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The Effects of Rhythmic Auditory Stimulation with Different Tempos on Spatio-Temporal Parameters and Gait Symmetry in Patients with Multiple Sclerosis: A Quasi-Experimental Study

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Original Article

Abstract

Introduction: Rhythmic auditory stimulation has been used clinically as a therapeutic intervention to improve gait function in patients with various neurological diseases. Therefore, the purpose of the present study was to investigate the effects of rhythmic auditory stimulation with different tempos on spatio-temporal parameters and gait symmetry in patients with multiple sclerosis (MS).

Materials and Methods: The present study participants included 13 women diagnosed with MS (EDSS: 3.5-5.5) and 14 healthy women. Walking of the subjects was examined under 4 different modes: baseline gait without rhythmic auditory stimulation and gait with rhythmic auditory stimulation at -10%, 0%, and +10% of the baseline tempo, applied in random order. A motion capture system with 6 cameras was used to collect kinematic data.

Results: The results of independent sample t-test showed that people with MS walked slower, shorter distance, and spent a greater percentage of a gait cycle in double support phase than healthy control subjects. Furthermore, the findings showed that with an increase in tempo, the parameters of stance duration, swing duration, double support duration, stride duration, and stride length decrease, and cadence increases. The results of repeated measures ANOVA showed that auditory rhythmic stimulation significantly improves the gait symmetry index compared to the condition of the gait without auditory rhythmic stimulation.

Conclusion: The findings of this study showed that the subjects who participated in this study adjusted well to the changing tempo, and gait improvement was also found at different tempos. Therefore, our findings suggest that rhythmic auditory stimulation has the potential to be a safe, effective, and low-cost intervention for gait disturbance in patients with MS.

Keywords: Multiple sclerosis; Acoustic stimulation; Gait; Symmetry

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Introduction

Multiple sclerosis (MS) is the most common, progressive, and debilitating neurological disease among young adults (1). The main pathological characteristic of MS is the progressive demyelination and disruption of the blood-brain barrier, which is caused by inflammatory changes that affect the function of axonal channels and ultimately lead to extensive neurological symptoms (1, 2). MS patients experience various clinical manifestations, such as impaired sensory, motor, and cognitive function. This disease is highly debilitating and can cause abnormal walking, balance disorder, muscle weakness, and fatigue due to dysfunction in the pyramidal pathway, cerebellum, and spinal cord (3).

Walking is a fundamental human skill that occupies a significant portion of our daily movement

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activities. Studies suggest that the inability to move freely due to physical limitations causes patients to experience fear and anxiety. About 85% of patients with MS face walking problems that they consider their most significant limitation (4). These individuals tend to walk slower, take shorter steps, and increase their balance to avoid falling while walking (5). They also spend more time in the double support phase and make more comprehensive efforts to increase support levels. MS disease harms spatio-temporal walking variables and the natural oscillations between limbs (6, 7). As the disease progresses, patients' gait becomes more asymmetric and less coordinated, which increases the risk of falling (8). Falling while walking is one of the leading causes of spinal cord injury (9). Spinal cord injury is associated with lower limb sensory-motor deficits and movement disorders. Diffraction tensor imaging of the cervical spinal cord in MS patients has shown that myelin and tissue damage in the posterior columns and lateral corticospinal tracts reduces walking speed. Corticospinal tract damage is often asymmetric, resulting in asymmetric motor function (6).

Early treatments for MS can slow the progression of disability, but usually do not improve gait disturbances. Therefore, the use of rehabilitation and rehabilitation strategies is recommended for the management and improvement of movement disorders in these patients. One of the newer therapeutic strategies for the prevention of movement problems in patients suffering from neurological disorders such as Parkinson's, MS, cerebral palsy, and injuries caused by concussions is the use of external sensory stimuli (10-12). Sensory disturbances in MS patients play a crucial role in movement control and coordination disorders (13); therefore, providing sensory stimuli to strengthen and improve movement execution may be a suitable approach to overcoming this deficiency. Limited studies have investigated the effect of external sensory stimuli (visual and auditory) on the motor performance of MS patients (10, 14-16). Nevertheless, the background literature emphasizes the dominant role of auditory stimulation compared to visual stimulation (11, 17). The auditory cortex often perceives rhythmic stimuli between 20 and 30 ms, much shorter than visual and tactile thresholds (18). Acoustic stimulation and music can be effective in the production and regeneration of nerve cells and plasticity. Changing the level of steroids in auditory circuits, emotional circuits, and the emotional system can affect spatial perception and cognitive functions, and cause physical changes in the brain in the form of harmonization and synchronization of neural patterns (19).

