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Original Article

Effects of virtual reality-based ankle exercise on the dynamic balance, muscle tone, and gait of stroke patients

Changho Yom[1)], Hwi-young Cho[2)], ByoungHee Lee[1)]*

[1)] Department of Physical Therapy, Sahmyook University: 815 Hwarang-ro, Nowon-gu, Seoul 139-742, Republic of Korea
[2)] Department of Physical Therapy, College of Health Science, Gachon University, Republic of Korea

Abstract. [Purpose] The purpose of this study was to investigate the therapeutic effects of virtual reality-based ankle exercise on the dynamic balance, muscle tone, and gait ability of stroke subjects. [Subjects and Methods] Twenty persons who were in the chronic stroke subjects of this study and they were included and assigned to two groups: experimental (VRAE; Virtual Reality-based Ankle Exercise group) (n=10) and control groups (n=10). The VRAE group performed virtual environment system ankle exercise, and the control group watched a video. Both groups performed their respective interventions for 30 minutes per day, 5 times per week over a 6-week period. To confirm the effects of the intervention, dynamic balance, muscle tone, and spatiotemporal gait were evaluated. [Results] The results showed that the dynamic balance and muscle tone was significantly more improved after the intervention compared to before in the VRAE group (dynamic balance: 5.50±2.57; muscle tone: 0.90±0.39), and the improvements were more significant than those in the control (dynamic balance: 1.22±2.05; muscle tone: 0.10±0.21). Spatiotemporal gait measures were significantly more increased in the paretic limb after the intervention compared to before in the VRAE group and the improvements were more significant than those in the control group. [Conclusion] This study demonstrated that virtual reality-based ankle exercise effectively improves the dynamic balance, muscle tone, and gait ability of stroke patients.

Key words: Stroke, Virtual reality-based ankle exercise, Gait

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INTRODUCTION

Functional weakness of the lower extremity due to stroke is caused by muscular weakness and by decreases in muscular endurance, stability of the joint, and loss of proprioceptive sense[1)]. Stroke patients have difficulty in movement control because of the muscular weakness, abnormal tonus of the muscle, and abnormal movement patterns. These changes are related to an increase in their postural sway during static standing posture[2)]. Among these, balance problems delay the improvement of independent activities of daily living (ADLs) and alter the standing or walking posture[3)].

Because of the decline in balance ability, compensation movements occur in each part of the body. This makes the patients consume more energy compared than healthy subjects, and an inefficient walking pattern develops[4)]. The decreased gait and balance abilities of stroke patients may be an important factor that limiting ADLs, reducing independence, and as a result, brings restricting participation in the local community[5, 6)]. In addition, the patients have difficulty in standing up without help, and negotiating obstacles start to emerge when walking[7)]. For these reasons, walking or balance training is important for stroke patients. The motor function of the ankle joint greatly affects balance and walking abilities.

When stroke occurs, flaccidity appears during the early stage; however, as time passes, flaccidity is accompanied by spasticity. Spasticity occurs in 90% of stroke patients. It limits voluntary movement because of the stiffness in the muscles. In particular, spasticity of the ankle plantarflexor disturbs static and dynamic balance problems as well as a normal gait pattern[8)]. Dorsiflexor weakness accompanied with spasticity is reported to be the factor that is most dangerous for falling[9)].

Virtual reality has been used to increase muscle strength, balance, gait function, and motor recovery during stroke rehabilitation[10)]. Virtual reality provides interest, fun, and motivation[11)], and it encourages active participation in active treatment to increase the needs for exercise[12)]. Additionally, in a virtual reality environment, the patient receives sound and sight feedbacks to enhancing the effects of exercise training[13)]. Moreover, focusing on a virtual reality environment is effective at increasing concentration[14)]. Virtual reality-based ankle exercise is effective for ankle movement, improving

*Corresponding author. ByoungHee Lee (E-mail: 3679@syu.ac.kr)

the plantar-flexor muscles coordination, and increasing gait speed[15]. However, it is unclear whether virtual reality-based ankle exercise improves gait and balance abilities as well as muscle tone in patients with a neurological disorder. Therefore, the aim of this study was to investigate the effects of virtual reality-based ankle exercise on the dynamic balance, muscle tone, and gait ability of stroke patients.

