Critical/ Systematic Review and Meta-Analysis

The influence of virtual reality on rehabilitation of upper limbs and gait after stroke: a systematic review

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ABSTRACT

Stroke is the leading cause of functional disability in adults. Its neurovascular origin and injury location indicates the possible functional consequences. Virtual rehabilitation (VR) using patient's motion control is a new technological tool for conventional rehabilitation, allowing patterns of movements in varied environments, involving the patient in therapy through the playful components offered by VR applications. The objective of this systematic review is to collect data regarding the influence promoted by VR in upper limb and hemiparetic gait. Full articles published between 2009 and 2015 in english were searched and selected in PubMed, Cochrane and Pedro databases. Eleven articles included (5 for VR and upper limbs; 4 for VR, gait and balance; and 2 for VR and neural mechanisms). The articles included demonstrate efficacy in VR treatment in hemiparetic patients in the variables analyzed.

Keywords: Virtual reality exposure therapy. Rehabilitation. Paresis.

1. BACKGROUND

Stroke is defined by the World Health Organization (WHO) as an vascular event of abrupt onset, with focal or generalized disturbance of the encephalic function with more than 24 hours of duration, leading to cognitive, motor, psychological and social impairments (BARCALA et al., 2011; SILVA et al., 2015; RODRIGUES et al., 2015). About 30% of stroke patients die in the first year of the ictus; 30% of survivors demonstrate neurological deficits and functional disabilities, making stroke the leading cause of functional disability in adults in the West (ROCHA et al., 2014; PONTES NETO, 2009).

The most prevalent motor impairment caused by stroke is the muscular weakness of contralateral side of body to the brain injury, called hemiparesis, involving both upper and lower limbs. Changes in tonus, strength, sensibility, coordination, balance and gait are also seen in these patients. These alterations besides the functional impairment can lead to loss of social skills and a significant impairment in quality of life (BARCALA et al., 2011; SILVA et al., 2015; RODRIGUES et al., 2015). Deficits or impossibility of walking is a contributing factor to frustration; dependence of walking remains in about 25% of patients after the acute phase (SILVA et al., 2015). Upper limb impairment is present in 80% of all stroke patients, and plays a highly significant role in functional dependence since the paretic upper limb may not fully recover its function in up to 66% of patients (TUROLLA et al., 2013).

Treatment of stroke involves multidisciplinary care and intensive and effective rehabilitation programs, to prevent secondary complications and minimize the effects of disabilities already installed as well as collaborate to improve the quality of life of the patient (PONTES NETO et al., 2009). In order to improve functional capacity, the virtual rehabilitation (VR) has been used as a promising alternative tool to aid rehabilitation. In the last decade, reports of improvement after stroke using VR have been remarkable (CAMEIRÃO et al., 2012; LOPES et al., 2013). VR programs uses the brain-computer interface (BCI), promoting interaction between patient and computer or VR appliance, creating virtual environments that promote exercise training in different situations, using various movement patterns and claiming the work of various motor and cognitive abilities, and playing a significant potential in neuroplasticity (MCEWEN et al., 2014; LEE et al., 2014).

We perform a systematic review on the effectiveness of the VR application as an aid to upper limb and gait treatment of post-stroke patients, aiming to synthetize relevant information to assist the clinical decision of rehabilitation team for the application of VR techniques.

2. METHODS

2.1 Search Methods

We performed a search of scientific papers published in period of 2009 to 2015 in PubMed, Cochrane and PEDro databases combining the DeCS (Health Science Descriptors, BIREME) *virtual reality exposure therapy* to *gait, upper extremity, rehabilitation* and *paresis*.

2.2 Selection Criteria

The following criteria were selected: controlled and randomized clinical trials, with human population, hemiparesis, all ages and both genders; with intervention based on virtual reality for upper and/or lower limbs; with analysis of gait, strength, balance, coordination, range of motion and/or functional abilities variables; in English language.

2.3 Data Collection

110 articles were found. 99 were excluded: 33 were duplicates, 2 are not available and 64 did not meet inclusion criteria, resulting in 11 articles for this review. 5 referred to correlation between VR and upper limbs, 4 referred to correlation between VR and gait and balance, and 2 correlated VR and neural mechanisms. The research steps are illustrate in Figure 1.

