J. Phys. Ther. Sci.
24: 755–762, 2012

Effects of Augmented Reality with Functional Electric Stimulation on Muscle Strength, Balance and Gait of Stroke Patients

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Abstract. [Purpose] This study examined the therapeutic effects of functional electrical stimulation (FES) with augmented reality (AR) during treadmill gait training on the muscle strength, balance and gait of stroke patients. [Subjects] Twenty-eight subjects with chronic stroke were divided into three groups: FES with AR during treadmill gait training (AR-FES group, n=9), gait training with FES on a treadmill (FES group, n=10), treadmill group (n=9). [Methods] All these groups were given 8 weeks of gait training 3 times a week, 20 minutes per session. To identify the effect of AR-FES, muscle strength was measured with a dynamometer, and the Berg balance scale (BBS) and timed upandgo (TUG) test were also assessed. [Results] The muscle strength increased significantly in the AR-FES and FES groups. The BBS showed a significant increase in all groups but there was no difference among the three groups. The TUG also improved significantly in all groups. The AR-FES group showed a better result than the treadmill group. [Conclusion] Although more study of gait training with FES on a treadmill and gait training with AR-FES will be needed, AR-FES improved the muscle strength and gait of stroke patients. These results suggest a variety of applications in clinical trials of conservative therapeutic methods.
Key words: Stroke, Augmented reality, FES

(This article was submitted Mar. 13, 2012, and was accepted Apr. 11, 2012)

INTRODUCTION

Stroke causes cognitive functional disorders including sensory and motor ability loss[1)], as well as difficulties in balance control[2)]. Moreover, postural sway is increased while standing up, and weight bearing on the unaffected side is also increased, resulting in a decrease in stable weight shifting[3)]. The loss of balance control ability decreases active movement, weakens muscle power, delays stroke patients' return to normal activities of daily living[4)], and becomes a major factor adversely affecting the standing posture and gait[5)].

The development of effective and systematic gait training programs for improving the balance and gait of stroke patients is important[6)]. Therefore, a range of training programs for gait, such as training using functional electrical stimulation[7)], treadmill training[8)], task orientated training[9)], and augmented reality training[10)] have been designed.

In treadmill training augmented reality, the weight support system has been used during gait training for stroke patients since 1992. Based on this, gait training, utilizing the weight support instrument for patients whose balancing and gait ability have been compromised because of a hemiplegic gait, has been suggested[11)]. Weight-supported treadmill gait training is effective at controlling the motor recovery of the lower extremity. It improves motor coordination of the lower limb; involuntary muscular contraction inhibition of the trunk of the upper limb; and normal movement of the trunk and lower limbs. In addition, it can improve functional balance and endurance[12)], and reduce the shuffling state[13)]. In addition, functional electrical stimulation, which is a therapy that induces active movement in a paralyzed muscle, is used in the early stages of the rehabilitation[1)]. It can be utilized as a treatment to accelerate the functional recovery of gait, and delivers an effect which is identical to that of ankle joint orthosis in dorsflexor activation of the ankle joint during the swing phase. This study examined how treadmill gait training with functional electrical stimulation and augmented reality affects the muscle power, balance and gait of stroke patients.

SUBJECTS AND METHODS

The subjects of this study were 38 patients with stroke who were participating in a rehabilitation program at hospital 'R' in Seoul. Subjects were recruited according to the following inclusion criteria: stroke with inset of six months or longer independent gait and Mini-Mental State Examination (MMSE) scores of 24 or higher. The aim of this research and overall series of experiments were explained to the patients who voluntarily agreed to participate. The 38 selected patients were divided randomly as follows: 12 subjects received functional electrical stimulation with augmented reality during treadmill gait training (AR-FES group), 13 subjects received functional electrical stimulation during treadmill gait training (FES group), and 13 subjects received treadmill gait training (treadmill group). The training was conducted for 8 weeks. Since some of the patients were discharged from hospital and others were not active enough, at the end of the 8 weeks there were 9 subjects in the AR-FES group, 10 subjects in the FES group, and 9 subjects in the treadmill group. Before and after the training, muscle strength, muscle tone, balance and gait were measured. The training was performed for 20 minutes, three times a week, for 8 weeks. In addition, each group of patients received general physical therapy for 30 minutes, five times a week, for 8 weeks. Bobath's neuro-developmental treatment and proprioceptive neuromuscular facilitation were performed as general physical therapy treatments, and the results were measured after 8 weeks. The present study was supported by Sahmyook University and approved by Sahmyook University Institutional Review Boards (SYUIRB2011-002) and written consent was provided by all patients.

