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Effect of Virtual Reality-Based Upper Extremity Rehabilitation combine with Real-Time Feedback on Upper Extremity Function, Activities of Daily Living, and Postural Control in Stroke Patients

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Abstract

Background: This study aimed to evaluate the effects of virtual reality (VR)-based upper extremity training combined with realtime feedback on upper extremity, activities of daily living(ADL) and postural control functions in patients with stroke hemiplegia.

Design: Randomized controlled trial.

Methods: Twenty adult algebra intervention adult patients were divided into two groups: 11 in the VR-based upper extremity training combined with real-time feedback group and 11 in the control group. In the VR-based upper extremity training with real time feedback group, the upper extremity exercise program was conducted in a VR environment for 30 min. The control group underwent the same upper extremity exercise program for 30 min. Training was provided five times for 1 week over four weeks. Before and after the training, the range of motion, hand strength test, Jebsen-Taylor hand function test, and box-and-block test were performed to evaluate the upper extremities. Postural control was evaluated with the Posture Assessment Scale for Stroke.

Results: The VR-based upper extremity rehabilitation training group showed significant improvement compared to the control group in supination, wrist flexion, and ulnar deviation in the range of motion ($p<0.05$). A significant difference was noted between the two groups in grip strength and lateral pinch strength ($p<0.05$). A significant difference was noted in the Jebsen-Taylor hand function, box, and block tests conducted between the two groups ($p<0.05$).

Conclusion: Based on these results, in addition to traditional physical therapy, VR-based upper extremity training with combined real-time feedback can be used as an effective exercise method to improve the range of motion, strength, and function of the distal extremity.

Key words: postural control, stroke, upper extremity function, virtual reality rehabilitation

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Ⅰ. Introduction

Physical disability is a common consequence of stroke, particularly upper-limb paralysis, which is one of the most significant impairments and a major obstacle to independence (Patten, Condliffe, Dairaghi, & Lum, 2013). Recovery of upper limb function is one of the primary goals of stroke patients and plays a crucial role in performing activities of daily living. Approximately 80% of patients with stroke experience impaired upper limb function, with 66% facing difficulties in performing activities of daily living due to limitations in upper limb function. These limitations persist into the chronic stage of stroke (Broeks, Lankhorst, Rumping, & Prevo, 1999; Buma, Lindeman, Ramsey, & Kwakkel, 2010; Kwakkel, Kollen, van der Grond, & Prevo, 2003). Furthermore, the shoulder girdle in patients with stroke often sustains severe damage and becomes the last body part to recover. Patients tend to avoid using the paralyzed side and compensate using the unaffected side (Rees, 1997). The symptoms of upper limb motor impairment include muscle weakness or atrophy, changes in muscle tone, joint laxity, and impaired motor control. These impairments result in difficulties in everyday activities such as grasping objects and writing, which in turn affect the performance of activities of daily living (ADL) and is closely related to the patient's quality of life (QoL) (Bleyenheuft & Gordon, 2014; Wolf et al., 2006).

Trunk control is the function of performing selective movements to maintain the body's upright posture, adjust weight shifting, and sustain the center of gravity within the trunk (Verheyden et al., 2004). Stroke is a major cause of impaired trunk control due to damage from various mechanisms, affecting weight shifting and balance reactions (Dault, de Haart, Geurts, Arts, & Nienhuis, 2003; Wee, Wong, & Palepu, 2003). Stroke patients experience decreased trunk muscle strength compared to the general population (Tanaka, Hachisuka, & Ogata, 1997, 1998), and chronic stroke patients develop significant positional errors in trunk sensation (Ryerson, Byl, Brown, Wong, & Hidler, 2008) and experience decrease in balance and postural control abilities (Dickstein, Shefi, Marcovitz, & Villa, 2004; Geurts, de Haart, van Nes, & Duysens, 2005). Trunk muscles contract to stabilize posture during movements such as shoulder or hip flexion while sitting, and the ability to adjust alignment of the trunk is necessary to counterbalance weight shifts during weight transfer movements (Lanzetta, Cattaneo, Pellegatta, & Cardini, 2004).

Virtual reality (VR) is a type of interface that allows users to engage in various interactions through multiple senses, enabling the real-time implementation of activities and differing environment on a computer (Adamovich, Fluet, Tunik, & Merians, 2009). VR is known to promote neuroplasticity by providing high-intensity, repetitive, and task-oriented training (Laver, George, Thomas, Deutsch, & Crotty, 2011; Saposnik & Levin, 2011). VR allows interactive practice and provides feedback on the intensity and performance of the exercises. Through intensive training focusing on the paralyzed side, it helps enhance patients' performance abilities and contributes to their motivation (Holden, Dyar, & Dayan-Cimadoro, 2007). Furthermore, through VR technology, various hypothesis tests and applications aimed at promoting motor recovery can be tested and applied (Merians, Poizner, Boian, Burdea, & Adamovich, 2006). Several motor rehabilitation training systems have been developed and implemented (da Silva Cameirao, Bermudez, Duarte, & Verschure, 2011; K. Laver, George, Thomas, Deutsch, & Crotty, 2015). In particular, significant research has been conducted in the field of upper limb rehabilitation for stroke patients, and the use of VR-based rehabilitation has been concluded to be more effective than traditional rehabilitation methods for improving upper limb function (Laver, George, Thomas, Deutsch, & Crotty, 2015). This study aimed to investigate the effects of applying real-time feedback along with VR-based upper limb training on improving the upper limb function, activities of daily living, and postural control abilities in stroke patients. This study aimed to assess the impact of this intervention on the improvement of upper limb function, activities of daily living, and postural control in stroke patients.

II. Methods

1. The study participants

This study included 24 adult stroke patients hospitalized at a rehabilitation hospital in Gyeonggi Province. All participants were provided with an explanation of the study procedures and objectives, and the study was conducted with those who signed the consent form. The selection criteria for the study participants were as follows: individuals with hemiparesis due to stroke, at least 9 months post-stroke to minimize the potential for natural recovery, capable of sitting in a wheelchair for at least 30 min, able to follow simple instructions provided by the researchers (with a Korean-Mini Mental State Examination score of 18 or above), and individuals with a Modified Ashworth Scale (MAS) score of 2 or less for upper limb spasticity. The exclusion criteria were individuals with cardiovascular and orthopedic disorders in the upper limbs, those with visual impairments or visual field deficits, those who declined to participate in the study after hearing the explanation of the study's purpose, and those who had recently participated in experiments similar to those in this study.

