

A pilot study of augmented reality-based postural control training in stroke rehabilitation

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Objective: The purpose of this study was to determine the effects of Augmented Reality-based Postural Control (ARPC) training on balance and gait function in patients with stroke.

Design: Single-blind randomized controlled trial.

Methods: Twenty participants who experienced a stroke were enrolled in the study and randomly assigned to the ARPC (n=10) or control group (n=10). Subjects in both groups received conventional physical therapy for 60 min per session, 5 days per week, for 4 weeks. In addition, subjects in the ARPC group received ARPC training for 30 min per day, 3 days per week, for 4 weeks. The participants watched established normal postural control patterns on a head-mounted display and repeated the movements in ARPC training. Outcome measurements were assessed using the Berg Balance Scale (BBS) and 10-Meter Walk Test (10MWT) before and after 4 weeks of training.

Results: Of the 20 randomized participants, only 18 completed the 4-week training program. The ARPC group showed significant improvement in the BBS and 10MWT after training ($p<0.05$). Meanwhile, the control group did not exhibit improvement in either variable. In addition, the ARPC group showed significantly greater improvement than the control group in the 10MWT ($p<0.05$), whereas no significant difference was observed between the groups for the BBS.

Conclusions: The results of this study confirmed the benefits of ARPC training on dynamic balance and functional gait ability. Additionally, this study may provide evidence supporting the use of an ARPC training program for improving balance and gait ability in patients after a chronic stroke.

Key Words: Balance, Gait, Postural balance, Stroke, Virtual reality

Introduction

Stroke causes neurological damage, altering walking and functional movement. Approximately two-thirds of hospitalized patients who experienced a stroke cannot walk [1]. The majority of stroke survivors experience walking difficulty that restricts community mobility [2], whereas some patients with recovered walking ability after a stroke continue to display limited endurance and reduced ability to adapt to tasks and environmental constraints [3,4]. Several studies identified gait deviations that are consistent with impaired gait patterns in the paretic limb and related compen-

satory strategies [5,6]. This compensatory action restricts functional walking recovery [7]. Therefore, improving walking ability is one of the most important rehabilitation goals of patients after a stroke [8].

In addition, compared to a normal person in the same age group, an individual who experienced a stroke exhibits increased body sway because of reduced stability. In particular, decreases in the movement of the center of gravity due to asymmetric weight bearing result in postural imbalance, which markedly compromises a patient's ability to walk after a stroke [9]. Postural problems are also common in patients after a stroke, and they can limit the rate of recovery of

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walking and functional independence [10]. Loss of postural control has been recognized as a major health problem in patients after a stroke, resulting in a high incidence of falls during rehabilitation [11]. Appropriate postural control for improved locomotion, gait, and balance is the most essential factor for successful stroke rehabilitation [12].

Clinical interventions applied to help patients recover their impaired walking ability and balance via postural control after a stroke include aquatic exercise [13], treadmill walking [3], task-oriented training [14], rhythmic auditory stimulation [15], and dual motor task training [16]. Recently, the application of virtual reality systems in stroke rehabilitation has attracted considerable attention [17]. Regarding the virtual reality-based rehabilitation of postural control, a number of systems that create virtual realities with 2D and 3D graphics using devices such as head-mounted devices and the Cave Automated Virtual Environment system have been developed [18].

Virtual reality systems that enable the acquisition of various skills in simulated environments similar to reality are being developed as motor functions measurement and therapeutic tools [19]. Virtual reality systems utilize interactive simulations that allow users to experience situations as similar to reality as possible via computer hardware and software [20]. In addition to virtual reality, augmented reality systems that blend computer graphic images into real scenes are being developed and applied in various fields. Augmented reality is a type of virtual reality, and it features computer interface technology that merges a graphic entity generated by a computer with the real world to provide additional information similar to what the user views in the real world.

In previous studies, virtual reality combined with exercise was found to improve Berg Balance Scale (BBS) and 10-Meter Walk Test (10MWT) performance [21], and You *et al.* [22] observed improvement in locomotion and motor assessment scores compared with the control after training with a virtual reality system that included stepping up and down, dodging a virtual shark, and snowboarding. In other studies, virtual reality-based balance training improved balance [17] as well as walking speed and community walking time [23] in patients who experienced a stroke.

