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Original Article

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Effects of Walking Training according to Rhythmic Auditory Stimulation Speed Control Balance of Stroke Patients

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Purpose: In this study, based on the error augmentation, we performed walking training with increased rhythmic auditory stimulation speed on the affected side (IRAS) and walking training with decreased rhythmic auditory stimulation speed on the unaffected side (DRAS). The purpose of this study was to verify whether motor learning was effective in improving balance ability.

Methods: Twenty-eight subjects with chronic stroke were recruited from a rehabilitation center. The subjects were divided into three groups: an IRAS group (10 subjects), a DRAS group (9 subjects), and control group (9 subjects). They received 30minutes of neuro-developmental therapy and walking training for 30minutes, five times a week for three weeks. Static and functional balance ability were measured before and after the training period. Static balance was measured by balancia software. Functional balance was measured by the timed up and go test (TUG) and the berg balance scale (BBS).

Results: After the training periods, the IRAS group showed a significant improvement in TUG, BBS, area 95% COP, and weight distribution on the affected side when compared to both the DRAS group and control group ($p < 0.05$).

Conclusion: Based on the results of this study, it is possible to consider error augmentation methods of motor learning if rhythmic auditory stimulation is applied to stroke patients in clinical practice. If the affected side is shorter than the unaffected side, the affected side should be adjusted to the increased rhythmic auditory stimulation speed, which is considered to be an effective intervention to improve balance ability.

Keywords: Balance, Error augmentation, Rhythmic auditory stimulation, Stroke

INTRODUCTION

The damage caused by a stroke causes hemiplegia, in which the side of the body opposite that of the brain injury site is affected, and delays the recovery of motor skills due to abnormal movement, loss of perception, and reduced cognitive function.[1] The delay in the recovery of exercise capacity results in a decrease in muscle strength on the affected side, abnormal muscle recruitment on the affected side, and asymmetric weight distribution due to reduced stability in the standing position.[2] Since these changes lead to the impairment of secondary functions, the improvement of balance ability after a stroke is one of the most important factors to be considered during rehabilitation.[3]

In order to maintain balance, nervous sensory systems such as the somatosensory, visual, and vestibular systems must be properly harmonized.[4] Balance also depends on the inter relationship of various musculoskeletal elements such as muscle strength, muscle tone, muscle endurance, and joint flexibility.[5] In clinical practice, many studies have been conducted to determine the effectiveness of feedback such as through visual or auditory during training to improve the balance ability of stroke patients.[6-9] In particular, a study was conducted to assess the effect of training incorporating rhythmic auditory stimulation on the balance ability of the stoke patients. Rhythmic auditory stimulation functions by synchronizing the motor and perceptual regions of the brain using sound with a specific rhythm.[10] When applied to patients with neurological disorders who have limited performance in daily life due to reduced sensory and motor skills or those with feedback disorders in sensorimotor control, the movement of the af-

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fected parts becomes smoother.[11-13]

However, the improvement of asymmetric weight bearing and weight shifting in stroke patients is limited when rhythmic auditory stimulation is applied at a regular speed. The brain injury causes problems in sensory integration and information processing at the supraspinal region and limits immediate responses to rhythm.[14] In order to compensate for this limitation, an error augmentation strategy for motor learning can be considered. The error augmentation strategy involves increasing the asymmetry between the walking speeds for both feet to facilitate adaptation and motor learning, ultimately improving symmetry.[15] For example, asymmetrical speeds can be used on the affected and unaffected sides during the stance phase in walking training.

Previous studies have demonstrated that error augmentation during walking training with separate treadmills for each foot for improving balance ability in stroke patients.[16-18] When rhythmic auditory stimulation is applied, the effect of feedback provision to augment the disparity between the affected and unaffected side on the balance ability of brain injury patients has also been confirmed.[19,20] However, the results from these studies have limited applicability for improving the balance ability of stroke patients with an asymmetric posture because the researchers controlled the speed of the rhythmic auditory stimulation applied for both lower limbs. Few studies have investigated the effect of rhythmic auditory stimulation speed control for the affected and unaffected sides on the balance ability of stroke patients.

Therefore, in this study, walking training was performed a fast rhythmic auditory stimulationspeed on the affected side or a slow speed on the unaffected side. Through this process, we attempted to determine whether this approach is effective for motor learning to improve symmetry in stroke patients.

