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Clinical usefulness of the virtual reality-based postural control training on the gait ability in patients with stroke

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This study is a single blind randomized controlled trial to determine the effect of virtual reality-based postural control training on the gait ability in patients with chronic stroke. Sixteen subjects were randomly assigned to either experimental group (VR, n = 8) or control group (CPT, n = 8). Subjects in both groups received conventional physical therapy for 60 min per day, five days per week during a period of four weeks. Subjects in the VR group received additional augmented reality-based training for 30 min per day, three days per week during a period of four weeks. The subjects were evaluated one week before and after participating in a four week training and follow-up at one month post-training. Data derived from the gait analyses included spatiotemporal gait parameters, 10 meters walking test (10 mWT). In the gait parameters, subjects in the VR group showed significant improvement, except for cadence at post-training and follow-up within the experimental group. However, no obvious significant improvement was observed within the control group. In between group comparisons, the experimental group (VR group) showed significantly greater improvement only in stride length compared with the control group ($P < 0.05$), however, no significant difference was observed in other gait parameters. In conclusion, we demonstrate significant improvement in gait ability in chronic stroke patients who received virtual reality based postural control training. These findings suggest that virtual reality (VR) postural control training using real-time information may be a useful approach for enhancement of gait ability in patients with chronic stroke.

Keywords: Virtual reality, Gait ability, Postural control, Stroke

INTRODUCTION

Stroke is one of the major causes of permanent disability and can be a serious burden for patients and their families (Herman et al., 1982). The various deficits in sensation, muscle strength, muscle tone and postural control on the paretic side of patients with stroke often affect activities of daily life (Lo et al., 2012). In particular, postural problems are common in patients after stroke and can limit the rate of recovery of walking and functional independence (Pedersen et al., 1996). The postural control system is regulated by stability limit, base of support (BOS) and balance. Postural control is defined as the ability to maintain the position of the body within base of support against the force of gravity: The position of the body is defined as the ability to regulate within specific boundaries of space.

Postural control requires a series of processes involving various systems, including sensory information for visual sense, vestibular sense and proprioception, cognitive integration, and cerebellum function and sensory-motor feedback system (Woollacott and Shumway-Cook, 2002). Loss of postural control has been recognized as a major health problem in patients with stroke, resulting in a high incidence of fall during rehabilitation (Nyberg and Gustafson, 1997). Appropriate postural control for improved locomotion, gait and balance are the most essential factors for successful stroke rehabilitation (Feigin et al., 1996). In addition, postural control is the best predictor of achievement of independent living and inpatient rehabilitation period (Lin et al., 2001).

Adults who have normal postural control mechanism can integrate sensory information from visual, somatosensory, and vestibular system, and during performance of routine tasks appropriate posture motion is achieved through activation of nervous and musculoskeletal system for maintenance of dynamic postural stability

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(Hsieh et al., 2002).

In general, a stroke patient with abnormal movement pattern and sensory impairment has difficulty in adapting posture according to the changes of gravity and environment. Loss of postural control can lead to disturbance in gait, balance and activities of daily living in patients after stroke (Yelnik et al., 1999).

Therefore, the primary aim of rehabilitation after stroke is to improve gait ability through recovery of postural control. In intervention such as neuro-development treatment (Kollen et al., 2009), task-oriented training (Leroux et al., 2006), and progressive resistance training (Flansbjer et al., 2008) have been devised to promote postural control in patients with stroke. However, the conventional postural control training, which patients might find boring and aimless, leads to a low participation rate and decreased motivation (Mancini et al., 2002). A multi-disciplinary approach for postural control is required for patients to maximize restoring lost function (Sisto et al., 2002). Recently, Virtual reality (VR), which will be helpful in promotion of visual, auditory, tactile input and motivation and motor learning has been applied to improvement of motor skill after stroke (Laver et al., 2011). The number of studies and experimental applications exploiting VR in the rehabilitation environment has shown a rapid increase over the last few years. VR technology uses the principles of motor learning and neural plasticity in order to optimize recovery after brain damage (You et al., 2005). Application of VR is also varied, including gait and balance retraining and upper and lower limb rehabilitation. VR is the most recent intervention in stroke rehabilitation (Merians et al., 2002). VR is a powerful tool in a rehabilitation environment, providing the patients with repetitive practice, feedback information, and motivation for endurance practice (Lehrer et al., 2011).

