



Original Article

Canoe game-based virtual reality training to improve trunk postural stability, balance, and upper limb motor function in subacute stroke patients: a randomized controlled pilot study

MYUNG-MO LEE, PT, PhD¹⁾, DOO-CHUL SHIN, PT, PhD²⁾, CHANG-HO SONG, PT, PhD^{2)*}

¹⁾ Department of Physical Therapy, Daejeon University, Republic of Korea

²⁾ Department of Physical Therapy, Sahmyook University: 26-21 Gongneung2-dong, Nowon-gu, Seoul 139-742, Republic of Korea

Abstract. [Purpose] This study was aimed at investigating the preliminary therapeutic efficacy and usefulness of canoe game-based virtual reality training for stroke patients. [Subjects and Methods] Ten stroke patients were randomly assigned to an experimental group (EG; n=5) or a control group (CG; n=5). Patients in both groups participated in a conventional rehabilitation program, but those in the EG additionally participated in a 30-min canoe game-based virtual reality training program 3 days a week for 4 weeks. Therapeutic efficacy was assessed based on trunk postural stability, balance, and upper limb motor function. In addition, the usefulness of canoe game-based virtual reality training was assessed in the EG and therapist group (TG; n=20), which consisted of physical and occupational therapists, by using the System Usability Scale (SUS). [Results] Improvements in trunk postural stability, balance, and upper limb motor function were observed in the EG and CG, but were greater in the EG. The mean SUS scores in the EG and TG were 71 ± 5.2 and 74.2 ± 4.8 , respectively. [Conclusion] Canoe game-based virtual reality training is an acceptable and effective intervention for improving trunk postural stability, balance, and upper limb motor function in stroke patients.

Key words: Virtual reality exposure therapy, Postural balance, Stroke

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INTRODUCTION

Virtual reality (VR) rehabilitation systems are computer-based processes that provide three-dimensional and direct sensorial feedback to which a person can respond, resulting in real-time interaction with the environment and enhanced enjoyment during exercise¹⁾. VR environments are common in treatment, training, and rehabilitation, and are widely used to increase the outcome of stroke rehabilitation²⁾. As VR programs are often more interesting and enjoyable than traditional therapy tasks, they provide motivation and encouragement for subjects to participate³⁾. Hence, the frequency of their use in clinical settings is increasing. VR rehabilitation training using a motion-controlled video game has been widely used as an intervention for motor improvement in stroke patients⁴⁾. Previous studies reported that game programs using a motion-controlled video game are effective for motor improvement of the upper limbs^{5–8)} and improvement of balance and gait ability in stroke patients^{9–12)}.

Good postural stability is essential not only for balance but also for the use of the extremities during daily functional activities¹³⁾. Previous studies have reported that trunk stability is related to balance and limb function improvement¹⁴⁾. The findings of these studies provide strong evidence for the importance of early assessment and management of trunk control after stroke¹⁵⁾. However, studies on game-based VR training for trunk stability are lacking. Recently, the need for VR training

*Corresponding author. Chang-Ho Song (E-mail: chsong@syu.ac.kr)

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that utilizes game software has emerged. Canoeing is a paddle sport that requires coordination between trunk control and upper limb function, and demands a good sitting balance¹⁶. Paddle sports are effective for improving postural and trunk stability¹⁷.

As most of the interventions that use motion-controlled video games have been applied only to patients with chronic diseases, cases of patients requiring intensive rehabilitation are lacking. Moreover, some reports have indicated that participation of the elderly in such rehabilitation program might be hindered by lowered interest and commitment if the program is difficult to use or its realism is low^{18, 19}. The application of VR training based on a motion-controlled video game in clinical settings requires a systematic investigation of its usefulness, including its acceptability, ease of use, and learnability²⁰. Studies to evaluate the usefulness of the intervention must be conducted with prototype VR rehabilitation systems to maximize its potential²¹.

Hence, the primary aim of this study was to investigate the effects of a canoe game-based VR training program for trunk postural control, balance, and upper limb motor function after stroke. Its secondary aim was to evaluate the usability of the approach.

SUBJECTS AND METHODS

All individuals who had a stroke and were admitted to the rehabilitation ward as inpatients at a university hospital in Gyeonggi Province, South Korea, were eligible after meeting the following inclusion criteria: (1) non-cerebellar stroke within the previous 6 months; (2) ability to understand and follow simple verbal instructions; (3) Mini-Mental State Examination score of ≥ 21 ²²; (4) minimum Berg Balance Scale score of 15 (the minimum level deemed safe for balance intervention participation)¹; and (5) ability to walk 10 m independently, with or without an assistance device. The exclusion criteria were as follows: (1) psychiatric disorder or dementia, (2) apraxia or hemi-neglect, (3) epilepsy or pacemaker use (as per Nintendo Wii safety guidelines), (4) severe pain in the hemiplegic shoulder, and (5) a participation rate of <80%. Ten subjects were enrolled in the trial. Figure 1 shows a Consolidated Standards of Reporting Trials diagram of all the potential and enrolled participants. Twenty physical or occupational therapists who worked in the hospital rehabilitation center participated in the System Usability Scale (SUS) questionnaire at the end of the intervention session. All protocols and procedures were approved by the institutional review board of Sahmyook University, and all the participants signed a statement of informed consent.

