

Review

# Virtual reality for cognitive rehabilitation after brain injury: a systematic review

HYEONHUI SHIN<sup>1)</sup>, KYEONGMI KIM<sup>2)\*</sup>

<sup>1)</sup> Department of Rehabilitation Science, Graduate School of Inje University, Republic of Korea

<sup>2)</sup> Department of Occupational Therapy, College of Biomedical Sciences and Engineering, Inje University: 197 Inje-ro, Gimhae-si, Gyeongsangnam-do 621-749, Republic of Korea

**Abstract.** [Purpose] The purpose of this review was to investigate various types of VR programs and their use in cognitive evaluations and interventions for patients with brain injury. [Subjects and Methods] PubMed, Cochrane, and OTseeker electronic databases were searched with the search terms. At of 350 titles and abstracts were retrieved, and 17 articles were selected for this review. Selected articles were assessed on the level of evidence using the Physiotherapy Evidence Database (PEDro) scale. [Results] Articles assessing the impact of cognitive impairments in memory were most commonly found, and VR interventions elicited positive effects in patients with brain injury. [Conclusion] VR can be considered a new tool for cognitive rehabilitation after brain injury. VR interventions also have a number of advantages, e.g. cost-effectiveness, compared to other interventions.

**Key words:** Virtual reality, Brain injury, Systematic review

*(This article was submitted Apr. 21, 2015, and was accepted May 23, 2015)*

## INTRODUCTION

Brain injury is caused by intrinsic or extrinsic factors and it can result in various disabilities such as motor, sensory, behavioral, or cognitive dysfunction depending on the area of the brain lesion<sup>1)</sup>. Cognitive impairment due to brain injury is an important factor affecting patients' independent functions and participation in activities<sup>2)</sup>, interfering with their return to daily living and work<sup>3)</sup>. It can also influence motivation and the ability to participate in rehabilitation programs and interfere with a return to the community. Therefore, for successful rehabilitation, accurate and comprehensive cognitive assessment and treatment are required<sup>4)</sup>.

For cognitive rehabilitation of patients with brain injury, traditional treatment and computer-based cognitive therapy are primarily used. Virtual reality (VR) technology is gaining recognition as a useful tool for cognitive research, evaluation, and rehabilitation<sup>5)</sup>. VR systems allow users to interact in various sensory environments and to obtain real-time feedback on their performance using computer technology<sup>6)</sup>. The virtual environment offered via VR technology makes it possible for patients to participate in activities in settings and environments similar to those encountered in real life<sup>7, 8)</sup>. In addition, VR tools can be used to record accurate measurements of the subject's performance<sup>9)</sup> and to deliver

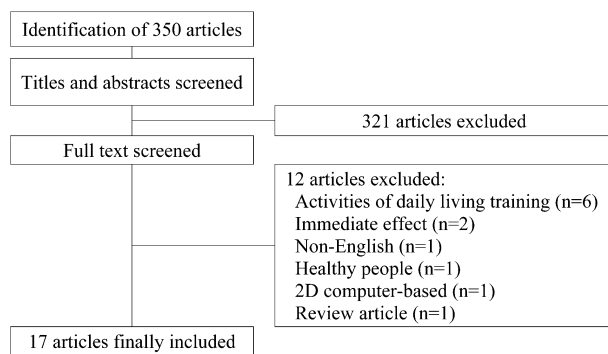
greater therapeutic stimulation to users<sup>5)</sup>. Recently, studies using VR programs to improve cognitive function have been reported<sup>9-11)</sup>. VR has been used as a tool to diagnose cognitive impairment and as a vehicle to provide new treatments<sup>5)</sup>. Although the use of VR in cognitive rehabilitation has been increasing, few systematic reviews have investigated the use of VR programs in cognitive rehabilitation and the overall effect of these programs on cognition. Therefore, this systematic review investigated the different types of VR programs used for cognitive evaluation and interventions for patients with brain injury. Studies using VR programs for cognitive intervention were reviewed according to PICO (patient, intervention, comparison, and outcome) methods.