In the present study, VR combining a real environment with the virtual objects and information provides better reality and immersiveness to the subjects. It provides a safer environment and a motivating context for skill practice. VR contains useful contents can put into practice by maximizing the interaction between real-time and sensory information (Azuma et al., 2001).

Previous studies have demonstrated that improvement of walking ability was achieved from four weeks of VR-based postural control training conducted on a patient with chronic stroke. Both Weghorst and Riess reported that an immobile, helpless person with Parkinson's disease (PD) could walk almost normally by enhancing visual feedback on self-motion using an augmented reality device.

Therefore, the aim of this study is to determine the effect of virtual reality-based postural control training on gait ability in patients with chronic stroke. Our study hypothesis was that addition of VR-based postural control to the conventional physical therapy (CPT) would be more effective for improvement gait ability than CPT alone.

MATERIALS AND METHODS

Participants

Sixteen potential subjects from the stroke units of a hospital were recruited. General characteristics such as age, sex, height, weight, paretic side, and onset time of hemiparesis were obtained from patient interview, and confirmed via review of medical records. Subjects were randomly assigned to the experimental or the control group. Inclusion criteria for subjects were: 1) a diagnosis of stroke at least six months prior to the start of the study; 2) ability to walk independently without use of a walking aids for more than 10 meters; 3) able to understand and follow simple verbal instructions (The Korean version of the Mini-Mental State Examination score greater than 24 of 30); 4) did not have a serious visual impairment or hearing disorder.

The exclusion criteria were; 1) patients with any comorbidity or neurologic or orthopedic disease that could potentially interfere with the study; 2) language difficulty that would affect information reception. The study was approved by the Sahmyook University institutional review board, and all the participants gave their informed consent.

Outcome measures

The study applied a randomized pretest and posttest, and follow up control group. All subjects were evaluated before the start of training (pre-training), at the end of the four-week training (post-training), and at one month after completion of training(follow-up). All evaluations were performed using the GAITRite system for spatiotemporal gait ability and 10 mWT for functional gait ability. After the pretest, the 16 participants were randomly assigned to either the experimental group (n = 8) or the control group (n = 8) by selection of a white or black go stones 1 hr before the start of the pretest.

All 16 participants underwent CPT for 60 min per day, five days per week for a period of four weeks. In addition, subjects in the experimental group underwent AR for 30 min per day, three day per week for a period of four weeks, whereas those in the control group underwent CPT for 30 min per day, three days (Mon, Wed, Fri day, respectively) per week for a period of four weeks.

Conventional physical therapy

The CPT protocol consisted of targeted lower extremity muscle strengthening and static, dynamic balance training, and gait training. A muscle-strengthening exercise for the gluteus medius and quadriceps muscle (esp. rectus femoris) was activated for improvement of eccentric controlled mobility of pelvis. In addition, strengthening of the tibial anterior and GCM was facilitated for improvement ankle dorsiflexion and push off (propulsion) at swing phase, respectively. For static balance training, patients were induced to shift their weight onto the paretic limb by verbal and tactile cues. In addition, in dynamic balance training, patients were induced to shift their weight in the AP and ML planes while performing a functional reaching task: It allowed them to shift their mobile weight during gait training.

Virtual Reality-based postural control program

The virtual reality-based postural control program consisted of a program for improvement of gait ability by visual feedback compared to reference motion scene and reality motion. The program consisted of three stages: trunk stability and pelvic tilting in a supine position (stage 1); in sitting position, trunk upright control and pelvic tilting exercise, and a selective movement between trunk and pelvic (stage 2); lower extremity muscle strengthening exercise and weight bearing under maintenance of trunk stability in a standing position (stage 3). The subjects were provided with the specific scene on HMD showing the simultaneous output, which were recorded postural control training program and actual posture for each subject's on computer hardware and ultra-mobile computer hardware. In advance, the subject saw the pre-recorded reference motion and practiced it again three times. This virtual reality program can allow for control of subject's posture through visual feedback by watching their actual motion.

Temporal-spatial gait ability

Gait ability was measured using an electrical spatial and temporal analysis system (CIR Systems Inc., Clifton, NJ, USA). The GAITRite system provided gait parameters via an electronic walkway connected to the serial port of a personal computer. The standard GAITRite Walkway contained six sensor pads encapsulated in a rolled-up carpet with an active area of 3.66 meters length and 0.61 m width. As a subject walks at a comfortable speed on the walkway without use of an assistive device, the sensors capture each footfall as a function of time and transfer the gathered information to a personal computer for processing into footfall patterns. The subjects were asked to walk on the GAITRite walkway at their self-determined comfortable gait speed three times at interval of 5 min. The GAITRite walkway was placed in the middle of a 10 meters hallway in order to eliminate the effect of acceleration or deceleration. The temporal-spatial parameters recorded were velocity (cm/s), cadence (steps/min), step length (cm), stride length (cm), functional ambulation profile (score) (McDonugh et al., 2001; Van Uden and Besser, 2004).

