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Original Article

Immediate Effects of Rhythmic Auditory Stimulation with Tempo Changes on Gait in Stroke Patients

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Abstract. [Purpose] The aim of this study was to investigate the effects of tempo changes in rhythmic auditory stimulation (RAS) on gait in stroke patients. [Subjects] Forty-one chronic stroke patients who had had a stroke with more than 6 months previously were recruited for this study. [Methods] All participants were asked to walk under 5 different conditions in random order: (1) no RAS (baseline); (2) baseline-matched RAS (0%); and (3) −10%, (4) +10%, and (5) +20% of the baseline. A GAITRite system was used to evaluate the spatial and temporal parameters of gait. [Results] Compared with under the RAS 0% conditions, the gait velocity, cadence, and stride length on the affected side were significantly decreased under the RAS −10% conditions. Gait velocity and cadence were significantly improved, but gait symmetry was significantly decreased under the RAS +10% and +20% conditions compared with under the RAS 0% conditions. [Conclusion] A faster RAS tempo significantly improved gait velocity and cadence, and applying RAS significantly improved the gait symmetry of stroke patients.
Key words: Gait, Rhythmic auditory stimulation, Stroke

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INTRODUCTION

Rhythmic auditory stimulation (RAS) is one of the neurological therapeutic methods that has physiological effects in rehabilitative exercise therapy, which improves movement control[1)]. It is reported to improve gait in terms of velocity, stride length, and cadence when applied to patients with cerebral palsy, stroke, and Parkinson's disease (various kinds of neurologic diseases) as a rehabilitation therapy[2–4)]. RAS guides the patients to hit the ground with their feet as they walk and simultaneously hear an external auditory cue, synchronizing the time of contact between the foot and ground with the sound[5)]. According to previous researchers, rhythm is an essential element of motor movement including motor control and output[6, 7)], because rhythmic auditory cuing facilitates movement by providing a mechanism for planning movements[3)]. Thaut et al. (2009) studied the effects of different RAS speeds (3%, 7%, 20%) on tapping in healthy adults and reported that both sides of the frontal lobe and occipital lobe showed increased neuronal population activation as the speed increased, and that the increased activity in the occipital lobe also included synchronized rhythm patterns when the rhythm was increased 20%[8)]. Patients with spinal cord injury (SCI) showed decreased gait velocity and cadence, and increased stride length at a normal RAS speed, but these walking abilities all decreased at a 5% faster tempo[9)]. Patients with Parkinson's disease showed a significantly decreased gait velocity and cadence, and significantly increased stride length and double limb support at an RAS speed of −10%. As the RAS tempo was increased, the gait velocity and cadence significantly increased[10)]. Most of the studies on stroke patients have used RAS with constant speed or time-based stimulation increase. Research on the effects of tempo changes on gait in stroke patients is currently insufficient. Therefore, this study attempted to determine the immediate effects of RAS tempo changes on the walking abilities of stroke patients.

SUBJECTS AND METHODS

A total of 41 patients who had recently had their first ischemic cerebrovascular accident (CVA) (24 men and 17 women) were recruited from K, H, and O rehabilitation centers in Korea. The inclusion criteria were as follows: (1) at least 6 months from the onset of stroke (ICD-10 code 160 and 163), (2) able to walk more than 10 m independently, (3) no hearing, visual deficits[10, 11)], and (4) a Mini-Mental State Examination (MMSE) score of 24 or higher[10–12)]. Any patient with one or more of the following conditions was excluded from the study: (1) symptomatic cardiac failure, (2) uncontrolled hypertension, (3) significant orthopedic or chronic pain conditions affecting gait performance, or (4)

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any neurologic disease except for the first stroke. Subjects were selected according to the inclusion criteria and were recruited from December 2010 to February 2011 for this cross-sectional study. Table 1 lists the general characteristics of the subjects. This research protocol was approved by the local Human Investigation Committee, and all participating patients signed a letter of informed consent after receiving a description of the project.

Subjects were examined under 5 different walking conditions: gait without RAS (baseline) and gait with RAS at −10%, 0%, +10%, and +20% of the baseline tempo. These conditions were applied in random order, and the frequency of the metronome was determined by each subject's comfortable walking speed[3]. All subjects were instructed to walk to the beat of the metronome, that is, to step in time with the rhythm[10]. To help the patients to adapt to the rhythm, they listened to the rhythm of the metronome for 30 seconds before walking with RAS[1]. The purpose, study procedure, and evaluation tools used in the study were explained to the subjects before the study. For safety, each patient was assisted by a research assistant, and walking aides (quad cane and straight cane) were allowed to be used during the experiment.

