, and functional mobility. These impairments progressively interfere with activities of daily living, independence, and overall quality of life. Although pharmacological treatment, particularly levodopa therapy, remains the cornerstone of symptomatic management, its effectiveness in addressing certain axial motor impairments, including gait disturbances, may be limited. Consequently, physiotherapy and structured rehabilitation interventions have become essential components of comprehensive Parkinson's disease management [1,2].

Gait dysfunction is among the most disabling motor manifestations of Parkinson's disease and is associated with substantial limitations in functional independence. Individuals with PD commonly demonstrate reduced walking speed, shortened step and stride length, decreased arm swing, increased double-support time, reduced trunk rotation, and impaired postural control. These abnormalities may become more pronounced as the disease progresses and can contribute to difficulties during walking, turning, initiating movement, and negotiating environmental obstacles. Freezing of gait, characterized by brief episodes of an inability to initiate or continue stepping despite the intention to walk, further increases mobility limitations and fall risk. The underlying mechanisms involve impaired basal ganglia function, reduced automaticity of movement, altered sensorimotor integration, and difficulties in generating and maintaining internally controlled rhythmic motor patterns. These changes collectively disrupt the normal temporal and spatial organization of walking and highlight the need for rehabilitation approaches that specifically target gait performance [1,3].

Gait asymmetry is another important aspect of Parkinsonian gait dysfunction that deserves particular attention in clinical rehabilitation. It refers to measurable differences between the two lower limbs during walking, particularly in step length, stride length, swing time, stance time, and weight-bearing distribution. Although asymmetry may also occur during normal aging, it can become more evident in individuals with PD because motor symptoms frequently develop or progress differently on the two sides of the body. One

lower limb may demonstrate shorter steps, reduced movement amplitude, or prolonged stance duration compared with the opposite limb. Such asymmetrical movement patterns interfere with coordinated locomotion, reduce walking efficiency, and may increase the difficulty of maintaining dynamic balance. Furthermore, gait asymmetry may persist even when general walking speed or other conventional gait parameters improve. Therefore, evaluating gait symmetry provides additional information about lower-limb coordination and walking quality that cannot be fully captured by measuring gait speed alone [3,4].

The clinical significance of gait asymmetry extends beyond differences in individual step characteristics. Normal human walking requires coordinated and relatively consistent contributions from both lower extremities to maintain forward progression, balance, and postural stability. In PD, impaired motor control and reduced automaticity can disrupt this bilateral coordination, producing differences in the duration and magnitude of movement between the affected and less-affected limbs. These abnormalities may become more apparent during activities requiring changes in walking speed, direction, or environmental adaptation. Consequently, rehabilitation strategies should not exclusively focus on increasing walking speed or stride length but should also consider improving the temporal and spatial consistency of bilateral lower-limb movement. This is particularly important because improvements in overall gait performance do not necessarily indicate normalization of the relationship between the two limbs [4,5].

Conventional physiotherapy interventions for Parkinson's disease commonly include strengthening exercises, flexibility training, balance activities, postural correction, overground gait training, aerobic conditioning, and task-specific movement practice. These approaches aim to improve physical capacity, functional mobility, and independence while minimizing secondary complications associated with reduced physical activity. Among these interventions, structured gait training has received considerable attention because it directly addresses the functional limitations experienced during walking. The American Physical Therapy Association's clinical practice guideline recommends gait training for individuals with PD to improve gait speed, stride length, mobility, balance, and motor function. The guideline also supports external cueing strategies as useful adjuncts to conventional physiotherapy, particularly when patients experience difficulties with internally generated movement patterns [2].

Treadmill training is a widely used rehabilitation intervention for improving walking performance in individuals with neurological disorders, including Parkinson's disease. It provides a controlled and repetitive walking environment in which speed, duration, and training intensity can be adjusted according to individual functional capacity. Unlike conventional overground walking, treadmill training offers a relatively consistent walking surface and allows patients to practice repetitive stepping movements under standardized conditions. Repeated exposure to rhythmic stepping may facilitate motor learning, improve lower-limb coordination, increase walking endurance, and enhance the ability to maintain a continuous walking pattern. Additionally, treadmill-based rehabilitation allows physiotherapists to progressively modify walking speed and training demands while providing appropriate supervision and safety support.

The therapeutic benefits of treadmill training in PD are supported by clinical and experimental evidence. Rutz et al. (2020), in their systematic review of physiotherapy interventions for freezing of gait and gait impairments in Parkinson's disease, reported that treadmill walking and external cueing strategies, including auditory and visual cues, were effective approaches for addressing gait disturbances. Their findings highlighted the potential value of combining different rehabilitation strategies to improve walking-related outcomes [1]. Similarly, the American Physical Therapy Association guideline identified gait training as an important intervention for improving stride length, gait speed, and functional mobility. It also reported that externally cued gait training could provide additional benefits compared with gait training without cueing [2].

More recently, research has investigated specialized treadmill protocols to improve specific components of gait control rather than focusing exclusively on general walking performance. Hulzinga et al. (2023) investigated split-belt treadmill training in individuals with Parkinson's disease through a randomized controlled study involving 52 participants. The intervention compared split-belt and conventional tied-belt treadmill training over four weeks. The findings demonstrated improvements in gait adaptation following split-belt training, with some benefits maintained at follow-up. However, improvements in gait adaptation did not consistently transfer to overground turning performance. This study suggests that

treadmill-based interventions can influence specific aspects of locomotor control, while also demonstrating that improvements in one gait-related outcome should not automatically be interpreted as improvements in all dimensions of walking [7].

Despite these benefits, treadmill training alone may not sufficiently address all the underlying mechanisms responsible for gait disturbances in PD. Although repetitive stepping provides opportunities to practice locomotor movements, patients may continue to experience difficulties with movement initiation, step timing, rhythm regulation, and bilateral coordination. These limitations are associated with impaired basal ganglia function and reduced capacity to generate automatic movement sequences. Consequently, incorporating external sensory information during treadmill training may provide an additional mechanism for facilitating more organized and coordinated walking. Among the available sensory cueing approaches, rhythmic auditory stimulation (RAS) has emerged as a particularly promising intervention.

Rhythmic auditory stimulation is a therapeutic technique that uses repetitive auditory signals, such as metronome beats or rhythmically structured music, to facilitate the timing and coordination of movements. It is based on the principle of auditory-motor synchronization, in which individuals naturally tend to coordinate their movements with an external rhythmic stimulus. Auditory information is processed through neural pathways involving auditory, premotor, supplementary motor, and motor networks, providing an alternative source of temporal information for regulating movement. In individuals with PD, external rhythmic cues may help compensate for impaired internal timing mechanisms by providing a predictable auditory reference for step initiation, continuation, and rhythm maintenance. When appropriately selected and synchronized with the patient's walking pattern, auditory cues may encourage more consistent step timing and facilitate improved locomotor performance [3,4].

RAS can be delivered through a metronome, rhythmic music, or other auditory signals with a clearly defined temporal structure. The cueing frequency is generally adjusted according to the individual's baseline cadence and rehabilitation goals. For example, cues may initially be provided at the patient's preferred walking cadence to facilitate rhythm synchronization. Depending on tolerance and treatment objectives, the frequency may subsequently be modified to encourage improvements in cadence or step length. However, cueing frequency should be individualized because an excessively rapid or slow rhythm may interfere with natural walking patterns. The objective is not simply to increase the number of steps per minute but to facilitate an appropriately coordinated and functional walking rhythm.