Functional electrical stimulation with augmented reality during treadmill gait training (AR-FES) was conducted to make subjects aware of their own shortcomings as well as improve balance and gait through an augmented reality environment. The augmented reality environment consisted of a computer with a head-mounted display (HMD) (i-visor, fx601, Daeyang E&C Co, Korea, 2008), an external switch (Ohmann, Cyber Medic Inc, Korea, 2009), functional electrical stimulation (FMGFE S3000, Cyber Medic Inc, Korea, 2006), treadmill with a partial weight-bearing suspension device (WNT-2000T, Wellness Track, Korea, 2005), and another treadmill without the suspension (WNT-2000i, Wellness Track, Korea, 2009).

A recording of gait featuring a normal person and an animated version were made. The HMD is designed to show two views. The modeled movement is shown on one side and the subjects actual movement is shown on the other side. Subjects can select with their actual the animated movement or the movement of the normal person, so that subjects can compare the normal movement movement. The virtual environment used in the augmented reality program played a sound when the subject walked at a stable speed on the treadmill. The augmented reality training provides a self-paced treadmill, considering the safety of the patients, and the gait speed was measured[14]. Before beginning the experiment, the patients were allowed 5 minutes to adjust to the virtual reality (VR) program with the HMD. Functional electrical stimulation was applied through an external switch. The functional electrical stimulation employed a single electrode, 5 × 5 cm^2, self-adhesion type, that was attached to the proximal part (5 cm below the head of the fibula) of the tibialis anterior muscle and the distal part (5 cm above the lateral malleous of the fibula). The external switch of the functional electrical stimulation was a heel-type switch that was attached to the calcaneus. The switch was "off" in the swing phase, and "on" in the stance phase. The function electrical stimulation was a rectangular bi-phasic wave and the current was set to between 20 and 70 mA, at which ankle dorsiflexion occurs and the patients can remain comfortable. The ramp-up interval to generate the maximum intensity was 2 seconds, and was adjusted to the gait speed. The pulse frequency and pulse width were 35 Hz and 250 µs, respectively[15]. The stimulation spots were decided when the exact response of each user had been determined, and the spots were marked on the skin with dielectric and semi-permanent ink. The electrodes were attached to the same spots during the entire 8-week intervention period. Treadmill gait training was performed on a self-paced treadmill considering the safety of the patients. The treadmill speed was measured at a stable velocity over a 10-m distance on flat ground, and the measurements were taken 3 times[16]. Each week, the gait speeds of the patients were measured again and the treadmill speed was reset. If the patients felt any fatigue during treadmill gait training, training was suspended and resumed after a 5-minute break. During the experiment, a physical therapist stood on the affected side of each patient for safety, and patients' ankle and stability of the lower body were supported. When needed, suspension devices or a safety bar was utilized for training[17], but an ankle orthosis was not used. The intervention period was 20 minutes per day, three times a week, for 8 weeks.

Functional electrical stimulation with treadmill gait training (FES) was performed in the same manner as AR-FES, but without the HMD. The intervention period was 20 minutes a day, three times a week, for 8 weeks.

Treadmill gait training was carried out on a treadmill in the same manner as AR-FES, but without the HMD. The electrode was attached to the subjects in a permanently "off" state. The intervention period was 20 minutes per day, three times a week, for 8 weeks.

