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Review article

Cognitive rehabilitation in patients with traumatic brain injury: A narrative review on the emerging use of virtual reality

Maria Grazia Maggio [a], Rosaria De Luca [a], Francesco Molonia [a], Bruno Porcari [a], Massimo Destro [a], Carmela Casella [b], Ramona Salvati [a], Placido Bramanti [a], Rocco Salvatore Calabro [a,*]

[a] IRCCS Centro Neurolesi "Bonino Pulejo", Messina, Italy
[b] Stroke Unit, University of Messina, Messina, Italy

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ABSTRACT

Traumatic brain injury (TBI) is a clinical condition characterized by brain damage due to an external, rapid and violent force. TBI causes attention, memory, affectivity, behaviour, planning, and executive dysfunctions, with a significant impact on the quality of life of the patient and of his/her family. Cognitive and motor rehabilitation programs are essential for clinical recovery of TBI patients, improving functional outcomes and the quality of life. Various researches have underlined the possible effectiveness of innovative techniques, with regard to virtual reality (VR), during the different phases of rehabilitation after TBI. This review aims to evaluate the role of VR tools in cognitive assessment and rehabilitation in individuals affected by TBI. Studies performed between 2010 and 2017 and fulfilling the selected criteria were found on PubMed, Scopus, Cochrane and Web of Sciences databases. The search combined the terms VR, assessment, rehabilitation and TBI. Our review has shown that VR has the potential to provide an effective assessment and rehabilitation tool for the treatment of cognitive and behavioral impairment on TBI patients.

1. Introduction

Traumatic brain injury (TBI) is a clinical condition characterized by brain damage due to an external, rapid and violent force. The injury can lead to an increased or altered state of consciousness, with impaired cognitive, neuro-somatic and emotional-behavioural functions. Following a TBI, about 70% of cases present with a mild brain injury (i.e. the patient can be conscious and oriented or slightly confused and disoriented, without any focal neurological lesions). In 10–12% of cases, instead, there are moderate injuries as a result of which the patient becomes unconscious and can be affected by personality change, headache, epileptic attack and mydriasis. Finally, in up to 10% of cases, there is a severe damage with a global dysfunction. The prevalence of TBI in the overall population is 12–16.7% in males and 8.5% in females [1]. TBI rarely causes focal and circumscribed damage, the patients usually undergo widespread lesions, and an "integrated and holistic" treatment and a diagnosis are needed, especially in young people (TBI mostly occur between 15 and 30 years) [2]. The cognitive impairment is due to both the focal/diffuse lesions due to the impact and secondary damage following possible complications, such as hypoxia and intracranial hypertension. The brain areas most involved in TBI are the frontal and temporal lobes, especially in the basal areas and in the subcortical white matter. This causes attention, memory, affectivity, behaviour, planning, and executive dysfunctions, with a significant impact on the quality of life of the patient and of his/her family [3–4]. To define a rehabilitative program, diagnosis and prognosis are fundamental to get a realistic evaluation of the possible functional recovery, also concerning social and work reintegration. Cognitive and motor rehabilitation programs are essential for clinical recovery of TBI patients, improving functional outcomes and the quality of life. These strategies are based on reparative, compensatory strategies and adapt to the patient's resources and disability. TBI induces both injurious and neuro-regenerative response including angiogenesis, neurogenesis and brain plasticity [5]. These spontaneous regeneration mechanisms are short-lived and too weak to contrast the worsening of the damage, but new therapeutic strategies could stimulate and boost such mechanisms. In fact, physical and cognitive exercise may increase the process of brain repair and plasticity after the lesions [6–7]. For this reason, it would be useful to implement rehabilitation interventions, stimulating specific sensory or motor neuronal circuits, considering the kind and the level of injury and the level of motor and cognitive disabilities [8–9]. Various

* Corresponding author at: IRCCS Centro Neurolesi "Bonino-Pulejo", S.S. 113, Contrada Casazza, 98124 Messina, Italy.
E-mail address: salbro77@tiscali.it (R.S. Calabro).

