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Neurofeedback Training Improves the Dual-Task Performance Ability in Stroke Patients

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Owing to the reduced capacity for information processing following a stroke, patients commonly present with difficulties in performing activities of daily living that combine two or more tasks. To address this problem, in the present study, we investigated the effects of neurofeedback training on the abilities of stroke patients to perform dual motor tasks. We randomly assigned 20 patients who had sustained a stroke within the preceding 6 months to either a pseudo-neurofeedback (n = 10) or neurofeedback (n = 10) group. Both groups participated in a general exercise intervention for 8 weeks, three times a week for 30 min per session, under the same conditions. An electrode was secured to the scalp over the region of the central lobe (Cz), in compliance with the International 10-20 System. The electrode was inactive for the pseudo-training group. Participants in the neurofeedback training group received the 30-min neurofeedback training per session for reinforcing the sensorimotor rhythm. Electroencephalographic activity of the two groups was compared. In addition, selected parameters of gait (velocity, cadence [step/min], stance phase [%], and foot pressure) were analyzed using a 10-m walk test, attention-demanding task, walk task and quantified by the SmartStep system. The neurofeedback group showed significantly improved the regulation of the sensorimotor rhythm ($p < 0.001$) and ability to execute dual tasks ($p < 0.01$). Significant improvements on selected gait parameters (velocity and cadence; $p < 0.05$) were also observed. We thus propose that the neurofeedback training is effective to improve the dual-task performance in stroke patients.

Keywords: dual tasks; gait patterns; neurofeedback training; stroke; task performance
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Introduction

A stroke is a frequently occurring neurological disease, defined as a problem with normal blood supply once normal neurological growth and development of the brain has been achieved (Kelley and Borazanci 2009). A stroke triggers various problems depending on the region involved, the size of the damaged area, and the cause of the stroke. Resulting impairments in sensorimotor function and postural control can greatly affect the independence of stroke patients with regard to daily living (Desrosiers et al. 2002). Many activities of daily living require simultaneous performance on more than one task (O'Shea et al. 2002). Therefore, when two motor tasks are performed simultaneously (Canning 2005), this is called dual-task performance (Pellecchia 2005). Most stroke patients experience problems, such as falls, due to the loss of physical ability under dual-task conditions (Pettersson et al. 2007; Yang et al. 2007). Experiencing a fall leads to a lack of confidence, which further contributes to limitations in independent life (Woollacott and Shumway-Cook 2002). Bowen et al. (2001) reported that patients with hemiplegia resulting from a stroke had a lower ability to concentrate, and thus had low dual task performance capabilities. When performing dual tasks, these patients needed to concentrate more on the tasks in order to perform the dual tasks. They also experienced difficulty caused by restricted information processing, which impairs the capacity to efficiently distribute concentration to two or more tasks (Woollacott and Shumway-Cook 2002).

Concentration is a cognitive function that contributes to the identification of errors in posture control, as well as to the control of voluntary movement (Morioka et al. 2005). Understanding the effects of neurological conditions on

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concentration is an important element for understanding the impairments in postural adjustment in patients with neurological damage, such as a stroke.

When a task is given to patients with stroke, they do not perform the task unconsciously and automatically, but they rather require a conscious and low response, which is affected by higher brain functions, such as concentration (Hyndman and Ashburn 2003).

When a cognitive and a motor task are performed simultaneously, cognitive-motor interference (CMI) occurs, and this interference has been shown to increase in elderly people and stroke patients (Yang et al. 2007; Dubost et al. 2008). Woollacott and Shumway-Cook (2002) predicted CMI to be an important factor when performing dual tasks, as these tasks require maximal mental effort.

In stroke patients, an increase in CMI results from a decrease in processing ability (Regnaux et al. 2005). Every patient has a different level of CMI; therefore, assessment of their performance on dual tasks may inform their treatment plan (Yang et al. 2007). In order to conduct complex tasks, two tasks need to be performed at the same time (Canning et al. 2008), and training to perform the unrelated task is necessary. Therefore, functional evaluation of stroke patients should include assessment of cognition and motor capabilities under dual-task conditions (Bowen et al. 2001). Providing training in an environment where the requirements are similar to a patient's real life environment will facilitate the transfer of learning. However, combined cognitive and motor training of stroke patients under diverse conditions is difficult.