The muscle strengths was measured using a manual myodynamometer (model 01163, Lafayette, USA, 2003), and the muscle strengths of the tibialis anterior muscle and quadriceps femoris muscle were measured[18]. The resistance was sustained to prevent joint movement for 5 seconds, until the device sounded a beep. In this study, a pre-to-post evaluation was performed by the same physical therapist at an office familiar to the patients. To minimize the influence of muscle fatigue, a minute break was given after each item was measured. The mean value was calculated from three measurements.

The muscle stiffness, which is defined as the change in passive tension per unit change in length, is an indication of a muscle's passive resistance to elongation. In this study, Myotonometer (Neurogenic Technologies, Inc., Montana, USA), which is a patented and computerized meter-type device, was used to measure the relaxed muscle stiffness levels. The myotonometer quantifies the tissue stiffness by measuring the level of resistance encountered when a probe is pushed downward onto the muscle and underlying tissue. The amount of tissue displacement (±0.1 mm) caused by the pressure of the probe is recorded relative to the applied force. During the application of the probe, the tissue displacement values were recorded at 8 force increments of the probe pressure (0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75 and 2.00 kg). The force displacement curves were generated from the data using computational software.

Lesser penetration of the probe and a less steep slope of the force-displacement curve indicates higher resistance (more stiffness). This use of Myotonometer to measure the muscle stiffness was demonstrated to be valid and reliable[19)]. In the present study, a pre-to-post evaluation was performed by the same physical therapist at an office familiar to the patients.

The balance performance was assessed using Berg Balance Scale (BBS). The BBS is widely used as an outcome measure to assess balance performance because it produces reliable data with strong internal consistency and excellent intrarater and interrater reliabilities (intraclass correlation coefficients of 0.99 and 0.98, respectively)[20)]. The BBS measures a person's ability to perform 14 activities and each of the 14 activities requires an ability to balance and can be considered a reflection of either functional activities or components of everyday functional activities, such as stair climbing or donning pants in a standing position. The scores range from 0 to 4 points for each of the 14 test items, giving possible total scores ranging from 0 to 56 points. Higher scores indicate greater balance ability and functional independence with respect to the activities tested[21)].

The gait ability was measured using the 'Timed Up & Go' test (TUG). In this test, the examiner times the patient as he or she stands independently from a sitting position in a standard-height armchair, walks back, turns around, and sits down again[22)]. Podsiadlo and Richardson[22)] suggested that the TUG has content validity because it evaluates a well-recognized series of maneuvers used in daily life, and has acceptable concurrent validity as the measurements correlate well with data obtained with more extensive measures of balance, gait speed and functional abilities. The intra-rater (r= 0.99) and inter-rater (r= 0.98) reliabilities are high[23)]. In this study, a pre-to-post evaluation was performed by the same physical therapist at an office familiar to the patients. To minimize the effects of muscle fatigue, a one minute break was allowed after each item was measured and the mean of 3 measurements was analyzed.

Statistical analyses were performed using SPSS 17.0. The Kolmogorov–Smirnov test was used to determine the homogeneity of the general properties and variables of the subjects. The paired t-test was used to determine the changes in the pre- and post-training values in each group, or one-way analysis of variance (ANOVA) was performed to compare the changes in the pre- and post-training values in each group. A post-hoc test using the Scheffe method was employed to compare each group. A p value <0.05 was considered significant.