SUBJECTS AND METHODS

The study participants were chosen from among 26 stroke patients who were undergoing physical therapy at a rehabilitation hospital. Participant selection criteria were: those who were hemiparesis due to stroke with onset of >6 months, the ability to follow verbal instructions, the ability to communicate at a certain level, and a score of >24 points on the Mini-Mental State Examination-Korean (MMSE-K). Patients were excluded if they had diplegia or visual or vestibular impairments. All patients who participated in this trial provided their signed written consent after receiving a full explanation of the expected result and side effects of the intervention fully explained. This study was approved by the Sahmyook University Institutional Review Board. The general characteristics of the subjects in the experimental group were as follows: a sex of 6 male and 4 female; a mean age of 64.60 years; a mean height of 166.20 cm; a mean weight of 61.20 kg; and a mean time since stroke onset of 11.14 months; and had right-side hemiplegia in 6 cases and a left-side hemiplegia in 4 cases. Those of the subjects in the control group had as follows: a sex of 5 males and 5 females; a mean age of 78.10 years; a mean height of 157.40 cm; a mean weight of 52.50 kg; a stroke onset of 11.63 months; and had right-side hemiplegia in 8 cases and a left-side hemiplegia in 2 cases. There were no significant differences between the two groups.

The general information including sex, age, weight, height, academic background, and medical information related to the stroke lesion were obtained from the medical records of the 26 hospitalized stroke patients. Four patients withdrew from the study. Twenty-two participants were randomly assigned to the experimental (n=11) and control groups (n=11). Participants in the experimental group performed a virtual environment system ankle exercise for 30 minutes a day, 5 times a week for 6 weeks. Subjects in the control group watched a documentary in the same condition as the experimental group. Before the intervention, all the participants received conventional physical therapy for 30 minutes per day, 10 times per week over a 6-week period. One subject in each group withdrew for personal reasons during the experiment. Dynamic balance, muscle tone, and gait ability were blindly assessed before and after the intervention.

The virtual reality-based ankle exercise (VRAE) was composed of 4 exercise programs: exercising on the floor, exercising on a balance board, exercising on a cushion ball, and standing on one foot. All the subjects maintained a standing position for the exercises. To create the virtual reality environment, we used a virtual reality-based ankle exercise program, notebook computer (X-note 280; LG, Korea), beam projector (PLC-XW55; Sanyo, Japan), and screens.

Virtual reality was projected onto a screen that is 2,200 mm and 1,900 mm screen positioned 3 m in front of the subjects via a 1,024 × 768 XGA type high quality beam projector. To maintain the movement speed of the subject, the keyboard function was used to change the speed of the virtual reality environment[16]. This helped maintain the subject's speed and the actual speed for parallelism. The screen was installed, and the beam projector was used for people and computers to interface through the camera, which installed equipped on the computer. One screen showed the virtual reality-based ankle exercise program while the other screen showed the target. Each exercise program was composed of a full shot, side shot, and the ankles. The screen changes with time in order to raise the participants' concentration. The participants could visualize all sides, which allowed the participants to modify their own posture. This allowed them to participate in the exercises using the correct posture. The target participated in the exercises progressed in the order from easy to hard. The four virtual reality-based ankle exercises trained the subjects in a back and forth movement of the ankles without any movement from the body or hip joints. The subjects used a gait belt for safety. To minimize instability, a therapist was stood at the beside to help the subject. All the exercise emphasized ankle stabilization for maintaining posture during the movement or performance. The subjects performed each virtual reality-based ankle exercise for 5 minutes. After each exercise, the subjects took 2-minute breaks to minimize tiredness. The control group watched an environmental documentary irrelevant to ankle exercise.

The timed-up and go (TUG) test was used to assess the subjects' dynamic balance function. The TUG test is frequently used which assesses fall risk, mobility, and dynamic balance in clinics[17]. The intra- and inter-reliability have been reported as $r = 0.99$ and 0.99, respectively[18].

To assess the muscle tonus, the Modified Ashworth Scale (MAS) and Tardieu scale were used. The MAS is the most frequently used method for assessing muscle tonus (spasticity) in clinics, and it measures abnormality in tone or the resistance to passive movement or stretch of a particular muscle[19]. The Tardieu scale can measure muscle spasticity by testing the response of the muscle to stretch at 3 types of velocity (i.e., slow as possible, speed of the limb segment when falling, and as fast as possible)[20].

