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Clin Rehabil 2012 26: 904 originally published online 3 February 2012
DOI: 10.1177/0269215511434648

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CLINICAL REHABILITATION

Clinical Rehabilitation
26(10) 904–914

DOI: 10.1177/0269215511434648
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Differential effects of rhythmic auditory stimulation and neurodevelopmental treatment/ Bobath on gait patterns in adults with cerebral palsy: a randomized controlled trial

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Abstract

Objectives: To investigate the effects of rhythmic auditory stimulation (RAS) on gait patterns in comparison with changes after neurodevelopmental treatment (NDT/Bobath) in adults with cerebral palsy.

Design: A repeated-measures analysis between the pretreatment and posttreatment tests and a comparison study between groups.

Setting: Human gait analysis laboratory.

Subjects: Twenty-eight cerebral palsy patients with bilateral spasticity participated in this study. The subjects were randomly allocated to either neurodevelopmental treatment ($n = 13$) or rhythmic auditory stimulation ($n = 15$).

Interventions: Gait training with rhythmic auditory stimulation or neurodevelopmental treatment was performed three sessions per week for three weeks. Temporal and kinematic data were analysed before and after the intervention. Rhythmic auditory stimulation was provided using a combination of a metronome beat set to the individual's cadence and rhythmic cueing from a live keyboard, while neurodevelopmental treatment was implemented following the traditional method.

Main measures: Temporal data, kinematic parameters and gait deviation index as a measure of overall gait pathology were assessed.

Results: Temporal gait measures revealed that rhythmic auditory stimulation significantly increased cadence, walking velocity, stride length, and step length ($P < 0.05$). Kinematic data demonstrated that anterior tilt of the pelvis and hip flexion during a gait cycle was significantly ameliorated after rhythmic auditory stimulation ($P < 0.05$). Gait deviation index also showed modest improvement in cerebral palsy patients treated with rhythmic auditory stimulation ($P < 0.05$). However, neurodevelopmental treatment

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showed that internal and external rotations of hip joints were significantly improved, whereas rhythmic auditory stimulation showed aggravated maximal internal rotation in the transverse plane ($P < 0.05$).
Conclusions: Gait training with rhythmic auditory stimulation or neurodevelopmental treatment elicited differential effects on gait patterns in adults with cerebral palsy.

Keywords
Rhythmic auditory stimulation, neurodevelopmental treatment, gait, cerebral palsy, gait deviation index

Received: 11 July 2011; accepted: 10 December 2011

Introduction

Martial music is used to help soldiers walk faster and more efficiently so it seemed sensible to ask whether music or rhythmic auditory stimulation could also help people with gait impairment such as cerebral palsy. Cerebral palsy is a non-progressive disorder occurring in early brain development that results in abnormal movement and posture.[1] The lack of selective movement and coordination due to spasticity and muscle weakness is the major impairment.[2,3] Attainment of functional walking is a common goal of rehabilitation in cerebral palsy because of its impact on activities of daily living and social activity.[4,5] Among a variety of traditional interventions, neurodevelopmental treatment has been predominantly used over the years.[6,7] The method focuses on establishing normal motor development by facilitating normal sensorimotor components such as muscle tone and reflexes, or by inhibiting abnormal movement patterns to improve functional movement.[7–10] The effectiveness of the neurodevelopmental treatment approach has been shown with improvements in motor performance, especially in gross motor ability, postural control, and stability.[11–14] However, Bobath noted that the treatment did not automatically carry over into the activities of daily living, as they had expected it would.[7–10]

Other treatment methods have been introduced for improving functional parameters, as the number of scientific findings regarding body movement increases. Based on evidence with varying degrees of certainty, therapeutic devices such as treadmills[15] or neuromuscular electrical stimulation[16] have been utilized in gait training for cerebral palsy. In paediatric patients, treadmill walking training produced consistent findings in walking speed and Gross Motor Function Measure.[15] However, evidence for the effects of the physiotherapy on adults with cerebral palsy is sparse.[17] Therefore, there is a need for additional treatment methods for gait training, especially in adults.

Rhythmic auditory stimulation, one of the new methods in gait training, emphasizes regular external auditory stimulation on footfalls of the gait cycle.[18] The key concept of rhythmic auditory stimulation is auditory–motor synchronization in the reticulospinal tract. The repetition of an external timing cue impacts the regulation of the movement pattern. Consequently, the spinal motor system is optimized for the movement pattern following the reticulospinal pathway at the level of the brainstem.[19] Studies investigating gait training with rhythmic auditory stimulation have demonstrated the improvement of gait parameters in the temporal data (velocity, cadence and stride length) and kinematic measures of neurologically impaired patients, such as Parkinson's disease[20–27] and stroke.[28,29] However, few studies have demonstrated the therapeutic effect of rhythmic auditory stimulation on gait patterns in patients with cerebral palsy.

