Virtual-Reality Balance Training with a Video-Game System Improves Dynamic Balance in Chronic Stroke Patients

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Stroke is one of the most serious healthcare problems and a major cause of impairment of cognition and physical functions. Virtual rehabilitation approaches to postural control have been used for enhancing functional recovery that may lead to a decrease in the risk of falling. In the present study, we investigated the effects of virtual reality balance training (VRBT) with a balance board game system on balance of chronic stroke patients. Participants were randomly assigned to 2 groups: VRBT group (11 subjects including 3 women, 65.26 years old) and control group (11 subjects including 5 women, 63.13 years old). Both groups participated in a standard rehabilitation program (physical and occupational therapy) for 60 min a day, 5 times a week for 6 weeks. In addition, the VRBT group participated in VRBT for 30 min a day, 3 times a week for 6 weeks. Static balance (postural sway velocity with eyes open or closed) was evaluated with the posturography. Dynamic balance was evaluated with the Berg Balance Scale (BBS) and Timed Up and Go test (TUG) that measures balance and mobility in dynamic balance. There was greater improvement on BBS (4.00 vs. 2.81 scores) and TUG (−1.33 vs. −0.52 sec) in the VRBT group compared with the control group (P < 0.05), but not on static balance in both groups. In conclusion, we demonstrate a significant improvement in dynamic balance in chronic stroke patients with VRBT. VRBT is feasible and suitable for chronic stroke patients with balance deficit in clinical settings.

Keywords: balance; postural sway; rehabilitation; stroke; virtual reality


The level and type of disability caused by stroke depend on the degree of brain injury and the region involved, but upper and lower extremity dysfunction and sensory, mood, and cognitive impairments predominate and manifest as reduced capacity for active exercise and loss of mobility (Kelley and Borazanci 2009). In particular, a reduced ability to balance properly due to an increase in postural sway, asymmetrical weight distribution, and loss of weight shift causes an increase in the risk of falling and results in significant economic and social burdens (Belgen et al. 2006).

Thus, various interventions, such as neurodevelopmental treatment (Graham et al. 2009), task-oriented training (Leroux et al. 2006), and progressive resistance training (Flansbjer et al. 2008) have been devised to improve the balancing ability in stroke patients. However, traditional balance training schemes rely on the repetition of specific movements, which many patients find aimless and boring, resulting in reduced motivation and compliance with training programs (Gil-Gomez et al. 2011).

Multidisciplinary rehabilitation approaches to postural control are necessary to maximize functional recovery. Recently, the application of virtual reality technology in stroke rehabilitation has attracted considerable attention (Burdea 2003). Virtual reality involves computer-generated interactive simulation that controls the information delivered to sensory organs to provide a virtual environment and makes the participant think that imaginary objects and incidents are real (Weiss and Katz 2004). In a virtual environment, subjects conduct tasks, such as walking and moving objects, which feel very much like the reality (Jack et al. 2001; Weiss et al. 2004).

However, despite their many advantages such as the ease with which training can be controlled by changing visual, auditory, and tactile inputs, and the enthusiasm and motivation provided by these systems (Weiss and Katz 2004), they are expensive and unavailable at many clinics. Thus, readily available, cheap equipment, such as active video game systems are currently being used for rehabilitative intervention (Miyachi et al. 2010; Saposnik et al. 2010b; Gil-Gomez et al. 2011; Hurkmans et al. 2011; Mouawad et al. 2011).

Obviously, virtual reality games were originally designed for entertainment, not for rehabilitation of stroke

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patients. Nevertheless, virtual reality games involve innovative technology that can improve the physical activity levels of subjects with chronic disabilities (Lanningham-Foster et al. 2009; Miyachi et al. 2010). In fact, in a recent pilot study, virtual reality game technology was examined as a potential intervention for promoting motor recovery after stroke (Saposnik et al. 2010a; Hurkmans et al. 2011).

Virtual reality game technology for sports such as tennis, golf, boxing, bowling, and baseball, was found to improve upper extremity function in patients with chronic stroke over a 2-week period (Mouawad et al. 2011). In another study, patients with chronic stroke were divided into two groups (a Wii tennis group and a boxing group). Energy expenditures were measured after 15 minutes of gaming, and it was found that games effectively maintained moderate-intensity exercise levels (Hurkmans et al. 2011). However, a majority of previous studies on the use of virtual reality games for improvement of upper extremity function in stroke patients only involved training lasting for about 2 weeks. In addition, in 1 study on balance ability improvement achieved using a virtual reality game (Gil-Gomez et al. 2011), patients with traumatic brain injury and benign cerebral neoplasm were included in the study; therefore, this study obtained confounded the results for stroke patients.

