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A CASE-STUDY VISION

Design of virtual reality environments applicable to assistive robotics systems: a literature review

Diseño de entornos de realidad virtual aplicables a sistemas de robótica asistencial: un análisis literario

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ABSTRACT

Virtual Reality (VR) environments can be applied to assistive robotics to improve the effectiveness and the user experience perception in the rehabilitation process due to its innovative nature, getting to entertain patients while they recover their motor functions. This literature review pretends to analyze some design principles of VR environments developed for upper limb rehabilitation processes. The idea is to identify features related to peripheral and central nervous systems, types of information included as feedback to increase the user's levels of immersion having a positive impact on the user's performance and experience during the treatment. A total of 32 articles published in Scopus, IEEE, PubMed, and Web of Science in the last four years were reviewed. We present the article selection process, the division by concepts presented previously, and the guidelines that can be considered for the design of VR environments applicable to assistive robots for upper limbs rehabilitation processes.

Palabras clave:
Robótica asistencial
Desempeño
Miembro superior
Experiencia del usuario
RV

RESUMEN

Los entornos de Realidad Virtual (RV) aplicables a sistemas de robótica asistencial pueden ser diseñados de manera que mejoren la efectividad y la experiencia de usuario de los procesos de rehabilitación debido a su naturaleza novedosa, logrando entretener a los pacientes mientras recuperan sus funciones motoras. Esta revisión literaria pretende analizar los criterios de diseño de entornos de RV utilizados en procesos de rehabilitación de miembro superior, identificando las características de entornos para rehabilitación de problemas asociados el sistema nervioso central y periféricos, los tipos de información que se realimenta al usuario para beneficiar los niveles de inmersión y su impacto en términos del desempeño y la experiencia del usuario en tratamiento. Un total de 32 artículos publicados en revistas indexadas de Scopus, IEEE, PubMed y Web of Science en los últimos cuatro años fueron revisados. Se presenta el proceso de selección de artículos, la división por las temáticas presentadas anteriormente y los lineamientos generales que pueden ser considerados para el diseño de entornos de RV aplicables a robots asistenciales en procesos de rehabilitación de miembro superior.

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1. Introduction

Assistive robotics is focused on the development of systems in order to promote improvements in the assistance of daily activities or health care. Some of its applications allow the increase of autonomy in people with reduced mobility [1], [2], the development of systems focused on teleoperation [3], and the support in rehabilitation processes of neuromotor functions [4], [5]. The latter has gained increasing interest and acceptance due to the advantages it offers compared to other conventional rehabilitation methodologies, where repetitive movements that can cause damage to the musculoskeletal system of therapists must be performed. In the same way, it is possible to develop systems that allow the proper execution of movements and the application of resistance allowing to recover ranges of motion, strength and elasticity, and additionally that allow greater motivation on the part of users, who tend to abandon therapies due to perceived pain and lack of motivation, among other aspects [6], [7]. Within strategies focused on increasing motivation, assistive robotics systems supported by virtual reality (VR) environments have been implemented [8].

Regarding upper limb rehabilitation, the authors have focused their studies on the recovery of motor functions due to pathologies such as cerebrovascular accidents (CVA) [9], *Intensive Care Unit Acquired Weakness* (ICUAW) [10], multiple sclerosis (*Multiple Sclerosis* or MS) [11], cerebral palsy (*Cerebral Palsy* or CP) [12], elbow epicondylitis (also called tennis elbow) [13] through art-oriented VR environments [14], games [15], tasks or imitations [16].

Another approach addressed by the authors as they continue to develop virtual reality environments is the orientation to improve the immersive experience of the user, an example of this is the proposal of the authors in [17] propose an alternative that allows implementing environments with the least amount of equipment needed to execute a rehabilitation process in people with a history of CVA, this alternative requires a flat monitor, a *Leap Motion©* controller and a support for the forearm involved in the current session.