2. Experimental Procedure

Before conducting the experiment, 32 adults who were undergoing rehabilitation and physical therapy for stroke and agreed to participate were recruited as experimental subjects. Prior to the experiment, the participants' characteristics, including medical history and other orthopedic or neurological examinations, were investigated through medical examinations by a physician. Following selective screening, 30 participants were selected, excluding one individual with a score of less than 18 on the Korean version of the Mini-Mental State Examination and one with an infectious disease. The pre-assessment included measurements of upper limb function, activities of daily living, and postural control. The 30 participants were then divided into a VR-based upper extremity training with real-time feedback group consisting of 15 individuals, and a control group consisting of 15 individuals. The VR-based upper extremity training with real-time feedback group underwent training following an upper limb exercise program in a VR environment.

They were trained five times a week for 30 min each session, for a total of 20 sessions over four weeks. Additionally, they received standard physical therapy twice a day for 30 min per session for a total of 10 sessions over four weeks.

The control group participated in the same upper limb exercise program as the VR-based training group, performing 30-minute sessions five times a week for four weeks, but without the use of VR. In addition, they received standard physical therapy, which was consistent with the therapy provided to the experimental group.

Participants who were discharged from the hospital or unable to participate in the experiment for personal reasons as well as those whose participation rate fell below 90% were excluded from the final study. In the VR-based upper limb training with real time feedback group, two participants were discharged from the VR-based upper limb training with real time feedback group and two withdrew for personal reasons, resulting in the final participation of 11 individuals. Additionally, in the control group, one participant was discharged and three withdrew for personal reasons, resulting in the final participation of 11 individuals. In total, 22 participants were included in the final study sample, all of whom participated in the experiment for four weeks. After completing the experiment, the effectiveness of the training was assessed by measuring the upper limb function, activities of daily living, and postural control abilities using the same assessment tools as in the pre-assessment for both the VR-based upper limb training and control groups.

1) VR-based upper extremity training with real-time feedback group

In this study, the VR-based upper limb training with real-time feedback was implemented as follows: 1) Motion Controller and Real-Time Feedback: A motion controller was connected to a laptop to monitor the patient's movements. This allowed the patient's paralyzed-side movements to be displayed on the screen in real-time (Figure 2). The laptop screen utilized a resolution of 1280 x 960 and a high-resolution webcam operating at 30fps. The recorded video was mirrored and provided to the patient, enabling them to perceive their unaffected-side upper limb movements as if both limbs were moving symmetrically. This setup provided visual feedback to enhance the patient's perception. 2) Use of Mirroring Intervention Technique: The feedback provided was based on a mirroring technique, designed to display the unaffected-side movements on the screen as if both sides were performing the same motion. This intervention technique helped patients practice and correct their paralyzed-side movements more naturally through visual feedback. 3) Application of a Movement Error Correction Mechanism: If a patient's movements were judged to be incorrect more than three times, the therapist intervened with a signal to correct the motion in real-time. This interactive approach between the therapist and the patient maximized learning effects and supported the acquisition of correct movement patterns.

Through this real-time feedback system, the visual support for the patient's paralyzed-side upper limb movements, combined with therapist intervention for immediate correction of errors, provided a more effective rehabilitation environment.

Figure 1. Virtual reality device

Figure 2. Virtual reality environment

2) Upper extremity training

The participants in the study performed upper limb training following the same upper limb exercise program as the experimental group. They performed the same six movements without VR as the VR-based upper extremity training with real-time feedback group, completing each movement once before taking a 5-min rest period to minimize fatigue. The intervention period consisted of 20 sessions, conducted five times a week for 30 min each session over a period of four weeks.

3) Standard physical therapy

Therapy follows a one-on-one approach between the therapist and patient based on the principles of the central nervous system developmental sequence. Participants received standard physical therapy according to the treatment plan of the hospital to which they were admitted, five times a week for four weeks, once a day, with each session lasting 30 min. The exercise program included joint mobilization, stretching, strength training, and cardiovascular, coordination, and agility exercises.

4. Measurement methods

1) Upper limb function

In this study, the Jebsen-Taylor Hand Function test and box and block test were conducted to assess the upper limb function. In addition, joint range of motion and handgrip strength tests, which are closely related to upper limb function, were performed.

Joint range of motion was measured using a goniometer to assess the wrist pronation, supination, flexion, extension, radial deviation, and ulnar deviation. A standard goniometer was used for measurement, and each movement was measured three times for accuracy. The measurements were conducted by the same examiner before and after the intervention, and the range of motion that the patient could achieve independently, without being affected by gravity, was measured. Hand grip strength testing was performed using the Jamar Hand Evaluation Set (model "Hands-On" hand evaluation kit, Sammons-Preston, USA, 2007). This test measures the maximum force exerted by the hand when gripping, and is used to evaluate the degree of hand function impairment and paralysis in patients with brain or upper limb injuries. The grip, palmar grasp, and lateral pinch were measured, with three measurements taken, and the average value was applied.

2) Activities of Daily Living

The Jebsen-Taylor Hand Function test (JTHFT) and box and block tests were used to assess hand function.. The Jebsen-Taylor Hand Function test is a standardized assessment tool designed by Jebsen et al. (1969) to evaluate the hand function during everyday activities. The JTHFT is used to assess fine motor skills, hand function, and dexterity through a series of daily activity simulations. The test consists of seven standardized tasks: Writing a short sentence, Turning over

3x5-inch cards. Picking up small common objects (e.g., coins) and placing them in a container, Simulated feeding using a spoon with beans, Stacking checkers, Moving light objects (empty cans), Moving heavy objects (weighted cans), Each task is timed in seconds, and testing is conducted for both the dominant and non-dominant hands. It was shorter completion times indicate better hand function and dexterity. Results are compared to pre-intervention scores to assess hand function or the effectiveness of therapeutic interventions. The inter-rater reliability ranges from r=0.67 to 0.99 for the dominant hand and from r=0.60 to 0.92 for the non-dominant hand (Jebsen, Taylor, Triechmann, Trotter & Howard, 1969).

The box-and-block test is a assessment method designed to evaluate simple hand function and coordination skills, primarily targeting individuals with limited hand function or low cognitive ability. The patient assumed a sitting position and moved wooden blocks from one side to another within a box. The therapist recorded the number of blocks transferred within 60 s. The measured values were recorded after a practice period of 15 s. The intra-rater reliability was r=0.99, and inter-rater reliability was high (r=0.99) (Connell, & Tyson, 2012).

This study used the Korean version of the Modified Barthel Index to measure activities of daily living. The Korean version of the Modified Barthel Index consists of 11 items related to activities of daily living, including personal hygiene, bathing, feeding, toilet use, climbing stairs, dressing, bowel control, bladder control, ambulation, chair transfer, and bed transfer. Scores were assigned based on the patients' level of independence in performing these activities. The reliability of the Korean version of the Modified Barthel Index showed high levels, with intra-rater reliability ranging from r=0.97 to 1.00 and inter-rater reliability ranging from r=0.93 to 0.98 (Jung et al., 2007).

