Virtual Reality and Cognitive Rehabilitation in People With Stroke: An Overview

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ABSTRACT

Objective: This review evaluates the use of virtual reality (VR) tools in cognitive rehabilitation of stroke-affected individuals. **Methods:** Studies performed between 2010 and 2017 that fulfilled inclusion criteria were selected from PubMed, Scopus, Cochrane, and Web of Sciences databases. The search combined the terms ''VR,'' ''rehabilitation,'' and ''stroke.'' **Results:** Stroke patients experienced significant improvement in many cognitive domains (such as executive and visual–spatial abilities and speech, attention, and memory skills) after the use of VR training. **Conclusions:** Rehabilitation using new VR tools could positively affect stroke patient cognitive outcomes by boosting motivation and participation.

Keywords: cognitive rehabilitation, stroke, virtual reality training

Cognitive rehabilitation (CR) helps restore normal function or compensate cognitive deficits in brain-injured or cognitively impaired individuals. In current clinical practice, there are 2 basic types of CR: restorative and compensatory rehabilitation. The former enables the patient to develop the lost function through specialized and manual cognitive exercises. The latter helps the patient to improve the use of aids and tools to overcome the impairment.[1] Cognitive rehabilitation techniques may be classified into 2 main categories: conventional (paper/pencil exercises) and computer assisted (computerized CR). Both techniques are based on the use of cognitive strategies to retrain or alleviate the patient's deficits in attention and concentration, visual processing, language, memory, reasoning, problem solving, and executive functions.[1]

Within neurorehabilitation, CR is based on the principle of neuroplasticity (the brain's capability to change in response to interactions with the external environment).[2] After a specific and complete neuropsychological assessment, most patients affected by behavioral and cognitive disorders due to neurological damage may be submitted to CR. In recent years, the application of new methods for motor, cognitive, and sensorial deficit rehabilitation has been implemented, and virtual reality (VR) has given the most promising results.[3,4]

Virtual reality consists of a set of informatics technologies that create interactive environments that involve the user while simulating the real world. These systems consist of specific software programs and input-output peripherals that reproduce complex and immersive experiences. Together with telemedicine, robotics, and computer-based rehabilitation,[5,6] VR constitutes a new frontier of rehabilitation and presents potential advantages to the rehabilitation team. VR regulates activity difficulty according to the patient's true abilities and potentialities and controls performance with visual and auditory feedback. Moreover, these systems potentiate the quality of rehabilitation sessions, as they provide the opportunity to propose playful activities, thus increasing motivation and involvement.

The instruments used in VR have many different experimental and clinical applications. They can be effective in different neurological pathologies and can be used at any age and for several purposes.[4] VR can be used to improve the impaired functions, stimulate and increase the spare capacities, and foster a sense of well-being with an improvement on the patient's level of

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participation and autonomy. Several studies confirm that VR can foster the reactivation and improvement of various cortex functions[7,8] and optimize the efficiency of the sensory cortex.[9]

Hence, VR and CR are therapeutic systems that, by means of a sensory involvement (incremented visual and auditory feedback), make the patients' rehabilitation easier in specific domains, such as attention, memory, language, executive functions, spatial cognition and perceptive abilities, and psychosomatic anxiety.[10] The patient interacts with virtual scenarios and audiovisual stimulations through the movement, resulting in total involvement of the senses. This review evaluates the role of VR tools in poststroke CR, demonstrating how a good cognitive recovery may lead to a better management of stroke.

Search Strategy

Studies were identified by an online search of Scopus, PubMed, Web of Science, and Cochrane databases. The search combined the following terms: "virtual reality" [MeSH Terms] OR "virtual"[All Fields] AND "reality" [All Fields] OR "virtual reality" [All Fields] AND "stroke rehabilitation" [MeSH Terms] OR "stroke" [All Fields] AND "rehabilitation" [All Fields] OR "stroke rehabilitation" [All Fields]. Studies met specified selection criteria and were published between 2010 and 2017. We selected only texts in English and removed duplicates. All articles were evaluated according to the title, abstract, and text. We included studies that examined VR in stroke patients, while excluding those with psychiatric history.