The GAITRite (CIR System Inc., Clifton, NJ, USA) was used to measure spatial and temporal parameters of gait ability. The collected information on the time and spatial variables was analyzed by the GAITRITE GOLD, version 3.2b software (CIR System Inc.). The measurement was performed 3 times, and to eliminate the fatigue of walking, the subjects took a 30 second rest after walking once. The temporal parameters (velocity and cadence) and the spatial parameters (step length, stride length, stance time percentage, swing time percentage, and double limb support percentage) were measured.

SPSS, version 18.0 (IBM Corp., Armonk, NY, USA) was used for all the statistical analyses. The data showed normal distribution using as assessed by following the Kolmogorov-Smirnov test. The paired t-test and Wilcox-signed rank test

Table 1. Changes of spasticity and dynamic balance ability (N=20)

	Values				Change values	
	VRAE group (n=10)		Control group (n=10)		VRAE group (n=10)	Control group (n=10)
	Before	After	Before	After	Before-after	Before-after
MAS (score)	1.67 ± 0.33	0.75 ± 0.54*	1.70 ± 0.34	1.60 ± 0.45	0.90 ± 0.39‡	0.10 ± 0.21
Tardieu scale (score)	2.20 ± 0.78	1.10 ± 0.73*	2.40 ± 0.69	2.20 ± 0.78	1.10 ± 0.31‡	0.20 ± 0.42
TUG (sec)	24.59 ± 14.42	19.09 ± 12.73*	35.96 ± 16.50	34.74 ± 16.20	5.50 ± 2.57†	1.22 ± 2.05

Values are expressed as mean ± SD. VRAE: Virtual-reality based ankle-exercise group; MAS: Modified Ashworth Scale; TUG: Timed-Up and Go test. *$p<0.05$, significant difference within group, † $p<0.05$, ‡ $p<0.001$, significant difference between groups

Table 2. Changes of temporal and spatial gait ability (N=20)

	Values				Change values	
	VRAE group (n=10)		Control group (n=10)		VRAE group (n=10)	Control group (n=10)
	Before	After	Before	After	Before-after	Before-after
Velocity (cm/sec)	51.03 ±20.76	65.65 ± 22.57**	43.13 ± 18.93	46.87 ± 18.36*	14.62 ± 3.80†	3.74 ± 0.65
Cadence (step/sec)	86.58 ±13.53	103.46 ± 12.45**	74.37 ± 18.93	83.60 ± 22.92*	16.88 ± 4.82†	9.23 ± 4.99
Step length (cm)	32.28 ± 11.78	43.26 ± 14.48**	27.90 ± 7.41	31.83 ± 7.77*	11.96 ± 4.05†	3.96 ± 0.69
Stride length (cm)	68.95 ± 21.81	78.27 ± 24.08*	58.51 ± 15.55	61.27 ± 15.71*	9.32 ± 2.99†	2.75 ± 0.78
Stance time percentage (%)	70.40 ± 7.00	63.72 ± 3.88**	72.50 ± 7.34	71.03 ± 7.28	6.68 ± 5.20‡	1.47 ± 0.70
Swing time percentage (%)	29.60 ± 7.00	36.38 ± 3.79**	27.51 ± 7.35	28.17 ± 7.29*	6.78 ± 5.26†	0.66 ± 0.67
Double limb support percentage (%)	36.04 ± 9.71	29.82 ± 9.24*	45.70 ± 15.05	43.45 ± 15.21	6.22 ± 2.06†	2.25 ± 1.70

Values are expressed as mean ± SD. VRAE: Virtual-reality based ankle-exercise group, *$p<0.05$, **$p<0.01$, significant difference within group, † $p<0.05$, ‡ $p<0.01$, significant difference between groups

were performed to compare the dependent variables within the groups before and after training. The independent t-test and Mann-Whitney U test were used to compare the differences in the dependent variables between the groups. A Results <0.05 were considered statistically significant.

RESULTS

The virtual reality-based ankle exercise was significantly improved in the MAS, Tardieu scale, and TUG test ($p < 0.05$) results; however, the control group did not show any significant changes after the intervention. There were also significant differences found between the groups in post-test values ($p < 0.05$) (Table 1).

Velocity, cadence, step length, stride length, stance time percentage, swing time percentage, and double limb support percentage had significantly improved after the intervention in the experimental group ($p < 0.05$). In addition, velocity, cadence, step length, stride length, and swing time percentage had significantly improved after the intervention in the control group ($p < 0.05$). There were also significant differences in the post-test value of these variables between the groups ($p < 0.05$) (Table 2).

