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Application of digital practice to improve head movement, visual perception and activities of daily living for subacute stroke patients with unilateral spatial neglect

Preliminary results of a single-blinded, randomized controlled trial

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Abstract

Background: Virtual reality (VR) based digital practice is an attractive way to provide a patient engagement, motivation and adaptable environment for stroke rehabilitation. However, clinical evidence of efficacy with VR-based digital practice is very limited. In this study, we investigated the effects of VR-based digital practice program on unilateral spatial neglect (USN) rehabilitation in patients with subacute stroke.

Methods: Twenty-four subacute stroke patients with USN were enrolled and randomly assigned to digital practice group (n=12) and control group (n=12). Patients in digital practice group received training programs with VR-based applications with leap motion environment. Control group received conventional USN specific training programs. All patients were underwent 4 week practice program (3 sessions/week, a half-hour/session). We analyzed training effects before and after training by assessing the line bisection test, Catherine Bergego Scale, modified Barthel index, Motor-Free Visual Perception Test Vertical Version (MVPT-V), and horizontal head movements (rotation degree and velocity during the VR-based applications), and compared the results between the two groups.

Results: Compared to control group, digital practice group showed significantly greater improvements in the line bisection test ($P=.020$), and visual perceptual tasks (MVPT-V, responded more on left visual task, $P=.024$; correctly respond more on both left and right visual tasks, $P=.024$ and $P=.014$, respectively; and faster response time, $P=.014$). Additionally, horizontal head movement of rotation degree and velocity during the VR based practice in the digital practice group were significantly increased more than control group (P=.007 and $P=.001$, respectively).

Conclusions: VR-based digital practice program might be an affordable approach for visual perception and head movement recovery for subacute stroke patients with USN.

Keywords: digital therapy, neglect, rehabilitation, stroke, virtual reality

1. Introduction

The most common cognitive deficit that follows a stroke is unilateral spatial neglect (USN), affecting approximately 50% of stroke survivors.[1] In 90% of those affected, USN occurs after encephalopathy of the right hemisphere, particularly the parietal, temporal, and/or frontal cortex and, sometimes, the subcortical nuclei.[2] Patients with USN may show several symptoms in everyday life, such as applying make-up on only the right side of their faces, eating food from only the right side of a plate, and forgetting to look to the left before crossing the street.[1]

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Although USN may be long lasting in patients with right hemisphere damage, several promising advances may help to mitigate the neglect. These methods generally involve augmentation attention and internal spatial representations, aimed at encouraging patients to respond to stimuli in previously neglected hemifield.[3] A form of attention disorder that has been addressed using digital practice with virtual reality (VR) technology concerns the area of visual neglect or inattention to a specific visual field. Visual neglect is defined as inattention to objects positioned in the visual space opposite a brain lesion. The cause of neglect is not damage to the vision apparatus but due neural damage affecting connectivity between vision and attention.[4]

The use of VR systems for the assessment and rehabilitation of USN could be more interesting and consequently more effective than the conventional methods used for USN rehabilitation.[5] VR based digital practice and applications have emerged as new therapy methods in stroke rehabilitation. These methods possess inherent advantages in providing the opportunities for repetitive practice of activities beyond what is possible with conventional therapy.[6] In addition, VR can automatically update task difficulty based on each user's progress, thus creating individual patient's learning environments. Within a head-mounted display (HMD)-delivered virtual environment, it is possible to systematically present cognitive tasks targeting attention performance beyond what is currently available using conventional methods.[5] VR appears to be a promising intervention, as it may provide more engaging, motivating and adaptable environments for stroke rehabilitation than without VR therapy.[7] Attempts to ameliorate neglect have involved laterally shifting visual input, using either prismatic distortion or VR.[8,9] Gesture recognition (GR) capture body movements using capture devices and send the acquired data to a computer.[10] VR with GR interface that allows users to interact with computer-generated virtual environment through engaging in different tasks in real time.