## SUBJECTS AND METHODS

The PubMed, Cochrane, and OTseeker electronic databases were searched. The search terms were “(virtual reality OR virtual OR game based virtual reality OR computer based virtual reality) AND (stroke OR cerebral vascular accident OR hemiplegia OR brain injury OR traumatic brain injury) AND (cognition OR cognitive OR memory OR attention OR executive function).” Inclusion criteria were: (1) subjects over the age of 19 years with brain injury; (2) articles written in English; and (3) studies that used VR in cognitive rehabilitation. Exclusion criteria were: (1) subjects who were animals or children; (2) review articles; and (3) 2D computer-based cognitive rehabilitation.

Randomized controlled trials (RCTs) and crossover studies were scored on the Physiotherapy Evidence Database (PEDro) scale<sup>12)</sup>. Two authors independently assessed the methodological quality of the included studies, and disagreements were resolved by reaching consensus.

\*Corresponding author. KyeongMi Kim (E-mail: kmik321@inje.ac.kr)



**Fig. 1.** Flowchart of the article search and study selection

## RESULTS

A total of 350 articles were identified. Of these, 17 trials were included in the final review (Fig. 1). Twelve papers reported the study of cognitive assessment using VR. Memory assessment was the most common study topic, followed by assessments of executive function and attention. A variety of VR programs were used (Table 1). Five of the studies focused on VR interventions for cognitive impairment. Three were RCTs<sup>24–26</sup>, one was a crossover study<sup>27</sup>, and one was a case report<sup>28</sup>. Excepting the case report, four studies were assessed using the PEDro scale. Two studies<sup>24, 25</sup> scored 4, and the remaining two studies scored 3<sup>26</sup> and 1<sup>27</sup>, respectively. Table 2 presents the characteristics of the five studies.

## DISCUSSION

In this review, the types of VR programs that have been used in cognitive evaluations of patients with brain injury were identified and studies of cognitive interventions were reviewed according to PICO methods. In the included studies, the VR programs could distinguish the cognitive disability of patients in comparisons with healthy subjects. Thus, VR could be used as a new assessment method of the cognitive function of patients with brain injury. VR methods can accurately record subjects' performances<sup>9</sup>. Therefore, in contrast to conventional cognitive assessments, VR programs can provide consistently accurate measurements of cognitive function. However, some methodological problems were found in the reviewed articles. In most of the studies, the VR tool used was not compared with a standardized assessment tool, and the inter-rater reliability was not measured. Therefore, additional research is needed to address these methodological issues.

The five studies of cognitive therapy using VR all reported positive effects. In the assessment of cognitive function, the VR interventions resulted in improvements in the areas of memory and attention but not executive function. Ben-Yishay et al.<sup>29</sup> stated that to effectively raise cognitive function, normal attention is needed. If the ability to concentrate on external information is impaired, memory, problem-solving skills, and appropriate behavior may be difficult. Thus, they suggested that the impairment of attention due to brain injury may interfere with the recovery of other

**Table 1.** Analysis of studies of cognitive assessment using VR

Author, year	Assessment area	Type of VR
Brooks et al. 2004 <sup>13</sup>	prospective memory	Superscape VRT software
Kang et al. 2008 <sup>14</sup>	memory, attention, executive function	HMD (head-mounted display)
Knight et al. 2006 <sup>15</sup>	prospective memory	Microsoft FrontPage
Ku et al. 2009 <sup>16</sup>	memory, attention, executive function	HMD
Lengenfelder et al. 2002 <sup>17</sup>	divided attention	VR-driving simulator
Matheis et al. 2007 <sup>10</sup>	memory	VR Office
Rand et al. 2009 <sup>18</sup>	executive function	IREX
Raspelli et al. 2010 <sup>19</sup>	executive function	NeuroVR software
Raspelli et al. 2011 <sup>20</sup>	executive function	NeuroVR software
Skelton et al. 2006 <sup>21</sup>	spatial memory	Unreal engine
Sweeney et al. 2010 <sup>22</sup>	prospective memory	The Removals Task
Titov & Knight, 2005 <sup>23</sup>	memory	Microsoft FrontPage 2002