Rhythmic auditory stimulation is a cost-effective, accessible, and motivational method for rehabilitating patients suffering from neurological disorders (20-22). Auditory rhythmic stimulation is a neurological approach to improving movement control in rehabilitation and treating acoustic rhythms' physiological effects on the motor system. It facilitates training intrinsically and biologically rhythmic movements, such as walking (23, 24). One of the essential parameters when using rhythmic auditory stimulation as a therapeutic method is choosing the appropriate tempo. Tempo measures the speed of playing music pieces, defined by the number of beats per minute, and is usually set with a metronome. In a piece of music, tempo is as important as melody, rhythm, harmony, and poetry, and it affects the emotions caused by understanding music. In a study, researchers studied the effects of different speeds of rhythmic auditory stimulation (3%, 7%, and 20%) in healthy adults. They reported that both sides of the frontal and occipital lobes showed increased neural activation with increase in tempo (25). In another study, researchers evaluated the immediate effect of auditory rhythmic stimulation with different tempos on the walking of stroke patients. They claimed that the patients’ walking speed and cadence increase with increase in tempo, but the symmetry of stepping decreases.

There is a limited amount of research conducted in music therapy for the improvement of the walking condition of patients with MS. Additionally, in the few studies conducted, the music tempo and structure have typically not received much attention. Therefore, the present study was conducted to investigate the immediate effect of rhythmic auditory stimulation, with different tempos, on the walking symmetry of patients with MS.

Materials and Methods

This study used a quasi-experimental design with an impact measurement model. The statistical population consisted of 258 members of the Kerman MS Association. Based on information from previous research and with the help of GPower software, to provide a confidence interval (CI) of 95%, test power of 80%, and an effect size of 0.2, 13 female participants were selected (27). Similarly, 14 people were selected as the control group based on their age, gender, height, and weight. The inclusion criteria were confirmation of the disease by a neurologist, disease severity of 3.5-5.5 based on the Kurtzke Expanded Disability Status Scale (EDSS), no vision or hearing problems, not undergoing any other active treatment, and the ability to walk without assistive devices. The exclusion criteria included subjects' inability to perform the tests and having severe attacks and relapses on the day of the test (28-30).

To comply with ethical considerations, each subject's research method and role were clearly explained, and subjects signed the informed consent form before participating in the study. Subjects were assured that the data would be analyzed as a group and their information would not be shared. To ensure subjects' safety while walking on the treadmill, all hard edges were covered with a soft and spongy cover, and a research assistant was present during all test stages. Due to the conditions of the coronavirus pandemic, each subject was given a specific time to be in the laboratory to avoid crowding. Only one subject, the laboratory operator, and the research assistant were present during the test. All protocols and health guidelines for dealing with coronavirus were followed carefully.

The demographic characteristics of the subjects, such as height and mass, were recorded on the information registration form after preliminary considerations. Then, each subject was asked to walk 3 times forward on a 10-meter path at a comfortable speed. The examiner noted the duration of the completion of the path, and after completing 3 runs, the average walking speed was used to adjust the treadmill's speed (31). Before data collection began, each person was given 3 minutes to familiarize themselves with walking on a treadmill at a specified speed. During this time, the number of steps the subject took in 30 seconds was counted and used to set the metronome's tempo (26, 29).

The walking motion of the subjects was evaluated using the plug-in-gate model, and 22 passive reflective markers were installed on their lower limbs using double-sided adhesive rubber bands. The subjects' walking was assessed in 4 modes: walking without rhythmic auditory stimulation (basic walking), with rhythmic auditory stimulation and tempo of 90%, 100%, and 110% of the cadence, and basic walking in random order (26). When walking was accompanied by auditory rhythmic stimulation, the metronome rhythm was played for each person for 30 seconds. Then, the subject walked for 2 minutes in each mode. The last 30 seconds of walking were recorded by a 3D motion analysis system with 6 optoelectronic cameras (Motion Analysis Corporation, Santa Rosa, CA, USA) and a frequency of 120 Hz. To prevent fatigue, subjects were given a 3-minute rest between each position (26).