The Role of VR in Stroke

Stroke is a leading cause of death and disability and has been described as a worldwide epidemic.[11] The effects of a stroke may include sensory, motor, and cognitive impairment as well as a reduced ability in self-care and participation in social and community activities. Cognitive dysfunction is common in stroke survivors and depends on the specific area involved. The prevalence of poststroke cognitive dysfunction varies from 23% to 55% within 3 months of stroke onset and declines to between 11% and 31% after 1 year.[12]

After stroke, many patients may have enduring difficulties in specific cognitive domains, such as attention, concentration, memory, spatial awareness, perception, praxis, and executive functioning.[13–16] Although most recovery is thought to occur in the first few weeks after stroke, patients may experience improvement in functional tasks many months after stroke. VR may be advantageous, because it offers several features, such as goal-oriented tasks and repetition, which are important in neurological recovery.[3–5]

Virtual reality may have the potential to provide enhanced scenarios in which people with stroke can solve problems and acquire new skills. Virtual tasks have been described as more interesting and enjoyable by both children and adults, thus obtaining a higher number of repetitions, with positive results on therapist compliance and patient functional outcomes.[17] The basis of VR-related functional recovery was first demonstrated by Jang et al,[18] who found that sensory feedback during VR training affected neuroplasticity and promoted brain reorganization. More recently, Tunik et al[19] carried out 2 experiments in which they studied the neural effects of visuomotor discordance during visually guided finger movements, using a functional glove for magnetic resonance imaging. They found that poststroke individuals activated the primary motor region (M1) when they were presented with discordant feedback, but not when feedback was not discordant. Notably, when discordant feedback corresponded to the affected and moving hand, the contralateral M1 region was recruited.[19] Bagce et al[20] conducted a study to determine whether the primary ipsilesional motor cortex (M1) in stroke patients processed the visuomotor discordance between the movement of the fingers and the observed VR feedback. Eight chronic stroke patients had to flex or extend their finger with real-time feedback of a virtual hand presented in VR. The results demonstrated that visual feedback can be an effective way to selectively modulate M1 activity.[20] The specular feedback that is activated after VR training recruits the areas of the ipsilesional brain relevant to the control of the affected hand, favoring the restoration of its function after stroke.[21]

These findings suggest that visual feedback in VR is a useful tool for rehabilitation. In fact, some programs are designed to adapt to the needs of patients with stroke, personalizing the exercises according to the rehabilitative needs. A study of 27 poststroke patients observed that VR allowed the operator to personalize the sessions. This stimulated the motivation of the patients, with greater effects on gait and balance.[22] The motivational and engaging effect of VR with its ability to stimulate both cognitive and motor function in stroke patients, even in the chronic phase, has been documented by other research. Calabrò et al[23] conducted a 2-group randomized clinical pilot trial of 24 patients with a first unilateral ischemic stroke in the chronic phase. One group performed 40 Lokomat (robot-assisted movement) sessions with VR, whereas the other group was subjected to Lokomat without VR. The authors found that robot-assisted rehabilitation plus VR induced a more significant improvement in gait and balance. The correlated electroencephalographic data suggested that the use of VR may involve different brain areas (probably including the mirror neuron system) involved in motor planning and learning, thus leading to improved motor performance.[23]

The effect of VR in improving cognitive function and motivation of stroke patients has also been examined. In

12 subjects randomized to VR treatment versus a non-VR control group, VR was more effective in improving attention, visuospatial deficits, and motor impairment.[3] Moreover, thanks to the more motivational and enjoyable virtual scenarios provided using the Nirvana (BTS Bioengineering Corp), the treatment permitted longer training sessions with greater patient compliance.[3] Russo et al,[24] in a pilot study of 20 poststroke patients, obtained better results when the patients' body shadow was represented in the virtual environment. This is probably due to a greater awareness of one's internal representation and better self-recognition.[24]

Although VR seems to be a promising tool in neurorehabilitation of stroke patients, there are limited data demonstrating the efficacy of VR in CR. Laver et al[25] conclude that VR is effective in improving stroke functional outcomes only when combined with conventional treatment. Furthermore, neither stroke onset, severity of the impairment, nor the type of device used (commercial or personalized) seems to be relevant in post-stroke functional recovery. The authors conclude that one of the most important features of VR is that the training session can be customized to obtain the best results.[25] The main findings of the studies dealing with the role of VR in CR are summarized in Table 1.

