J. Phys. Ther. Sci.
27: 1883–1888, 2015

Original Article

Effects of virtual reality-based training and task-oriented training on balance performance in stroke patients

Hyung Young Lee, PT, MS[1)], You Lim Kim, PT, MS[1)], Suk Min Lee, PT, PhD[1)]*

[1)] *Department of Physical Therapy, Sahmyook University: 26-21 Gongneung2-dong, Nowon-gu, Seoul 139-742, Republic of Korea*

Abstract. [Purpose] This study aimed to investigate the clinical effects of virtual reality-based training and task-oriented training on balance performance in stroke patients. [Subjects and Methods] The subjects were randomly allocated to 2 groups: virtual reality-based training group (n = 12) and task-oriented training group (n = 12). The patients in the virtual reality-based training group used the Nintendo Wii Fit Plus, which provided visual and auditory feedback as well as the movements that enabled shifting of weight to the right and left sides, for 30 min/day, 3 times/week for 6 weeks. The patients in the task-oriented training group practiced additional task-oriented programs for 30 min/day, 3 times/week for 6 weeks. Patients in both groups also underwent conventional physical therapy for 60 min/day, 5 times/week for 6 weeks. [Results] Balance and functional reach test outcomes were examined in both groups. The results showed that the static balance and functional reach test outcomes were significantly higher in the virtual reality-based training group than in the task-oriented training group. [Conclusion] This study suggested that virtual reality-based training might be a more feasible and suitable therapeutic intervention for dynamic balance in stroke patients compared to task-oriented training.
Key words: Stroke, Virtual reality, Task orientation

(This article was submitted Jan. 27, 2015, and was accepted Mar. 7, 2015)

INTRODUCTION

Stroke, along with cancer and cardiac disorders, is one of the leading causes of death in Korea. Every year, 50.7 individuals (males 48.6, females 52.8) per 100,000 population die of this condition[1)]. The clinical features of stroke include sensory and motor disturbances as well as perceptual and language disorders[2)]. More than 85% of these patients experience hemiplegia immediately after stroke[3)]. Balance disorders in patients with stroke cause restrictions in daily living activities, which in turn decreases their independence and their level of participation in the community[4, 5)].

Both virtual reality-based training and task-oriented training have been used clinically in stroke rehabilitation as therapeutic interventions for functional recovery[6–8)]. Task-oriented training is based on Carr and Shepherd's motor learning theory[9)]. In a previous study, task-oriented training was used in a program that focused on special functional tasks requiring a combined use of musculoskeletal and neuromuscular systems[10)] and found that the training improved daily living functions in the elderly with disabilities and in patients with traumatic brain injuries[11)]. Virtual reality-based training provides a variety of environments that can be selected, based on the patient's requirements, for recovery of motor skills[12)], and with the recent developments in scientific computer technology and programs, it has been applied in a wide range of patients. Previous studies have reported that physical activities using virtual reality programs are helpful for functional improvement in patients with neurologic disorders[13)], and more specifically, rehabilitation through games has the advantages of being interesting and inexpensive[14)]. You et al.[15)] reported that virtual reality-based training in patients with stroke showed significant improvement in motor recovery and brain reorganization, which played an important role in the recovery of functional movement. In addition, some studies involving senior citizens have reported significant effects on muscular strength and balance in the lower limbs[16)].

Several studies have reported that task-oriented training and virtual reality-based training improve motor function in patients with stroke. However, there are no studies on the comparison of these 2 types of therapeutic intervention in the clinical setting. This study therefore aimed to examine the effects of virtual reality-based training and task-oriented training on balance in patients with stroke.

SUBJECTS AND METHODS

Twenty-four patients with stroke, who were hospitalized at the K Hospital in Seoul, were selected based on the fol-

*Corresponding author. Suk Min Lee (E-mail: leesm@syu.ac.kr)

lowing selection criteria: (1) stroke of >6 months duration; (2) a score of >24 points on the Korean version of the Mini-Mental State Examination; (3) ability to walk a distance of 10 m with or without an auxiliary device[17]; (4) no history of orthopedic conditions involving the lower limbs; (5) ability to follow instructions and perform the exercise programs; and (6) no visual or hearing impairment[18]. All experimental protocols and procedures were explained to each subject and approved by the Institutional Review Board (IRB) of the Sahmyook University.

