Effects of virtual reality immersive training with computerized cognitive training on cognitive function and activities of daily living performance in patients with acute stage stroke

A preliminary randomized controlled trial

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Abstract
Objective: The purpose of this study was to investigate the impact of virtual reality immersive training with computerized cognitive training on the cognitive function and activity of daily living in patients with acute stroke.

Method: We included 42 patients with acute stage stroke from C hospital in Sungnam from May, 2017 to September, 2017. The patients were randomly selected and divided into the experimental (n=21) and control (n=21) group. The experimental group performed virtual reality training, including Head Mount Display with computerized cognitive therapy, and the control group performed computerized cognitive therapy. Both groups trained for 30 minutes a day 5 times a week; the intervention lasted 4 weeks. To evaluate the improvement in each group, pre-post-test evaluation was conducted using the Loewenstein Occupational Therapy Cognitive Assessment and Computerized Neurocognitive Function Test for cognitive function, and Functional Independent Measure for activities of daily living.

Results: Attention and memory in cognitive function and activity of daily living performance were improved in both groups.

Conclusion: Virtual reality immersive training might be an affordable approach for cognitive function and activity of daily living performance recovery for patients with acute stroke.

Abbreviations: ACPT = Auditory Continuous Performance Test, ADL = activity of daily living, CNT = Computerized Neurocognitive Function Test, HMD = head-mounted display, LOTCA = Loewenstein Occupational Therapy Cognitive Assessment, VCPT = Visual Continuous Performance Test, VLT = Verbal Learning Test, VRT = Visual Recognition Test.

Keywords: activities of daily living performance, cognitive function, stroke, virtual reality training

1. Introduction

Strokes are a central nervous system disorder that causes impaired function because blood is not properly circulated to brain tissue due to sudden ischemia or bleeding in cerebral blood vessels. Some part of the brain function may also be lost.[1] Cognitive impairment is caused by strokes and cognitive impairment such as comprehension, reasoning, problem-solving, judgment, planning, and awareness occurs.[2]

Some studies found that neuroplasticity, cortical reorganization, and regeneration showed the highest level of reaction in 3 to 4 weeks after a stroke. The recovery plateau is reached within 3 months. Also, the rehabilitation delivered in this period can facilitate the underlying mechanisms of spontaneous recovery.[3–5] So, the first few months after stroke represent a critical time period for therapeutic approach.

Computerized neurocognitive training provides personalized treatment based on a patient’s neuropsychological patterns so that it can stimulate the damaged area of the cerebrum.[6] This training was first used for memory intervention and recently applied to not only memory but also attention, problem-solving, visual perception, executive function, self-healing, and other various areas of cognitive function.[7]

Along with computerized neurocognitive training, virtual reality training is applied to improve cognitive function with stroke patients. Virtual reality training is a system similar to the traditional computer-based treatment method; differently provides patients with computer-based virtual reality content for a situation where it is difficult for him or her to participate physically; the patients interact with the computer in a virtual reality space.[8] Mirror neurons—virtual reality training’s neurological background—were activated in the premotor cortex when a monkey performed this training.[9]

A variety of healthcare programs and hardware using a virtual reality system have been developed for multiple treatment purposes.[10] The video-captured virtual reality training represents a patient on screen and allows the patient to interact with a
virtual reality tasks on screen,[11] and it uses hardware like Nintendo Wii, X-box Kinetic, and IREX. These are non-immersive. Participants can see out-of-screen real environment while training. The head-mounted display (HMD)—type of virtual reality immersive device, screening out other stimulations coming from out of virtual reality—was introduced recently and is capable of tracking changing head positions in virtual reality and reflect on the screen virtual reality training.[12] HMD can make participant more concentrate on virtual reality and motivate virtual reality training.

There are many studies on virtual reality training using video capture devices, and such studies were conducted for games and exercises, not for professional rehabilitation of stroke patients. So, images, input systems, and difficulty control in those products are not very suitable for stroke patients. In addition, despite various effects mentioned above, there are few studies on virtual reality immersive training using HMD; also there is almost no paper in South Korea and around the world about research combining virtual reality training and computerized neurocognitive training.

In this regard, this study intends to examine the effect of treatment combined with virtual immersive reality training and computerized neurocognitive training on the cognitive function and daily living performance of acute stroke patients.

### 2. Methods

#### 2.1. Participants

This study’s subjects were 42 acute stroke patients hospitalized or treated as outpatients in Hospital C in Gyeonggi Province from May to September 10, 2017. A notice was posted on the bulletin board for 2 weeks to gather the subjects, and they signed the consent form in handwriting for voluntary participation.