cognitive functions, such as memory, executive function, and planning. The results of this systematic review indicate that the cognitive improvement of attention using VR programs will have a positive impact on the recovery of general cognitive function. The advantage of cognitive rehabilitation using VR is that it provides a variety of environments similar to those encountered in real life<sup>30</sup>. The results of this review suggest that patients are more motivated in virtual environments than they are in conventional settings. Therefore, VR programs can be expected to lead to an improvement in cognitive function. In VR interventions, patients can be treated in a safe environment compared to real settings. In addition, VR programs can be tailored to the type of injury and easily adjusted to the level of cognitive disability, the complexity of a task, the reaction conditions, and the characteristics and patterns of feedback<sup>30</sup>. As VR systems are constantly evolving and becoming smaller and more easily adjustable, they can be expected to provide specialized therapy in new settings, such as patients' homes or clinics. These advantages of VR systems can benefit patients who find it difficult to visit health care organizations<sup>5</sup>.

The results of this systematic review suggest that VR is an effective cognitive therapy for patients with brain injury compared to control therapy. However, uncertainties remain because the included studies had methodological problems. In particular, there was a significant risk of bias with regard to allocation concealment and blinding. Given the heterogeneity of the included studies, the ability to draw conclusions is limited. Well-designed RCTs and blind studies will be needed to provide evidence of the benefits of VR on cognitive function. Meta-analyses are needed to derive comprehensive conclusions.

**Table 2.** Analysis of studies with cognitive interventions using VR

Study	Patient		Intervention		Comparison	Outcome	
	N	Mean age	Type of VR	Intensity		Outcome measure(s)	Findings
Akinwuntan et al., 2010 <sup>24)</sup>	69	EG 55 CG 54	STISIM Drive system	60 min/day, 3 times/week, total 5 weeks	Non-computer based cognitive therapy	UFOV test	Significant within group improvements but no significant difference between two groups
Caglio et al., 2012 <sup>28)</sup>	1	24	Midtown madness 2	90 min/day, 3 times/week, total 5 weeks	-	FDST, BDST, RAVLT-IR, DR, RBMT-IR, DR, Corsi's block tapping test, Corsi's supraspan test-IR, DR, TMT-A, B, Phonemic fluency MMSE, ADAS	Significant improvements in RAVLT-IR and Corsi's supraspan-IR, DR
Grealy et al., 1999 <sup>27)</sup>	13	32.38	Nonimmersive VR exercise bicycle	25 min/day, 3 times/week, total 4 weeks	No treatment	FDST, BDST, Digit symbol Test, TMT-A & B, Auditory learning test, VeLT, ViLT, Logical memory, Complex figure test	EG showed significant improvements in Digit symbol test, VeLT, ViLT compared to CG
Jacoby et al., 2013 <sup>25)</sup>	12	EG 27.83 CG 30.67	IREX	45 min/day, 3–4 times/week, total 3 weeks	Conventional OT	MET-SV, EFPT	EG showed significant improvements in all outcome measures compared to the CG
Kim et al., 2011 <sup>26)</sup>	28	EG 66.5 CG 62.0	IREX	30 min/day, 5 times/week, total 4 weeks	Computer based cognitive therapy	K-MMSE, TOL, VCPT, ACPT, Word-color test, FDST, BDST, FVST, BVST, ViLT, VeLT, TMT-A	Significant difference between experimental group and control group in VCPT and BVST

EG: experimental group, CG: control group, MET-SV: Multiple Errands Test-Simplified Version, EFPT: Executive Function Performance Test, FDST: forward digit span test, BDST: backward digit span test, TMT-A: trail making test-type A, TMT-B: trail making test-type B, VeLT: verbal learning test, ViLT: visual learning test, UFOV: Useful Field of view test, K-MMSE: Korean version of the Mini-mental status examination, TOL: Tower of London test, VCPT: Visual continuous performance test, ACPT: Auditory continuous performance test, FVST: forward visual span test, BVST: backward visual span test, RAVLT: Rey Auditory Verbal Learning Test, IR: immediate recall, DR: delayed recall, RBMT-The Rivermead Behavioural Memory Test, ADAS: Alzheimer's Disease Assessment Scale