The motion analysis system processed the recorded data with the Cortex software (Motion Analysis Corporation, Santa Rosa, CA, USA). To reduce the noise caused by the movement of the markers and to smooth the data, a 4-level Butterworth low-pass filter with a cutoff frequency of 6 Hz was used. To reduce the data, 10 consecutive steps were extracted from the walking of each subject. Gait events and spatiotemporal variables were extracted using the velocity based treadmill algorithm and MATLAB software (Math Works Inc., Natick, MA, USA). The desired spatiotemporal parameters were calculated, including stance duration, swing duration, step duration, step length, double support duration, stride duration, stride length, stride width, cadence, stride duration symmetry index, and stride length symmetry index (33-35).

The data was analyzed using SPSS software (Version 26.0.; IBM Corp., Armonk, NY, USA). The normality of data distribution was checked using the Shapiro-Wilk test. To compare the data of 2 groups of patients, an independent t-test was used. To obtain intragroup differences, repeated measures ANOVA was used along with Bonferroni's post hoc test to determine significant points. A significance level of 0.05 was considered in all statistical tests.

Results

Table 1 presents the characteristics of the subjects, such as age, weight, height, self-selected walking speed, duration of illness, and severity of disability. It was observed that the MS patients and healthy individuals did not differ significantly in terms of demographic variables, except for the subjects' self-selected walking speed, which was the only significant difference between the 2 groups.

Table 2 reports the spatio-temporal variables of subjects' walking.

Table 1. Demographic and clinical characteristics of subjects

Variable	MS group (n = 13) (mean ± SD)	Healthy group (n = 14) (mean ± SD)	P-value
Age (years)	38.00 ± 6.04	38.36 ± 6.52	0.884
Weight (kg)	62.12 ± 9.95	63.59 ± 12.29	0.736
Height (cm)	161.62 ± 4.36	164.36 ± 6.18	0.199
Self-selected walking speed (m/s)	2.96 ± 0.41	3.91 ± 0.25	0.001*
Duration of illness (years)	7.15 ± 4.24		
Kurtzke Expanded Disability Status Scale	4.50 ± 0.73		

*P < 0.05, SD: Standard deviation

Table 2. Spatiotemporal variables of the multiple sclerosis (MS) patients and healthy group in four different walking modes (mean ± standard deviation)

Variable	Group	Walking without auditory rhythmic stimulation	Walking at 90% tempo	Walking at 100% tempo	Walking at 110% tempo
		Mean ± SD			
Right stance duration (seconds)	MS group	0.72 ± 0.10	0.80 ± 0.11	0.73 ± 0.09	0.66 ± 0.09
	Healthy group	0.66 ± 0.03	0.73 ± 0.04	0.66 ± 0.03	0.61 ± 0.04
Left stance duration (seconds)	MS group	0.71 ± 0.10	0.79 ± 0.11	0.72 ± 0.09	0.66 ± 0.08
	Healthy group	0.66 ± 0.04	0.72 ± 0.04	0.66 ± 0.03	0.61 ± 0.04
Right swing duration (seconds)	MS group	0.44 ± 0.05	0.48 ± 0.06	0.45 ± 0.05	0.41 ± 0.04
	Healthy group	0.45 ± 0.02	0.50 ± 0.03	0.45 ± 0.02	0.42 ± 0.02
Left swing duration (seconds)	MS group	0.45 ± 0.05	0.49 ± 0.05	0.45 ± 0.04	0.41 ± 0.04
	Healthy group	0.46 ± 0.02	0.50 ± 0.03	0.46 ± 0.02	0.43 ± 0.02
Right step duration (seconds)	MS group	0.58 ± 0.06	0.65 ± 0.08	0.59 ± 0.06	0.54 ± 0.06
	Healthy group	0.56 ± 0.03	0.61 ± 0.03	0.55 ± 0.02	0.52 ± 0.03
Left step duration (seconds)	MS group	0.56 ± 0.08	0.64 ± 0.09	0.59 ± 0.07	0.53 ± 0.06
	Healthy group	0.56 ± 0.02	0.62 ± 0.04	0.56 ± 0.02	0.52 ± 0.03
Right step length (cm)	MS group	44.50 ± 6.40*	49.27 ± 7.38*	44.18 ± 5.62*	41.05 ± 6.02*
	Healthy group	56.69 ± 3.32	62.83 ± 4.26	57.89 ± 3.11	53.30 ± 3.57
Left step length (cm)	MS group	42.61 ± 7.04*	46.81 ± 6.05*	43.71 ± 7.83	39.47 ± 5.92*
	Healthy group	57.29 ± 3.75	62.71 ± 3.35	57.26 ± 3.31	53.15 ± 3.41
double support duration (second)	MS group	0.29 ± 0.07*	0.32 ± 0.09*	0.27 ± 0.07*	0.25 ± 0.06*
	Healthy group	0.21 ± 0.02	0.22 ± 0.03	0.21 ± 0.02	0.19 ± 0.03
Stride time (second)	MS group	1.16 ± 0.15	1.28 ± 0.16	1.17 ± 0.30	1.07 ± 0.11*
	Healthy group	1.12 ± 0.05	1.23 ± 0.07	1.12 ± 0.05	1.04 ± 0.05
Stride length (cm)	MS group	87.12 ± 12.91*	96.09 ± 12.69*	87.89 ± 13.31*	80.52 ± 11.44*
	Healthy group	113.96 ± 6.88	125.56 ± 6.88	115.16 ± 6.08	106.45 ± 6.67
Stride width (cm)	MS group	9.88 ± 2.40	10.96 ± 2.85	10.68 ± 3.16	10.14 ± 3.34
	Healthy group	9.16 ± 2.47	9.62 ± 3.09	9.17 ± 2.44	8.83 ± 3.07
Cadence (step/minutes)	MS group	103 ± 11	95 ± 11	103 ± 10	113 ± 11
	Healthy group	107 ± 5	98 ± 6	107 ± 4	116 ± 6

