Novel Virtual Reality Application in Field of Neurorehabilitation

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Highlights

• Virtual reality (VR) technologies have been developed and are used variously in the field of medicine.
• VR-assisted neurorehabilitation can be applied in motor, sensori-motor, cognitive, activities of daily living (ADL), and telerehabilitation.
• Recent advances of VR technologies and their clinical use in the field of neurorehabilitation are reviewed.
Virtual reality (VR) therapy has many benefits to promote neurological and functional recovery in the field of neurorehabilitation after brain injury. VR-assisted neurorehabilitation can be applied in motor, sensori-motor, cognitive, activities of daily living (ADL), and telerehabilitation. Recent reports found that VR therapy appears to be a safe intervention that is effective at improving arm function and ADL function following stroke. Greater improvements were seen at a higher VR therapeutic dose. There has been insufficient evidence that VR therapy improved lower extremity gait speed, balance, and cognitive function after brain injury. As a result, the number of commercially available devices have increased and large-scale controlled trials have reported positive effects recently. Interface devices, various feedback methods, and the advancement of augmented reality technology are quickly developing, therefore, the potential value of VR therapy in neurorehabilitation will be high and its clinical application will be diversified.

Keywords: Virtual Reality; Rehabilitation; Stroke

INTRODUCTION

Virtual reality (VR) has been defined as the “use of interactive simulations created with computer hardware and software to present users with opportunities to engage in environments that appear and feel similar to real-world objects and events” [1]. VR technology, based on advanced computer technology, was initially used for exposure therapy for patients with phobia and as a simulator for surgical training in the medical field. It currently has been expanding its application field, particularly in the rehabilitation field for uses such as physical therapy, cognitive rehabilitation program, activities of daily living (ADL) training, and occupational therapy. Furthermore, the application of VR has been widely applied to telerehabilitation and so on.

The previous studies suggest that the current amount of rehabilitation therapy is insufficient to cause significant brain reorganization and brain plasticity after stroke [2]. Additional rehabilitation training may be effective in restoring stroke, though it would require a change in the paradigm of conventional treatment, which depends on the therapist. Rehabilitation using VR technology allows patients to be trained by themselves, is repetitive so that the
amount of the training can be increased, and it could change the rehabilitation environment which currently depends on the therapist’s resources. Additionally, combined mobile and VR technology could provide objective records regarding a patient’s performance history that could be effectively used for setting the therapeutic strategy.

In this article, we reviewed VR technology advances and their clinical applications in the field of neurorehabilitation (especially for stroke patients), its therapeutic level of evidence, and introduced a new VR application field with robots, neuromodulation, brain computer interface (BCI), and telerehabilitation.

**RECENT ADVANCED VR TECHNOLOGIES IN NEUROREHABILITATION**

The VR hardware have been greatly improved. Recently introduced is the head mounted display (HMD) from Oculus or Vive system, which could provide a much more realistic and immersive environment (Fig. 1A and B). Even more recently, a mobile version of the HMD has been utilized. In addition, other interactive methods, such as a walking platform or body tracking system, have also been recently introduced (Fig. 1C and D).

VR has great advantages when applied in the field of neurorehabilitation. VR has characteristics to provide an immersive and illusionary environment so that a user can interact as if he/she was actually there and can even regard the virtual body as if it were their own. The virtual environments have been designed to increase one’s engagement so that patients would receive the rehabilitation therapy without boredom and positive outcomes could be expected as a result. In addition, this environment could be very attractive because well-designed environments could evoke the sensations or illusions, thereby activating corresponding neural circuits and facilitate neural plasticity.

Technological advances regarding the interaction between a computer and VR allows for more realistic environments for the user, enabling very realistic spatial-temporal stimuli in order to help the user learn various skills. Particularly, there have been many emerging studies reporting that visual stimuli provided by VR could activate the mirror neuron system (MNS) as well as large-scale cortical regions through various feedback mechanisms, which could promote patients’ neuroplasticity following a brain injury [3,4].

**VR-ASSISTED REHABILITATION**

It has been suggested that VR is beneficial in several population groups including stroke survivals, Parkinson’s sufferers, multiple sclerosis sufferers, and hospitalized older adults. This section will introduce the major VR interventions according to main outcome.

**Upper extremity function**

Over 50% of patients after stroke consistently suffer from upper limbs disability even after treatment. It has been insisted that conventional intervention would not be enough to induce the meaningful brain reorganization and plasticity [2]. Recently, VR technology has proven its ability to provide realistic or augmented environments which could facilitate
physical learning using various feedback mechanisms. Thus, its importance has increased in rehabilitation for upper limbs function.