Evidence supporting RAS in Parkinson's disease has increased substantially in recent years. Ye et al. (2022) conducted a systematic review and meta-analysis evaluating the effects of rhythmic auditory stimulation on gait recovery in patients with PD. Their analysis included 18 studies involving 774 participants. The findings demonstrated significant improvements in stride length and gait speed among individuals receiving RAS compared with control interventions. Improvements were also reported in freezing-related outcomes, motor function, and quality of life. These findings suggest that rhythmic auditory stimulation can influence several clinically relevant aspects of mobility and functional performance in individuals with Parkinson's disease [3].

Similarly, Wang et al. (2022) conducted a systematic review and meta-analysis of randomized controlled studies to investigate the effects of RAS on gait and motor function in patients with PD. Their findings supported the beneficial effects of rhythmic auditory stimulation on gait-related outcomes and motor performance. The authors emphasized the potential role of auditory cueing as a rehabilitation approach for improving walking ability and reducing the functional consequences of Parkinsonian motor dysfunction. Collectively, these findings support the use of external rhythmic cues as a complementary intervention in neurological rehabilitation [4].

Further evidence was provided by Burrai et al. whose systematic review and meta-analysis examined the effectiveness of rhythmic auditory stimulation on gait speed, stride length, and cadence in individuals with Parkinson's disease. The analysis included five randomized controlled trials involving 209 participants. RAS was associated with significant improvements in gait speed and stride length compared with control interventions. However, the authors also identified methodological limitations, including the relatively small number of included studies, risk of bias, and low overall certainty of evidence. They

recommended adequately powered randomized controlled trials to establish the effectiveness of RAS more precisely [5].

An important development in literature is the investigation of auditory cueing as an addition to conventional walking rehabilitation rather than as an independent intervention. Nascimento et al. (2024) conducted a systematic review of randomized trials to compare walking training with external cueing against walking training alone in ambulatory individuals with Parkinson's disease. Ten trials involving 309 participants were included. The findings demonstrated that walking training combined with auditory cueing improved walking speed by an additional 0.09 m/s compared with walking alone. Although the estimated improvement in stride length was also favorable, the confidence interval was relatively wide. The authors concluded that adding auditory cueing to walking training may provide clinically meaningful benefits, although the quality of evidence was considered low and further research was required [6].

These findings are particularly relevant to the proposed combination of RAS and treadmill training. Treadmill training provides repetitive and task-specific stepping practice, whereas rhythmic auditory stimulation provides an external temporal reference that may facilitate synchronization and coordination of lower-limb movements. Their combined application may therefore address complementary components of gait dysfunction. While treadmill training encourages repeated locomotor activity under controlled conditions, auditory stimulation may assist patients in maintaining a consistent stepping rhythm. The combination could potentially improve the organization of gait cycles, reduce differences in temporal stepping characteristics, and enhance the coordination of bilateral lower-extremity movements. Importantly, auditory cueing may influence gait performance through mechanisms that are not entirely dependent on increasing walking speed. In patients with PD, rhythmic signals can provide an external timing reference that may assist in regulating the initiation and duration of individual steps. This may be particularly relevant when one lower limb demonstrates a different stepping pattern from the opposite limb. By providing a continuous and predictable rhythmic stimulus during treadmill walking, RAS may encourage more consistent timing and improve the temporal relationship between the two lower extremities. Nevertheless, whether these changes translate into measurable improvements in gait symmetry requires direct investigation rather than being assumed from improvements in conventional gait parameters.

The potential effectiveness of combining RAS with treadmill training can also be understood through the concept of auditory-motor entrainment. Entrainment refers to the synchronization of an individual's motor activity with an external rhythmic stimulus. While walking, auditory beats can act as temporal markers that help organize successive stepping movements. This may be particularly beneficial for individuals who have trouble maintaining a consistent gait rhythm because of impaired internal movement regulation. When auditory stimulation is delivered simultaneously with treadmill walking, patients receive both repetitive locomotor practice and continuous rhythmic feedback. This combination may promote more structured movement execution and facilitate the development of improved walking patterns through repeated practice.

The relationship between auditory cueing and gait adaptation has also been explored in clinical research examining different forms of gait instruction. Li et al. (2024) conducted a randomized controlled trial involving 45 individuals with Parkinson's disease to investigate the effects of different verbal instructions during treadmill and overground gait training. Participants received 12 training sessions using either instructions emphasizing larger steps or instructions emphasizing heel strike. Both groups demonstrated improvements in gait performance, while the heel-strike instruction group showed better maintenance of certain improvements during follow-up. Although verbal instructions are not equivalent to rhythmic auditory stimulation, the findings highlight the importance of externally provided information in modifying walking patterns and supporting the retention of gait improvements [10].

In addition to conventional rhythmic cueing, the use of specialized treadmill protocols has provided further insight into how external information can influence locomotor adaptation. Hulzinga et al. (2023) demonstrated that split-belt treadmill training could improve gait adaptation in individuals with PD, although the transfer of improvements to overground walking and turning was not uniform [7]. This distinction is important because rehabilitation outcomes should ideally reflect improvements in functional walking rather than changes restricted to the training environment. Therefore, evaluating gait

parameters outside the treadmill environment may provide valuable information about the functional transfer of rehabilitation-related improvements.

Other rehabilitation approaches have also been investigated to address the complex motor and cognitive demands associated with walking in Parkinson's disease. Du et al. (2023) conducted a systematic review and meta-analysis examining the effects of dual-task training on gait and motor abilities in patients with PD. Their analysis included seven randomized controlled trials involving 406 participants. The findings indicated significant improvements in several outcomes, including gait velocity, cadence, and functional mobility. These findings further support the importance of task-specific rehabilitation strategies that address the multiple mechanisms contributing to impaired walking [8].

Hvingelby et al. (2022), in a systematic review and network meta-analysis of randomized controlled trials, investigated different interventions for improving gait in Parkinson's disease. Their work emphasized that gait rehabilitation encompasses several intervention approaches, including treadmill-based exercise, external cueing, and other forms of structured physical training. The findings support the importance of selecting rehabilitation interventions according to the specific gait deficits being targeted rather than relying exclusively on general improvements in motor performance [9].

The clinical relevance of rhythmic auditory stimulation is further supported by research examining its application during treadmill and overground walking. A case series published by researchers investigating targeted rhythmic auditory cueing during treadmill and overground gait training demonstrated improvements in walking speed and stride length following a six-week intervention. The intervention involved adjusting metronome frequencies according to the participants' walking cadence and applying different cueing frequencies during treadmill and overground training. Although the study included only three participants and therefore cannot establish treatment effectiveness conclusively, it illustrates the importance of individualized auditory cue selection and the potential value of integrating rhythmic cueing with task-specific gait practice [11].

Local evidence also supports the clinical relevance of incorporating external cueing into treadmill-based rehabilitation. A randomized controlled study published in the Pakistan Journal of Health Sciences in 2023 compared treadmill training alone with treadmill training incorporating external cues in patients with Parkinson's disease. The study involved 74 participants and reported greater improvements in selected gait characteristics and functional activity measures in the group receiving treadmill training with external cueing. Although the intervention involved external cues more broadly rather than isolating the effect of rhythmic auditory stimulation, its findings provide contextually relevant evidence supporting the integration of cueing strategies into neurological rehabilitation practice [12].

