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Effect of Rhythmic Auditory Stimulation Versus Non-Rhythmic Auditory Stimulation Training on Lower Extremity Motor Control and Functional Mobility in Sub-Acute and Chronic Stroke Patients: An Experimental Study

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ABSTRACT

Stroke frequently damages the brain pathways responsible for planning and carrying out movement, leaving many survivors with weakness, poorly coordinated lower limb movements that make standing, walking and turning difficult. Pacing a patient's steps to an external sound, generally called rhythmic auditory stimulation (RAS), is a promising add-on to ordinary physiotherapy, but it remains unclear how much of the benefit comes from the steady beat itself rather than from listening to sound during exercise in general. This experimental study compared a rhythm-based auditory cueing programme with a non-rhythmic (ambient) auditory programme, using identical balance and gait exercises, in patients recovering from stroke. Twenty-two sub-acute and chronic stroke patients aged 40-70 years were selected by purposive sampling and divided into two equal groups. Group A practiced balance and gait exercises paced to metronome beats matched to their own walking cadence; Group B performed the same exercises while listening to ambient music with no fixed beat. Both groups additionally received conventional physiotherapy, three sessions a week for four weeks. Lower-limb motor control, dynamic balance and walking speed were assessed by using Fugl-Meyer Assessment (Lower Extremity), the Dynamic Gait Index and the Ten-Meter Walk Test. Both groups improved significantly on all measures ($p<0.001$), but gains were consistently larger in the rhythm-cued group, particularly in voluntary motor control, coordination/speed, dynamic balance and walking speed ($p<0.05$ to $p<0.001$); reflex-related scores changed little in either group. These findings indicate that pairing balance and gait training with a steady auditory beat produces greater improvement in lower-limb motor control and functional mobility than the same training paired with non-rhythmic sound, supporting rhythmic auditory stimulation as a simple, cost effective addition to stroke rehabilitation.

Keywords: *Stroke Rehabilitation, Rhythmic Auditory Stimulation, Auditory-Motor Entrainment, Lower Extremity Motor Control, Functional Mobility, Gait Training*

1. INTRODUCTION

A stroke occurs when blood supply to part of the brain is suddenly cut off or a blood vessel bursts, and the resulting tissue damage is one of the leading causes of death and long-term disability worldwide [1]. Roughly eighty-five percent of strokes are caused by a blockage in a blood vessel, while the remainder result from bleeding inside or around the brain. Global data collected between 1990 and 2019 show that new stroke cases rose by about seventy percent and stroke-related deaths rose by over forty percent in that period [2]. In India, stroke is now among the top five causes of years lived with disability, with several million people affected and stroke contributing to a substantial share of all recorded deaths [3]; a person's lifetime risk of stroke after the age of fifty-five is roughly one in five for women and one in six for men [4].

Which parts of the body are affected after a stroke depends heavily on where the damage occurs, but impaired movement is by far the most common and most disabling consequence. Damage to the motor cortex, the corticospinal tract, the basal ganglia or related pathways interferes with the brain's ability to plan and carry out voluntary movement, producing muscle weakness, abnormal tone, presence of abnormal synergies [5], that stop a joint from moving on its own [6]. Because standing balance and walking depend on the brain, nerves and muscles working together smoothly [7], damage to the lower limb often leaves patients unable to shift their weight evenly, walk at a normal pace, or move confidently between directions and different surfaces, with asymmetrical step length, reduced speed and a slower cadence typical of the resulting gait pattern [8]. These increases risk of fall and reduces independence in everyday life.

A growing number of rehabilitation techniques aim to rebuild this lost coordination, and one that has drawn particular interest is rhythmic auditory stimulation (RAS). In RAS patient is asked to move in time with an external sound, usually a metronome beat or music with a strong, steady pulse. The underlying idea is that the brain's auditory and motor systems are closely linked, so a predictable beat can act as an external clock that the motor system locks onto, a phenomenon known as auditory-motor entrainment. When a rhythmic cue is heard, the auditory cortex appears to synchronize with motor-planning regions such as the premotor cortex, supplementary motor area, cerebellum and basal ganglia, and imaging work has shown that this synchronization engages the same striatal circuits that are central to movement control [9]. With repeated practice, this mechanism is thought to encourage the nervous system to reorganize around surviving pathways, so that movements gradually become better timed, better ordered and more coordinated. Because the beat gives patients a steady target to move towards, it can also make steps length even and lower the risk of fall.

