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Effects of Rhythmic Auditory Stimulation Using Music on Gait With Stroke Patients

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Abstract

This study aimed to determine the effects of Rhythmic Auditory Stimulation (RAS) using music and a metronome on the gait of stroke patients. 13 female and 15 male volunteers were randomly allocated to two groups: namely a group to receive RAS using music and a metronome group (the experimental group; n_1=14) and a group to receive RAS using a metronome only (the control group; n_2=14). The affected side was the left side in 15 subjects and the right side in 13 subjects. The mean age of the subjects was 56.6 years, and the mean onset duration of stroke was 8.6 months. Intervention was applied for 30 minutes per session, once a day, 5 times a week for 4 weeks. To measure the patients' gait improvement, we measured gait velocity, cadence, stride length, double limb support using GAITRite, body center sway angle using an accelerometer, and Timed Up-and-Go test. Functional Gait Assessment were conducted before and after the experiment. The paired t-test was used for comparisons before and after the interventions in each group. Analysis of covariance was used for comparisons between the groups after the interventions. Statistical significance was set at α=.05. Within each of the two groups, significant differences in all of the dependent variables before and after the experiment ($p<.05$) were observed. However, in the comparison between the two groups, the experimental group showed more significant improvements in all dependent variables than the control group ($p<.05$). Our results also suggest that in applying RAS in stroke patients, the combination of music and a metronome is more effective than using a metronome alone in improving patients' gait.

Key words: Gait; Music; Rhythmic auditory stimulation; Stroke.

Introduction

Stroke not only causes serious motor limitations, but also interferes with patients' social activities, relationships, and emotional life, leading to considerable reductions in the patients' quality of life (Poynter et al, 2009). In particular, gait problems appear in most stroke patients (McFadyen et al, 2009). Restoration and improvement of walking is highly relevant for the social and vocational reintegration of stroke survivors (Eich et al, 2004). Compared with healthy persons, stroke patients show a lower velocity, reduced cadence and stride and asymmetry between the two lower limbs (Marigold and Eng, 2006; Yang et al, 2007a). Bearing more body weight on the non-paretic limb may cause these typical spatio-temporal gait problems (Mansfeild et al, 2013). Commonly, stroke patients show the typical abnormal gait patterns such as circumduction, genu recurvatum, and spastic paretic stiff-legged gait (Kerrigan et al, 1999). These abnormal gait patterns take a long time to improve for reeducating gait in rehabilitation, which is the most important goal in stroke patients (Mirelman et al, 2010). Therefore, an appropriate approach for improving gait in stroke patients is important and a critical issue in stroke rehabilitation (Yang et al, 2007b).

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Recently, new intervention methods that emphasize sensual elements and use external sensory impulses have been studied to improve the aforementioned symptoms. These new intervention methods have been shown to have positive results (Michel and Mateer, 2006; Moon, 2012). Cha (2009) reported that the sensual experience can change brain plasticity and that the rhythm affects and provides timing and anticipatory information for effective control of brain activations. However, the neural network in the brain that sends signals to execute gait patterns is altered in stroke patients. This results in interrupted rhythm during walking (Ford et al, 2007). Recent data suggest that rehabilitative procedures involving highly repetitive, rhythmically patterned movement training are particularly effective (Büetefisch et al, 1995), possibly by facilitating long-term potentiation in the sensorimotor cortex as a mechanism for motor learning (Asanuma and Keller, 1991). Among these rehabilitative procedures, Rhythmic Auditory Stimulation (RAS) has been reported to be effective in improving stroke patients' gait ability (Thaut, 2003). In their experiment, Thaut et al (1997) showed improved symmetry in gait patterns after RAS using metronome. Jeong and Kim (2007) showed positive effects of RAS using tambourine for 2 hours per week for 8 weeks on for example, range of motion, mood, and interpersonal relationship, but not in walking. Hayden et al (2009) used intervention durations of 30, 20, and 10 minutes during RAS to improve gait speed, stride length, and gait cycle, but found no significant differences between these training times. Most RAS approaches improved gait ability in stroke patients (Kadivar et al, 2011). However, other studies reported that, although RAS showed effects on balance ability, the improvement of gait ability was not obvious (Hayden et al, 2009; Pelton et al, 2010).

