Virtual Reality Applications in Rehabilitation

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Abstract. One of the most valuable applications of virtual reality (VR) is in the domain of rehabilitation. After brain injuries or diseases, many patients suffer from impaired physical and/or cognitive capabilities, such as difficulties in moving arms or remembering names. Over the past two decades, VR has been tested and examined as a technology to assist patients' recovery and rehabilitation, both physical and cognitive. The increasing prevalence of low-cost VR devices brings new opportunities, allowing VR to be used in practice. Using VR devices such as head-mounted displays (HMDs), special virtual scenes can be designed to assist patients in the process of re-training their brain and reorganizing their functions and abilities. However, such VR interfaces and applications must be comprehensively tested and examined for their effectiveness and potential side effects. This paper presents a review of related literature and discusses the new opportunities and challenges. Most of existing studies examined VR as an assessment method rather than a training/exercise method. Nevertheless, promising cases and positive preliminary results have been shown. Considering the increasing need for self-administered, home-based, and personalized rehabilitation, VR rehabilitation is potentially an important approach. This area requires more studies and research effort.

Keywords: Virtual reality · Virtual rehabilitation · Cognitive impairment · Biomedical engineering

1 Introduction

Virtual reality (VR) technologies use multimedia devices and computer simulation to allow users to interact with a simulated environment, creating life-like experience. Display devices present sensory information, such as vision, auditory, and touch sense, to the user; control devices collect user actions such as motion, gesture, and voices. The term VR is a very broad term, and researchers have used it to refer to a wide range of systems. A system using motion sensing gloves and a desktop display can be called VR, which emphasizes life-like hand control and feedback. In some studies, especially early studies, a system using standard computer input (keyboard and mouse) and output (desktop displays) devices can also be called VR, which emphasizes the virtual environment generated by the software. In this sense, many first-person computer games can be called VR. Recently, VR is used more to specifically referring to systems using head-mounted displays (HMDs), which can create 3D depth perception and change the view as the head moves.

M. Kurosu (Ed.): HCI 2016, Part I, LNCS 9731, pp. 3–10, 2016.
DOI: 10.1007/978-3-319-39510-4_1

Since VR enables users to gain experience without exposing them to risks in the real environment, VR has been widely used for gaming and training purposes. A relatively new and less explored area of VR applications is rehabilitation, helping patients who have lost some of their physical and/or cognitive abilities to regain the abilities. The goals of the current paper are to summarize recent research efforts, discuss the benefits and potential side effects of VR, and discuss practical issues for researchers who are interested in conducting their studies in this area.

In general, rehabilitation in healthcare refers to the treatment and process to restore good health and regain impaired functions and abilities. The impaired functions can be categorized into physical and cognitive groups. Physical functions include movement and control of physical body parts such as limbs, hands, fingers, and head. In contrast, cognitive functions are related to information processing such as vision, hearing, task execution, memory, and decision. While some loss of physical functions happens in the motor system, the most challenging cases are due to injuries or diseases in the central neuron system (i.e., brain). Different brain areas are in charge of different functions. The type of function loss depends on the damaged area. In Parkinson's disease, the degeneration of brain cells mainly affects the motor system, so the symptoms are mainly related to walking and hand movement. In Alzheimer's disease however, the degeneration of brain cells starts in brain areas that control cognitive functions, so memory and language are mostly affected. For stroke and traumatic brain injuries, the impaired functions can be both physical and cognitive, depending on the specific areas of damage.

Current neuroscience theories commonly believe that adult brains have very limited capability to replace damaged and dead cells, but new connections can be formed between existing cells to support reorganization of impaired brain functions [1, 2]. Rehabilitation therapy and treatment often use repetitive physical and cognitive exercises as a way to stimulate neuron reorganization and achieve restoring and regaining some functions and abilities. Complete recovery is not common, but many patients can gain improved quality of life and do better in their activities of daily life (ADL). In general, there are the following five important components in a rehabilitation program [3].

1. Diagnostic assessment and evaluation.
2. Introducing assistant devices.
3. Educating the patients about the diseases.
4. Repeated practice of exercise and training activities.
5. Developing compensation and adaptation strategies.