Because the recovery of postural control is a prerequisite for independent activities of daily living, it must be an important goal of stroke rehabilitation (Fong et al. 2001). Thus, the purpose of this study was to investigate the effects of 6 weeks of rehabilitation program by using a virtual reality game on static and dynamic balance abilities in chronic stroke patients.

Subjects and Methods

Participants

Twenty-four stroke patients who were undergoing standard rehabilitation were recruited on a voluntary basis from the stroke unit. Subjects were chosen according to the following inclusion criteria: a hemiparetic status resulting from a single stroke at least 6 months earlier; the ability to walk 10 m independently with or without an assistive device; a Mini-Mental State Examination (MMSE) score of ≥ 24 (Folstein et al. 1975); the absence of a musculoskeletal condition that could potentially affect the ability to walk safely; and the absence of serious visual impairment or a hearing disorder. The exclusion criteria were as follows: severe dementia or aphasia; hemispatial neglect, ataxia or any other cerebellar symptom; or participation in other studies or rehabilitation programs. All experimental protocols and procedures were explained to each subject and approved by the Institutional Review Board of Sahmyook University. All subjects signed a consent form.

This study used a randomized pre- and post-test control group design. Participants were randomized to the VRBT group (n = 12) or the control group (n = 12). The randomization was computer-generated by using a basic random number generator. One subject in the training group withdrew from the training after 1 week for reasons of poor concentration, and 1 subject in the control group began taking antihypertensive medication before completion of the training and was excluded from the study. Thus, 11 participants in each group were included in our analysis.

All patients participated in the same standard rehabilitation program (5 times weekly for 6 weeks), which consisted of physical therapy (30 min), occupational therapy (30 min), and speech-language therapy (if appropriate). In addition, the training group underwent 30 min of virtual reality balance training 3 times weekly for 6 weeks.

Virtual reality balance training

The hardware components of the virtual reality system consisted of a conventional 42-inch LCD screen television. A subject stands on the balance board, with performing virtual reality balance training. Subjects were encouraged to increase the challenge level and to try to improve their performance of each activity during the intervention period.
Virtual Reality Training in Chronic Stroke Patients

min (excluding set-up and rest time). The training was conducted in a quiet room to ensure the subjects’ attention. To prevent subjects from experiencing a fall during training, a therapist stood within arm’s reach of the subject.

Static balance abilities (postural sway velocity)

The following outcome measures were evaluated at baseline and on completion of the 6-week training period. Static balance abilities were measured with the postural sway velocity using a Good balance force platform system (Metitur Ltd, Finland). The force platform is an equilateral triangle (800 mm) and is connected to a 3-channel DC amplifier. Signals from the amplifier were converted into digital form using a 12-byte converter (sampling frequency = 50 Hz) and stored on the hard disk of a personal computer. The X and Y coordinates of the center of pressure (COP) were defined on the basis of the data. The following variables were calculated: the extent of medio-lateral COP movement (X movement), the extent of the antero-posterior COP movement (Y movement), and the mean value of all of measurement points in relation to the midline of the platform (lateral displacement). When a subject stood on the footprints marked symmetrically on the force platform in relation to midline (feet 20 cm apart and feet together), mean values (positive or negative) indicates the relative loadings on left and right legs, where a positive mean value indicates a higher loading on the right leg. The mean velocities of X and Y COP movements were determine by dividing X and Y displacements by time (in seconds) (Era et al. 1996).

To measure postural sway velocity, a subject stood on the force plate with legs spread at shoulder width, and then looked at a number on a monitor three times for 30 seconds, this procedure was repeated three times with eyes closed. 3 repeats of each measurement were performed and the average was used in the statistical analysis. A rest of 3 minutes was provided between the measurements.

Dynamic balance ability

Dynamic balance ability was measured using the Berg Balance Scale (BBS) and the Timed Up and Go test (TUG). BBS is a valid and reliable instrument for measuring both the static and dynamic aspects of balance in the elderly people after stroke. BBS scores range from 0 to 56 points and higher scores indicate better balance (Berg et al. 1995). TUG is measured as time (seconds) required to perform the following series of actions: stand up from a chair, walk 3 m at normal walking speed, turn around, walk back, and sit down. Assistive devices were permitted when necessary (Ng and Hui-Chan 2005).