Neurofeedback training is a method that can be used to improve motor and cognitive ability in stroke patients using electromagnetic stimulation and biofeedback (Serruya and Kahana 2008). Neurofeedback training provides a non-invasive method to change brain function (Sterman and Egner 2006). Neurofeedback can be used for different disorders affecting brain functions, including chronic pain (Evans et al. 2014). Neurofeedback training has also been used to improve emotional control (Heinrich et al. 2007), enhance concentration and memory (Berner et al. 2006), and improve cognitive and motor functions following brain injury (Angelakis et al. 2007). This is called neurotherapy, which is the use of feedback from brain activity itself (e.g., electroencephalogram biofeedback) to modify brain function (Wing 2001).

Brain waves are divided into slow waves and fast waves, and the enhancement of concentration is closely related to activation of sensorimotor rhythm (SMR) waves and β wave activity (Wing 2001; Putman 2002; Vernon 2005). Performance of motor activities that require concentration requires that the sensorimotor cortex resolve brain waves specific to the task (Egner and Gruzelier 2001). Therefore, the study of neurofeedback training using SMR waves to improve concentration for motor activities would be of benefit within the context of stroke recovery. The goal of this study was to examine changes in brain waves with neurofeedback training using assessments of compensation-inhibition control and gait performed under dual-task conditions.

Participants and Methods

Participants

The participants in this study were in-patients in our institution's hospital with a clinical diagnosis of stroke, confirmed by computed tomography or magnetic resonance imaging. The inclusion criteria were: a stroke sustained in the previous 6 months and resulting in hemiplegia; a score of 18 to 23 points on the mini-mental Korean assessment; ability to communicate and follow-instructions, and ability to walk 10 m. Participants were also screened on the following set of exclusion criteria: previous neurofeedback training, presence of medical devices inserted in the heart or head, visual impairment or visual field defect, and presence of orthopedic disorders limiting walking for a minimum of 10 m.

All participants provided voluntary consent prior to participation in this study. Data collection was initiated after the approval by the Dongshin University Institutional Review Board (IRB No. BM-003-01). Table 1 lists the characteristics of the participants.

Intervention and measurements

This study utilized a pre-test, post-test control group design. Among the 35 patients who voluntarily consented to participate in this study, 25 patients met the set of inclusion and exclusion criteria and were entered into the study. Participants were randomly assigned to the pseudo-neurofeedback group (n = 13) and neurofeedback group (n = 12) using a selection of white and black cards. Participants in both groups received rehabilitation intervention three times per week for 8 weeks. In the pseudo-neurofeedback group, sham neurofeedback training was used, omitting the brain wave control stimulation. In the neurofeedback group, biofeedback was provided with brain wave control stimulation, provided for 30 min per session for a total of 24 sessions. Data of patients who participated in less than 80% of the training were excluded from the final analysis. In the pseudo-neurofeedback group, three patients dropped out due to discharge from the hospital and other personal reasons. In the neurofeedback group, two patients dropped out for personal reasons. Therefore, both the pseudo-neurofeedback group and neurofeedback groups ended up with 10 patients, for a total of 20 patients remaining in the study group (Fig. 1).

The Procomp Infiniti system (SA7951 version 5.1, Thought Technology, Canada) was used for neurofeedback training. The participants were seated on a comfortable table. Sufficient explanation of the training was provided, and patients were then instructed to concentrate on the experimental task during brain-wave training. Using the guidelines of the International 10-20 System, an electrode was secured over the location of the central fissure (Cz) of the central lobe (Hommond 2005) (Fig. 2). The SMR wave, which is activated when focusing, was set to Reward threshold, the Delta wave (1-4 Hz), which is activated when sleeping, was set to low 'Inhibit' threshold, and the Gamma wave (43-50 Hz), which is activated when nervous, was set to high 'Inhibit' threshold (Egner and Gruzelier 2004). Visual feedback of brain activity was provided during performance of visual animation tasks used for training. The training was performed by alternately changing between three different tasks, bowling, roller coaster, and boat racing. The feedback for each of these tasks is as follows: for the bowling task, bowling pins fall over when the

Table 1. Characteristics of the study participants (mean ± S.D.).