By maximizing the interaction between the user's senses and the real world, augmented reality provides a user with information that both helps him/her accomplish tasks in the real world and enhances a sense of immersion and reality compared with previous postural control exercise [24,25].

Despite the high predictive value of postural control and virtual reality concerning functional outcomes after stroke, the determinants of augmented reality combined with postural control have not yet been extensively studied in patients after a stroke.

Therefore, the purpose of this study was to investigate the effect of Augmented Reality-based Postural Control (ARPC) training on the dynamical balance and functional gait ability of patients who experienced a stroke.

Methods

Subjects

Twenty potential subjects from the stroke unit of a rehabilitation hospital or Bobath Memorial Hospital were recruited. Participants were randomly assigned to either the ARPC (n=10) or control group (n=10) via simple randomization which selection of a white or black stone before the start of the pretest: black stone were assigned to ARPC group and white were assigned to control group. The inclusion criteria for participants were a diagnosis of stroke at least 6 months prior to the start of the study and the ability to walk more than 10 m independently without using any assistive device. Participants were excluded if they had any musculoskeletal disease that interferes with balance and walking performance, other neurological problems such as Parkinsonism or vascular dementia, and communication and cognitive deficits as tested by the Korean-Mini Mental State Examination (score < 24 of 30).

The present study was approved by the Sahmyook University Institutional Review Board (SYUIRB 2011-005). All participants were given an explanation of the objective of the study and its requirements, and all those who participated provided their written informed consent.

Procedures

This study was a single-blind, randomized, controlled trial. The experimental group underwent ARPC training to improve balance and gait ability, and the control group completed a conventional physical therapy program.

The ARPC environment was implemented using a server computer mounted with a camera and an Super Video Graphics Array head-mounted display (HMD) (i-visor, fx601; Dae-Yang E&C Co., Daejeon, Korea, 2008) consisting of an 800×600 resolution display connected to an ultra-mobile personal computer (NT-Q1U; Samsung, Tianjin, China, 2007) for the patients. The two computers were

equipped for wireless signal exchange. The virtual reality used in the ARPC program included videos of postural control training instructing patients to perform ideal postural control motions. The HMD was designed to show two views. The modeled movement was shown on one side, and the movement was shown on the other side. The patient could watch the modeled movement and listen to a recorded sound to compare the normal movement with his/her own movement (Figure 1). The ARPC training was designed to be adjustable to match the subject's ability to minimize substitution and ensure safety. In addition, after turning on the HMD, the patients were given 5 min to familiarize themselves with the ARPC program before the start of the experiment [25,26]. Once the participants matched more than 80% of the normal postural control patterns, they moved on to the next step.

Fundamentally, the ARPC program consisted of exercise performed in three positions, namely lying, sitting, and standing. First, for the lying position, core exercise was performed in a supine position, and after trunk rotation exercise using upper extremity movements, the patients transitioned to a seated position (Figure 2A). Second, in the seated position, the patients performed segmented movement of the trunk and pelvis and weight-bearing exercise using functional tasks on stable or unstable ground (Figure 2B). Third, in the standing position, the patients performed a squat exercise to strengthen the muscles of the lower extremities and single-leg exercise by controlling the trunk and pelvis (Figure 2C). In addition, the participants performed task training using an exercise ball to increase dynamic balance [27,28].



Figure 1. The augmented reality device head gear.

Outcome measures

In both groups, balance was assessed using the BBS, and functional gait ability was evaluated using the 10MWT, both before and after the intervention. The BBS was developed to measure balance among people with impaired balance function by assessing the performance of functional tasks. It is an instrument with excellent intra-rater and inter-rater reliability (intraclass correlation coefficient=0.99 and 0.98, respectively), and it is used to evaluate the effectiveness of interventions and provide quantitative descriptions of functional ability in clinical practice and research. The BBS consists of 14 items, each of which is scored on a scale of 0-4 points and summed to provide a total score between 0 and 56 points. A higher score indicated better balance ability [29,30].

The 10MWT is a commonly used measure for assessing walking speed. It requires a 14-m path that includes 2 m each for acceleration and deceleration. To minimize the effects of acceleration and deceleration, walking speed was measured over the middle 10 m of the 14-m walkway. The subject was asked to walk 10 m from a standing position at his/her preferred speed. Time was recorded using a stopwatch, and the number of steps taken was counted. The test was conducted three times, and the average time was used for the analysis. The inter-rater and intra-rater reliability were high ($r=0.89-1.00$) [31,32].