Despite the growing evidence supporting auditory cueing and treadmill training, several important limitations remain in the existing literature. First, many studies investigating RAS have focused primarily on conventional gait parameters, including walking speed, stride length, and cadence. Although these variables provide useful information about walking performance, they do not necessarily establish whether bilateral lower-limb movement has become more symmetrical. A patient may demonstrate increased walking speed and longer strides while maintaining considerable differences between the two limbs. Consequently, improvements in conventional gait outcomes should not be considered equivalent to improvements in gait symmetry.

Second, the available studies have employed different auditory cueing protocols, treadmill speeds, intervention durations, training frequencies, and outcome assessment methods. This methodological variation makes direct comparison between studies difficult and limits the development of standardized rehabilitation protocols. The selection of auditory cue frequency is particularly important because individual patients may respond differently to rhythmic stimuli depending on their baseline cadence, disease severity, motor impairment, and ability to synchronize movement with external sounds. Therefore, individualized cueing protocols and standardized intervention procedures are necessary to establish reproducible treatment outcomes.

Third, although systematic reviews and meta-analyses have demonstrated beneficial effects of RAS on gait performance, the evidence specifically addressing bilateral gait symmetry remains comparatively limited. Most available research has emphasized overall walking improvement rather than investigating the relationship between the affected and less-affected lower limbs. Similarly, treadmill training studies have

frequently examined walking endurance, gait speed, motor function, and gait adaptation without making gait symmetry the principal outcome. This represents an important research gap because gait asymmetry is a clinically meaningful component of Parkinsonian locomotor dysfunction that may not respond in the same manner as other gait characteristics.

Furthermore, improvements observed immediately after rehabilitation may not necessarily be maintained over time or transferred to everyday walking activities. The findings of treadmill-based gait adaptation research suggest that improvements in trained locomotor tasks do not always translate into equivalent improvements in overground mobility [7]. Therefore, the evaluation of gait symmetry should ideally include standardized baseline and post-intervention assessments, with appropriate attention to the conditions under which walking performance is measured. Monitoring the medication state, treadmill speed, testing environment, and assessment procedures is also important to minimize potential sources of variability.

In this context, the combination of rhythmic auditory stimulation and treadmill training represents a promising rehabilitation approach that warrants further investigation. The intervention integrates two complementary therapeutic components: repetitive treadmill-based locomotor practice and externally generated rhythmic auditory cues. Treadmill training provides a controlled environment for repeated stepping, while RAS may assist in regulating the timing and coordination of successive movements. Their combined application may improve the temporal consistency of stepping and encourage more balanced participation of both lower extremities during walking. However, the magnitude and clinical relevance of these potential benefits, particularly in relation to gait symmetry, need to be established through controlled experimental research.

A randomized controlled trial is therefore appropriate for investigating the effectiveness of this combined intervention. By randomly allocating participants to intervention and comparison groups, the study can provide a more reliable assessment of whether adding rhythmic auditory stimulation to treadmill training produces greater improvements than treadmill training alone or another appropriately defined conventional rehabilitation protocol. The use of standardized gait assessment procedures can help quantify changes in bilateral step characteristics and determine whether the intervention produces measurable improvements in symmetry. In addition, evaluating gait speed, cadence, stride length, and functional mobility as secondary outcomes may provide a more comprehensive understanding of the intervention's effects.

The rationale for the present study is based on the need to move beyond general improvements in walking performance and investigate whether a combined auditory and treadmill-based rehabilitation approach can specifically address gait asymmetry in individuals with Parkinson's disease. Although previous research has demonstrated the beneficial effects of rhythmic auditory stimulation and treadmill training on different aspects of gait, comparatively less attention has been directed toward their combined effectiveness in improving bilateral gait symmetry. Establishing the effectiveness of this approach may contribute to the development of more targeted, evidence-based physiotherapy interventions for Parkinsonian gait dysfunction.

Accordingly, this randomized controlled trial aims to determine the effectiveness of rhythmic auditory stimulation combined with treadmill training on gait symmetry in patients with Parkinson's disease. By comparing the combined intervention with an appropriate control rehabilitation program, the study intends to establish whether the addition of rhythmic auditory stimulation provides greater improvements in gait symmetry. The findings may contribute to clinical decision-making in neurological physiotherapy and provide evidence for incorporating individualized rhythmic auditory cueing into treadmill-based gait rehabilitation programs.

GENERAL OBJECTIVE

To determine the effectiveness of rhythmic auditory stimulation combined with treadmill training on gait symmetry in patients with Parkinson's disease.

Specific Objectives

1. To evaluate the effect of rhythmic auditory stimulation combined with treadmill training on gait symmetry in patients with Parkinson's disease.
2. To compare the effectiveness of combined rhythmic auditory stimulation and treadmill training with treadmill training alone in improving gait symmetry in patients with Parkinson's disease.
3. To assess changes in secondary gait parameters, including step length, stride length, cadence, and walking speed, following the intervention.

Methodology

Study Design

A two-arm, parallel-group randomized controlled trial was conducted to determine the effectiveness of rhythmic auditory stimulation combined with treadmill training on gait symmetry in patients with Parkinson's disease. The study compared the combined intervention with treadmill training alone to evaluate whether the addition of rhythmic auditory stimulation produced greater improvements in gait symmetry and other gait-related parameters.

Study Setting

The study was conducted at IIMCT – Railway General Hospital, Rawalpindi, Pakistan. Participants were recruited from patients diagnosed with Parkinson's disease who attended the hospital for medical consultation and rehabilitation services.

Study Population

The study population consisted of male and female patients diagnosed with Parkinson's disease who fulfilled the predefined inclusion and exclusion criteria. Patients with mild to moderate disease severity who were capable of independent ambulation and able to participate safely in treadmill-based gait training were considered eligible.

Sample Size

A total sample of 54 participants was included in the study. Participants were randomly allocated into two equal groups using a 1:1 allocation ratio. Group A (experimental group) consisted of 27 participants who received rhythmic auditory stimulation combined with treadmill training, whereas Group B (control group) consisted of 27 participants who received treadmill training alone.

Sampling Technique

A non-probability consecutive sampling technique was used to recruit participants from IIMCT – Railway General Hospital, Rawalpindi. Patients who fulfilled the eligibility criteria and voluntarily agreed to participate were enrolled consecutively until the required sample size of 54 participants was achieved.

Randomization and Group Allocation

Following eligibility screening and baseline assessment, participants were randomly allocated into two groups in a 1:1 ratio. Group allocation was performed using a predefined randomization procedure. The experimental group received rhythmic auditory stimulation combined with treadmill training, while the control group received treadmill training alone. Allocation concealment was maintained through an appropriate allocation procedure, and the outcome assessor was kept unaware of group allocation wherever feasible to minimize assessment bias.

Inclusion Criteria

Participants were included in the study if they met the following criteria:

1. Patients diagnosed with idiopathic Parkinson's disease by a qualified neurologist.
2. Male and female patients within the age range of 40–75 years.
3. Patients classified within Hoehn and Yahr stages I–III.
4. Patients who were able to walk independently, with or without walking aid.

5. Patients who were medically stable and capable of following verbal and auditory instructions.
6. Patients who provided written informed consent to participate in the study.

Exclusion Criteria

Participants were excluded from the study if they met any of the following criteria:

1. Presence of other neurological disorders affecting gait.
2. Significant musculoskeletal conditions affect walking or mobility.
3. Severe cognitive impairment.
4. Significant hearing or visual impairment interfering with the intervention.
5. History of recent lower-limb surgery or fracture.
6. Cardiovascular or other medical conditions contraindicating treadmill exercise.
7. Advanced Parkinson's disease with inability to ambulate safely on a treadmill.