RESULTS

General characteristics and results of the homogeneity test of the subjects are shown in Table 1. The muscle strength of the tibialis anterior muscle on the affected side showed a significant change with a 2.13 kg increase from 5.16 kg before training to 7.29 kg afterwards ($p<0.01$) in the AR-FES group, and the FES group showed a significant change with a 2.41 kg increase from 3.38 kg to 5.79 kg ($p<0.01$). On the other hand, the treadmill group showed only a slight a 0.23 kg increase from 3.60 kg to 3.83 kg. A comparison of the differences between before and after training among the three groups revealed significant changes ($p<0.05$) (Table 2). The muscle power of the quadriceps femoris muscle on the affected side was significantly changed with a 2.11 kg increase from 5.89 kg before training to 8.00 kg afterwards in the AR-FES group ($p<0.01$), and the FES group showed a significant change with a 2.29 kg

Table 1. General characteristics of the participants

		VR based FES plus treadmill train group (n=9)	FES plus treadmill train group (n=10)	treadmill train group (n=9)
Gender (n, %)	Male	6 (66.7)	5 (50.0)	6 (66.7)
	Female	3 (33.3)	5 (50.0)	3 (33.3)
Side of hemiplegia	Right	5 (55.6)	7 (70.0)	5 (55.6)
	Left	4 (44.4)	3 (30.0)	4 (44.4)
Age (y)		47.44 ± 8.39[a]	51.50 ± 12.90	49.11 ± 11.02
Height (cm)		166.11 ± 9.02	158.70 ± 8.84	168.00 ± 11.25
MMSE-K (score)		25.33 ± 1.65	26.10 ± 1.97	26.22 ± 1.79
Months of poststroke		9.74 ± 4.19	9.19 ± 2.74	10.39 ± 3.09
Muscle strength	quadriceps femoris muscle of affected side (kg)	5.89 ± 2.58	3.79 ± 1.92	6.32 ± 3.87
	tibialis anterior muscle of affected side (kg)	5.16 ± 2.22	3.38 ± 2.80	3.60 ± 2.55
Muscle tone (1.5 kg)	gastrocnemius maximum contraction (mm)	9.48 ± 3.47	9.92 ± 2.22	7.39 ± 1.61
	gastrocnemius relaxation (mm)	11.42 ± 3.95	11.33 ± 2.49	8.03 ± 1.67
BBS (score)		32.33 ± 6.89	30.10 ± 7.38	26.67 ± 3.67
TUG (sec)		33.61 ± 5.82	35.35 ± 8.38	32.39 ± 6.73

(N=28) Abbreviations : [a]mean ± SD

Table 2. Changes in muscle power in accordance with the experimental differences

		VR based FES plus treadmill train group (n=9) A	FES plus treadmill train group (n=10) B	treadmill train group (n=9) C
Tibialis anterior MMT(kg)	Pre test	5.16 ± 2.22[a]	3.38 ± 2.81	3.60 ± 2.55
	Post test	7.29 ± 2.28	5.79 ± 2.23	3.83 ± 2.43
	Post-Pre	2.13 ± 1.49**	2.41 ± 2.34**	0.23 ± 1.66§
Quadriceps femoris MMT(kg)	Pre test	5.89 ± 2.58	3.79 ± 1.92	6.32 ± 3.87
	Post test	8.00 ± 2.29	6.08 ± 2.85	6.68 ± 3.30
	Post-Pre	2.11 ± 1.72**	2.29 ± 1.64**	0.36 ± 1.20§,†

(N=28) Abbreviations : [a]mean ± SD, MMT: Digital Manual Muscle Test, **p<0.01 from pretest, § p<0.05 from Post-Pre among the three groups, † p<0.05 from post hoc, (B) showed a larger increase than (C)

Table 3. Medial gastrocnemius muscle tone for a case of the affected side maximum contraction through pre-to-post examinations according to each method

		VR based FES plus treadmill train group (n=9) A	FES plus treadmill train group (n=10) B	treadmill train group (n=9) C
1.5 (kg)	Pre test	9.48 ± 3.47[a]	9.92 ± 2.22	7.39 ± 1.61
	Post test	6.69 ± 1.65	8.25 ± 1.42	7.84 ± 2.49
	Pre-Post	2.79 ± 3.22*	1.67 ± 3.10	–0.46 ± 3.00
1.75 (kg)	Pre test	10.07 ± 3.64	10.39 ± 2.29	7.87 ± 1.61
	Post test	7.08 ± 1.61	8.66 ± 1.34	8.31 ± 2.54
	Pre-Post	2.99 ± 3.35*	1.73 ± 3.09	–0.44 ± 2.93
2 (kg)	Pre test	10.51 ± 3.70	10.79 ± 2.35	8.23 ± 1.58
	Post test	7.36 ± 1.60	8.99 ± 1.32	8.66 ± 2.52
	Pre-Post	3.15 ± 3.35*	1.80 ± 3.16	–0.42 ± 2.88