## REFERENCES

- Roth EJ, Harvey RL: Rehabilitation of stroke syndrome. In: Physical Medicine and Rehabilitation. Philadelphia: Elsevier Health Sciences, 1996, pp 1053–1056.
- Leys D, Hénon H, Pasquier F: White matter changes and poststroke dementia. *Dement Geriatr Cogn Disord*, 1998, 9: 25–29. [[Medline](#)] [[CrossRef](#)]
- Zhang L, Abreu BC, Masel B, et al.: Virtual reality in the assessment of selected cognitive function after brain injury. *Am J Phys Med Rehabil*, 2001, 80: 597–604, quiz 605. [[Medline](#)] [[CrossRef](#)]
- Diamond PT, Felsenthal G, Macciocchi SN, et al.: Effect of cognitive impairment on rehabilitation outcome. *Am J Phys Med Rehabil*, 1996, 75: 40–43. [[Medline](#)] [[CrossRef](#)]
- Cherniack EP: Not just fun and games: applications of virtual reality in the identification and rehabilitation of cognitive disorders of the elderly. *Disabil Rehabil Assist Technol*, 2011, 6: 283–289. [[Medline](#)] [[CrossRef](#)]
- Saposnik G, Levin M, Outcome Research Canada (SORCan) Working Group: Virtual reality in stroke rehabilitation: a meta-analysis and implications for clinicians. *Stroke*, 2011, 42: 1380–1386. [[Medline](#)] [[CrossRef](#)]
- Broeren J, Claesson L, Goude D, et al.: Virtual rehabilitation in an activity centre for community-dwelling persons with stroke. The possibilities of 3-dimensional computer games. *Cerebrovasc Dis*, 2008, 26: 289–296. [[Medline](#)] [[CrossRef](#)]
- Henderson A, Korner-Bitensky N, Levin M: Virtual reality in stroke rehabilitation: a systematic review of its effectiveness for upper limb motor recovery. *Top Stroke Rehabil*, 2007, 14: 52–61. [[Medline](#)] [[CrossRef](#)]
- Parsons TD, Rizzo AA: Initial validation of a virtual environment for assessment of memory functioning: virtual reality cognitive performance assessment test. *Cyberpsychol Behav*, 2008, 11: 17–25. [[Medline](#)] [[CrossRef](#)]
- Matheis RJ, Schultheis MT, Tiersky LA, et al.: Is learning and memory different in a virtual environment? *Clin Neuropsychol*, 2007, 21: 146–161. [[Medline](#)] [[CrossRef](#)]
- Parsons TD, Larson P, Kratz K, et al.: Sex differences in mental rotation and spatial rotation in a virtual environment. *Neuropsychologia*, 2004, 42: 555–562. [[Medline](#)] [[CrossRef](#)]
- Sherrington C, Herbert RD, Maher CG, et al.: PEDro. A database of randomized trials and systematic reviews in physiotherapy. *Man Ther*, 2000, 5: 223–226. [[Medline](#)] [[CrossRef](#)]
- Brooks BM, Rose FD, Potter J, et al.: Assessing stroke patients' prospective memory using virtual reality. *Brain Inj*, 2004, 18: 391–401. [[Medline](#)] [[CrossRef](#)]
- Kang YJ, Ku J, Han K, et al.: Development and clinical trial of virtual reality-based cognitive assessment in people with stroke: preliminary study. *Cyberpsychol Behav*, 2008, 11: 329–339. [[Medline](#)] [[CrossRef](#)]
- Knight RG, Titov N, Crawford M: The effects of distraction on prospective remembering following traumatic brain injury assessed in a simulated naturalistic environment. *J Int Neuropsychol Soc*, 2006, 12: 8–16. [[Medline](#)] [[CrossRef](#)]
- Ku J, Lee JH, Han K, et al.: Validity and reliability of cognitive assessment using virtual environment technology in patients with stroke. *Am J Phys Med Rehabil*, 2009, 88: 702–710. [[Medline](#)] [[CrossRef](#)]
- Lengenfelder J, Schultheis MT, Al-Shihabi T, et al.: Divided attention and driving: a pilot study using virtual reality technology. *J Head Trauma Rehabil*, 2002, 17: 26–37. [[Medline](#)] [[CrossRef](#)]
- Rand D, Basha-Abu Rukan S, Weiss PL, et al.: Validation of the Virtual MET as an assessment tool for executive functions. *Neuropsychol Rehabil*, 2009, 19: 583–602. [[Medline](#)] [[CrossRef](#)]
- Raspelli S, Carelli L, Morganti F, et al.: Implementation of the multiple errands test in a NeuroVR-supermarket: a possible approach. *Stud Health Technol Inform*, 2010, 154: 115–119. [[Medline](#)]
- Raspelli S, Pallavicini F, Carelli L, et al.: Validation of a Neuro Virtual Reality-based version of the Multiple Errands Test for the assessment of executive functions. *Stud Health Technol Inform*, 2011, 167: 92–97. [[Medline](#)]