Discussion

This review highlights how VR represents a promising methodological approach in poststroke rehabilitation. For this reason, VR may boost the effects of conventional

TABLE 1. The Principal Studies Concerning the Use of Virtual Reality in Stroke Patients

Study	Study Design	Patients	Major Findings
Lewis and Rosie[17] (2012)	Exploratory study	6 stroke patients with hemiparesis No control group	The authors found that VR can be motivating and attractive for stroke patients.
Tunik et al[19] (2013)	Observational study	3 stroke patients with unilateral hemiplegia 12 healthy subjects	The authors found that manipulating the visual feedback of the movement of one's hand through virtual reality can be used to potentiate activity in brain networks.
Bagce et al[20] (2012)	Observational study	8 stroke patients No control group	The authors found that visual feedback may be a valid way to selectively modulate M1 activity.
Saleh et al[21] (2014)	Observational study	15 stroke patients with hemiparesis No control group	The study showed that mirrored VR feedback may be beneficial as a therapy for restoring function after stroke.
Pedreira da Fonseca et al[22] (2017)	Randomized clinical control trial	14 stroke patients with hemiparesis 13 control group	The authors found that therapy with VR games was a useful tool for gait balance rehabilitation in poststroke patients with reduction of falls.
Calabrò et al[23] (2017)	Randomized clinical control trial	34 stroke patients (randomized into experimental and control groups)	The authors found that robotic rehabilitation combined with VR in patients with chronic hemiparesis induced a better improvement in gait and balance. EEG data suggest that different brain areas involved in motor planning and learning are activated by VR.
Russo et al[24] (2017)	Pilot study	20 poststroke patients	The authors showed that patients undergoing VR training, powered by their body shadow, tend to be more motivated to treatment with a greater awareness of internal representation and better "self-recognition."
De Luca et al[3] (2018)	Pilot study	12 stroke patients (randomly divided into experimental group and control group)	VR can be considered a useful complementary treatment to potentiate functional recovery, with regard to attention, visual-spatial deficits, and motor function in patients affected by stroke.

Abbreviations: EEG, electroencephalographic; VR, virtual reality.

therapies. Interactive virtual training is a useful treatment capable of stimulating cognitive abilities (amnesic-attentive functions and visuospatial cognition), executive processes, and behavioral abilities in patients with neurological disorders.

Rehabilitation of poststroke cognitive deficits is a complex process involving different healthcare professionals. Nurses play a pivotal role in the patient's recovery. Beyond medication administration, they train patients and help them adapt to adjustments that promote their health, potentiate their adaptive capabilities, and promote achievable independence. To do this, patient compliance is fundamental; cognitive deficits may compromise recovery. The advantage of incorporating VR into rehabilitative programs is to create a positive learning experience that can also be fun and motivating for the patient.[4]

The playful aspect is generally welcomed by patients, who express greater involvement and allow longer rehabilitation sessions.[23] Moreover, the virtual and real environments are similar, and VR allows the patient to experience situations without the limits of their disabilities (ecological experience, ie, skiing, swimming, cooking). This effect has positive outcomes on the patient's mood and acceptance of the limits due to disease. Better patient compliance due to cognitive recovery allows healthcare personnel, especially nurses, to manage stroke patients more efficiently, improving their relationship and reducing nurses' stress.[23,24] Given that attention could interfere with the other cognitive domains, cognitive treatment based on attention rehabilitation should precede other cognitive function training in patients affected by brain injuries.

The available data support that VR training has the potential to foster the attention processes' rehabilitation in stroke patients. The processes potentiate CR by promoting brain plasticity processes through complex mechanisms.[26] These effects can be correlated to the reactivation of several brain neurotransmitter pathways (cholinergic and dopaminergic), through VR cognitive treatment.[20,22] Different surveys establish the association between cognitive and motor functions, highlighting the positive influence that improved cognitive function has on motor rehabilitation, especially when training is performed in a virtual environment.[20] Furthermore, it has been demonstrated that the patient's psychological well-being, enhanced by the virtual setting, may positively affect cognitive and motor outcomes.[21] These effects should be considered in future studies.

Conclusions

This review supports the idea that VR may be a feasible and effective tool in improving cognitive function in stroke patients. VR may provide a means to encourage greater treatment compliance and better patient management in the hospital setting. However, given that the data come from only a few studies, randomized clinical trials are needed to confirm these promising results. It may also be useful to investigate psychological benefits for healthcare providers, including nurses. Objective assessment tools (including electroencephalogram and other noninvasive brain monitors) should be used in larger samples to confirm the extent to which VR is effective, on its own or as an adjunct to conventional training, in CR.

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