Characteristics	pseudo-neurofeedback group (n = 10)	neurofeedback group (n = 10)
Age (year)	54.7 ± 3.77	53.2 ± 6.46
Sex (male/female)	7/3	6/4
Time since onset (months)	3.5 ± 1.35	3.7 ± 1.16
MMSE-K (Score)	20.7 ± 1.16	21.0 ± 1.49
Affected side (right/left)	7/3	8/2
Cause (hemorrhge/ischemic)	6/4	5/5

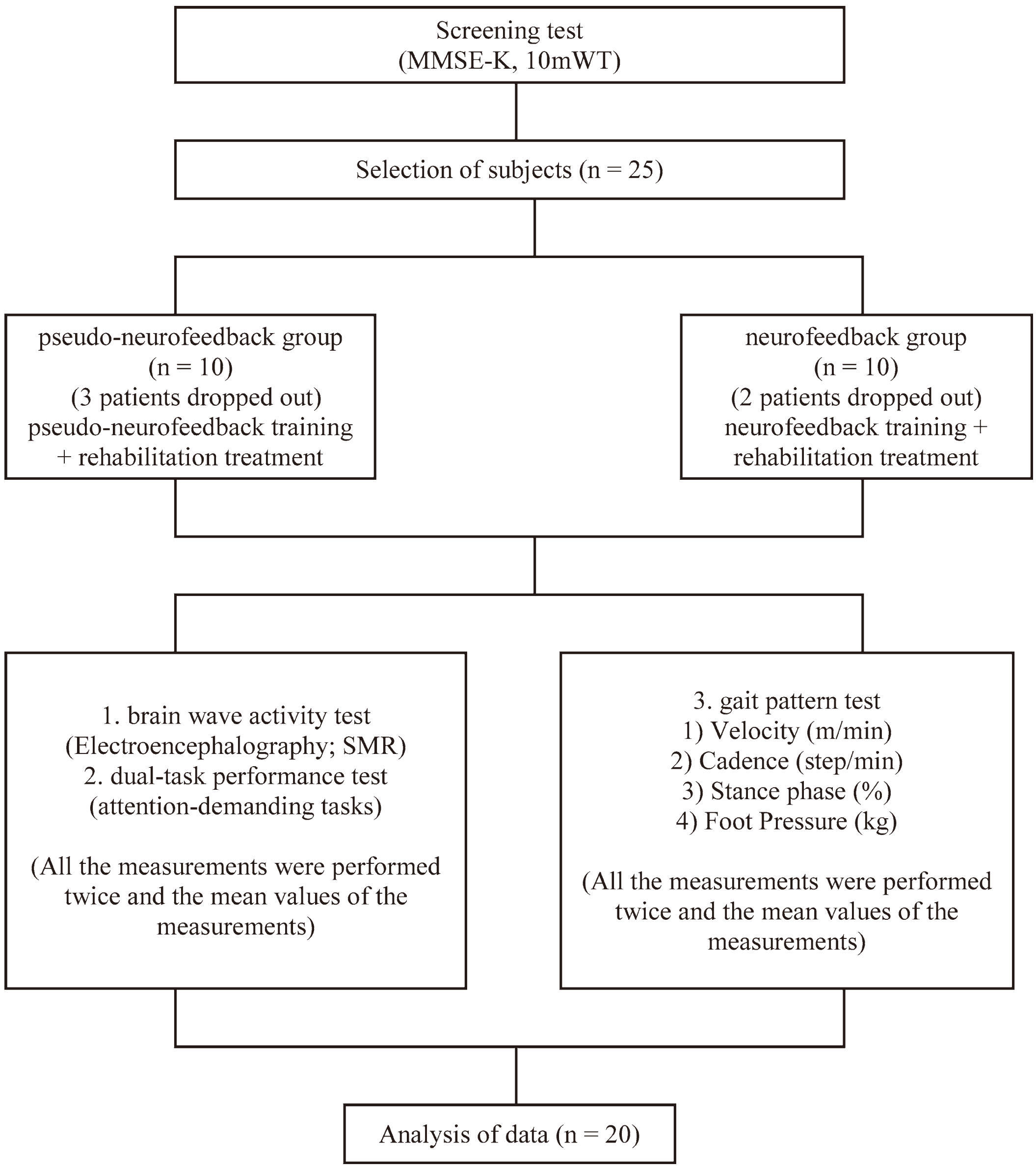

Fig. 1. Flowchart of participants of the study.
MMSE-K, mini-mental state examination-korean; 10mWT, 10-meter walk test.

concentration and SMR waves are activated beyond threshold, and the roller coaster and boats start. Each virtual task can be completed in 10 min, with a 1-minute rest between tasks (Fig. 3). Performance of the training was monitored by the therapist on a separate monitor. Pseudo-neurofeedback training was conducted using the same virtual tasks but in the absence of the EEG sensor.

The QEEG-8 (LXE3208, LAXHA Inc., Korea) system was used to measure brain waves in order to examine changes in concentration.

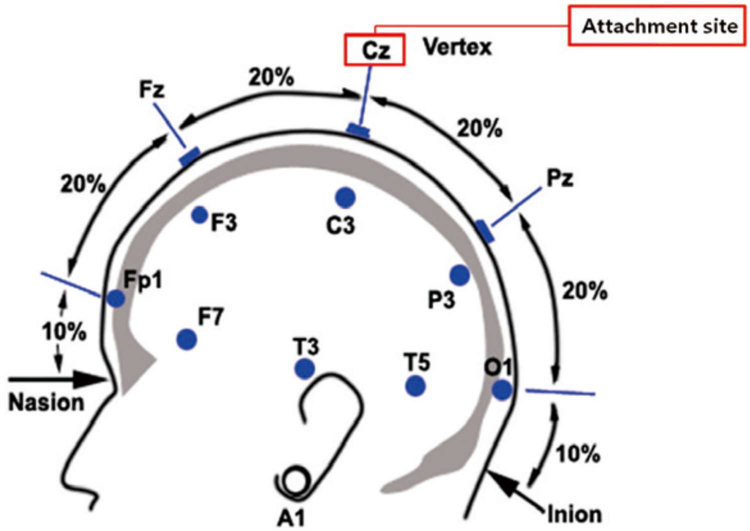