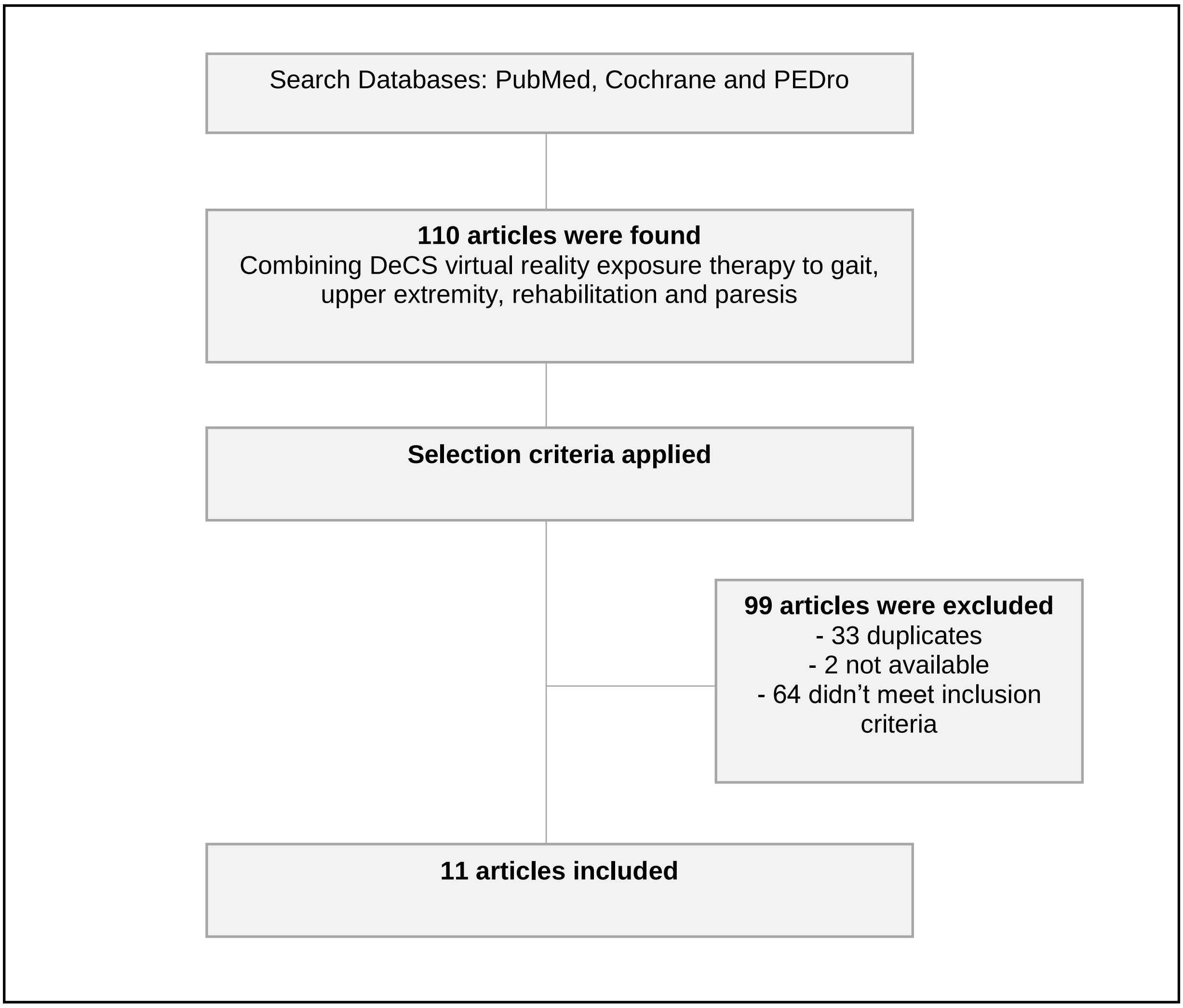

Figure 1. Stages of this review: search, selection and inclusion of studies.

3. MAIN RESULTS

Statistical improvement was demonstrate in all groups of patients involved with VR therapy in the upper limb function studies. It was observed an increase in velocity index, task performance of reaching and holding, and levels of activity (SUBRAMANIAN et al., 2013); and increase in Fugl-Meyer Assessment (FMA), Functional Independence Measure (FIM), Modified Barthel Index (TUROLLA et al., 2013; LEE et al., 2014; KIPER et al., 2014), Wolf Motor Function Test, Ashworth Modified Scale and grip strength (VIANA et al., 2014). Significant results were also observed in studies about gait and balance: large increase in Berg Balance Scale (BBS) and Time Up and Go test (TUG) in the VR group, but without significant improvement in the balance, in both groups (CHO et al., 2012; CHO et al., 2013); and improvement in anteroposterior and postural oscillation on treadmill with VR (KIM et al., 2015). Minimal relevant clinical differences after training was also observed for 2 Minute Walk Test (MCWEWEN et al., 2014).