These studies demonstrate how it may be possible to implement assistive robots [5] together with VR environments to support the rehabilitation of upper limbs caused by different pathologies [18], therefore, this work aims to analyze different approaches, features and considerations to design VR environments applicable to assistive robotic systems in upper limb rehabilitation processes, these processes require a physical and virtual architecture consistent with each pathology and their respective implications on the user [19].This review consists of 32 articles belonging to different indexed journals found in *IEEE, Scopus, PubMed* and *Web of Science* during the last four years, which were grouped according to the type of condition that led the study, additionally subcategories were created to classify the information delivered to the user in order to define the level of immersion sought for each upper limb rehabilitation system through VR applicable to assistive robotics, in order to establish general guidelines for the design of VR environments to improve the rehabilitation processes of upper limbs by unconventional therapeutic methods.

2. Methodology

This section describes the methodology applied for the selection of articles to be included in the literature review, which was carried out according to the protocol statement for systematic literature reviews of the 2020 PRISMA (*Preferred Reporting Items for Systematic reviews and MetaAnalyses*)[20], following the flow diagram shown in Figure 1. In this way, we describe the processes of identification of articles from the different databases, their subsequent screening to preliminarily exclude publications and finally the eligibility criteria for the final selection of articles that will allow us to evaluate the general characteristics for the design of VR environments for use in robotic-assisted upper limb rehabilitation.

2.1. Item identification

A literary identification was performed using four databases: IEEE Xplore®, Web of Science, PubMed and Scopus with a window of publication dates defined between January 2018 to December 2021, using a combination of character strings and logical operators as shown in Table 1. As a result of this search, a total of 251 articles were obtained among the selected databases, which contain information on Engineering and Medicine.

From the 251 articles initially identified, 35 duplicate articles and 4 articles were discarded because they were published in a language other than English.

2.2. Article screening

The next selection step applied to the 212 records was screening, which consisted of reviewing the abstracts

Table 1. Article search parameters.

Base de Datos	Fecha de Búsqueda	Cadena de caracteres
SCOPUS IEEE Xplore® PubMed Web of Science	Enero2018 a Diciembre 20121	"Virtual Reality" AND "Rehabilitation" AND "Upper Limbs" AND "Rpbotics"

Source: own.

to discard those publications that were not based on work associated with upper limb rehabilitation processes through VR environments or assistive robotics systems in conjunction with VR environments.