METHODS

1. Subjects

This study is based on the declaration of Helsinki among stroke patients admitted to a rehabilitation hospital located in Jeonju, approved by the IRB (1040621-201901-HR-007-02) and the purpose of the study. The experiment was initiated with 45 subjects who understood and applied to participate in the study. The experiment was conducted with a total of 28 subjects, excluding those who were excluded due to personal problems before starting training or among the subjects participating in the experiment. Subjects who participated in this study were randomly assigned to three groups, using a method of pairing subjects with similar physical by using the Fugl-Meyer lower-limb scale. The walking training with increased rhythmic auditory stimulation speed (IRAS group) consisted of ten people, and the walking training with decreased rhythmic auditory stimulation speed (DRAS group) consisted of nine people, and the walking training with rhythmic auditory stimulation (control group) consisted of nine people. The training was performed five times a week for three weeks.

Table 1. General characteristics of subjects

	IRAS group (n=10)	DRAS group (n=9)	Control group (n=9)
Age (years)	53.6±9.2	51.9±11.0	55.4±8.7
Gender (Male/Female)	6/4	6/3	6/3
Time since stroke (months)	11.2±3.8	11.4±3.9	12.1±4.2
Type of lesion			
Hemorrhagic	4	4	3
Infarction	6	5	6
Side of lesion (Rt/Lt)	6/4	4/5	5/4
Height (㎝)	169.7±9.9	168.2±9.7	163.6±9.7
Weight (㎏)	63.9±15.4	64.1±7.3	66.7±11.4
Fugl-Meyer lower extremity (score)	24.2±2.6	24.0±2.7	23.3±2.8

Mean±standard deviation. IRAS: Walking training with increased rhythmic auditory stimulation of the affected side group, DRAS: Walking training with decreased rhythmic auditory stimulation of the unaffected side group.

The inclusion criteria for the subjects who had had a stroke were (1) more than 6 months after the onset of stroke and less than 2 years, (2) absence of neurotic diseases such as amblyopia, vertigo, and abnormal vestibular function, (3) not effect walking on a subjects without an orthopedic problems, (4) cognitive function allowing an understanding of researchers' instructions. The exclusion criteria for all subjects were (1) having other neurologic conditions that would interfere with walking. The general characteristics of the subjects are shown in Table 1. No significant differences between the groups were found for age, duration of disease, height, or weight ($p > 0.05$).

2. Experimental procedures

All groups, after 30 minutes of neuro-developmental therapy, walking training were performed 30 minutes, 5 times a week for a total of 3 weeks. Before walking training, the subjects were asked to walk at a comfortable speed on a gait analyzer (Optogait system, Microgate, Italy) place on the ground, and the speed of rhythmic auditory stimulation was determined based on the cycle times of the affected and unaffected sides measured. After the researcher operated the computer metronome program in the same space where walking training was conducted, the subject was asked

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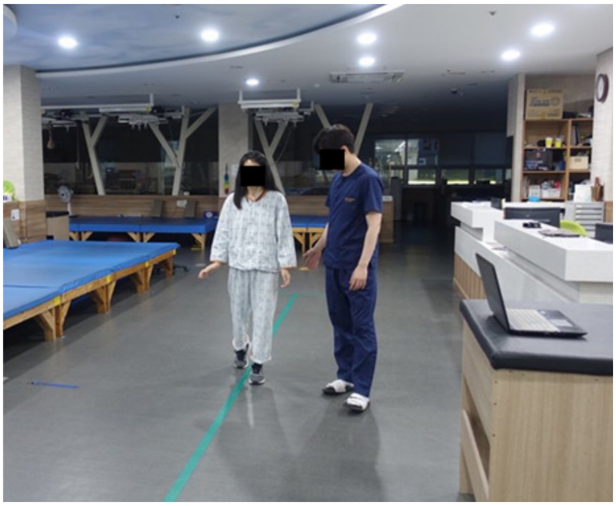

Figure 1. Walking training with rhythmic auditory stimulation

to wore a wireless headset to provide rhythmic auditory stimulation.

Before the walking training, to increase adaptability to the rhythmic auditory stimulation, the subjects were instructed to keep tapping their feet while listening to this stimulation for 2 minutes, and then they performed the walking training with rhythmic auditory stimulation for 10 minutes. After walking with no rhythmic auditory stimulation for 1 minute, the subjects were given a break for 2 minutes to minimize the level of fatigue, and then they performed the walking training again two times.[21] If the subject complained of fatigue or dizziness during walking training, rest was provided to minimize the subject's fatigue, and one therapist assisted the subject from behind for the subject's safety. Before and after training, the balance ability of the subjects was measured (Figure 1).