In regards to the mechanisms and characteristics of these alternative methods, rhythmic auditory stimulation can lead to improve functional gait parameters including efficient changes in gait pattern, while neurodevelopmental treatment emphasizes each component of the movement. Previous comparison between neurodevelopmental treatment and rhythmic auditory stimulation in hemiparetic stroke patients indicated better temporal parameters in patients treated with rhythmic auditory stimulation.[30] Therefore, the purpose of this study was to investigate the effects of rhythmic auditory stimulation on gait patterns in comparison with those of neurodevelopmental treatment in adults with cerebral palsy.

Methods

A total of 28 cerebral palsy patients with bilateral spasticity were recruited from inpatient and outpatient clinics. The treatment procedure was approved by the Institutional Review Board. We obtained informed consent from each participant. Each participant in this study (1) had no discernible hearing deficit, (2) was able to walk independently at least 10 m without a walking aid or a helper, and (3) was able to understand the command to walk following rhythmic auditory stimulation. Before the procedure, the participants were randomly allocated to either the neurodevelopmental treatment group ($n = 13$) or the rhythmic auditory stimulation group ($n = 15$) using a central telephone randomization service.

For both groups, treatment was performed for 30 minutes per each session, three sessions per week for three weeks. Gait training in the neurodevelopmental treatment group was conducted following the traditional method by the specialized physiotherapists. On the other hand, the rhythmic auditory stimulation procedure consisted of the following steps: (1) a participant walked barefoot along the walkway (10 m) three times, at the individual's preferred walking speed, before rhythmic auditory stimulation application; (2) the individual's cadence (steps/min) was calculated based on the gait parameters in step 1; (3) the tempo of metronome beats (bpm) was set to the participant's cadence obtained in step 2; and (4) rhythmic auditory stimulation was provided by music therapists, who played a simple rhythm pattern synchronized with the beats of a metronome, using chord progressions on a Yamaha keyboard (PSR-E213, Yamaha Electronics Co., Japan).

Temporal and kinematic data were collected for the pelvis, hip, knee, ankle and foot by the assessor blinded to the allocation and were analysed for trials performed before and after rhythmic auditory stimulation or neurodevelopmental treatment. A three-dimensional, six-camera Vicon 370 Motion Analysis system (Oxford Metrics Inc, Oxford, UK) was used to capture these data. This system comprises six infrared-sensitive solid-state cameras for locating and tracking fixed retro-reflective markers through space. Temporal parameters such as cadence (steps/min), walking velocity (m/s), stride length (m), step length (m), stride time (seconds), step time (seconds), stance phase (%) and swing phase (%) were calculated. The motion analysis system was calibrated before each gait analysis.

Kinematic data of the pelvis, hip, knee, ankle and foot were also analysed using the Vicon 370 Motion Analysis system. The system recorded kinematics that described the spatial movement of the individual's body during gait performance. All data were processed and plotted using Vicon clinical manager software, and the graphs were visualized using Polygon software. Fifteen passively reflective markers were adhered with specialized tape to the sacrum, both sides of the anterior superior iliac spine, middle thigh, lateral knee, middle shank of the tibia, lateral malleolus, heel and the forefoot. Kinematic data included the angles of pelvic tilt, pelvic obliquity, pelvic rotation, hip flexion, hip adduction or abduction, hip internal rotation or external rotation, knee flexion, ankle dorsiflexion or plantarflexion, and foot progression. Measurements were recorded in three-dimensional planes including sagittal, coronal and transverse planes. For statistical analysis, initial contact, minimum and maximum points during a gait cycle were designated and analysed in each limb for all participants.

To obtain a more global index of three-dimensional kinematic changes, the gait deviation index[31] was assessed before and after rhythmic auditory stimulation and neurodevelopmental treatment. A multivariate measure of overall gait pathology, called the gait deviation index, was calculated to account for the overall effect of the kinematic changes across all three planes at the hip, knee and ankle throughout a gait cycle. In other words, the gait deviation index incorporated pelvic tilt, pelvic obliquity, pelvic rotation, hip flexion, hip adduction and abduction, hip internal rotation and external rotation, the sagittal angles of the knee and ankle, and foot progression on the transverse plane.