Most of the existing studies using VR in rehabilitation mainly focused on applications in Step 1 Assessment. A relatively small number of studies have also examined the effectiveness of VR designed for Step 4 Exercise.

2 Previous VR Applications in Rehabilitation

2.1 VR Applications for Rehabilitation Assessment

Many studies have examined VR as a tool to assess the level and type of cognitive impairment; for reviews, see [4, 5]. The following studies are reviewed as an illustration of typical research in this area. An early study in 1998 used HMD (486 PC platform) to present a household kitchen environment [6]. A meal preparation task was used to evaluate memory and executive functions of patients with traumatic brain injury (TBI). Thirty participants were tested twice within 7 to 10 days, and the results showed good test-retest reliability; however, there was no comparison between VR and traditional assessment methods.

A study in 1999 [7] reported an HMD-VR system (Pentium 166 MHz) developed to assess patients' driving abilities. Driving test performance such as lane keeping and stop sign stopping were compared between 17 brain-injured adults and uninjured participants matched in age, gender, and education. The results showed some trend of worse performance by brain-injured patients, but no statistical significance was reported.

A study in 2008 [8] showed that HMD-VR (Onyx2 Reality; 640×480) can be used to differentiate two types of Parkinson's disease. Participants were asked to walk while wearing the system that showed a virtual corridor with optic flow. Patients with predominant left-hemisphere dysfunction deviated right of centre, whereas patients with predominant right-hemisphere dysfunction did not.

In a recent study in 2012 [9], the authors implemented a simple driving simulation with PC and a projector, which allows a user to navigate a virtual city or town passively as a passenger or actively as a driver. After the exploration, participants' episodic memory about the virtual place was tested in recall and recognition questions. The results showed that the method was sensitive enough to tell the difference between three groups, healthy older adults, early clinical manifestations of Alzheimer's disease, and amnesic mild cognitive impairment.

2.2 VR Applications for Rehabilitation Exercise

In contrast to the high number of rehabilitation assessment studies, there are very few studies that have investigated VR applications in rehabilitation training and exercise. In a case report in 2001 [10], a 65-year old woman with impaired memory functions received a 24-week rehabilitation exercise with both music-story therapy and HMD-VR experiences (Pentium III) that visualized the scenes told in the stories. The results showed improved clinical conditions, and the authors suggested that the interactive and immersive features of VR could benefit music-enhanced therapy and better involve the patient during the training.

A later controlled study by the same research group in 2010 [11] compared HMD-VR memory training (Pentium III) and traditional face-to-face music training, where the participants were encouraged to sing and play music instruments, in six months. The VR scenes included home, park, and streets familiar to the participants. The tasks were exploration and navigation using a joystick. The results showed that the VR training was more effective than the music therapy training. The fifteen elderly patients (with memory deficits) in the VR group showed significantly improved memory test scores; in contrast, the sixteen elderly patients in the control group of the face-to-face music therapy showed progressive declined memory.

In addition to HMD-VR studies, there are also studies demonstrating the effectiveness of non-wearable VR systems using computer monitors or projectors as displays.

An early study in 1999 [12] reported the case of an amnesia patient (female, age 53) who received route finding training and testing in eight weeks using a desktop VR system (Pentium 133 MHz; 15″ monitor). She was able to learn the three routes practiced in VR but not the one route practiced in the real world. A potential explanation is that training in VR allows the isolation of the core route knowledge and avoids the distraction of other objects and events in the real world.

A study in 2003 [13] examined a simple VR shopping exercise created by digital photos, programmed navigation steps, and interactive functions on a touch screen. Nine patients with Alzheimer's disease received four-week training. Their performance (speed and error rates) and Mini-Mental State Examination (MMSE) scores improved after the training and sustained after following-up three weeks later.

A recent study in 2011 [14] examined a desktop VR exercise where patients see their image mirrored in a virtual space and wave hands to hit virtual targets. Fifteen stroke patients were assigned to the VR group, where they received the VR exercise and computer-based cognitive rehabilitation training (tasks such as matching cards, memorizing numbers, and finding pictures by names); thirteen patients were assigned to the control group, where they received only the cognitive rehabilitation training. The results after four-week training showed that the VR group had significantly larger improvement than the control group in visual attention and short-term visuospatial memory related tests.