Previous studies on the effects of existing programs that introduced simple gamification such as Playstation (Sony, Tokyo, Japan) and Nintendo Wii (Nintendo, Kyoto, Japan) in the upper extremity rehabilitation of patients with stroke have not been sufficiently evidenced in terms of the number of subjects and the amount of research [5]. This result is thought to be due to the lack of equipment available before 2010 and because the program was developed using the existing entertainment game market, which was not useful for rehabilitation purposes in terms of content and equipment. Recently, however, the variety of commercially available equipment has been increasing (Table 1) and reports of positive studies in large-scale patient control studies have been reported. According to the Cochrane Review of 2017, VR and interactive video game therapy in post-stroke rehabilitation does not improve upper limb function in comparison to the same amount of conventional rehabilitation, but when applied in addition to conventional treatment, the upper limb function was better than the single treatment alone [6].
Lower extremity function (gait speed and balance)

The recent Cochrane Review revealed that there was insufficient evidence to reach conclusions about the effect of VR and interactive video gaming on gait speed and balance [6]. However, trials have been continued to apply VR or gamification paradigm to the field of balance and lower extremity training. Several commercial game consoles have also been developing [7-9]. In this kind of system, a patient could experience an interactive VR game displayed on the screen using a balance plate, remote control sensor, or motion capture camera. Patients could also be trained more effectively with various interfaces by also incorporating VR to improve pedal force with cycling [10], or stand balance on the treadmill [11] or the motion platform [12] which provides movements in several directions.

Activity of daily diving and activity training

VR has many great advantages over other forms of ADL rehabilitation and activity training because it offers a safe realistic training environment. Using VR technology, we can assess patients in ways relevant to daily living, which provides a level of realism unattainable by other techniques. According to a recent Cochrane Review [6], VR may be beneficial in ADL function when used as an adjunct to usual care (to increase overall therapy time). Most studies adopted few commercial game consoles (Eye Toy game, IREX) on ADL training [13,14] and several trials involved activity training, automobile driving retraining [15], scooter driving retraining [16], and retraining skills in using public transport [1].

Cognitive rehabilitation

To date, assessment of cognitive function has been extensively used in written tests and in recent computerized cognitive function evaluation. However, they cannot accurately reflect the impairment of cognitive function in daily life. VR can simulate the real environment, so there is a great advantage in evaluating and treating cognitive and behavioral disorders, such as assessing the necessary cognitive elements in a simulated environment. Furthermore, training and correcting behavioral disorders is achieved by exposing them to specific environments. Since 2000, attempts have been made to evaluate and train attention, memory, executive function, and spatial perception through VR programs [17], but clinical trials are still lacking and the development of practically usable equipment and evidences about its usefulness is still necessary [6].

Kim et al. [18] reported that subacute stroke patients with unilateral spatial neglect improved more when VR training using the IREX system was applied. In another subacute stroke group, visual attention and short-term visuospatial memory function was more improved.

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Table 1. Commercially available gaming consoles or VR programs in the field of neurorehabilitation

<table>
<thead>
<tr>
<th>Training</th>
<th>Name of product</th>
<th>Company</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper extremity function</td>
<td>Eye Toy</td>
<td>Playstation</td>
</tr>
<tr>
<td></td>
<td>IREX</td>
<td>GestureTek</td>
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<td></td>
<td>Armeo</td>
<td>Hocoma</td>
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<td>CAREN</td>
<td>Motek Medical</td>
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<td></td>
<td>RGS</td>
<td>SPECS Research Laboratory</td>
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<tr>
<td>Lower extremity function</td>
<td>Wii Fit balance</td>
<td>Nintendo</td>
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<td></td>
<td>X-box Kinect</td>
<td>Microsoft</td>
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<tr>
<td></td>
<td>3Dweb VR treadmill training</td>
<td>Superscape</td>
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<td></td>
<td>Locomat</td>
<td>Hocoma</td>
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<td></td>
<td>Balance Rehabilitation Unit+</td>
<td>Medicaa Balance Suite</td>
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<tr>
<td>Neglect</td>
<td>RehAtt</td>
<td>BrainStimulation</td>
</tr>
<tr>
<td>ADL</td>
<td>IREX (V mall)</td>
<td>GestureTek</td>
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ADL, activities of daily living.
than the control group [19]. In addition, since patients with schizophrenia or obsessive-compulsive disorder often have cognitive deficits or behavioral disorders, studies evaluating and treating them in VR simulated environment have been reported [20]. Therefore, it is expected that behavioral adaptive treatment using VR program could be widely used.

**Telerehabilitation**
Telerehabilitation provides rehabilitation services through each home or area-based network, which can reduce the number of hospital days for patients requiring stroke rehabilitation and can promote self-motivation in the home of chronic patients. Piron et al. [21] compared the results of remote rehabilitation therapy with low-cost VR equipment for one month in patients with chronic stroke to those who used conventional rehabilitation therapy. The significant improvement in the VR group was observed when evaluating the Fugl-Meyer scale and lasted up to 3 months.

**MULTIMODAL APPROACHES USING VR**

**VR and robots**
Robot therapy could be chosen for the degree of functional impairment of the patient who is too severe to repeatedly perform the correct exercise. In the rehabilitation paradigm using a robot, VR technology is considered an essential technology because VR could give various interactive environments, having cognitive factors, which is hard to provide in real situations. In addition, when the patient makes movements as they intended in a well-designed virtual environment, it would activate the motor system network and the cortical reorganization could be augmented in the process of learning to correct errors. Therefore, combining VR and robot technology in rehabilitation may have high impacts on the effectiveness in various perspectives such as a multimodal approach for the gate training of individuals after stroke [22], giving a more attentive environment like soccer game for children with cerebral palsy [23], and using pinch training using a force feedback robot [24,25].