The studies about neural mechanisms mentioned that during VR training there is activation of motor cortex contralateral to the lesion and cerebellum, and compensatory activation of prefrontal cortex (ORIHUELA-ESPINA et al., 2013), suggesting that VR should maximize the compensatory and recovery neural mechanisms (CAMEIRÃO et al., 2012). The results of the mentioned researches are show in Attachment A.

3.1 Upper limb function

The integrity of upper limb function represents a valorization of independence, making it essential to rehabilitation for stroke patients (SOARES et al., 2011). 80% of post-stroke survivors with upper limb paresis, and only one third retrieves functionality (KWAKKEL et al., 2003). The virtual environment of VR training for arms and hands offers the simulation of functional activities performing tasks associated with observation of the projected virtual members and stimulating the participation of patient in the active movement for paretic member to achieve a goal proposed by VR application (POMPEU et al., 2014).

In 2013, Subramanian et al. conducted an investigative study on the efficacy of the virtual environment in upper limb clinical recovery, using a 3D supermarket virtual simulator with the aim to reproduce the function activity of shopping. One group of patients used the real (physical) environment of supermarket. Both groups demonstrated improvement in upper limb measurements, clinical scores and activity levels but possibly because of the visual feedback, patients with mild impairment in VR group obtained greater changes in motor performance, with lower compensation.

Turolla et al. (2013) evaluated the efficacy of VR for upper limb functional recovery and the impact on quality of life of 376 post-stroke patients, divided in two groups of rehabilitation (conventional rehabilitation and VR). The groups achieved better scores of FIM, but the experimental group in particular obtained more notable results in FMA[6]. Kiper et al. tested reinforced feedback in virtual environment, demonstrating improvements in motor function.

Studies with the association of VR and other therapies also show positive effects. Lee et al. (2014) and Viana et al. (2014) combined VR with transcranial direct current stimulation (tDCS): the first study, with subacute stroke, demonstrate an improvement in manual muscle function, FMA and Korean-Modified Barthel Index scores. The application of the two therapies (VR + tDCS) presented greater recovery than each isolated therapy. In the second study, the authors identified improvements in all measures except in Stroke Specific Quality of Life Scale (SS-QOL) for both groups (control and experimental). We can say that the combination of new technologies in treatment of stroke patients has clinical reproducibility proven by these studies, allowing the association of VR not only with conventional therapy.

Analyzing these studies is notable that the application of VR with traditional physical therapy rehabilitation can boost the functional recovery of upper limb, and can represent an effective alternative for stroke treatment.

3.2 Balance and gait

The biggest complaints of patients after stroke often are balance and gait. The hemiparesis can impair social and functional domains, making it difficult to perform activities that were once simple and aggravating other deficits related to the ictus (ROCHA et al., 2014). Balance and gait depend on sensorial integration (vision, vestibular system, and peripheral nervous system) associated with central commands and neuromuscular responses: the two processes are interdependent.

Cho et al. (2012) investigated the efficacy of virtual gait training in chronic stroke patients using Nintendo Wii™ console and the Wii Fit™ balance board (Nintendo, Japan). After six weeks of training, the authors didn’t find significant differences for anteroposterior and mid-lateral oscillations between control (conventional rehabilitation) and experimental (conventional + VR) group, but both groups showed improvement in the balance measured by BBS and TUG; and the experimental group showed greater evolution than control group. The authors investigated only the balance of the patients involved without gait evolution analysis after VR, however report that there’s a close relationship between balance and gait factor. A new study conducted by same authors using treadmill gait training associated to a video record of real locations identified an increase in BBS and TUG in experimental group, with improvements in speed and cadence, corroborating the findings of the previous study (CHO et al., 2013). Similarly Kim et al. (2015) analyzed the association of treadmill training with VR based on community locations and the effects on the static balance, obtaining similar results to previous studies.

In a study about the aid provided by VR in recovery of balance, mobility and gait of post-stroke patients, McEwen et al. (2014) used an interactive software added to conventional treatment. The groups obtained differences and reached the minimum clinical differences for TUG, as attested by the previous studies, and in 2 Minute Walk Test. The patients demonstrated greatest improvements, proving that balance and mobility exercises with virtual reality are effective in rehabilitation of patients with stroke disabilities.