The VR based digital practice would help treat USN and examine if this treatment was as effective as using background digital practice rehabilitation system. Various digital therapy with VR rehabilitation for USN are suggested, but few studies have compared VR rehabilitation with conventional USN specific training programs. In addition, few studies have investigated the effectiveness of these treatments compared to the control group, with continuous treatment for a specific period of time using a HMD.[5,11] If a VR based digital practice rehabilitation system reduces the signs of neglect, it can be used as an effective treatment for USN. The purpose of this study was to observe the effect of digital therapy with VR on degree of neglect, visual perception and activities of daily living in stroke.

2. Materials and methods

2.1. Subjects

Subjects were 24 individuals who had had strokes and who had been admitted to a rehabilitation center in the Republic of Korea. The inclusion criteria were:

1) more than 1 month and less than 6 months after stroke onset;
2) Sufficient awareness with an MMSE score of 24 or higher;
3) not participating in experimental rehabilitation or drug research; and
4) test for neglect in a clinical setting was the line bisection test (LBT).

The LBT was based on patients who deviated ≥15% to the right from the center [12,13].

The exclusion criteria were:

1) A patient with a severely impaired sitting posture, unable to sit on a chair with a back and armrests;
2) Patients with limited neck range of motion due to orthopedic disorders;
3) patients who experienced problems such as headache and dizziness while using the HMD; or
4) Patients with severely impaired vision, unable to recognize HMD objects.

All participants were informed of the use of the test and the results and were asked to sign a written statement formally agreed to participate in the study. Patient recruitment, allocation, and retention is summarized in Figure 1.

2.2. Ethical considerations

The study was approved by the Daejeon University Institutional Review Board, 1040647-201803-HR-003-03.

2.3. Study design and procedures

This study was a single blind randomized controlled trial. Evaluators who do not know group assignments have experience with testing and are eligible. Participants performed the test after gaining sufficient knowledge of the test protocol.

Participants were randomized into 2 groups (directly after the test) by a therapist not involved in the study: a digital practice group and a control group. The randomization was performed by selecting an opaque closed envelope from envelopes in which the group assignment was written. It was given to the physiotherapist in sealed numbered envelopes.

In addition, the patients in the digital practice group underwent digital practice for 30 minutes, 3 times a week for 4 weeks. The control group underwent conventional USN specific training for 30 minutes, 3 times a week for 4 weeks, for total of 12 sessions. In both groups, the training was provided at the rehabilitation clinic during a 1-hour therapy session, 5 days per week, for 4 weeks (a total of 20 sessions). The training was based on established motor learning and neurodevelopmental treatment.

2.4. Interventions

General surveys of the subjects and pre-tests were conducted before the intervention. For both groups, the intervention progressed during the regularly scheduled therapy sessions, and all other routine interdisciplinary stroke rehabilitation proceeded as usual. If two or more study participants were present in the clinic at the same time, they were assigned different treatment areas without any opportunity to observe each other, or their treatment times were rearranged to prevent unintended crossover.

The Oculus Rift (Facebook Inc., Menlo Park, CA) Developer Kit 2 (DK2) with the Oculus Rift 1.3.2 Software Development Kit (SDK) and Windows Runtime 0.8.0-beta were used to create the virtual reality environment. Participants wore Oculus Rift DK2 and Leap Motion (Leap Motion Inc., San Francisco, CA) and were seated in a chair (with a seat back and arm rest or wheelchairs) to perform 10 different applications (e.g. Blocks, Element L, Warlock, Laser, Pinch Draw, RPS island, VR table tennis) from Oculus share and Leap Motion developers. Attach the Leap Motion to the front of your Oculus Rift using the