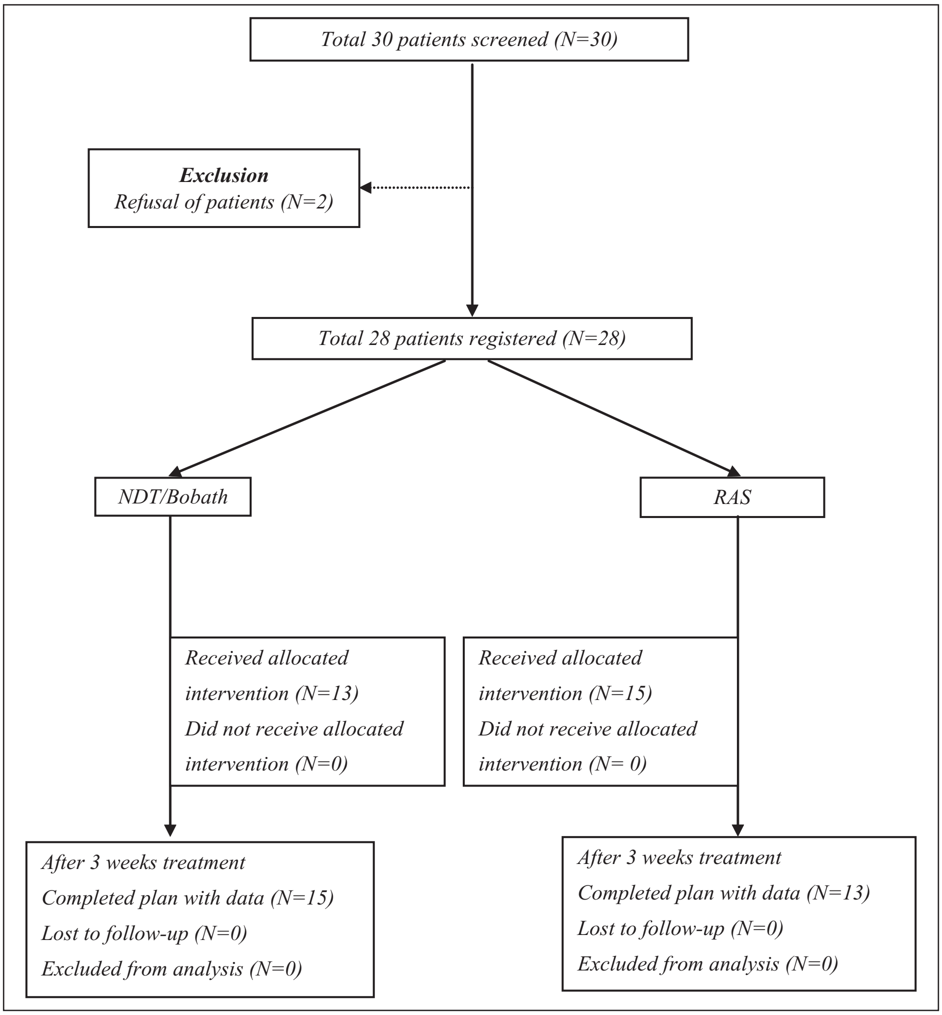

Figure 1. Flow diagram for the study design, NDT, neurodevelopmental treatment; RAS, rhythmic auditory stimulation.

Statistical analysis was performed using the premier vendor for Statistical Package for Social Sciences, Predictive Analytics Software Statistics. Paired *t*-tests were used to evaluate within-subject pairwise comparisons in temporal and kinematic gait measures between the pretreatment and post-treatment tests of the neurodevelopmental treatment and rhythmic auditory stimulation conditions. Mann–Whitney *U*-tests were also used to compare the parameters between groups. A *P*-value of <0.05 was considered statistically significant.

Results

Twenty-eight cerebral palsy patients with bilateral spasticity participated in this study. The participants were randomly allocated to neurodevelopmental treatment (n = 13) or rhythmic auditory stimulation (n = 15). Two patients refused to participate in this study before initial treatment. Figure 1 shows the design and the progress of the study in each step. Baseline and demographic characteristics of the patients, including age, gender, height, weight, body mass index and functional independence measure

Table 1. General characteristics of the subjects

	NDT/Bobath (*n* = 13)	RAS (*n* = 15)	Total (*n* = 28)
Gender (M/F)	7/6	10/5	18/10
Age (years)	27.3 ± 2.5	27.3 ± 2.4	27.3 ± 1.7
Height (cm)	162.9 ± 2.2	161.5 ± 2.2	162.2 ± 1.5
Weight (kg)	59.0 ± 3.1	55.5 ± 2.6	57.1 ± 2.0
BMI (kg/m^2)	22.1 ± 0.8	21.2 ± 0.8	21.6 ± 0.5
FIM	114.5 ± 3.8	112.5 ± 3.9	113.5 ± 2.7

Values are mean ± SE.
NDT, neurodevelopmental treatment; RAS, rhythmic auditory stimulation; BMI, body mass index; FIM, functional independence measure.

are described in Table 1. No statistical difference was found among the general characteristics.

