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ORIGINAL ARTICLE

Influence of Rhythmic Auditory Feedback on Gait in Hemiparetic Children

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Background: The spastic hemiparetic gait pattern is characterized by temporal and spatial asymmetries, which are resistant features to correction. More information about the effect of new therapeutic modalities on the hemiparetic gait pattern should be investigated and obtained. **Aim:** The purpose of this study was to investigate the effect of rhythmic auditory-cued gait training on spatiotemporal asymmetries of gait in hemiparetic children. **Methods:** A randomized controlled study was conducted on 30 spastic hemiparetic children (15 boys and 15 girls) in the age range of 6–10 years. They were randomly allocated in two equal groups. The investigator performed two-dimensional gait analysis for every child before and after the treatment program to assess the gait symmetry. Gait Symmetry Index (SI) was applied to investigate the spatiotemporal gait symmetry. The study group received rhythmic auditory-cued gait training in addition to traditional physical therapy program training, whereas the control group received the traditional physical therapy program training, three times/week for 4 months. **Results:** There was a statistically significant decrease in SI of step length, stride length, stance time, and swing time posttreatment in the study and control groups compared with that pretreatment ($P > 0.01$). Furthermore, comparison between the study and control groups posttreatment revealed a significant decrease in SI of step length, stride length, stance time, and swing time of the study group compared with that of the control group ($P > 0.01$) which indicate improvement of symmetry. **Conclusions:** Gait training using rhythmic auditory feedback is superior to conventional physical therapy training for improving the gait symmetry of children with spastic hemiparesis.

Key words: Spastic hemiparesis, rhythmic auditory feedback, gait symmetry, gait symmetry index, two-dimensional gait analysis

INTRODUCTION

Spastic hemiparesis is a neural deficit that occurs in patients with neurological disorder such as cerebral palsy, cerebrovascular accident, and traumatic brain injury, and it causes abnormal selective motor activation, muscle weakness, and spasticity.[1]

The hemiparetic gait is characterized by increased the asymmetry in the distribution of body weight between the affected and unaffected lower limbs. The shift of the center of gravity away from the affected side is expressed in asymmetrical gait pattern. Both spatial and temporal gait asymmetry are common impairments in hemiparetic patients.[2] Spatiotemporal gait asymmetry is accompanied with abnormal balance control, abnormal movement synergies, and musculoskeletal overload, on the unaffected side.[3]

Rhythmic auditory feedback is one of the new modalities used for gait training in many neurological lesions.[4] It provides the feedback to synchronize the footfalls with the ground as the child walks[5] and can be applied as an auditory-cued gait training to improve gait asymmetry in patients with hemiparesis.[6]

Studies have shown that feedback of the auditory rhythm can facilitate the muscle activation sequence through the audiomotor pathways on the reticulospinal level, thereby reducing the amount of time needed for the muscle to respond to a given motor command[7] and produce long-term improvements in the sensorimotor cortex.[8]

Rhythmic auditory-cued gait training emphasizes on rhythmic bilateral movements of both lower limbs in hemiparetic patients. It provides rhythmic cueing using metronome tempo and beats to act as external regulator of the movement.[9]

Rhythmic auditory feedback synchronizes the movements of both lower limbs into a stable time frame of reference

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during walking. Therefore, interlinking between the auditory feedback and motor response regulates the gait pattern in patients with gait deficits.[9]

Accordingly, this study aimed to determine the effect of rhythmic auditory-cued gait training on gait symmetry in spastic hemiparetic children. This may help establish an effective rehabilitation treatment. The hypothesis of this study was that gait training using auditory rhythmic feedback may improve gait symmetry in children with spastic hemiparesis.

METHODS

The protocol of this study was approved by the ethical committee, Faculty of Physical Therapy, Cairo University, before its commencement. Patients were included if they were referred with diagnosis of spastic hemiparesis with involvement of one side of the body (including one upper and one lower limb of the same side of the body). The underlying etiology of their condition listed in Table 1. Their age was between 6 and 10 years chronologically, their lower limb spasticity was graded as 1, 1+ according to modified Ashworth Scale for grading spasticity. The upper limb spasticity was graded also as 1, 1+ according to modified Ashworth Scale for grading spasticity to permit the normal arm swinging movement during gait.[10] They were graded according to Gross Motor Function Classification System[10] as Level I and II. The weight for boys was ranged between 45.5 and 70.5 lb and for girls was ranged between 44.0 and 70.5 lb. The height for boys was ranged between 45.5 and 54.5 inches and for girls was ranged between 45.5 and 54.5 inches.