Intervention Protocol

The intervention was divided into two groups. Group A received rhythmic auditory stimulation combined with treadmill training, whereas Group B received treadmill training alone. Both groups were supervised by a qualified physiotherapist.

Table 1. Intervention protocol for experimental and control groups

Intervention components	**Group A: Experimental group (n=27)**	**Group B: Control group (n=27)**
Intervention	Rhythmic auditory stimulation combined with treadmill training	Treadmill training alone
Initial assessment	Baseline gait assessment and comfortable walking cadence measurement	Baseline gait assessment and comfortable walking cadence measurement
Treadmill training	Walking on treadmill at an individually adjusted speed	Walking on treadmill at an individually adjusted speed
Auditory stimulation	Metronome beats or rhythmic auditory signals provided during treadmill walking	No auditory rhythmic cueing
Cueing frequency	Individualized according to baseline walking cadence	Not applicable
Step synchronization	Participants synchronized their steps with the auditory rhythm	Participants maintained their natural walking rhythm
Training focus	Bilateral coordination, step consistency, temporal gait organization, and gait symmetry	Walking performance, lower-limb coordination, and gait consistency
Progression	Treadmill speed and auditory cueing adjusted according to individual tolerance and performance	Treadmill speed adjusted according to individual tolerance and performance
Supervision	Qualified physiotherapist	Qualified physiotherapist
Safety monitoring	Continuous monitoring of walking performance, fatigue, and adverse events	Continuous monitoring of walking performance, fatigue, and adverse events

Outcome Measures

The primary outcome measure was gait symmetry. Secondary outcome measures included step length, stride length, cadence, and walking speed. All outcome measures were evaluated at baseline before the

intervention and immediately after completion of the intervention using standardized assessment procedures.

Primary Outcome: Gait Symmetry

Gait symmetry was assessed by comparing the spatial and temporal characteristics of the right and left lower extremities during walking. Step length symmetry was considered a principal measure, while stance-time and swing-time symmetry were also evaluated where the assessment equipment permitted. Bilateral measurements were used to calculate the Symmetry Index (SI), which quantified the degree of difference between the two lower extremities.

The Symmetry Index was calculated using the following formula:

SI (%) = [(Right limb value − Left limb value) / (0.5 × (Right limb value + Left limb value))] × 100

The absolute value of the symmetry index was used for interpretation. A value closer to zero indicated greater symmetry between the right and left lower extremities, whereas higher values indicated greater asymmetry.

Secondary Outcome Measures

Step length was measured as the distance between the initial contact of one foot and the subsequent initial contact of the opposite foot. Measurements were recorded separately for the right and left lower extremities. Stride length was defined as the distance covered between two consecutive initial contacts of the same foot during walking. It was used to evaluate the spatial characteristics of the gait cycle. Cadence was determined by calculating the total number of steps taken per minute during walking and was expressed in steps per minute (steps/min). Walking speed was assessed by measuring the distance covered per unit of time during a standardized walking assessment and was expressed in meters per second (m/s).

Data Collection Procedure

After obtaining ethical approval and administrative permission, eligible participants were screened according to the predefined eligibility criteria. The study objectives, procedures, potential benefits, and possible risks were explained to each participant, and written informed consent was obtained before enrollment. Baseline demographic and clinical information, including age, gender, duration of Parkinson's disease, disease severity, and relevant medical history, was recorded using a structured data collection form. Baseline gait assessment was subsequently performed to document gait symmetry, step length, stride length, cadence, and walking speed. After baseline evaluation, participants were randomly allocated to either the experimental or control group. Both groups received their respective interventions according to the predefined treatment protocols. Following completion of the intervention, post-treatment assessments were conducted using the same assessment procedures and measurement conditions applied at baseline. To minimize potential measurement variability, the assessment procedures were standardized. Medication status and the timing of gait assessments in relation to antiparkinsonian medication were kept consistent between baseline and post-intervention measurements wherever possible. Participants' performance and any adverse events during the intervention were monitored and documented.

Data Analysis

Data was entered and analyzed using IBM SPSS Statistics version 27. Descriptive statistics were used to summarize participants' demographic and clinical characteristics. Continuous variables were presented as mean and standard deviation for normally distributed data, whereas median and interquartile range were used for non-normally distributed data. Categorical variables were presented as frequencies and percentages. The normality of continuous variables was assessed using the Shapiro–Wilk test. Within-group differences between baseline and post-intervention measurements were evaluated using the paired-samples t-test for normally distributed data and the Wilcoxon signed-rank test for non-normally distributed data. Between-group comparisons were performed using the independent-samples t-test or Mann–Whitney U test, as appropriate. Additionally, analysis of covariance (ANCOVA) was used, where appropriate, to compare post-intervention outcomes between the experimental and control groups while

adjusting for baseline measurements. The primary analysis focused on the between-group difference in change in gait symmetry. The level of statistical significance was set at $p < 0.05$, and all statistical tests were two-tailed.

Ethical Considerations

Ethical approval was obtained from the relevant institutional ethics review committee before the commencement of the study. Administrative permission was also obtained from IIMCT – Railway General Hospital, Rawalpindi. Written informed consent was obtained from all participants before data collection. Participants were informed about the purpose of the research, intervention procedures, potential benefits, and possible risks associated with treadmill training and auditory stimulation. Confidentiality and anonymity of participants were maintained throughout the study. Participation was voluntary, and participants were informed of their right to withdraw from the study at any stage without affecting their routine medical care. Appropriate safety measures were implemented during treadmill training, and any adverse events were documented.

RESULTS

Participants' Characteristics

A total of 54 patients with Parkinson's disease participated in the study. Participants were randomly allocated into two groups: Group A (experimental group), which received rhythmic auditory stimulation combined with treadmill training (n = 27), and Group B (control group), which received treadmill training alone (n = 27). All participants completed the intervention and post-intervention assessment; therefore, data from all 54 participants were included in the analysis.