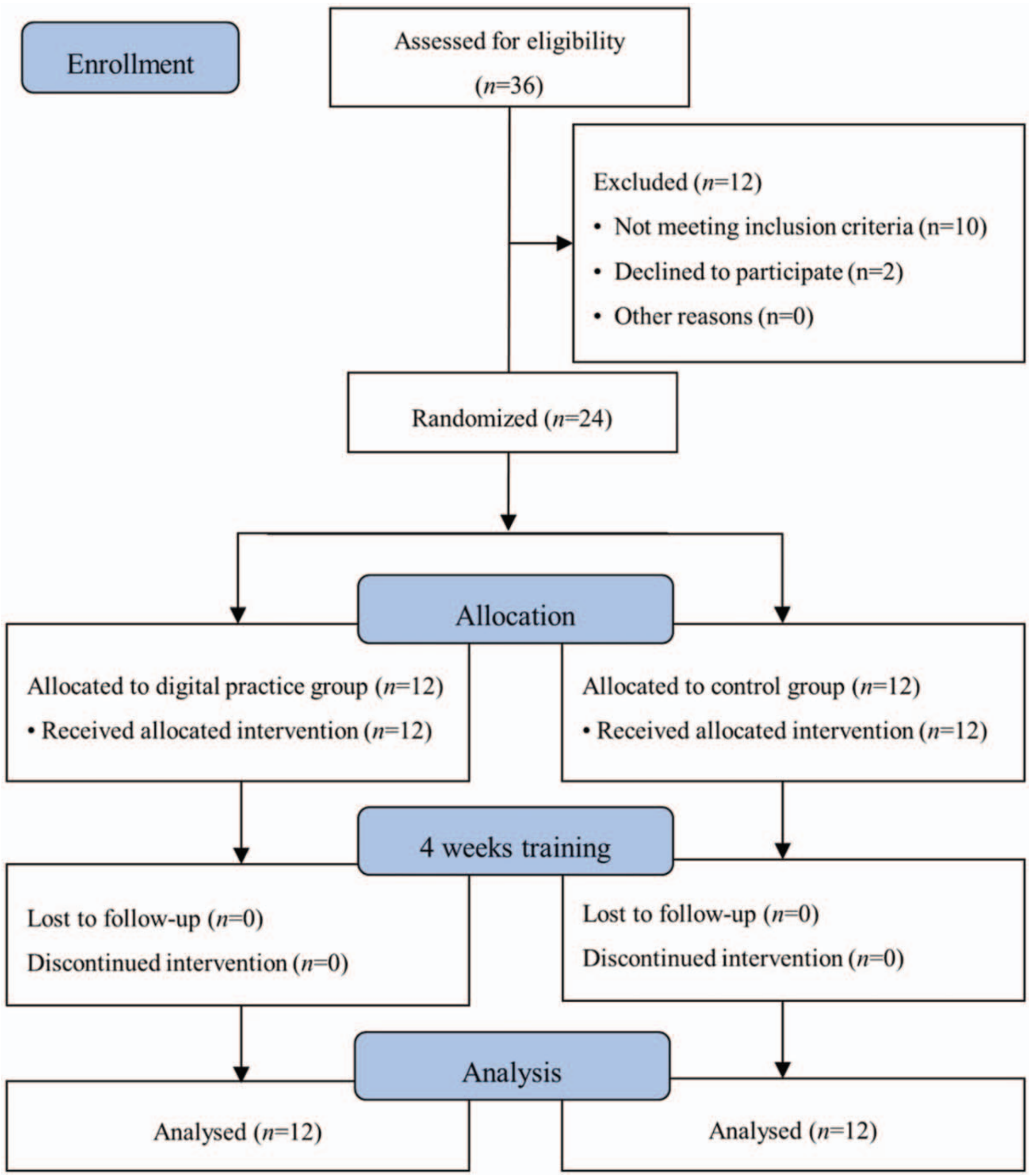

Figure 1. Flowchart.

supplied mounting bracket. VR displayed was to the patient on the Oculus Rift DK2. Participants were instructed to perform the VR applications task with their non-affected hand. The therapist's role was to explain the sessions' procedures (Fig. 2).