The patients were excluded if they had cognitive impairments preventing them from following instructions or auditory/auditory perceptual impairments reducing their ability to hear and follow the metronome. If they had a history of epilepsy, leg length discrepancy, fixed deformity of the musculoskeletal system, polyneuropathy, neuromuscular junction diseases, muscular dystrophy, myopathy, or myelitis, they were excluded. The study was approved by Research Ethical Committee, Faculty of Physical Therapy, Cairo University. Approval number: P.T.REC/012/001711 & Approval Date:10/9/2017.

Table 1: The underlying etiology of spastic hemiparesis

The underlying etiology	Number of patients
Head trauma (intracerebral hemorrhage and subdural hematoma)	24
Intracranial infection	3
Benign brain tumor (meningioma)	2
Stroke secondary to congenital heart disease	1

Randomization

Forty spastic hemiparetic children from both genders were assessed for eligibility. Six children did not meet the inclusion criteria and four refused to participate. Thirty children (15 boys and 15 girls) were enrolled in this randomized controlled study [as shown in flow chart in Figure 1] and their caregivers agreed to participate in the study with written informed consent. They randomly allocated as odd participant number for the study Group A (*N* = 15 odd participant number) and even numbers for the control Group B (*N* = 15 even participant number). The study is approved by Institutional Review Board of Research Ethical Committee, Faculty of Physical Therapy, Cairo University. The approval number is P.T.REC/012/001711.

Assessment of gait (gait analysis system)

Gait parameters were recorded using Digital camera (Canon XM2 PAL Mini DVD series, Japan, ×20 optical zoom, ×100 digital zoom, max shutter speed 1/6000 s, display format 200 megapixels) which was mounted on a level tripod, with optical axis perpendicular to the plane of movement at a distance of 2.5 m. The height of the camera was 30 cm above the floor,[11] since it was only the lower limbs that to be recorded. Video of each participant was recorded using this digital camera to capture the sagittal plane profile of the lower limbs. The camera was placed to cover the field of the middle 3 m of the walkway.[12]

Three spherical adhesive markers of 1.5-cm sphere were placed on the skin surface covering the following anatomical sites: calcaneus, lateral malleolus, and head of fifth metatarsal bone.[12]

Before data collection, patients performed one walking trail (bare feet) to familiarize themselves with the procedure. For the pre- and post-measurements, a 14-m walkway was

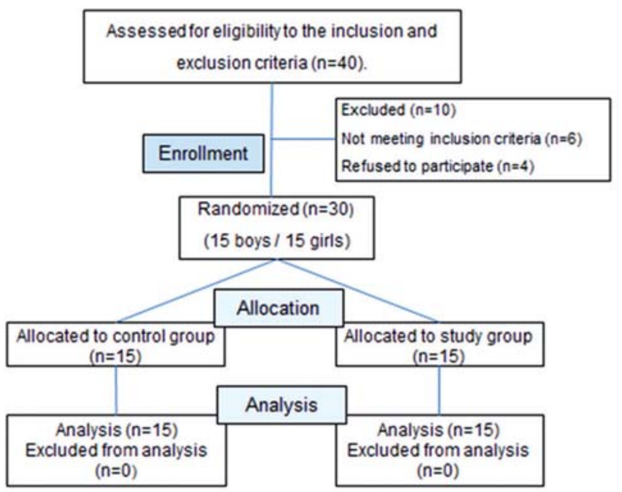

Figure 1: Flowchart of the study

marked at 10 m for test measurement with a 2-m allowance for acceleration and 2-m allowance for deceleration.[9]

Each child was asked to walk (bare feet) at his/her preferred pace through the walkway in a straight line guided by two parallel lines that were drawn on the floor, after which baseline data for gait was recorded[13] as shown in Figure 2.

The camera was fixed on a tripod and the participant walked between two parallel lines to keep the right angle distance and avoid the distorted pathways hence different camera angles.

All videos were imported into a laptop and analyzed using Kinovea software (Bordeaux, Novuelle Aquitaine, France), which is free, open-source software created for movement analysis (Kinovea 0.8.15 for Windows).[14] The Kinovea software is very easy to use and does not require previous experience in video analysis to obtain highly valid and reliable measurements of spatial and temporal variables.[14] It has both intra- and inter-reliability in measuring the height of attack jump (cm) and between the timing lights (s) for volleyball players.[15]

The following spatiotemporal variables were obtained twice for both paretic and nonparetic lower limbs in both groups: step length (cm), stride length (cm), stance time (s), and swing time (cm). Each variable was calibrated for three successive steps at the middle 3 m of the walkway to get accurate results.