Table 1 shows the general characteristics of the subjects. The average age of the patients in the virtual reality-based and task-oriented groups was 45.91 ± 12.28 and 49.16 ± 12.85 years, respectively. The average height of the patients in these 2 groups was 169.66 ± 7.19 and 166.08 ± 10.16 cm, and the average weight was 63.58 ± 12.95 and 65.16 ± 13.18 kg, respectively.

For the virtual reality-based training, the Wii and Wii Balance Board (Nintendo, Japan, 2010, WBB) provided by Nintendo (Kyoto, Japan) and the Wii Fit Plus software were used. The equipment consisted of the Nintendo Wii (RVL-001, Nintendo, Japan, 2008), Wii remote control (RVL-003, Nintendo, Japan, 2008), Sensor bar for Wii only (RVL-014, Nintendo, Japan, 2008), and the WBB. The subjects were instructed to stand on the WBB, which is connected to the Wii by Bluetooth, and their movement was displayed on the monitor by a representative Avatar (This allows a non-egoistic self-expression). For the Wii Fit Plus software, the users' basic registration information is entered into the system before starting the program. Movement of the physical center of gravity (COG) and the body mass index (BMI) are measured by the WBB, and the individual exercise time and results are recorded.

The virtual reality-based program was selected depending on the subjects' interests and motivation, and the levels of difficulty were decided based on information provided in previous studies regarding suitable levels for balance improvement[19]. The program consisted of: (1) sitting posture, (2) The knee bend and the other leg knee extend, (3) tightrope walking, (4) penguin teeter-totter seesaw, (5) balance skiing, (6) rolling marble board, and (7) balance Wii (Table 2).

The subjects participated in the virtual reality-based training program for a total of 30 min. They performed all 7 programs once and then freely participated in the games of their choice for the remainder of the session. In this study, the subjects stood in front of the monitor at a distance of 2 m. An auxiliary table was placed next to the contralateral side, and an assistant waited next to the affected side for the subject's safety. If abnormal myotonus was noted in the affected limbs due to compensatory movements, the assistant lowered it with assistance before the initiation of the training. When the subjects successfully completed the program that was based on individual abilities, the level of difficulty was adjusted to an advanced level. All the subjects who participated in the experiment also received general exercise therapy for 60 min/day, 5 days/week for 6 weeks. They participated in the virtual reality-based training program for an additional 30 min/day, 3 days/week for 6 weeks.

The task-oriented training consisted of 6 tasks besides

Table 1. General subject characteristics

		Virtual reality-based training group (n = 12) mean ± SD	Task-oriented training group (n = 12) mean ± SD
Gender	male	8[a] (66.7)	8 (66.7)
	female	4 (33.3)	4 (33.3)
Age (yrs)		45.91 ± 12.28	49.16 ± 12.85
Height (cm)		169.66 ± 7.19	166.08 ± 10.16
Weight (kg)		63.58 ± 12.95	65.16 ± 13.18

a: number (%)

the warm-up and cool-down phases. For warm-up and cool-down, range-of-motion and stretching exercises were carried out to prevent injury[18]. The 6 tasks were as follows: (1) sit-to-stand from different heights, (2) task training in standing, (3) balance training on an unstable surface, (4) lifting a leg in place, (5) kicking a ball, and (6) stair climbing and descending (Table 3).

The duration of the task-oriented training program was 30 min. Each task took 3 min to perform, and a 1-min break was provided between tasks. Each of the warm-up and cool-down phases lasted for 2 min[17, 18]. The level of difficulty and frequency for each task were gradually increased during the 6 weeks with the patients' consent, starting with 3 sets (12 times/set). All the subjects who participated in the experiment also received general exercise therapy for 60 min/day, 5 days/week for 6 weeks. They participated in the virtual reality-based training program for an additional 30 min, 3 times/week for 6 weeks.

For the general exercise therapy, Brunnstrom one on one movement therapy, neurodevelopmental therapy, and proprioceptive neuromuscular facilitation were carried out for 60 min/day, 5 times/week for 6 weeks, with the help of a physical therapist[20].