Data analysis

All statistical analyses were performed using SPSS version 15.0 software. Descriptive statistics were used to describe patient characteristics. Comparisons of group general characteristics were performed using the independent t-test or the Chi-squared test. Pre- and post-rehabilitation data were analyzed using the paired t-test within groups and the independent t-test for between groups. Results were considered significant when P values were < 0.05. All data are presented as means ± standard deviations.

Results

No significant differences between the general characteristics or dependent variables of the two groups were detected at recruitment (Tables 1 and 2). After completing the 6-week intervention program, in the dynamic balance test, BBS was significantly improved from 39.09 to 43.09 in the VRBT group (P < 0.05), and 41.09 to 43.90 in the control group (P < 0.05). TUG was significantly improved from 21.74 sec to 20.40 sec in the VRBT group (P < 0.05), and from 19.60 sec to 19.08 sec in the control group (P < 0.05). However, when comparing the two groups, the degrees of the changes in BBS and TUG were statistically greater in the VRBT group than the control group (P < 0.05). Thus, there was greater improvement on dynamic balance ability in VRBT group than the control group. In static balance test, antero-posterior and medio-lateral postural sway velocity with eyes open or closed was not significantly improved before and after the intervention in both groups (Table 3), indicating that VRBT did not improve static balance ability in VRBT group.

Table 1. Homogeneity test for general characteristics.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>VRTG (n = 11)</th>
<th>CG (n = 11)</th>
<th>χ²/t value</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male/Female (%)</td>
<td>8/3 (72.7/27.3)</td>
<td>6/5 (54.5/45.5)</td>
<td>0.786</td>
<td>0.375</td>
</tr>
<tr>
<td>Paretic side</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right/Left (%)</td>
<td>10/1 (90.9/9.1)</td>
<td>8/3 (72.7/27.3)</td>
<td>1.222</td>
<td>0.269</td>
</tr>
<tr>
<td>Type of stroke</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infarction/Hemorrhage (%)</td>
<td>7/4 (63.6/36.4)</td>
<td>6/5 (54.5/45.5)</td>
<td>0.188</td>
<td>0.665</td>
</tr>
<tr>
<td>Height, cm</td>
<td>165.91 (5.48)</td>
<td>164.45 (7.25)</td>
<td>0.530</td>
<td>0.602</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>63.95 (9.32)</td>
<td>62.29 (7.59)</td>
<td>0.652</td>
<td>0.522</td>
</tr>
<tr>
<td>Age, years</td>
<td>65.26 (8.35)</td>
<td>63.13 (6.87)</td>
<td>1.180</td>
<td>0.252</td>
</tr>
<tr>
<td>Duration, months</td>
<td>12.54 (2.58)</td>
<td>12.63 (2.54)</td>
<td>-0.083</td>
<td>0.935</td>
</tr>
<tr>
<td>MMSE, score</td>
<td>26.27 (1.61)</td>
<td>26.45 (2.84)</td>
<td>-0.184</td>
<td>0.856</td>
</tr>
<tr>
<td>Brunnstrom stages, score</td>
<td>3.18 (0.87)</td>
<td>3.36 (1.12)</td>
<td>-0.379</td>
<td>0.705</td>
</tr>
</tbody>
</table>

Values are n (%) or mean (s.d.).

VRTG, Virtual Reality Training Group; CG, Control Group; MMSE, Mini Mental State Examination.
Balance is the ability to maintain one's center of gravity and control posture appropriately during various movements and external fluctuations, and it can be classified as static or dynamic (Cohen et al. 1993). Static balance is the ability to stand still on a stationary floor, whereas dynamic balance is the ability to respond to a moving floor and external stimuli (Berg et al. 1992). In clinics, static balance ability and postural sway are usually measured using a force plate (Era et al. 2002; Sihvonen et al. 2004), whereas BBS and TUG are used to evaluate dynamic balance ability. Virtual reality training has been used in previous studies and has shown to improve walking (Crosbie et al. 2007) and upper extremity function (Saposnik et al. 2010a, 2010b) in stroke patients.

Thus, the purpose of this study was to investigate the effects of a 6-week rehabilitation program by using a virtual reality game on static balance ability assessed by measuring postural sway velocity and dynamic balance ability with BBS and TUG in chronic stroke patients.