The evaluation process was conducted for each participant (in both groups) before the initiation of the study (pretreatment measurement) and after 4-months at the end of treatment period (posttreatment measurement). The cadence of each patient was assessed just once at the beginning of the study.

Treatment procedure

The study group received the rhythmic auditory-cued gait training which was applied using software metronome program running on laptop. The mean of all participants' cadences was estimated at the beginning of the study. The rhythm of metronome (beats/min) was matched to that mean. For this study, the rhythm was set at 100 beat/min.

At the first session, instructions were given to the participants. The researcher demonstrated how they can follow the beat and how they can walk with the beat rhythm. Participant was instructed to listen to the first 5 tones before initiating his/her first step response. The child was asked to walk through unrestricted space, while trying to time and synchronize his/her footfalls with the rhythmic auditory beats produced by the metronome. The patients underwent treatment course for 4 months with three times a week and 15-min/session.[8]

In addition to the metronome-cued gait training, the study group received traditional method program, as following: the child was trained to walk backward, walk and stop, walk and turn, walk up/downslope, walking through obstacle, hop and skip, ascend/descend stairs, standing on one lower limb while keeping balance, walking on balance board,[16] neurodevelopmental approaches, and core strengthening exercise. The participants of the control group received only the previous traditional physical therapy program.

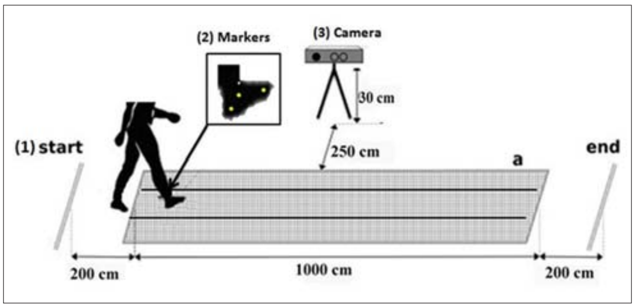

Figure 2: Walkway of assessment procedure for gait analysis . (1) Start point (2)spherical adhesive markers (3) the digital camera

Analysis

Each obtained gait variable was applied in the following Symmetry Index (SI) equation presented by Sadeghi *et al*.[17]

$$\mathrm{SI} = \frac{X_{Lt} - X_{Rt}}{0.5\left(X_{Lt} + X_{Rt}\right)}\,100\%$$

Where X_{Lt} is the gait variable of the left side and X_{Rt} is the gait variable of the right side. Regardless to the negative sign, the value of SI = 0 indicates perfect symmetry, while the value of SI ≥100% indicates its asymmetry. The decreasing of the percent value means improving of the symmetry.[18]

Statistical analysis

Descriptive statistics, paired *t*-test, and unpaired *t*-test were conducted for the study. Paired *t*-test was conducted for comparison between pre- and post-treatment SI in each group. Descriptive statistics and unpaired *t*-test were conducted for comparison of participant characteristics between both groups. Chi-squared test was used for comparison of sex and affected side distribution between groups. Normal distribution of data was checked using the Shapiro–Wilk test. Levene's test for homogeneity of variances was conducted to ensure the homogeneity between groups. Unpaired *t*-test was conducted to compare the mean values of SI between the study and control groups. The level of significance for all statistical tests was set at $P < 0.05$. All statistical analysis was conducted through the Statistical Package for the Social Sciences (SPSS) version 19 for Windows (IBM SPSS, Chicago, IL, USA).

RESULTS

Baseline characteristics of the participants are shown in Table 2. No statistically significant differences existed between groups with regard to age, height, and weight. Furthermore, there was no statistically significant difference in sex and affected side distribution between groups ($P > 0.05$).

There was a statistically significant decrease in SI of step length, stride length, stance time, and swing time posttreatment in the study and control groups compared with that pretreatment ($P > 0.01$). The percent of decrease in SI of step length, stride length, stance time, and swing time in the study group was 73.67%, 76.14%, 63.54%, and 58.4%, respectively, and that of control group was 48.57%, 47.92%, 52.73%, and 27.7%, respectively, as shown in [Table 3 and Figure 3].

There was no significant difference in symmetry indices between both groups pretreatment ($P > 0.05$). Comparison between the study and control groups posttreatment revealed a significant decrease in SI of step length, stride length, stance time, and swing time of the study group compared with that of the control group ($P > 0.01$), as shown in [Table 3 and Figure 3].