The standing balance tools used to measure and analyze balance included the WBB, balance measuring equipment, Bluetooth for receiving and analyzing signals, and notebook with software. The size of the WBB, which includes 4 load cells, was 5 × 26.5 cm. Data on the measured values were sent to the notebook using the WBB and Bluetooth Balancia software ver. 2.0 (Mintosys, Seoul, Korea). The sampling data were obtained at 50 Hz, low-pass filtered at 12 Hz, and analyzed. Balance was evaluated using the Balancia software 3 times in each of the following conditions: eyes-open wide base (EOWB), eyes-closed wide base (ECWB), eyes-open narrow base (EONB), and eyes-closed narrow base (ECNB). The measurements were performed for 30 s, with a break of 15 s after each measurement. A 60-s break was provided between the above-mentioned 4 different assessments. The reliability and validity of the center of pressure (COP) were ICC (Intraclass correlation coefficient) = 0.66–0.94 and ICC = 0.77–0.89, respectively[21].

Dynamic balance was evaluated using the functional reach test (FRT). A standard ruler was fixed to the wall to the height of the subject's acromion. The subjects were instructed to stand up immediately on contact of their feet with the floor, and the measurements were performed[22]. The

Table 2. Virtual reality-based training program

Item	Training method	Time (min)
Sitting posture	Both shoulders are in a 30° bent posture. In addition, both knees are in a 30° bent posture. The subjects are expected to maintain this position for 30 s, with their center of gravity coinciding with the red center in a yellow circle on the monitor.	2
The knee bend and the other leg knee extend	The subjects maintain the sitting position for 30 s, with their center of gravity coinciding with the red center in a yellow circle on the monitor. On weight-bearing, the red stick rises, and the number of times the blue target is exceeded is recorded. The knee flexion angle is gradually increased to 30°, 45°, 60°, and 90°.	2–4
Walking a tightrope	The subjects walk a tightrope by alternate weight shifting to left and right and are expected to reach the target without falling. They are required to widen bent knees quickly to go over obstacles, with the wind and flags providing a visual and balance challenge.	2
Penguin teeter-totter seesaw	By alternate weight shifting to the left and right, the subjects are expected to catch fish without falling on the ice, which will cause the ice to tilt. The scores that can be obtained in accordance with the fish are diverse.	1.5
Balance skiing	By moving the body's center of gravity to the left or right, the subject passes between 19 flags; moving the center of the body forward helps increase the speed. Do not pass the flag, 7 s deduction is given per one.	1.5–2
Rolling marble board	The subjects tilt the platform in multiple directions by shifting weight onto the ankle joints to place the ball in the target. If it passes through the stage, added additional time to the next stage.	1.5–3
Balance Mii	The experimenter moves the body's center of gravity in multiple directions with the subject's Avatar (Mii) in a soap bubble; the goal is to steer to the target point. The subject has to be careful not to hit the wall, rock, or bees.	1.5

Table 3. Task-oriented training program

Item	Training method
Standing up from different heights	With the knees in 90° flexion, the subjects perform sit-to-stand from different heights. The height is changed by lowering the height of the chair gradually, 10 cm at a time.
Task training in standing	To enable shifting of weight to the affected side in standing, the subjects perform tasks such as moving cups and rings. As the training progresses, the shoulder flexion angle is gradually increased to 70°, 90°, and 110°.
Balance training on an unstable surface	Subjects maintain their balance on the Balance Pad (Alcan Airex, Switzerland) in standing, with the feet shoulder-width apart. If the subject appears anxious, an auxiliary table is provided for hand placement. As the training progresses, the distance between the feet is gradually reduced by 5 cm.
Lifting a leg in place	The feet are raised alternately to bend the knees. If the subject appears anxious, an auxiliary table is provided for support. As the training progresses, the hip flexion angle is gradually increased to 30°, 45°, 60°, and 90°.
Kicking a ball	The subject kicks a ball with the affected and unaffected sides towards the 1 m in front of the wall. An auxiliary table is placed next to the patient's unaffected side. The upper limb assistance is gradually decreased as the training progresses, and the distance between the wall and subjects is increased by a maximum of 50 cm.
Stair climbing and descending	Using the stair training machine, the subjects climb and descend one step. If required, the subjects are provided with a table for assistance. As the training progresses, the height of the stair training machine 5 cm, 10 cm, 15 cm, and 20 cm.