The results of an experiment using functional magnetic resonance imaging and position emission tomography suggest that when patients were concentrated on sounds, the movements of their paretic-side limbs appear more normal and had smoother patterns and their brain activity increases (Horenstein et al, 2009). Furthermore, considerable evidence in motor control research indicate that auditory rhythm can improve timing and variability of motor responses (Smyth and Wing, 1984). Moreover, sound can control cognition in movement (Mazza et al, 2007) and affects brain waves, which is a related event (Beer and Röder, 2005; Eimer, 2001). These results show that concentrated sounds affect and improve the learning process. Futhermore, treadmill gait training using music increased the symmetry of gait pattern, stride length, and step length, and decreased stride time (Roerdink et al, 2007). Therefore, music with rhythm during treadmill gait training will improve gait ability in stroke patients. In this context, the present study aimed to examine the effects of gait training using music and a metronome in order to maximize external sensory impulses toward the improvement of stroke patients' gait.

Methods

Subjects

The subjects of the present study were selected from a pool of patients who had been diagnosed with stroke and hospitalized at H hospital located in Gyeonggi-do (13 women, 15 men). Of these subjects, 28 who had a stroke at least 6 months earlier, obtained 24 points or more in the Korean version of the Mini-Mental State Examination, had no hearing defect, had no orthopedic injury in any of the 2 lower limbs, can walk independently without any aids during 30 minutes, provided written informed consent and understood the purpose of this experiment, had no problems to participate in the experiment as confirmed by their physicians were selected. Those who had diplegia, had cerebellar disease, or could not communicate were excluded. The 28 selected patients were divided into two groups of 14 patients each as follows: a group to receive RAS using music and a metronome (the experimental group) and a group to receive RAS

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using a metronome only (the control group). The affected side was the left side in 15 patients and the right side in 13 patients. The type of stroke was infarction in 14 patients and hemorrhage in the other 14 patients. The mean age of the subjects was 56.6 years, and the mean onset of stroke was 8.6 months. The subjects were assigned into two groups by random drawings of numbered card: Those who draw an odd number were assigned to the experimental group, and those who got an even number were assigned to the control group. The meaning of the random assignments was not explained to the subjects and physiotherapists who were involved in the experiment.

Measurement

GAITRite (GAITRite, CIR System Inc., New Jersey, USA) was used to collect spatiotemporal gait measurement data such as velocity, cadence, stride length, and double limb support (McDonough et al, 2001; van Uden and Besser, 2004). The walkway was 5 m in distance, 60 ㎝ in width, and .6 ㎝ in height, with an electrical foot pressure system. It had 16,128 sensors installed at every 1.27 ㎝ of the walkway in order to collect quantitative data during walking. Instructed by the experimenter, the subjects walked at comfortable velocities on the walking board to which the special sensors were attached. The subjects walked an additional 3 m before and after the walking board. The intrarater reliability of the spatiotemporal gait variables in the gait analyzer used for stroke patients was r=.72～.94. The interrater intraclass correlation coefficients were r=.76～.95 for velocity, r=.83～.97 for cadence, and r=.69～.95 for the paretic and non-paretic side step lengths (Kuys et al, 2011).

A wireless 3-axis accelerometer (MMA7331L, Freescale, Texas, USA) was used to measure the body center sway angles. When the subject was walking on the walking board, an accelerometer attached to a region between L3 and L4 in each subject was used to measure acceleration. The body center sway angle x-theta was calculated around the X-axis of the coronal plane. Rotation angle y-theta was calculated around the Y-axis of the sagittal plane, and rotation angle z-theta was calculated around the Z-axis of the transverse plane. The angles by which the body center moved from each axis were obtained. The body center sway angles (Δx-theta, Δy-theta, and Δz-theta) were obtained as the differences between the maximum and minimum values (Tuck, 2007). The accelerometer showed high reliability of r=.98 for measuring the stroke patients' gait velocity and r=.99 for determining the number of steps (Dobkin et al, 2011). To measure walking capacities for examining changes in the subjects' basic motility and balance, the Timed Up-and-Go (TUG) test was performed. The intrarater reliability of the test in the stroke patients was r=.99, and its interrater reliability was r=.98 (Podsiadlo and Richardson, 1991). Next, Functional Gait Assessment (FGA) was conducted to measure walking capacities. This assessment showed high intrarater reliability of r=.95～.98 and high interrater reliability of r=.89～.97 in stroke patients (Thieme et al, 2009). The physiotherapists only participated in the measurements before and after the interventions, and were blinded to any information about the experiment. All data on the measured parameters were expressed as mean values after 3 measurements were obtained. The subjects did not use any walking aids and were barefoot during the walking test. Measurements were performed by the physiotherapists in special rooms in order to prevent other factors that would affect the measurement results of the gait parameters.