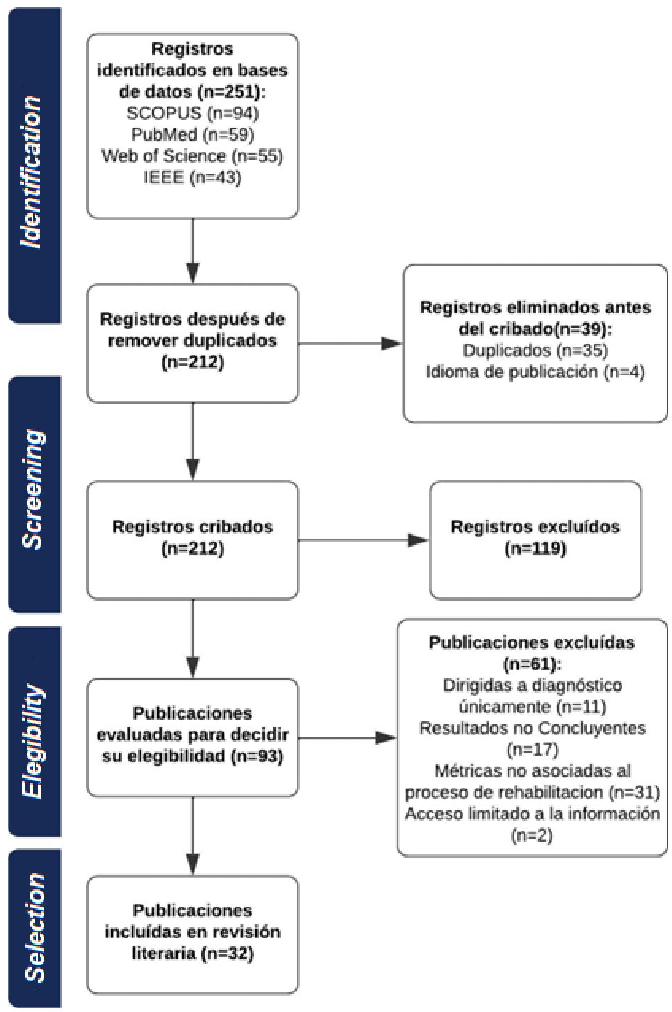
2.3. Item Eligibility

Finally, from the 93 publications obtained during the screening phase, 61 articles were additionally excluded, which, when fully reviewed, contained applications for diagnosis but not for rehabilitation processes.

On the other hand, we excluded works that were not evaluated in people with situations requiring upper limb rehabilitation, or that did not evaluate complete rehabilitation processes and therefore do not have conclusive results for the evaluation of the applied environments.

From the 32 publications included, two main categories were created to classify these studies, these two categories allude to the type of condition that generates the need to apply an upper limb rehabilitation process: problems associated with the central nervous system, and problems associated with the peripheral nervous system. Additionally, in each work, aspects such as feedback elements that affect the user's immersion and the types of evaluation performed in each case were reviewed to evaluate mainly aspects such as performance and user experience.

Figure 1. PRISMA flow chart.



Source: own.

3. Results

This section shows the categorization of the resulting items according to: type of condition, types of feedback and types of evaluation as shown in Table 2.

Table 2: Upper limb movements [29].

Part of the upper limb	Movements
Shoulder	Flexion - Extension Abduction - Adduction Internal - External Rotation
Elbow	Flexion - Extension Abduction - Adduction Pronation- Supination
Wrist	Flexion - Extension Radial - uinar deviation
Finger	Flexion - Extension Abduction - Adduction

3.1. Type of Affection

The nervous system is usually divided into: the Central Nervous System (CNS), composed of the brain and spinal cord, and the Peripheral Nervous System (PNS), composed of the cranial and spinal nerves [21]. The CNS controls most bodily activities by transmitting motor impulses in response to sensory impulses generated by different nerves of the PNS. Thus, damage to PNS nerves can cause pain, weakness, numbness, constipation, among others. On the other hand, damage to the CNS directly affects the exchange of motor and sensory impulse information to the point of generating problems of coordination, balance, cognitive changes, seizures, among others [22].

This category presents the VR environments performed for rehabilitation of CNS and PNS conditions, and their main characteristics, as well as the joints involved in each of the activities to be performed in the environments presented.

3.1.1.VR systems for rehabilitation of problems associated with the CNS

Rehabilitation processes for CNS conditions focus on the ability of this system to self-organize, since this feature makes possible the functional recovery of the affected areas of the brain or spinal cord (neuroplasticity), as a result of pathologies such as stroke, paralysis, epilepsy, among others, this type of functional recovery process is known as neurorehabilitation [23]. Within the VR works associated with this type of condition are: For example the authors in [24] implemented a semi-immersive VR environment in people affected by CVA, these environments were designed in such a way that they modify their behavior from electromyography (EMG) signals, this adaptive system was implemented in order to contribute to the neurorehabilitation process in favor of the recovery of their motor functions since the latter are significantly impaired and makes the patient's performance measurements through kinematic models unreliable in early stages of treatment. With the same intention of evaluating the feasibility of employing more immersive environments to treat CNS conditions, the authors in [19] implemented reaching and dropping virtual item activities in children with a history of cerebral palsy using two different techniques to represent them within the VR environment: a realistic avatar or an abstract representation of the hand, with the aim of knowing which of these techniques has a more significant impact for their rehabilitation process, finding that the abstract representation obtained a better quality in the reaching movements in addition to a lower kinetic cost, while the realistic avatar encourages to perform a greater amount of movement and thus greater energy expenditure.