subjects' shoulders were flexed to 90° for the front measurement. The elbows were stretched as much as possible to be in line with the hands. The subjects moved the upper limbs and trunk to the front, if possible, and the distances were measured with the end of the middle finger as the reference point, using a standard ruler. For the measurement toward the contralateral side, the shoulder joints were abducted to 90°, and the elbows were stretched as much as possible to be in line with hands. For the measurement toward the affected side, the subjects were asked to rotate the trunk to the affected side, if possible, and the distances from the acromion were measured. The tests were repeated 3 times, and the average value was recorded. The reliability of the FRT between the inspectors was high (r = 0.97)[23].

This study calculated the averages and standard deviations using the SPSS ver. 19.0 (SPSS Inc., Chicago, IL, USA). Descriptive statistics were used for the general subject characteristics, and t-tests were used for matched samples

Table 4. COP path length and velocity in eyes-open wide base and eyes-closed wide base conditions (n = 24)

		Virtual reality-based training group (n = 12)	Task-oriented training group (n = 12)
		mean ± SD	mean ± SD
EOWB			
COP path length (cm)	Pretest	63.86 ± 33.53	60.65 ± 30.14
	Posttest	51.25 ± 27.29	49.52 ± 18.50
	Post-pre	12.61 ± 9.90*	11.13 ± 15.74*
COP velocity (cm/s)	Pretest	2.12 ± 1.11	2.02 ± 1.00
	Posttest	1.70 ± 0.90	1.65 ± 0.61
	Post-pre	0.42 ± 0.33*	0.37 ± 0.52*
ECWB			
COP path length (cm)	Pretest	75.71 ± 37.61	65.85 ± 34.95
	Posttest	59.92 ± 23.95	59.00 ± 24.88
	Post-pre	15.79 ± 15.99**	6.85 ± 18.16
COP velocity (cm/s)	Pretest	2.52 ± 1.25	2.19 ± 1.16
	Posttest	1.99 ± 0.79	1.96 ± 0.82
	Post-pre	0.53 ± 0.53*	0.23 ± 0.60

EOWB: eyes-open wide base; ECWB: eyes-closed wide base; COP: center of pressure
Significant difference, Paired t-test: *, p<0.05; **, p<0.001; ***, p<0.0001
Significant difference, Independent t-test: †, p<0.05; ††, p<0.001; †††, p<0.0001

Table 5. COP path length and velocity with eyes-open narrow base and eyes-closed narrow base (n = 24)

		Virtual reality-based training group (n = 12)	Task-oriented training group (n = 12)
		mean ± SD	mean ± SD
EONB			
COP path length (cm)	Pretest	92.24 ± 37.52	79.16 ± 37.27
	Posttest	73.83 ± 31.27	65.93 ± 30.99
	Post-pre	18.41 ± 15.73*	13.23 ± 27.23
COP velocity (cm/s)	Pretest	3.07 ± 1.25	2.63 ± 1.24
	Posttest	2.46 ± 1.04	2.19 ± 1.03
	Post-pre	0.61 ± 0.52*	0.44 ± 0.90
ECNB			
COP path length (cm)	Pretest	118.74 ± 45.95	100.77 ± 45.42
	Posttest	95.34 ± 38.98	93.95 ± 43.13
	Post-pre	23.40 ± 29.94*	6.82 ± 31.99
COP velocity (cm/s)	Pretest	3.95 ± 1.53	3.36 ± 1.51
	Posttest	3.17 ± 1.29	3.13 ± 1.43
	Post-pre	0.78 ± 0.99*	0.23 ± 1.06

EONB: eyes-open narrow base; ECNB: eyes-closed narrow base; COP: center of pressure
Significant difference, Paired t-test: *, p<0.05; **, p<0.001; ***, p<0.0001
Significant difference, Independent t-test: †, p<0.05; ††, p<0.001; †††, p<0.0001

to compare the conditions before and after training in the 2 groups. The independent samples t-test was carried out to examine the differences between the groups according to the training methods. The significance level was set at 0.05.

RESULTS

The COP path length and velocity of the virtual reality-based training and task-oriented training groups before and after the treatment with EOWB and ECWB are shown in Table 4. The measured pre- and post-test values for the stable COP path length and COP velocity in the EOWB and ECWB conditions increased significantly in both groups ($p < 0.05$).