The interaction with the VR environment was performed using a portable marker less finger position capture device, the Leap Motion controller.[14] The Leap Motion sensor was able to capture hand and finger positions in detail and using proprietary algorithm transform the data into hand poses. It works by projecting infrared light upward from the device and detecting reflections using monochromatic infrared cameras. To track the hand poses of the user, using the Leap Motion Orion beta SDK and the core assets package version 4.0.2. Its field of view extends from 25 mm to 600 mm, with a 150° spread from the device, and it has high frame rate (>200 fps) and precision (1/100 mm per finger).[15]

The control group training programs, included structured visual tracking, reading and writing, drawing and copying, and puzzles. The training was conducted for 30 minutes a day, 3 days a week for 4 weeks.

2.5. Outcome measures

For evaluation of unilateral spatial neglect were assessed using the LBT, the Catherine Bergego Scale (CBS), the modified Barthel

Figure 2. Virtual reality based digital practice.

index (MBI), the Motor-Free Visual Perception Test Vertical Version (MVPT-V), and the head tracking sensor data.

The LBT is a quick measure to detect USN. The patient is asked to divide the line in half by placing an "X" on the center point. Usually, a displacement of the bisection mark towards the side of the brain lesion is interpreted as an indicator of neglect.[16] The test is scored by measuring in millimeters (mm) the deviation of the bisection from the true center of the line. A deviation of more than 6 mm from the midpoint or the omission of two or more lines on one half of the page indicates USN.

The CBS is a standardized checklist to detect the presence and degree of unilateral neglect during the observation of everyday life situations. The scale also measures patients' self-awareness of behavioral neglect (anosognosia). The CBS comprises 10 everyday tasks that a therapist observes during performance of self-care activities.[17] The CBS uses a four-point rating scale to indicate the severity of neglect for each item. This results in a total score out of 30, and arbitrary ratings of neglect severity according to total scores: 0 (no behavioral neglect), 1~10 (mild behavioral neglect), 11~20 (Moderate behavioral neglect), or 21~30 (severe behavioral neglect).[18] Severity of neglect was evaluated with the CBS, a test that shows good reliability, validity, and sensitivity.[18,19]

The MBI measures the extent to which people can function independently and have mobility in their ADL. The index also indicates the need for assistance in care. The Barthel index is a widely used measure of functional disability. Using a five-level ordinal scale for each item to improve the sensitivity of detecting change: a score of 0–20 suggests total dependence, 21–60 severe dependence, 61–90 moderate dependence, and 91–99 slight dependence. The internal consistency of the MBI was excellent, with a Cronbach's alpha of 0.94 (Cronbach's alpha of the functional independence measure ranged from 0.89 - 0.96).[20]

The MVPT is a widely used, standardized test of visual perception. Unlike other typical visual perception measures, this measure is meant to assess visual perception independent of motor ability. The MVPT-V can be used to determine differences in visual perception across several different diagnostic groups and is often used by therapists to screen those who have suffered a stroke or a head injury.[21] Response sets are presented in a vertical layout rather than in the horizontal layout found in other versions of the MVPT. This layout allows for an accurate assessment of the visual perceptual abilities in adults who have hemifield visual neglect, which is commonly found in patients who have suffered strokes or traumatic brain injuries. The MVPT-V contains 36 items. Each item consists of a black-and-white line drawing stimulus, along with four multiple-choice response options (A, B, C, D) from which patients must choose the item that matches the example.

The head-tracking sensor data are used to test visual field and head rotation angles. The Oculus Rift DK 2 sensor data are read using a Java-based program with Eclipse 4.5.2. These values indicate the head position, orientation, angular velocity and angular acceleration from the Oculus Rift HMD, and the values are printed both to the terminal window and to a time-stamped text file.