(N=28) Abbreviations : [a]mean ±SD, *p<0.05 from pretest

Table 4. Affected side relaxation medial gastrocnemius muscle tone through pre-to-post examinations of the experiment according to each method

		VR based FES plus treadmill train group (n=9) A	FES plus treadmill train group (n=10) B	treadmill train group (n=9) C
1.5 (kg)	Pre test	11.42 ± 3.95[a]	11.33 ± 2.49	8.03 ± 1.67
	Post test	8.01 ± 1.61	9.82 ± 1.93	8.68 ± 2.01
	Pre-Post	2.13 ± 1.49*	1.51 ± 3.35	–0.64 ± 1.49§,†
1.75 (kg)	Pre test	11.91 ± 4.00	11.84 ± 2.55	8.44 ± 1.60
	Post test	8.42 ± 1.65	10.24 ± 1.93	9.16 ± 2.07
	Pre-Post	3.48 ± 4.01*	1.60 ± 3.29	–0.71 ± 2.34§,†
2 (kg)	Pre test	12.16 ± 3.95	12.20 ± 2.56	8.90 ± 1.80
	Post test	8.72 ± 1.69	10.55 ± 1.94	9.48 ± 2.08
	Pre-Post	3.43 ± 3.95*	1.65 ± 3.29	–0.58 ± 2.46

(N=28) Abbreviations : [a]mean ± SD, **p<0.01 from pretest, § p<0.05 from Pre-Post among the three groups, † p<0.05 from post hoc, (A) showed a larger increase than (C)

increase, from 3.79 kg to 6.08 kg (p<0.01). In contrast, the treadmill group did not show a significant change with only a 0.36 kg increase from 6.32 kg to 6.68 kg. A comparison of differences between before and after training among the three groups revealed significant changes (p<0.05). In the post hoc result, the FES group showed a larger increase in

Table 5. Balance changes before and after experiments in accordance with each method

		VR based FES plus treadmill train group (n=9) A	FES plus treadmill train group (n=10) B	treadmill train group (n=9) C
BBS (score)	Pre test	32.33 ± 6.89[a]	30.10 ± 7.38	26.67 ± 3.67
	Post test	39.33 ± 6.84	36.10 ± 7.73	32.33 ± 3.28
	Post-Pre	7.00 ± 1.58***	6.00 ± 2.11***	5.67 ± 1.87***

(N=28) Abbreviations: [a] mean ± SD, BBS: Berg Balance Scale, ***p<0.001 from pretest

Table 6. Gait changes before and after the experiments in accordance with each method

		VR based FES plus treadmill train group (n=9) A	FES plus treadmill train group (n=10) B	treadmill train group (n=9) C
TUG (sec)	Pre test	33.61 ± 5.82[a]	35.35 ± 8.38	32.39 ± 6.73
	Post test	26.07 ± 7.29	29.21 ± 7.87	28.09 ± 6.83
	Post-Pre	–7.54 ± 2.74***	–6.14 ± 2.57***	–4.30 ± 1.57***,§,†