The authors in [25] have found that intensive training of upper limbs with assistive robotics and VR-based systems in people with less than one month post-CVA in addition to usual care, can have a significantly greater impact in terms of reducing disabilities compared to a treatment based entirely on traditional care, obtaining more significant improvements in the recovery of motor functions for the same preset time of treatment. In [26], where they proposed a process of neuroreha bilitation of upper limbs with an immersive VR environment for people affected by stroke, the therapies consisted of thinking the movements that would be performed with the arms to row in a virtual boat set on the water, thanks to its *BrainComputer Interface (*BCI), the patient's electroencephalography (EEG) signals corresponding to the following are recorded and processed the intention of these movements to provide visual feedback through a *Head Mounted Display (HMD*), auditory and haptic feedback to the animation of the virtual boat, the results of this rehabilitation process were reflected in functional magnetic resonance imaging (fMRI) of the brain where the level of brain activity was higher than that recorded before starting the case study.

Some pathologies affecting the CNS may be less common, making it even more difficult to propose strategies for their rehabilitation from assistive robotics systems with VR environments, as in the case of the authors in [27] where they implemented different therapies in a patient with brainstem radionecrosis until it was possible to implement an assistive robotics system to achieve significant advances in all diagnostic scales of motor functions used for upper limbs.

However, among the different conditions, there have been observed trends in research and implementation of increasingly adaptive VR environment designs based on electrophysiological activation signals, where authors have even proposed assistive robotics systems with configurable dynamics for different types of patients.

3.1.2. VR systems for rehabilitation of problems associated with PNS

The rehabilitation process for PNS conditions focuses on the recovery of damage or deterioration at the muscle or joint level due to trauma, overexertion of muscle fibers or injuries, as is the case of tennis elbow. For example, the authors in [15] designed different goal-oriented VR environments through games where the user can execute different joint movements to promote their rehabilitation process through repeated executions in fun contexts that motivate them to continue with their treatment, similarly. The authors in [13] implemented a virtual version of the popular *Buzz Wire Game* for rehabilitation processes of people suffering from tennis elbow, applying a context-sensitive architecture thanks to different sensors arranged on the upper limb under treatment, analyzing the evolution of the patients during one month in terms of the difficulty observed during the execution of the exercises involved in the game.

Orthopedics is a medical specialty dedicated in part to the treatment of the musculoskeletal system and the use of assistive robotics has been little explored, as proposed by the authors in [28], who also propose a method of rehabilitation with assisted robotics for the forearm based on VR physiotherapy by means of different exercise games.

3.1.3. Joints Involved

Regarding upper limb rehabilitation, there are different devices supported by virtual reality environments that can be configured to favor the monitoring and adaptability of the kinetics and force production of different parts of the upper limb in rehabilitation. Table 3 shows the different movements that can be performed by each of the parts of the upper limb, which is composed of groups of joints arranged in such a way as to allow the movements presented in the table.

Table 3. Articles reviewed.

Title of publication	Published in	Year of publication	Type of condition	Type of feedback	Articulation(s) involved	Type of Evaluation
Connected elbow exoskeleton system for rehabilitation training based on virtual reality and context-aware [13].	Sensors (Switzerland)	2020	Peripheral Nervous System	Visual Immersive Auditory	Elbow	Performance
Development of virtual reality games for motor rehabilitation [15].	Journal of Telecommunication, Electronic and Computer Engineering	2018		Visual Immersive Visual Non-immersive Haptics	Elbow Wrist Fingers	Performance
Vision-based game design and assessment for physical exercise in a robot-assisted rehabilitation system [30]	IET Computer Vision	2018		Non-immersive Visual	Shoulder Elbow Wrist	User Experience
An Orthopedic Robotic Assisted Rehabilitation Method of the Forearm in Virtual Reality Physiotherapy [28]	Journal of Healthcare Engineering	2018		Visual Non-immersive Haptic	Elbow Wrist	User Experience, Performance
Effects of Exergame on Patients' Balance and Upper Limb Motor Function after Stroke: A Randomized Controlled Trial [31]	Journal of Stroke and Cerebrovascular Diseases	2019		Visual Immersive Auditory	Shoulder Elbow Wrist	Performance
Design expanded BCI with improved efficiency for VR-embedded neurorehabilitation systems [32]	19th CSI International Symposium on Artificial Intelligence and Signal Processing, AISP 2017	2018		Immersive Visual	Wrist	Performance
Efficacy and Brain Imaging Correlates of an Immersive Motor Imagery BCI-Driven VR System for Upper Limb Motor Rehabilitation: A Clinical Case Report [26]	Front Hum Neurosci	2019		Visual Immersive Haptic	None	Performance