Fig. 2. International 10/20 system of electrode placement.
The anode was attached to Central fissure (Cz), the central lobe.

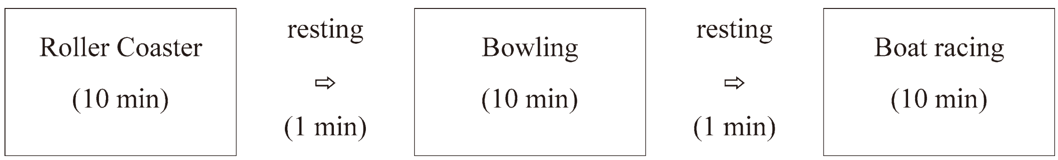

Fig. 3. Neurofeedback training session.

In order to minimize contact resistance between the electrodes and the skin during measurement, the surface of the scalp was cleaned with rubbing alcohol. The active electrode was secured over the location of the Cz, and the reference electrodes to the back of both ears. As a baseline reference, participants completed the Stroop recognition task, while sitting comfortably in a chair, and brain waves collected over a 3-min duration. The initial 30-s of each brain wave recording was eliminated to remove movement artifacts. The band power spectrum of the SMR (12-15 Hz) wave was calculated and log-transformed to quantify the rate of increase or decrease in the background brain wave (van der Hiele et al. 2007). Participants sufficiently listened to instructions as to not to move or speak during the measurement.