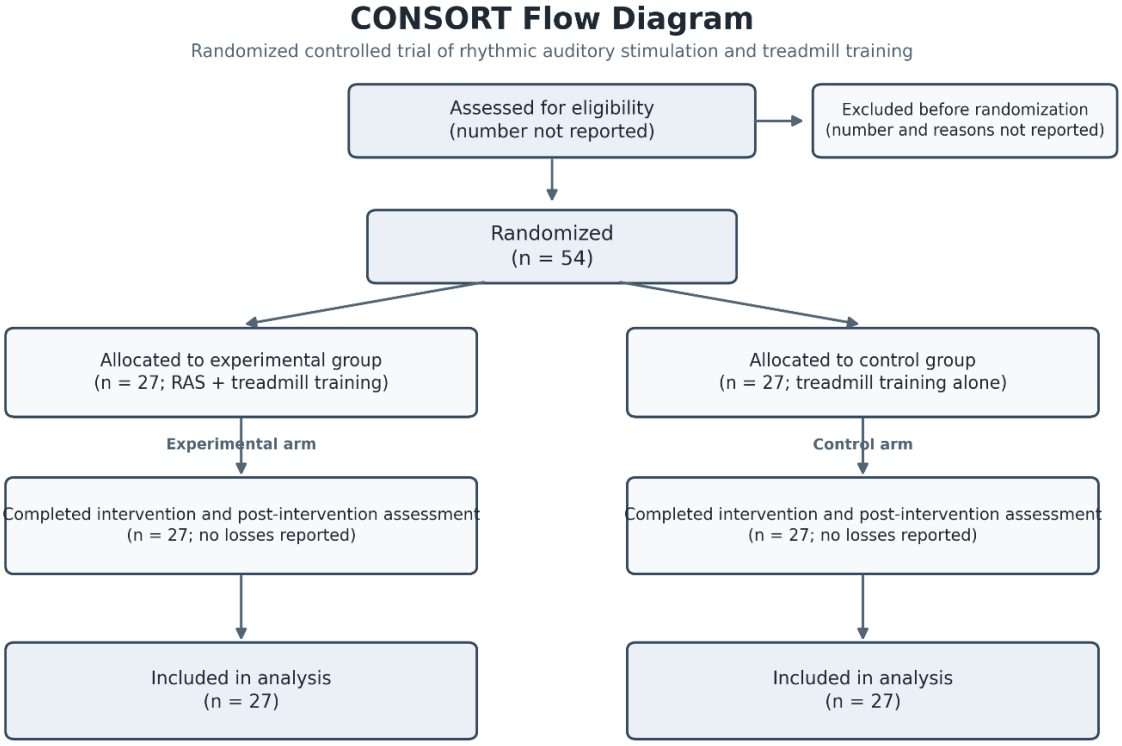


Figure 1: CONSORT flow diagram illustrating participant screening, randomization, group allocation, intervention completion, and analysis.

Demographic and Clinical Characteristics

The demographic and clinical characteristics of the participants are presented in Table 1. The mean age was 61.93 ± 6.85 years in Group A and 62.18 ± 7.05 years in Group B. Male participants constituted 55.6% of Group A and 59.3% of Group B, while female participants accounted for 44.4% and 40.7%, respectively. The mean duration of Parkinson's disease was 5.15 ± 2.05 years in Group A and 5.08 ± 1.95 years in Group B.

Regarding disease severity, 22.2% of participants in Group A and 18.5% in Group B were classified as Hoehn and Yahr stage I. Stage II was observed in 48.1% of Group A and 51.9% of Group B, while stage III was recorded in 29.6% of participants in each group. No statistically significant between-group differences were observed in age ($p = 0.891$), gender ($p = 0.786$), disease duration ($p = 0.894$), or Hoehn and Yahr stage ($p = 0.941$), indicating comparable baseline demographic and clinical characteristics.

Table 1. Demographic and clinical characteristics of participants (N = 54)

Variables	Group A (n = 27)	Group B (n = 27)	p-value
Age (years), mean ± SD	61.93 ± 6.85	62.18 ± 7.05	0.891
Gender, n (%)			0.786
Male	15 (55.6%)	16 (59.3%)	
Female	12 (44.4%)	11 (40.7%)	
Disease duration (years), mean ± SD	5.15 ± 2.05	5.08 ± 1.95	0.894
Hoehn and Yahr stage, n (%)			0.941
Stage I	6 (22.2%)	5 (18.5%)	
Stage II	13 (48.1%)	14 (51.9%)	
Stage III	8 (29.6%)	8 (29.6%)	

Between-Group Comparison of Gait Symmetry at Baseline and Post-Intervention

Gait symmetry, the primary outcome, was assessed using the Symmetry Index (SI). As shown in Table 2, the mean SI in Group A decreased from 18.25 ± 5.05 at baseline to 10.45 ± 4.25 after the intervention, representing a mean reduction of 7.80 points. This within-group change was statistically significant ($p < 0.001$). In Group B, the mean SI decreased from 18.35 ± 4.90 to 15.40 ± 4.55, representing a mean reduction of 2.95 points; this change was also statistically significant ($p = 0.012$). The between-group comparison demonstrated a statistically significant difference in gait symmetry in favor of Group A ($p < 0.001$). The greater reduction in SI in Group A indicated a larger improvement in gait symmetry among participants who received rhythmic auditory stimulation combined with treadmill training than among those who received treadmill training alone.

Table 2. Comparison of gait symmetry between experimental and control groups

Group	Baseline (Mean ± SD)	Post-intervention (Mean ± SD)	Mean change	Within-group p-value	Between-group p-value
Group A (n = 27)	18.25 ± 5.05	10.45 ± 4.25	−7.80	<0.001	<0.001
Group B (n = 27)	18.35 ± 4.90	15.40 ± 4.55	−2.95	0.012	

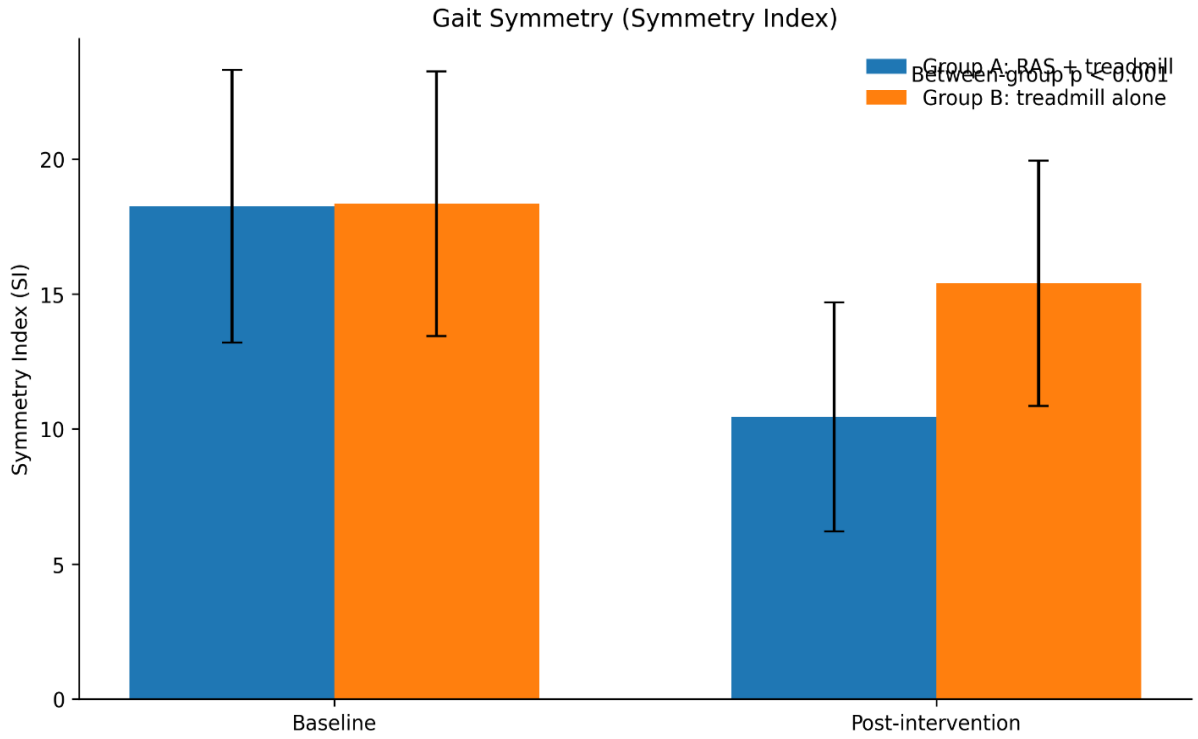


Figure 2: Comparison of gait symmetry (Symmetry Index) at baseline and post-intervention between the experimental and control groups. Lower values indicate greater gait symmetry.