Data analysis

The SPSS Statistics 17.0 program (SPSS Inc., Chicago, IL, USA) was used for statistical analyses. The Shapiro-Wilk test was used to determine the general properties and variables of the subjects. A paired t-test was used for comparisons of the pretest and posttest results within each group, and an independent t-test was performed to analyze changes of dependent variables between the groups. $p < 0.05$ denoted statistical significance.

Results

Of the 20 randomized participants, 18 completed the 4-week training program. Regarding patient withdrawal in the ARPC group, one participant was discharged from the hospital, and another participant was excluded due to low participation rates ($< 80\%$). The general characteristics of the subjects in the ARPC group included a mean age of 47.38 years, a mean height of 164.25 cm, a mean weight of



Figure 2. Postural control training program. (A) Trunk control training involving reaching with the arm on the paretic side. (B) Anterior and posterior tilting control training of the pelvis in the seated position. (C) Weight-bearing training on the paretic side using a single-leg standing position.

Table 1. Demographic characteristics and baseline data of the subjects (N=18)

	ARPC group (n=8)	Control group (n=10)	<i>t/x</i>	<i>p</i>
Sex (male/female)	6/2 (75/25)	6/4 (60/40)	0.450	0.502
Age (y)	47.38 (13.44)	53.50 (12.43)	-1.003	0.331
Weight (kg)	68.25 (8.08)	62.30 (10.93)	1.281	0.218
Height (cm)	164.28 (5.90)	165.40 (7.69)	-0.348	0.732
Time since stroke (mo)	11.38 (3.96)	11.30 (4.86)	0.035	0.972
Side of lesion right/left	3/5 (37.5/62.5)	7/3 (70/30)	1.901	0.168
Type of stroke (infarction/hemorrhage)	5/3 (62.5/37.5)	6/4 (60.40)	0.012	0.914
BBS (score)	44.75 (5.45)	41.30 (5.66)	1.307	0.210
10MWT (cm/s)	54.71 (21.11)	42.17 (23.49)	1.176	0.257

Values are presented as n (%) or mean (SD).

ARPC: Augmented Reality-based Postural Control program, BBS: Berg Balance Scale, 10MWT: 10-Meter Walk Test.

Table 2. Comparison of balance and gait parameters within and between the groups (N=18)

		ARPC group (n=8)	Control group (n=10)	<i>t^b</i>
BBS (score)	Pre	44.75 (5.45)	41.30 (5.66)	
	Post	49.88 (6.50)	43.10 (6.08)	
	Pre - Post	-5.13 (3.44)	-1.80 (4.02)	-1.855
	<i>t^a</i>	3.75*	2.445	
10MWT (cm/s)	Pre	54.71 (21.11)	42.17 (23.49)	
	Post	76.32 (26.92)	48.13 (32.53)	
	Pre - Post	-21.61 (10.72)	-5.97 (12.61)	-2.791**
	<i>t^a</i>	-5.703*	-1.496	

Values are presented as mean (SD).

ARPC: Augmented Reality-based Postural Control program, BBS: Berg Balance Scale, 10MWT: 10-Meter Walk Test.

^aPaired t-test, ^bIndependent t-test.

* $p < 0.05$, ** $p < 0.01$.

68.25 kg, and a mean onset time of 11.38 months, compared to values of 53.50 years, 165.40 cm, 62.30 kg, and 11.30 months, respectively, in the control group. There were no significant differences in these variables between the groups before training (Table 1).

Table 2 presents the clinical outcomes (BBS and

10MWT) of the participating patients. The ARPC group showed a significant improvement in the BBS score from 44.75±5.45 before treatment to 49.88±6.50 after treatment ($p < 0.05$), whereas the 10MWT speed was improved from 54.71±21.11 cm/s before treatment to 76.32±26.92 cm/s after treatment ($p < 0.05$). Conversely, neither value was sig-

nificantly improved by treatment in the control group.

The ARPC group exhibited significantly greater improvement than the control group in the 10MWT speed ($p < 0.05$), whereas no significant difference was found between the groups for the BBS score.