Functional walking ability

Ten meters walking test was used for evaluate of walking speed of patients with neurological disorders. A total distance of 14 meters was marked using the type of 10 cm width; subjects were measured over the intermediate 10 meters, resulting in a "flying start" eliminating the acceleration and deceleration phase of walking. Walking speed was calculated by the average of three times at a comfortable walking speed. Ten mWT has shown high reliability (ICC = 0.95-0.98) with stroke patients (Rosser and Wade, 2001; Tyson and Connell, 2009).

Statistical analyses

Statistical analyses were processed using the SPSS statistical package. Descriptive statistics were calculated for the Clinical characteristics of each group. Given the small sample size, the baseline demographic characteristics and the pre-training variables between groups were compared using the Mann-Whitney U test for continuous and ordinal variables and Chi-square test for categorical variables. To elucidate the effect of training and follow-up, the differences in each dependent variable within group were analysis by one-way repeated analysis of variance. Change values were calculated for each subject by subtracting the pre-training data from the post-training data or by subtracting the pre-training data from the follow-up data. Multivariate analysis of variance was used to determine difference of mean change values of each dependent variable between groups. The level of significance was set at $P < 0.05$.

RESULTS

General characteristics of subjects

All subjects successfully completed the required test and intervention. Subject characteristics at baseline, including age, sex, height, weight, stroke type and paretic side and time since stroke. No obvious significant differences in the baseline demographic characteristics and the baseline measures of parameters before training were observed between the two groups (Table 1).

Gait ability comparison

After training, for comparison within the group, the experimental group showed significant improvements in all selected outcomes, excluding velocity, cadence at the post-training period and showed significant improvements in all selected outcomes, excepting cadence during the follow-up period. On the other hand, the control group showed no significant improvement in all selected outcomes at post-training and during the follow-up period (Table 2). For comparison between the two groups, only stride length showed significantly greater differences in the experimental group than in the control group during follow-up period. No significant difference in order to outcomes was observed between groups (Table 3).

Table 1. Bsaeline demographic characteristics of the control and experimental groups

Variables	Control (n=8)	Experimental (n=8)	z^a/χ^{2b}	*P*
Age (yr)	48.75±8.81	46.25±6.84	-0.106^a	0.959
Sex (male/female)	5/3	6/2	$.0291^b$	0.590
Height (cm)	163.75±7.09	166.36±3.20	-0.632^a	0.574
Weight (kg)	62.50±8.47	69.50±6.05	-1.791^a	0.083
Stroke type (infarction/ hemorrhage)	4/4	5/3	0.254^b	0.614
paretic side (right/left)	4/4	4/4	0.000^b	1.000
Time since stroke (yr)	11.25±4.53	11.63±4.44	-0.106^a	0.959

Values are mean±standard deviation (range) or frequency; z^a test for age, height, weight, years post-stroke; χ^{2b} test for gender, stroke type, hemiparetic side.

DISCUSSION

The purpose of this study is to determine the effects of Virtual reality-based postural control training on gait ability in stroke rehabilitation. Clinically, gait restoration is considered a primary goal in stroke rehabilitation and levels of functional recovery is used as a criterion (Yang et al., 2008). For this reason, various VR trainings studies have been conducted in an effort to improve ambulation function in patients who have had a stroke. In the present study, VR-based postural control training led to improvement of gait ability in patients with stroke by providing the better reality, so that it aroused their interest. Walker et al., who investigated the effect of a partial body weight supported treadmill based on VR in patients who have had a stroke, reported an increase of approximately 30% in functional gait assessment, and an increase of approximately 38% in over-ground walking speed after train-