2.6. Data processing and statistical analysis

The descriptive statistics and the chi-square independence test were used to examine for the subjects' general characteristics. The chi-square independence test was used to compare significant differences between group means at baseline, whereas the Mann-Whitney U test was used to evaluate the change in each measurement pre- and post-training in each group. The Wilcoxon signed-rank test was used to compare the average changes within the groups. Data were presented as mean and SD. The statistical significance was set at $P < .05$.

3. Results

Twenty-four people fulfilled the inclusion criteria and voluntarily agreed to participate in this study. The participants were randomly assigned into the digital practice group (n = 12) or the control group (n = 12). All participants completed the entire study. There were no significant differences in the gender, age, height, weight, duration of onset, and mini-mental state examination of the individuals in the groups (Table 1). At the end of the fourth week, mean scores significantly increased in outcome measures (LBT, MBI, MVPT-V raw, MVPT-V left response behavior, MVPT-V left performance behavior, MVPT-V right performance behavior, MVPT-V processing time, head rotation angle, and head rotation velocity) in both digital practice and control groups.

The mean change LBT scores in digital practice group was significantly greater than in the control group ($P = .020$). There were no statistically significant changes in MBI and CBS between the two groups. ($P = .052$ and P = .143). The results are summarized in Table 2.

Table 1

Basic characteristics of participants.

Characteristics	Digital Practice Group (n=12)	Control Group (n=12)	P
Gender (n)			
Men	5	6	.660
Women	7	6	
Age (yr)	63.00±10.02[a]	61.58±9.99	.713
Height (cm)	160.25±9.17	164.17±8.58	.799
Weight (kg)	68.17±8.53	69.83±8.40	.799
Duration of onset (month)	4.33±1.56	4.58±1.62	.590
MMSE (scores)	27.08±1.44	28.02±1.68	.952
Side of stroke (n)			
Right (%)	1 (8.3)	2 (16.7)	.537
Left (%)	11 (91.7)	10 (83.3)	

MMSE = mini-mental state examination.

The mean change of MVPT-V raw scores ($P=.024$), response behavior left ($P=.017$), performance behavior left (P=.024), performance behavior right ($P=.014$), and processing time ($P=.014$) in the digital practice group was significantly greater than in the control group. The mean change of response behavior right in the digital practice group was non-significantly different between the control groups ($P=.932$). The MVPT-V scores are summarized in Table 3.

The mean change head rotation angle in digital practice group was significantly greater than in the control group ($P=.007$). The mean change head rotation velocity in digital practice group was significantly greater than in the control group ($P=.001$). The head-tracking sensor data are summarized in Table 4.

4. Discussion

The major findings of our study is that use of a digital practice with VR rehabilitation system led to greater recovery of self-awareness of behavioral neglect, cognitive and visual perception than did Non-VR standardized training in stroke patients with USN.[22] This result indicates that digital practice could help stroke survivors to look towards the contra-lesional side. Both groups of patients showed improvements in their LBT, CBS, MBI, MVPT-V scores and head-tracking sensor data over time; however, between-group differences were limited to the LBT, CBS, MVPT-V scores, and the head-tracking sensor data.

VR is a highly visual medium. Therefore, the quality of visuals, graphics, animation, and images are important for influencing perception and emotion to encourage therapeutic practice.[23] This is true across generations. When asked to explicitly rank different versions of a VR game according to the player experience, elderly adults preferred high-fidelity graphics. For applications without head mounted displays, there were few available options. While more exotic visualization methods exist, such as projecting environments onto the walls of a room, these still have limited applications and are not easy to obtain by the average developer. Therefore, with the possibility of applications the Oculus Rift functionality would be the methods for the virtual environment viewing system. However, due to the limitations of this iteration of the interaction system, only the monitor would be implemented. This is due to the complexities of managing frames of reference between the Leap Motion and the Oculus Rift and the determined application using the Oculus Rift.