Evaluation of dual-task performance was conducted by revising attention-demanding task (Haggard et al. 2000), as for example, sequentially subtracting 7 from 100; 100-93-86-79-72). During the 10-m walk test, the number of wrong answers provided was compared to evaluate task performance. Prior to the performance of dual-task training, participants were clearly informed of the method and order of the tasks, using both explanation and demonstration, with supervision and assistance provided in order to prevent negligent accidents.

To evaluate the 10-m gait performance, the Smartstep (Andante Medical Device Ltd., Israel) was used (van Iersel et al. 2007). Smartstep is a portable instrument that provides measurement and training at the same time. The 10-m walk test included 2 m regions of deceleration and acceleration from each end. The gait pattern over 10 m (within the 14-m gait section) was measured three times, and the average values of measured variables used in the analysis. Information on velocity, cadence, stance phase percentage, and plantarfoot pressure was recorded using a portable, computerized air insole device. Outcomes were evaluated by a therapist blind to participants' group assignment.

Statistical analysis

Normality of distribution of assessment scores was evaluated using the Shapiro-Wilks test. Pre- and post-training data were compared using paired *t*-test within each group. Between-group differences at each measurement time were evaluated by independent *t*-test. The statistical significance level was set at α = 0.05. All statistical analyses were performed using SPPS (Windows version, 18.0).

Results

There were significant changes in SMR waves between pre- and post-training for neurofeedback group ($p < 0.001$). The magnitude of change was higher for the neurofeedback group, compared to the pseudo-neurofeedback training ($p < 0.001$) (Table 2) (Fig. 4). Performance on the dual-task 10-m walk was measured to evaluate the improvement on cognitive ability for both groups. There were significant within- and between-group differences ($p < 0.001$), with the number of errors in task performance during the 10-m walk being significantly lower for the neurofeedback group (Table 3).

Effects of neurofeedback training on the recovery of stroke patients were estimated from performance on the

Table 2. Change of brain wave between pseudo-neurofeedback group and neurofeedback group.

Parameters	pseudo-neurofeedback group (n = 10)		neurofeedback group (n = 10)	
	Pre	Post	Pre	Post
SMR (%)	0.25 ± 0.02	0.24 ± 0.02	0.24 ± 0.02	0.29 ± 0.02***###

SMR is presented as the mean ± S.D.

The paired *t*-test was conducted to compare the before and after training values within each group (***p < 0.001). The independent *t*-test was carried out to average value of difference before and after (###p < 0.001).

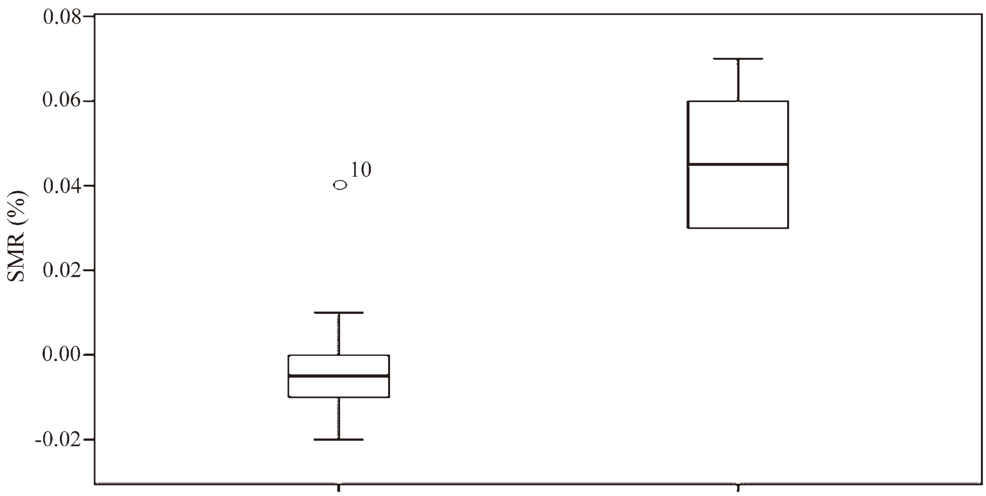

Fig. 4. Changes in SMR in pre-date collection vs. post-data collection in the two groups.

