Effects of 3-dimensional balance trainer in combination with a video-game system on balance and gait ability in subacute stroke patients

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Objective: The purpose of this study was to investigate the effects of a three dimensional balance trainer in combination with a video-game system and visual feedback on balance recovery and gait function in subacute stroke patients.
Design: Randomized controlled trial.
Methods: Twenty-three subacute stroke patients were assigned to either an experimental (n=12) or a control group (n=11) using a random permuted block design and sealed envelopes. The experimental group received additional 3-dimensional balance training combined with visual feedback and a game program for 30 min/day, 5 days/week for 4 weeks. Both groups received 30-min of conservative physical therapy sessions based on neurodevelopmental therapy. Before and after the 20 sessions, walking abilities were evaluated by the the GaitRite system and balances were evaluated using the Berg Balance Scale (BBS). The Trunk Impairment Scale (TIS) was used to assess trunk muscle performances.
Results: After the 4-week intervention, BBS and TIS scores were significantly increased in both groups ($p<0.05$), and increases in these scores were significantly greater in the experimental group ($p<0.05$). After the 4-week intervention, gait speed and cadence were significantly increased in both groups ($p<0.05$), and as was observed for BBS and TIS scores, changes of gait speed and cadence were significantly greater in the experimental group ($p<0.05$).
Conclusions: The study shows that the 3-dimensional balance trainer combined with visual biofeedback and a video-game system provides a therapeutic means for improving balance and gait ability in subacute stroke patients.

Key Words: Balance, Gait, Stroke

Introduction

Stroke is one of the major causes of permanent disability, with the majority of survivors having a combination of sensory, motor, cognitive, and emotional impairments, which lead to disabilities of balance and gait and adversely affect the activities of daily living [1]. Accordingly, improving balance and gait ability are the major goals for rehabilitation of stroke patients [2].

Balance is the ability to maintain or move within a weight-bearing posture without falling [3]. It requires that the body's center of gravity (COG) lies over the base of support [4]. If an individual is provided an accurate visual representation of the position of his/her CoG, motor behaviors can be improved. Many researchers have demonstrated moderate relationships between balance function [5] and gait speed, independence, and appearance [6]. Balance is an essential function of gait and normal movement in stroke patients, and thus, various therapeutic methods have been used to improve balance, such as, core strength exercises [7], vis-

ual feedback training [8], and task-related training [9].

Recently, many authors have reported on visual feedback systems for the rehabilitation of stroke patients. In these studies, visual feedback training was found to be effective at improving symmetric stance, balance, and gait performance in stroke patients [10]. Additional research indicated that balance performance, as assessed using biofeedback systems, is well correlated with measures of balance [11]. Furthermore, visual feedback training using a game program has been used for balance training in normal subjects. Shumway-Cook and Horak [12] reported that task-related training taught motor skills more effectively than conventional repetitive training. Lee *et al*. [13] showed that balance training using a newly developed Balance Control Trainer (BCT) provided an effective means of improving balance and gait in ambulatory chronic stroke patients. In addition, BCT using a task-oriented approach was found to be effective in regaining gait function and balance following stroke when used in conjunction with conventional therapies. Thus, balance training combined with visual feedback and a task-oriented approach has been recommended for improving balance and gait in stroke patients. Several studies have been conducted for balance training with visual feedback [10,14]. However, only a few have included the combination of visual feedback and task-oriented approach.

The purpose of this study was to investigate the effects of a 3-dimensional (3D) balance trainer in conjunction with a task-oriented video-game program and visual feedback on balance recovery and gait function in subacute stroke patients [10,15].

Methods

Subjects

Twenty-three subacute stroke patients (13 men and 10 women) participated to this study at the Myungji Choonhey Hospital. The study inclusion criteria were: (1) a diagnosis of stroke (ischemic or hemorrhagic stroke) and a stroke onset at ＞3 months and ＜6 months prior to study commencement; (2) sufficient cognition to follow simple instructions and understand the content and purpose of the study (Korean Mini-Mental State Examination Score＞24); (3) a muscle power of the affected hip and knee extensors of more than fair grade; and (4) an ability to maintain standing balance and walk more than 10 m independently. Subjects that met the following criteria were excluded: (1) a visual deficit or a visual field deficit problem; (2) an orthopaedic disease of the

lower limbs; or (3) severe vascular disorders of the lower limbs. All participants provided consent after being provided with an explanation of the purpose of this study. The study protocol was approved by the institutional review board (IRB) of Sahmyook University in Seoul.