In this study, the LBT differed significantly between the digital practice and control groups, but the CBS and MBI differed non-significantly. The results of CBS and MBI were low effectiveness on behavioral aspect and function independently.[24] In patients with acute stroke, VR training was effective for CBS, but in

Table 2

Comparison of mean Line Bisection Test, Catherine Bergego Scale, and Modified Barthel Index between two groups.

Variable	Within-Group						Between-Groups
	Digital practice group (n=12)			Control group (n=12)			
	Pre-test	Post-test	P Value	Pre-test	Post-test	P Value	P Value
LBT (scores)	8.25±5.89	11.75±5.83	.002*	7.83±6.28	9.67±6.61	.005*	.020*
CBS (scores)	8.33±5.87	11.25±5.03	.003*	9.33±6.16	10.42±6.33	.006*	.052
MBI (scores)	37.42±8.73	47.17±9.73	.003*	38.08±9.80	44.50±10.19	.002*	.143

CBS=Catherine Bergego Scale, LBT=Line Bisection Test, MBI=Modified Barthel Index.
* $P<.05$.

Table 3

Comparison of mean Motor-Free Visual Perception Test Vertical Version between two groups.

Variable	Within-Group						Between-Groups
	Digital practice group (n=12)			Control group (n=12)			
	Pre-test	Post-test	P Value	Pre-test	Post-test	P Value	P Value
Raw (scores)	19.42±4.74	26.33±4.39	.002*	20.08±6.27	24.50±5.54	.003*	.024*
Response Left (score)	16.92±2.28	19.58±1.68	.002*	17.00±2.37	18.17±2.04	.020*	.017*
Response Right (score)	18.17±3.56	18.67±4.25	.002*	18.50±3.53	18.75±3.79	.180	.932
Performance Left (score)	10.25±3.67	14.92±4.25	.002*	9.67±3.26	12.33±3.50	.005*	.024*
Performance Right (score)	10.92±2.81	13.33±2.57	.003*	11.25±3.42	11.83±3.41	.020*	.014*
Processing time (s)	5.52±0.17	3.36±1.19	.002*	5.50±0.19	4.43±1.34	.011*	.014*

* $P<.05$.

Table 4

Comparison of head tracking sensor data between two groups.

Variable	Within-Group						Between-Groups
	Digital practice group (n=12)			Control group (n=12)			
	Pre-test	Post-test	*P* Value	Pre-test	Post-test	*P* Value	*P* Value
Head rotation (degree)	9.00±1.21	56.42±8.72	.002*	9.83±1.47	45.92±9.59	.002*	.007*
Head rotation velocity (radians / s)	9.83±1.47	45.92±9.59	.002*	0.92±0.16	1.54±0.46	.002*	.001*

* $P<.05$.

subacute patients, it was not more effective than control group.[25] The area of neglect had a profound effect on self-care activities, as other factors, such as motor performance of four limbs and coordination that work together for daily activities, not to mention USN.[26] Previous studies also had conflicting findings, which emphasize the impact of anosognosia instead of neglect on poor recovery and functional outcome.[27]

The MVPT-V is an evaluation tool that is regularly used in rehabilitation as an instrument for detecting deficiencies in visual function. In previous studies reporting on the digital practice using VR to improve remapping of brain space, capitalizing on the deficit in an internal representation of the contra-lesional side of space among the hypotheses, they reported that only patients who had non-damaged inferior parietal and superior parietal lobes showed improvements.[5] It was subsequently presumed that this area played an important role in improving USN. Our study results are improvement in attention and arousal seemed to lead to improvement of neglect. Compared with trainings, a digital practice with VR can easily stimulate interest and participation because it gives immediate feedback to incorrect responses in a three-dimensional space [6], which keeps patients in an arousal state for a prolonged time.[11] Such effects are thought to have positive influences on improvement of attention and arousal, as compared with conventional training methods. In addition, the head-tracking sensor data was used to assess the unilateral spatial neglect. For example, neglect patients wore prism goggles that displaced the visual field 10° to the right, resulting in them visually perceiving objects to be situated 10° to the right of their actual location.[13]