These investigations suggest that application of VR is effective and reproducible. The combination of conventional therapy and VR therapy can promote more improvements in balance and gait recovery than just conventional therapy. Although the studies were not conducted with the same VR system, the results are equivalents, indicating that VR can promote greater efficacy in the gait rehabilitation post-stroke, regardless the brand or model used (POMPEU et al., 2014).

3.3 Behavior and neural mechanisms

Recovery after stroke depends on the process of neuroplasticity, since the vascular event affects both motor and sensorial cortex, organized into functional somatotopic maps with high levels of plasticity, indicating that they are modified according to the experiences that each individual is subjected. Motor expressions and learning ability creates motor engrams – traces of memory related to motor aspect. When regions of the cortex are destroyed by stroke the motor engram is lost. A possible way to achieve the full recovery of the patient would be by "replacing" destroyed neuronal circuits (MURPHY et al., 2009). The investigation of strategies to promote neuroplasticity seems to be the future of rehabilitation and research in neurology.

In order to test the VR technology and understand its effects on the brain, Cameirão et al. (2012) brought a population of 44 post-stroke patients with severe to moderate upper limb paresis with rehabilitation discharge three months ago. The authors used the Rehabilitation Gaming System (RGS), which has the primary function of performing bimanual oriented tasks combined with first-person observation of virtual members. Participants were randomly divided into three treatment groups according to RGS configuration: RGS group, RGS tactile group (tactile interface with two mechanical arms) and RGS exoskeleton group (passive bimanual exoskeleton with support adjustable arm). The exoskeleton group did not retain most gains 12 weeks after end of treatment, unlike the other two groups. The tactile group, however, retained all gains after the same period, suggesting that the addiction of tactile feedback in moments when the subject visualize virtual hands touching objects in the VR environment increases the effectiveness of RGS. All patients were satisfied with RGS treatment in any configuration. RGS system is referred as a facilitator of stroke recovery, causing the brain to receive more information about task performance, increasing mirror neurons transmission, attesting that RGS system explores compensation and recovery neural mechanisms, modulating according to the movement strategies.

Orihuela-Espina et al. (2013) recruited 8 patients with chronic upper limb hemiparesis for gestural therapy, demonstrating clinical reproducibility for the positive behavioral results obtained; however, didn't find any ipsilateral activation of the primary sensorimotor cortex. The gestural therapy here applied may not have been sufficient to stimulate ipsilateral activity, often associated with better prognosis. In the other hand cerebellar recruitment (also associated with better prognosis) was found in a large part of the group. Compensatory activation of the prefrontal cortex was observed, although each injured brain performs its own reorganization strategies.

Both authors discuss how VR works in central nervous system, studying different factors. By combining the results of each study we can complement that strategies based on the application of virtual environments and situations possibly collaborate for cerebral recovery after stroke since cortical activation and reorganization occurs, mainly in specific areas for the motor rehabilitation resulting in mechanisms of neuroplasticity (MONTEIRO JUNIOR et al., 2012). In addition, the visual feedback proposed by the VR applications associated to movements and senses used in VR therapy makes the patient more involved with the treatment, allowing him to see his results and to elaborate corrective ways and movements when possible and necessary, monitoring the evolution in each session. The active participation of patient during his rehabilitation process has been studied as a promoter of cortical plasticity during reorganization of somatotopic functional maps (ZIMMERLI et al., 2013).

4. CONCLUSIONS

Virtual rehabilitation is able to aid conventional therapy in the stroke treatment, being effective in hemiparesis and demonstrating positive results in rehabilitation of upper limb and gait, potentializing its function as well as in other variables such as balance, functional independence and quality of life.

However, further studies are needed, maybe mainly on the involvement of neurological mechanisms associated with application of VR in post-stroke patients.

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ATTACHMENT A

Main findings of studies that analyzed the influence of virtual reality on rehabilitation of upper limbs and gait of hemiparetic patients including related variables.