This study was an unpowered pilot and usability study designed as an assessor-blinded, randomized, controlled trial. Over a 2-month period (June 2014 to July 2014), 53 patients participated in post-stroke rehabilitation. Thirty-nine patients

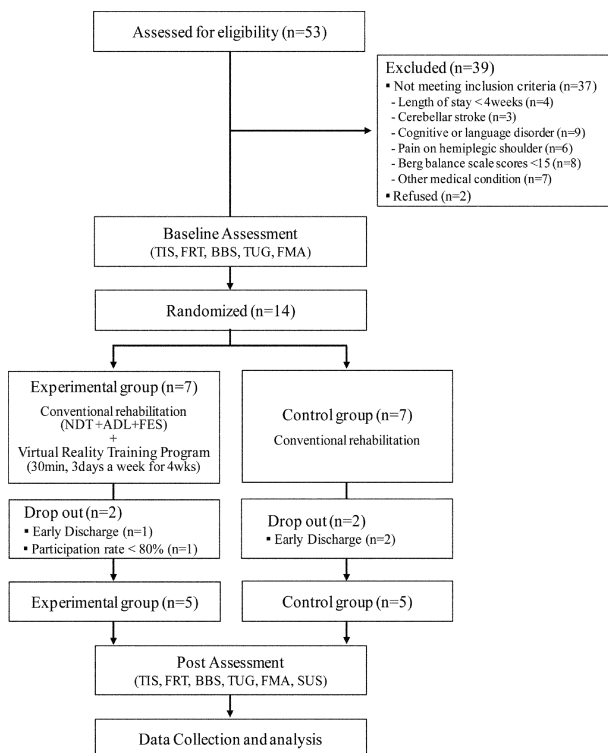


Table 1. Characteristics of the subjects in the experimental and control groups

	EG (n=5)	CG (n=5)
Male/Female	3/2	2/3
Age (years)	65.2 ± 5.0	66.2 ± 3.4
Height (cm)	161.4 ± 10.5	158.2 ± 8.7
Weight (kg)	59.2 ± 7.2	61.2 ± 4.7
Stroke type (Infarct/hemorrhage)	4 / 1	4 / 1
Affected side (left/right)	4 / 1	3 / 2
Onset time (months)	3.1 ± 1.6	3.3 ± 1.1
MMSE-K	24.4 ± 2.4	24.2 ± 3.0

Values are expressed as n or mean ± standard deviation.
EG: Experimental group; CG: Control group; MMSE-K: Mini Mental State Examination-Korea version

Fig. 1. Flowchart of the participant selection for the study

were ineligible based on the inclusion criteria, and 2 refused participation in the trial. Finally, 14 participants were enrolled in the trial and assessed in the pretest. After the pretest, the participants were randomly allocated to the experimental group (EG, n=7) or control group (CG, n=7). The randomization process was performed by using computer-generated numbers produced by a basic random number generator²³. Two participants in the EG and two in the CG dropped out because of early discharge and a participation rate of <80%. Thus, 5 participants in the experimental and control groups, respectively, completed the study. Safety-related incidents such as falls, dizziness, and epilepsy did not occur during the intervention. The general characteristics of the participants are shown in Table 1. The patients in the experimental and control groups participated in the same conventional rehabilitation program that consisted of physical therapy, occupational therapy, and functional electrical stimulation (FES). Physical therapy was conducted for gait training and lower limb strengthening, based on the neuro-developmental treatment (NDT) concept, for 30 min twice a day, 5 days a week, for 4 weeks. Occupational therapy was also administered for 30 min twice a day, 5 days a week, for 4 weeks, to improve performance in activities of daily living. FES was applied simultaneously to both the upper and lower limbs for 15 min a day, 5 days a week, for 4 weeks.

The EG additionally participated in the canoe game-based VR training program. The canoeing game in the Nintendo Wii Sports Resort package was used as a VR training program. To create realistic effects (e.g., swaying from side to side), a canoe was made by attaching a chair to a springboard (width, 45 cm; diameter, 150 cm; height, 20 cm). The participants paddled by grasping the motion controller, which was inserted in a canoe paddle accessory, alternating between hands while sitting on the springboard. The grip gloves were provided to the participants who had difficulty grasping the motion controller. The participants controlled the paddling according to the direction of the movement of the virtual character that was shown on the LCD screen. They also adjusted their trunk to maintain balance on the springboard during paddling. For safety, the program was conducted with the participants wearing a belt around the waist.