The digital therapy with VR increased the head rotation degree and velocity, and this had a positive effect on the attention and arousal on the contra-lesional side of space. These effects were shown in max head rotation angle and max head rotation velocity. Head-tracking data could allow for attention to be tested in situations that are more ecologically valid. Subjects can be evaluated in an environment that simulates the real world, not a contrived testing environment. Previous studies have reported the effect of VR application when a patient is placed to grab a centrally placed physical object and the object provides a centered rearranged virtual reality.[28] Many VR applications focus on either the arm or the hand alone. Indeed, VR training paradigms have demonstrated encouraging results for use in upper extremity rehabilitation after stroke. Human task performance, however, predominantly requires coordinated use of both the head control, arm and hand. For example, the arm may stabilize hand position during object manipulation or the hand may maintain grasp of an object while the line of vision with head control moves the object to a new location. Yet, while gaming consoles are commonplace in clinical settings, the number of specialized VR programs designed for rehabilitation is relatively small. Using digital practice in the virtual environment, a person could be tested and trained on attention tasks that more systematically target specific levels of attention. These tasks include stimulus demands and response requirements that simulate real-world cognitive challenges.[4]

The necessary collaboration between clinicians and technicians to set up digital practice, and maintenance and use of a VR rehabilitation system with GR, should be further considered. In addition, it is crucial to take into account potential transient side effects of immersive VR, such as cyber-sickness, which occurs as a result of conflicts between visual, vestibular and proprioceptive signals. Technological advancements, reducing the VR sessions and giving precise explanations may alleviate any symptoms of discomfort. With the development of VR technology, several researchers have exploited the potential of digital practice for the rehabilitation of USN. The digital practice with VR can also improve traditional assessment methods by providing information about head movements, postural deviations, and limb kinematics, which can be useful in detecting subtle deficits.

These findings suggest that the use of digital practice may be more helpful in improving the degree of neglect in stroke patients than conventional training methods. However, the limitations of this study include the training applications. Participants performed general game applications from Oculus share and Leap Motion developers. And it was small because it was difficult to increase the number of patients treated in each group. Therefore, it is advisable to consider this data as a preliminary result. The digital practice could be more effective at improving degree of neglect, visual perception, and ADL, if the applications can be diversified and suitably applied to stroke patients with USN.

5. Conclusion

This study investigates the effects of digital practice on subacute stroke patients with USN. The results indicate that a combining these technologies improves the degree of neglect, and visual perception suggest that can be used for clinical rehabilitation. More effectively reduce patients' degree of neglect and improve their head-movement and visual perception stroke patients with USN.

Author contributions

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Validation: Dae-Hyouk Bang.

Visualization: Won-Seob Shin, Dae-Hyouk Bang.
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References