- 21) Skelton RW, Ross SP, Nerad L, et al.: Human spatial navigation deficits after traumatic brain injury shown in the arena maze, a virtual Morris water maze. *Brain Inj*, 2006, 20: 189–203. [[Medline](#)] [[CrossRef](#)]
- 22) Sweeney S, Kersel D, Morris RG, et al.: The sensitivity of a virtual reality task to planning and prospective memory impairments: group differences and the efficacy of periodic alerts on performance. *Neuropsychol Rehabil*, 2010, 20: 239–263. [[Medline](#)] [[CrossRef](#)]
- 23) Titov N, Knight RG: A computer-based procedure for assessing functional cognitive skills in patients with neurological injuries: the virtual street. *Brain Inj*, 2005, 19: 315–322. [[Medline](#)] [[CrossRef](#)]
- 24) Akinwuntan AE, Devos H, Verheyden G, et al.: Retraining moderately impaired stroke survivors in driving-related visual attention skills. *Top Stroke Rehabil*, 2010, 17: 328–336. [[Medline](#)] [[CrossRef](#)]
- 25) Jacoby M, Averbuch S, Sacher Y, et al.: Effectiveness of executive functions training within a virtual supermarket for adults with traumatic brain injury: a pilot study. *IEEE Trans Neural Syst Rehabil Eng*, 2013, 21: 182–190. [[Medline](#)] [[CrossRef](#)]
- 26) Kim BR, Chun MH, Kim LS, et al.: Effect of virtual reality on cognition in stroke patients. *Ann Rehabil Med*, 2011, 35: 450–459. [[Medline](#)] [[CrossRef](#)]
- 27) Grealy MA, Johnson DA, Rushton SK: Improving cognitive function after brain injury: the use of exercise and virtual reality. *Arch Phys Med Rehabil*, 1999, 80: 661–667. [[Medline](#)] [[CrossRef](#)]
- 28) Caglio M, Latini-Corazzini L, D'Agata F, et al.: Virtual navigation for memory rehabilitation in a traumatic brain injured patient. *Neurocase*, 2012, 18: 123–131. [[Medline](#)] [[CrossRef](#)]
- 29) Ben-Yishay Y, Piasetsky EB, Rattock J: A systematic method for ameliorating disorders in basic attention. In: *Neuropsychological rehabilitation*. New York: Guilford Press, 1987, pp 165–181.
- 30) Lee NY, Lee DK, Song HS: Effect of virtual reality dance exercise on the balance, activities of daily living, and depressive disorder status of Parkinson's disease patients. *J Phys Ther Sci*, 2015, 27: 145–147. [[Medline](#)] [[CrossRef](#)]