3) Trunk Control

This study utilized the Stroke Patients' Posture Assessment Scale (PSAS) to evaluate trunk control. This scale was specifically designed as an assessment tool for individuals with stroke and comprises 12 items. It assesses balance by distinguishing between static states to measure balance maintenance and dynamic states to measure stability during positional changes. The item scores range from 0 to 3 points, with a total score ranging from 0 to 36, structured on a 4-point scale. The intra-rater reliability for trunk control was found to be r=0.72, and the inter-rater reliability was r=0.88 (Benaim, Perennou, Villy, Rousseaux, & Pelissier, 1999).

5. Data Analysis

All data processing and statistical analyses were conducted using SPSS version 18.0, and the means and standard deviations were calculated. The entire sample population was tested for normality, and the general characteristics of the participants were analyzed using descriptive statistics. An independent t-test was performed to examine the differences between the two groups. Paired t-tst was performed to compare the differences before and after within each group. The statistical significance level for all data was set at p<.05.

III. Results

1. The general characteristics of the study participants

The general characteristics of the participants are listed in Table 1. Both the VR-based upper limb training and control groups exhibited homogeneity in their general characteristics.

Table 1. General characteristics of participants (*N*=22)

Characteristics	UEVRRTF Group (*n*=11)	Control Group (*n*=11)	t(*p*)
Gender (M/F)	8 / 3	6 / 5	-0.866(0.386)
Age (years)	67.82 ± 8.471a	63.73 ± 9.199	1.085(0.291)
Height (cm)	167.64 ± 9.479	164.18 ± 9.075	0.873(0.393)
Weight (kg)	62.45 ± 10.501	60.09 ± 7.569	0.606(0.552)
Lesion sites (Left/Right)	8 / 3	6 / 5	-0.866(0.386)
Onset period (month)	17.27 ± 4.147	17.36 ± 7.775	-0.34(0.973)
K-MMSE (score점)	22.82 ± 2.183	25.27 ± 3.823	-1.849(0.079)

[a]M(SD); UEVRRTF= Upper extremity virtual rehabilitation training with real-time feedback; K-MMSE=Korean mini-mental state examination

2. Upper Extremity Function

The changes in the upper limb joint range of motion and strength before and after the intervention between the two groups are shown in Table 2. Regarding the within-group differences in upper limb joint range of motion, the VR-based upper extremity training with real-time feedback group showed statistically significant increases in the wrist supination, wrist flexion, wrist extension, and ulnar deviation compared to those recorded before training (p<0.05). Examining the differences between groups, wrist supination, wrist flexion, and ulnar deviation showed statistically significant increases in the VR-based upper extremity training with real-time feedback group compared to those in the control group (p<0.05). The within-group changes in hand grip strength were statistically significant for both the VR-based upper extremity training with real-time feedback group and control group ($p < 0.05$). When comparing the groups, grip and lateral pinch strengths showed statistically significant increases in the VR-based upper extremity training with real-time feedback group compared to those in the control group (p<0.05).

Table 2. Comparison of Upper limb range of motion and hand grip strength (*N*=22)

Parameters			UEVRRTF Group (*n*=11)	Control Group (*n*=11)	*t*(*p*)
Range of motion (degree)	Wrist supination	Before	75.45 ± 11.93a	69.55 ± 15.24	
		After	84.09 ± 5.84	70.91 ± 14.63	
		Before-after	8.64 ± 9.51	1.36 ± 3.23	2.40(0.033)
		t (*p*)	-3.01(.013)	-1.40(.192)	
	Wrist pronation	Before	80.00 ± 10.25	75.45 ± 11.28	
		After	83.18 ± 6.81	77.73 ± 9.32	
		Before-after	3.18 ± 5.60	2.27 ± 4.10	0.43(0.669)
		t (*p*)	-1.88(.089)	-1.84(.096)	
	Wrist flexion	Before	66.82 ± 14.37	65.45 ± 11.28	
		After	75.45 ± 12.14	66.36 ± 11.85	
		Before-after	8.64 ± 8.39	0.91 ± 2.02	2.97(0.013)
		t (*p*)	-3.41(.007)	-1.49(.167)	
	Wrist extension	Before	54.55 ± 19.42	55.45 ± 15.40	
		After	61.36 ± 13.06	56.82 ± 14.88	
		Before-after	6.82 ± 8.74	1.36 ± 3.23	1.94(0.066)
		t (*p*)	-2.59(.027)	-1.40(.192)	
	Radial deviation	Before	18.64 ± 5.05	17.73 ± 5.64	
		After	23.18 ± 5.13	18.64 ± 5.05	
		Before-after	4.55 ± 6.88	0.91 ± 2.02	1.68(0.119)
		t (*p*)	-2.19(.053)	-1.49(.167)	
	Ulnar deviation	Before	26.36 ± 7.10	26.82 ± 10.55	
		After	31.82 ± 5.13	28.18 ± 9.82	
		Before-after	5.45 ± 4.16	1.36 ± 2.34	2.85(0.010)
		t (*p*)	-4.35(.001)	-1.94(.082)	
Hand grip strength (kg)	Grasping	Before	11.92 ± 6.94	9.86 ± 2.50	
		After	15.10 ± 7.73	11.41 ± 2.80	
		Before-after	3.18 ± 1.64	1.55 ± 1.34	2.56(0.019)
		t (*p*)	-6.44(.000)	-3.84(.003)	
	Palmar grasp	Before	1.80 ± 1.62	1.10 ± 0.32	
		After	2.17 ± 1.61	1.43 ± 0.36	
		Before-after	0.38 ± 0.32	0.32 ± 0.36	0.40(0.695)
		t (*p*)	-3.89(.003)	-2.95(.015)	
	Lateral pinch	Before	2.61 ± 1.51	2.42 ± 0.47	
		After	3.41 ± 1.63	2.67 ± 0.51	
		Before-after	0.48 ± 0.48	0.24 ± 0.29	3.29(0.004)
		t (*p*)	-5.50(.000)	-2.81(.018)	

[a]M(SD); UEVRRTF= Upper extremity virtual rehabilitation training with real-time feedback

3. Activity of daily living

The changes in upper limb function and activities of daily living according to the training method Changes in upper limb function and activities of daily living between the two groups before and after the intervention are shown in Table 3. Regarding within-group differences in upper limb function, the VR-based upper extremity training with real-time feed-back group showed statistically significant increases in all subdomains of the Jebsen-Taylor Hand Function Test compared to those recorded before training ($p<0.05$), while the control group showed statistically significant increases in all sub-domains of the Jebsen-Taylor Hand Function Test, except for the task of moving small objects, including writing, card turning, eating imitation, stacking checkers, moving large and light objects, and moving large and heavy objects, compared to before training ($p<0.05$). When examining the differences between the groups, statistically significant increases were observed in the VR-based upper extremity training with real-time feedback group compared to the control group in the subdomains of card turning, moving small objects, moving large and light objects, and moving large and heavy objects ($p<0.05$). When examining the Box and Block Test, the VR-based upper extremity training with real-time feedback group showed a statistically significant increase compared with that before training ($p<0.001$). Furthermore, when comparing between groups, the VR-based upper extremity training with real-time feedback group exhibited a statistically significant increase compared to the control group ($p<0.001$). Both the VR-based upper limb training and control groups showed a statistically significant increase in performing activities of daily living after training compared to that before training ($p<0.001$).