Among temporal gait parameters, cadence, walking velocity, stride length and step length were significantly increased following three weeks of gait training, while stride time and step time were significantly decreased in cerebral palsy treated with rhythmic auditory stimulation ($P < 0.05$ by paired *t*-test) (Table 2). However, in cerebral palsy treated with neurodevelopmental treatment, cadence, walking velocity, stride length and step length were significantly decreased after gait training, while stride time was significantly increased ($P < 0.05$). In addition, the rhythmic auditory stimulation application modestly normalized parts of the gait cycle such as stance phase and swing phase ($P < 0.05$). When changes in temporal data relative to pretreatment (Δ) after gait training with rhythmic auditory stimulation were evaluated in comparison with neurodevelopmental treatment, the change in cadence significantly increased after rhythmic auditory stimulation ($P < 0.05$ by Mann–Whitney

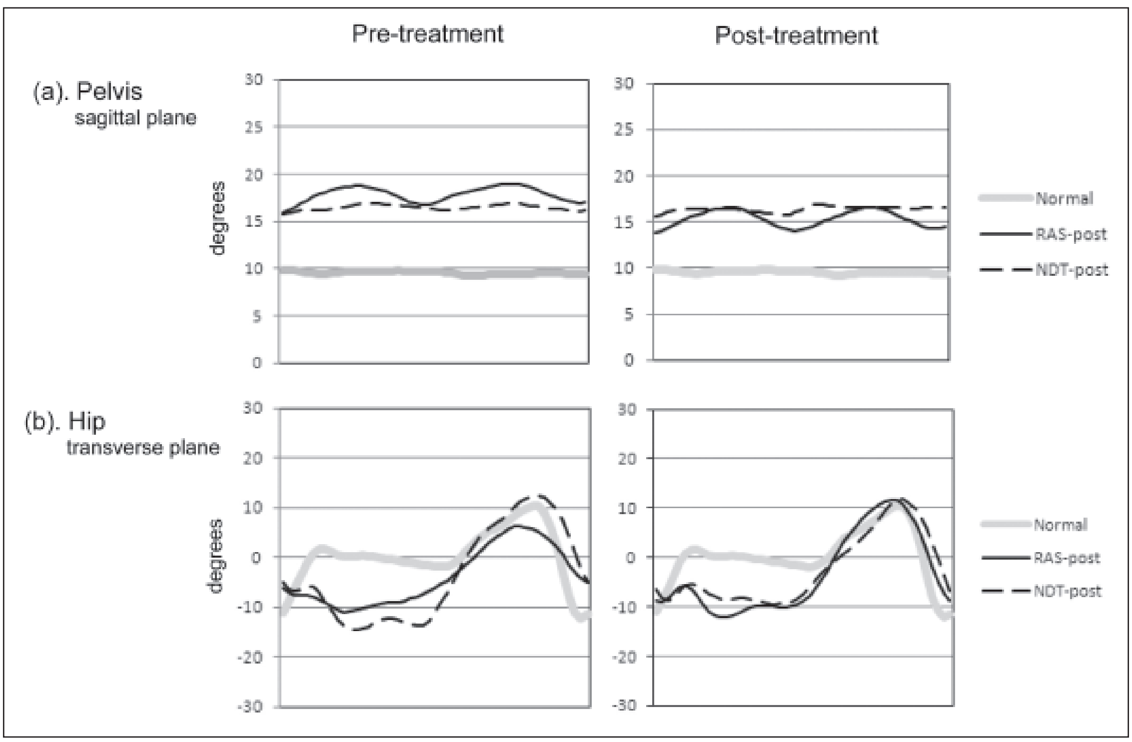

Figure 2. Kinematic figures of the pelvis and hip joint. (a) In the sagittal plane, the anterior tilt of the pelvis was significantly ameliorated after rhythmic auditory stimulation. (b) In the transverse plane, cerebral palsy treated with neurodevelopmental treatment showed that the maximal internal and external rotations of the hip joint were significantly ameliorated, suggesting that neurodevelopmental treatment and rhythmic auditory stimulation have differential effects on gait pattern in adults with cerebral palsy. RAS, rhythmic auditory stimulation; NDT, neurodevelopmental treatment; Normal, normal mean value.

Table 2. Changes in temporal data and overall gait pathology after neurodevelopmental treatment/Bobath and rhythmic auditory stimulation

	NDT/Bobath				RAS				*P*-value between two groups (Δ)
	Pre	Post	*P*-value	Δ	Pre	Post	*P*-value	Δ	
Cadence (step/min)	90.4 ± 7.0	82.3 ± 6.9*	0.001	−7.0 ± 1.8	79.6 ± 6.3	85.7 ± 5.6*	0.035	6.1 ± 2.8†	<0.001
Velocity (m/s)	0.7 ± 0.1	0.6 ± 0.1*	0.001	−0.1 ± 0.03	0.5 ± 0.1	0.7 ± 0.1*	<0.001	0.1 ± 0.03†	<0.001
Stride length (m)	0.9 ± 0.1	0.8 ± 0.1*	0.003	−0.05 ± 0.03	0.7 ± 0.1	0.8 ± 0.1*	0.001	0.2 ± 0.04†	<0.001
Step length (m)	0.5 ± 0.03	0.4 ± 0.03*	0.002	−0.04 ± 0.02	0.3 ± 0.02	0.4 ± 0.03*	0.001	0.1 ± 0.02†	0.001
Stride time (s)	1.8 ± 0.3	2.0 ± 0.4*	0.013	0.2 ± 0.1	2.1 ± 0.3	1.7 ± 0.2*	0.022	−0.3 ± 0.1†	0.001
Step time (s)	0.9 ± 0.2	1.0 ± 0.2	0.224	0.05 ± 0.04	1.0 ± 0.1	0.9 ± 0.1*	0.033	−0.1 ± 0.1†	0.001
Stance phase (%)	68.8 ± 1.8	69.9 ± 1.7	0.177	1.0 ± 0.7	73.4 ± 1.7	70.8 ± 1.6*	0.036	−2.6 ± 1.2†	0.011
Swing phase (%)	31.2 ± 1.8	30.1 ± 1.7	0.177	−1.0 ± 0.7	26.6 ± 1.7	29.2 ± 1.6*	0.036	2.6 ± 1.2†	0.011
GDI	76.9 ± 2.1	75.6 ± 2.0	0.296	−1.3 ± 1.3	73.9 ± 1.8	77.8 ± 1.9*	<0.001	3.9 ± 0.9†	0.001