(N=28) Abbreviations: [a] mean ± SD, TUG: Timed Up and Go, **p<0.01 from pretest, § p<0.05 from Post-Pre among the three groups, † p<0.05 from post hoc, (A) showed a larger increase than (C)

the muscle strength of the quadriceps femoris muscle on the affected side than the treadmill group (Table 2). The medial gastrocnemius muscle tone of the stroke patients on the affected side during contraction showed a significant change with a 2.79 mm decrease from 9.48 mm before training to 6.69 mm afterwards at 1.5 kg (p<0.05) in the AR-FES group. At 1.75 kg, the AR-FES group showed a significant change with a 2.99 mm decrease from 10.07 mm to 7.08 mm. At 2 kg, a significant 3.15 mm decrease from 10.51 mm to 7.36 mm was observed. Therefore, the muscle tone increased after training. The FES group and treadmill group showed decreases in muscle tone, but the difference was not significant. The potential muscle strength is shown in graphs to illustrate the differences between each group at the maximum contraction before and after examining the medial gastrocnemius muscle tone (Table 3). The medial gastrocnemius muscle tone of the stroke patients on the affected side in relaxation after intervention showed a statistically significant change with a 2.13 mm decrease from 11.42 mm before training to 8.01 mm afterwards at 1.5 kg in the AR-FES group (p<0.05). At 1.75 kg, the AR-FES group showed a significant change with a 3.48 mm decrease from 11.91 mm to 8.42 mm (p<0.05). At 2 kg, a significant 3.43 mm decrease from 12.16 mm to 8.72 mm was observed (p<0.05). A comparison of the differences among the three groups between pre- and post-training showed significant changes at 1.5 kg and 1.7 kg (p<0.05), and the AR-FES group showed larger increases at 1.5 kg and 1.7 kg than the treadmill group (Table 4). The BBS showed significant changes with a 7.00 point increase from 32.33 points before training to 39.33 points afterwards (p<0.001) in the AR-FES group, and the FES group showed significant changes with a 6.00 point increase from 30.10 points before training to 36.10 points afterwards (p<0.001). The treadmill group showed a significant increase of 5.67 point from 26.67 to 32.33 points (p<0.001) (Table 5). Gait ability as assessed by TUG showed significant changes with a 7.54 sec decrease from 33.61 sec before training to 26.07 sec afterwards (p<0.001) in the AR-FES group, and the FES group showed significant changes with a 6.14 sec decrease from 35.35 sec before training to 29.21 sec afterwards (p<0.001). The treadmill group showed a lower but significant decrease of 4.30 sec from 32.39 to 28.09 sec (p<0.001). A comparison of the differences between before and after training among the three groups revealed significant changes (p<0.05). In the post hoc result, the AR-FES group showed a larger increase in gait speed than the treadmill group (Table 6).

DISCUSSION

This study examined the influence of 8 weeks training on the muscle strength, muscle tone, balance and gait of stroke patients classified into three different groups: AR-FES group, FES group, and treadmill group. Verheyden, Vereeck, Truijen et al.[24] reported that stroke patients experienced muscle weakness and sensory changes, resulting in functional disorders, such as difficulties in trunk control, disability of balance, decrease in gait ability, and difficulties with performing their normal activities of daily living. Dunning et al.[25] reported that the VR ankle training program increased the ankle muscle strength and gait speed of stroke patients, through training with lower extremity exercise and a VR ankle exercise program for 60 minutes, 3 times a week, for 8 weeks, targeting stroke patients 9 months after onset. Their results showed improvements in the gait speed, ankle movement, and plantar flexion when the ankle was pushed.

