Three-Dimensional Balance Training Using Visual Feedback on Balance and Walking Ability in Subacute Stroke Patients: A Single-Blinded Randomized Controlled Pilot Trial

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Background: Trunk-activating exercises for balance are important because trunk weakness is relevant to the functional performance of individuals with stroke. This study aimed to explore the effects of three-dimensional balance training using visual feedback on balance and walking ability in subacute stroke patients. *Methods*: Twenty-four participants with subacute stroke were randomly assigned to the experimental or control group. Each group underwent twenty sessions (30 min/day, 5 days/week for 4 weeks). Patients were assessed using the Berg balance scale, gait parameters (gait speed, cadence, step length, and double-limb support period) using GAITRite, and activity-specific balance confidence score, before and after the intervention. *Results*: The three-dimensional balance training using visual feedback exhibited greater changes in the Berg balance scale, gait speed, cadence, step length, double-limb support period, and activity-specific balance confidence compared with the control group. Statistical analyses showed significant differences in Berg balance scale ($P = .012$; 95% CI, 2.585-6.415), gait speed ($P = .001$; 95% CI, .079-.155), cadence ($P = .001$; 95% CI, 1.622-4.392), step length ($P = .003$; 95% CI, 1.864-3.908), double-limb support period ($P = .003$; 95% CI, -3.259 to -0.761) and activity-specific confidence ($P = .008$; 95% CI, 6.964-14.036) between groups. *Conclusion*: Three-dimensional balance training using visual feedback may be more effective than conventional training in improving balance, walking ability, and activity-specific balance confidence in patients with subacute stroke.
Key Words: Balance—stroke—subacute—three-dimensional balance training—walking ability
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Introduction

Gait is typically preceded and accompanied by a sequence of anticipatory postural control that stabilizes posture to allow the stepping leg off the floor.[1] Anticipatory postural control accelerates the center of mass forward and toward the stance limb by shifting the center of pressure backward and toward the stepping leg while stepping and stance legs.[2] Impairment of these functions are associated with decreased gait velocity, step length, and increased fall risk.[3] Impairments in postural control can be a consequence of changes in the sensory and integrative aspects of motor control.[4] Stroke survivors typically have difficulties in balance, mobility, activities of daily living (ADLs), and task performance caused by loss of anticipatory postural control.[5]

Loss of balance decreases ADLs, particularly in gait ability, and it can be caused by various factors, such as stroke, spinal cord injury, or traumatic brain injury.[6] Anticipatory postural control is the ability to selectively control the trunk muscles such that the body can be held upright in a vertical line and exert appropriate control over weight shift and is related with trunk control.[7] In most stroke patients, appropriate trunk control ability should precede functional recovery.[8] A systematic review has reported that balance training may be a viable strategy for improving trunk control and dynamic sitting balance, standing balance and gait in stroke patients.[8] Fear of falling in these survivors reduce their activity level and make daily ADLs difficult.[5] Therefore, improvement in balance and anticipatory posture control are important rehabilitation goals.

Three-dimensional (3D) balance training using visual feedback has been used in rehabilitation to improve postural control and balance of individuals poststroke, as well as to reduce the risk of falling.[9] A combination training of several factors, including vestibular, visual, somatosensory, and trunk control, may improve functional ability. Therefore, comprehensive and objective training methods are needed. However, few studies have reported on the functional ability (balance and gait) of this method. Given the importance of balance, this study aimed to investigate the effect of 3D balance training using visual feedback to conventional therapy on improving balance and walking ability in sub-acute stroke patients.

Methods

Experimental Design

This study was a single-blinded randomized controlled pilot trial and reported according to the CONSORT statement.[10] A blinded assessor was experienced and well qualified in the use of the tests. Patients were recruited from the Wonkwang University Medical Center (Iksan, Republic of Korea) between January 2016 and April 2017. A 4-week training were designed to evaluate the effect of 3D balance training using visual feedback on balance and walking ability. The Berg balance scale (BBS), gait parameters (gait speed, cadence, step length, and double-limb support period) using GAITRite (CIR Systems Inc, Clifton, NJ) system, and activity-specific balance confidence (ABC) score were assessed before and after the intervention. All procedures are shown in the flow diagram (Fig 1).