Title of publication	Published in	Year of publication	Type of condition	Type of feedback	Articulation(s) involved	Type of Evaluation
Immersive Virtual Environments and Wearable Haptic Devices in rehabilitation of children with neuromotor impairments: a single-blind randomized controlled crossover pilot study [33]	Journal of Neuroengineering and Rehabilitation	2020	Peripheral Nervous System	Visual Immersive Haptic	Elbow Wrist Fingers	Performance
Virtual body representation for rehabilitation influences on motor performance of cerebral palsy children [19].	Virtual Reality	2021		Non-immersive Visual	Shoulder Elbow	Performance
Coordinative motion-based bilateral rehabilitation training system with exoskeleton and haptic devices for biomedical application [34]	Micromachines	2018		Non-immersive Visual Haptic	Elbow Wrist	Performance
Virtual Reality for Upper Limb Rehabilitation in Subacute and Chronic Stroke: A Randomized Controlled Trial [35].	Arch Phys Med Rehabil	2018		Visual Non-immersive Auditory	Shoulder Elbow	Performance
An Innovative STRoke Interactive Virtual therapy (STRIVE) Online Platform for Community-Dwelling Stroke Survivors: A Randomized Controlled Trial [36]	Archives of Physical Medicine and Rehabilitation	2020		Visual Non-immersive Auditory	Shoulder Elbow Wrist	Performance
A case report on intensive, robot-assisted rehabilitation program for brainstem radionecrosis [27]	Medicine (Baltimore)	2020		Visual Non-immersive Haptic	Shoulder Elbow Wrist Fingers	Performance
Beyond motor recovery after stroke: The role of hand robotic rehabilitation plus virtual reality in improving cognitive function [37]	J Clin Neurosci	2021		Visual Non-immersive Haptic	Fingers	Performance

Title of publication	Published in	Year of publication	Type of condition	Type of feedback	Articulation(s) involved	Type of Evaluation
Effects of robotassisted training on upper limb functional recovery during the rehabilitation of poststroke patients [38].	Technology and Health Care	2018	Peripheral Nervous System	Visual Non-immersive Haptic	Wrist Fingers	Performance
Feasibility and preliminary efficacy of a combined virtual reality, robotics and electrical stimulation intervention in upper extremity stroke rehabilitation [39].	Journal of Neuroengineering and Rehabilitation	2021		Visual Non-immersive Haptic	Shoulder Fingers	Performance
Intensive virtual reality and robotic based upper limb training compared to usual care, and associated cortical reorganization, in the acute and early subacute periods poststroke: a feasibility study [25].	Journal of Neuroengineering and Rehabilitation	2019		Visual Non-immersive Haptic	Wrist Fingers	Performance
Mirror Visual Feedback Prior to Robot-Assisted Training Facilitates Rehabilitation After Stroke: A Randomized Controlled Study [40].	Frontiers in Neurology	2021		Visual Non-immersive Haptic	Elbow Wrist Fingers	Performance
The Combined Effects of Adaptive Control and Virtual Reality on Robot Assisted Fine Hand Motion Rehabilitation in Chronic Stroke Patients: A Case Study [41].	Journal of Stroke & Cerebrovascular Diseases	2018		Visual Non-immersive Haptic	Fingers	Performance
The Impact of a Novel Immersive Virtual Reality Technology Associated with Serious Games in Parkinson's Disease Patients on Upper Limb Rehabilitation: A Mixed Methods Intervention Study [42]	Sensors (Basel)	2020		Visual Immersive Auditory	Wrist Fingers	User Experience, Performance