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researches have underlined the possible effectiveness of innovative techniques, with regard to virtual reality (VR), during the different phases of rehabilitation after TBI [10–12]. VR consists of an interactive and virtual environment the patient can interact with, created by computer graphics and with different degrees of immersive sensations [12]. VR can offer real and ecological demands of the real world (i.e. finding objects, carrying out actions and buying things) that can improve brain plasticity and regenerative processes [12,14–16]. VR has been used in the motor and cognitive rehabilitation of different pathologies, with good results obtained thanks to the flexibility, the sense of presence (i.e. the feeling of "being there") and the emotional involvement it gives to the patient [13]. Indeed, VR allows a sense of global well-being, thanks to the stimulation of multiple perceptual channels, implemented by the use of auditory and visual feedback, which stimulate the patient's awareness of his performance. Finally, the playful environment allows increasing the patient's compliance, amplifying the effects of the rehabilitation treatment itself, which can also be customized according to the actual needs of the subject [17–18]. All together, these are the reasons why this new technology, may have advantages in the treatment patients affected by TBI. In fact, TBI leads to very heterogeneous symptoms and clinical manifestations (especially frontal lobe dysfunction) with a significant negative impact on daily life.

This review aims to evaluate the role of VR tools in Cognitive Rehabilitation of TBI patients.

2. Search strategy

The studies were identified by searching on Scopus, PubMed, Web of Science, and Cochrane database. The studies fulfilling our selected criteria and published between 2010 and 2017 were evaluated for possible inclusion. The search combined the following terms: ("virtual reality"[MeSH Terms] OR ("virtual"[All Fields] AND "reality"[All Fields]) OR "virtual reality"[All Fields]) AND ("brain injuries, traumatic"[MeSH Terms] OR ("brain"[All Fields] AND "injuries"[All Fields] AND "traumatic"[All Fields]) OR "traumatic brain injuries"[All Fields] OR ("traumatic"[All Fields] AND "brain"[All Fields] AND "injury"[All Fields]) OR "traumatic brain injury"[All Fields]). We have only selected texts in English and removed duplicates. The articles have been evaluated according to title, abstracts and text. We included studies that examined VR in TBI patients, excluding studies with patients who had a psychiatric history.

3. TBI and VR

Following TBI, patients may present motor, cognitive and social changes with a devastating impact on important aspects of their life. Various research has shown that new cognitive interventions, including VR training, can be useful in TBI patients. In fact, in the literature there are many studies, in which VR has been used successfully as both as assessment tool and therapeutic intervention (see Table 1) [10–19].

4. VR assessment tool in TBI patients

As an assessment tool, VR was used to identify both cognitive and behavioral disorders in TBI patients. Onakomaiya et al. have carried out a study using the computer-assisted rehabilitation environment (CAREN) to identify co-morbidity post-traumatic stress disorder (PTSD) in service members (214 individuals with a history of TBI). The results showed that VR has an important potential in the evaluation of PTSD, as the performance of the service members with PTSD was significantly slower than TBI patients without PTSD [20]. Levy et al. [21] examined the potential usability of V-Mart, a VR grocery store, as an assessment and intervention tool for veterans with mild TBI. V-Mart was found useful in assessing the presence of behavioral disorders and difficulties in patients' daily autonomy (IADL). VR has been also used as an ecologically valid tool to assess IADL in patients affected by TBI. In a recent study, 19 adults with TBI and 19 healthy controls were asked to perform real and virtual tasks concerning coffee preparation. The results showed that subjects affected by TBI achieved a worse performance, especially in terms of planning and executive skills, if compared to healthy control subjects, so virtual cooking proved to be a valuable tool for IADL assessment in patients with TBI [22]. Moreover, many authors have shown that VR is a promising tool to assess cognitive function with regard to memory and executive function [23–25]. In fact, Robitaille et al. developed a reliable VR avatar interaction platform to evaluate the residual executive functions in subjects affected by mild TBI. The platform reproduced the subjects' movements in a virtual body with the ability to move and explore a simulated environment (i.e. a village) [26]. Finally, VR was used to detect visual-vestibular deficits in adults after TBI. Wright et al. have developed a screen with VR allowing subjects to perform exploratory and postural tasks, so to detect data related to vestibular deficits [27]. Taking into consideration the current data, VR can be considered a valuable tool for the observation and evaluation of patients affected by TBI, although further studies are needed to better evaluate its potential.