An interesting study in 2013 [15] examined desktop VR vocational training on schizophrenic patients with cognitive impairments. The VR environment (Pentium IV; 38″ monitor) simulates a clothes shop where the patient was trained for a shop clerk job, performing tasks such as sorting clothes and handling customers' requests. The results showed that VR vocational training was more effective than therapist-administered vocational training and conventional training without the shop scenario, in terms of better problem solving and executive control abilities measured by Wisconsin Card Sorting Test and better self-efficacy scores. The findings suggest that an immersive environment and real-world purposes are both important in rehabilitation.

It would be interesting to compare VR implemented on HMDs and desktop displays. Since 2D displays are less expensive and more available, if VR training using desktop displays can be equally effective for certain types of exercises, there will be no need to use HMDs. Previous studies showed that both HMD and non-wearable VR systems have value for rehabilitation. Unfortunately, no study found in the current review directly compared HMD-VR with non-wearable VR.

3 Potential Advantages and Side Effects of VR Rehabilitation

Although there is not sufficient evidence to confirm the effectiveness of VR exercise or its advantages over traditional training methods, it is expected to have several benefits in comparison to conventional computer-based rehabilitation training [16, 17].

1. Increase the degrees of immersion and interaction (especially HMD-VR), making the exercise interesting and motivating persistent practice.
2. Allow tests and exercise of activities (such as driving) that would be too dangerous for patients to do in the real world.

3. Allow tests and exercise (such as visual perception and field of view tasks) that are otherwise too difficult, time-consuming, or impossible to do in the real world.

As a computerized method, VR rehabilitation also has similar benefits as computer-based rehabilitation training over traditional therapist administered training, for example, improved standardization of protocols, better control of stimulus presentation, and easier collection of response measures.

However, the potential side effects of VR must be thoroughly studied before wider rehabilitation applications of the technology. The first major area of concern is simulator sickness. It is a kind of motion sickness experienced by people in motion or vehicle simulation. In most virtual simulators, the visual and auditory stimuli can be presented closer to real-life experience, but real acceleration and orientation are difficult to create. The discrepancies between the stronger motion perceived by vision and hearing and the weaker motion perceived by the vestibular system and proprioception can lead to simulator sickness. Typical syndromes include discomfort, fatigue, nausea, and disorientation.

From the literature, it seems that there is a large individual difference in simulator sickness. There are case studies that reported no or little simulator sickness, e.g., [6]. There are also cases where participants were excluded due to strong simulator sickness. In 2000, Kesztyues et al. [18] compared the difference of side effects between a HMD (800×600; Pentium-II 266 MHz; two Vodoo2 graphic cards) and a projector. Simulator sickness was measured by a subjective questionnaire—Simulator Sickness Questionnaire (SSQ) [19]. The tasks were to navigate (walking) and find targets in relatively simple virtual environments (a maze and a park). Valid results were collected from 21 healthy participants (most in age 20–29). One of them (5 %) could not complete the tasks using HMD due to strong nausea. For both HMD and projector conditions, simulator sickness was reported, but the levels were considered tolerable.

Since the level of simulator sickness also depends on the device (HMD vs. non-wearable displays) and the type of tasks (e.g., walking vs. driving), these factors need be considered for the cost-benefit trade-off of VR rehabilitation.

The second major group of side effects is eye strains related issues, such as eye dryness, redness, discomfort, and reduced visual acuity. Some subjective measuring methods of simulator sickness (e.g., SSQ) include eye fatigue and discomfort as part of the scales. The effects of using standard non-wearable displays have been relatively well-established as the computer vision syndrome [20]. Regarding HMD, previous studies have examined its effects on visual perception (e.g., flicker fusion frequency, distance estimation), subjective comfort (e.g., fatigue, comfort), and visual acuity [21]. In comparison to projectors, HMDs were reported to result in significantly higher levels of subjectively reported eye strains and fatigue [18]. However, there is a lack of evidence for comparison about eye dryness and redness between HMDs and standard displays. These important ocular health concerns require future research.