A GAITRite system (GAITRite, CIR Systems Inc, USA, 2008), which is an electronic walkway used to measure the spatial and temporal parameters of gait, was used in this study. It has been shown to provide valid and reliable data[13, 14]. The walkway is 457 cm long, and the active area is 366 cm in length and 61 cm in width. A series of pressure sensors (16,128 sensors) are embedded in the electronic walkway. The GAITRite system recorded the gait velocity, cadence, stride length, double limb support (% of cycle), and double single limb support (% of cycle)[15]. Each patient walked on the mat at his/her usual comfortable walking speed. For accurate data collection, the first and last few steps of each trial were not recorded; patients started walking from a point 2 m before the mat and stopped at a point 2 m after the mat, and walking aids were allowed to be used when necessary. Measurement was repeated 3 times, and a 3-minute break was given in between trials.

An electronic metronome was used to assess each patient's walking tempo in order to provide an accurate rhythm for each patient. The tempo (beats per minute) was set according to the baseline cadence, and the subjects were to step in time with the beat in two-one time. All subjects listened to the rhythm of the metronome for 30 seconds before walking to the beat[1].

In this study, the temporal symmetry ratio proposed by Patterson was used, and the details are as follows[16]. The gait symmetry ratio was used to calculate the time of the swing phase/stance phase of the leg on the affected and unaffected side, separately. The ratio was an the absolute value; gait symmetry increases as the value gets closer to 1, and it decreases as it gets farther away from 1.

Data were analyzed using SPSS ver. 12.0 for statistics and processing. The Kolmogorov-Smirnov test was used for analysis of the general properties and variables of the subjects. One-way repeated measures ANOVA was used, and the LSD post hoc test was performed. Significance was set at $p<0.05$.

Table 1. General characteristics of subjects (n=41)

	Subjects (n=41)
Gender (M/F)	24/17
Age (years)	60.8±19.8
Height (cm)	165.7±7.5
Weight (kg)	65.3±7.4
Paretic side (right/left)	19/22
Since onset (months)	8.68±2.35
MMSE-K[a]	26.6±1.6
Berg Balance Scale	43.8±6.4
Brunnstrom stage (lower limb)	3.2±0.7

Mean±SD
[a]MMSE-K: Mini Mental State Examination-Korean version

RESULTS

Table 2 shows the study results in terms of the spatiotemporal parameters of gait. The gait with RAS 10% slower than the baseline significantly decreased the gait velocity to 35.6±19.5 cm/sec, cadence to 70.8±20.6 steps/min, stride length on the affected side to 59.4±18.9 cm, and the stride length on the unaffected side to 59.2±18.7 cm. The double

Table 2. Spatiotemporal parameters of gait under the five conditions (n=41)

	Baseline	-10%	0%	+10%	+20%
Gait velocity (cm/sec)	42.1 ± 23.3	35.6±19.5*[bcd]	41.3±23.2[acd]	46.3±25.5*[abd]	51.0±28.4*[abc]
Cadence (step/min)	76.5 ± 19.8	70.8±20.6*[bcd]	77.1±22.0[acd]	83.6±22.4*[abd]	88.4±23.1*[abc]
Stride length on the affected side (cm)	63.2 ± 21.6	59.4±18.9*[bcd]	63.5±20.8[ad]	65.2±22.9[ad]	67.9±25.1*[abc]
Stride length on the unaffected side (cm)	63.6 ± 21.3	59.2±18.7*[bcd]	62.9±20.3[ad]	65.0±22.9[a]	66.6±24.3*[ab]
Double limb support (% of cycle)	39.2 ± 11.9	41.6±10.6*[bcd]	38.2±10.4[a]	38.6±11.8[ad]	36.5±12.2*[ac]
Gait symmetry (%)	1.4 ± 1.1	1.2±0.8[b]	1.0±0.6*[acd]	1.3±0.7[b]	1.3±0.9[b]

Mean±SD
*Significantly different from baseline (no RAS) tempo ($p<0.05$)
[a] Significantly different from −10% RAS tempo ($p<0.05$)
[b] Significantly different from 0% RAS tempo ($p<0.05$)
[c] Significantly different from +10% RAS tempo ($p<0.05$)
[d] Significantly different from +20% RAS tempo ($p<0.05$)

limb support (% of cycle) was significantly increased to 41.6±10.6 (% of cycle). In the gait with RAS 10% faster than the baseline, the gait velocity was significantly increased to 46.3±25.5 cm/sec, and cadence was significantly increased to 83.6±22.4 steps/min. In the gait with RAS 20% faster than the baseline, the gait velocity was significantly increased to 51.0±28.4 cm/sec, cadence was significantly increased to 88.4±23.1 steps/min, stride length on the affected side was significantly increased to 67.9±25.1 cm, stride length on the unaffected side to 66.6±24.3 cm, and double limb support (% of cycle) was significantly decreased to 36.5±12.2 (% of cycle) compared with the baseline gait. Gait symmetry was significantly decreased to 1.0±0.6 in the gait with RAS 0% when compared with the baseline gait (1.4±1.1). This means that gait symmetry was significantly improved under the RAS 0% conditions.