5. VR and rehabilitation in TBI patients

As a rehabilitation tool, VR has been shown to increase cognitive abilities in TBI patients. In fact, VR could stimulate motivation and enjoyment, which are important factors for successful rehabilitation training [28]. Dahdah et al. carried out a study on 15 TBI patients using a VR version of the Stroop. The authors observed that immersive VR interventions are effective in improving executive functions and the information processing speed in TBI patients, during the sub-acute phase [29]. VR has also been used to train attention in severe TBI, with positive outcomes. Larson et al. used virtual attention exercises on 15 TBI patients, maximizing the patients' response thanks to auditory and visual feedback. As results, VR was engaging and well tolerated by the patients, with significant improvements in cognitive function [30]. Dvorkin et al. developed a "practically minimal" approach using interactive visual-haptic environments supporting attention on a visuomotor tasks to train 21 TBI patients in the early stages of recovery. The instrument was well tolerated and allowed to improve the attention of patients [31]. Finally, VR simulation has been applied to facilitate the driving ability of 11 TBI patients. VR was considered realistic and effective, encouraging driving performance and IADL skills in patients [32].

6. Discussion

Current literature is demonstrating that VR could be useful both as an assessment and rehabilitation tool in cognitive recovery post-TBI. However, the evaluation protocols with VR have been mainly applied in mild TBI, which is difficult to evaluate with traditional tools [33]. Instead, VR treatment protocols for cognitive rehabilitation are more widely used (i.e. from mild to severe conditions), although the efficacy of these interventions should be further explored [28]. Indeed, although studies suggest that VR training can provide innovative treatment options for the TBI, the use of VR in clinical practice is limited by two main factors, i.e. the accessibility and costs of VR. Yet, VR technology is diffusing, as more accessible economic solutions emerge [34]. There are several tools

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Table 1
Shows the main studies concerning the use of VR as an assessment and rehabilitation tool on TBI subjects.

Study	Design	Patients	VR Tool	Major findings
Onakomaiya MM et al. 2017	Retrospective Analysis	214 TBI patients (6 female and 208 males)	Computer-Assisted Rehabilitation Environment (CAREN)	The authors highlighted the effectiveness of CAREN as a new tool for assessing PTSD in patients with a history of TBI
Levy CE et al. 2018	Prospective Study	Six focus groups with therapists, veterans with neither TBI nor PTSD, and veterans with TBI with or without PTSD	V-Mart, a VR grocery store as an assessment and intervention tool	Focus group and SUS data indicate that the V-Mart has great potential as an assessment tool and intervention for veterans with mTBI/PTSD
Besnard J et al. 2016	Pilot study	19 adults suffering from TBI and 19 healthy controls	Non immersive Virtual Coffee Task - a virtual kitchen to assess daily-life activities	The authors show that virtual cooking is a valid tool for IADL assessment in patients with TBI.
Martínez-Pernía D et al. 2017	Pilot Study	7 dyads of europsychologists/ patients and 1 dyad containing an occupational therapist/patient	Game authoring platforms: screen-based simulated naturalistic task that consisted of preparing a cup of tea.	The authors have shown that the use of these types of authoring platforms is effective and may have long-term positive implications for evaluation in neuropsychological research.
Canty AL et al. 2014	Prospective Study	30 TBI patients and 24 uninjured adults	VR prospective memory task (i.e., the VR Shopping Task)	The results indicate that VR has sensitivity, convergent and ecological validity.
Teel E et al. 2016	Retrospective Study	128 controls (no concussion) and 24 concussed college-age athletes	VR-based NP assessment battery	Use of a VR-based NP platform can assess persistent cognitive impairments resulting from a concussion in clinically asymptomatic participants.
Robitaille N et al. 2017	Proof of concept	6 TBI patients 6 healthy controls	Avatar-based VR platform	The authors have shown that VR is a useful tool to control specific context factors for assessment and intervention.
Wright WG et al. 2017	Cohort Study	14 TBI patients 58 healthy age-matched cohort	Novel VR -based balance assessment	The authors found that VR is useful in assessing visuo-vestibular deficits in adults after TBI.
Dahdah MN et al. 2017	Prospective Study	15 patients with TBI	VR Stroop	The results showed that the use of VR in neurorehabilitation is effective in specific improvement executive functions and information processing speed in TBI patients
Larson EB et al. 2011	Observation Study	15 TBI patients	VR and robotics technology	Attention exercises using virtual environments are well tolerated and engaging and may be useful in patients with TBI.
Dvorkin AY et al. 2013	Pilot Study	21 in patients with severe TBI	"Virtually minimal" approach using robot-rendered haptics in a virtual environment	Interactive visual-haptic environments could be useful for training attention for patients with severe TBI in the early stages of recovery.
Cox DJ et al. 2010	A feasibility study.	11 men with TBI	VR driving simulation	VR has been well received and considered realistic for patients. The results observed that VR is an effective tool in improving driving performance.
Wright WG et al. 2017	Pilot Study	56 healthy adults and 11 adults with TBI	Portable VR-based balance screening device (Virtual Environment TBI Screen)	The authors showed that the VR-based device is a valid measure to detect the deterioration of the balance after TBI