DISCUSSION

Stroke individuals have a high risk of falling. Among the risk factors of falling, a balance deficit and abnormal muscle tone are the chief factors, and these elicit asymmetric posture, reduction in appropriate weight distribution, and reduce in sensory input during the standing position in stroke survivors. Thus, the management of balance and muscle tone is regarded as important in stroke rehabilitation.

In our study, a virtual reality-based ankle exercise effectively improved dynamic balance. This finding is similar to that of a previous study of the tibialis anterior and soleus, muscles essential for dynamical balance, which these muscles showed an increase in alternative vitality after performance of the virtual reality-based ankle exercise[21)]. This is because the postural sway in the anterior to posterior direction decreased. In addition, during the primary postural disturbance, the ankle moves advances before the movement of the hip joint, which is well used by stroke patients. Because the movement of the hip joint decreases, demands on the body's balance control most likely increases during single-leg support. Lastly, this exercise intervention increased proprioception activation and movement of the ankles which we assume improved the dynamic balance was improved.

Muscle tonus is the resistance of muscles in the passive stretch during resting condition, and it is also means the continuous and passive partial contraction, which helps to maintain the body's posture[22)]. In previous research into virtual reality's influence on muscle tonus, the virtual reality-based ankle and leg exercises effectively increased the stroke patient's gait velocity, ankle movement, and muscle strength of the soleus[15)]. Similarly, in our study, spasticity decreased by 55% based on the MAS, and by 50% based on the Tardieu scale. For patients with an upper motor neuron disease, a decrease in muscle tonus increases the speed of adaptation for the changes in the environment. Moreover, because of a decrease in stretch reflex, the threshold for the phasic reflex is raised to reduce for future reflexes. In this study, because of the increase before and after the ankle movement increased after the intervention, the virtual reality-based ankle exercise increased the muscle strengths of the tibialis anterior and triceps surae and also decreased spasticity. This study proved that the virtual reality-based ankle exercise is effective at reducing spasticity. Therefore, this exercise is effective at decreasing spasticity following stroke.

Gait is the movement of transferring from one place to another, and it is an essential element for the performance of ADLs and functional activities[23]. The gait of stroke patients is different from that of normal people, because stroke patients' temporal and spatial walking abilies movements are decreased[24]. Previous studies have reported that virtual reality gait training or augmented reality-based treadmill training improved stroke patients' walking speed and community walking time, as well as cortical reorganization associated with locomotion in patients with stroke[25, 26]. In this study, the virtual reality-based ankle exercise effectively improved gait velocity. Through visual feedback from the visual sense and proprioception, this exercise accelerated the reorganization of the cerebral cortex's neural circuits for accelerating nerve reorganization[27]. Additionally, through vitalization of the cerebral cortex and central nerve territories, exercises were re-learned, and the movement of the ankles increased. And The gait velocity probably increased because of the improvement in dynamic balance due to the improvement of ankle movement and the reduction of spasticity in the soleus during the swing phase term, which is a factor that affects walking speed. In previous studies, the 6-minute walking test was used as an evaluation tool. However, this study used the GAITRite for a more objective evaluation.

In Dunsky's study, they provided a home-based motor imagery gait training program for chronic stroke patients, and reported that there were significant increases in stride length, cadence, and single limb support time of the affected lower limb and a decrease in the double limb support time[28]. Similarly, our findings demonstrated that the virtual reality-based ankle exercise effectively improved the cadence, step length, stride length, and swing time percentage of stroke patients. Virtual reality-based exercise allows patients to recognize movements by participating in a virtual reality that is similar to their actual environment. Moreover, we consider that ankle movement control increased (in the paralyzed leg) in order to maintain the body's balance for executing the task in the virtual reality program.

The virtual reality-based ankle exercise reduced walking time because of the increase in the gait velocity of the affected side, and it also increased security and stride length which reduced the time of the double limb support time. Thus, the virtual reality-based ankle exercise had a great influence on the subjects' gait ability.

This study did not investigate the correlations of temporal and spatial gait ability; thus, it is not clear whether the virtual reality-based ankle exercise can influence their 2 relations. In addition, the amount of increase in walking ability and decrease in muscle tonus that was elicited should be discussed, and the correlations should be measured. The virtual reality-based ankle exercise is effective at improving walking ability.

This study had some limitations to this study. First, the sample size was relatively small. Second, the long-term effects of our intervention and the follow-up were not clear. Thus, further studies need to confirm our findings using a large sample or a long-term application of the intervention.

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