Study design

This study was a randomized controlled trial. Participants were assigned to either an experimental (n=12) or a control group (n=11) using a random permuted block design and sealed envelopes. The experimental group received additional 3D balance training for 30 min/day, 5 days/week for 4 weeks. Both groups received a regular 30-min conservative physical therapy session based on neurodevelopmental therapy. Before and after the 20 sessions, walking ability and balance were evaluated by a blinded examiner.

Procedure

A 3D BCT (BALPRO; Man&Tel Co., Gumi, Korea, 2012) was used for the intervention (Figure 1). This trainer consist of a balance board with weight bearing sensors on the right and left sides, a conventional touch screen, and a tilting sensor that measures the amount of affected knee flexion and extension in degrees. Each subject was asked to stand on the balance board and perform balance training using a game system. Subjects were encouraged to increase the levels of difficulty and to improve their performances at each activity during intervention. The weight bearing sensor under the balance board and the tilting sensor detected side-to-side and back-to-front weight distribution. The game involved controlling weight distribution to move a

Figure 1. Three dimensional balance trainer combined with a visual feedback and game program.

cursor on the screen and had 7 levels of difficulty. The game contents were to pick fruits from the tree by moving the cursor on the screen. The levels of the game were determined by fruits size such as watermelons, pumpkins, apples, persimmons, chestnuts, jujubes and strawberries. Levels of training were individualized based on assessments of weight distribution and degrees of tilt in the hips and knees. The subjects received the 3D balance training over two 15 minute sessions, that is, for 30 minutes daily. Each 20 session comprised 10 minutes of training and 5 minutes of rest to prevent fatigue.

Measurements

Berg Balance Scale

Subjects in both groups were assessed by an examiner before and after the 4 week-intervention period using the Berg Balance Scale (BBS) since this scale has been shown to have validity, strong internal consistency, and excellent intra-rater and inter-rater reliability (intraclass correlation coefficient=0.99). It has is widely used as an outcome measure of balance performance. BBS scores correlate well with measurements obtained using other clinical balance scales for elderly subjects and patients with hemiplegia secondary to stroke and with measurements of gait speed in patients with hemiplegia [5,16].

Trunk Impairment Scale

The Trunk Impairment Scale (TIS) was used to assess the trunk muscles. This scale is used clinically to evaluate trunk impairment in stroke patients, and can measure core muscle performance statistically and dynamically in a sitting position. The TIS has 17 provisions: static equilibrium, 3; dynamic equilibrium, 10; and core coordinated abilities, 4. TIS scores range from 0 to 23, with higher points indicating better core control. The inter-tester reliability of the TIS ranges from 0.87 to 0.96 and its intra-tester reliability ranges from 0.85 to 0.99, which indicate high reliability and internal validity [17].

Gait analysis

A gait analysis system (GAITRite 2008; CIR System Inc., USA) was used to assess gait speed and cadence. The GAITRite system provides a common objective measure of gait and comprises a mat covered portable electronic walkway of ∼5.3 meters long with embedded pressure-activated sensors that detect footfalls as an individual walks across the length of the mat. The active area of the mat is 4.42 meters

long and 66 cm wide and sensors are placed at an interval distance of 1.27 cm. Data are sampled at 80 Hz. Instrumental software then calculates a range of temporal and spatial gait parameters, which include walking speed, cadence, and step length. The GAITRite system has been shown to have high levels of concurrent validity as compared with the 3D motion analysis system [18].

Data analysis

Statistical analyses were performed using IBM SPSS Statistics 19.0 (IBM Co., Armonk, NY, USA). The Kolmogorov-Smirnov verification was used to confirm the normality of data, which were found to be normally distributed. The Mann-Whitney U test and the chi-square test were used to assess the homogeneity of the experimental and control groups. The Wilcoxon's signed rank test was used to determine the significances of changes before-to-after intervention and intergroup differences. The Mann-Whitney U test was used to compare to changes between the control group and the experimental group. Statistical significance was accepted for *p*-values < 0.05.

Results

In terms of general subject characteristics, age, height, weight, time after stroke onset and the Korean version of the Mini Mental State Examination (MMSE-K) scores were not significantly different in the experimental and control groups (Table 1). Intergroup and intragroup analyses of BBS and TIS scores are summarized in Table 2, Figure 2. After the 4-week intervention, BBS and TIS scores were sig-

Table 1. General characteristics of subjects (N=23)

Parameter	Experimental group (n=12)	Control group (n=11)
Gender		
Male/female	6/6 (50.0/50.0)	7/4 (63.6/36.4)
Paretic side		
Right/left	5/7 (41.7/58.3)	3/8 (27.3/72.7)
Type of stroke		
Infarction/hemorrhage	7/5 (58.3/41.7)	7/4 (63.6/36.4)
Age (y)	50.8 (6.0)	52.4 (6.3)
Height (cm)	164.2 (7.6)	165.8 (7.7)
Weight (kg)	59.9 (8.15)	64.4 (7.3)
Duration after onset (d)	196.8 (17.7)	191.4 (21.2)
MMSE-K (score)	26.3 (1.0)	26.5 (1.1)

Values are presented as n (%) or mean (SD).
MMSE-K: Mini Mental State Examination-Korean.