Comparison of Secondary Gait Parameters

The secondary outcome measures included step length, stride length, cadence, and walking speed. The baseline and post-intervention values for these parameters are presented in Table 3. Both groups demonstrated increases in all four gait parameters following their respective interventions; however, the increases were greater in Group A.

In Group A, mean step length increased from 46.85 ± 5.95 cm at baseline to 55.10 ± 6.35 cm post-intervention. In Group B, it increased from 47.05 ± 6.05 cm to 49.20 ± 5.95 cm. Mean stride length increased from 93.90 ± 10.95 cm to 110.25 ± 11.85 cm in Group A, compared with an increase from 94.20 ± 11.05 cm to 98.75 ± 11.20 cm in Group B.

Mean cadence increased from 91.95 ± 9.95 steps/min to 100.85 ± 10.30 steps/min in Group A and from 92.15 ± 10.05 steps/min to 95.40 ± 9.90 steps/min in Group B. Similarly, mean walking speed increased from 0.73 ± 0.11 m/s to 0.90 ± 0.13 m/s in Group A and from 0.72 ± 0.12 m/s to 0.79 ± 0.11 m/s in Group B.

Between-group comparisons showed statistically significant differences in step length ($p = 0.003$), stride length ($p = 0.001$), cadence ($p = 0.021$), and walking speed ($p = 0.005$). These differences favored Group A, which demonstrated greater post-intervention values across all secondary gait parameters.

Table 3. Comparison of secondary gait parameters between experimental and control groups

Outcome measures	Group A baseline	Group A post-intervention	Group B baseline	Group B post-intervention	Between-group p-value
Step length (cm)	46.85 ± 5.95	55.10 ± 6.35	47.05 ± 6.05	49.20 ± 5.95	0.003
Stride length (cm)	93.90 ± 10.95	110.25 ± 11.85	94.20 ± 11.05	98.75 ± 11.20	0.001
Cadence (steps/min)	91.95 ± 9.95	100.85 ± 10.30	92.15 ± 10.05	95.40 ± 9.90	0.021

Walking speed (m/s)	0.73 ± 0.11	0.90 ± 0.13	0.72 ± 0.12	0.79 ± 0.11	0.005

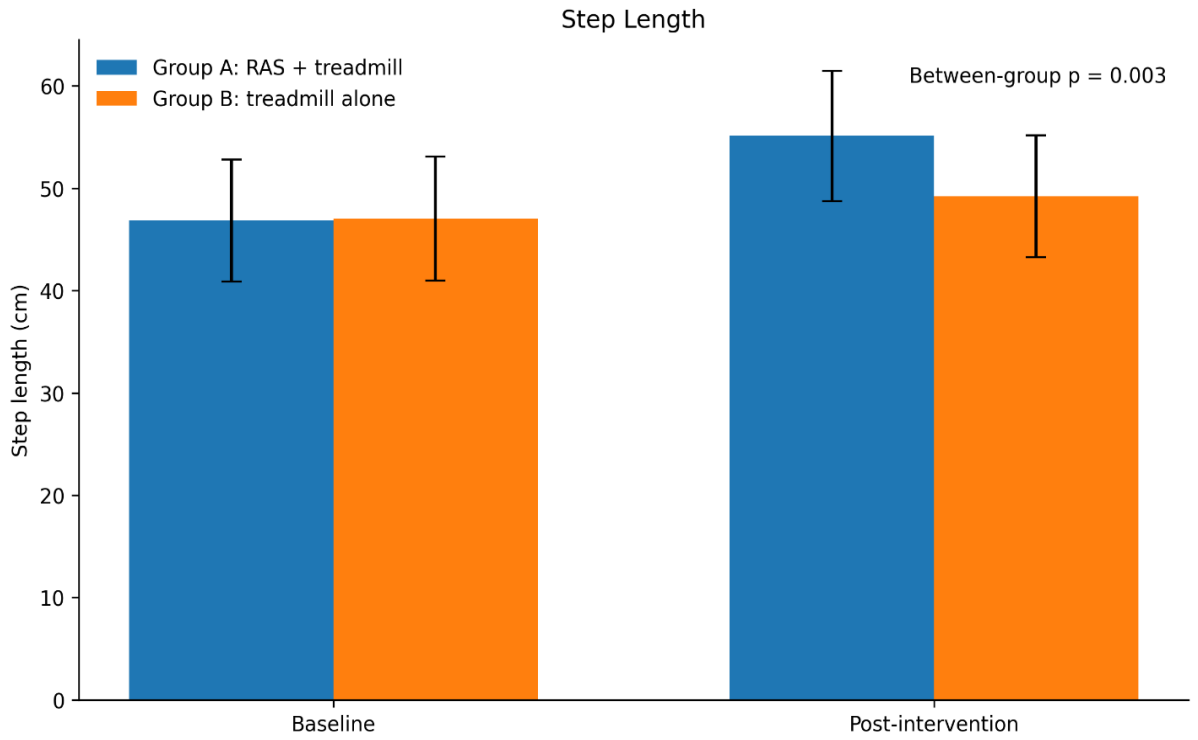


Figure 3: Comparison of step length at baseline and post-intervention between the experimental and control groups.

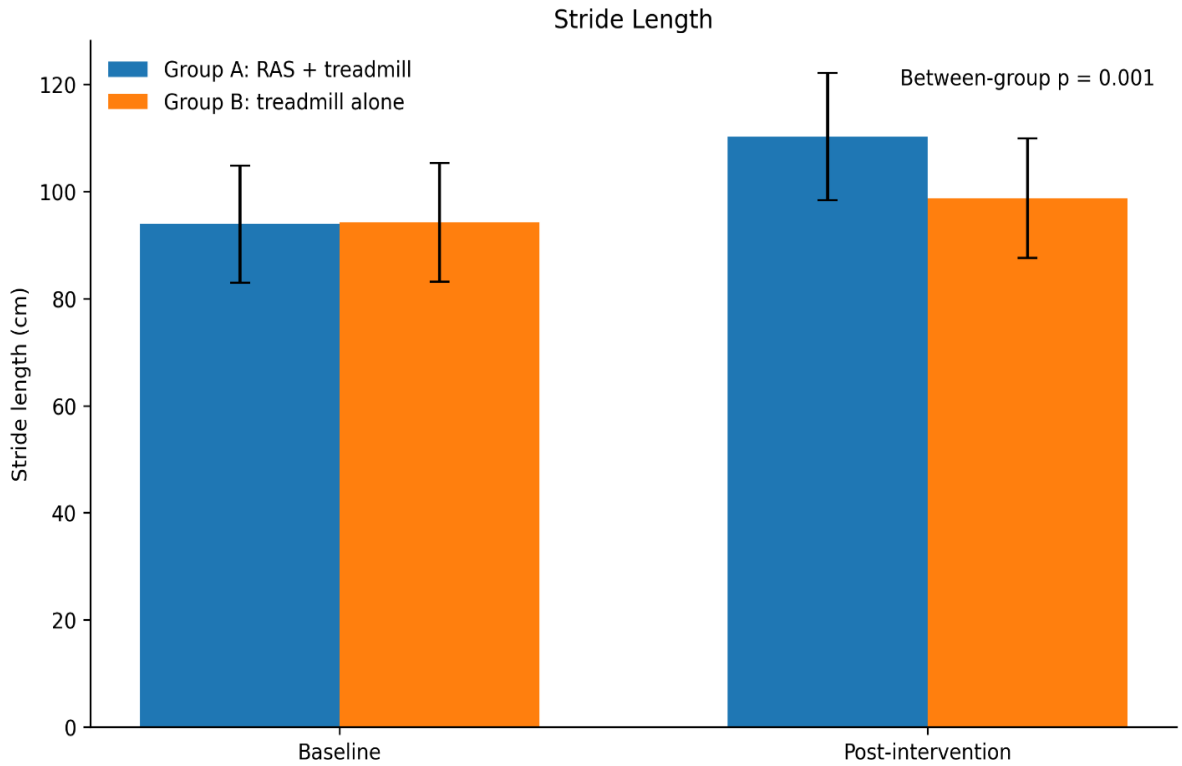


Figure 4: Comparison of stride length at baseline and post-intervention between experimental and control groups.