After 6 weeks of training, anteroposterior and mediolateral postural sway velocity with eyes open and closed were not significantly different in the 2 groups. In contrast, after 6 weeks of training, both groups showed significant improvement in dynamic balance abilities as measured by BBS and TUG (P < 0.05). Furthermore, the postural sway improvements achieved using virtual reality training.

### Table 2. Homogeneity test for static and dynamic balance abilities.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>VRTG (n = 11)</th>
<th>CG (n = 11)</th>
<th>t</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static balance abilities</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PSV-apeo, mm/s</td>
<td>7.37 (2.20)</td>
<td>6.01 (1.85)</td>
<td>1.558</td>
<td>0.135</td>
</tr>
<tr>
<td>PSV-apec, mm/s</td>
<td>9.97 (2.69)</td>
<td>9.67 (2.72)</td>
<td>0.260</td>
<td>0.798</td>
</tr>
<tr>
<td>PSV-mleo, mm/s</td>
<td>11.40 (2.24)</td>
<td>9.92 (1.28)</td>
<td>1.902</td>
<td>0.072</td>
</tr>
<tr>
<td>PSV-mlec, mm/s</td>
<td>16.78 (2.25)</td>
<td>14.41 (4.08)</td>
<td>1.679</td>
<td>0.109</td>
</tr>
<tr>
<td>Dynamic balance abilities</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBS, score</td>
<td>39.09 (5.66)</td>
<td>41.09 (4.01)</td>
<td>-0.956</td>
<td>0.351</td>
</tr>
<tr>
<td>TUG, sec</td>
<td>21.74 (3.41)</td>
<td>19.08 (4.52)</td>
<td>1.554</td>
<td>0.136</td>
</tr>
</tbody>
</table>

Values are mean (s.d.).

VRTG, Virtual Reality Training Group; CG, Control Group; PSV, Postural Sway Velocity; apeo, antero-posterior with eye open; apec, antero-posterior with eye close; mleo, medio-lateral with eye open; mlec, medio-lateral with eye close; BBS, Berg Balance Scale; TUG, Timed Up and Go test.

### Table 3. Comparison of static and dynamic balance abilities within groups and between groups.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Pre</th>
<th>Post</th>
<th>Pre</th>
<th>Post</th>
<th>Pre-Post</th>
<th>Post-Pre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static balance abilities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PSV-apeo, mm/s</td>
<td>7.37 (2.20)</td>
<td>6.20 (1.70)</td>
<td>6.01 (1.85)</td>
<td>5.64 (1.57)</td>
<td>1.17 (2.08)</td>
<td>0.37 (0.56)</td>
</tr>
<tr>
<td>PSV-apec, mm/s</td>
<td>9.97 (2.69)</td>
<td>9.18 (1.75)</td>
<td>9.67 (2.72)</td>
<td>9.14 (2.31)</td>
<td>0.79 (1.64)</td>
<td>0.52 (1.30)</td>
</tr>
<tr>
<td>PSV-mleo, mm/s</td>
<td>11.40 (2.24)</td>
<td>11.22 (2.06)</td>
<td>9.92 (1.28)</td>
<td>9.82 (1.20)</td>
<td>0.19 (0.51)</td>
<td>0.10 (0.16)</td>
</tr>
<tr>
<td>PSV-mlec, mm/s</td>
<td>16.78 (2.25)</td>
<td>15.50 (3.59)</td>
<td>14.41 (4.08)</td>
<td>14.12 (4.01)</td>
<td>1.28 (3.68)</td>
<td>0.29 (0.44)</td>
</tr>
<tr>
<td>Dynamic balance abilities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBS, score</td>
<td>39.09 (5.66)</td>
<td>43.09 (4.80)***</td>
<td>41.09 (4.01)</td>
<td>43.90 (4.06)***</td>
<td>4.00 (1.18)</td>
<td>2.81 (0.40)**</td>
</tr>
<tr>
<td>TUG, sec</td>
<td>21.74 (3.41)</td>
<td>20.40 (3.19)***</td>
<td>19.60 (4.42)</td>
<td>19.08 (4.52)*</td>
<td>1.33 (0.76)</td>
<td>0.52 (0.46)***</td>
</tr>
</tbody>
</table>

Values are mean (s.d.).