1) Walking training with increased rhythmic auditory stimulation speed on the affected side (IRAS group)

The rhythmic auditory stimulation provided was based on the cycle time of the affected side measured through a gait analyzer during gait evaluation before training. Rhythmic auditory stimulation provided a speed corresponding to 110% based on 100% comfortable speed in order to increase the speed of the affected side. The subject performed walking training by moving the lower extremity on the affected side in accordance with the increased speed of rhythmic auditory stimulation. In addition, the speed of rhythmic auditory stimulation was increased by 10% for each week, and a questionnaire was conducted on the subject to confirm whether or not they can keep pace with the speed.[15,20,22]

2) Walking training with decreased rhythmic auditory stimulation speed on the unaffected side (DRAS group)

The rhythmic auditory stimulation provided was based on the cycle time of the unaffected side measured through a gait analyzer during gait evaluation before training. Rhythmic auditory stimulation provided a speed corresponding to 90% based on 100% comfortable speed in order to decrease the speed of the unaffected side. The subject performed walking training by moving the lower extremity on the unaffected side in accordance with the decreased speed of rhythmic auditory stimulation. In addition, the speed of rhythmic auditory stimulation was decreased by 10% for each week, and a questionnaire was conducted on the subject to confirm whether or not they can adjust their feet to the speed.[15,20,22]

3) Control group

The rhythmic auditory stimulus provided to the walking training group according to the bilateral rhythmic auditory stimulus was provided based on the average value of the cycle time of the affected side and the unaffected side measured through the gait analyzer during gait evaluation before training.

Rhythmic auditory stimulation provided a comfortable speed of 100%, so that the affected side and the unaffected side were adjusted respectively. In addition, the speed of rhythmic auditory stimulation was increased by 10% for each week, and a questionnaire was conducted to the subject to confirm whether or not they can meet the speed.[20,22]

3. Assessment

1) Static balance

The balancia (Balancia software, Mintosys, Korea) was used to analyze the static balance ability of the subjects. This equipment is analyzed by collecting information on the center of pressure (COP) of the subject while providing it to the computer program (Balancia software) via Bluetooth while the subject is static standing on the Wii balance board. The variables used in this study are the velocity average of the moving distance of the COP divided by the time, the path length of the moving distance of the COP, and the area 95% COP area formed in the shape of an ellipse around the center and weight distribution of the affected side.

Subjects on a pressure plate, put their arms down and measured in a comfortable static standing position. The measurement was conducted in 1minute, and the average value was used by repeating the measurement three times. Researchers assisted at close range to prevent falls during the measurement.

2) Functional balance

Timed up and go test (TUG) is a method that can quickly measure balance ability and has been used to predict the risk of falls, and is also applied to stroke patients.[23] In this study, for the TUG, the subjects stood up in a sitting position in a chair, walked a distance of 3m according to the commander's 'start', and then came back and measured the speed of sitting on the chair. During the measurement, to reduce the subjects' fear of falling, the return direction was directed toward the unaffected side of the stroke subject.[24] Before starting, after having to practice once, it was analyzed by the recorded average value by measuring it repeatedly three times. The berg balance scale (BBS) is an evaluation tool developed to observe functional balance ability and evaluate treatment effects, and is mainly designed to be used to select subjects with risk factors for falls and to determine prognosis. This scale consists of three areas: sitting (1 item), standing (8 items), and posture change (5 items), and consists of a total of 14 items. This scale is a 5 point ranking scale from 0 (impossible) to 4 (completely independent performance), and the total score of 14 questions is 56, and 45 or less is classified as a fall risk group.[25]

4. Statistical analysis

The data were stored in SPSS version 22.0 for Window software (IBM Inc., Chicago, IL, USA) for analysis. The Shapiro-Wilk test was used to test the normality. For the analysis of the study results, a paired t-test was used to compare before and after the group according to the training period before and after 3 weeks of training, and the pre-intervention value was set as a covariate and analysis of covariance was performed. LSD was performed for the post hoc, and the significance level was set to 0.05.