Participants

All patients (age, 56.42 ± 5.85 years) who had experienced their first stroke, whether ischemic or hemorrhagic, within the last 6 months were eligible for inclusion. Stroke diagnosis was confirmed by clinical examination and magnetic resonance imaging. Twenty-four stroke patients

admitted to Wonkwang University Medical Center in the Republic of Korea were randomized into either the 3D balance training (n = 12) or control (n = 12) groups (directly after obtaining baseline measures) by a physical therapist not otherwise associated with the study. Randomization was performed by selection of an opaque closed envelope from envelopes wherein the group assignment was written, and a sealed envelope was given to the physical therapist. The inclusion criteria were (1) history and clinical presentation (hemiparesis) of stroke (first hemorrhage or infarction); (2) stroke experienced more than 2 weeks and less than 6 months before the study; (3) physical ability (ability to stand for >30 min with walking aid) sufficient for the testing and exercise procedures; (4) sufficient cognition to participate in the training including a Mini-Mental State Exam (MMSE) score of more than or equal to 24; (5) absence of visual impairments and orthopedic problems; (6) no excessive spasticity, defined as a grade of more than or equal to 3 on the modified Ashworth scale. The exclusion criteria were (1) presence of vertigo or abnormal vestibular function; and (2) any uncontrolled health condition for which exercise is contraindicated. Participation in the study was voluntary, and patients fully understood the purpose of the study. All participants were informed about the tests and the use of the results. Informed written consent was acquired from all participants before participation. This study was approved by the Institutional Review Board at Wonkwang University Hospital and followed the principles outlined in the Declaration of Helsinki.

Training Interventions

The experiment began on the day after randomization. For both groups, the intervention progressed during the regularly scheduled therapy session, and all other routine interdisciplinary stroke rehabilitation proceeded as usual.

All patients were provided the conventional therapy during the 1-h therapy session, 5 days per week, for 4 weeks (total, 20 sessions). The conventional therapy program was patient-specific and consisted mainly of physical therapy, such as tone facilitation, strengthening, and task-oriented training for the improvement of balance and functional ability for 30 minutes.

The experimental group was trained with 30 minutes sessions of space balance 3D training, 5 days per week, for 4 weeks (total, 20 sessions). The control group was trained with conventional rehabilitation exercise only.