4. Trunk control

The changes in postural control ability between the two groups before and after the intervention are shown in Table 4. Regarding within-group differences, the VR-based upper extremity training with real-time feedback group showed statistically significant increases in the static balance, dynamic balance, and total score compared to those recorded before training ($p< 0.05$), while the control group showed an increase in these factors after training compared to those before training. However, there was no statistically significant difference, in the change between the two groups before and after training.

Table 4. Comparison of PASS (N=22)

Parameters			UEVRRTF Group (n=11)	Control Group (n=11)	$t(p)$
PASS (score)	Static	Before	13.00 ± 2.10	12.64 ± 1.86	
		After	13.45 ± 1.64	13.00 ± 1.55	
		Before-after	0.45 ± 0.52	0.36 ± 0.51	0.42(0.682)
		t (p)	-3.36(.007)	-2.39(.038)	
	Dynamic	Before	18.36 ± 3.01	17.64 ± 2.50	
		After	19.18 ± 2.36	17.91 ± 2.34	
		Before-after	0.82 ± 0.98	0.27 ± 0.91	1.36(0.190)
		t (p)	-2.89(.016)	-1.00(.341)	
	Total score	Before	31.36 ± 5.03	30.18 ± 4.24	
		After	32.55 ± 3.93	30.82 ± 3.77	
		Before-after	1.18 ± 1.17	0.64 ± 1.12	1.12(0.277)
		t (p)	-2.76(.020)	-1.88(.089)	

[a]M(SD); UEVRRTF= Upper extremity virtual rehabilitation training with real-time feedback; PASS=postural assessment scale for stroke

Table 3. Comparison of upper limbs Function and activities of daily living (*N*=22)

Parameters			UEVRRTF Group (*n*=11)	Control Group (*n*=11)	*t*(*p*)
JHFT (sec)	Writing	Before	51.17 ± 25.99[a]	60.10 ± 10.26	
		After	41.16 ± 22.49	54.84 ± 9.80	
		Before-after	-10.01 ± 9.94	-5.26 ± 4.63	-1.44(0.166)
		t (*p*)	3.34(.007)	3.77(.004)	
	Card flipping	Before	18.05 ± 8.85	15.04 ± 2.74	
		After	10.87 ± 5.08	11.82 ± 2.23	
		Before-after	-7.19 ± 4.52	-3.23 ± 3.46	-2.31(0.032)
		t (*p*)	5.27(.000)	3.09(.011)	
	Moving small objects	Before	18.25 ± 10.51	16.57 ± 3.58	
		After	11.96 ± 7.11	14.01 ± 2.79	
		Before-after	-6.30 ± 3.98	-2.56 ± 4.15	-2.15(0.044)
		t (*p*)	5.24(.000)	2.05(.068)	
	Imitating eating	Before	18.76 ± 9.75	20.33 ± 3.81	
		After	15.29 ± 7.42	16.78 ± 2.92	
		Before-after	-3.47 ± 3.93	-3.55 ± 3.99	0.05(0.961)
		t (*p*)	2.93(.015)	2.96(.014)	
	Stacking blocks	Before	13.04 ± 7.34	11.79 ± 2.24	
		After	9.43 ± 6.48	9.86 ± 1.94	
		Before-after	-3.62 ± 2.52	-1.92 ± 1.80	-1.81(0.085)
		t (*p*)	4.75(.001)	3.54(.005)	
	Moving large and light objects	Before	14.04 ± 11.34	8.76 ± 1.36	
		After	8.09 ± 6.00	6.80 ± 1.05	
		Before-after	-5.94 ± 5.62	-1.96 ± 1.49	-2.27(0.034)
		t (*p*)	3.51(.006)	4.38(.006)	
	Moving large and heavy objects	Before	15.13 ± 11.44[a]	8.79 ± 1.43	
		After	7.76 ± 4.10	8.12 ± 1.30	
		Before-after	-7.37 ± 8.05	-0.67 ± 0.92	-2.74(0.020)
		t (*p*)	3.04(.013)	2.41(.036)	
	Total score	Before	148.45 ± 74.30	141.38 ± 22.07	
		After	104.55 ± 51.10	122.22 ± 18.68	
		Before-after	-45.64 ± 22.58	-19.16 ± 13.11	-3.33(0.004)
		t (*p*)	5.74(.000)	4.85(.001)	
BBT (numners)		Before	26.36 ± 12.31	24.82 ± 4.71	
		After	34.73 ± 15.52	27.68 ± 5.22	
		Before-after	8.36 ± 3.88	2.86 ± 4.32	3.14(0.005)
		t (*p*)	-7.15(.000)	-2.20(.053)	
K-MBI (score)		Before	62.18 ± 16.14	68.64 ± 14.53	
		After	66.27 ± 13.24	70.27 ± 14.27	
		Before-after	4.09 ± 4.01	1.64 ± 2.11	1.80(0.088)
		t (*p*)	-3.38(.007)	-2.57(.028)	

[a]M(SD); UEVRRTF= Upper extremity virtual rehabilitation training with real-time feedback; JHFT=jebsen-taylor hand function test; BBT=box and block test; K-MBI=korean modified bathel index