Table 2. Comparisons of trunk function and balance ability within and between study groups (N=23)

Parameter	Experimental group (n=12)			Control group (n=11)			z^a	p
	Pre-test	Post-test	Changes	Pre-test	Post-test	Changes		
BBS (score)	41.67 (2.46)	48.75 (1.60)***	7.08 (1.38)	42.09 (3.02)	43.45 (2.70)**	1.36 (0.92)	−4.095	0.001
TIS (score)	13.50 (1.17)	17.58 (1.24)***	4.08 (1.24)	13.55 (1.29)	14.18 (1.33)*	0.64 (0.67)	−4.089	0.001

Values are presented as mean (SD).
BBS: Berg Balance Scale, TIS: Trunk Impairment Scale.
aMann-Whitney U test.
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Table 3. Comparison of gait abilities within and between study groups (N=23)

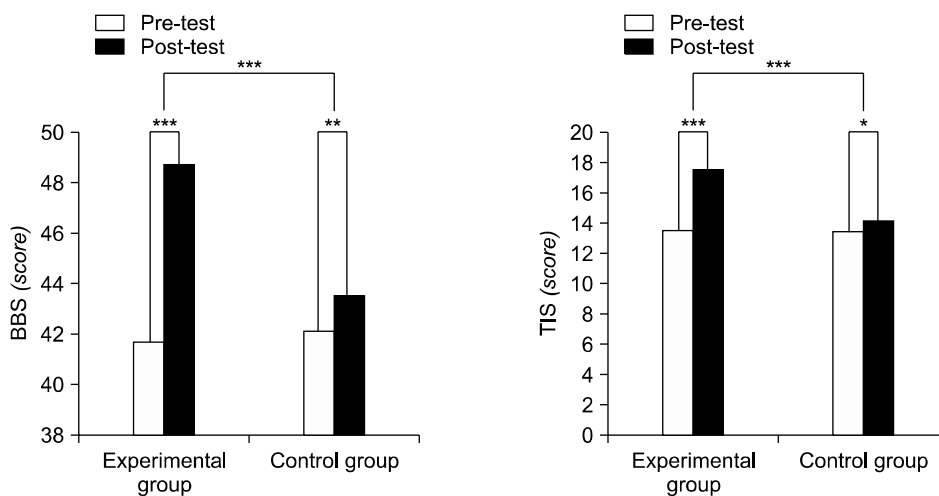| Parameter	Experimental group (n=12)			Control group (n=11)			z^a	p
	Pre-test	Post-test	Changes	Pre-test	Post-test	Changes		
GV (m/s)	41.13 (4.57)	50.79 (3.86)***	9.66 (5.48)	41.83 (4.47)	43.55 (3.92)***	1.73 (1.00)	−3.818	0.001
Cd (steps/m)	55.19 (5.19)	73.70 (4.32)***	18.52 (4.55)	52.84 (6.30)	57.43 (3.96)**	4.32 (3.71)	−4.032	0.001

Values are presented as mean (SD).
GV: gait velocity, Cd: cadence.
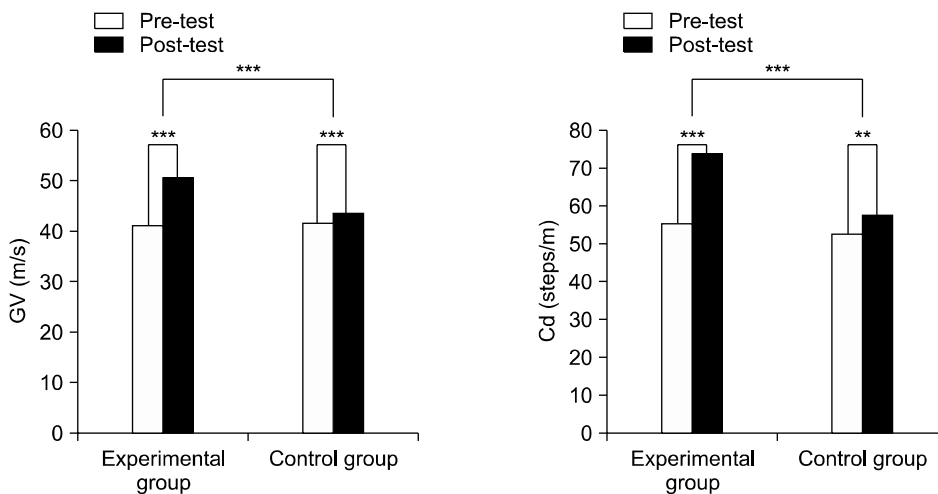aMann-Whitney U test.
**$p < 0.01$, ***$p < 0.001$.