The intervention program consisted of 3 session modes. The first session, conducted for 5 min, was a free-practice mode for familiarization and warm-up. The second session, conducted for 10 min, was a timed-run mode, designed to achieve a personal record of the distance travelled in a limited time period. The third session, conducted for 15 min, was a competition mode designed to improve motivation through competition with the caregiver or therapist. The canoe game-based VR training programs were conducted for 30 min a day, 3 days a week, for 4 weeks. The posttest and SUS evaluations were conducted 1 day after the end of the intervention period. All assessments were performed by two physical therapists who were blinded to the treatment allocations.

Outcome was determined by using measures of trunk postural stability, balance ability, and upper limb motor function. To assess and compare trunk postural stability between before and after the intervention, the Trunk Impairment Scale (TIS) and functional reach test (FRT) were used. To compare balance ability before and after the intervention, the Berg Balance Scale (BBS) and timed up-and-go (TUG) tests were used. The Fugl-Meyer assessment (FMA) was used to assess motor function of the upper limbs. The SUS measures the usefulness of interface technologies after intervention. Levels of agreement with 10 statements were scored by using a 5-point Likert scale anchored with “strongly disagree” and “strongly agree.” The SUS yielded percentage scores, which were calculated as described by Brooke²⁴. The SUS provides a point estimate of percentage of usefulness. Scores of >70 are acceptable, and highly useful products score >90. Scores of >50 indicate unacceptably low levels of usefulness²⁵.

Statistical analysis was performed by using SPSS version 19.0. The Shapiro-Wilk test was used to confirm that all outcome variables were normally distributed. The paired t-test was used to compare dependent variables within the groups, and the independent t-test and χ^2 analysis were used to compare dependent variables between the groups. Descriptive statistical analysis was used to analyze data on usefulness. In addition, the Mann-Whitney U test was conducted for between-group comparison of outcomes that indicate usefulness. A statistical significance level of 0.05 was used in all the measurements.

RESULTS

No significant differences in general characteristics and dependent variables were observed between the experimental and control groups. Regarding trunk postural stability after completing the 4-week intervention program, the TIS score significantly improved in the EG but not in the CG. The FRT result showed significant improvement both in the experimental and control groups. When the two groups were compared, the changes in the TIS and FRT scores were statistically greater in the EG than in the CG. In balance ability, the BBS score showed significant improvement both in the experimental and control groups. The TUG times significantly improved in the EG but not in the CG. When the two groups were compared, the changes in the BBS and TUG scores were statistically greater in the EG than in the CG. In upper limb motor function, the FMA score showed significant improvement both in the experimental and control groups. When the two groups were compared, the changes in the FMA scores were statistically greater in the EG than in the CG (Table 2). The mean SUS score for the entire sample was 73.16 ± 4.95 . The mean scores for the experimental and therapist groups were 71 ± 5.2 and 74.3 ± 4.8 , respectively. The difference between the two groups was not significant (Mann-Whitney U test, $z=-1.2$, $p=0.2$).

DISCUSSION

The canoe game-based VR training program was newly applied to improve trunk postural stability, balance ability, and upper limb motor function. The effectiveness of the canoe game-based VR training program can be determined based on

improvements in trunk postural stability, balance ability, and upper limb motor function. The changes in trunk postural stability were evaluated by using TIS and FRT scores, and the EG showed significantly greater improvements than the CG. Unlike VR balance training performed in the standing position, the present study was performed by using the canoeing game in the sitting position. In addition, the participants were asked to maintain their balance in the sitting position in the chair attached to the springboard during canoe game-based VR training. The participants maintained balance by using the trunk muscles while paddling on the board, wavering from side to side. The effort to maintain balance seemed to have contributed to the increase in trunk stability through an interactive process.

Balance training in the standing position is effective in improving the balance and gait ability of stroke patients. However, postural control skills acquired during dynamic balance training are not suitable for maintaining static postural stability²⁶. Cho et al.⁹) reported that game-based VR balance training using a balance board for 6 weeks improved dynamic balance ability assessed by using the BBS and TUG test scores but did not improve static balance ability. Furthermore, Cuthbert et al.¹) reported that balance training using only body positioning and weight shifting on the balance board in the standing position did not improve dynamic balance ability as much as static balance ability. In fact, stroke patients minimized their movements when controlling their posture in the standing position and made less effort to maintain their center of mass²⁷. These results indicate that improvements in static and dynamic balance abilities might depend on the balance training method used and suggest the need for a training method that can improve both static and dynamic balance abilities. Balance training in the sitting position is easy on weight shifting and weight-control ability²⁸). As in previous studies, improvement in trunk stability contributed to improvement in balance ability in the present study. The changes in balance ability were evaluated by using BBS and TUG test scores, and the EG showed significantly greater improvement than the CG.