RESULTS

1. Static balance

Among the variables of static balance ability, the velocity average, path length, and weight distribution of the affected side showed statistically significant decreases after training in the IRAS group and the control group compared to before training ($p < 0.05$). The area 95% COP, only the IRAS group showed a statistically significant decrease after training compared to before training ($p < 0.05$). In the comparison between groups, there were statistically significant differences in the area 95% COP and weight distribution of the affected side among the balance variables compared to other groups in the IRAS group ($p < 0.05$)(Table 2).

2. Functional balance

The TUG measured for the change in functional balance ability showed a statistically significant decrease after training compared to before training in all groups ($p < 0.05$). In comparison between groups, the IRAS group showed a statistically significant decrease compared to other groups ($p < 0.05$).

The BBS, all groups showed statistically significant decrease after training compared to before training ($p < 0.05$). In comparison between groups, the IRAS group showed a statistically significant decrease compared to

Table 2. Comparison of pre and post training outcome measures of static balance within and between groups

		IRAS group (n=10)	DRAS group (n=9)	Control group (n=9)	F	p	Post-hoc
Velocity average (cm/s)	Pre	2.70±0.45	2.58±0.52	2.50±0.33			
	Post	2.56±0.52	2.46±0.64	2.40±0.36	0.50	0.610	
	p	0.030*	0.080	0.010*			
Path length (cm)	Pre	81.08±13.60	77.32±15.68	72.86±7.90			
	Post	76.67±15.73	73.50±19.91	69.86±6.18	0.70	0.510	
	p	0.03*	0.09	0.05			
Area 95% (cm^2)	Pre	4.30±2.32	3.16±1.16	3.51±0.67			
	Post	2.17±1.29	2.45±1.13	3.14±0.44	9.49	<0.001†	a>b, c
	p	<0.001*	0.08	0.08			
Weight distribution							
Affected (%)	Pre	45.82±1.76	46.85±2.54	47.16±0.15			
	Post	48.60±1.45	48.05±0.91	47.78±0.31	4.17	0.030†	a>b, c
	p	<0.001*	0.15	<0.001*			

Mean±standard deviation. IRAS: Walking training with increased rhythmic auditory stimulation of the affected side group, DRAS: Walking training with decreased rhythmic auditory stimulation of the unaffected side group. *Significant difference between pre and post intervention within the group ($p<0.05$), †significant difference between the change values among the groups ($p<0.05$).

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Table 3. Comparison of pre and post training outcome measures of functional balance within and between groups

		IRAS group (n=10)	DRAS group (n=9)	Control group (n=9)	F	p	Post-hoc
TUG (s)	Pre	29.17±8.63	23.90±8.71	23.82±3.27			
	Post	25.37±8.45	22.42±9.14	22.88±3.62	9.90	<0.001†	a>b, c
	p	<0.001*	<0.001*	0.050			
BBS (score)	Pre	42.20±3.05	42.20±3.23	44.33±5.67			
	Post	47.10±2.56	45.20±3.03	46.89±4.83	4.97	0.020†	a>b, c
	p	<0.001*	<0.001*	<0.001*			

Mean±standard deviation. IRAS: Walking training with increased rhythmic auditory stimulation of the affected side group, DRAS: Walking training with decreased rhythmic auditory stimulation of the unaffected side group. *Significant difference between pre and post intervention within the group ($p<0.05$), †significant difference between the change values among the groups ($p<0.05$).

other groups ($p<0.05$)(Table 3).

DISCUSSION

This study applied a strategy to error augmentation in walking training according to rhythmic auditory stimulation, and tried to find out which methods are effective in motor learning to improve the symmetry of stroke patients and affect balance ability.

The average velocity and path length measured to determine the static balance ability decreased in both the IRAS group and the control group after training, but there was no difference between all groups. A study by Cha et al.,[6] also demonstrated that walking training with rhythmic auditory stimulation on the affected side is effective at improving static balance ability. This was due to repeated weight shifting to the affected side in accordance with the rhythmic auditory stimulation during walking training. In this study, the improvement in static balanceability compared to the level before training was attributed to increased weight distribution tothe affected side because rhythmic auditory stimulation was applied on the affected side in both groups, unlike the DRAS group.