The space balance 3D training system (CyberMedic Co., Ltd., Iksan City, Republic of Korea) is equipped with two force plates. It can record the distribution of weight on four plates placed under the left and right forefeet and heels. This equipment includes a footrest to measure foot pressure, a pelvic tightening ring to hold the pelvis in a nonmoving state for balance measurement or exercise, a sensor to detect changes in the center of the trunk relative
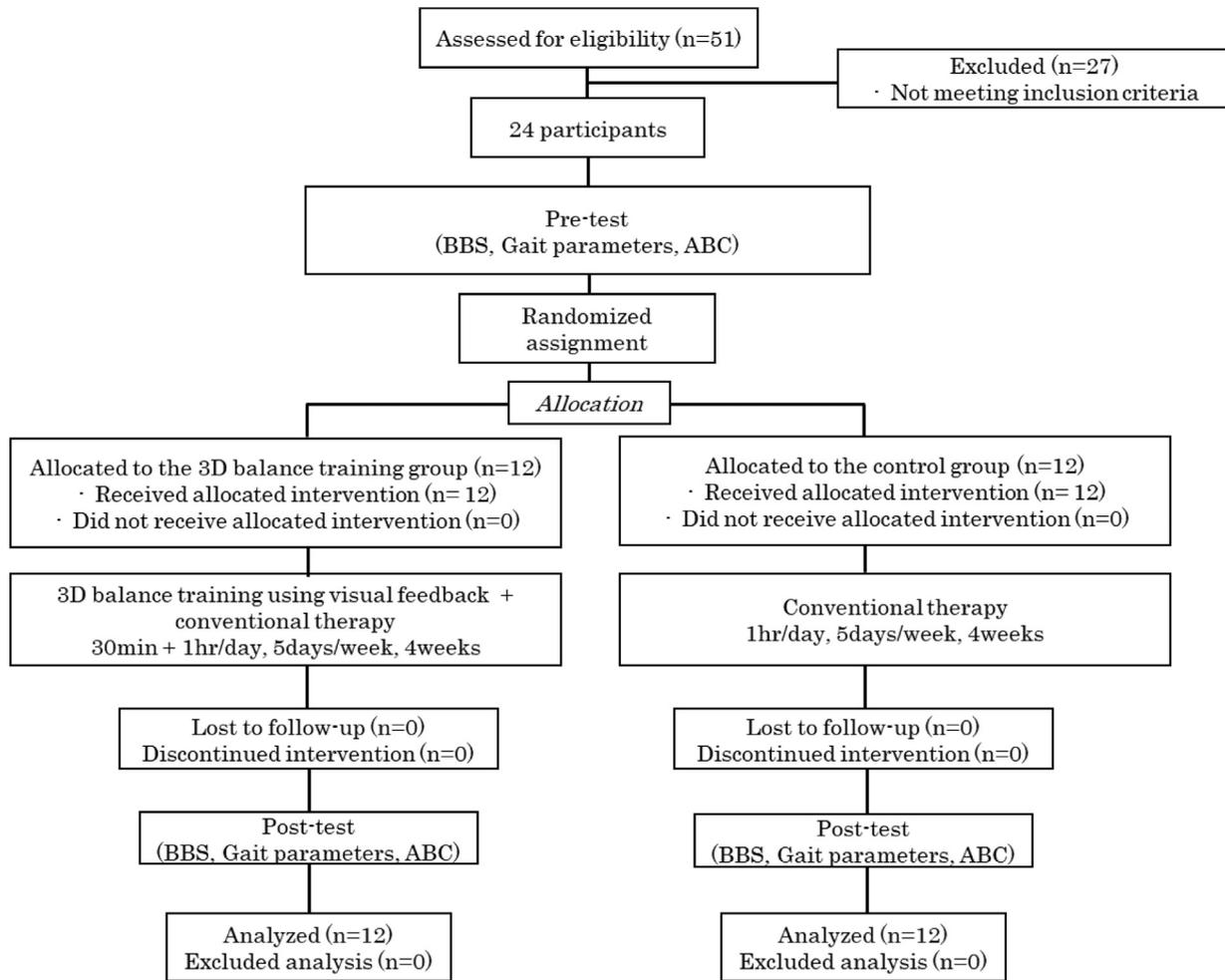
Figure 1. *Flow diagram of the study. Gait parameters conclude the gait speed, cadence, step length, and double-limb support period.* Abbreviations: *ABC, activity-specific balance confidence; BBS, Berg balance scale; 3D, three-dimensional.*

to the anteroposterior and lateral angles, a monitor to show visual information on the screen and a planner that can limit the angle of body tilt. The body tilt angle was displayed on a computer in real time. The starting posture of the exercise was gathering both hands on the chest and gazing at the monitor in straight posture. The participants tilted their bodies and performed the task displayed on the monitor. The exercise program consisted of 3 programs that allowed movement in the sagittal, frontal, and

transverse planes (Fig 2). For frontal plane exercise, we used a game that induced left and right movements. For sagittal plane exercise, we used a game that induces upward and downward movements. For horizontal plane exercise, we used a game that induced random movement within the 3D environment. The difficulty level of each exercise program was composed of 1-10 steps. When the exercise ability score exceeded 75%, the difficulty level was increased one step higher. For patient safety, the

Figure 2. *The exercise program. (A) Frontal plane exercise; (B) Sagittal plane exercise; (C) Horizontal plane exercise.*

exercise was supervised by a therapist, and the range of motion for body tilt was limited to within 20° for the front, back, left, and right.

