

Effects of a virtual reality-based exercise program on functional recovery in stroke patients: part 1

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Abstract. [Purpose] This study aimed to determine the effects of a virtual reality exercise program using the Interactive Rehabilitation and Exercise System (IREX) on the recovery of motor and cognitive function and the performance of activities of daily living in stroke patients. [Subjects] The study enrolled 10 patients diagnosed with stroke who received occupational therapy at the Department of Rehabilitation Medicine of Hospital A between January and March 2014. [Methods] The patients took part in the virtual reality exercise program for 30 minutes each day, three times per week, for 4 weeks. Then, the patients were re-evaluated to determine changes in upper extremity function, cognitive function, and performance of activities of daily living 4 weeks after the baseline assessment. [Results] In the experimental group, there were significant differences in the Korea-Mini Mental Status Evaluation, Korean version of the modified Barthel index, and Fugl-Meyer assessment scores between the baseline and endpoint. [Conclusion] The virtual reality exercise program was effective for restoring function in stroke patients. Further studies should develop systematic protocols for rehabilitation training with a virtual reality exercise program.

Key words: Stroke, Virtual reality-based exercise program, Functional recovery

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INTRODUCTION

Stroke can be secondary to ischemic or hemorrhagic brain injury, resulting in chronic neuromuscular disturbances¹⁾. Stroke patients who develop cognitive, sensory, and motor dysfunction are at an increased risk for developing motor imbalance, and therefore, post-stroke recovery of function is essential for these individuals²⁾. Recently, we have used robot-assisted rehabilitation or virtual reality (VR) equipment to treat stroke patients³⁾. A VR-based exercise program (VREp) involves applying engineering technology to rehabilitation. It promotes motor learning in the paralyzed upper extremities of patients⁴⁾. The VREp provides auditory, visual, and proprioceptive feedback in a virtual reality environment, offering individualized exercise training programs. In addition, it creates a training environment that can adjust the difficulty of the exercise to the individual's level of adaptation⁵⁾. VR environments have been used for post-stroke rehabilitation⁶⁾. In these cases, it has been mainly used as an interventional tool for the functional recovery of the upper extremities⁷⁾, and it is effective in achieving recovery of upper extremity function in stroke patients⁸⁾. Accordingly, this study examined the effects of a VREp on the post-stroke

recovery of cognitive function and activities of daily living (ADL) in the rehabilitation of stroke patients.

SUBJECTS AND METHODS

This study initially enrolled 22 patients who were diagnosed with stroke and underwent occupational therapy at the Department of Rehabilitation Medicine of hospital A between January and March 2014. Of these, 12 patients were ineligible for the study, and the remaining 10 were enrolled. The 10 patients had hemiparesis, hemiplegia, or quadriplegia (Table 1).

The inclusion criteria for the study were: 1) stroke diagnosis; 2) able to maintain posture for approximately 30 minutes while sitting in a wheelchair; 3) able to follow level 1 instructions; 4) able to contract the muscles of any part of the upper extremities, such as the shoulder, elbow, and wrist; and 5) not participating in any similar studies. All patients provided written, informed consent.

Before the exercise intervention, the patients' upper extremity function, cognitive function, and ability to perform ADL were evaluated. Then, they participated in the VREp for 30 minutes, 3 times per week, for 4 weeks. Following the 4-week intervention, the patients were re-evaluated and the changes in the measurements between the baseline and endpoint were analyzed. To avoid measurement bias, all assessments were performed by other investigators who were blinded to this study. The investigators involved in this study were occupational therapists with at least 3 years of experience using the measurement tools.

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approved by the Baekseok University Institutional Review Board (Approval: BUIRB-201410-HR-009). All data were collected anonymously from electronic medical records.

The VREp used in this study was the Interactive Rehabilitation and Exercise System (IREX; GestureTek Health, Toronto, Canada)⁹⁾. The VR programs for the upper extremities included Airborne Rangers, Birds and Balls, Coconut, Conveyor, Drums, Juggler, and Soccer. Depending on the patient's status, 3 to 5 programs could be used within 30 minutes. The investigators informed the patients of the details of the VREp, the proper posture to use, and safety precautions to follow. They then monitored the patients until they had completed the exercise intervention.