Legend: CG Control Group; EG Experimental Group; PTSD Post-traumatic stress disorder; TBI Traumatic Brain Injury; VR Virtual Reality.

that can be used with different costs and complexity. Currently, studies with VR use advanced and complex instrument. An example is the CAREN, used by Onakomaiya et al. [20] with good results in the evaluation of PTSD in patients with TBI. This tool is a dome-simulator equipped with a screen (up to 360°), with multiple VR screens for the improvement of motor and cognitive performance in neurological and orthopedic patients. The CAREN is composed of a series of software and peripherals, including sensorized treadmill (with plantar pressure sensors), high speed infrared cameras that map the position of the reflecting markers positioned on the patient and a moving platform. Thus, it allows patients to be immersed in a fully reactive physical and virtual environment. Notably, the high technology used in rehabilitation leads to an increase in costs, so other low-cost devices could make VR more usable. They are part of "serious games" and could have a significant potential in the field of cognitive assessment and rehabilitation. Serious games are digital games that integrate playful aspects with educational elements. These devices also allow interactive virtual simulation with the aim of developing skills to be applied in the real world, with exercise in a simulated and protected environment. These games allow experiential learning: the feelings experienced allows the player to improve the perception, attention, and memory, encouraging behavioral changes through learning by doing [35]. Serious games can be flexible and adaptable to the context of use. They create a protected environment in which the patient has the opportunity to be involved in a safe and secure way. These solutions are highly competitive and economical, although they have not yet obtained the level of immersion and effectiveness of the most complex devices. It would be very useful to encourage the use of VR in TBI patients, as demonstrated by our review. In fact, as discussed, the VR allows concrete, ecological and realistic experiences, which require the control of the individual on different sensor-motor, cognitive and social domains, which are usually difficult to reproduce in a clinical setting. The exercises performed in a virtual environment make an "increase feedback" that allows the patient to develop the "awareness of the results" of the movements performed and the "awareness of the quality" of the movements themselves with positive repercussions on the cognitive and motor level. Indeed, multisensory feedback and repeated implementation of cognitive and physical tasks with sensory stimulation improves overall cognitive functioning, promoting brain plasticity processes through complex mechanisms [14]. In fact, VR offers a new strategy to improve and amplify the neural plasticity processes in the early phase of the TBI and in the subsequent recovery in daily life [26]. These effects may be related to the reactivation of brain neurotransmitters, due to exercise in the virtual environment [36]. Furthermore, VR allows activation of mirror neurons with integration between perception, cognition, and action and reinforce the subject's empowerment and self-efficacy [37]. Moreover, VR makes it possible to create a positive, motivating and enjoyable learning experience for the patient, with greater compliance and longer training sessions [12]. The simulation of real life scenes, through playful elements, increases the patient's involvement and his/her confidence in

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own abilities promoting practical experience. This allows a total ability of the "explored" dynamics in the VR environment, which can be repeated in the real situation. Therefore, VR is effective for rehabilitating and assessing the patient's ability to perform everyday activities (i.e. virtually cooking, driving a virtual machine or shopping in a virtual supermarket). Through VR environments, behaviors can be evaluated and trained, encouraging the patient's cognitive improvement. VR allows interventions on memory, attention, executive function, behavioral control and mood regulation that reduce the problems and long-term disabilities of subjects with TBI, with a positive effect on their quality of life.

Unfortunately, evidence of the feasibility and efficacy of VR in TBI cognitive rehabilitation is very poor.

As data from this review have shown that VR has the potential to provide an effective assessment and rehabilitation tool for the treatment of cognitive and behavioral disorders in patients with TBI, these promising findings should be confirmed by further studies on larger samples and long-term follow-up.

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