*P < 0.05

SD: Standard deviation; MS: Multiple sclerosis

The research findings indicate that as the walking tempo increases, the stance duration, swing duration, double support duration, stride duration, and stride length decrease, whereas the cadence increases.

The findings related to the symmetry index of step duration and the symmetry index of step length are shown in figure 1 and figure 2.

Figure 1. Step time symmetry index

*P < 0.05

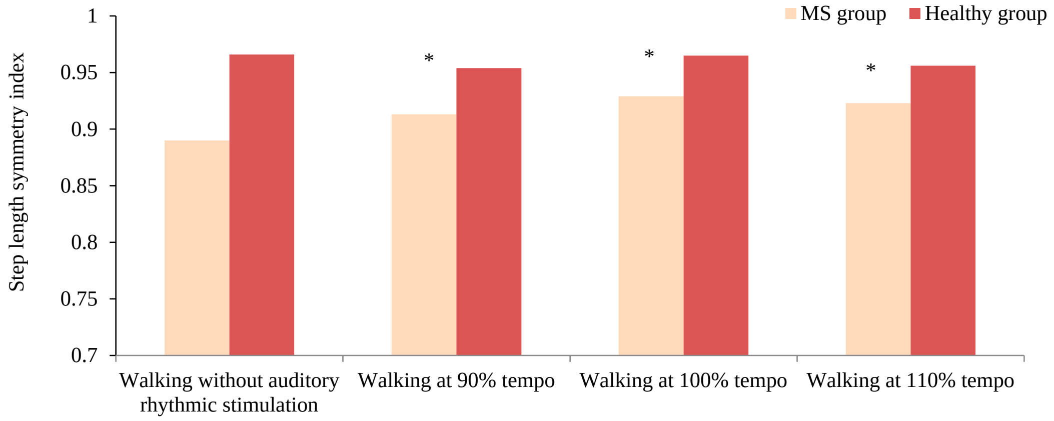

Figure 2. Step length symmetry index
$^{*}P < 0.05$

Discussion

This study was conducted with the aim to investigate the effects of rhythmic auditory stimulation with different tempos on the gait symmetry and spatiotemporal variables of MS patients. The results indicated that walking with auditory rhythmic stimulation of varying tempos can significantly enhance the gait symmetry index and spatiotemporal walking parameters. The study found that when rhythmic auditory stimulation was applied with a tempo of 90%, the cadence decreased, while the stride length, double support duration, and stride width increased. On the other hand, applying rhythmic auditory stimulation with a tempo of 110% resulted in a significant increase in cadence, but a decrease in stride length, double support duration, and stride width. Since walking speed was constant for each subject, and the tempo of the music was variable, the findings suggest that using rhythmic auditory stimulation with a faster tempo can increase cadence and improve walking abilities. As the tempo increased, the duration of the double support decreased significantly, which indicates an improvement in walking performance. Therefore, using rhythmic auditory stimulation at a faster tempo can also improve balance and stability.