Procedure

The 28 patients were randomly assigned to the experimental (n_1=14) and control groups (n_2=14). The subjects received explanations about the testing methods and the intervention programs before the first testing session. The tests for measuring the gait parameters were performed 1 day before the intervention was started. The interventions were conducted for 30 minutes, 5 times per week for 4 weeks. After 4 weeks of the interventions, post-tests were performed by using the same procedures as those used in the pre-tests. Gait training was implemented in an oval track structure with a total length of 4173.4 ㎝. To implement gait training, each subject wore a wireless headset (BT65N, Abe, Shenzhen, China) and synchronized their steps to the rhythm of the music. The RAS in the experimental group was given by creating an MP3 file containing music that was inserted in the metronome sounds by using a metronome program (FretwayMetro, Fretway, Minnesota, USA) and a digital MIDI (Logic, Sample, Pennsylvania, USA). The file was replayed by using Windows Media Player (Windows Media Player, Microsoft, New York, USA). The music selected was composed of 2 beats with four-four and two-four time signatures, considering the 2-point gait cycle that were preferred by the subjects in Korean pop, pop, and classic music (Cho, 2010). To facilitate the subjects in keeping the beat while hearing the music, one beat of the metronome sound was given to one beat of the music. The procedure was as follows: for the first 2 minutes, the subjects swayed theirs shoulders from side to side or tapped on the floor with their soles while listening to the music. During the next 10 minutes, the patients underwent gait training with RAS. Then, they walked without any rhythm for 1 minute. Finally, they took a rest for 2 minutes. This procedure was repeated 2 times. Massage and extensional exercises were then provided during the second 2 minutes of rest (Hayden et al, 2009). Music provided the frequency of the metronome in the initial contacts of both feet during walking for deciding the beats in the first walk. The instruction was to take a step with the beats. The subjects were then guided according to the regular stimulation rhythm on both sides for walking that was set before the intervention. The speed of adaptation during RAS was calculated based on step counts measured by using GAITRite before starting the training. The speed of the provided rhythms was set to the cadence in the first week and increased by 10% from the initial cadence in the second week. In the third week, the cadence was measured again, and the speed of the rhythms was increased by 10% from the increased cadence. Finally, in the fourth week, RAS was intermittently removed to train the subjects for carry-over (Thaut et al, 1997). The experimental and control groups used the same track for gait training and walked according to the rhythm of the sound from the wireless headset. The beats were set before the training, and the instruction was to match heel strike with the metronome beats during walk for symmetrical walking. The training time schedules were assigned to the control and experimental groups. During the resting time after the second session, stretching exercises and massage were provided. The speed of the metronome was gradually increased in both groups during 4 weeks of intervention. In the control group, we used only metronome by using a computer program without music.

Data analysis and statistics

In the present study, statistical analyses were performed by using PASW ver. 18.0 (SPSS Inc., Chicago, IL, USA). The normal distribution of data for all variables was determined by the Kolmogorov-Smirnov test. General characteristics and homogeneity of dependent variables were analyzed by using the chi-squared test and independent t-test. A paired t-test was performed to compare intragroup differences before and after the training in each group. Analysis of covariance (ANCOVA) was used to compare the differences in the dependent variables after training between the groups. In the ANCOVA, the pretest values of measured dependent variables were used as covariates for each group. Statistical significance level was set at α=.05.

Results

The homogeneity of the subjects was showed no significant differences between the control and experimental groups (Table 1).

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Table 1. Homogeneity of the subjects

Factor	Subjects (N=28)	Experimental group (n_1=14)	Control group (n_2=14)	X^2/t	p
	Mean±SD[a]	Mean±SD	Mean±SD		
Gender					
Female/Male (%)	13/15 (46.4/53.6)	8/6 (51.7/42.9)	7/7 (50.0/50.0)	.144	.705
Affected side					
Left/Right (%)	15/13 (53.6/46.4)	6/8 (42.9/57.1)	9/5 (64.3/35.7)	1.292	.256
Type of stroke					
Infarction/Hemorrhage (%)	14/14 (50.0/50.0)	8/6 (57.1/42.9)	6/8 (42.9/57.1)	.571	.450
Age (year)	56.6±7.9	55.8±8.0	57.4±8.0	.544	.591
Duration[b]	8.6±2.1	8.3±2.3	8.9±1.9	.720	.478
Velocity (㎝/s)	44.8±19.7	39.2±16.0	50.4±22.0	1.539	.136
Cadence (steps/min)	80.7±17.6	77.8±14.3	83.6±20.5	.864	.396
Stride length (㎝)	59.4±26.4	58.0±18.5	60.8±33.1	.272	.788
Double limb support (%)	49.5±14.4	53.7±14.8	45.2±13.1	-1.618	.118
Δx-theta (㎭)	31.4±10.8	34.4±12.0	28.4±8.8	-1.515	.142
Δy-theta (㎭)	21.2±10.2	22.1±10.2	20.3±10.4	-.452	.655
Δz-theta (㎭)	23.7±13.7	23.9±14.5	23.6±13.5	-.060	.952
TUG[c] (s)	30.6±6.8	28.6±3.6	32.5±8.6	1.583	.131
FGA[d] (score)	16.3±2.3	16.1±2.5	16.4±2.3	.240	.812