To assess cognitive function, we used the Korea-Mini Mental Status Evaluation (K-MMSE), which has been standardized for elderly Koreans^{3, 10)}. To assess the performance of ADL, Mahoney and Barthel developed the Barthel Index based on the degree to which the ADL could be performed³⁾. This was subsequently revised to become the modified Barthel index¹¹⁾. We assessed the ADL performance in a step-wise manner, calculating the total score using the Korean version of the modified Barthel index (K-MBI)¹²⁾.

The Fugl-Meyer assessment (FMA) is a tool for assessing the degree of post-stroke functional recovery in patients with hemiplegia. It is composed of items evaluating motor function, balance, sensation, range of motion, and pain. It assesses the motor recovery of 15 upper extremity items concerning the shoulder, elbow, and forearm; 5 involving the wrist; 7 involving the hand; and 3 involving coordination. It has a maximum score of 66. Furthermore, its inter-rater reliability and test-retest reliability for the upper extremity scale are $r = 0.99$ and $r = 0.9932$, respectively. The results are graded based on a 3-point scale; a higher score indicates a greater degree of functional recovery. In this study, we used only the tool for assessing the upper extremities, such as reflexes, voluntary movement, and coordination of the shoulder, elbow, wrist joint, and hand¹⁾. The results are presented as the mean \pm standard deviation (mean \pm SD). The nonparametric Wilcoxon's signed-rank test was used to compare the differences in motor recovery, cognitive function, and performance of ADL within and between the groups and between the baseline and endpoint. All statistical analyses were performed using SPSS ver. 22.0 for Windows (SPSS, Chicago, IL, USA). A p-value of < 0.05 was considered statistically significant.

RESULTS

Following the 4-week intervention, there were significant improvements in the total K-MMSE and K-MBI scores, indicating improvement in cognition and the performance of ADL after VREp compared to baseline ($p < 0.05$). However, there were no significant differences in the MMSE subscores (Table 2). Of the K-MBI items, there was no significant difference in the score for 'Stair Climbing' (Table 3). The changes in the upper extremity function scores 4 weeks after baseline are shown in Table 4. There was a significant increase in the FMA scores in the experimental group ($p < 0.05$).

Table 1. Baseline characteristics (n = 10)

Patient	Gender	Age (years)	Diagnosis
1	female	73	Rt. hemiparesis
2	female	51	Lt. hemiparesis
3	male	73	Rt. hemiparesis
4	male	51	Rt. hemiplegia
5	male	74	Quadriparesis
6	female	38	Lt. hemiparesis
7	female	56	Quadriparesis
8	male	78	Lt. hemiparesis
9	female	73	Lt. hemiparesis
10	female	66	Rt. hemiparesis

Rt.: right; Lt.: left

Table 2. Changes in the K-MMSE scores 4 weeks after baseline

	At baseline	At 4 weeks
	(n = 10)	(n = 10)
	mean \pm SD	mean \pm SD
Orientation to time	2.90 \pm 2.23	3.60 \pm 1.95
Orientation to place	3.70 \pm 2.00	4.40 \pm 0.69
Registration	2.40 \pm 1.26	3.00 \pm 0.00
Attention and calculation	2.70 \pm 2.31	2.70 \pm 2.31
Recall	1.40 \pm 1.17	2.70 \pm 2.31
Language	6.00 \pm 3.83	7.40 \pm 1.83
Total	19.1 \pm 10.61	22.9 \pm 5.23 *

* $p < 0.05$ with Wilcoxon's signed-rank test. SD: standard deviation; K-MMSE: Korea-Mini Mental Status Evaluation

DISCUSSION

This study examined the effect of a VREp using the IREX on the recovery of cognitive function and the performance of ADL in stroke patients. Our patients participated in the VREp for 4 weeks. Comparing the values at 4 weeks to those at baseline, we found the following:

(1) In the study group, the total cognitive function score improved significantly ($p < 0.05$) after the 4 weeks, although there were no significant differences in the individual MMSE items between the baseline and endpoint. Kim et al.¹³⁾ reported that cognitive function improved significantly in acute stroke patients with cognitive impairment who received VR training plus computer-assisted cognitive rehabilitation, compared to those who received VR training only. These authors suggested that stroke patients with cognitive impairment experienced significantly improved visual attention and short-term visuospatial memory after therapy that included computer-assisted cognitive rehabilitation and VR training together. Grealy et al.¹⁴⁾ suggested that interactive exercise was associated with improved function and that a relatively simple physical exercise program could improve learning ability by reducing the attention overload through VR. In contrast, we did not observe significant differences in the MMSE subscores for cognitive function in our stroke patients.