The study found that auditory rhythmic stimulation with a tempo of 90%, 100%, and 110% led to significant improvements in the symmetry index of walking compared to walking without any auditory rhythmic stimulation. MS patients are at higher risk of falling while walking due to asymmetry and increased variability in their walking (8). Therefore, improving the symmetry between the right and left limbs is a critical goal of their rehabilitation program. The findings of this study suggest that auditory rhythmicity with different tempos can enhance the coordination of motor hearing in the central nervous system and reflect the acoustic rhythm in the functional motor output. During walking, the auditory rhythm activates the brain's motor and auditory areas (36). The activation of motor areas leads to less muscle activation and better walking control. The study confirms that rhythmic auditory stimulation affects brain activity by synchronizing movement and rhythm through sensory stimulation. Concentration and motor control are enhanced when a person tries to synchronize their movement with music (37).

The results of this research were consistent with that of previous studies (10, 38, 39) regarding the positive effect of using rhythmic auditory stimulation and music therapy on the kinematic parameters of walking in brain and spinal cord injury patients, people with Parkinson's disease, and stroke patients. Moreover, the results of the present study were in line with the findings of studies (40) that reported improvement in step length and step time when using rhythmic auditory stimulation in MS patients. Most of the studies conducted in this field reported improved walking parameters in a specific rhythm. However, 3 different tempos were used in the present study, and the effects of tempo changes were investigated. It seems that high-tempo walking exercises can be used if the goal of the rehabilitation program for MS patients is to reduce the duration of double support, increase walking speed, and improve balance. If the purpose of the rehabilitation program is to increase stride length, lower tempos can be used. Using auditory rhythmic stimulation with any tempo can improve the symmetry parameters between the left and right limbs of MS patients. It should be considered that auditory rhythmic stimulation has no side effects, is cost-effective, can be used independently or in combination with other treatments, and can also reduce muscle fatigue during physical exercises (41). External stimuli enhance the energy required for locomotion through coordinated and integrated physical movement (42), and auditory stimulation can improve walking ability by redefining walking patterns and motor control (43). Furthermore, in the present study, it was found that rhythmic auditory stimulation can be used to improve spatiotemporal parameters and walking symmetry patterns.

Limitations

According to previous research, music has been found to positively affect cognitive tasks (44). It has been reported that when a person's interest is stimulated acoustically, he/she can effectively deal with stress, arousal, excitement, reward, motivation, memory, attention, and executive performance (41). Such psychological factors may have influenced the performance of the patients studied in the present study, and it is possible that the improvements associated with rhythmic auditory stimulation seen in this study were mediated by positive mood or self-efficacy. However, it was impossible to separate these factors from the research results, which is considered a limitation of the study.

Recommendations

The findings of this study suggest that auditory rhythmic stimulation can be a beneficial intervention for the improvement of the walking symmetry and ability of MS patients. Further research is necessary to determine the most effective use of auditory rhythmic stimulation and to verify the long-term effects of walking training with rhythmic acoustic stimulation.

Conclusion

The present study demonstrated that using auditory rhythmic stimulation while walking can improve the gait of MS patients. This technique increases walking speed and cadence, improves stride length and walking symmetry, and reduces the duration of double support. The study participants adapted to different tempos, and improvements in walking symmetry were observed across all tempos. Therefore, incorporating walking exercises with auditory rhythmic stimulation at different tempos can be recommended as a safe, effective, low-cost rehabilitation program for MS patients.

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Authors’ Contribution

Study design and ideation: Sasan Naderi, Heydar Sadeghi, and Mohammadreza Amirseyfaddini
Obtaining financial resources for the study: Heydar Sadeghi
Scientific and executive support of the study: Heydar Sadeghi and Mohammadreza Amirseyfaddini
Providing equipment and study samples: Sasan Naderi and Mohammadreza Amirseyfaddini
Data collection: Sasan Naderi
Analysis and interpretation of the results: Sasan Naderi
Specialized statistics services: Sasan Naderi
Manuscript preparation: Sasan Naderi, Heydar Sadeghi, and Mohammadreza Amirseyfaddini
Specialized scientific evaluation of the manuscript: Sasan Naderi, Heydar Sadeghi, and Mohammadreza Amirseyfaddini
Confirmation of the final manuscript for submission to the journal website: Sasan Naderi, Heydar Sadeghi, and Mohammadreza Amirseyfaddini
Maintaining the integrity of the study process from the beginning until publication, and responding to the referees’ comments: Sasan Naderi, Heydar Sadeghi, and Mohammadreza Amirseyfaddini

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Conflict of Interest

The authors declared no conflicts of interest.

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