Title of publication	Published in	Year of publication	Type of condition	Type of feedback	Articulation(s) involved	Type of Evaluation
A virtual reality muscle-computer interface for neurorehabilitation in chronic stroke: A pilot study [24].	Sensors (Switzerland)	2020	Peripheral Nervous System	Immersive Visual	Wrist	User Experience, Performance
Efficacy of Virtual Reality Combined With Real Instrument Training for Patients With Stroke: A Randomized Controlled Trial [43]	Archives of Physical Medicine and Rehabilitation	2019		Visual Immersive Haptic	Shoulder Elbow Wrist Wrist Fingers	User Experience, Performance
Effects of virtual reality associated with serious games for upper limb rehabilitation inpatients with multiple sclerosis: randomized controlled trial [11]	J Neuroeng Rehabil	2020		Visual Non-immersive Auditory	Wrist Fingers	User Experience, Performance
Leap motion controlled video game-based therapy for upper limb rehabilitation in patients with Parkinson's disease disease: a feasibility study[44]	J Neuroeng Rehabil	2019		Visual Non-immersive Auditory	Wrist Fingers	User Experience, Performance
Virtual reality games for rehabilitation of upper extremities in stroke patients[8].	J Bodyw Mov Ther	2021		Visual Non-immersive Auditory	Shoulder Elbow	User Experience, Performance
A pilot study into reaching performance after severe to moderate stroke using upper arm support[45].	PLoS One	2018		Visual Non-immersive Haptic	Elbow Wrist	User Experience, Performance
Using an upper extremity exoskeleton for semiautonomous exercise during inpatient neurological rehabilitation: a pilot study[46].	J Neuroeng Rehabil	2018		Visual Non-immersive Haptic	Shoulder Elbow Wrist	User Experience, Performance
Changes in arm kinematics of chronic stroke individuals following Assist-As-Asked robot-assisted training in virtual and physical environments: A proof-of-concept study [9]	Journal of Rehabilitation and Assistive Technologies Engineering	2020		Visual Non-immersive Haptic	Shoulder Elbow	User Experience, Performance
Influence of New Technologies on Post-Stroke Rehabilitation: A Comparison of Armeo Spring to the Kinect System [47]	Medicina Lithuania	2019		Visual Non-immersive Haptic	Shoulder Elbow Wrist Fingers	User Experience, Performance
Patients' perspective and usability of innovation technology in a new rehabilitation pathway: An exploratory study in patients with multiple sclerosis[48]	Multiple Sclerosis and Related Disorders	2020		Visual Non-immersive Haptic	Shoulder Elbow Wrist	User Experience, Performance
The feasibility, acceptability and preliminary efficacy of a low-cost, Virtual-reality based, Upper-limb stroke rehabilitation device: a mixed methods study[49]	Disability and Rehabilitation	2019		Visual Non-immersive Auditory	Shoulder Elbow Wrist	User Experience, Performance

Source: own.