Not all sound-based rehabilitation relies on a fixed beat, however. Ambient or patient-preferred music with no clear pulse has also been reported to improve motor recovery, largely by making exercise more engaging and by activating brain regions linked to motivation, arousal and reward, which can indirectly support motor learning even without a precise timing cue. This raises an important clinical question: does the benefit of auditory cueing come mainly from the rhythm itself, or simply from listening to sound while exercising? Most existing studies compare RAS with ordinary physiotherapy that includes no sound at all, making it difficult to isolate the specific contribution of rhythm, and very few trials have directly compared rhythmic and non-rhythmic auditory cueing using otherwise identical exercise programs. The present study was addresses this literature gap by comparing a rhythm-based auditory training programme with a matched, non-rhythmic auditory training programme, using the same balance and gait exercises, in patients with sub-acute and chronic stroke.

Aim: To compare the effect of rhythmic auditory stimulation training with non-rhythmic auditory stimulation training on lower-extremity motor control and functional mobility in sub-acute and chronic stroke patients.

Objectives: (1) To determine the effect of rhythmic auditory stimulation on lower-extremity motor control and functional mobility using the FMA-LE, DGI and 10mWT. (2) To determine the effect of non-rhythmic auditory stimulation on the same outcomes. (3) To compare the effect of the two interventions on lower-extremity motor control and functional mobility.

2. REVIEW OF LITERATURE

A systematic review of twenty-one trials found that RAS-based gait training was consistently linked to improved walking ability, gait parameters and balance compared with conventional rehabilitation that did not use auditory cues [10]. In a randomized trial pairing treadmill training with RAS in hemiplegic stroke patients, both the RAS and non-RAS treadmill groups improved on step length, walking speed and step cycle, but the rhythmically cued group improved significantly more [11]. including eighteen randomized trials, a meta-analysis likewise concluded that RAS produces meaningful gains in gait parameters, FMA-LE motor scores and balance compared with conventional treatment [12]. In a smaller study, a home- and community-based auditory cueing programme delivered with a simple metronome was found to be effective, safe, acceptable and easy for stroke survivors to sustain over six weeks [13]. Looking at non-rhythmic musical approaches, a review of ten trials involving background music, patient-preferred music and structured music training concluded that music of any kind can support motor recovery, motivation and engagement after stroke, even without a fixed beat [14].

In the literature the FMA-LE has been shown to have high agreement between different raters and across repeated assessments soon after stroke, supporting its use as a motor-control outcome [15]. Simple smartphone-based step counters have been shown to agree well with standard measurement methods in people with chronic stroke, regardless of where on the body the phone is worn [16]. The Dynamic Gait Index has been confirmed as a reliable and valid tool for dynamic balance in chronic stroke, correlating well with other established balance and mobility scales [17], and a descriptive meta-analysis of nine studies covering more than nine hundred stroke patients established the Ten-Meter Walk Test as the standard method for measuring walking speed in the months following a stroke [18]. This body of work confirms that RAS reliably improves gait and balance outcomes relative to conventional care, that non-rhythmic music also offers some benefit, and that the FMA-LE, DGI and 10mWT are dependable tools for tracking lower-limb recovery. What it does not settle is how much extra benefit the rhythmic component of RAS provides once it is tested directly against a matched, non-rhythmic auditory condition rather than against silence, which is the specific question this study addresses.

3. RESEARCH METHODOLOGY

3.1 Study Design and Setting

Comparative experimental study carried out over a one-year period (2025-2026), with the treatment duration of four weeks. Participants were recruited from old-age homes, rehabilitation centers and outpatient facilities in and around Vadodara, Gujarat, and training was delivered at the participant's home or at the relevant institution. Ethical approval was obtained from the Institutional Ethics Committee of Pioneer Physiotherapy College and Shri Govind Guru University (proposal no. PPC/OW/1325I/2025) before recruitment, and written informed consent was obtained from every participant.

3.2 Sample Size and Sampling

Participants were recruited by purposive sampling. The required sample size was calculated using G*Power software (version 3.1.9.7) with the Dynamic Gait Index as the primary outcome, based on effect sizes reported in an earlier trial of rhythmic gait training, at a significance level of 0.05 and a power of eighty percent; this yielded a requirement of twenty-two participants, eleven per group.

3.3 Inclusion and Exclusion Criteria

Adults aged 40-70 years of either gender, in the sub-acute to chronic stage after stroke, were included if they scored twenty-four or above on the Mini-Mental State Examination, had a Brunnstrom lower-limb stage of three or above, could walk with or without a mobility aid, and were cooperative and willing to participate. Patients were excluded if they had apraxia or perceptual deficits; significant psychological or emotional difficulties; hearing or vision problems that could affect the outcome measures or training; a lower-limb fracture or surgery within the previous six months; or any other neurological, musculoskeletal, cardiovascular or respiratory condition that could interfere with assessment or intervention.