Selection criteria included those who were diagnosed with a stroke within 3 months, those who scored 80 or more in the Motor-free Visual Perception Test and had no visual perception including unilateral neglect, and those who scored 24 or higher in the Korean Version of Mini-Mental Status Examination and could understand what the examiner said and read texts. Exclusion criteria included those who could not control high blood pressure or angina pectoris, those who had a history of seizure, and those who had a problem with visual or auditory acuity. Forty-two subjects were divided based on simple random sampling using the random number table into the experimental group and the control group. The participants were given an intervention one on one in a separate space so that they did not know which group they belonged to (Table 1).

#### 2.2. Intervention

The total study period ranged from May to September, 2017 after the institutional review board approval. Before training, the occupational therapist with more than 6 clinical years performed a pretest. The same occupational therapist provided training, and training was 5 times for 4 weeks in 20 sessions in total. The experimental group’s training program consisted of each 30minutes of virtual reality training and computerized neurocognitive training while the control group took 60 minutes of computerized neurocognitive training. Both groups had been taking the standard occupational and physical therapy without cognitive training. The post-test was performed by the same occupational therapist on both groups (Fig. 1).

#### 2.2.1. Computerized neurocognitive training program.

This study used the Korean Rehacom version 6.2 upgraded in 2015 and ran Eriksson and Dahlin-Ivanoff’s program for reactive behavior, short-term memory, and shopping.

#### 2.2.2. Virtual reality immersive training devices.

The device developed by Company S (2014) was used as the HMD’s virtual reality training display device. A HMD is wearable on the head or as part of a helmet that has a small display optic in front of one (monocular HMD) or each eye (binocular HMD). It consists of goggles, the main body, and the camera. The HMD’s hardware uses the gyro sensor, the acceleration sensor, and the magnetometer to allow the goggles to detect head movements in real time. The attached sensors recognize head coordinates in 3 axes. The coordinate system consists of pitch on the X-axis, yaw on the Y-axis, and roll on the Z-axis, and provides a particular visual image in any direction the head is headed. Through this technology, the characteristic of HMD is that immersive feeling and presence are different from existing virtual reality.[11]

#### 2.2.3. Virtual reality immersive training program.

This program is developed by SIDENINE (2014). This program consists of 2 performances (Fishing and Picture matching) having 4 activities. Fishing have “Easy,” “Normal,” and “Hard” level depending on the accuracy of hand and finger movements, and the user can press F1 for exit, F2 for restart, and R for align. The

### Table 1

| General characteristics | Experimental group (n=21) (M ± SD) | Control group (n=21) (M ± SD) | χ²/T | P |
|-------------------------|-----------------------------------|-------------------------------|------|---|
| Sex         | Male | 10 | Female | 14 | 1.55a | .01|
| Diagnosis     | Infarction | 11 | Hemorrhage | 7 | 0.38a | .05|
| Affected side | Rt. side | 9 | Lt. side | 10 | 0.86a | .35|
| Dominant hand | Rt. side | 8 | Lt. side | 11 | 0.23a | .63|
| MVPT-3       | 44.48±10.87 | 43.78±9.67 | 10.23b | .37|
| Age         | 58.43±14.61 | 54.71±16.23 | -1.04b | .31|
| Onset period | 37.19±11.6 | 38.57±12.91 | 0.39b | .41|

*χ² value.
*a* value.
virtual reality program begins after the user puts on goggles, completes a fishing tutorial, and maintains the arrow with the goggle camera for a certain time (Fig. 2). After the program begins, the user catches fish using upper extremities and ends with success or failure when he or she tells a therapist it is done after completing a mission to catch the displayed number of fish. Its feature is that it can be effective for upper extremity function to catch fish, and attention and memory to remember and retain the number of fish to catch in a mission.

Picture matching program is that the user flips cards and finds a match, and the initial screen has 8 cards; the user can turn or look back to see all the cards. The user needs to place his or her hand on the card whose picture they want to check as if they reach out and touch it. When the card flips, one of the various pictures (eg, animal, fruit, and chair) is shown randomly. In the same manner, the user flips another card to find a match with the picture on the previous card he or she just flipped.

The program restarts when the user presses “Start” in the right upper corner or “F2” on the keyboard. When the user presses “F2” even if he or she has not completed it, the program restarts. This task can be effective for attention and memory and helpful for balance training as the user has to continue to move while standing straight up (Fig. 3).