Table 2. Comparison of main measures within groups

Measures		Contro l(n = 8)			Experimental (n = 8)		
		Pretraining	Posttraining	Follow-up	Pretraining	Posttraining	Follow-up
Velocity (cm/s)		47.62±31.66	50.59±33.84	49.55±35.59	45.75±19.41	56.94±21.23	60.51±17.10*
Cadence (step/min)		73.56±22.02	75.29±21.31	74.94±23.77	75.05±20.70	80.39±15.95	81.74±11.64
Step length (cm)	P	35.63±12.65	37.46±12.66	36.82±14.56	36.31±9.87	41.50±10.50*	44.74±11.00***
	NP	36.33±10.33	37.41±11.49	36.27±12.06	34.82±10.23	45.58±16.67*	44.07±9.10***
Stride length (cm)	P	71.54±22.56	74.99±23.68	72.97±25.14	71.33±19.36	83.11±19.44*	88.08±20.60**
	NP	71.91±22.21	74.90±23.46	73.36±25.35	71.27±19.01	83.07±19.60*	88.82±19.74***
10 mWT (cm/s)		29.40±13.92	27.46±12.97	27.84±14.07	22.29±11.03	15.55±6.37*	15.29±4.83**

Values are mean±standard deviation. 10 mWT: 10 meter walking test; P: paretic side; NP: non-paretic side.
**P*<0.05, ***P*<0.01, ****P*<0.001, respectively, vs. pretest in within comparison.

Table 3. Comparison of change values of main measures between groups

Measures		Posttraining-pretraining			Follow-pretraining		
		Control (n=8)	Experimental (n=8)	*P**	Control (n=8)	Experimental (n=8)	*P**
Velocity (cm/s)		2.96±6.42	11.19±14.74	0.170	1.93±11.49	14.76±19.34	0.129
Cadence (step/min)		1.73±7.35	5.34±13.97	0.528	1.38±9.83	6.69±18.51	0.485
Step length (cm)	P	1.83±2.39	5.19±5.12	0.115	1.19±7.87	8.44±7.12	0.074
	NP	1.09±3.34	10.76±13.89	0.076	-0.06±4.44	4.01±15.60	0.490
Stride length (cm)	P	3.45±4.63	11.77±10.76	0.064	1.43±11.67	16.74±14.15	0.033*
	NP	3.00±5.36	11.81±10.41	0.052	1.45±11.95	17.56±13.20	0.023*
10 mWT (cm/s)		-1.9±3.09	-6.74±6.76	0.089	-1.56±4.43	-7.00±7.28	0.092

Values are mean±standard deviation. P: paretic side; NP: non-paretic side. *Significance level for between-group comparison.

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ing. In their neuroimaging study, VR intervention can induce cortical reorganization of the neural locomotor system. There researchers concluded that VR has a positive effect on motivation and function in patients who have has a stroke. In our study, all selected parameters, excepting cadence, showed significant improvement in the group after postural control training based on VR. Use of VR systems after stroke can lead to improvement in motor retraining and learning by visual feedback. A various visual feedback provided by VR is considered essential for effective learning of complicated motor tasks, and training activities that closely mimic real-world tasks have been shown to maximize the training effects (Walker et al., 2000). In addition, various forms of visual feedback have long been used for improvement of balance and gait symmetry of stroke patients and found to be effective by providing information on different aspects of the targeted task (Winstein et al., 1989). Thus, it is hypothesized that the postural control training based to VR contributed to visual feedback and resulted in greater improvement compared with the control group. However, only stride length in follow-up of temporo-spatial gait parameters showed greater improvement in the experimental group than in the control group. Because at wearing HMD was induced for inconvenience and dizziness, and the reference motion and real-time motion scene was occurred in temporal delay, information of visual feedback was didn't a enough relay. Although, there results suggest that augmented reality based postural control training is more effective at improving gait ability. In conclusion, we believe that the postural control training based on VR may be used as an intervention for increasing of gait ability in patients who have has a stroke. In addition, a virtual reality system was found to have potential as a device for use in assessment and training in stroke rehabilitation.

The Virtual reality-postural control training has been shown that to improved gait ability in patients after stroke. In particular, the experimental group made improvements in their gait ability, but significant has been no differences between the two group. A larger trial is required to determine the differences in gait ability between the two groups. However, our results were confirms the effects of intervention and justify further clinical trials.

Findings of this study demonstrated that the virtual reality training has positive effects on gait ability but has some limitation. First, the sample size was small. Second, study participants were limited to patients who have has chronic stroke with high function (participants who did not have communication, or visual, auditory impairment, and patients who walk without use of a walking aid). Therefore, these results cannot be generalized to all patients with stroke. Subsequently, studies using a larger sample size and various types of stroke should be conducted. In addition, development of new HMD equipment is needed.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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