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Clinical Feasibility of Integrating Fast-Tempo Auditory Stimulation with Self-Adopted Walking Training for Improving Walking Function in Post-Stroke Patients: A Randomized, Controlled Pilot Trial

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Abstract. [Purpose] This study tested the clinical feasibility of using fast-tempo auditory stimulation (FTAS) incorporated into self-adopted walking training for improving walking function in patients with post-stroke hemiparesis. [Subjects] A total of 26 patients volunteered for the study and were randomly allocated to either the experimental group (EG) or the control group (CG), with 13 patients in each group. [Methods] The patients in the EG received 30-minute self-adopted walking training with FTAS twice a day, five days a week for two weeks. Walking speed, number of steps, and Wisconsin gait scale were measured before and after intervention. [Results] Significant differences between pre-test and post-test were found for all variables in the EG; however, only the number of steps was affected in the CG. A post-test comparison of the 2 groups revealed significant differences in all variables. The improvement rate for all variables was significantly higher for the EG than the CG. [Conclusion] These findings support the clinical use of FTAS integration into walking training as an efficient option for improving walking function in patients with post-stroke hemiparesis.
Key words: Auditory stimulation, Stroke, Walking

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INTRODUCTION

Walking impairment in patients with hemiparesis is characterized by asymmetrical stride time and length, decreased velocity, muscle weakness, poor posture control, hypertonus, and abnormal muscle activation patterns, mostly affecting the hemiparetic side[1)]. Loss of walking ability is a serious problem following stroke, and presents one of the most difficult barriers to functional performance. The majority of rehabilitation efforts focus on walking training to facilitate restoration of functional independence[2)].

Walking function is a significant factor influencing the patients' chances of returning to their premorbid lives. In some cases, walking training is insufficient to achieve successful restoration of function. In neurological rehabilitation, specific approaches have been developed to enhance walking ability, and treatment concepts have gradually expanded to include lower limb strengthening[3)], task-oriented exercises[4)], and

Table 1. Demographic characteristics of the subjects

	EG (N = 13)	CG (N = 12)
Age (yrs)	59.20 ± 11.00	52.90 ± 13.00
Gender (Male/Female)	8/5	8/4
Hemiparetic side (Right/Left)	9/4	5/7
Types of stroke (Hemorrhage/Infarction)	4/9	4/8
Onset period (Months)	15.50 ± 5.00	14.00 ± 8.00
Modified Barthel Index (Score)	89.46 ± 9.46	82.83 ± 10.49
Brunnstrom Stage of Lower Extremity (Stage 4/Stage 5)	6/7	9/3

EG: Experimental Group, CG: Control Group

mental practice[5)], all of which are suggested as adjuncts to exercise therapy. Functional electrical stimulation[6)], and treadmill walking training[7)] are also commonly used to improve walking ability. More recently, robotic instrumentation has been specifically performed as therapeutic practice for walking recovery[8)].

One recent adaptation of gait therapy utilizes fast-tempo rhythmic auditory stimulation to provide rhythmic sensory cuing of the motor system. Rhythm serves as an anticipatory and continuous time reference on which movements are mapped within a stable temporal template. The fast-acting physiological entrainment mechanisms between auditory rhythm and motor response serve as coupling mechanisms to stabilize and regulate walking patterns[9)]. Recent studies have reported successful outcomes with the application of rhythmic auditory stimulation to facilitate recovery of functional movement in patients with neurological deficits[9–11)].

Although some clinicians have reported that rhythmic auditory stimulation might provide an additional loading in synchronization with sustained walking movement[12)], it has been recently suggested to be an effective tool in the functional rehabilitation of patients with hemiparesis[13)]. The use of rhythmic auditory stimulation has not been widely adopted in the clinical environment and has garnered little attention in the research field. The purpose of this study was to characterize the utility of integrating fast-tempo auditory stimulation with self-adopted walking training as a specific method for improving walking function of patients with post-stroke hemiparesis.

SUBJECTS AND METHODS

Subjects

Twenty-six patients with post-stroke hemiparesis volunteered for this study. The subjects were randomly assigned, 13 subjects each, to an experimental group (EG) and a control group (CG). Inclusion criteria were as follows: (1) unilateral post-stroke hemiparesis, (2) a minimum 6-month time lapse since stroke onset, (3) ability to walk at least 10-m without any assistance, (4) slow walking speed (<0.8 m/s)[14)], (5) no other neurological or orthopedic diseases, (6) and no cognitive impairment (>24 on the Mini-Mental Status Examination)[15)]. During the study, one CG subject was eliminated from the data analysis due to a history of irregular participation in repeated trials. Subject demographic characteristics are summarized in Table 1. There were no statistically significant differences in age ($t = -1.34$, $p = 0.19$), onset period ($t = -0.45$, $p = 0.66$), and modified Barthel index ($t = 1.66$, $p = 0.11$) between the two groups.