The COP path length and velocity of the virtual reality-based training and task-oriented training groups before and after treatment in the EONB and ECNB conditions are shown in Table 5. The measured pre- and post-test values for the stable COP path length and COP velocity in the EONB and ECNB conditions increased significantly in both groups ($p < 0.05$).

The FRT scores of the virtual reality-based training and task-oriented training groups before and after treatment are shown in Table 6. The measured pre- and post-test values for stable FRT increased significantly in both groups ($p < 0.05$). There was a difference in the FRT between the virtual reality-based training and task-oriented training groups ($p < 0.0001$).

Table 6. FRT before and after the treatment (n = 24)

		Virtual reality-based training group (n = 12)	Task-oriented training group (n = 12)
		mean ± SD	mean ± SD
FRT (cm)	Pretest	15.84 ± 6.32	16.40 ± 5.91
	Posttest	24.75 ± 7.44	21.39 ± 6.31
	Post-pre	8.91 ± 3.16***†††	4.99 ± 2.05***

FRT: Functional reach test
Significant difference, Paired t-test: *, p<0.05; **, p<0.001; ***, p<0.0001
Significant difference, Independent t-test: †, p<0.05; ††, p<0.001; †††, p<0.0001

DISCUSSION

Small physical movements referred to as postural sway are produced even when standing still. The degree of the sway is influenced by the width of the base of support and foot position. The range and direction of postural sway can be measured by calculating the COG on the bearing surface[24–26]. In this study, the COP path length and velocity were measured to examine the static balance ability with the eyes-open base, eyes-closed base, wide base, and narrow base. A comparison of these revealed that the COP path length and velocity with the eyes-closed base were greater than those with the eyes-open base; this indicates that balance ability is sensitive to visual information[27]. Relearning of postural control using visual and auditory feedback is known to be effective for balance improvement[20]. A previous study targeting patients with chronic stroke found that training in weight shifting with visual feedback is significantly effective for postural control and weight bearing on the contralateral side[28]. Lai, Peng, Chen, Huang, Hsiao, and Chen[27] reported that balance training using visual and auditory feedback showed a significant reduction in the COP path length and velocity in a balance study involving use of video games. Similarly, the virtual reality-based training group in this study showed a significant increase in the group due to a reduction in path length and velocity of all the pressure points in the EOWB, ECWB, EONB, and ECNB conditions. The task-oriented training group did not have a significant difference in path length and velocity compared to the pretest status in any of the conditions except the EOWB. In the virtual reality-based training group, all the variables showed a significant increase, but there were no differences in the changes between the 2 groups. This was thought to be due to the standard deviations in the results. It is thought that the virtual reality-based training task that improved the patients' static balance ability, during which the subject was seated in a chair, maintained the red center point of gravity in the yellow circle on the monitor with visual and auditory feedback.

Ragnarsdóttir[29] defined static balance as the ability to stand on a fixed weight-bearing surface without swaying and dynamic balance as the ability to maintain that posture when the surface shifted due to external stimuli or movement caused by the subjects. It is generally assumed that lesser movement of the COP is associated with better balance ability. In addition, previous studies have also shown a tendency for the balance ability to decrease when the COP movement increases due to disease or aging[30]. However, the COP's path length was shown to decrease in those with Parkinson's disease[31, 32]. Moreover, the COP path length in dancers with good balance tends to increase in the static standing posture[32]. The FRT was used to examine improvement in dynamic balance. This method can be used to measure dynamic balance in clinical settings without special equipment[22]. The average FRT scores in males and females, 41–69 years old, are 37.8 cm and 35.1 cm, respectively. Dean and Shepherd[33], in their study, conducted the reach test in the sitting position after the patients had participated in task orientation training and found that the score had increased by 0.9 cm (pretest: 11.2 cm, posttest: 12.1 cm). The present study evaluated the reach in 3 directions: front, the contralateral side, and the affected side, and differences between the virtual reality-based training and task-oriented training groups were noted. It is thought that both the training programs were more effective in the improvement of dynamic balance, as their focus was on dynamic movements rather than static movements.