Values are mean ± SE.
*$P < 0.05$ by paired *t*-test; $P < 0.05$ by Mann–Whitney *U*-test.
NDT, neurodevelopmental treatment; RAS, rhythmic auditory stimulation; Pre, pretreatment test; Post, posttreatment test; GDI, gait deviation index.

Table 3. Changes in kinematic data of the pelvis after neurodevelopmental treatment/Bobath and rhythmic auditory stimulation

	NDT/Bobath				RAS				*P*-value between two groups (Δ)
Pelvis	Pre	Post	*P*-value	Δ	Pre	Post	*P*-value	Δ	
Sagittal plane									
Anterior tilt at initial contact	14.6 ± 1.6	15.7 ± 1.7	0.427	1.1 ± 1.4	14.0 ± 1.5	12.0 ± 1.3*	0.006	−2.0 ± 0.7†	0.021
Maximal angle of anterior tilt	18.8 ± 1.5	20.1 ± 1.4	0.284	1.3 ± 1.2	19.5 ± 1.4	16.6 ± 1.3*	<0.001	−2.8 ± 0.6†	0.003
Minimal angle of anterior tilt	11.6 ± 1.6	12.4 ± 1.6	0.496	0.9 ± 1.2	10.9 ± 1.6	8.8 ± 1.3*	0.001	2.2 ± 0.6†	0.011
Coronal plane									
Add/Abd at initial contact	0.1 ± 1.0	1.4 ± 1.2	0.144	1.3 ± 0.8	1.5 ± 1.2	1.6 ± 0.9	0.961	0.04 ± 0.9	0.148
Maximal adduction angle	4.1 ± 0.9	4.2 ± 1.1	0.891	0.1 ± 0.8	6.0 ± 0.9	5.3 ± 0.9	0.380	−0.7 ± 0.8	0.200
Maximal abduction angle	−4.9 ± 1.2	−4.1 ± 1.2	0.549	0.8 ± 1.3	−4.8 ± 1.0	−4.0 ± 0.8	0.069	0.8 ± 0.4	0.349
Transverse plane									
IR/ER at initial contact	4.0 ± 2.3	4.8 ± 1.8	0.559	0.9 ± 1.5	5.6 ± 2.3	6.2 ± 1.9	0.651	0.6 ± 1.3	0.730
Maximal internal rotation	8.9 ± 2.2	8.8 ± 1.9	0.952	−0.1 ± 1.3	11.7 ± 2.4	11.5 ± 1.8	0.833	−0.3 ± 1.3	0.818
Maximal external rotation	−7.3 ± 2.5	−8.7 ± 2.0	0.416	−1.3 ± 1.6	−5.6 ± 2.7	−5.4 ± 2.2	0.910	0.1 ± 1.1	0.501

Values are mean ± SE, units are degrees (°).
*$P < 0.05$ by paired *t*-test; †$P < 0.05$ by Mann–Whitney *U*-test.
NDT, neurodevelopmental treatment; RAS, rhythmic auditory stimulation; Pre, pretreatment test; Post, posttreatment test; IR/ER, internal/external rotation.

U-test). Changes in walking velocity, step length, stride length and swing phase also increased while stride time, step time and stance phase decreased after rhythmic auditory stimulation ($P < 0.05$).

When a comprehensive measure of overall gait pathology called the gait deviation index was calculated using three-dimensional angles of the pelvis and hip, the sagittal angles of the knee and ankle, and foot progression in the transverse plane, the overall gait pattern exhibited a modest improvement, a higher score after gait training with rhythmic auditory stimulation ($t = 4.442$, $P < 0.001$ by paired *t*-test) (Table 2). However, gait deviation index scores were not improved in cerebral palsy treated with neurodevelopmental treatment ($t = 1.068$, $P = 0.296$). Consequently, change in gait deviation index relative to pretreatment (Δ) significantly increased after rhythmic auditory stimulation, as compared with neurodevelopmental treatment ($P < 0.05$ by Mann–Whitney *U*-test).