Outcome Measures

The BBS was used as a balance test.[11] This scale consisted of 14 balance activities, ranging from sit-to-stand and to standing on one leg. A participant's performance on each task was graded using a 5-point ordinal scale ranging from 0 to 4, with higher scores given based on speed, stability, and degree of assistance required for task completion. The task scores were summed for a total BBS score of a possible 56 points, with higher scores representing better balance.

The GAITRite (CIR Systems Inc, Clifton, NJ) system measures spatial and temporal gait parameters[12] and has high intrarater and retest reliability and validity.[13] The GAITRite system forms an electronic walkway with pressure sensors embedded in a horizontal grid, 4.6 m long and .89 m wide, that connects to a computer's serial port. The sensors close under the pressure of the participant walking over the walkway, enabling collection of spatial and temporal gait parameters. Data were sampled from the walkway at a frequency of 80 Hz, allowing a temporal resolution of 11 ms. A rail on the wall beside the walkway was available for the participants to grasp if they felt unstable or unbalanced.

The ABC scale consists of 16 items and is used to assess participants' balance confidence.[14] The participants rated their confidence level on a scale of 0% (no confidence) to 100% (complete confidence) when performing activities, such as climbing stairs, reaching above the head, and walking on different surfaces. Responses were summed and divided by 16 to provide an overall mean balance confidence score. If the participant did not currently perform the activity in question, the participant was asked to imagine how confident they would be performing the activity. Results of more than 80%, 50%-80%, less than 50% represented high, moderate, and low levels, respectively.[15]

Data and Statistical Analysis

All data were analyzed using the Statistical Package for the Social Science (version 18.0; SPSS Inc., Chicago, IL). Descriptive and analytical statistics were performed (Tables 1, 2). Data were presented as mean and standard deviation (SD). Between-group differences at the time points of measurement were evaluated using independent *t* tests. Within-group changes from pre- to post-test measurements were evaluated using paired t-test. Effect size was calculated as the difference between the means of the experimental and control groups divided by the mean SD at baseline.[16] Significance was set at $P < .05$.

Results

The patients were randomized into two groups: experimental (n = 12) and control groups (n = 12) (Fig 1). Table 1 shows the characteristic of both groups at baseline. No differences were found between the two groups for the collected demographic variables. Comparisons between the groups at baseline also showed no difference for any physical outcome measure ($P > .05$).

The mean age of the participant was 56.5 (6.39) years and 56.33 (5.55) years in experimental and control groups, respectively. The number of patients who had ischemic or hemorrhagic stroke was 17 (70.8%) and 7 (29.2%), respectively. At the end of 4 weeks, the mean scores significantly increased in all outcome measures, BBS, gait parameter,

Table 1. *General characteristics of the subjects*

Sex (n)	3D balance training group (n = 12)	Control group (n = 12)	*P* value
Male	7	6	.68
Female	5	6	
Side of stroke (n)			
Right	6	7	.68
Left	6	5	
Type of stroke (n)			
Infarction	9	8	.65
Hemorrhage	3	4	
Time after stroke (week)	12.17 (2.59)	12.42 (2.61)	.82
Age(year), mean (SD)	52.08 (12.81)	56.33 (5.54)	.31
MMSE (score), mean (SD)	26.67 (.95)	26.17 (1.53)	.35

NOTE. Baseline demographic data for participants include in the two different groups and significance level at $P < .05$ for difference between the groups.

Abbreviations: MMSE, mini-mental state examination; 3D, three-dimensional.