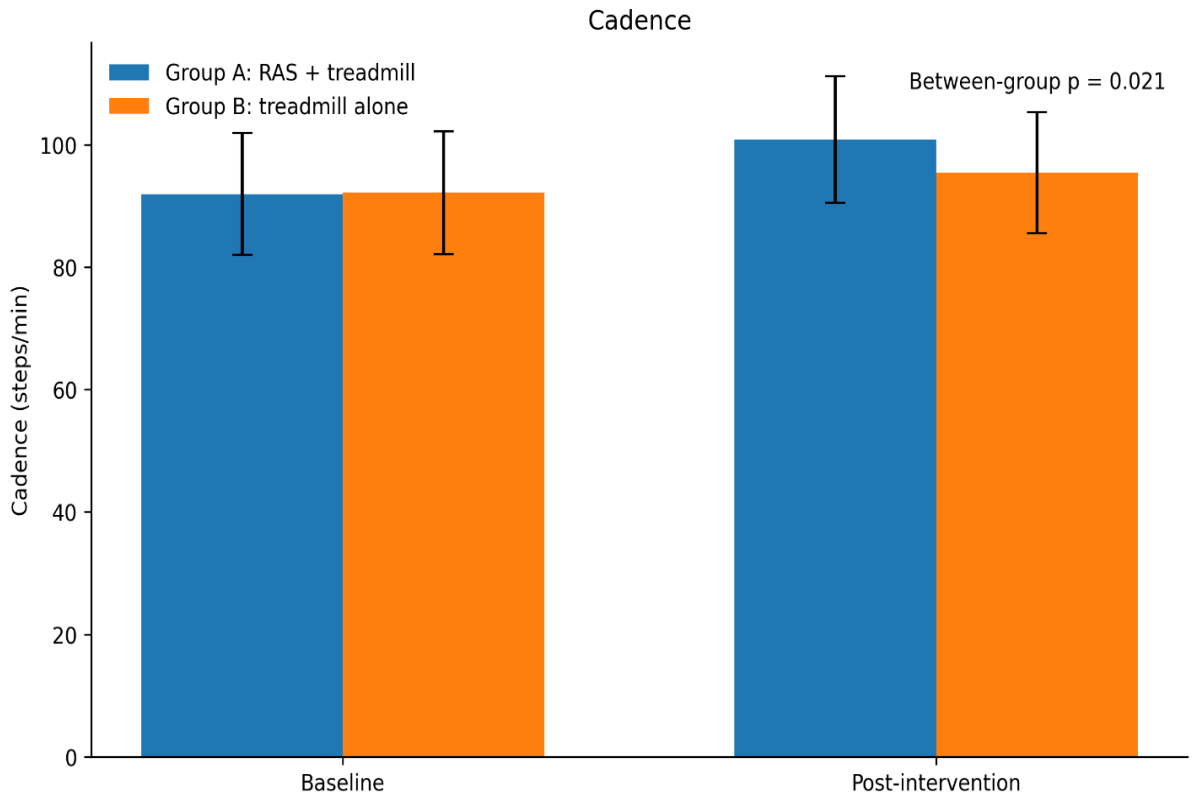


Figure 5: Comparison of cadence at baseline and post-intervention between the experimental and control groups.

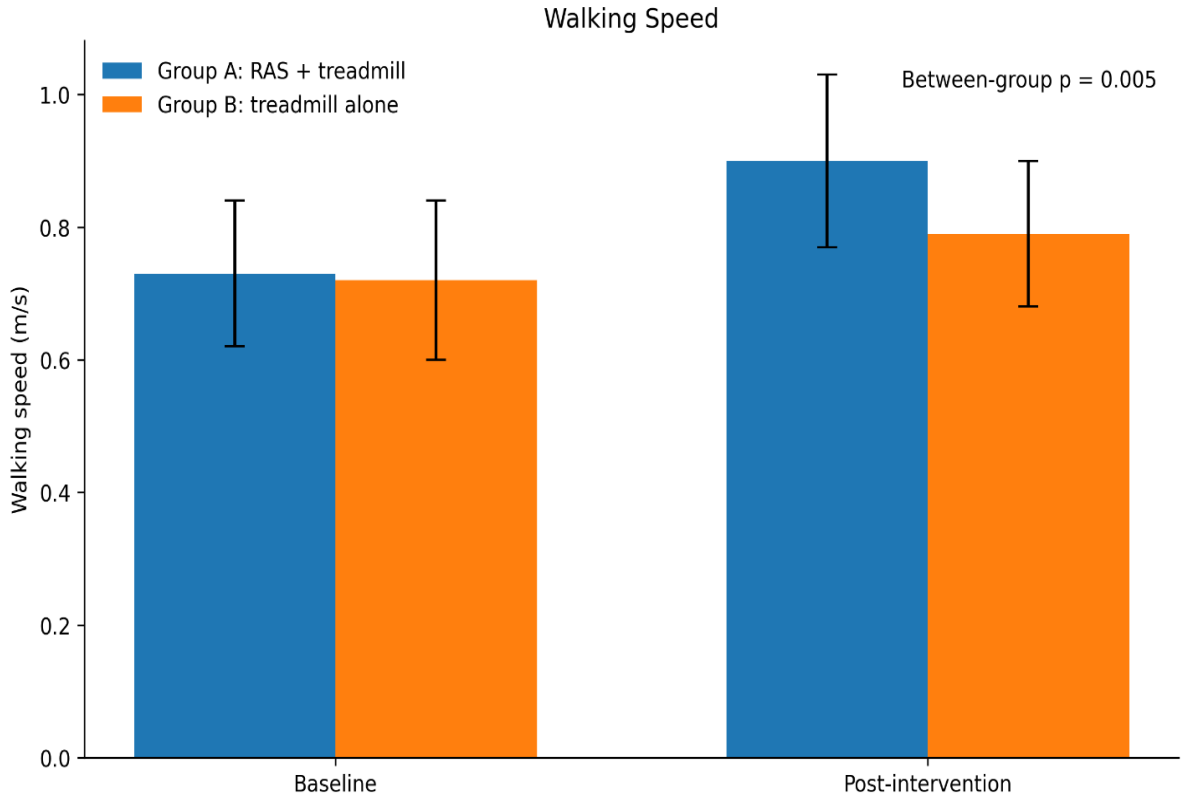


Figure 6: Comparison of walking speed at baseline and post-intervention between experimental and control groups.

Summary of Main Findings

Both groups demonstrated improvements in gait-related outcomes following their respective interventions. However, Group A, which received rhythmic auditory stimulation combined with treadmill training, showed a greater reduction in the Symmetry Index and greater improvements in step length, stride length, cadence, and walking speed than Group B, which received treadmill training alone. Between-group differences were statistically significant for gait symmetry and all secondary gait parameters. Overall, the findings indicated that the addition of rhythmic auditory stimulation to treadmill training was associated with greater improvements in gait performance among patients with Parkinson's disease.

