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UPPER EXTREMITY VIRTUAL REALITY REHABILITATION IN POST-STROKE PATIENTS-A LITERATURE REVIEW

REALITATEA VIRTUALA IN REABILITAREA MEMBRULUI SUPERIOR LA PACIENTII CU SECHELE POST AVC-REVIZUIRE DE LITERATURA

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Abstract
Introduction: The sequelae after a stroke cause proprioceptive disorders that cause disabilities in the individual, negatively influencing the performance of daily activities.
Objectives: This paper aims to analyze the effectiveness of virtual reality (VR) rehabilitation methods through various technologies in post-stroke patients.
Material and method: Web of Science Core Collection database was interrogated. Clinical trials from the last five years were included in the review.
Results: Twelve papers were included in the literature review. Immersive and non-immersive technologies were used as an adjunct or standalone therapy in post-stroke rehabilitation, with 30 to 40 minutes daily sessions or 3 to 4 times a week. Virtual reality therapy was performed. The length and the therapy were heterogenous, with patients receiving conventional physiotherapy exercises, mirror therapy or robotic therapy.
Conclusions: VR therapy seems to improve patients functioning and positively influences the rehabilitation of the upper extremities in post-stroke patients, especially in association with conventional physiotherapy.

Rezumat
Introducere: Sechelele după un accident vascular cerebral (AVC) provoacă tulburări proprioceptive care determină dizabilități la individ, influențând negativ desfășurarea activităților zilnice.
Obiective: Această lucrare își propune să analizeze eficacitatea metodelor de reabilitare în realitate virtuală (VR) prin diverse și tehnologii la pacienții post-AVC.
Material și metodă: A fost interogată baza de date Web of Science Core Collection. Studiile clinice din ultimii 5 ani au fost incluse în revizuire.
Rezultate: Doisprezece lucrări au fost incluse în analiza literaturii de specialitate. Tehnologiile imersive și non-imersive au fost utilizate ca terapie adjuvantă sau de sine stătătoare în reabilitarea post-accident vascular cerebral, cu ședințe zilnice de 30 până la 40 de minute sau de 3 până la 4 ori pe săptămână, au fost efectuate terapii cu realitate virtuală. Durata terapiei și terapiile combinate au fost eterogene, pacienții primind și exerciții convenționale de fizioterapie, terapie cu oglindă sau terapie robotică.
Concluzii: Terapia VR pare să îmbunătățească funcționarea pacienților și influențează pozitiv reabilitarea extremităților superioare la pacienții post-AVC, în special în asociere cu kinetoterapie convențională

Key-words: *proprioception, virtual reality, rehabilitation, post-stroke*
Cuvinte cheie: *propriocepție, realitate virtuală, reabilitare, post-AVC*

Introduction

Approximately 66% of stroke patients suffer from impairments that affect the patient's daily life due to motor, cognitive and language dysfunction. Most post-stroke survivors maintain impairments manifested predominantly in the upper extremity. Therefore, many deficiencies can be observed, such as changes in muscle tone, vascular deconditioning, sensory impairment, fatigue, balance disorders, discoordination and gait disturbances. The upper extremity disability negatively influences the patient's capacity to perform activities of daily living (ADL) and quality of life *(Cormican, Hirani & McKeown, 2022; Brusco et al., 2022; Jeong et al., 2021)*

Virtual Reality Rehabilitation

Virtual reality (VR) is a technology used in neurorehabilitation to promote and stimulate the intentional movement of the upper and lower extremities or the whole body in a simulated environment. VR is "...a way for people to visualize, manipulate, and interact with computers and highly complex data". VR therapy is also used in rehabilitating post-stroke patients, enhancing locomotor capacity by favoring neuroplasticity through real-time feedback *(Jin et al., 2022; Ahmad et al., 2019).*

Immersive and non-immersive VR technology

Immersive VR allows the patient participating in the program to move in a computer-generated world, enhancing the patient's interaction with the virtual environment through multisensory integration (visual, auditory, tactile).

In contrast, non-immersive VR technology uses gaming systems via a keyboard, mouse, game interface devices or video-camera sensors to navigate the virtual environment that appears on the screen. Non-immersive virtual systems present several advantages, such that participants can view and modulate their movements in real-time and manage to perform tasks that are complicated in the real world.

Another advantage is the customization of the exercises tailored to the participant's ability; at the same time, it also increases his motivation. The system also can monitor the level of reproduction of the movements performed by the patient *(Maier et al., 2019; Levin et al., 2012; Schuster-Amft et al., 2018)*

Technology using RV has a direct influence on motor function, namely an impact just on cortical reorganization. It has been suggested that goal-directed tasks coupled with performance feedback improve neural network activity, thereby positively influencing neuroplasticity *(Levin et al., 2012).*

Material and methods

We searched the Web of Science and PubMed databases on virtual reality in upper extremity stroke recovery. Eligible studies and articles were identified based on the English keywords: "virtual reality, stroke and upper extremity" and "virtual reality stroke and upper extremity".