The third area of concern is related to particular groups of patients who are afraid of new devices or are very sensitive to their environment. For example, introducing VR devices may agitate schizophrenia patients with persecutory delusion and paranoia. The cost-benefit trade-off of using VR rehabilitation needs to be evaluated for each patient based on their specific cases. There is no existing standard or guideline available in the literature.

4 Practical Issues for Researchers in This Field

HMD vs. Standard Display. Wearable HMDs are expected to create better immersion and life-like experience than standard non-wearable displays (e.g., desktop monitor, projector) because HMDs support 3D depth perception through binocular discrepancy and a dynamic field of view through head tracking. However, many participants reported oppressiveness using HMD [18]. It is very difficult to wear HMD while wearing frame glasses. Cost-benefit analysis should be conducted to select a suitable display for each kind of VR rehabilitation applications.

Control Groups. Many existing studies (especially case studies) lack the comparison between VR and traditional rehabilitation methods. A control group that consists of randomly assigned patients with matching background is needed.

Access to Patients. It is important to have access to a large patient pool. This may be achieved by collaborating with hospitals and assisted home care providers. When planning a study, researchers should be prepared that many patients may be ineligible or refuse to participate for various reasons, and elderly patients may die or become unable to continue their participation later in the study. For example, in one study focusing on elderly patients (age 65 years or older) with cognitive impairments, 159 individuals lived in a rest-care home were assessed for eligibility, 123 (77 %) were excluded, 5 died or left the rest-care home during the study, and finally data from only 31 individuals (19 %) were good for analysis [11].

Ethics and Safety. Although VR rehabilitation does not involve medication and drugs, research ethics and safety of patients still require careful planning and administration. The ethics review process may take a long time, especially if the VR device is categorized as a medical device by the reviewing authority. Safety of the participants needs to be considered not only during but also after the experiment. In one case [22], the authors specifically emphasized the importance of arranging transportation for elderly persons after they have participated in a VR study. Because even if one case of a car accident happened after exposing to VR, it would be extremely detrimental to the research project, no matter whether there was a causal link or not between VR and the accident.

Development Cost. The cost of VR devices have dropped significantly during the last decade. An HMD device can be purchased with only a few hundred dollars right now. However, the programming and development of the virtual scenes and interactions still require a lot of effort. Time and programmer salaries should be properly estimated when writing research proposals, especially if customized virtual scenes for each individual is needed.

5 Conclusions

Over the past two decades, VR applications have been proposed and examined for rehabilitation purposes. Existing studies are mostly preliminary ones with low participant numbers, and most studies examined VR as an assessment method rather than a training/ exercise method. The reviewed case studies and control studies showed positive and promising results of using VR for rehabilitation exercise. Considering the increasing availability of low-cost VR devices and the increasing need for self-administered, home-based, and personalized rehabilitation approaches, VR applications are expected to play an important role in reducing healthcare cost and improving rehabilitation outcomes. The existing literature lacks controlled studies to support cost-benefit analysis required for practical applications. More studies are needed to examine the effectiveness and side effects of VR systems, especially HMD-VR, for health and work rehabilitation.