In the rehabilitation process, as mentioned above and depending on the type of injury is sought mainly: the recovery of the range *of* motion (*Range Of Motion* or ROM), flexibility and strength, for the activities focused on the recovery of ROM are usually implemented schemes with a high number of repetitions using a medium or low weight in each of them, for the case of the recovery of flexibility are implemented schemes of few repetitions with sustained movements for several seconds with zero weight, while for the activities related to the recovery of strength are used schemes of few repetitions with moderate high weight taking into account adequate rest times for all recovery schemes, Taking this into account, the authors in [31] implemented six different exercise games (*Exergames*) of the Motion Rehab AVE 3D involving abduction, adduction and shoulder flexion movements, as well as elbow and wrist extension to evaluate their improvement in upper limb motor functions when using this VR system, where they found that these VR rehabilitation processes outperformed the results obtained through conventional rehabilitation sessions with physiotherapy. On the other hand, the authors in [47] compare how two technologies widely used in upper limb rehabilitation applications through VR: *Kinect* and *Armeo Spring*© contribute to the recovery of the range of motion (ROM) of the shoulder, elbow and wrist joints during the execution of several different tasks preprogrammed for each person under study, obtaining that in terms of detection and performance both technologies are at a similar level, a similar case to the authors in [38], where thanks to kinematic data obtained with the help of an *Armeo Spring*© they were able to quantify the ROM recovery compared to a control group that was not intervened in their recovery process with VR environments with assistive robotics systems, while the authors in [46] conducted a similar study, with the difference that the one proposed in their study evaluates the progress of patients through the maximum force generated (which was measured using weights in the wrists) compared to that obtained before starting the rehabilitation process with the same robotic assisted the rehabilitation process with the same robotic-assisted system, obtaining positive results after three weeks of positive results after three weeks of training. The authors in [45] used the functionality of the *HapticMaster* to compensate for the weight of the arm, with the aim of implementing a VR system with assisted robotics based on tasks involving the elbow and wrist in applications of force generation from repetitions of the same exercises.

3.2. Type of Feedback

Among the fundamental functionalities that VR has to offer are immersion and interaction and thanks to the large number of peripherals available on the market to implement, these functionalities have come to be exploited at the cognitive, sensory motor and functional level from the feedback of information to the user, which can be visual, auditory AND/OR haptic depending on the senses involved in VR environments and their activities [50].

The feedback of information or stimuli to the user involved in the execution of tasks in virtual reality environments is of great importance in rehabilitation processes, since this can favor the levels of immersion of the proposed system and therefore the levels of enjoyment and commitment of the participant to continue with the rehabilitation process[51].

The different types of feedback to the user usually act as an output or response to stimuli or actions generated by the same user, which have as inputs or triggers actions or stimuli can be voluntary (through joint movements as explained in section IIIA.3) or involuntary (through electrophysiological signals), the authors in [32] implemented a BCI, which had an immersive visual feedback delivered through an HMD and stimulated through EEG, while the authors in [34], implemented a VR assistive robotics system for their rehabilitation processes, which delivered a tactile feedback as well as a non-visual visual feedback immersive (delivered from a flat panel monitor).

Haptic feedback is associated with stimuli from the sense of touch and the authors have shown how this can be done in different ways, the authors in [9] and [39] implemented the *HapticMaster* robotic arm to deliver assistive force (force performed by the robotic system in the same direction as the patient, in order to reduce the effort made by the latter) to the user when requested, so that it compensates for gravity and adequately guides the movement of the forearm during the process, promoting personal challenges for each person by requesting less and less assistive force.

The strategy of providing assistive force when requested has also been approached from the machine learning (ML) approach, as proposed by the authors in [41] it is possible to use the kinematics and force of the different joints involved to predict when the patient requires assistance to complete a task without compromising the upper limb rehabilitation process. Visual feedback can be considered immersive when it is delivered as a stereo image or a three-dimensional (3D) image, one of the most widely implemented technologies due to its low cost and wide compatibility with different VR environment development engines are HMDs, which are mostly available as binoculars with a screen located near each eye, on which two different images will be generated and thus reproduce a stereoscopic image to the user. The authors in [33] used this technology to visualize in an immersive way different games proposed for rehabilitation of children with neuromotor impairment. However, it is not always sought to implement a visually immersive environment, since it is preferred that the user does not leave aside his own perception from the objectives outlined for a rehabilitation process of upper limbs with VR environments, the authors in [44] implemented a *Leap Motion*® controller which manipulates the virtual avatar that represents the wrist and finger movements of 12 people with a history of Parkinson's disease represented on a flat monitor, promoting improvements in fine motor skills of patients as well as a high satisfaction when using such a system, since the implementation of the *Leap Motion*® controller requires being attentive not to move the hands away from their work area to ensure its correct functioning, considering this, the authors in [42] used this controller in conjunction with an *Oculus Rift 2* to take advantage of its integrated cameras in order to promote a more immersive experience of different games implemented for upper limb rehabilitation processes with VR environments.