Normal adults utilize 3 postural control strategies, namely the ankle, hip, and stepping strategies for maintenance of anteroposterior stability. The ankle strategy is most commonly used in situations that require balancing small collapses. The hip strategy is used to recover balance that has been affected by a sway; it is larger and occurs faster than the ankle strategy. In the stepping strategy, the individual bending people's steps to create the new base of support by responding to the phenomena that the center moves outside it when the ankle strategy and the hip strategy are not enough[30]. The rolling marble board and Balance Wii in the virtual reality program were more suitable for utilizing the hip strategy required for larger movements than the ankle strategy required for minute movements. We think that the left and right weight shift to prevent falling on ice in the penguin teeter-totter seesaw task affected the mediolateral stability. It is thought that compared to task orientation programs, the virtual reality-based program provided a greater variety of concrete environments to improve dynamic balance, and this indicates that there would be significant differences in dynamic balance between the groups. The task-oriented training group also showed a significant improvement in dynamic balance. This is thought to be due to the effect of balance training on an unstable bearing surface. Previous studies have reported a significant improvement in dynamic balance with the balance exercise on an unstable bearing surface[34].

This study found both the virtual reality-based program and task-oriented program to be effective therapeutic interventions for functional improvement in stroke patients. This study had the following limitations. The sample size used in this study was small, and the study duration was short, with an insufficient long-term follow-up survey after the training. It is therefore difficult to generalize the results of our study. Future studies with a larger sample size and a longer follow-up are warranted. Additionally, the training involved should include muscular endurance, cardiovascular endurance, and coordination training.

REFERENCES

1) Statistics Korea: Statistics cause of death report. Statistics Korea, 2011.
2) Barclay-Goddard R, Stevenson T, Poluha W, et al.: Force platform feedback for standing balance training after stroke. Cochrane Database Syst Rev, 2004, 184: CD004129. [Medline]
3) Saposnik G, Teasell R, Mamdani M, et al. Stroke Outcome Research Canada (SORCan) Working Group: Effectiveness of virtual reality using Wii gaming technology in stroke rehabilitation: a pilot randomized clinical trial and proof of principle. Stroke, 2010, 41: 1477–1484. [Medline] [CrossRef]
4) Perry J, Garrett M, Gronley JK, et al.: Classification of walking handicap in the stroke population. Stroke, 1995, 26: 982–989. [Medline] [CrossRef]
5) Cho KH, Lee JY, Lee KJ, et al.: Factors related to gait function in post-stroke patients. J Phys Ther Sci, 2014, 26: 1941–1944. [Medline] [CrossRef]
6) Park J, Lee D, Lee S: Effect of virtual reality exercise using the nintendo wii fit on muscle activities of the trunk and lower extremities of normal adults. J Phys Ther Sci, 2014, 26: 271–273. [Medline] [CrossRef]
7) Tanaka T, Kudo A, Sugihara S, et al.: A study of upper extremity training for patients with stroke using a virtual environment system. J Phys Ther Sci, 2013, 25: 575–580. [Medline] [CrossRef]
8) An HJ, Kim JI, Kim YR, et al.: The effect of various dual task training methods with gait on the balance and gait of patients with chronic stroke. J Phys Ther Sci, 2014, 26: 1287–1291. [Medline] [CrossRef]
9) Susan EB, James LK: Neurological Disabilities: Assessment and treatment. Lippincott Williams & wilkins, 1998, pp 77–81.
10) Yang YR, Wang RY, Lin KH, et al.: Task-oriented progressive resistance strength training improves muscle strength and functional performance in individuals with stroke. Clin Rehabil, 2006, 20: 860–870. [Medline]
11) Corriveau H, Hébert R, Raîche M, et al.: Evaluation of postural stability in the elderly with stroke. Arch Phys Med Rehabil, 2004, 85: 1095–1101. [Medline] [CrossRef]
12) Crosbie JH, Lennon S, McGoldrick MC, et al.: Virtual reality in the rehabilitation of the arm after hemiplegic stroke: a randomized controlled pilot study. Clin Rehabil, 2012, 26: 798–806. [Medline] [CrossRef]
13) Burdea GC: Virtual rehabilitation—benefits and challenges. Methods Inf Med, 2003, 42: 519–523. [Medline]
14) Bateni H: Changes in balance in older adults based on use of physical