3.4 Outcome Measures

Standardized outcomes were used at baseline and after the four-week intervention. The Fugl-Meyer Assessment (Lower Extremity) (FMA-LE) scores reflex activity, voluntary movement within and outside typical muscle synergies, and coordination/speed, with a higher score indicating better motor control. The Dynamic Gait Index (DGI) is a 0–24-point scale that scores a patient's ability to adapt walking to changing demands such as speed changes, head turns, obstacles and stairs, with lower scores indicating greater fall risk. The Ten-Meter Walk Test (10mWT) records the time taken to cover a specific distance of ten meters of a walkway to calculate comfortable walking speed.

3.5 Procedure and Intervention

After screening and consent, participants were randomly allocated to one of two groups. Group A practiced a structured exercise programme involving thirteen balance and gait exercises, including weight shifting, stepping, turning, marching, obstacle negotiation and indoor/outdoor walking, while listening to metronome beats delivered through a speaker or headphones. Beat frequency was individually matched to each patient's own walking cadence, measured with a smartphone cadence application. Group B performed the identical thirteen exercises while listening to ambient background music with no distinct or fixed beat. Both groups received thirty minutes of this auditory-cued exercise followed by thirty minutes of conventional physiotherapy, three sessions per week for four weeks, delivered under therapist supervision with standard safety precautions. All three outcome measures were recorded at baseline and again after the four-week programme.

3.6 Statistical Analysis

Data were entered in Microsoft Excel master chart was prepared and analyzed in SPSS (version 27). The Shapiro-Wilk test confirmed a normal distribution for all three outcome variables. Baseline comparability between groups was checked with an unpaired t-test. Within-group change from baseline to post-intervention was analyzed with a paired t-test, and between-group differences in the amount of change were analyzed with an independent-samples t-test, with significance set at $p<0.05$ (95% confidence interval).

4. RESULTS AND DISCUSSION

4.1 Results

At baseline, the two groups were matched: there was no significant difference in age (Group A 54.81±1.99 years vs Group B 54.63±2.35 years, p=0.954) or Mini-Mental State Examination score (26.36±0.43 vs 27±0.60, p=0.704), confirming that the groups were comparable before training began.

Within Group A, the paired t-test showed statistically significant improvement (p<0.001) from baseline to post-intervention on the FMA-LE sub-domains of voluntary movement within synergy, voluntary movement mixing synergy, voluntary movement with little or no synergy, and coordination/speed; the reflex-activity and normal-reflex sub-scores did not change significantly (p=0.167 and p=0.192). DGI and 10mWT also improved significantly (p<0.001) in Group A. Group B showed the same overall pattern: significant improvement (p<0.001) on the voluntary-movement and coordination/speed sub-domains, no significant change in the reflex sub-domains, and significant improvement in DGI and 10mWT. However, the size of the change was consistently smaller than in Group A, as summarized in Table 1.

Table -1: Within-Group Comparison of FMA-LE, DGI and 10mWT (Group A: RAS vs Group B: NRAS)

Outcome Measure	Group A (RAS) Pre → Post (mean±SD)	Group A p-value	Group B (NRAS) Pre → Post (mean±SD)	Group B p-value
FMA-LE: Reflex activity	1.45±0.93 → 1.81±0.60	0.167 (NS)	1.45±0.93 → 1.81±0.60	0.167 (NS)
FMA-LE: Voluntary movement within synergy	2.90±1.44 → 6.18±1.99	<0.001	2.90±1.44 → 6.18±1.99	<0.001
FMA-LE: Voluntary movement mixing synergy	1.36±0.50 → 3.09±1.04	<0.001	1.63±0.80 → 2.45±0.82	<0.001
FMA-LE: Voluntary movement, little/no synergy	1.27±0.46 → 3.09±1.04	<0.001	1.18±0.40 → 2.18±0.98	<0.001
FMA-LE: Normal reflex	1.45±0.52 → 1.72±0.46	0.192 (NS)	1.45±0.52 → 1.72±0.46	0.194 (NS)
FMA-LE: Coordination / speed	1.18±0.75 → 4.00±1.67	<0.001	1.72±0.78 → 3.36±0.92	<0.001
Dynamic Gait Index (DGI)	9.18±3.57 → 13.30±4.20	<0.001	9.10±0.35 → 13.36±4.20	<0.001
10-Metre Walk Test, s (10mWT)	50.40±20.85 → 36.62±17.01	<0.001	24.14±12.19 → 17.12±9.48	<0.001

NS = not significant; S = significant (p<0.05).

When the amount of improvement was compared directly between groups (Table 2), Group A showed a significantly larger gain than Group B on voluntary movement within synergy, voluntary movement mixing synergy, and coordination/speed (all $p<0.05$), and a significantly larger improvement in DGI ($p<0.001$) and 10mWT ($p=0.028$); the change in reflex-related items and in the little/no-synergy sub-domain did not differ significantly between groups.