Table 3. Change of dual-task error between pseudo-neurofeedback group and neurofeedback group.

parameters	pseudo-neurofeedback group (n = 10)		neurofeedback group (n = 10)	
	Pre	Post	Pre	Post
dual-task error	4.50 ± 0.70	3.80 ± 0.63	4.40 ± 0.84	3.10 ± 0.57***##

Dual-task errors are presented as the mean ± S.D.

The paired *t*-test was conducted to compare the before and after training values within each group (***p < 0.001). The independent *t*-test was carried out to average value of difference before and after (##p < 0.001).

dual-task 10-m walk test. The pseudo-neurofeedback training produced significant improvement cadence ($p < 0.05$). In comparison, neurofeedback training yielded significant improvement in gait velocity ($p < 0.01$), cadence ($p < 0.01$), stance phase index ($p < 0.001$), entire foot weight ($p < 0.01$), forefoot weight ($p < 0.001$), and hindfoot weight ($p < 0.01$). Therefore, under the dual task condition of cognitive task performance, overall gait performance improved for the neurofeedback group compared to pseudo-neurofeedback group (Table 4).

Discussion

As single-task evaluation is insufficient for measuring gait functions, dual-task intervention is an important element for measuring gait function of daily activities (Yang et al. 2007). Therefore, dual-task evaluation reflects motor function and cognitive function, providing an efficient and practical assessment for gait improvement (Pellecchia 2005; Yang et al. 2007). Improvement on dual-task gait performance can also enhance independence and quality of life by facilitating recovery of self-confidence (Plummer-D'Amato et al. 2008). Dual-task performance requires a high level of concentration, which results in decreased gait ability in stroke patients (Woollacott and Shumway-Cook 2002; Hyndman et al. 2009). Recently, neurofeedback training, in which feedback from brain activity is used as the training stimulus to improve regulation of brain activity, has been increasingly used (Stapleton et al. 2001; Salbach et al.

Table 4. Change of walking pattern between pseudo-neurofeedback group and neurofeedback group.

parameters		pseudo-neurofeedback group (n = 10)		neurofeedback group (n = 10)	
		Pre	Post	Pre	Post
Velocity (m/min)		24.88 ± 2.76	23.87 ± 4.05	25.69 ± 1.99	28.70 ± 3.57**#
Cadence (step/min)		58.62 ± 8.88	67.03 ± 7.85*	61.09 ± 9.55	72.03 ± 9.06**#
Stance phase (%)		52.16 ± 2.39	50.87 ± 2.56	54.01 ± 2.29	53.75 ± 2.07***
Plantar Foot Pressure (kg)	Entire foot	49.40 ± 6.61	52.57 ± 3.52	49.78 ± 7.34	55.14 ± 3.62**##
	Forefoot	34.47 ± 5.54	35.30 ± 4.89	35.47 ± 7.57	38.32 ± 4.20***#
	Hindfoot	39.00 ± 4.14	41.85 ± 4.99	39.61 ± 3.75	43.38 ± 4.67**

Gait parameters are presented as the mean ± S.D.

The paired *t*-test was conducted to compare the before and after training values within each group (*p < 0.05; **p < 0.01; ***p < 0.001). The independent *t*-test was carried out to average value of difference before and after (#p < 0.05; ##p < 0.01).

2004; Droppelmayr et al. 2007). Improvements in regulation of brain function may reflect re-organization of the damaged brain areas by neuroplasticity (Wing 2001; Vernon 2005; Droppelmayr et al. 2007). Neurofeedback training helps patients to strengthen or inhibit certain frequencies, regulating their brain waves using visual and auditory feedback of brain activity during the training (Thornton and Carmody 2008). Neurofeedback training has been presented as a method to simultaneously improve motor and cognitive function in patients (Sterman and Egner 2006; Serruya and Kahana 2008). This study intended to evaluate the effects of neurofeedback training under dual-task conditions on gait performance. The measurement of brain waves provides an objective and simple method to quantify activity levels of the brain. We provided self-training of brain wave compensation-inhibition control to chronic stroke patients whose cognitive function had been reduced. Neurofeedback training produced significant improvements in brain function. Activation of the SMR (12-15 Hz) wave is closely related to concentration (Wing 2001; Stapleton et al. 2001; Droppelmayr et al. 2007). Lowering the motor interference through regulation of SMR activity may facilitate attentional processing (Sterman 1996; Vernon et al. 2003). Vernon et al. (2003) reported positive effects of training the regulation of the Cz component of the SMR wave on concentration and working memory in patients having sustained a brain injury, compared to a control group. SMR training through neurofeedback was also found to be efficient for improving problem-solving skills. Keller (2001) reported that neurofeedback training in patients with traumatic brain injury regulated β wave activity, which was closely related to improvements in concentration.