**VR and neuromodulation**
The field of neuromodulation encompasses a wide spectrum of interventional technologies that modify the pathological activity within the nervous system to achieve a therapeutic effect. One device for stimulating the brain is the transcranial direct current stimulation (tDCS), which utilizes a portable, battery-powered stimulator to apply a fixed weak electrical current to the brain [26,27]. The neuromodulation paradigm has been applied in the rehabilitation field for upper limb rehabilitation [28] and also in the recovery of post-stroke gait disturbance [29]. When combined tDCS with VR, the augmentation of neural plasticity could be expected since VR asks users to interact with the environment by using various sensory inputs, which could involve affected brain region activations at the same time. Application of anodal tDCS with VR-based wrist exercising showed stronger and longer corticospinal facilitation compared to tDCS only or VR only training in patients with stroke [30]. Another study revealed a methodology where tDCS was applied with a cathode electrode on a motor cortex over the hand area of the unaffected motor cortex during VR therapy so that patients could receive cathodal tDCS and VR game, which showed functional improvements than tDCS only or VR only training [31].

**VR and BCI**
BCI is a technology that interprets a user’s intention from brain signals, such as electroencephalography (EEG) or functional near-infrared spectroscopy (fNIRS), so that
the user could command to a computer to operate another device or interact with content in the computer. Using BCI technology, patients could control their wheel chair with their thought. BCI technology has been actively applied in the field of neurofeedback for modulating brain circuits. In the perspective of utilizing facilitations of the human brain as a rehabilitation paradigm, VR has advantages in providing specific tasks, including the ability to activate corresponding brain regions selectively. Combined VR and BCI technology which could monitor human brain activities in real time, could be powerful to facilitate human brain circuits in a proper way as rehabilitation strategy intended. For example, a subject could be trained to modulate, augment or lessen, a specific brain signal or rhythm through performing tasks in VR environments giving feedbacks according to the brain signal or rhythm. Using EEG based BCI paradigm for motor activity and motor imagery, it can provide a neurofeedback training and promote brain reorganization after stroke [32]. Other Researchers used a flickering action video to evoke steady state visual evoked potential (SSVEP). Combine SSVEP signals and VR, a computer can give motor intention during ankle robot training [33]. SSVEP based BCI paradigm could detect user's watching and give feedbacks and activate MNS at the same time while experiencing VR contents. This paradigm during rehabilitation training might induce more powerful MNS activation of facilitating their neural plasticity after brain injury [34].

**Adverse effects of VR therapy**

The use of HMD has the advantage of increasing immersion, but it can also cause virtual motion sickness. Kang et al. [35] showed that the frequency of virtual motion sickness was not significantly different between the normal group and the stroke group in the immersive VR experience using HMD. Motion sickness is an important factor that does not sustain the experience of VR and diminishes the sense of reality that plays an important role in VR experience. In order to reduce the sickness, relevant technologies should be developed such as the improvement of the hardware and software system to minimize the timing gap between the user’s motion and the corresponding visual display. According to a recent review, 24 studies reported only few adverse events after VR therapy which included symptoms such as mild dizziness, headache, and pain [6].

**USABILITY, ECONOMY, AND ACCESSIBILITY ISSUE OF VR EQUIPMENT**

For successful neurorehabilitation, special interfaces and various feedback mechanisms are designed for neurologically impaired patients. In the rehabilitation units using VR, sensory augmentation or providing force feedback could make VR more utilizable. For example, providing force or tactile feedback, heat sensation, and so on make VR experience exquisite and it could promote functional and neurological recovery. Also, it is encouraged to develop low-cost equipment and mobile applications so that it could be widely used for patients in rehabilitation facilities and homes.

**CONCLUSION**

The numbers of commercially available VR devices have increased and large-scale controlled trials have been reported positive effects. Specifically, recent reports found that VR appears to be a safe intervention that is effective at improving arm function and ADL function following
stroke. Moreover, a greater improvement was seen at a higher VR therapeutic dose [6]. Future interface devices, various feedback methods, and the advancement of augmented reality technology are developing, therefore, the potential value of VR therapy in neurorehabilitation will be high and its clinical application will be diversified.

VR therapy, combined with other rehabilitation equipment such as the robot, treadmill, and cycle may have beneficial effects in facilitating recovery. In addition, VR therapy, combined with other techniques such as neuromodulation and BCI may have a synergistic effect in facilitating the recovery in the field of neurorehabilitation. For remote intervention, VR combined with telerehabilitation could be powerful in that it could overcome limitations of space and time with possibilities to provide rehabilitation scheme in home as well as hospital. In the near future, large-scale comparative studies with existing conventional therapies, studies on the synergistic effects of simultaneous treatment with other therapies, the degree of improvement with different therapeutic doses, long-term effects after treatment, various feedback methods, and training methods of VR therapy should be investigated.

REFERENCES

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