Table -2: Between-Group Comparison of Change in FMA-LE, DGI and 10mWT (Group A: RAS vs Group B: NRAS)

Outcome Measure	Group A change (mean±SD)	Group B change (mean±SD)	t-value	p-value / Result
FMA-LE: Reflex activity	0.36±0.80	0.36±0.80	0.00	1.000 (NS)
FMA-LE: Voluntary movement within synergy	8.54±1.43	3.27±1.19	9.36	<0.001 (S)
FMA-LE: Voluntary movement mixing synergy	2.09±0.94	0.81±0.87	3.28	0.004 (S)
FMA-LE: Voluntary movement, little/no synergy	1.36±1.28	1.00±1.09	0.71	0.484 (NS)
FMA-LE: Normal reflex	0.45±0.52	0.45±0.52	0.00	1.000 (NS)
FMA-LE: Coordination / speed	3.90±1.37	1.09±1.04	5.41	<0.001 (S)
Dynamic Gait Index (DGI)	8.45±1.50	4.18±0.98	7.87	<0.001 (S)
10-Metre Walk Test, s (10mWT)	14.69±9.24	7.03±5.48	2.36	0.028 (S)

NS = not significant; S = significant (p<0.05).

4.2 Discussion

Both training programs with auditory cueing and with ambient music improved lower-limb motor control, dynamic balance and walking speed. This fits with the general understanding that structured, repeated practice helps stroke survivors to relearn the normal movement patterns. Patients who trained with a steady beat consistently gained more, particularly in the domains that depend on planned movement rather than reflex. This proves that rhythm itself, rather than the mere presence of sound, helps in these gains.

One likely reason is the way a predictable beat engages the nervous system. A steady external rhythm appears to give the auditory and motor systems a shared clock to synchronize around, drawing in premotor, supplementary motor, cerebellar and basal-ganglia circuits that plan and time movement. A similar pattern of improved lower-limb motor function on the FMA-LE has been reported after RAS-paired gait training [19], and pairing footsteps with an acoustic beat has been shown to help stroke survivors adjust stride length to keep pace with a changing rhythm, evidence of the same auditory-motor coupling [20]. The reflex-related items on the FMA-LE are largely governed at the spinal cord and brainstem level rather than by the cortical planning areas that a rhythmic beat engages, so it is unsurprising that neither group changed much on those items. The same pattern, improved voluntary motor scores after rhythmic training with reflex measures left unchanged, has been reported elsewhere [21].

Group B's improvement, though smaller, was still real. This is in coordination with the literature that music in general, even without a fixed beat, can support motor recovery by improving mood, motivation and attention and by encouraging dopamine release in movement-related circuits [14]. What non-rhythmic music does not supply is a steady external timing signal, so it cannot entrain step-by-step movement as precisely; a direct comparison has likewise found RAS to produce significantly larger gait improvements than non-rhythmic auditory input [22], and rhythmic cueing has been linked specifically to better movement synchronization rather than to reflex change [23],[24]. Rhythm also appears to influence the same basal-ganglia and cortical circuits that are already compromised after a stroke, offering a route through which repeated rhythmic practice could gradually make movements better timed and better ordered [25].

The larger gain in DGI scores among the RAS group similarly reflects an improved ability to adjust gait to changing task demands, such as speeding up, turning the head, or stepping around obstacles. This kind of skill depends on exactly the anticipatory motor planning that rhythmic cueing is thought to sharpen. The greater reduction in 10mWT time in Group A tells the same story from a different angle: patients who trained with a beat walked measurably faster afterward than those who trained with unstructured sound, in line with earlier reports that rhythmic cueing improves walking speed, cadence and stride length more than non-rhythmic approaches.

These results suggest that rhythm is not a minor detail in auditory-cued training; it appears to be the feature doing most of the work, while non-rhythmic sound offers a smaller, more general boost through motivation and engagement. For clinicians, this argues for choosing a properly paced, patient-matched metronome or rhythmic track over unstructured background music whenever auditory cueing is added to a stroke rehabilitation programme.

5. CONCLUSION

This study found that four weeks of balance and gait training paired with rhythmic auditory stimulation produced significantly greater improvement in voluntary lower-limb motor control, dynamic balance and walking speed than the same training paired with non-rhythmic ambient sound, in patients with sub-acute and chronic stroke. Both approaches improved outcomes to some extent, but the structured, patient-matched beat used in the RAS group appears to give the nervous system a more effective external cue for organizing and timing movement. Given that RAS is simple, inexpensive, and easy to combine with standard physiotherapy, it can reasonably be recommended as a practical addition to stroke rehabilitation programs aimed at improving lower-limb function and everyday mobility. The main limitations of this study are its short, four-week intervention period, the absence of longer-term follow-up to confirm whether gains are maintained, and some variability introduced by delivering training across different home and community settings; future work should explore longer follow-up and compare RAS with other emerging approaches such as task-oriented training, virtual reality and robotic-assisted gait training.

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