IV. Discussion

1. Upper Extremity Function

Brain tissue damage due to injury can alter the muscle activation, impair muscle strength, and disrupt coordinated contractions, thereby reducing coordination ability and causing a loss of selective movement. Additionally, it can impair motor control, planning, and the integration of sensory information (Krabben et al., 2011). In this study, when examining the differences between the groups, statistically significant increases were observed in the wrist supination, wrist flexion, and ulnar deviation in the VR-based upper extremity training with real-time feedback group compared with those in the control group ($p<0.05$). This suggests that VR training promotes the reorganization of neural motor pathways in the cerebral cortex, leading to enhanced practice and reduced dependency in the paralyzed arm. Furthermore, VR programs enhance patient interest, enabling more active participation than conventional therapy methods such as the passive exercise range provided by therapists. They also provide real-time feedback on movement, allowing patients to correct errors promptly. Therefore, VR applications can enhance learning through repetition, intensity, and task-oriented training, all of which promote upper limb function. To further elaborate on our findings, the outcomes of VR therapy may have resulted in significant improvements, particularly in the upper extremities. This phenomenon appears to be attributable to the promotion of active and repetitive functional movements of the upper limb through the VR program used in our study, facilitating motor relearning and resulting in positive effects on upper limb strength. In this study, the Jamar Hand Function Test, used to assess hand grip strength, showed a significant improvement in grip strength by 3.18 kg ($p<0.05$) compared to baseline in the VR-based upper extremity training with real-time feedback group. Additionally, there was a 0.38 kg improvement in the lateral pinch strength. Both grip and lateral pinch strengths showed statistically significant increases in the VR-based upper extremity training with real-time feedback group compared to those in the control group ($p<0.05$). Therefore, the experimental group in this study received feedback through VR and obtained information about errors more effectively than the control group without such feedback, enabling them to engage in more precise and discerning movements. It is inferred that individuals in the experimental group, who may have difficulty performing intricate movements, resorted to repeating overall movements, resulting in a significant increase in grip strength. Conversely, for tasks requiring more precise movements, such as the lateral pinch grip, there was a relatively weaker increase, indicating a focus on gross movements rather than fine motor skills. Indeed, this study confirmed that VR-based upper limb training has a positive effect on improving the wrist and hand grip strength. Therefore, it can be concluded that administering VR-based training is effective in improving the upper limb strength in stroke patients.

2. Activity of daily living

Brain hemorrhage or stroke in patients often results in motor deficits in the upper limbs, which are considered significant impairments that lead to functional loss in the upper extremities (Feys et al., 1998). The recovery of the impaired upper limb depends on the regularity and intensity of training (Kwakkel, Wagenaar, Twisk, Lankhorst, & Koetsier, 1999). Increasing evidence suggests that training on the paralyzed side should be repetitive, task-oriented, intensive, and motivationally engaged (Kleim & Jones, 2008). Furthermore, upper limb impairments affect limb use or render it unusable, thereby impeding independent performance of activities of daily living (Broeren, Rydmark, & Sunnerhagen, 2004). The intervention method used in this study, mirror therapy, regulates excitability in the primary motor cortex during motor and perceptual activities (Garry, Loftus, & Summers, 2005). This is achieved by actively observing the movements of the unaffected limb (activating the primary motor cortex on the same side) and passively observing the movements reflected in the mirror of the affected limb (activating the primary motor cortex on the opposite side) (Dohle, Kleiser, Seitz, & Freund, 2004; Ezendam, Bongers, & Jannink, 2009). These simultaneous changes in the excitability of the primary motor cortex promote cortical reorganization, which is conducive to functional recovery (Ezendam et al., 2009). In this study, when examining the differences between groups, statistically significant increases were observed in the subdomains of card turning, moving small objects, moving large and light objects, and moving large and heavy objects in the VR-based upper extremity training with real-time feedback group compared with the control group ($p < 0.05$). This is attributed to the implementation of an intensive repetitive training program focusing on the affected upper limb in this study, which is based on joint movements underlying delicate functional movements. Providing feedback through simultaneous movements of the unaffected side allows the movement of the affected side to feel more like normal movements, thereby aiding in improving symmetry of the body and reducing abnormal muscle tension, further promoting recovery of upper limb motor function. Gustavo et al. (2010) reported statistically significant improvements in box and block tests among stroke patients using a VR environment with Nintendo Wii for training, such as card games and bingo ($p < 0.05$). Additionally, Dongjin et al. (2013) found a statistically significant improvement in the Box and Block Test in the VR therapy group, with an increase from an average of 16.58 blocks before pre-treatment to 24.00 blocks after post-treatment, representing a 7.42 block increase ($p < .001$). In this study, the VR-based upper extremity training with real-time feedback group showed statistically significant improvements in the Box and Block Test, which assesses the upper limb function before and after training ($p < 0.05$). This finding is consistent with previous research, suggesting that the symmetrical upper limb training program implemented in this study, based on VR, facilitated simultaneous movements of the affected limb, activating a balanced interaction between the cerebral hemispheres. This stabilization was provided to the affected limb (Cauraugh et al., 2009), and it was inferred that the participants' interest and concentration increased as a result of receiving continuous feedback in the VR environment, facilitating motor learning. Consequently, the upper limb function improved. This process enhances the agility and dexterity of the upper limbs.. Furthermore, as a result of the VR upper limb training program utilizing joint range of motion exercises, participants in this study showed improvement in wrist range of motion, increased usage of the affected upper limb, and continuous feedback facilitated accurate and repetitive practice on the affected side. This led to an improvement in upper limb symmetry, indicating that the increased stability of the upper limbs results in enhanced upper limb function.

3. Trunk control

After a stroke, patients with hemiparesis often exhibit weakened postural muscles, reduced sensory perception, interpretation difficulties, impaired trunk control, and cognitive function decline. This leads to decreased efficiency compared to healthy individuals and dependence on postural control and walking (Wee, Wong et al., 2003). In particular, difficulties in recognizing and interpreting real-time sensory information negatively affect body awareness, leading to challenges in maintaining postural stability (Ryerson et al., 2008). In a previous study utilizing VR training, Myung-Mo et al. applied

VR-based training using canoeing games on stroke patients. The average score on the Body Impairment Scale increased significantly from 14.0 to 16.8 points, while the average score on the Functional Reach Test significantly increased from 20.4 cm to 22.4 cm. Moreover, the average score on the Berg Balance Scale significantly increased from 41.8 to 46.2 points, while the average time on the Timed Up and Go Test significantly decreased from 16.6 s to 15.1 s. In a previous study, the experimental group showed significant differences compared to the control group in all the tests mentioned above. In this study, using the Postural Assessment Scale for Stroke Patients, significant differences were observed in the static, dynamic, and total scores in the pre- and post-tests of the experimental group. However, there were no significant differences between the groups. This suggests that the program in this study, which was designed to focus more on the movements of the proximal upper limb than the distal upper limb, may not have significantly impacted postural control, leading to the lack of significant differences between the groups.

V. Conclusion

This study was conducted to investigate the effects of VR-based upper limb training on the upper limb function and postural control in stroke patients. The results of this study indicated significant improvements in wrist supination, wrist flexion, and radial deviation in joint range of motion in the VR-based upper extremity training with real-time feedback group compared to the control group ($p<0.05$). Additionally, significant differences were observed between the two groups in grip strength for both the grasping and lateral pinching tasks ($p<0.05$), indicating that, through VR, appropriate motivation was provided to the patients, enabling them to engage in repetitive exercises and resulting in increased joint range of motion and grip strength. Furthermore, significant differences were observed between the groups in the Jebsen-Taylor Hand Function test and box and block test results ($p<0.05$). This suggests that the real-time feedback provided through VR may have activated the primary motor cortex, resulting in improved hand function. No significant differences were noted in performing daily activities between the VR-based upper limb training and control groups. This suggests that further research with longer intervention periods may be necessary to draw definitive conclusions compared to the current study.