2.3. Outcome measures
2.3.1. Loewenstein Occupational Therapy Cognitive Assessment (LOTCA). The LOTCA is developed by Katz et al to assess the standardized cognitive and perception function of adult patients with strokes, those with brain damage, and normal people. It consists of 4 areas including orientation, perception, visuomotor organization, and thinking operations, and has 20 items for these areas. Inter-rater reliability ranged from 0.82 to 0.97 for the 20 items, and validity was $r=0.68$.[15]

2.3.2. Computerized Neurocognitive Function Test (CNT). The development of the CNT was a part of a healthcare technology R&D project, and research was performed to develop and standardize the neurocognitive function test for Koreans. It consists of subtests for attention, memory, executive function, and motor function. It takes 2 hours to operate all these items. This system collects and reports exact response number and reaction time according to subtests. In this research, the CNT conducted the Visual Continuous Performance Test (VCPT) for visual attention, the Auditory Continuous Performance Test (ACPT) for auditory attention, the Verbal Learning Test (VLT) for verbal memory, and the Visual Recognition Test (VRT) for...
Changes of performance between groups.

|                         | Experimental group (n = 21) | Control group (n = 21) | Z     | P    |
|-------------------------|-----------------------------|------------------------|-------|------|
| CNT score               |                             |                        |       |      |
| ACPT (second)           | 10.24 ± 0.5                 | 3.29 ± 15.4            | −2.50 | .01  |
| VRT-1st                 | 1.76 ± 1.3                  | 0.76 ± 1.6             | −2.83 | .00  |
| VRT-recall              | 1.81 ± 1.4                  | 0.81 ± 1.7             | −2.67 | .00  |
| FIM score               |                             |                        |       |      |
| Grooming                | 0.86 ± 1.3                  | 0.38 ± 1.2             | −2.19 | .02  |
| Dressing, upper body    | 1.05 ± 1.3                  | 0.52 ± 1.3             | −2.41 | .01  |
| Walk/wheel chair locomotion | 1.02 ± 1.8               | 0.48 ± 1.8             | −1.96 | .05  |
| FIM total score         |                             |                        |       |      |
| FIM (motor)             | 19.19 ± 13.2                | 9.43 ± 15.0            | −2.32 | .02  |

FIM = Functional Independence Measure, VRT = Visual Recognition Test.

* P < .05.

3. Results

3.1. Comparison of changes in cognitive function and daily living performance between the groups

Changes before and after the intervention in LOTCA items between the groups were not significant. For changes before and after the intervention in CNT items between the groups, the experimental group scored 10.24 in the ACPT, whereas the control group scored 3.28; the experimental group scored 1.76 in VRT-1, whereas the control group scored 0.76; and the experimental group scored 1.81 in VRT-recall, whereas the control group scored 0.81. They were statistically significant (Table 2).

For changes before and after the intervention in FIM items between the groups, the experimental group scored 0.86 in grooming, whereas the control group scored 0.38; the experimental group scored 1.05 in dressing-upper body, compared with the control group, which scored 0.52; the experimental group scored 1.02 in walk/wheelchair locomotion, compared with the control group, which scored 0.48. There were statistically significant changes. For FIM total motor function, the experimental group scored 19.19 and the control group 9.43; it was statistically significant (Table 2).

3.2. Comparison of cognitive function and daily living performance within the experimental group

The experimental group showed significant improvements in all LOTCA, CNT, and FIM items, and total scores (Table 3).

4. Discussion

Virtual reality training for rehabilitation has been applied on diverse patient groups in including those with stroke. Lee[18] used a virtual reality training intervention that employed the pressure sensitive platform and the 3D motion detector on 10 patients with spinal cord injury and found improvements in balance and daily living performance, and Zimmerli et al[19] used a virtual reality training intervention that utilized a robot for 12 patients with spinal cord injury and found significant results in daily living performance. Furthermore, Han and Ko[20] reported that a virtual reality program using an electronic game showed significant improvements in the balance and daily living performance of children with spastic cerebral palsy. Therefore,
virtual reality training can be viewed as applicable to various central nervous system diseases.