therapy vs the Wii Fit gaming system: a preliminary study. Physiotherapy, 2012, 98: 211–216. [Medline] [CrossRef]
15) You SH, Jang SH, Kim YH, et al.: Virtual reality-induced cortical reorganization and associated locomotor recovery in chronic stroke: an experimenter-blind randomized study. Stroke, 2005, 36: 1166–1171. [Medline] [CrossRef]
16) Kim J, Son J, Ko N, et al.: Unsupervised virtual reality-based exercise program improves hip muscle strength and balance control in older adults: a pilot study. Arch Phys Med Rehabil, 2013, 94: 937–943. [Medline] [CrossRef]
17) Dean CM, Richards CL, Malouin F: Task-related circuit training improves performance of locomotor tasks in chronic stroke: a randomized, controlled pilot trial. Arch Phys Med Rehabil, 2000, 81: 409–417. [Medline] [CrossRef]
18) Salbach NM, Mayo NE, Wood-Dauphinee S, et al.: A task-orientated intervention enhances walking distance and speed in the first year post stroke: a randomized controlled trial. Clin Rehabil, 2004, 18: 509–519. [Medline] [CrossRef]
19) Deutsch JE, Brettler A, Smith C, et al.: Nintendo Wii sports and Wii fit game analysis, validation, and application to stroke rehabilitation. Top Stroke Rehabil, 2011, 18: 701–719. [Medline] [CrossRef]
20) Eser F, Yavuzer G, Karakus D, et al.: The effect of balance training on motor recovery and ambulation after stroke: a randomized controlled trial. Eur J Phys Rehabil Med, 2008, 44: 19–25. [Medline]
21) Clark RA, Bryant AL, Pua Y, et al.: Validity and reliability of the Nintendo Wii Balance Board for assessment of standing balance. Gait Posture, 2010, 31: 307–310. [Medline] [CrossRef]
22) Duncan PW, Weiner DK, Chandler J, et al.: Functional reach: a new clinical measure of balance. J Gerontol, 1990, 45: M192–M197. [Medline] [CrossRef]
23) Katz-Leurer M, Fisher I, Neeb M, et al.: Reliability and validity of the modified functional reach test at the sub-acute stage post-stroke. Disabil Rehabil, 2009, 31: 243–248. [Medline] [CrossRef]
24) Gatev P, Thomas S, Kepple T, et al.: Feedforward ankle strategy of balance during quiet stance in adults. J Physiol, 1999, 514: 915–928. [Medline] [CrossRef]
25) Day BL, Steiger MJ, Thompson PD, et al.: Effect of vision and stance width on human body motion when standing: implications for afferent control of lateral sway. J Physiol, 1993, 469: 479–499. [Medline] [CrossRef]
26) Kirby RL, Price NA, MacLeod DA: The influence of foot position on standing balance. J Biomech, 1987, 20: 423–427. [Medline] [CrossRef]
27) Lai CH, Peng CW, Chen YL, et al.: Effects of interactive video-game based system exercise on the balance of the elderly. Gait Posture, 2013, 37: 511–515. [Medline] [CrossRef]
28) Yavuzer G, Eser F, Karakus D, et al.: The effects of balance training on gait late after stroke: a randomized controlled trial. Clin Rehabil, 2006, 20: 960–969. [Medline] [CrossRef]
29) Ragnarsdóttir M: The concept of balance. Physiotherapy, 1996, 82: 368–375. [CrossRef]
30) Shumway-Cook A, Woollacott MH: Motor control theory and practical applications, 3rd ed. Lippincott Williams & Wilkins, 2007, pp 212–231.
31) Panzer VP, Hallett M: Biomechanical assessment of upright stance in parkinson's disease: a single-subject study. Clin Biomech (Bristol, Avon), 1990, 5: 73–80. [Medline] [CrossRef]
32) Brauer S: Mediolateral postural stability: Changes with age and prediction of fallers. Doctoral Dissertation, University of Queensland, 1998.
33) Dean CM, Shepherd RB: Task-related training improves performance of seated reaching tasks after stroke. A randomized controlled trial. Stroke, 1997, 28: 722–728. [Medline] [CrossRef]
34) An WH, Jeong MK, Kim CK: The training effect of balance pad in stroke. Phys Educ Sports, 2008, 32: 803–811.