We assessed and analyzed the abstracts of each potentially eligible article and excluded those: which were not in English, with participants less than 18 years old, no post-stroke pathology, other neurological diseases, papers presenting the VR equipment, VR therapy protocols, reviews and meta-analysis.

The studies included in the work are based on the following criteria: to use VR as a method of rehabilitation (immersive or non-immersive); apply VR technology in upper extremity therapy; assessment the upper extremity functionality.

The diagram flow of the papers included in the review is found in Figure 1.

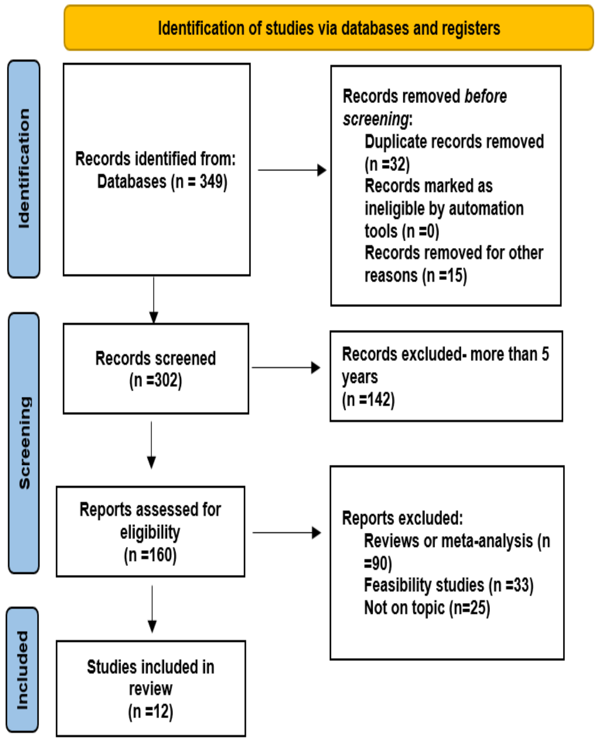

Fig. 1. PRISMA flow diagram

Results and discussions

The research included in this literature review depict the VR technology and shows the benefits of the upper extremity rehabilitation after stroke. Most studies (nine) have analyzed the effectiveness of non-immersive VR and only in one research dedicated technology for rehabilitation was mentioned, besides the two papers which reported the use of Armeo which is a combination of exoskeleton and VR.

The subjects from the revised papers were in the chronic stage following a stroke, except Miclaus et al., who reported data for subacute patients in small numbers (five in the control group vs six in the experimental group).

Most of the exclusion criteria were given by lack of cognitive function, especially by patients diagnosed with aphasia who could not understand and execute commands. Subjects with auditory, visual and orthopedic dysfunctions or other pathologies that limited movement performance was also excluded. Patients participating simultaneously in other similar studies were excluded from the studies, being considered ineligible.

The most used functional assessment methods in the presented studies were represented by: Fugl-Meyer Upper Extremity Scale (FMA-UE), Functional Independence Measurement (FIM) and Arm Action Research Test (ARAT). Statistical tests were used to determine the effectiveness of treatment and to observe statistical differences between groups.

	Technology and study length	**Intervention**	**Assessments /outcomes**	**Results**
1. Weber et al. 2020	Immersive VR (Occulus fit) 12 sessions of 30 min/day; 4 weeks	Exercises based on mirror therapy using a touch controller with the healthy hand (n=10)	ARAT FMUE	No significant changes pre- and post-therapy, slight improvements FM score.
2. Song & Lee 2021	Immersive VR (Occulus fit) 20 sessions of 30 min/day 4 weeks	ADL bilateral-based VR training (EG, n=5) and conventional PT Standard bilateral arm training (CG, n=5) and conventional PT	Manual function Proprioception Stereognosis Sensory function	Both groups had significant differences pre- and post-therapy for manual function, while the VR group's proprioception improved better than the control group.
3. Shahmoradi et al. 2020	Non-immersive VR (Xbox Kinect) 12 sessions of 40 min for 3 times/week	Exercises based on VR games using Xbox Kinect aiming to imitate the tasks of the Brunnstrom stages (n=10)	ROM MAS Brunstromm	Improvements for horizontal shoulder abduction, forearm supination, elbow and wrist flexion. No significant changes for elbow and wrist extension.
4. El-Kafy et al. 2021	Non-immersive VR (Armeo Spring) 2 hours of training, 3 times/ week, for 3 months	EG (n=20) VR training and conventional PT CG (n=20) conventional PT training	ARAT WMFT HGS	Significant differences post-therapy in the EG for ARAT and WMFT tests.
5. Long et al. 2020	Non-immersive (touch-controlled computer screen) 45 minutes/ 5 times a week/ for 3 weeks	60 patients RV group (n=30) performed game-based training, and the control group (n=30) performed conventional training	FMUE COPM SSEQ FTHUE	RV-based training helps improve self-efficacy and daily activities (SSEQ and MBI) significantly compared to conventional training. No differences between conven-tional training in improving upper extremity functions and occupational performance.
6. Ogun et al. 2019	Immersive VR (Leap Motion Controller) 3 times/week for 6 weeks	EG (n=33) 1h/day RV therapy training. CG9n=32) conventional training 45 minutes + 15 minutes VR program based on visual scenes.	ARAT FIM FMUE PASS	Paired sample t-test results showed that FMUE, ARAT, FIM, and PASS scores increa-sed significantly compared to baseline in the VR group, but differences in PASS-BADL and PASS-IADL scores were not significant. The final results showed a significant difference in favor of the VR group.
7. Yang et al. 2021	Non-immersive VR (touch-controlled computer screen)	EG 1 trunk support group (n=14) and EG 2 trunk restraint (n=14); active sensory-motor (smart)	PASS FRT	All assessments showed significant differences pre and post therapy for both groups. In trunk support group, significant