[1] Nijboer TC, Kollen BJ, Kwakkel G. Time course of visuospatial neglect early after stroke: a longitudinal cohort study. Cortex 2013;49:2021–7.
[2] Buxbaum L, Ferraro M, Veramonti T, et al. Hemispatial neglect subtypes, neuroanatomy, and disability. Neurology 2004;62:749–56.
[3] Pisella L, Mattingley JB. The contribution of spatial remapping impairments to unilateral visual neglect. Neurosci Biobehav Rev 2004;28:181–200.
[4] Rizzo AA, Buckwalter JG, Bowerly T, et al. The virtual classroom: a virtual reality environment for the assessment and rehabilitation of attention deficits. Cyberpsychol Behav 2000;3:483–99.
[5] Tsirlin I, Dupierrix E, Chokron S, et al. Uses of virtual reality for diagnosis, rehabilitation and study of unilateral spatial neglect: review and analysis. Cyberpsychol Behav 2009;12:175–81.
[6] Adamovich SV, Merians AS, Boian R, et al. A virtual reality-based exercise system for hand rehabilitation post-stroke. Presence Teleop Virt 2005;14:161–74.
[7] Kang SH, Kim DK, Seo KM, et al. Modifying and evaluating efficacy of interactive computerized program using motion tracking technology to improve unilateral neglect in patients with chronic stroke. Medicine 2018;97.
[8] Castiello U, Lusher D, Burton C, et al. Improving left hemispatial neglect using virtual reality. Neurology 2004;62:1958–62.
[9] Frassinetti F, Angeli V, Meneghello F, et al. Long-lasting amelioration of visuospatial neglect by prism adaptation. Brain 2002;125:608–23.
[10] Kurosu M. Human-Computer Interaction Advanced Interaction, Modalities, and Techniques. Heraklion, Crete, Greece: Springer; 2014.
[11] Kim YM, Chun MH, Yun GJ, et al. The effect of virtual reality training on unilateral spatial neglect in stroke patients. Ann Rehabil Med 2011;35:309–15.
[12] Folstein MF, Robins LN, Helzer JE. The mini-mental state examination. Arch Gen Psychiatry 1983;40:812.
[13] Rossetti Y, Rode G, Pisella L, et al. Hemispatial neglect and prism adaptation: when adaptation to rightward optical deviation rehabilitates the neglected left side. Nature 1998;395:166–9.
[14] Tung JY, Lulic T, Gonzalez DA, et al. Evaluation of a portable markerless finger position capture device: accuracy of the Leap Motion controller in healthy adults. Physiol Meas 2015;36:1025–35.
[15] Han J, Gold N. Lessons Learned in Exploring the Leap Motion™ Sensor for Gesture-based Instrument Design. Proceedings of the International Conference on New Interfaces for Musical Expression Goldsmiths, London, UK, 2014; 371–374.
[16] Schenkenberg T, Bradford D, Ajax E. Line bisection and unilateral visual neglect in patients with neurologic impairment. Neurology 1980;30: 509–17.
[17] Plummer P, Morris ME, Dunai J. Assessment of unilateral neglect. Phys Ther 2003;83:732–40.
[18] Azouvi P, Olivier S, De Montety G, et al. Behavioral assessment of unilateral neglect: study of the psychometric properties of the Catherine Bergego Scale. Arch Phys Med Rehabil 2003;84:51–7.
[19] Halligan P, Marshall J, Wade D. Visuospatial neglect: underlying factors and test sensitivity. Lancet 1989;334:908–11.
[20] Hobart J, Thompson A. The five item Barthel index. J Neurol Neurosurg Psychiatry 2001;71:225–30.
[21] Brown GT, Rodger S, Davis A. Motor-free visual perception test—revised: an overview and critique. Br J Occup Ther 2003;66:159–67.
[22] Cho DR, Lee SH. 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. Medicine 2019;98.
[23] Tsoupikova D, Stoykov NS, Corrigan M, et al. Virtual immersion for post-stroke hand rehabilitation therapy. Ann Biomed Eng 2015;43:467–77.
[24] Marques CLS, Souza JTd, Gonçalves MG, et al. Validation of the Catherine Bergego Scale in patients with unilateral spatial neglect after stroke. Dement Neuropsychol 2019;13:82–8.
[25] Kim YM, Chun MH, Yun GJ, et al. The effect of virtual reality training on unilateral spatial neglect in stroke patients. Ann Rehabil Med 2011;35:309.
[26] Jehkonen M, Laihosalo M, Kettunen J. Impact of neglect on functional outcome after stroke–a review of methodological issues and recent research findings. Restor Neurol Neurosci 2006;24:209–15.
[27] Paolucci S, Antonucci G, Grasso MG, et al. The role of unilateral spatial neglect in rehabilitation of right brain–damaged ischemic stroke patients: a matched comparison. Arch Phys Med Rehabil 2001;82:743–9.
[28] Glover S, Castiello U. Recovering space in unilateral neglect: a neurological dissociation revealed by virtual reality. J Cogn Neurosci 2006;18:833–43.