DISCUSSION

The present randomized controlled trial investigated the effectiveness of rhythmic auditory stimulation (RAS) combined with treadmill training on gait symmetry in patients with Parkinson's disease (PD), compared with treadmill training alone. The findings demonstrated greater improvements in the experimental group across the primary outcome of gait symmetry and all secondary outcomes, including step length, stride length, cadence, and walking speed. These results support the potential additional benefits of incorporating rhythmic auditory stimulation into conventional treadmill-based gait rehabilitation.

Gait Symmetry

The most important finding was the greater improvement in gait symmetry in the experimental group. The mean Symmetry Index decreased from 18.25 ± 5.05 to 10.45 ± 4.25, representing a reduction of 7.80 points. In comparison, the control group demonstrated a reduction of 2.95 points, from 18.35 ± 4.90 to 15.40 ± 4.55. The between-group difference was statistically significant ($p < 0.001$). This improvement may be associated with the ability of external rhythmic cues to facilitate auditory-motor synchronization. Patients with Parkinson's disease commonly experience impaired internal movement regulation due to basal ganglia dysfunction, resulting in difficulties maintaining consistent stepping patterns. Rhythmic auditory stimulation provides an external temporal reference that may assist in organizing successive stepping movements and improving bilateral coordination [3,4]. These findings are consistent with Ye et al. (2022), who reported improvements in gait performance following rhythmic auditory stimulation in patients with Parkinson's disease [3]. Similarly, Wang et al. (2022) demonstrated beneficial effects of auditory rhythmic cueing on gait and motor function [4]. Burrai et al. (2024) also reported significant improvements in gait-related outcomes, particularly walking speed and stride length, following rhythmic auditory stimulation [5]. The present study extends this evidence by demonstrating a greater reduction in gait asymmetry when auditory stimulation was combined with treadmill training. This is particularly relevant because improvements in conventional gait parameters do not necessarily indicate improvements in bilateral gait symmetry.

Effectiveness Compared with Treadmill Training Alone

Both groups demonstrated improvements in gait symmetry, indicating that treadmill training alone was also associated with better gait performance. However, the greater reduction in SI in the experimental group suggests an additional benefit from incorporating rhythmic auditory stimulation. Treadmill training provides repetitive, task-specific walking practice in a controlled environment, whereas auditory cueing provides external rhythmic information to facilitate stepping consistency. Their combined application may therefore address complementary aspects of locomotor dysfunction. Rutz et al. (2020) identified treadmill training and external cueing as useful physiotherapy approaches for addressing gait impairments in Parkinson's disease [1]. Similarly, Osborne et al. (2022) recommended gait training and external cueing strategies to improve walking-related outcomes [2]. Importantly, Nascimento et al. (2024) reported that walking training combined with auditory cueing improved walking speed by an additional 0.09 m/s compared with walking training alone [6]. This supports the present findings and highlights the potential value of adding auditory stimulation to conventional gait rehabilitation.

Step Length and Stride Length

The experimental group demonstrated greater improvements in both step length and stride length. Step length increased by 8.25 cm in Group A compared with 2.15 cm in Group B, while stride length increased by 16.35 cm and 4.55 cm, respectively. The between-group differences were statistically significant for step length ($p = 0.003$) and stride length ($p = 0.001$). Reduced step and stride lengths are common characteristics of Parkinsonian gait and contribute to inefficient walking patterns and reduced mobility. Rhythmic auditory stimulation may facilitate the regulation of stepping movements by providing predictable temporal cues during repetitive treadmill walking. The findings are consistent with Ye et al. (2022) and Burrai et al. (2024), who reported improvements in stride length following rhythmic auditory stimulation [3,5]. Nascimento et al. (2024) also identified additional benefits of incorporating auditory cueing into walking training [6]. The greater improvements observed in the experimental group therefore support the use of combined auditory and treadmill-based rehabilitation to address spatial gait abnormalities.

Cadence and Walking Speed

Cadence increased by 8.90 steps/min in the experimental group compared with 3.25 steps/min in the control group. Similarly, walking speed increased by 0.17 m/s in Group A and 0.07 m/s in Group B. The between-group differences were statistically significant for cadence ($p = 0.021$) and walking speed ($p = 0.005$). The improvement in cadence may reflect better regulation of stepping rhythm through external auditory signals. Patients with Parkinson's disease frequently experience difficulties generating and maintaining internally controlled rhythmic movements. Auditory cueing may provide an alternative temporal reference that assists in maintaining a more consistent walking pattern [3,4]. The improvement in walking speed is also consistent with Nascimento et al. (2024), who demonstrated additional benefits of auditory cueing during walking training [6]. Similarly, Ye et al. (2022) and Burrai et al. (2024) reported improvements in gait speed following rhythmic auditory stimulation [3,5]. These findings indicate that combining rhythmic auditory stimulation with treadmill training may improve both spatial and temporal characteristics of gait rather than influencing walking speed alone.

Clinical Implications

The findings have practical implications for neurological physiotherapy. Incorporating rhythmic auditory stimulation into treadmill-based rehabilitation may provide additional benefits for patients with mild to moderate Parkinson's disease who experience gait asymmetry, reduced step length, and impaired walking rhythm. The intervention combines repetitive locomotor practice with external rhythmic feedback, potentially facilitating more consistent stepping patterns and improved walking performance. Individualized auditory cueing according to baseline cadence may also help physiotherapists adapt treatment to the functional capacity of individual patients. These findings support the clinical recommendations of Osborne et al. (2022), which emphasize gait training and external cueing as important components of Parkinson's disease rehabilitation [2].

Strengths and Limitations

The randomized controlled design, equal allocation of participants, and direct comparison of treadmill training with and without rhythmic auditory stimulation were important strengths of this study. Furthermore, the inclusion of gait symmetry as the primary outcome and four additional gait parameters provided a broader evaluation of rehabilitation outcomes. However, the study had some limitations. The sample size was relatively small, with 54 participants recruited from a single hospital setting, which may limit generalizability. The study included patients with mild to moderate Parkinson's disease, and therefore the findings may not be applicable to individuals with advanced disease. Additionally, only baseline and immediate post-intervention assessments were reported, limiting conclusions regarding the long-term retention of improvements. Falls, balance, functional independence, and quality of life were also not included among the reported outcomes. Future studies should include larger multicenter samples, longer follow-up periods, and additional functional outcomes to establish the long-term clinical benefits of combining rhythmic auditory stimulation with treadmill training.

CONCLUSION

The present study concluded that rhythmic auditory stimulation combined with treadmill training was more effective than treadmill training alone in improving gait symmetry and other gait-related parameters in patients with Parkinson's disease. Although both intervention groups demonstrated improvements following treatment, the experimental group showed a significantly greater reduction in the Symmetry Index, indicating a greater improvement in bilateral gait symmetry. Similarly, greater improvements were observed in step length, stride length, cadence, and walking speed in the experimental group compared with the control group. These findings suggest that rhythmic auditory stimulation provides additional benefits when incorporated into conventional treadmill-based gait rehabilitation. Therefore, the combination of rhythmic auditory stimulation and treadmill training may be considered a beneficial physiotherapy approach for improving gait performance and addressing gait asymmetry in patients with Parkinson's disease.

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