	3o minutes/day, 3 times/week, for 4 weeks	rehabilitation treatment for the upper extremity	ROM (shoulder flexion) MMT (triceps brachii) FMUE	differences vs restraint group for PASS, FRT and FMUE.
8. Ain et al. 2021	Non-immersive VR (Xbox Kinect) 5 days a week/35-45 minutes per session/for 6 weeks	EG (Xbox Kinect) n=28 performed training based on games with the Xbox console but also conventional training exercises, and CG n=28 performed standard physical therapy.	MAS FMUE BBT	After treatment, significant improvements were shown in both groups on FMUEand BBT, but also a significant improvement was identified in the experimental group vs control group.
9. Miclăuș et al. 2020	Non-immersive rehabilitation VR (rehabilitation technology) 60 minutes/day for 10 days	EG1 subacute (n=6) EG 2 chronic (n=20); RV based training CG1 (n=5) subacute and GC2 (n=21) chronic; conventional PT	MAS FMUE MRS FIM MMT ROM FRT	In both experimental groups, significant results were obtained in AROM, MMT, FMUE, FIM, FRT; in both control groups, significant differences were observed in the evaluations of MMT, FMUE, and FIM. Except for FRT, all assessments found differences for the subacute EG 1.
10. Grigoraș et al. 2018	Non-immersive VR (See me) 12 training sessions/ 20 minutes each/ for two weeks	The 8 participants underwent VR (see me system) training using 8 games but also underwent standard therapy.	FMUE SIS	None of the primary efficacy endpoints (FMA or SIS) changed following the 12-day VR training program in any of the patients.
11. Aguilera-Rubio et al. 2022	Non-immersive RV-Leap motion controller 2 sessions of 1h/ week for 2 weeks	All (n=10) patients received RV-based upper extremity training and conventional therapy.	ARAT BBT	Outcomes after treatment show improvements on the BBT and ARAT scales, pre-and post-treatment assessments
12. Gueye et al. 2020	Non-immersive VR (ArmeoSpring) 12 sessions, 45 minutes/session, for 3 weeks	EG (n=25) supported training based on RV, and the control group (Armeo CG, N=25) supported training based on conventional therapy.	FMUE FIM	After treatment, paretic arm function improved significantly in both groups, significant differences in the Armeo EG vs than the CG.

EG=experimental group, CG=control group, ROM=range of motion, BBT=box block test, FRT=functional reach test, SSEQ=stroke self-efficacy questionnaire, COPM=Canadian occupational performance measure, MBI=modified Barthel index, SIS= stroke impact scale, MMT=manual muscle testing, MAS= modified Ashworth scale, PASS=postural assessment scale for stroke

Table 1. Principal characteristics of the revised papers

Although many studies have suggested that VR technology is effective in upper extremity function rehabilitation in post-stroke patients in association with conventional therapy, other research has advocated that tailored specific VR may lead to functional improvements also. In the experimental groups from the analyzed papers 233 patients received VR therapy as standalone treatment or in association with conventional therapy, while 140 participants were in the control groups receiving only conventional physiotherapy training. The enrolled patients were mostly in the chronic stage post-stroke.

Unfortunately, the heterogeneity of the analyzed papers makes it challenging to create a solid framework regarding VR efficiency in post-stroke rehabilitation since the length of the research, the technology used, and the clinical features of the patients are particular. Another innovative technology used in association with

VR is robotic therapy which offers new ground in neurorehabilitation, facilitating the rehabilitation process even more significantly. The results of the research performed on Armeo demonstrated favorable results in hand grip function. The disadvantage of VR and robotic rehabilitation technology is that it requires qualified and well-trained personnel. The results of the analyzed studies suggest that VR is a promising tool in post-stroke rehabilitation although specific guidelines and protocols are required to facilitate motor function restoration.

Conclusions

VR technology positively influences the rehabilitation of the upper extremities in post-stroke patients as an adjunct therapy to standard physiotherapy and has also potential as an independent therapy method. Further clinical research is needed to identify guidelines and therapy usability protocols.

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