[a]mean±standard deviation, [b]months between stroke onset and assessment, [c]timed up-and-go test, [d]functional gait assessment.

Table 2. Changes in spatiotemporal gait

		Experimental group (n_1=14)	Control group (n_2=14)
		Mean±SD[a]	Mean±SD
Velocity (㎝/s)	Pre-	39.19±16.03	50.36±21.95
	Post-	48.91±20.27*†	56.55±23.55*
Cadence (steps/min)	Pre-	77.81±14.25	83.58±20.50
	Post-	87.58±15.81*†	89.01±21.93*
Stride length (㎝)	Pre-	58.00±18.51	60.76±33.11
	Post-	68.73±21.80*†	64.17±33.79*
Double limb support (%)	Pre-	53.74±14.80	45.19±13.08
	Post-	45.92±11.45*†	42.26±12.18*

[a]mean±standard deviation, *intragroup statistically significant at $p<.05$, † intergroup statistically significant at $p<.05$.

Changes in spatiotemporal gait

In the within-group comparisons, both groups showed significant differences in velocity and cadence before and after the experiment. In the between-group comparison, however, the experimental group showed more significant improvements in velocity and cadence than did the control group (Table 2).

Changes in body center sway angle

In the within-group comparisons, both groups

Table 3. Changes in body center sway angle

		Experimental group (n_1=14)	Control group (n_2=14)
		Mean±SD[a]	Mean±SD
Δx-theta (rad)	Pre-	34.43±11.99	28.40±8.81
	Post-	22.56±8.88*†	23.00±8.55*
Δy-theta (rad)	Pre-	22.09±10.24	20.33±10.41
	Post-	13.88±5.51*†	15.82±6.33*
Δz-theta (rad)	Pre-	23.87±14.52	23.55±13.45
	Post-	12.20±6.34*†	17.48±7.69*

[a]mean±standard deviation, *intragroup statistically significant at p<.05, † intergroup statistically significant at p<.05.

Table 4. Changes in walking capacity

		Experimental group (n_1=14)	Control group (n_2=14)
		Mean±SD[a]	Mean±SD
TUG[b] (s)	Pre-	28.57±3.59	32.50±8.56
	Post-	20.79±3.62*†	25.36±5.36*
FGA[c] (score)	Pre-	16.14±2.45	16.36±2.27
	Post-	21.21±2.36*†	19.36±2.90*

[a]mean±standard deviation, [b]timed up-and-go test, [c]functional gait assessment, *intragroup statistically significant at p<.05, † intergroup statistically significant at p<.05.

showed significant differences in all axes of the body center sway angles before and after the experiment. In the between-group comparison, the experimental group showed more significant improvements in all axes of the body center sway angles than did the control group (Table 3).

Changes in walking capacity

In the within-group comparisons, both groups showed significant differences in TUG and FGA before and after the experiment. In the between-group comparison, the experimental group showed more significant improvements in TUG and FGA than did the control group (Table 4).

Discussion

In the present study, RAS using music and a metronome was applied in stroke patients divided into an experimental group and a control group. The effects of RAS on the two groups were compared. The effects that improved gait after training in the individual groups were then compared. Our results suggest that the patients' gait improved more in the experimental group. The specific findings of our study are as follows: First, the measurements of the temporal gait variables showed greater improvement after the experiment than before the experiment. Intragroup velocity changes increased by 19.87% in the experimental group and by 10.94% in the control group. Cadence changes increased by 9.76±4.82 steps/min in the experimental group and by 5.44±3.74 steps/min in the control group. Therefore, as compared with the control group, the experimental group showed more significant increases in both variables. This result is consistent with those reported by Schauer and Mauritz (2003), where velocity was improved when music exercise feedback gait training was applied five times per week in 23 stroke patients. Moreover, Kim (2007) reported that gait speed significantly increased when the music was