Figure 2. Balance parameter (BBS, TIS) were assessed before the intervention and after the 4 weeks intervention. After the 4 weeks, both groups showed significant improvements in the parameters. BBS: Berg Balance Scale, TIS: Trunk Impairment Scale. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

nificantly increased in both groups ($p < 0.05$), and increases in these scores were significantly greater in the experimental group ($p < 0.05$). Gait abilities were assessed using the GAITRite system based on gait speed and cadence. After the 4-week intervention, gait speed and cadence were significantly increased in both groups ($p < 0.05$), and as was observed for BBS and TIS scores, changes in gait speed and cadence were significantly greater in the experimental group ($p < 0.05$; Table 3, Figure 3).

Discussion

Recently, weight bearing training using visual feedback has been used in stroke patients to improve balance ability [10]. According to a previous study, this type of treatment can increase the weight carried by the hemi-paretic leg of hemiplegic patients after stroke [19]. Other studies have reported that task-oriented somatosensory training with visual feedback is significantly better than conventional physical therapy in terms of improving balance, lower limb strength, and gait speed in stroke patients [20]. Cho *et al.* [15] found

Figure 3. Gait ability parameter (GV, Cd) were assessed before the intervention and after the 4 weeks intervention. After the 4 weeks, both groups showed significant improvements in the parameters. GV: gait velocity, Cd: cadence. $^{**}p < 0.01$, $^{***}p < 0.001$.

that 6 weeks of virtual reality balance training using a video-game system was effective in improving dynamic balance. Static balance is the ability to maintain a given posture and withstand external perturbations in an upright position, whereas dynamic balance is the ability to control the center of mass (COM) during movement and to fixate the body against fluctuating outside forces. Generally, the BBS provides an appropriate measure of dynamic balance in stroke patients [21]. In addition, trunk muscles play an important role in the dynamic balance of stroke patients [22], and BBS and TIS have been used to assess balance in subacute stroke patients. The majority of stroke patients have disabilities of trunk stability and dynamic balance due to mild to severe trunk muscle weakness. In the present study, we investigated the effects of visual feedback training using a video-game system on balance abilities that probably influence functional activities and walking. As has been reported in previous studies, BBS and TIS scores were found to be significantly increased by intervention in the present study as compared with controls that underwent conventional physical therapy ($p < 0.05$).

Many studies have previously addressed the effects of visual feedback training on standing balance and gait function in stroke patients [14,23]. Liston and Brower's BBS-based study suggested that improvements in COM control were related to improved functional activities [5], and Sackley and Lincoln [24] reported that visual biofeedback with a force plate system enhanced motor performances. In the present study, gait speed and cadence were assessed using the GAITRite system, and found that gait speed and cadence were significantly greater in the experimental group than in the control group ($p < 0.001$). Like the results of

above studies, our findings suggest that improved balance, gait function, motor performance, and functional activities increase gait speed in stroke patients.

Furthermore, it has been previously reported that visual feedback balance training combined with force plates enables stroke patients to support body weight on the paretic leg for longer times, and thus, improve the symmetry of gait patterns [14]. The positive effects of a symmetrical gait pattern on gait quality have been reported for visual feedback training [14,23]. We believe that significant improvements in gait speed and balance performance were observed in the experimental group because of the 3D balance trainer/game program intervention. This therapeutic method has many advantages such as the ease in which training can be controlled by changing visual and auditory input. Also, this method can provide enthusiasm and motivation [15,25-28]. Thus, active video-game systems can be used as a rehabilitation intervention [29-31]. As with the results of previous studies and our results, the 3D balance trainer combined with visual biofeedback and a video-game system provides a therapeutic means for improving balance and gait ability in subacute stroke patients.

The present study suggests that the 3D balance trainer/video-game system with visual biofeedback is an appropriate intervention for improving balance and gait in subacute stroke patients. Limitation of our study is that we did not attempt to evaluate gait quality and the small number of participants. Accordingly, we suggest a further study to be conducted using gait quality assessment tools, such as a 3D motion analysis system.

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