When kinematic parameters of the pelvis were evaluated in the sagittal plane, the anterior tilt of the pelvis at initial contact was significantly improved after gait training with rhythmic auditory stimulation ($t = 2.974$, $P = 0.006$ by paired *t*-test) (Table 3). The maximal and minimal angles of the anterior tilt of the pelvis during the gait cycle were also significantly attenuated after rhythmic auditory stimulation application ($t = 4.695$, $P < 0.001$ in maximal angle; $t = 3.842$, $P = 0.001$ in minimal angle) (Figure 2a). However, there were no statistical changes in kinematic pelvic movement in the three-dimensional planes of cerebral palsy treated with neurodevelopmental treatment. Consequently, the changes in kinematic data of the pelvis in the sagittal plane relative to pretreatment (Δ) showed a significant decrease after rhythmic auditory stimulation, as compared with neurodevelopmental treatment ($P < 0.05$ by Mann–Whitney *U*-test).

When the kinematic parameters of the hip joint were evaluated in the sagittal plane, angles of minimal hip flexion during the gait cycle were significantly improved after gait training with rhythmic auditory stimulation ($t = 5.869$, $P < 0.001$ by paired *t*-test) (Table 4). However, hip adduction angles during the gait cycle in the coronal plane and maximal internal rotation in the transverse plane were

Table 4. Changes in kinematic data of the hip joint after neurodevelopmental treatment/Bobath and rhythmic auditory stimulation

	NDT/Bobath				RAS				*P*-value between two groups (Δ)
Hip	Pre	Post	*P*-value	Δ	Pre	Post	*P*-value	Δ	
Sagittal plane									
Flexion at initial contact	44.5 ± 1.8	43.4 ± 2.2	0.338	−1.1 ± 1.1	42.3 ± 1.8	41.7 ± 1.6	0.638	−0.6 ± 1.2	0.818
Maximal flexion angle	47.6 ± 1.8	47.9 ± 2.0	0.800	0.3 ± 1.1	45.9 ± 1.7	44.1 ± 1.4	0.193	−1.8 ± 1.4	0.107
Minimal flexion angle	5.3 ± 1.7	6.3 ± 1.8	0.469	1.0 ± 1.4	10.4 ± 1.9	4.2 ± 1.7*	<0.001	−6.2 ± 1.1†	<0.001
Coronal plane									
Add/Abd at initial contact	−4.5 ± 1.5	−3.0 ± 1.3	0.115	1.6 ± 1.0	−1.8 ± 1.5	−3.8 ± 1.3*	0.005	−2.0 ± 0.7†	0.009
Maximal adduction angle	5.4 ± 1.2	6.6 ± 1.2	0.152	1.2 ± 0.8	7.3 ± 1.1	6.1 ± 1.0*	0.041	−1.2 ± 0.6†	0.018
Maximal abduction angle	−8.0 ± 1.3	−7.3 ± 1.5	0.458	0.8 ± 1.0	−5.8 ± 1.5	−7.2 ± 1.2*	0.028	−1.5 ± 0.6†	0.024
Transverse plane									
IR/ER at initial contact	−4.9 ± 2.6	−6.6 ± 2.9	0.445	−1.7 ± 2.2	−5.8 ± 2.0	−8.8 ± 2.2	0.155	−3.0 ± 2.0	0.611
Maximal internal rotation	21.6 ± 1.5	17.8 ± 1.8*	0.008	−3.9 ± 1.3	14.4 ± 1.2	18.2 ± 1.3*	0.007	3.7 ± 1.3†	<0.001
Maximal external rotation	−21.1 ± 1.2	−18.1 ± 1.6*	0.037	3.0 ± 1.3	−18.6 ± 1.3	−19.3 ± 1.3	0.608	−0.7 ± 1.3†	0.037

Values are mean ± SE, units are degrees (°).
*$P < 0.05$ by paired *t*-test; †$P < 0.05$ by Mann–Whitney *U*-test.
NDT, neurodevelopmental treatment; RAS, rhythmic auditory stimulation; Pre, pretreatment test; Post, posttreatment test; IR/ER, internal/external rotation.

Table 5. Changes in kinematic data of the knee, ankle and foot after neurodevelopmental treatment/Bobath and rhythmic auditory stimulation