VRTG, Virtual Reality Training Group; CG, Control Group; Pre, values measured before the rehabilitation program; Post, values measured after the 6-week rehabilitation program; PSV, Postural Sway Velocity; apeo, antero-posterior with eye open; apec, antero-posterior with eye close; mleo, medio-lateral with eye open; mlec, medio-lateral with eye close; BBS, Berg Balance Scale; TUG, Timed Up and Go test. **P < 0.01, ***P < 0.001.

**Discussion**

Balance is the ability to maintain one’s center of gravity and control posture appropriately during various movements and external fluctuations, and it can be classified as static or dynamic (Cohen et al. 1993). Static balance is the ability to stand still on a stationary floor, whereas dynamic balance is the ability to respond to a moving floor and external stimuli (Berg et al. 1992). In clinics, static balance ability and postural sway are usually measured using a force plate (Era et al. 2002; Sihvonen et al. 2004), whereas BBS and TUG are used to evaluate dynamic balance ability. Virtual reality training has been used in previous studies and has shown to improve walking (Crosbie et al. 2007) and upper extremity function (Saposnik et al. 2010a, 2010b) in stroke patients.

Postural stability impairment observed in stroke patients during quiet stance includes increased postural sway (Walker et al. 2000), and decreased postural stability is one of the primary factors leading to falls in stroke patients (Barclay-Goddard et al. 2004). Few studies have been conducted on postural sway improvements achieved using virtual reality training.

Thus, the purpose of this study was to investigate the effects of a 6-week rehabilitation program by using a virtual reality game on static balance ability assessed by measuring postural sway velocity and dynamic balance ability with BBS and TUG in chronic stroke patients.

After 6 weeks of training, anteroposterior and mediolateral postural sway velocity with eyes open and closed were not significantly different in the 2 groups. In contrast, after 6 weeks of training, both groups showed significant improvement in dynamic balance abilities as measured by BBS and TUG (P < 0.05). Furthermore, the
VRBT group showed a more significant improvement than the control group ($P < 0.05$).

According to previous studies, repeat therapy (Hamman et al. 1992) and visual feedback training (Walker et al. 2000; Barclay-Goddard et al. 2004) have a non-significant effect on standing postural sway in stroke patients. In contrast, Cheng et al. (1998) reported improvement in both static and dynamic balance measurements in stroke patients after 3 weeks of visual feedback rhythmic weight-shift training. The difference may be due to the dissimilar evaluation and training procedures used. Furthermore, Yang et al. (2011) found no significant improvement in center of pressure-related measures and symmetric indices after virtual reality treadmill training for 3 weeks (3 sessions, 20 min per week), but found a significant improvement in the paretic leg stance phase and paretic foot contact area during walking.

Postural sway is used as a clinical measure of balance ability, but a decrease in postural sway does not always reflect functional improvement (Horak et al. 1997). Furthermore, in humans, separate neural pathways exist for the task-specific characteristics of postural control learning and for static and dynamic balance control (Horak 1987).

The virtual reality balance training used in this study and in a previous treadmill training study (Yang et al. 2011) involve a weight-shift in various directions. Postural control skills learned during dynamic challenges may be inappropriate for maintaining static postural stability (Yang et al. 2011). In fact, stroke patients minimize movements when controlling their posture in the standing position and repeatedly make efforts to maintain their center of mass (Winstein et al. 1989). Thus, virtual reality balance training in this study did not affect postural sway during static standing.

Walking, which uses the musculoskeletal and nervous systems during gait, are closely related to postural sway and balance abilities (Bohannon and Walsh 1992). However, in this study, we only investigated changes in balance ability. Further study is required to examine changes in walking ability using virtual reality balance training and to investigate the correlation between walking and balance ability. Furthermore, when setting the virtual reality game program for individual subjects, we found it difficult to tailor the game difficulty based on stroke severity and individual balance ability. This topic requires additional study.

This study was undertaken to investigate the effects of 6 weeks of rehabilitation program by using a virtual reality game on static balance ability by measuring postural sway velocity and dynamic balance ability with BBS and TUG in chronic stroke patients. This study shows that after 6 weeks of training, BBS and TUG were significantly improved, whereas static balance abilities were not significantly improved. These results suggest that virtual reality balance training is more effective at improving dynamic balance control than static balance control. We believe that these results provide basic information on improvement in balance ability after stroke.

**Acknowledgments**

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**Conflict of Interest**

We declare no conflict of interest.

**References**