Postural control did not show significant differences between the VR-based upper limb training and control groups. This finding suggests that further research targeting patients without ceiling effects is necessary to draw definitive conclusions. This study confirmed that VR-based upper limb training causes changes in joint range of motion, grip strength, and function in the proximal portion of the upper limb. Based on these results, VR-based upper limb training may be an effective treatment method for patients with limitations and cognitive impairments in the proximal portion of the upper limb due to stroke. We anticipate that this method will be utilized more actively in clinical practice.

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Reference

Adamovich, S. V., Fluet, G. G., Tunik, E., & Merians, A. S. (2009). Sensorimotor training in virtual reality: a review. NeuroRehabilitation, 25(1), 29-44.

Arya, K. N., Verma, R., Garg, R. K., Sharma, V. P., Agarwal, M., & Aggarwal, G. G. (2012). Meaningful task-specific training (MTST) for stroke rehabilitation: a randomized controlled trial. Top Stroke Rehabil, 19(3), 193-211.

Benaim, C., Perennou, D. A., Villy, J., Rousseaux, M., & Pelissier, J. Y. (1999). Validation of a standardized assessment of postural control in stroke patients: the Postural Assessment Scale for Stroke Patients (PASS). Stroke, 30(9), 1862-1868.

Bleyenheuft, Y., & Gordon, A. M. (2014). Precision grip in congenital and acquired hemiparesis: similarities in impairments and implications for neurorehabilitation. Front Hum Neurosci, 8, 459.

Brodie, J., Holm, M. B., & Tomlin, G. S. (1994). Cerebrovascular accident: relationship of demographic, diagnostic, and occupational therapy antecedents to rehabilitation outcomes. Am J Occup Ther, 48(10), 906-913.

Broeks, J. G., Lankhorst, G. J., Rumping, K., & Prevo, A. J. (1999). The long-term outcome of arm function after stroke: results of a follow-up study. Disabil Rehabil, 21(8), 357-364.

Broeren, J., Rydmark, M., Björkdahl, A., & Sunnerhagen, K. S. (2007). Assessment and training in a 3-dimensional virtual environment with haptics: a report on 5 cases of motor rehabilitation in the chronic stage after stroke. Neurorehabilitation and neural repair, 21(2), 180-189.

Broeren, J., Rydmark, M., & Sunnerhagen, K. S. (2004). Virtual reality and haptics as a training device for movement rehabilitation after stroke: a single-case study. Arch Phys Med Rehabil, 85(8), 1247-1250.

Buma, F. E., Lindeman, E., Ramsey, N. F., & Kwakkel, G. (2010). Functional neuroimaging studies of early upper limb recovery after stroke: a systematic review of the literature. Neurorehabil Neural Repair, 24(7), 589-608.

Burdea, G. C. (2003). Virtual rehabilitation—benefits and challenges. Methods Inf Med, 42(5), 519-523

Carolei, A., Sacco, S., De Santis, F., & Marini, C. (2002). Epidemiology of stroke. Clin Exp Hypertens, 24(7-8), 479-483.

Cauraugh, J. H., Kim, S. B., & Duley, A. (2005). Coupled bilateral movements and active neuromuscular stimulation: intralimb transfer evidence during bimanual aiming. Neurosci Lett, 382(1-2), 39-44.

Chae, J. B., & Han, S. H. (2014). A Comparison of Hand Function According to Cognitive Status and Age. Journal of Korea Proprioceptive Neuromuscular Facilitation Association, 12(4), 217-224.

Chu, J. M., Bao, Y. H., & Zhu, M. (2015). [Effects of Acupuncture Intervention Combined with Rehabilitation on Standing-balance-walking Ability in Stroke Patients]. Zhen Ci Yan Jiu, 40(6), 474-478.

Connell, L. A., & Tyson, S. F. (2012). Clinical reality of measuring upper-limb ability in neurologic conditions: a systematic review. Arch Phys Med Rehabil, 93(2), 221-228.

Connelly, L., Jia, Y., Toro, M. L., Stoykov, M. E., Kenyon, R. V., & Kamper, D. G. (2010). A pneumatic glove and immersive virtual reality environment for hand rehabilitative training after stroke. IEEE Trans Neural Syst Rehabil Eng, 18(5), 551-559.

da Silva Cameirao, M., Bermudez, I. B. S., Duarte, E., & Verschure, P. F. (2011). Virtual reality based rehabilitation speeds up functional recovery of the upper extremities after stroke: a randomized controlled pilot study in the acute phase of stroke using the rehabilitation gaming system. Restor Neurol Neurosci, 29(5), 287-298.

Dault, M. C., de Haart, M., Geurts, A. C., Arts, I. M., & Nienhuis, B. (2003). Effects of visual center of pressure feedback on postural control in young and elderly healthy adults and in stroke patients. Hum Mov Sci, 22(3), 221-236.

Dickstein, R., Shefi, S., Marcovitz, E., & Villa, Y. (2004). Electromyographic activity of voluntarily activated trunk flexor and extensor muscles in post-stroke hemiparetic subjects. Clin Neurophysiol, 115(4), 790-796.

Dohle, C., Kleiser, R., Seitz, R. J., & Freund, H.-J. (2004). Body scheme gates visual processing. Journal of neurophysiology, 91(5), 2376-2379.

Eng, J. J., & Tang, P. F. (2007). Gait training strategies to optimize walking ability in people with stroke: a synthesis of the evidence. Expert Rev Neurother, 7(10), 1417-1436.

Ezendam, D., Bongers, R. M., & Jannink, M. J. (2009). Systematic review of the effectiveness of mirror therapy in upper extremity function. Disability and rehabilitation, 31(26), 2135-2149.

Fasoli, S. E., Krebs, H. I., Stein, J., Frontera, W. R., & Hogan, N. (2003). Effects of robotic therapy on motor impairment and recovery in chronic stroke. Arch Phys Med Rehabil, 84(4), 477-482.

Feys, H. M., De Weerdt, W. J., Selz, B. E., Cox Steck, G. A., Spichiger, R., Vereeck, L. E., et al. (1998). Effect of a ther-apeutic intervention for the hemiplegic upper limb in the acute phase after stroke: a single-blind, randomized, controlled multicenter trial. Stroke, 29(4), 785-792.

Frandin, K., Gronstedt, H., Helbostad, J. L., Bergland, A., Andresen, M., Puggaard, L., et al. (2016). Long-Term Effects of Individually Tailored Physical Training and Activity on Physical Function, Well-Being and Cognition in Scandinavian Nursing Home Residents: A Randomized Controlled Trial. Gerontology, 62(6), 571-580.

Garry, M., Loftus, A., & Summers, J. (2005). Mirror, mirror on the wall: viewing a mirror reflection of unilateral hand movements facilitates ipsilateral M1 excitability. Experimental Brain Research, 163(1), 118-122.