Tong et al.[1] examined the influence of electric gait training and functional electrical stimulation with gait training on the lower extremity muscle strength and gait of subacute stroke patients. Through training for 20 minute a day for 4 weeks, the electric gait training group and functional electrical stimulation with electric gait training group showed larger increases in lower extremity muscle strength and gait than the conventional physical therapy group ($p<0.05$). On the other hand, none of the three groups showed significant changes in balance. These results show electric gait training and functional electrical stimulation increase the lower extremity muscle strength and gait. In this study, the AR-FES and FES groups showed a significant increase muscles in the strengths of both the tibialis anterior muscle and quadriceps femoris muscle on the affected side ($p<0.01$). The AR-FES and FES groups also showed a larger increases ($p<0.05$) in the tibialis anterior muscle and quadriceps femoris muscle strengths on the affected side than the treadmill group. Active resistance exercise is more effective than passive exercise at improving muscle strength. In the gait cycle, in the transition from the pre-swing phase to the post-swing phase, the tibialis anterior muscle resists gravity and causes ankle dorsiflexion. When the affected side tibialis anterior muscle has foot-drop caused by neurological damage, it leads to muscle weakness and finally to gait disorder. In this experiment, functional electrical stimulation activated this muscle, and the patients performed active assistance exercise with electrical stimulation and active movement. Moreover, the gravity acted as resistance, so that the exercise became an active resistance exercise, which increases the muscle strength. In prior research, a treadmill was reported to increase the muscle power. In this experiment, however, the gait training group showed only a slight increase in muscle power. Mayer[26] divided the movement disorder symptoms of UMN syndrome into a positive reaction in terms of a loss of the stretch reflex and a negative reaction in terms of dexterity and muscle weakness. Dexterity among negative reactions is the ability to carry out an exercise task accurately, swiftly, reasonably and proficiently. Therefore, if dexterity is impaired, the patient would not be able to adjust flexibly to the changes in environment, and abilities of selected movement or isolated movement in a particular joint would be attenuated. The treadmill group significant effective changes in balance and gait with an increase in dexterity but the increase in muscle power was insufficient.

Kim[27] reported that the measurements of muscle stiffness indirectly measure muscle stregth, which is because the muscle stiffness is linearly proportional to the strength of the muscle contraction. If a muscular fiber becomes stiffer, the muscle contraction strength will increase with a concomitant increase in muscle tone[28]. Rydahl and Brouwer[19] examined the influence of the muscle tone of the ankle and elasticity on gait, targeting stroke patients, and the tone of the ankle plantar flexor was compared using the modified Ashworth scale and a muscle tone testing machine. The mean total ankle muscle tone appeared to be relatively high in stroke patients ($p<0.05$), but the passive muscle tone was little changed. Elasticity did not change remarkably, unlike the active function of the muscle, but it decreased in the treadmill group when the ankle plantar flexor was contracted ($p<0.05$). In this study, the muscle tone in maximum contraction and relaxation of the affected side gastrocnemius was measured. According to the within group differences, the muscle tone of the gastrocnemius increased in affected side maximum contraction and relaxation in the AR-FES group ($p<0.05$). Among the three groups, the muscle tone increased at 1.5 kg and 1.75 kg in affected side relaxation ($p<0.05$), and the AR-FES group showed a larger increase in muscle tone than the treadmill group ($p<0.05$). In the AR-FES group, the myotonic resistance decreased after the experiment, indicating a decrease in the quantity of insertion of the internal cylinder relative to the external cylinder of the muscle tone testing machine. This is because augmented reality provides visual feedback, which increases weight bearing on the affected side to sustain the posture, whereas patients lost their balance during treadmill training. Therefore, patients' treadmill speeds increased with a concomitant increase in the strength and tone of the gastrocnemius muscle. In the functional electrical stimulation with the treadmill group, the myotonic resistance of the gastrocnemius muscle increased in tandem with muscle strength and improvements in balance. Consequently, the muscle tone increased with a concomitant decrease in the level of insertion of the internal cylinder. On the other hand, stimulation of the tibialis anterior muscle, which is an antagonist, appeared to decrease the tone of the gastrocnemius, which is an agonist, therefore it failed to have a significant effect.