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provided to healthy adults. These studies supported our finding that music contributed to the improvement of gait speed. Thaut et al (2007) indicated that compared with neurodevelopmental treatment, rhythmic stimulation using music led to greater improvement in stroke patients' cadence. Iwanaga et al (2005) suggested that music inhibited parasympathetic nerve system and facilitated the sympathetic nerve system, therefore festinating heartbeats and increasing blood flow, which contribute to the efficacy of physical movement. The results of these studies support our results that gait speed and cadence were improved. As auditory feedback not only adjusts muscle tone through the reticulospinal tract but also affects actions that are directly controlled by the neocortex, such as walking, velocity and cadence could increase because of the gradual increase in the speed of music and rhythms. Furthermore, both groups showed significant differences in the changes in stride lengths and double limb support, which are spatial gait variables. The experimental group showed significantly greater improvement than the control group. Prassas et al (1997) reported that musical rhythms increased the step lengths of stroke patients. Similarly, consistent with our results, the results of the study by Schauer and Mauritz (2003) indicated that when RAS was applied in stroke patients for 20 minutes, double limb support decreased. However, contrary to the results of the present study, decreases in stride and step lengths were reported in a study by Roerdink et al (2007) where treadmill training and RAS were combined. The results of the study by Roerdink et al (2007) differed from those reported in the present study possibly because training in the former/latter study was implemented on flatland, as treadmills show a characteristic of producing shorter step lengths compared with flatland. Therefore, the decreases in double limb support could have resulted from the quickened toe take-off of the paretic side and the shortened stance phase of the non-paretic side. Physical responses occur easily when dancing or marching to music. Thus, spatial gait variables showed greater improvements in the experimental group.

Both groups showed significant decreases in body center sway angles around the X-, Y-, and Z-axes. Our results are consistent with those of a study indicating that when RAS was applied to stroke patients, pelvic stability and trunk sway decreased, thus shortening gait time (Malcolm et al, 2009). Musical rhythms play the role of a promoter to lead irregular movements to harmonious activities and activate the limbic system in order to increase changes in emotions and to ensure the continuity of movements. That is, musical rhythms maintained the rhythmicalness of movements as a timekeeper, thereby reducing the body center sways.

In addition, both groups showed a significant increase in TUG and FGA. Similar to the measurement results reported in the present study, the average TUG of stroke patients reported in previous studies was 22.6 seconds. FGA was reported to be 13.86 points (Ng and Hui-Chan, 2005; Thieme et al, 2009). However, contrary to the results of the present study, in a study conducted by Hayden et al (2009) where stroke patients were divided into 3 groups and musical rhythmic auditory gait training was implemented 10, 20, and 30 times, respectively, the groups showed no improvement in TUG. The reason underlying this divergence in the results can be the fact that unlike in the previous study where the amount of training increased, speeds were changed in the present study. The improvements in TUG and FGA are considered to have resulted from the improvement of the stroke patients' cadence, stride lengths, and double limb support.

Musical rhythms improves the interactions between the brain and muscles because auditory stimulation is transmitted to the cerebral cortex through the supraspinal auditory system. Musical rhythms draw unconscious responses and positively affect sensory and instinctive movement control (Peterson and Thaut, 2007; Thaut et al, 1997). Edworthy and

Waring (2006) reported that fast and loud music optimally improved exercise capacity. Copeland and Franks (1991) suggested that slow and smooth music improved endurance, and physical and emotional stabilities. Preferred music decreased stress by fatigue when exercising physical performance (Yamashita et al, 2006). In former studies, walking with and without music affected gait parameters and physical functions, and RAS is thought to have brought about gait improvement based on this neurological mechanism. Our results suggest that graded increasing speed affected gait speed, and RAS with preferred music maximized the effect on gait ability. Further studies are needed on RAS with preferred music as additional programs in gait training of stroke patients.

One limitation of this study was that it did not consider various contexts of walking in stroke patients because the experiments were performed in a special room that is not interrupted by any noise or other factors. In addition, the music was used for rhythm and sound in training session. Thus, we could not consider various beats and songs. Further study is needed to investigate the effects of various songs or beats of music as RAS on gait ability. The results of the present study should be further substantiated in clinical studies. We expect that RAS using music will be effectively used in training for gait improvement.

Conclusion

This study demonstrate that stroke patients can successfully apply music with RAS, and that improvements in velocity, cadence, stride length, and double limb support, 3 axes body center sway angles, TUG and FGA support can be achieved when this device is provided in combination with music and gait exercise using rhythmic sensation or other treatment intervention and interdisciplinary rehabilitation.

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