	NDT/Bobath				RAS				*P*-value between two groups (Δ)
	Pre	Post	*P*-value	Δ	Pre	Post	*P*-value	Δ	
Knee sagittal plane									
Flexion at initial contact	31.0 ± 2.3	28.8 ± 2.5	0.120	−2.2 ± 1.3	30.4 ± 1.9	31.0 ± 2.0	0.603	0.6 ± 1.2	0.243
Maximal flexion at swing	62.2 ± 2.1	63.7 ± 2.8	0.348	1.5 ± 1.5	55.8 ± 2.2	57.6 ± 1.6	0.206	1.8 ± 1.4	0.974
Minimal flexion at stance	15.0 ± 1.9	14.8 ± 1.9	0.877	−0.1 ± 0.9	15.2 ± 2.3	14.9 ± 2.0	0.779	−0.2 ± 0.9	0.935
Ankle sagittal plane									
Flexion at initial contact	−0.5 ± 1.7	−0.2 ± 1.7	0.716	0.3 ± 0.9	1.4 ± 1.2	2.4 ± 1.5	0.146	1.1 ± 0.7	0.831
Maximal DF at stance	15.9 ± 1.3	16.1 ± 1.4	0.874	0.1 ± 0.9	16.0 ± 1.7	17.2 ± 1.3	0.093	1.2 ± 0.7	0.358
Minimal PF at preswing	−10.6 ± 2.3	−11.4 ± 2.6	0.597	−0.8 ± 1.4	−4.5 ± 1.6	−4.9 ± 1.8	0.718	−0.3 ± 0.9	0.987
Foot transverse plane									
IR/ER at initial contact	−6.2 ± 1.7	−3.6 ± 1.6	0.052	2.6 ± 1.3	−6.1 ± 2.0	−7.8 ± 2.1	0.902	−1.7 ± 1.2†	0.038
Maximal internal rotation	2.9 ± 2.6	4.3 ± 2.2	0.297	1.4 ± 1.3	0.9 ± 2.4	1.1 ± 2.6	0.661	0.1 ± 1.1	0.568
Maximal external rotation	−15.6 ± 2.7	−12.9 ± 2.3	0.055	2.7 ± 1.3	−16.7 ± 2.4	−16.3 ± 2.5	0.608	0.4 ± 1.0	0.332

Values are mean ± SE, units are degree (°).
*$P < 0.05$ by paired *t*-test; †$P < 0.05$ by Mann–Whitney *U*-test.
NDT, neurodevelopmental treatment; RAS, rhythmic auditory stimulation; Pre, pretreatment test; Post, posttreatment test; DF, dorsiflexion; PF, plantarflexion; IR/ER, internal/external rotation.

aggravated in cerebral palsy treated with rhythmic auditory stimulation ($P < 0.05$). On the other hand, cerebral palsy treated with neurodevelopmental treatment showed significant amelioration of maximal internal and external rotations of the hip joint ($P < 0.05$), suggesting that neurodevelopmental treatment and rhythmic auditory stimulation have differential effects on gait pattern in adults with cerebral palsy (Figure 2b).

Whereas the kinematic parameters of the pelvis and hip joint were significantly changed after gait training with rhythmic auditory stimulation, no statistical differences were observed in the kinematic parameters of the knee, ankle and foot, suggesting that the effects of rhythmic auditory stimulation application primarily affected pelvic and hip movement rather than distal movement of the knee, ankle or foot as previously described (Table 5).[31]

Discussion

Changes in immediate gait pattern were previously observed in adults with cerebral palsy when walking with rhythmic auditory stimulation.[31] The kinematic patterns of pelvic and hip movements were particularly changed, indicating reduced anterior tilt of the pelvis and hip flexion during the gait cycle. The array of positive outcomes suggests that rhythmic auditory stimulation may be applied to gait training for cerebral palsy who already have brain damage.[32,33] As with previous applications of rhythmic auditory stimulation, regulated auditory input to the individual's motor system provides a timing cue for muscle activation in rhythmic leg movements; consequently, pathological gait deviation can be reduced. In addition, synchronizing steps to a steady and rhythmic auditory cue induce greater velocities and lower variability during gait.[34] Increased walking speed and improved gait pattern can be helpful to adults with cerebral palsy who are experiencing a steady state or functional decline after completing motor development[35,36] as well as pain and fatigue.[37,38]

The aim of this study was to examine the differential effects of rhythmic auditory stimulation and neurodevelopmental treatment on gait performance after a certain period of gait training in adults with cerebral palsy. In this study, the results of the temporal parameters revealed that rhythmic auditory stimulation significantly improved functional gait measures such as cadence, walking velocity, stride length, step length, stride time and step time, whereas neurodevelopmental treatment did not show the same improvements of temporal measures. When kinematic parameters of the pelvic and hip movements were evaluated in both groups, cerebral palsy treated with rhythmic auditory stimulation also showed significant amelioration of anterior tilt of the pelvis, while cerebral palsy treated with neurodevelopmental treatment did not show improvement of pelvic movement in the sagittal plane. On the other hand, a significant difference was noted among the kinematic parameters of the hip joint, indicating differential effects for each of the treatments. Whereas excessive hip flexion in the sagittal plane was significantly reduced after rhythmic auditory stimulation, there were no statistical improvements after neurodevelopmental treatment. In contrast, kinematic data of the hip joint in the coronal and transverse planes showed aggravation of the hip movement in cerebral palsy treated with rhythmic auditory stimulation, while cerebral palsy treated with neurodevelopmental treatment showed significant amelioration of internal and external rotations of the hip joints.