Table 3. Changes in the K-MBI scores 4 weeks after baseline

	At baseline (n = 10)	At 4 weeks (n = 10)
	mean ± SD	mean ± SD
Feeding	3.90 ± 2.99	6.30 ± 3.49 **
Personal hygiene	1.30 ± 1.25	2.70 ± 1.63 *
Bathing self	0.30 ± 0.94	1.90 ± 1.72 *
Dressing	1.70 ± 1.49	6.20 ± 3.42 **
Toilet	1.70 ± 2.75	5.40 ± 3.37 **
Bladder Control	4.60 ± 4.52	9.20 ± 2.53 **
Bowel Control	3.60 ± 4.30	9.00 ± 2.53 **
Chair/bed transfers	4.20 ± 4.44	9.60 ± 4.35 **
Ambulation	1.40 ± 2.63	7.80 ± 4.87 **
Stair Climbing	0.00 ± 0.00	2.00 ± 3.77
Total	22.70 ± 21.70	60.10 ± 24.47 **

*p < 0.05 with Wilcoxon's signed-rank test. SD: standard deviation; K-MBI: Korean version of the modified Barthel index

Table 4. Changes in the FMA scores 4 weeks after baseline

	At baseline (n = 10)	At 4 weeks (n = 10)
	mean ± SD	mean ± SD
Shoulder	17.60 ± 13.00	25.90 ± 13.38 **
Wrist	5.50 ± 3.20	7.00 ± 3.36 *
Fingers	7.20 ± 4.58	10.60 ± 4.64 **
U/E coordination	2.30 ± 1.33	3.70 ± 2.31 *
Total	32.60 ± 20.70	47.20 ± 22.17 **

*p < 0.05 with Wilcoxon's signed-rank test. SD: standard deviation; FMA: Fugl-Meyer assessment; U/E: upper extremity

(2) In the experimental group, the total K-MBI scores, measuring ADL performance, differed significantly ($p < 0.01$) at 4 weeks. There were also significant differences in the individual K-MBI items between the baseline and endpoint ($p < 0.01$). We observed a significant improvement in the ability to perform ADL in patients treated with VR. Piron et al.¹⁵ reported a significant difference in the ADL scores of 24 acute stroke patients receiving either non-immersive VR or conventional therapy, though the level of initial impairment in these subjects was not reported. Holden et al.¹⁶ studied 2 subjects and found little to no change in ADL performance after training. However, repetitive movements of the upper extremities are used in the VR programs, while fine motor movements of the hand, such as catching and moving things, are usually required for the performance of ADL. However, of the K-MBI items in our study, the 'stair climbing' score did not differ significantly between baseline and endpoint. A limitation of our study is that we did not assess differences in the lower extremities, which were not trained with the VREp.

(3) In the experimental group, the upper extremity motor function scores differed significantly ($p < 0.01$) at 4 weeks. There were also significant ($p < 0.01$) differences in the FMA items from baseline. Henderson et al.¹⁷ compared a VR group to conventional therapy or no therapy for the upper limb. Similarly, Broeren et al.¹⁸ reported that the VR group

showed improved manual dexterity, grip force, and control of the affected upper limb in stroke patients after training in an immersive VR environment. Jang et al.¹⁹ reported the effects of immersive VR training with an IREX system on cortical reorganization and arm and hand motor function in participants with chronic stroke with mild to moderate impairment.

(4) Analyzing the measurements in the study group after 4 weeks of VREp therapy, there were significant differences in cognitive function, performance of ADL, and upper extremity motor function between the baseline and endpoint assessments. Similarly, Lee²⁰ reported that VR using video games resulted in significant improvements in the muscle strength of the upper extremities and performance of ADL.

One limitation of our study is that we could not completely rule out the effects of rehabilitation therapies other than the VREp. In addition, the number of study subjects was relatively small.

Studies suggest that rehabilitation interventions for stroke patients should be task oriented and provide visuoauditory feedback²¹. This might confer significant benefits for muscle strength training of the upper extremities and performance of ADL.

In summary, our results showed that rehabilitation training with a VREp improved cognitive function, the MBI assessment of ADL performance, and upper extremity motor function. Therefore, rehabilitation training with a VREp is a potentially effective and clinically applicable modality for achieving recovery of function in stroke patients. Further studies are warranted to develop systematic protocols for rehabilitation training with a VREp.

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