In this research, cognitive function of patients with acute stroke was improved similar to existing virtual reality training. In a 2009 study on mild cognitive impairment using virtual reality training (n = 45), Barnes et al found that it was statistically significantly associated with learning, delayed memory, and spatial and temporal relations. Kang’s virtual shopping simulation program (2014) found that there were significant differences in memory recognition (P = .001), attention (P = .003), and executive function (P < .001) between the experimental group and the control group. Kim et al reported that a virtual reality program providing for cognitive function training effectively improved attention, executive function, memory, and delayed recall. Lee et al reported on cognitive function measured using the Mini-Mental Examination-Korea (MMSE-K) after a virtual reality game using ping pong and sword martial arts for 8 weeks. He found that the MMSE-K score was significantly better in the experimental group than in the control group (P = .00); the interactions were significantly better in the experimental group, compared with the control group. Kim compared MMSE-K test results between patients who underwent virtual reality training (n = 13), and controls (n = 11) who had paper, pen, ink, and tabletop training, before and after the intervention. Kim found that the experimental group had significantly better average values before versus after the experiment (P = .05). Hofmann et al evaluated an internally developed virtual reality program in patients with Alzheimer disease and found that the number of errors, time taken to perform a task, and answers to multiple choice questions improved in the experimental group, compared with the control group. These researches including the present show the positive effect on cognitive function of virtual reality immersive training. Also, using HMD could be a considerable option to apply virtual reality training.

The improvements of cognitive function are likely the results of virtual reality training increasing the release of neurotransmitters and the choline system. Flannery stated that upper-extremity function movements through virtual reality training activated brain metabolism, increased the cerebral blood flow and the release of neurotransmitters, and were effective in improving cognitive function. Perry et al reported that the choline system was associated with an attention and memory mechanism, whereas Decker et al suggested that cognitive function training such as memory caused changes in the choline system.

Improvements in ADL functions in this research are consistent with those of Ji and Lee, who reported statistically significant improvements in self-care, bathing, dressing, and sphincter control in 30 patients with acute stroke undergoing virtual reality training in the experimental group, compared with the control group. Also, there are few researches reported supporting to our research results. Turoll et al reported a significant change in FIM items such as bladder management, bowel management, comprehension, expression, and social interaction in patients with stroke undergoing a virtual reality intervention. Yavuzer et al found a significant increase in self-care and dressing in 20 patients with hemiplegia who had a stroke 6 months prior who underwent virtual reality training 30 minutes every day for 4 weeks, compared with FIM results before and after the intervention. These studies might indicate that virtual reality immersive training with computerized cognitive training using the HMD can improve activities of daily living performance similar to computerized cognitive training.

These research data could demonstrate that applying a virtual reality immersive training to rehabilitation stimulates the brain’s activity, provides suitable visual feedback during training, and makes patients motivating and interesting. Notably, researchers believe that task-oriented training-induced proactive experience-dependent plasticity led to neurological changes in the brain and improved daily living performance. A previous study proved that a virtual reality training intervention promoted the reorganization of the cerebral cortex through functional magnetic resonance imaging (FMRI), presented evidence for
neuroplasticity through lateralization towards the cerebral cortex, and activation of the primary motor cortex and the somatosensory cortex. In this regard, it is conjectured that the virtual reality immersive training using HMD was highly likely to have a positive effect on improving daily living performance through the activation of experience-dependent plasticity and neuroplasticity.

There were the following limitations in this study: as it was conducted with acute stroke patients, time-dependent recovery could not be ruled out and recovery due to other treatment methods were not controlled as well. In addition, an HMD virtual reality training program did not include daily living activities contents, but it was comprised mostly of the tasks that would improve cognitive and motor activities; it is therefore needed to conduct research developing and applying daily living activities.

Furthermore, the number of the subjects was small that it is difficult to generalize the findings, and the intervention period was 4 weeks, which is considered short to identify the treatment effect. Accordingly, a future study would need to increase the number of the subjects and perform a test during and after the intervention to identify when the intervention effect starts and how long the effect of training continues.

This study holds significance as it was the first attempt to apply HMD-based virtual reality immersive training to acute stroke patients, and use the training effect for cognitive and daily living as performance factors. If clinical therapists combine virtual reality training and computerized neurocognitive training for an intervention for stroke patients based on this study findings, it will serve as an effective therapeutic strategy to recover cognitive and daily living performance.

5. Conclusions

We sought to examine the effect of an intervention combining virtual reality immersive training using the HMD and computerized neurocognitive training on cognitive function and daily living performance in patients with acute stroke. In our research, the combined intervention positively recovered cognitive function and daily living performance in patients with acute stroke. From the results, HMD-based virtual reality immersive training intervention could be an eligible strategy to improve cognitive function and daily living performance in patients with acute stroke.

Author contributions

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