Methods

Walking function was measured by the 10-m walk test, number of steps taken during 20-m walking, and the Wisconsin gait scale (WGS). The 10-m walk test, in which subjects are timed while walking a distance of 10-m at a comfortable speed, evaluates walking speed. The 10-m walk test has been recognized for its high test-retest reliability in people with stroke (ICC = 0.87)[16)]. The number of steps was measured while the subjects walked 20-m at a self-adopted comfortable speed, according to the method of Pizzi et al.[17)]. A qualitative assessment of the subjects' walking from clinical aspects was performed using the WGS, which is designed to measure the visible walking characteristics of patients with hemiparesis by examining body movements at each phase of walking. The WGS utilizes 14 observable variables that assess and score clinically relevant components of walking; scores range from 14 to 45, with higher scores indicating increasing gait deviation[18]. The WGS has been found to have high intra-rater (ICC = 0.93) and inter-rater (ICC = 0.90) reliability[19]. All measurements were collected before and after intervention. To avoid the potential bias of immediate intervention effects, post-test measurements were made a day after the final training session. All measurements were made in triplicate and averaged for analysis.

Fast-tempo auditory stimulation (FTAS) for the EG was prescribed with a modification to the treatment protocol described by Prassas et al.[20]. For auditory stimulation with a fast beat, classical music at 120 metronome beat/min (J.S. Bach Harpsichord Concerto No.4 in A major, BWV 1055) was chosen. This tempo matched the number of accentuated musical beats per minute to the average number of steps per minute averaged by five patients with a 0.8–1.2 m/s walking speed and who did not experience difficulty in ambulation in their communities[14], prior to the beginning of the study. These data were used only to identify a suitable piece of classical music. The EG subjects listened to the classical music using earphones and an MP3 player (YP-910GS, Samsung, Korea) while walking at their self-adopted speed. For the CG, walking training was performed without any specific auditory stimulation. To ensure safety during training, a physical therapist followed the patients while they trained, but did not provide any verbal encouragement to the subjects. In both groups, training was performed on a 20-m track for 30 minutes, twice a day, five days a week, for two weeks. Both groups also received neurodevelopmental treatment for an hour per day, according to the routine schedule of the rehabilitation unit.

Data were analyzed by using SPSS 12.0 (SPSS Inc., Chicago, IL, USA). The values of the experimental and control groups were expressed as means and standard deviations. The independent t-test was used to compare demographic characteristics (age and onset period) of the subjects between the 2 groups. For each group, the difference between the pre-test and post-test results was analyzed using the paired t-test. Comparisons of each variable between the groups were made with the independent t-test. The significance level was set at 0.05 for all analyses.

RESULTS

The values of walking speed, number of steps, and WGS score of the EG and CG and the improvement rate of each variable are listed in Table 2. In the EG, significant pre- to post-test differences were found in walking speed, number of steps, and WGS score ($p<0.05$), while the CG showed a significant difference only in number of steps ($p<0.05$). There were significant differences in all variables between the two groups at post-test ($p<0.05$). Statistical analysis of the improvement rate of walking speed, number of steps, and WGS score showed significant differences between the EG and CG ($p<0.05$).

DISCUSSION

Study efforts directed toward the long-term maintenance of walking function in a variety of situations are a more essential requirement for the treatment of hemiparetic patients than the exploration of treatment modes for short-term improvements in walking performance[21]. To improve patient participation and motivation to complete a given course of therapy, accessibility to treatment is regarded as one of the important concerns in managing patients with post-stroke hemiparesis. Based on this therapeutic need in clinical settings, this study was designed to verify the clinical feasibility of using fast-tempo rhythmic auditory stimulation as a therapeutic adjunct to reinforce the efficacy of walking training.

To improve the efficacy of walking training, we used two training options: 1) self-adopted walking training at a comfortable speed, or 2) walking training with auditory stimulation with a fast beat. Patients may experience additional physical and psychological burdens when asked to perform steady walking tasks at a defined pace, synchronized to a rhythmic auditory stimulus[22]. Therefore, the self-adopted pace in walking training may be a good way to avoid superfluous burdens caused by intra- and extra-loading of a pre-defined walking speed.