Paper Id	Intervention	Population	Variables	Main results
Cameirão et al., 2012	Virtual bimanual task in three modalities: Rehabilitation Gaming System (RGS), RGS Tactile and RGS Exoskeleton. 35 minutes, 5 sessions per week, 4 weeks.	44 patients with vascular event for at least one year and severe to moderate upper limb paresis, divided in 3 groups.	Barthel Index Motricity Index Fugl-Meyer Assessment (FMA) Ashworth Modified Scale Box and Block Test Chedoke Arm and Hand Activity Inventory (CAHAI)	Improvement on most scales for all groups; Modulation of benefits of VR treatment according to the use or non-use of compensatory movement strategies and sensory-motor demand.
Cho et al., 2012	Conventional rehabilitation (60 minutes), 5 sessions per week, 6 weeks, using Wii Fit Balance Board for 30 minutes, 3 times per week, 6 weeks (VR just for the experimental group).	22 patients with hemiparesis and single stroke in the last six months, randomly divided into control and experimental groups.	Berg Balance Scale (BBS) Time Up and Go (TUG) Static and dynamic balance Mobility	Improvement in BBS and TUG in the experimental group.
Cho et al., 2013	Conventional (both groups) and virtual rehabilitation (experimental group) with treadmill gait training associated with recording of real environments. 30 minutes/day, 3 times per week, 6 weeks.	14 patients with hemiparesis and single stroke in the last six months, randomly divided into control and experimental groups.	BBS TUG Velocity Cadence	Improvement in BBS and TUG in the experimental group; Increased speed and cadence in the experimental group.

Orihuela-Espina et al., 2013	Virtual rehabilitation with Armeo System with varying levels of challenge but constant difficulty. 45 minutes, 20 sessions. Acquisition of magnetic resonance imaging (MRI) before and after therapy.	8 patients with chronic upper extremity hemiparesis (vascular event in more than 6 months).	FMA Motricity Index Brain MRI	Significant behavioral improvement; Activation of motor cortex contralateral to the injury, cerebellar recruitment and compensatory activation of the prefrontal cortex; Increased motor skill after beginning of therapy related to total recruited brain activity.
Subramanian et al., 2013	Conventional rehabilitation in physical environment and virtual rehabilitation using 3D supermarket simulator. 12 sessions for 4 weeks.	32 patients with history of stroke between 6 and 60 months before the study.	Clinical and kinematic evaluation of upper limb	Increased speed, overall reach and grip performance and levels of activity for both groups; Major changes in patients in virtual environment.
Turolla et al., 2013	Conventional upper limb rehabilitation and virtual rehabilitation using Virtual Reality Rehabilitation System (VRRS). 2 hours, 5 times per week, 4 weeks.	376 patients with stroke without severe neuropsychological deficits.	FMA Functional Independence Measure (FIM)	Significant increase in scores in both scales for both groups (higher in experimental group).
Kiper et al., 2014	Conventional upper limb rehabilitation and virtual rehabilitation using Virtual Reality Rehabilitation System (VRRS). 2 hours, 5 times	44 patients with stroke classified according the etiology (ischemic or hemorrhagic).	FMA FIM	Improvement in FMA for experimental group; No improvement in speed of upper limb; Patients with hemorrhagic stroke had a significant improvement in FIM; Patients with

	per week, 4 eeks.			ischemic stroke had improved speed when treated with VR.
Lee e Chun, 2014	Conventional rehabilitation, virtual rehabilitation and transcranial direct current stimulation (tDCS). 15 sessions, 30 minutes, 5 times per week, 3 weeks.	59 patients with a history of stroke one month before the start of study divided into 3 groups (for each intervention).	Ashworth Modified Scale Manual Muscle Test Manual Function Test FMA Box and Block Test Korean-Modified Barthel Index	Improvement in manual function and muscle tests; Improvement in FMA and Barthel; Improvement in FMA and manual function for combined therapy.
McEwen et al., 2014	Conventional rehabilitation and virtual rehabilitation using Interactive Rehabilitation Exercise Software. 10 to 12 minutes daily, 3 weeks.	59 hospitalized stroke patients.	BBS TUG 2 Minute Walk Test Chedoke-McMaster Stroke Assessment	VR group obtained improvement in TUG and 2 Minute Walk Test.
Viana et al., 2014	Virtual rehabilitation using the Nintendo Wii console and tDCS. 15 sessions, 13 minutes for tDCS and 1 hour for VR.	20 patients with stroke.	FMA Wolf Motor Function Test Ashworth Modified Scale Grip strength Stroke Specific Quality of Life scale (SS-QOL)	Improvements in all areas analyzed in both groups; Clinically relevant changes in the levels of wrist spasticity in experimental group.
Kim et al., 2015	Conventional rehabilitation 1 hour per day, 5 times per week, 4 weeks; Virtual	20 patients with stroke.	Static balance Postural oscillations Velocity	Experimental group showed a significant improvement in the postural oscillation; Significant

	rehabilitation 30 minutes per day, 3 times per week, 4 weeks.		improvement for experimental group.