Nyberg and Gustafson[29] reported that problems of balance caused by a stroke vary according to the levels and areas of damage, but stroke mainly causes physical disabilities, such as hemiplegia. For hemiplegic stroke patients, the major part of weight is loaded on the unaffected side lower extremity, and weight-bearing on the affected side is not loaded. Accordingly, stroke patients had problems with the equilibrium reaction and static standing position due to imbalance. In addition, Bobath (1990)[30] reported that hemiplegic stroke patients had trouble with balance and postural control, and their postural sway in the standing position was twice that of a normal person of the same age due to asymmetric posture, abnormal balance, decreased ability of weight-shifting. In prior research, Jiang, Dou, Wen and et al.[31] examined 26 stroke patients and young adults. The subjects performed cycling ankle flexion and coordination ability of the tibialis anterior, vastus medialis and gastrocnemius at the moment of flexion and extension of the ankle were determined. The Burg balance scale was assessed and muscle contraction speed was also measured using electromyography. The affected side tibialis anterior showed a faster flexion and extension reaction speed of the ankle than the vastus medialis and gastrocnemius ($p<0.05$), which was more remarkable on ankle flexion than extension. Wen et al. concluded that the balance ability had decreased because of the faster flexion, but the result was derived because they did not evaluate dynamic balance and static balance separately. Walker et al.[32] conducted weight-bearing treadmill training in a virtual environment for 6 chronic stroke patients. In the experiment, gait was measured using a functional performance capability assessment, and balance was evaluated using the Burg balance scale. They reported an increase in gait and balance from 13.8 to 18 and from 43.8 to 48, respectively. Hence, the treadmill training with virtual reality was more effective at improving gait and balance than general treadmill training. In this study, the balance of all three groups was improved after the training ($p<0.001$) but there were no significant differences among the three groups.

In prior research, Mirelman[33] carried out a lower extremity improvement program using a robot VR system for 4 weeks, and reported more significant improvements in velocity, gait, distance and cadence in the experimental group using both robot and VR environments than in the group using only the robot system ($p<0.05$). Their results show that augmented reality improved the gait speed more than treadmill training. Yang et al.[14] conduced treadmill gait training for 20 stroke patients with augmented reality for 4 weeks. The gait velocity increased by 0.07 sec ($p<0.05$), whereas the total gait time was decreased by 6.14 sec ($p<0.05$). Therefore, treadmill training with augmented reality produced an increase in gait speed. Daly and Ruff[34] conducted gait training for 90 minutes a day, 4 days a week for 12 weeks, and reported that the gait training was more effective when combined with other treatments ($p<0.005$). Barbeau and Visintin[35] conducted treadmill gait training for 50 stroke patients for less than 20 minutes a day, 4 days a week, for 6 weeks, and repeated this program 3 times. The patients were divided into three groups, 30%, 20% and 10% of partial weight-bearing. The results showed that partial weight-bearing training was more effective at improving the gait and postural ability of patients with more serious stroke conditions than full weight-bearing. Moreover, gait off the treadmill improved when elderly stroke patients attempted weight-bearing, demonstrating that the effect of treadmill training was maintrained when not on the treadmill. In the present experiment, all three groups showed improved gait velocity after training ($p<0.001$). After training, the AR-FES group showed a larger increase in gait speed than the treadmill gait training group ($p<0.05$). All three groups showed improved muscle strength, balance ability and gait speed after training. The AR-FES group exhibited a larger increase in gait speed than the treadmill gait training group. For the FES group, the interval of ramp-up generating the maximum intensity was set, which affected the muscle reaction time of the patients because the muscle contraction time was fixed during gait.

This study examined the effects of functional electrical stimulation with augmented reality during treadmill gait training on the muscle strength, muscle tone, balance and gait of chronic stroke patients. The patients were divided into three groups, 9 subjects in the AR-FES group, 10 subjects in the FES group, and 9 subjects treadmill group. The AR-FES and FES groups showed larger increases in muscle strength than the treadmill group. Moreover, the AR-FES group showed greater improvement in gait speed the TUG than the treadmill group. These results show that the muscle strength of the quadriceps femories was affected more in the FES group, and the medial gastrocnemius muscle tone, gait speed was affected more in the AR-FES group. AR-FES can be utilized more actively in conjunction with conventional physical therapy as an exercise for improving functional activity because it can increase the muscle strength and gait ability of chronic stroke patients. Furthermore, the development of AR-FES is absolutely necessary for the provision of a range of therapies for stroke patients.

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