DISCUSSION

This study was conducted to evaluate whether rhythmic auditory-cued gait training could improve the gait symmetry as compared to traditional physical therapy rehabilitation program in spastic hemiparetic children. The main finding of the present study accepts the hypothesis as the gait symmetry significantly improved including functional gait variables such as step length, stride length, stance time, and swing time in the study group, as compared with traditional treatment approach which did not show the same improvements.

The hemiparetic gait characterized by increased step length,[19] prolonged swing phase, and shortened single limb support time on the paretic limb.[20] In addition, increased weight bearing on the nonparetic limb,[21] limited ability to shift the body weight toward the paretic limb resulting in further instability in the stance phase and shortened swing phase of the

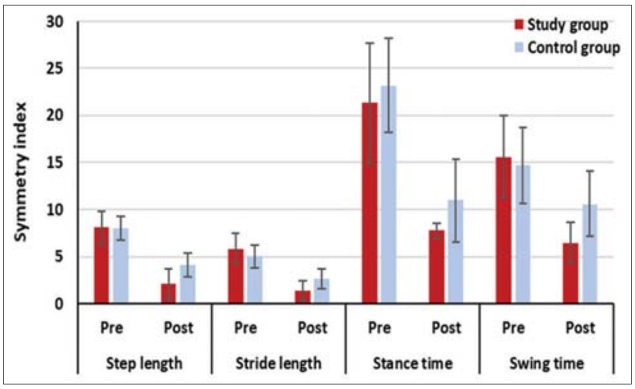

Figure 3: Mean symmetry index of step length,stride length,stance time, and swing time pre- and post-treatment of the study and control groups

Table 2: Comparison of participant characteristics between study and control groups

	Mean±SD		t	P
	Study group (n=15)	Control group (n=15)		
Age (years)	8.2±1.37	7.73±1.33	0.94	0.35
Weight (kg)	25.76±4.57	25.33±4.27	0.26	0.79
Height (cm)	127.66±6.77	127.86±5.01	−0.09	0.92
Sex				
Boys	8	7	χ^2=0.13	0.71
Girls	7	8		
Affected side				
Right	5	7	χ^2=0.55	0.45
Left	10	8		

SD=Standard deviation

Table 3: Mean Symmetry Index of step length, stride length, stance time, and swing time pre- and post- treatment of the study and control groups

Symmetry index (%)	Mean±SD		t	P
	Study group (n=15)	Control group (n=15)		
Step length				
Pre	8.13±1.73	8.07±1.28	0.09	0.92
Post	2.14±1.61	4.15±1.3	−3.77	0.001*
Percentage of change	73.67	48.57		
t	8.47	8.39		
P	0.001*	0.001*		
Stride length				
Pre	5.87±1.65	5.05±1.22	1.54	0.13
Post	1.4±1.04	2.63±1.05	−3.21	0.003*
Percentage of change	76.14	47.92		
t	9.9	6.14		
P	0.001*	0.001*		
Stance time				
Pre	21.34±6.4	23.19±5.05	−0.87	0.38
Post	7.78±0.79	10.96±4.35	−2.78	0.01*
Percentage of change	63.54	52.73		
t	8.69	10.76		
P	0.001*	0.001*		
Swing time				
Pre	15.58±4.35	14.69±4.05	0.58	0.56
Post	6.48±2.15	10.62±3.42	−3.79	0.001*
Percentage of change	58.4	27.7		
t	7	3.13		
P	0.001*	0.007*		

*Significant. SD=Standard deviation

nonparetic limb,[22] as well as increased difficulties in balance control during walking.[23] The energy expenditure increased[24] and the overall daily activity level decreased as a result of asymmetric gait pattern.[25]

The significant improvement of the temporal parameters in the control and study group may be attributed to the selected traditional physical therapy program. The program aimed at improving the anteroposterior and mediolateral weight shift. In addition, it allowed more sustained weight bearing and stable stance on the paretic limb, thereby resulting in prolonged swing time of the nonaffected lower limb and improved the gait temporal symmetry. This is consistent with the findings of Patterson *et al*.[22] While the significant improvement of the spatial gait parameters in both groups is justified by improving the selective muscle control via controlling spasticity, enhance the cocontraction between the agonistic and antagonistic muscle groups superimposing controlled performance on the spastic muscles, and muscular strengthening consequently enhances the functional controlled movement of the lower limb during gait stepping and improve the spatial gait asymmetries. Report of An *et al*.[3] supports this explanation.