The changes in upper limb motor function were evaluated by using the FMA, and the EG showed significantly greater improvement than the CG. Most of the previous studies that used Nintendo games were conducted with chronic stroke patients because the study designs required partial movement of the upper limbs. However, Kwon et al.²⁹) reported that a VR training program combined with conventional therapy can be expected to produce greater improvement in upper limb motor function and activities of daily living (ADL) in the acute stages of stroke. Furthermore, Da Silva Cameirao et al.³⁰) reported that game-based VR rehabilitation improved upper limb motor function in the early stages of stroke and led to the restoration of function faster than that in the CG during the experimental period.

In this study, the participants paddled by using bilateral movements in which assistance of the non-affected upper limb was used to induce movement of the affected upper limb. Initially, the study participants complained of pain caused by overuse of the non-affected upper limb or difficulty using the affected upper limb. However, as they adapted to the game and became immersed in the activity, the frequency of the use of affected upper limb increased. Conventional training leads to poor engagement and lack of interest by participants due to the repetitive nature of the exercises, whereas VR training is interesting and motivates participants to improve their concentration and increase their time of participation in training. Interactive VR training provides immediate visual feedback on performance, providing participants a more active and enjoyable experience in the training program. However, Horlings et al.¹⁹) reported that VR training that fails to provide realistic environments can lower participants' immersion.

The canoeing game, used as an intervention method in this study, not only provides a realistic simulation of paddling a canoe but includes a free-practice mode for familiarization and warm-up, as well as timed-run and competition modes for recording individual accomplishments. The program components and system environment enhance the participants' interest and participation and increase their immersion. As a result, the EG had better trunk postural stability, balance ability, and upper limb motor function than the CG.

Table 2. Within- and between-group comparisons of trunk postural stability, balance, and upper limb motor function

Variables	EG (n=5)		CG (n=5)		EG (n=5)	CG (n=5)
	Pretest	Posttest	Pretest	Posttest	Post-pre	Post-pre
Trunk postural stability						
TIS (score)	14.0 ± 0.7	16.8 ± 1.3**	12.6 ± 1.7	13.6 ± 1.7*	2.8 ± 1.3†	1.0 ± 0.7
FRT (cm)	20.4 ± 3.5	22.4 ± 3.9***	17.8 ± 0.9	18.7 ± 0.9***	0.9 ± 0.6††	0.9 ± 0.2
Dynamic balance ability						
BBS (score)	41.8 ± 4.2	46.2 ± 4.3***	38.8 ± 3.7	41.2 ± 2.9**	0.40 ± 0.9††	2.4 ± 1.1
TUG (sec)	16.6 ± 4.3	15.1 ± 4.0**	18.1 ± 2.7	18.2 ± 1.5	-1.43 ± 0.5†	0.1 ± 1.4
Upper limb motor function						
FMA (score)	35.4 ± 2.8	39.8 ± 3.1**	29.4 ± 8.8	31.2 ± 9.1*	4.4 ± 1.1†	1.8 ± 1.3

Values are expressed as mean ± standard deviation.

EG: Experimental group; CG: Control group; TIS: Trunk Impairment Scale; FRT: Functional Reach Test; BBS: Berg Balance Scale; TUG: Timed Up and Go test; FMA: Fugl-Meyer Assessment.

*Significant difference within the group.

†Significant difference between the groups.

The application of new rehabilitation interventions in clinical setting demands primary systematic investigation regarding the acceptability, ease of use, learnability, and confidence to maximize their potential. Assessment of usefulness is required in both the participants and testers. The SUS scores in this study were >70% in both the experimental and therapist groups. No significant differences between the two groups were observed. These results suggest that the canoe game-based VR training program is an acceptable and useful approach for subacute inpatient stroke rehabilitation. The results of this study indicate that an additional canoe-game based VR training program is feasible and effective for improving trunk postural stability, balance ability, and upper limb motor function in subacute stroke patients.

However, the study had several limitations. First, it was a pilot study with a small sample size. Therefore, its results are difficult to generalize to stroke patients. For meaningful analysis of SUS, data based on at least 12 people are required³¹. In the future, a randomized controlled trial with an adequate sample size should be conducted. Second, the effect of canoe game-based VR training on the static balance ability of the stroke patients in the standing position was not assessed. In order to fully understand the effects of VR physical therapy in stroke patients, further studies that include methods performed by blinded assessors are clearly needed.

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