These findings support the mechanisms of each method of gait training. In temporal results, rhythmic auditory stimulation improved functional gait ability manifested by faster walking velocity; however, neurodevelopmental treatment achieved stability of gait, rather than mobility, manifested by a longer stride time. As the neurodevelopmental treatment aimed to stabilize muscle tone and postural alignment, the movement of the pelvis and hip were stabilized. The kinematic findings also suggest that common kinematic problems of excessive anterior tilt of the pelvis and dynamic deformity of hip flexion could be alleviated using rhythmic auditory stimulation training in patients with spastic cerebral palsy. The most significant change was seen in pelvic and hip movements, which demonstrated that reduction in anterior tilt of the pelvis could yield significant improvement in the overall pathologic gait pattern of cerebral palsy who characteristically had hip flexor spasticity. Finally, a comprehensive measure of overall kinematic gait patterns, the gait deviation index, improved after rhythmic auditory stimulation training, as it ameliorates the common problem of excessive anterior tilt of pelvic movement in spastic cerebral palsy. In contrast, aggravation of hip movement in the coronal and transverse planes during rhythmic auditory stimulation training may be explained by a secondary musculoskeletal problem or poor pelvic-limb dissociation in individuals with cerebral palsy. Consequently, the increased cadence might cause aggravation of hip movements, suggesting that the effect of rhythmic auditory stimulation has a limitation in the patients with poor pelvic-limb dissociation, whereas the differential effect of neurodevelopmental treatment could alter hip movements in the coronal and transverse planes by increasing pelvic-limb dissociation.

The effect of rhythmic auditory stimulation was found to be related to improvements in axial and proximal muscles activation, which were achieved by influencing and regulating the reticulospinal pathway in the brain.[18,39] A possible mechanism is that repetitive rhythmic sound patterns evoke the excitability of spinal motor neurons through the reticulospinal pathway, and thereby the coordination of axial and proximal movement to a given motor command can be entrained.[24] Rhythmical auditory cues may activate subcortical neuronal loops, which are thought to control balance and bilateral movement in the trunk and proximal muscles to adjust reactive feedback-driven motor coordination.[18,34,40] Gait requires input from various levels of the motor control system including the cerebral cortex, brainstem, cerebellum or central nervous system. The effectiveness of rhythmic auditory stimulation has been reported in mainly two populations – stroke and Parkinson's disease – despite their difference in brain lesions.[20–29] It also implies that individuals with cerebral palsy may be eligible to attend gait training with rhythmic auditory stimulation.

The results of this study indicate that there are differential effects of rhythmic auditory stimulation and neurodevelopmental treatment. Gait training with rhythmic auditory stimulation may bring about improvement in functional gait parameters, but hip movement in the coronal and transverse planes may be aggravated. Gait training with neurodevelopmental treatment is beneficial for stabilizing hip movement; however, improvement of temporal gait parameters should not be expected. This suggests that rhythmic auditory stimulation training can be a promising tool for functional gait mobility in spastic cerebral palsy, while neurodevelopmental treatment application is beneficial tool for stability of gait and posture, as well as pelvic-limb dissociation. Deciding which of these therapies to implement should be based on individual gait patterns.

The limitation of this study includes a small sample of patients which restricts the generalization of these findings. In children with cerebral palsy, the findings need to be replicated before practice is changed. In hemiplegic cerebral palsy, the symmetry and the side-to-side variability of temporal and kinematic measures should be compared between two groups receiving neurodevelopmental treatment or rhythmic auditory stimulation. Taken together, a larger sample is necessary to investigate how age, subtypes, cognitive function, severity of spasticity, muscle power and functional level, and the tempo of external cueing can affect the efficacy of rhythmic auditory stimulation for future studies.

Clinical messages

- Rhythmic auditory stimulation and neurodevelopmental treatment differentially improve gait patterns of the pelvis and hip joints in adults with cerebral palsy.
- Rhythmic auditory stimulation leads to a faster gait and improves temporal measures in adults with cerebral palsy.

Author contributions

The role of the authors in this study is as follows: Soo Ji Kim – primary author, experimental procedure, manuscript writing; Eunmi Emily Kwak – experimental procedure, manuscript writing; Eun Sook Park – critical discussion, management of the study; Sung-Rae Cho – corresponding author, manuscript writing, interpretation of the results.

Acknowledgements

We would like to thank Don Shin Lee for his assistance in gait analysis and Soo Jin Oh for her assistance in gait training with rhythmic auditory stimulation. The experimental procedure was approved by the Institutional Review Board (IRB) of Yonsei University Severance Hospital (IRB No. 4-2009-0662).

Conflict of interest

There are no conflicts of interest regarding this research.

Funding

This study was supported by grants from National Research Foundation(NRF-2010-332-B00407;2010-0020408;2010-0024334; SC-4160) funded by the Ministry of Science and Technology, Republic of Korea and the Ewha Global Top 5 Grant 2011 of Ewha Womans University.

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