References

1. Lee, W.-C.A., Huang, H., Feng, G., Sanes, J.R., Brown, E.N., So, P.T., Nedivi, E.: Dynamic remodeling of dendritic arbors in GABAergic interneurons of adult visual cortex. PLoS Biol. **4**, e29 (2005)
2. Buonomano, D.V., Merzenich, M.M.: Cortical plasticity: from synapses to maps. Annu. Rev. Neurosci. **21**, 149–186 (1998)
3. Raymond, M.J., Bennett, T.L., Malia, K.B., Bewick, K.C.: Rehabilitation of visual processing deficits following brain injury. NeuroRehabilitation **6**, 229–239 (1996)
4. Rizzo, A., Kim, G.: A SWOT analysis of the field of virtual reality rehabilitation and therapy. Presence **14**, 119–146 (2005)
5. Rose, F.D., Brooks, B.M., Rizzo, A.A.: Virtual reality in brain damage rehabilitation: review. Cyberpsychol. Behav. **8**, 241–262 (2005)
6. Christiansen, C., Abreu, B., Ottenbacher, K., Huffman, K., Masel, B., Culpepper, R.: Task performance in virtual environments used for cognitive rehabilitation after traumatic brain injury. Arch. Phys. Med. Rehabil. **79**, 888–892 (1998)
7. Liu, L., Miyazaki, M., Watson, B.: Norms and validity of the DriVR: a virtual reality driving assessment for persons with head injuries. Cyber Psychol. Behav. **2**, 53–67 (1999)
8. Davidsdottir, S., Wagenaar, R., Young, D., Cronin-Golomb, A.: Impact of optic flow perception and egocentric coordinates on veering in Parkinson's disease. Brain **131**, 2882–2893 (2008)
9. Plancher, G., Tirard, A., Gyselinck, V., Nicolas, S., Piolino, P.: Using virtual reality to characterize episodic memory profiles in amnestic mild cognitive impairment and Alzheimer's disease: influence of active and passive encoding. Neuropsychologia **50**, 592–602 (2012)
10. Optale, G., Capodieci, S., Pinelli, P., Zara, D., Gamberini, L., Riva, G.: Music-enhanced immersive virtual reality in the rehabilitation of memoryrelated cognitive processes and functional abilities: a case report. Presence Teleoperators Virtual Environ. **10**, 450–462 (2001)
11. Optale, G., Urgesi, C., Busato, V., Marin, S., Piron, L., Priftis, K., Gamberini, L., Capodieci, S., Bordin, A.: Controlling memory impairment in elderly adults using virtual reality memory training: a randomized controlled pilot study. Neurorehabil. Neural Repair. **24**, 348–357 (2010)
12. Brooks, B.M.: Route learning in a case of amnesia: a preliminary investigation into the efficacy of training in a virtual environment. Neuropsychol. Rehabil. **9**, 63–76 (1999)
13. Hofmann, M., Rösler, A., Schwarz, W., Müller-Spahn, F., Kräuchi, K., Hock, C., Seifritz, E.: Interactive computer-training as a therapeutic tool in Alzheimer's disease. Compr. Psychiatry **44**, 213–219 (2003)

14. Kim, B.R., Chun, M.H., Kim, L.S., Park, J.Y.: Effect of virtual reality on cognition in stroke patients. Ann. Rehabil. Med. **35**, 450–459 (2011)
15. Tsang, M.M.Y., Man, D.W.K.: A virtual reality-based vocational training system (VRVTS) for people with schizophrenia in vocational rehabilitation. Schizophr. Res. **144**, 51–62 (2013)
16. Schultheis, M.T., Rizzo, A.A.: The application of virtual reality technology in rehabilitation. Rehabil. Psychol. **46**, 296 (2001)
17. Cherniack, E.P.: Not just fun and games: applications of virtual reality in the identification and rehabilitation of cognitive disorders of the elderly. Disabil. Rehabil. Assist. Technol. **6**, 283–289 (2011)
18. Kesztyues, T.I., Mehlitz, M., Schilken, E., Weniger, G., Wolf, S., Piccolo, U., Irle, E., Rienhoff, O.: Preclinical evaluation of a virtual reality neuropsychological test system: occurrence of side effects. Cyberpsychol. Behav. **3**, 343–349 (2000)
19. Kennedy, R.S., Lane, N.E., Berbaum, K.S., Lilienthal, M.G.: Simulator sickness questionnaire: an enhanced method for quantifying simulator sickness. Int. J. Aviat. Psychol. **3**, 203–220 (1993)
20. Rosenfield, M.: Computer vision syndrome: a review of ocular causes and potential treatments. Ophthalmic Physiol. Opt. **31**, 502–515 (2011)
21. Nichols, S., Patel, H.: Health and safety implications of virtual reality: a review of empirical evidence. Appl. Ergon. **33**, 251–271 (2002)
22. McGee, J.S., van der Zaag, C., Buckwalter, J.G., Thiebaux, M., Van Rooyen, A., Neumann, U., Sisemore, D., Rizzo, A.A.: Issues for the assessment of visuospatial skills in older adults using virtual environment technology. Cyberpsychol. Behav. **3**, 469–482 (2000)