Adult information processing capacity allows postural adjustments and balance control to be regulated automatically without additional cognitive load (O'Shea et al. 2002). In our study, we compared the number of errors during performance of a 10-m walk test under dual-task conditions as a function of neurofeedback training. Our results show an improvement in attention and concentration with neurofeedback training.

For an independent life, the recovery of gait is an important outcome of rehabilitation for stroke patients (Canning 2005). Stroke patients exhibit decreased gait ability, with a slower gait cycle and velocity, shorter stance phase, and relatively longer swing phase of the paretic side (Vernon 2005) in combination with decreased weight support on the lower extremity of the paretic side (Putman 2002). In this study, gait ability was measured using a 10-m gait test. The 10-m walking test is widely used as an assessment method due to its high reliability and validity in assessing the gait ability of patients with neurological damage (Dean et al. 2000).

In our study, temporal parameters of gait of the stroke patients in both training groups were objectively compared using Smartstep. Patients in the pseudo-neurofeedback group showed a significant improvement in cadence after training. Patients in the neurofeedback group showed a significant improvement on all measured gait parameters after training. Therefore, between-group comparisons included significant differences in gait velocity, cadence, entire foot weight, forefoot weight after training favoring the neurofeedback group. Structural problems within the frontal lobes and the motor areas resulting from a stroke result in reduced concentration and increased CMI (Woollacott and Shumway-Cook 2002). Consequently, concentration during performance of dual-tasks is directed toward the cognitive component of the task while concentration on other task components decreases (Lennon 2001). For a stroke patient to have a smooth gait pattern, concentration is necessary to correct for errors in involuntary postural adjustments (Woollacott and Shumway-Cook 2002). Our results demonstrated that improvement in concentration with neurofeedback training enhanced dual-task performance and had a significant effect on gait patterns. In addition, neurofeedback training adjusts psychological conditions and maximizes repetitive learning effects. We considered that improvement in attention and concentration resulting from the visual stimuli provided by neurofeedback training was a secondary factor mediating improvements in measured gait parameters.

Improvement in cognitive task performance of stroke patients has been reported to increase the weight support period of the paretic side and to shorten the swing phase on the non-paretic side, suggesting positive effects on gait variables (Hsu et al. 2003). Therefore, assessment of cognition and motor control contribute to understanding the mechanisms of the recovery of motor control after neurological damage. Gait is a meaningful to examine the effects of cognition. Functional recovery requires activation of the damaged areas of the cerebral cortex. Moreover, activation and facilitation of the undamaged cerebral cortex should be increased (Plummer-D'Amato et al. 2010).

The major limitation of this study is the small number and homogeneity of participants. All participants were in the sub-acute phase of stroke recovery and had sustained mild stroke-related brain damage. Therefore, findings cannot be generalized. In addition, the dual task used in this study was relatively simple. Therefore, outcomes of this study cannot be effectively used to explain effects of neurofeedback training on gait parameters during highly difficult dual tasks. Thus, further research is needed on the therapeutic benefits of neurofeedback training in stroke patients. Future research should include a wider range of participants and examine the effects of diverse dual tasks on gait pattern.

The researchers suggest that neurofeedback training can be used to increase the ability to self-adjust the motor function of the lower extremity, thereby achieving functional improvement of the paretic side. Our study closely examined neurofeedback training under dual-task conditions as a useful method for promoting functional improvement of stroke patients in their quest to return to a daily of life.

Conflict of Interest

The authors declare no conflict of interest.

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