The area 95% COP area decreased only in the IRAS group after training. A comparison between the groups revealed that the area 95% COP area was significantly reduced on the IRAS group compared to the DRAS group and control group. The weight distribution on the affected side increased after training in both the IRAS group and the control group. A comparison between the groups revealed that the weight distribution on the affected side was significantly increased compared to the DRAS group and control group. Stroke patients have an asymmetric posture due to a decrease in weight distribution to the affected side while standing, which leads to issues with balance. Adjustments in neurosensory systems such as the proprioceptive and musculoskeletal systems are necessary to a symmetrical posture.[26] A study by Betschart et al.,[27] demonstrated that error augmentation strategy by increasing the speed of the treadmill on the affected side during walking training using was effective at improving symmetry. This was attributed to the induction of adaptation and motor learning at the faster treadmill speed through the muscle and joint proprioception systems. In this study, error augmentation strategy was also performed in the IRAS group by having them move in sync with rhythmic auditory stimulation at an increased speed on the affected side. In order to control the error, motor learning through muscle and proprioceptive system control is thought to have occurred, resulting in decrease area 95% COP and increased weight distribution on the affected side. In the DRAS group, it was thought that weight distribution on the affected side would increase because walking training was performed in sync with rhythmic auditory stimulation on unaffected side. However, it is possible that the neurosensory and musculoskeletal elements on the affected side were not sufficiently affected.

In the TUG and BBS, which were conducted to evaluate the functional balance ability of the patients, improved after training in all groups. In a study investigating changes in the functional balance ability of stroke patients with the application of rhythmic auditory stimulation during backward walking training, the results were better for the TUG. In addition, following treadmill training with rhythmic auditory stimulation, the results for the TUG and BBS improved.[28,29] It was reported that the repetitive rhythm of rhythmic auditory stimulation promoted rhythmic movement in patients with central nervous system and improved their motor performance.[12] When a rhythmic auditory stimulus is input through the ear, it is transmitted to the central pattern generator along the reticulospinal tracts, which are the descending pathways that control voluntary movement. In addition, the stimulus is transmitted to the primary auditory cortexthrough the supraspinal auditory system, which structures and adjusts the motor pattern, improving functional motor performance through motor learning.[10,30] Therefore, in this study, the improvement in functional balance ability in all groups after training was attributed to improved exercise performance due to the rhythmic auditory stimulation.

In a comparison between the groups, the IRAS group showed improved results in both the TUG and BBS compared to the DRAS group and the control group. This means that the erroraugmentation strategy provided on the affected side more effective in improving the functional balance ability. A study by Mieville et al.,[31] reported that error augmentation strategy duringgait training on a separate treadmill did not affect the improvement of balance due to difficulties in maintaining posture. On the other hand, a study by O'Brien et al.,[32] verified that visualfeedback error augmentation strategy was effective in improving balance ability. For motor learning, it is important to explore errors that differ from current abilities in the early stages. Theerror augmentation strategy induces movement changes and promotes motor learning whilethe subject explores to reduce errors.[33,34] In this study, the error augmentation strategy based on the affected side is thought to be the result of motor control and motor learning that change the movement of the affected side to reduce errors.

The patients in this study were asked to move their feet in rhythm while listening to a rhythmic auditory stimulus in a sitting position. The process was performed a total of two times for 2 minutes each time to enable the patients to become familiar with the rhythmic auditorystimulus before walking training. In addition, when the tempo of the rhythmic auditory stimulus was changed each week, a questionnaire was given to the patients to determine whether training using the new rhythmic auditory stimulus. The DRAS group reported difficulties in responding to the new rhythmic auditory stimulation. This may have been a result of anxiety caused by an increase in the time for the affected side as the tempo was reduced. In consideration of these factors, during walking training using rhythmic auditory stimulation, it is necessary to anticipate the weight movement in advance by synchronizing the foot in a standing position rather than a sitting position to become familiar with the rhythmic auditory stimulation. Since this study was only conducted with patients currently admitted to rehabilitation hospitals and receiving treatment, there is a limit to generalization of the results to the daily lives of all individuals with stroke-related hemiplegia. In addition, during walking training, the patients focused only on rhythmic auditory stimulation and potential compensatory movements were not considered. This factor should be taken into account in the development of training strategies incorporating rhythmic auditory stimulation in the future.

Based on the results of this study, physical therapists who wish to attempt walking training with rhythmic auditory stimulation for stroke patients in clinical practice can consider a strategy to increase the disparities on the affected and unaffected sides to improve motor learning. In particular, when the step length on the affected side is shorter than that on the unaffected side, synchronizing the affected side to a faster rhythmic auditory stimulation is consideredan effective intervention for improving balance ability.

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