Table 2. *Descriptive measurements*

Variables	3D balance training group (n = 12)		Control group (n = 12)		Between groups *P* values (95% CI) - 2 tailed	Effect sizes
	Pretest	Post-test	Pretest	Post-test		
BBS (scores)	42.88 (2.44)[a]	50.75 (2.67)*,†	42.25 (2.56)	46.25 (1.76)*	.012 (2.585-6.415)	1.64
Gait parameters						
Gait speed (m/s)	.47 (.05)	.64 (.04)*,†	.46 (.04)	.52 (.04)*	.001 (.079-.155)	.28
Cadence (steps/min)	64.01 (.93)	69.33 (.87)*,†	63.87 (1.61)	66.33 (2.14)*	.001 (1.622-4.392)	2.06
Step length (cm)	28.94 (1.85)	34.77 (1.19)*,†	28.57 (1.86)	31.88 (1.22)*	.003 (1.864-3.908)	1.64
Double-limb support period (%)	34.69 (1.82)	31.38 (1.01)*,†	35.32 (2.33)	33.39 (1.83)*	.003 (-3.259 to -.761)	.79
ABC scale (scores)	46.67 (8.35)	70.08 (4.39)*,†	46.08 (6.75)	59.58 (3.94)*	.008 (6.964-14.036)	1.69

Pretest was performed before the intervention, and post-test was performed after 4 weeks.
In the pre-test between groups, there was no significant difference (*P*>.05).
The significance level was set at *P*<.05 for differences between the groups.
Abbreviations: ABC, activity-specific balance confidence; BBS, Berg balance scale; 3D, Three-dimensional.
Effect sizes of Cohen: .15 = small; .4 = medium; .75 = large; 1.1= very large; 1.45 = huge effect size.
[a]Means (SD);
*Significant difference within groups;
†Significant difference between groups.

and ABC in both groups. However, the mean value in the experimental group was greater than that in the control group, showing better improvement in the experimental group (*P* < .05) (Table 2).

The mean change in BBS as the changes of balance ability in the experimental group was significantly greater than that in the control group (7.92 ± 3.26 scores versus 4 ± 1.95 scores, *P* = .02). The mean change in gait speed in the experimental group was significantly greater than in that control group (.16 ± .04 m/s versus .05 ± .02 m/s, *P* = .001). The mean change in cadence in the experimental group was significantly greater than that in the control group (5.32 ± 1.14 steps/min versus 2.46 ± 2.04 steps/min, *P* = .01). Similarly, the mean change in step length of the more affected side in the experimental group was significantly greater than that in the control group (5.83 ± 2.19 cm versus 3.31 ± 1.74 cm, *P* = .005), as was the mean change in the double-limb support period (−3.31 ± 1.58 % versus −1.93 ± 1.36 %, *P* = .031). The mean ABC score change in the experimental group was significantly higher than that in the control group (23.42 ± 8.21 scores versus 12.92 ± 4.38 scores, *P* = .001).

Discussion

This study highlights the importance of balance training in patients with stroke. The major findings of this study were that the balance training using visual feedback showed a more significant improvement compared with the control group in the BBS, gait parameter, and ABC over time. Our study provided evidence of the benefit of 3D balance training using visual feedback in improving balance function (BBS), walking ability (gait speed, cadence, step length, and double-limb support period),

and balance confidence (ABC). These results confirm that 3D balance training using visual feedback effectively improves balance, walking ability, and confidence of balance in people with subacute stroke.

To increase the efficiency of rehabilitation program, appropriate participant criteria in subacute stroke are critical components.[17] The improvement of trunk control is not only a key component to regain balance ability, but the upright of trunk within early-stage post-stroke also seems to be the most important factor of determination of the outcome of balance and walking ability.[8] Therefore, the ability to control some voluntary trunk control (inclusion criteria; maintaining the standing position for 30 min) at subacute stage may be required for a positive effect of 3D balance training.