Discussion

The purpose of this study was to investigate the effects of ARPC training on balance and gait of patients who experienced a stroke.

In previous research on the BBS, Noh *et al.* [13] assigned 25 patients who experienced a stroke to either an experimental group with hydrotherapy treatment or a control group with general physical therapy. According to their result, the BBS score was significantly different between the groups because of a 7.6-point improvement in the hydrotherapy group ($p < 0.05$). Srivastava *et al.* [33] utilized a force plate with visual feedback for 40 subjects who experienced a stroke for balance training. Their result illustrated that the BBS score was significantly improved from 34.94 points before training to 46.85 points after training ($p < 0.05$). Although six subjects withdrew from the study, the BBS score increased from 34.93 points before training to 48.44 points after training, illustrating a significant difference in a follow-up test after 3 months ($p < 0.05$). In this study, ARPC training significantly increased the BBS score ($p < 0.05$). In a study reported by Eng *et al.* [34], patients who previously experienced a stroke felt most comfortable when they moved their weight laterally. However, the subjects felt the most discomfort when they moved their weight anteriorly. Patients who experienced a stroke have difficulty with antero-posterior weight bearing, and an improvement of weight bearing affects the BBS score [13]. More specifically, an increase of the BBS score is associated with improvements of muscular strength in a paralyzed lower limb [35]. In this study, the improvement of the BBS score was affected by the muscular strength of the paralyzed lower limb. In the study, the participants performed various activities, including side-lying exercises to improve the stability and mobility of the pelvis, trunk rotation to increase core stability, lateral weight bearing via posture movement from side lying to sitting, anteroposterior weight bearing with selective movement of the pelvis while sitting, and core stability and postural tone exercises while standing to improve the muscular strength of the paralyzed lower limb. According to our results, ARPC improved the dynamic balance of patients

who experienced a stroke.

This study investigated the effect of ARPC training on functional gait, with a change of gait velocity determined by the 10MWT. In previous research using this test, Regnaud *et al.* [36] evaluated treadmill gait training for 20 min in 10 patients who experienced a stroke via weight bearing on the non-paralyzed ankle. Their result revealed a significant increase in gait velocity from 0.33 m/s before training to 0.39 m/s after training ($p < 0.05$). In a follow-up test, gait speed was maintained at 0.42 m/s in the treadmill gait training group ($p < 0.05$). Yang *et al.* [23] randomly assigned 24 patients who experienced a stroke to an experimental group consisting of virtual reality-based treadmill training or a control group consisting of treadmill training. Their results indicated a significant increase in the 10MWT speed in the experimental group (from 0.69 m/s to 0.85 m/s, $p < 0.05$), and the speed was maintained at 0.86 m/s after 1 month in a follow-up test ($p < 0.05$). Although the training method used in this study significantly improved gait speed in the 10MWT in the experimental group ($p < 0.05$), no significant difference was observed in the control group. Gait velocity was associated with the severity of stroke, asymmetry of step length [5], and a compensative mechanism for correction of a defect [37], and dynamic balance as assessed by the BBS was associated with the 10MWT, cadence, and step length [22]. In this study, ARPC training included items that led to increased weight bearing by the non-paralyzed lower limb and the accomplishment of learning of sequential gait. Increases in dynamic balance, gait velocity concerning spatiotemporal variables, and step length were helpful. It appears that ARPC training increased weight bearing by the paralyzed lower limb and postural control during walking. These changes may have promoted significant improvements in the 10MWT. Based on these results, the functional gait ability of patients who experienced a stroke could be enhanced by ARPC training.

Some of the limitations of this study include external validity, or the generalizability of the study. There were only 18 participants who participated in the complete study, and some participants felt dizziness when they saw the screen with wearing HMD gear. Therefore, further studies should be considered those limitations including sample size and sufficient time to offset dizziness.

This study investigated the effect of ARPC training on the balance and gait of patients who experienced a stroke. The results of this study indicated that ARPC improved dynamic balance and functional gait ability. In addition, the program,

which featured real-time feedback support, appears to be more effective than video games such as the Nintendo and X-box. These results indicate that ARPC training is suitable for patients who experienced a stroke. Further research is needed to develop and propagate diverse ARPC training programs, and we will need to compare real-time feedback systems with a variety of game methods.

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