DISCUSSION

RAS is reported to improve movement patterns by activating the internal timekeeping mechanism, which leads to movement synchronization[17]. Recently, RAS has been clinically applied as a therapeutic intervention to improve the upper and lower extremity functions in the patients with various neurological diseases[3, 11, 18–20]. Thus, this study was conducted to determine the effects of RAS tempo variations on the walking abilities of stroke patients.

Most of the previous studies reported significant changes in gait velocity at a certain rhythm tempo. Based on these findings, this study used 4 different tempo variations of RAS (−10%, 0%, +10% +20%) for higher significance in proving the effects[10, 11, 21]. The results of this study showed significant improvements in gait velocity, cadence, stride length on the affected side, double limb support on the affected side, and gait symmetry as the RAS tempo was increased compared with the no RAS or RAS 0% condition. When RAS −10% was applied, gait velocity, cadence, and stride length on the affected side significantly decreased and double limb support on the affected side significantly increased. Under the RAS +10% conditions, gait velocity and cadence were significantly increased, and gait symmetry was significantly decreased. When RAS +20% was applied, the gait velocity and cadence increased, and double limb support on the affected side and gait symmetry decreased ($p<0.05$). Increased gait velocity, which is determined by cadence and stride length, is commonly used as the gait evaluation index[16]. These results showed that application of a faster RAS tempo increased gait velocity, revealing the potential to immediately improve walking abilities. Double limb support was significantly decreased as the gait velocity was increased. This means that gait function was improved, and therefore application of afaster RAS tempo can also improve balance and stability.

A previous study reported no significant difference in walking ability between a no music group and a 0% speed group in healthy adult subjects[11]. A study on stroke patients also reported no significant difference in stride length when RAS equal to the baseline speed was applied[22]. This means that stimulations with rhythmical tempo variations have a positive influence on the gaits of stroke patients but that a rhythm equivalent to the gait velocity does not have significant effects on the gaits of patients. Previous studies reported improved gait symmetry when RAS was applied[23], but they only compared groups with RAS application with groups without RAS. These studies did not analyze the effects of RAS tempo. However, the present study applied 4 different RAS tempos (−10%, 0%, +10%, +20%), and found that gait symmetry was the highest at RAS 0%. Gait velocity improved as the RAS tempo was increased; RAS 20% showed the highest gait velocity among the four conditions. All of these results were significantly higher compared to with those under the no rhythm conditions.

According to the results of previous studies, auditory stimulation plays an important role in feedback and feedforward in an unstable posture; it was reported to increase immediate postural stability by controlling the feedback and sensory response[24, 25]. The results of the present study also showed improved gait symmetry as the subjects learned to use feed-forward control to take steps at the given RAS tempo. RAS can increase the excitability of spinal motor neurons via the reticulospinal pathway, thereby reducing the amount of time needed for the muscle to respond to a given motor command. In order to improve the quality of walking abilities, immediate sensory response is needed, and variations in auditory stimulation can be effective in improving the quality of gait[26].

RAS was proved to have an effect on cerebral activity by inducing synchronization of movement and rhythm through sensory stimulation. By applying RAS, a movement can be synchronized to the beat as the movement is actively repeated at the same rhythm[27], and as the person tries to synchronize their movement with the music, concentration and motor control are both promoted. In terms of setting of movement goals, the sensory information, visual feedback, and somatosensory feedback from an auditory cue seemed to be effective in movement relearning, which is based on motor learning[28]. RAS has no side effects, is cost effective, can be used independently or in combination with other treatments, and can decrease muscle fatigue during physical training[17]. External stimuli promote the essential energy needed for movement through synchronized and integrated physical movement[29], and auditory stimulation can improve walking abilities by redefining gait patterns and motor control[19, 30]. Auditory stimulation can also be used for cadence to speed up the gait[31], and application of rhythm can improve independent gait and gait pattern[17].

Using music as an auditory stimulation was reported to induce positive effects on improvement of performance of cognitive tasks[32] Previous studies also reported that pleasant auditory stimulation can have effects on coping with stress[33] and can mediate arousal, emotion, reward, motivation, memory, attention, and executive functioning[34]. Such psychological factors may have influenced the patients'performance in this study, and it is possible that RAS-related improvements seen in the study were mediated by positive mood or self-efficacy. However, these factors were not considered in this study, as this was a cross-sectional study that investigated the immediate effects of different RAS tempos. Further research to determine the emotional and cognitive effects of RAS is needed.

The present study also showed that applying RAS to the gait of stroke patients not only increases the gait velocity but also increases the stride length and gait symmetry at the same time. The subjects who participated in this study adjusted well to the changing tempo, and gait improvement was also found at a tempo that was as high as 20% RAS baseline. We expect to find positive long-term effects after a certain period of training, as Thaut et al. (2007) reported improvements in gait velocity, stride length, cadence, and symmetry after applying RAS with a 5% increase from the baseline tempo for 3 weeks[3]. Further studies are needed in order to ascertain whether using graded increases in tempo throughout the training process will produce improvements in stroke patients.

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