Trunk-activating exercises for balance are important because trunk weakness is relevant in functional performance in stroke patients. In previous studies, the abdominal muscle is related to gait and balance, and improvement in trunk regulation increases dynamic balance, gait speed, and symmetrical movement of gait in stroke patients.[18,19] Active balance training with space balance 3D system may induce concentric, isometric, and eccentric contractions in the trunk muscle by tilting, maintaining, and recovering in the process of achieving the tasks. Visual information also may compensate for the loss of somatosensory and facilitate the motor control and learning with patients.[20] Visual feedback training with symmetric distribution of body weight had benefits for symmetry standing recovery in stroke patients.[21] Active movement for body control and feedback about body position are important factors that lead to improvements in proprioceptive sensation, postural sense, and neuro-muscular control.[20]

Similar to the findings in previous study,[7] the findings of a within-group comparison showed that both groups significantly improved in all parameters tested after 4 weeks. These results may be the direct result of the task-oriented training applied in this study, which emphasized active participation, intensive, and repetitive training for improving functional ability.[22] In stroke rehabilitation, balance training has been suggested as an essential component to promote the ADLs of patients through the active practice of various tasks.[4]

Loss of balance ability for performing ADLs is one of the decreased function factors.[5] The improvement in balance in the experimental group as assessed by the BBS was almost two times (7.92 ± 3.26 scores versus 4 ± 1.95 scores) more than the control group. This result may be because the patients in the experimental group directly participated in intensive and repetitive balance training using visual feedback than the control group, thus allowing them to experience the more difficult trunk control tasks. In addition, proper sensory input that alerts the central nervous system about interactions between the body and the environment, which provides constant feedback and allows refinement of movement.[4]

The results of this study also showed the existence of a positive relationship between balance training and gait. The improvement of balance may affect the confidence of balance and the increase of walking ability. Previous studies reported a relationship between improved balance ability and walking.[23,24] Our study suggests a positive effect of 3D balance training using visual feedback on the walking capacity (gait speed, cadence, step length, and double-limb support period). The experimental group exerted a small effect size (*d*-value, .28) in gait speed, a huge effect size (*d*-value, 2.06) in cadence, a huge effect size (*d*-value, 1.64) and a large effect size (*d*-value, .79) in double-limb support period. In this study, both groups showed an increase in the gait speed, cadence, step length, and double-limb support period. However, the experimental group showed a more significant increase than the control group. 3D balance training may increase the ability of stroke patients by modulating the center of gravity. Segmental movements of the body in various directions by trunk control have frequently been emphasized in walking training programs to improve balance and functional motor skills in central nervous system disorders.[25]

Study Limitations

A few limitations to this study warrant consideration. First, the small sample size is a major limiting factor that prevents the generalization of our results to the entire population with stroke. Therefore, our results must be validated by further studies with a larger sample size. Second, the length of follow-up prevents us from assessing the long-term impact of the observed effects. Third, we did not balance training in the control group. Because this

study aimed to investigate the effect of 3D balance training using visual feedback to conventional therapy on improving balance and walking ability in sub-acute stroke patients. As a result, whether the 3D balance training is more effective method than other balance training may have remained undetected. Thus, the results should be considered with caution.

Conclusion

The 3D balance training using visual feedback led to significant improvement in balance (BBS) and walking ability (gait speed, cadence, step length, and double-limb support period) compared with the control group. The results of our study indicate that 3D balance training using visual feedback improved balance and walking ability, suggesting the applicability of this method for clinical rehabilitation. Improving balance and walking ability in stroke patients are important for independent and social participation. However, additional studies will be needed to confirm the effectiveness of this method in various directions.

Author Contributions

The roles of the authors in this study are as follow: Hyun-Jeong Noh − primary author, experimental procedure, manuscript writing; Soon-hyun Lee − cooperation authors, experimental procedure, and management of study; Dae-hyouk Bang − corresponding author, critical discussion, interpretation of the results, manuscript writing, and management of the study.

Declaration of Interest

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