In this study, classical music was selected based

Table 2. Comparison of walking speed, number of steps, and WGS score between the experimental and control groups

	EG	CG	t
Walking speed (m/s)			
Pre-test	0.38 ± 0.14	0.35 ± 0.14	–0.54
Post-test	0.54 ± 0.21	0.37 ± 0.15	–2.45*
t	–6.70*	–1.85	
Improvement rate (%)	47.61 ± 16.34	3.63 ± 6.6	–8.67**
Number of steps			
Pre-test	59.15 ± 18.16	74.25 ± 28.95	1.58
Post-test	49.46 ± 13.44	67.17 ± 23.21	2.36*
t	5.29*	3.05*	
Improvement rate (%)	15.31 ± 7.12	8.81 ± 6.42	2.39*
WGS score			
Pre-test	22.49 ± 4.22	24.86 ± 4.32	1.39
Post-test	20.37 ± 3.79	23.66 ± 3.53	2.25*
t	8.64*	2.10	
Improvement rate (%)	9.34 ± 3.42	4.19 ± 7.04	2.36*

EG: Experimental Group, CG: Control Group, WGS: Wisconsin Gait Scale, *: $p<0.05$, **: $p<0.01$.

on the result of a previous study, which demonstrated that subjects experienced greater self-reported pleasure with the classical genre than with other musical styles[23]. The tempo chosen for the application of FTAS was determined by calculating the average step numbers of five patients who had a relatively rapid walking speed (0.8–1.2 m/s) and were able to ambulate in the community without any specific problems[14]. The subjects participating in this study were those who presented with slow walking speed (<0.8 m/s). Rhythms with a comfortable, or slightly higher, tempo can be beneficial for improving the walking function of patients with hemiparesis, depending on the degree of paralysis[24]. Based on prior results, we considered the average pace of patients who could walk more rapidly to establish a musical tempo for the FTAS that was faster than the average pace of the subjects.

We found that the EG subjects, who performed self-adopted walking training with the FTAS, showed greater improvements in walking speed, number of steps, and WGS score at post-test than the CG subjects. Also, in the comparison of pre-test and post-test results, EG subjects showed significant improvements in all variables, while CG subjects showed improvements only in the number of steps. Post-stroke walking is characterized by reduced walking speed, cadence, and stride length, as well as reduced gait symmetry, with prolonged stance duration on the unaffected side and reduced step length of the affected limb[25]. Walking speed reflects aspects of walking ability, balance function, and overall physical condition. In the present study, the rate of improvement was highest for the walking speed of EG subjects, and its between-group significance was also the highest. This finding indicates that FTAS has a more significant relationship with walking speed, which greatly affects patients' ability to perform routine daily activities[26]. In the EG, improved walking speed and increased number of steps might be related to the improvement of walking function which showed increased walking symmetry. In addition, improved subjective WGS scores support these findings. The results of this study are supported by previous studies[1,13,20].

Numerous studies have developed a variety of therapeutic strategies with the goal of enhancing walking recovery[3–8]. In most cases, the given intervention was performed for over 6 weeks. Although this study was conducted over a short period of two weeks with twice daily performances, the findings were similar to the results of previous studies with specific approaches performed over longer periods. In this study, the patients of the EG did not meet with the criteria (0.8–1.2 m/s) for appropriate walking speed for community ambulation[14]; however, we believe that patients' walking speed could be further improved by the use of this method for long-term therapy. Neurophysiological evidence supports the use of FTAS for the rehabilitation of patients with post-stroke hemiparesis. Rhythmic auditory stimulation increases the excitability of spinal motor neurons via the reticulospinal pathway, reducing the amount of time required for muscular response to a given motor command[27]. Based on the best explanation for the effect of rhythm on walking pace, the "smoothing-out" of the spatial walking mechanism may be controlled more centrally by using the anticipatory stimulus of rhythmic patterns as time-related movement endpoints to enhance predictive control on a motor program level[28]. Walking can be described as a coordinated and sequential movement of lower limbs; therefore, the rhythmic facilitation of its related factors may contribute to successful walking[13]. Previous studies have reported that auditory stimulation may be an effective means of reinforcing functional movement when it is rhythmically performed in coordination with the motor response in an appropriate time relationship[9–11,29].

The results of this study and previous studies support the clinical use of integrating FTAS into walking training. The FTAS is easily performed, and may have greater adaptability to home-based training and self-management protocols for patients with post-stroke hemiparesis. Our study has some limitations, which can be addressed in future studies. The small sample size of this study greatly limits the generalization of our findings to the entire hemiparetic population. In addition, the long-term effects of FTAS combined with self-adopted walking training were not addressed. Further studies with larger sample sizes and longer interventions are required to determine the clinical benefits of this intervention as a walking training protocol for patients with post-stroke hemiparesis.

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