Geiger, R. A., Allen, J. B., O'Keefe, J., & Hicks, R. R. (2001). Balance and mobility following stroke: effects of physical therapy interventions with and without biofeedback/forceplate training. Phys Ther, 81(4), 995-1005.

Geurts, A. C., de Haart, M., van Nes, I. J., & Duysens, J. (2005). A review of standing balance recovery from stroke. Gait Posture, 22(3), 267-281.

Goldie, P., Evans, O., & Matyas, T. (1996). Performance in the stability limits test during rehabilitation following stroke. Gait & Posture, 4(4), 315-322.

Grealy, M. A., Johnson, D. A., & Rushton, S. K. (1999). Improving cognitive function after brain injury: the use of exercise and virtual reality. Arch Phys Med Rehabil, 80(6), 661-667.

Greenleaf, W. J., & Tovar, M. A. (1994). Augmenting reality in rehabilitation medicine. Artif Intell Med, 6(4), 289-299.

Holden, M. K., Dyar, T. A., & Dayan-Cimadoro, L. (2007). Telerehabilitation using a virtual environment improves upper extremity function in patients with stroke. IEEE Trans Neural Syst Rehabil Eng, 15(1), 36-42.

Huh, J. S., Lee, Y. S., Kim, C. H., Min, Y. S., Kang, M. G., & Jung, T. D. (2015). Effects of Balance Control Training on Functional Outcomes in Subacute Hemiparetic Stroke Patients. Ann Rehabil Med, 39(6), 995-1001.

Jebsen, R. H., Taylor, N., Trieschmann, R. B., Trotter, M. J., & Howard, L. A. (1969). An objective and standardized test of hand function. Arch Phys Med Rehabil, 50(6), 311-319.

Jorgensen, H. S., Nakayama, H., Raaschou, H. O., Vive-Larsen, J., Stoier, M., & Olsen, T. S. (1995). Outcome and time course of recovery in stroke. Part I: Outcome. The Copenhagen Stroke Study. Arch Phys Med Rehabil, 76(5), 399-405.

Karatas, M., Cetin, N., Bayramoglu, M., & Dilek, A. (2004). Trunk muscle strength in relation to balance and functional disability in unihemispheric stroke patients. Am J Phys Med Rehabil, 83(2), 81-87.

Kim, C., & Min, W.-K. (2013). The effects of virtual reality-based physical therapy in stroke patients. Physical Therapy Rehabilitation Science, 2(1), 7-11.

Kim, J. H., Lee, S. M., & Jeon, S. H. (2015). Correlations among trunk impairment, functional performance, and muscle activity during forward reaching tasks in patients with chronic stroke. J Phys Ther Sci, 27(9), 2955-2958.

Kleim, J. A., & Jones, T. A. (2008). Principles of experience-dependent neural plasticity: implications for rehabilitation after brain damage. J Speech Lang Hear Res, 51(1), S225-239.

Krabben, T., Molier, B. I., Houwink, A., Rietman, J. S., Buurke, J. H., & Prange, G. B. (2011). Circle drawing as evaluative movement task in stroke rehabilitation: an explorative study. J Neuroeng Rehabil, 8, 15.

Kwakkel, G., Wagenaar, R. C., Twisk, J. W., Lankhorst, G. J., & Koetsier, J. C. (1999). Intensity of leg and arm training after primary middle-cerebral-artery stroke: a randomised trial. Lancet, 354(9174), 191-196.

Kwakkel, G., Kollen, B. J., van der Grond, J., & Prevo, A. J. (2003). Probability of regaining dexterity in the flaccid upper limb: impact of severity of paresis and time since onset in acute stroke. Stroke, 34(9), 2181-2186.

Lai, S. M., Studenski, S., Duncan, P. W., & Perera, S. (2002). Persisting consequences of stroke measured by the Stroke Impact Scale. Stroke, 33(7), 1840-1844.

Lanzetta, D., Cattaneo, D., Pellegatta, D., & Cardini, R. (2004). Trunk control in unstable sitting posture during functional activities in healthy subjects and patients with multiple sclerosis. Arch Phys Med Rehabil, 85(2), 279-283.

Laver, K. E., George, S., Thomas, S., Deutsch, J. E., & Crotty, M. (2011). Virtual reality for stroke rehabilitation. Cochrane Database Syst Rev(9), Cd008349.

Laver, K., George, S., Thomas, S., Deutsch, J. E., & Crotty, M. (2015). Virtual reality for stroke rehabilitation: an abridged version of a Cochrane review. Eur J Phys Rehabil Med, 51(4), 497-506.

Lee, D., Lee, M., Lee, K., & Song, C. (2014). Asymmetric training using virtual reality reflection equipment and the enhancement of upper limb function in stroke patients: a randomized controlled trial. J Stroke Cerebrovasc Dis, 23(6), 1319-1326.

Liao, W. W., Wu, C. Y., Hsieh, Y. W., Lin, K. C., & Chang, W. Y. (2012). Effects of robot-assisted upper limb rehabilitation on daily function and real-world arm activity in patients with chronic stroke: a randomized controlled trial. Clin Rehabil, 26(2), 111-120.

Lin, K. C., Chen, Y. A., Chen, C. L., Wu, C. Y., & Chang, Y. F. (2010). The effects of bilateral arm training on motor control and functional performance in chronic stroke: a randomized controlled study. Neurorehabil Neural Repair, 24(1), 42-51.

Merians, A. S., Poizner, H., Boian, R., Burdea, G., & Adamovich, S. (2006). Sensorimotor training in a virtual reality environment: does it improve functional recovery poststroke? Neurorehabil Neural Repair, 20(2), 252-267.

Nakayama, H., Jorgensen, H. S., Raaschou, H. O., & Olsen, T. S. (1994). Recovery of upper extremity function in stroke patients: the Copenhagen Stroke Study. Arch Phys Med Rehabil, 75(4), 394-398.

Nichols-Larsen, D. S., Clark, P. C., Zeringue, A., Greenspan, A., & Blanton, S. (2005). Factors influencing stroke survivors' quality of life during subacute recovery. Stroke, 36(7), 1480-1484.

Page, S. J., Fulk, G. D., & Boyne, P. (2012). Clinically important differences for the upper-extremity Fugl-Meyer Scale in people with minimal to moderate impairment due to chronic stroke. Phys Ther, 92(6), 791-798.

Park, J. H., & Chung, Y. (2016). The effects of providing visual feedback and auditory stimulation using a robotic device on balance and gait abilities in persons with stroke: a pilot study. Physical Therapy Rehabilitation Science, 5(3), 125-131.

Park, Y. H., Lee, C. H., & Kim, H. J. (2014). A pilot study of augmented reality-based postural control training in stroke rehabilitation. Physical Therapy Rehabilitation Science, 3(1), 13-19.