The synergistic effect of both rhythmic auditory-cued gait training program and the traditional physical therapy rehabilitation exercise may explain the significant improvement in the gait SI in the study group compared to the control group, and this is supported by Kwak[9] who reported that a set of balance and equilibrium exercises accompanied with rhythmic auditory feedback is useful in improving balance abilities in patients with pathological gait pattern. Adding the gait training using metronome as rhythmic auditory feedback improved the ability to develop a proper immediate motor response. Cha *et al*.[26] also showed improved gait symmetry as the participants learned to use feed-forward cue to take steps at the given rhythmic auditory beats.

The results of Kim *et al*.,[4] Prassas *et al*.,[27] and Thaut *et al*.[28] that showed significant improvement of spatiotemporal parameters such as cadence, stride length, step length, stride time, and step time following gait training with rhythmic auditory stimulation is consistent with the findings of this study. The results of this study further explained by Wright *et al*.[29] who stated that the motor system is very sensitive to stimulation by the auditory system, and their studies have demonstrated the ability to time footfalls to auditory cues that decrease the gait variability between both sides. The application of metronome during gait replaces the lost mental ability to estimate accurate gait spatially and temporally by providing real-time beats. This rhythm enables the child to correct the timing error as it occurs.

Brain plasticity can also explain the results of this study clearly with regard to rhythmic auditory feedback. When part of the brain gets injured or damaged, it does not completely stop functioning, as various brain area have more than one connection pathway. According to Kim *et al*.,[4] the auditory activity is mediated by internal unconscious perceptual shaping at the subcortical level and can arouse the excitability of spinal motor neurons mediated by auditory-motor circuitry at the reticulospinal level.

The learning theory explains how the motor performance can be gained, modified, and refined through repeated practice on regular basis. By the repeated practice and repeated trials and errors during rhythmic auditory-cued gait training, the child gains motor experience. This agrees with the conclusion drawn by Gharib *et al*.[16] who reported that providing necessary stimulus to retrain neural pathways improves the gait pattern through improving the step length. Furthermore, Suh *et al*.[8] proved that attempts to synchronize the movements promote both motor control and concentration.

The somatosensory feedback provided by the highly repetitive and rhythmic auditory beats during gait training facilitates the long-term changes in the sensorimotor cortex related to movement relearning. Greenspan and Wiede[30] concluded that the therapeutic modality aiming at strengthening sequencing, timing, and rhythmicity plays a crucial role in improving the capacity of attending to specific task and learning.

The findings of the present studies may be attributed to decrease the compensatory mechanism and subsequently the decrease in the energy expenditure during walking. This explanation is parallel with Thaut *et al*.[28] who stated that auditory feedback influences the compensatory strategies caused by asymmetric gait through improving the muscle activation, increasing muscle endurance, cocontraction of antagonistic muscles, and electromyographic muscle coordination.

Rhythmical auditory cue controls balance through the vestibular system by activating the medial geniculate nucleus in ears before reaching the auditory cortex in the temporal lobe,[31] and it also improves the bilateral movement in the trunk and proximal muscles to adjust reactive feedback-driven motor coordination.[32] These justify the significant improvement in terms of stance time of the affected lower limb in the study group. This explanation is further supported by McIntosh *et al*.[33] who suggested that repetitive rhythmic sound patterns entrain the coordination of axial and proximal movement to a given motor command.

A study by Geurts *et al*.[34] showed that weight-bearing stance time on the paretic side and stride symmetry improved with rhythmic cueing. Furthermore, the variability of integrated amplitude ratios decreased during the midstance/push off phase on the paretic side. Furthermore, previous studies of patients with cerebral palsy by Thaut *et al*.[28] indicated improvement of cadence, nontemporal parameters, and symmetry. These findings are consistent with results of this study in terms of significant improvement of stride length of the study group.

The significant improvement in temporal parameters in this study comes in parallel with Wright *et al*.[7] who reported that the rhythmic auditory feedback directs the temporal regulation of a movement. In addition, the metronome-cueing resulted in a decrease in variability for step, stance, and double support times and joint kinematics.

The limitations of this study are as follow: (1) The step length was not normalized in relation to the leg length; however, the total participant's height was considered; (2) longer treatment duration with multiple reassessments may reveal more detailed findings; and (3) only the important gait variables were measured. Future studies are needed to explore the effect of auditory feedback on other gait parameters, also three-dimensional gait assessment can be used as evaluation tool.

CONCLUSIONS

The symmetric gait pattern is challengeable in spastic hemiparetic children, as it is the most efficient pattern. The metronome as rhythmic auditory feedback represents the valuable, cheapest, and easiest used method to overcome this challenge. This study can share in providing evidence-based practice for this nontraditional modality, and this, in turn, will improve the health-care service the patient receives.

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Conflicts of interest
There are no conflicts of interest.

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