Patten, C., Condliffe, E. G., Dairaghi, C. A., & Lum, P. S. (2013). Concurrent neuromechanical and functional gains following upper-extremity power training post-stroke. J Neuroeng Rehabil, 10, 1.

Prange, G. B., Jannink, M. J., Stienen, A. H., van der Kooij, H., Ijzerman, M. J., & Hermens, H. J. (2009). Influence of gravity compensation on muscle activation patterns during different temporal phases of arm movements of stroke patients. Neurorehabil Neural Repair, 23(5), 478-485.

Rees, D. (1997). Pathophysiology of the Motor Systems: Principles and clinical presentations. Physiotherapy, 83(2), 99.

Reid, D. T. (2002). Benefits of a virtual play rehabilitation environment for children with cerebral palsy on perceptions of self-efficacy: a pilot study. Pediatr Rehabil, 5(3), 141-148

Ryerson, S., Byl, N. N., Brown, D. A., Wong, R. A., & Hidler, J. M. (2008). Altered trunk position sense and its relation to balance functions in people post-stroke. J Neurol Phys Ther, 32(1), 14-20.

Samuelkamaleshkumar, S., Reethajanetsureka, S., Pauljebaraj, P., Benshamir, B., Padankatti, S. M., & David, J. A. (2014). Mirror therapy enhances motor performance in the paretic upper limb after stroke: a pilot randomized controlled trial. Arch Phys Med Rehabil, 95(11), 2000-2005.

Saposnik, G., & Levin, M. (2011). Virtual reality in stroke rehabilitation: a meta-analysis and implications for clinicians. Stroke, 42(5), 1380-1386.

Saposnik, G., Teasell, R., Mamdani, M., Hall, J., McIlroy, W., Cheung, D., et al. (2010). Effectiveness of virtual reality using Wii gaming technology in stroke rehabilitation: a pilot randomized clinical trial and proof of principle. Stroke, 41(7), 1477-1484.

Schmid, A. A., & Rittman, M. (2009). Consequences of poststroke falls: activity limitation, increased dependence, and the development of fear of falling. Am J Occup Ther, 63(3), 310-316.

Smania, N., Picelli, A., Gandolfi, M., Fiaschi, A., & Tinazzi, M. (2008). Rehabilitation of sensorimotor integration deficits in balance impairment of patients with stroke hemiparesis: a before/after pilot study. Neurol Sci, 29(5), 313-319.

Soysal Tomruk, M., Ozalevli, S., Dizdar, G., Narin, S., & Kilinc, O. (2015). Determination of the relationship between cognitive function and hand dexterity in patients with chronic obstructive pulmonary disease (COPD): a cross-sectional study. Physiother Theory Pract, 31(5), 313-317.

Suh, J. H., Han, S. J., Jeon, S. Y., Kim, H. J., Lee, J. E., Yoon, T. S., et al. (2014). Effect of rhythmic auditory stimulation on gait and balance in hemiplegic stroke patients. NeuroRehabilitation, 34(1), 193-199.

Tanaka, S., Hachisuka, K., & Ogata, H. (1997). Trunk rotatory muscle performance in post-stroke hemiplegic patients. Am J Phys Med Rehabil, 76(5), 366-369.

Tanaka, S., Hachisuka, K., & Ogata, H. (1998). Muscle strength of trunk flexion-extension in post-stroke hemiplegic patients. Am J Phys Med Rehabil, 77(4), 288-290.

Tanaka, T., Kudo, A., Sugihara, S., Izumi, T., Maeda, Y., Kato, N., et al. (2013). A study of upper extremity training for patients with stroke using a virtual environment system. J Phys Ther Sci, 25(5), 575-580.

Tessem, S., Hagstrom, N., & Fallang, B. (2007). Weight distribution in standing and sitting positions, and weight transfer during reaching tasks, in seated stroke subjects and healthy subjects. Physiother Res Int, 12(2), 82-94.

Thielbar, K. O., Lord, T. J., Fischer, H. C., Lazzaro, E. C., Barth, K. C., Stoykov, M. E., et al. (2014). Training finger individuation with a mechatronic-virtual reality system leads to improved fine motor control post-stroke. J Neuroeng Rehabil, 11, 171.

Tinga, A. M., Visser-Meily, J. M., van der Smagt, M. J., Van der Stigchel, S., van Ee, R., & Nijboer, T. C. (2016). Multisensory Stimulation to Improve Low- and Higher-Level Sensory Deficits after Stroke: A Systematic Review. Neuropsychol Rev, 26(1), 73-91.

Tyson, S. F., Sadeghi-Demneh, E., & Nester, C. J. (2013). The effects of transcutaneous electrical nerve stimulation on strength, proprioception, balance and mobility in people with stroke: a randomized controlled cross-over trial. Clin Rehabil, 27(9), 785-791.

van de Port, I. G., Kwakkel, G., Schepers, V. P., & Lindeman, E. (2006). Predicting mobility outcome one year after stroke: a prospective cohort study. J Rehabil Med, 38(4), 218-223.

Verheyden, G., Nieuwboer, A., Mertin, J., Preger, R., Kiekens, C., & De Weerdt, W. (2004). The Trunk Impairment Scale: a new tool to measure motor impairment of the trunk after stroke. Clin Rehabil, 18(3), 326-334.

Wade, D. T., & Hewer, R. L. (1987). Motor loss and swallowing difficulty after stroke: frequency, recovery, and prognosis. Acta Neurol Scand, 76(1), 50-54.

Wade, D. T., Langton-Hewer, R., Wood, V. A., Skilbeck, C. E., & Ismail, H. M. (1983). The hemiplegic arm after stroke: measurement and recovery. J Neurol Neurosurg Psychiatry, 46(6), 521-524.

Wee, J. Y., Wong, H., & Palepu, A. (2003). Validation of the Berg Balance Scale as a predictor of length of stay and discharge destination in stroke rehabilitation. Arch Phys Med Rehabil, 84(5), 731-735.

Weiss, P. L., Kizony, R., Feintuch, U., & Katz, N. (2006). Virtual reality in neurorehabilitation. Textbook of neural repair and rehabilitation, 51(8), 182-197.

Wolf, S. L., Winstein, C. J., Miller, J. P., Taub, E., Uswatte, G., Morris, D., et al. (2006). Effect of constraint-induced movement therapy on upper extremity function 3 to 9 months after stroke: the EXCITE randomized clinical trial. Jama, 296(17), 2095-2104.

Wu, C. Y., Chuang, L. L., Lin, K. C., Chen, H. C., & Tsay, P. K. (2011). Randomized trial of distributed constraint-induced therapy versus bilateral arm training for the rehabilitation of upper-limb motor control and function after stroke. Neurorehabil Neural Repair, 25(2), 130-139.