3.3. Type of Evaluation

This subcategory presents the types of evaluation applied by the different authors, which depend on the purpose of the study: to quantify their contribution to the recovery of the type of condition addressed or to evaluate the user's experience when using the different environments in upper limb rehabilitation processes.

3.3.1. Performance

It is associated to metrics associated to physical variables measured either from within the VR environment, through kinematic models, scoring systems, task execution times, among others; or from outside it, through different sensors arranged in a designated work area or attached to the user's body. This type of evaluations focuses on obtaining objective data on the design of VR environments, evolution of the rehabilitation process, among others[17][52].

For example, the authors in [43] used different indicators globally accepted in the field of physical therapy such as the nine-hole peg test, the box and block test, the Ashworth scale, among others, to assess user improvement when using non-immersive VR upper limb rehabilitation systems from the average score obtained among all participating volunteers. On the other hand, the authors in [34], used kinematic models in conjunction with inertial sensors to estimate the angular positions of the elbow in flexion and extension movements, to deliver tactile feedback translated as an upward or downward force so that the user can synchronize this same movement in the unaffected elbow.

The authors in [36] quantified the improvement in motor functions (grip, stability, range of motion, sensation, coordination, among others) of 30 stroke survivors who underwent virtual rehabilitation or therapy for 45 minutes daily for 8 weeks, using the *Fugl Meyer* upper extremity scale (FMAUE), among others. Another approach addressed with the aim of improving the performance obtained by patients involved in virtual rehabilitation processes is to train users prior to the start of the recovery program with mirror visual feedback, the authors in [40] replicated the movements performed by the affected limb on a screen with the help of cameras, promoting user awareness of the limitations that are sought to mitigate, this strategy managed to obtain results in the FMAUE as well as in other assessments of motor disability level significantly higher than those obtained in the control group, which implemented conventional rehabilitation methodologies.

CNS conditions can lead to impairment of different areas of the brain in addition to those related to motor functions of people, the authors in [37] used the Montreal Cognitive Assessment (MoCA) to assess the level of cognitive impairment in addition to the FMAUE for motor functions in people affected by stroke, both before and after being involved in rehabilitation processes of wrist and finger joints with an assistive robotics system with VR environments arranged as games, obtaining favorable results compared to the levels obtained at the beginning of therapy, while the authors in [8] used goniometers and the Modified Motor Assessment Scale (MMAS) to quantify the impact of games designed in VR environments for upper limb rehabilitation processes, with the aim of assessing muscle spasticity and functionality of the limbs of patients, obtaining favorable results by applying these fun alternatives that motivate users to continue with the process of recovery of motor functions in upper limbs.

3.3.2. User Experience

This type of evaluation is associated with metrics of a subjective nature, but equally important in the process of validation and acceptance of VR environments in rehabilitation applications, among the most used metrics in studies of upper limb rehabilitation with VR systems and assistive robotics are:

- Experienced immersion level: Understood as the ability to blur between the real world and the virtual environment thanks to sensory feedback technologies, it is often understood as the sense of presence in VR environments.
- Enjoyment: Defined as the level of sense of enjoyment experienced with VR environments.
- Perceived difficulty: which manifests itself at different levels for each activity performed.
- Sensation of effort: This is usually reported as a sensation in response to the force exerted to carry out a bodily movement.

For example, the authors in [49] used the IGroup Presence Questionnaire (or IPQ) to assess from the volunteers' experiences during the rehabilitation protocol how proprioception and movement perception were experienced by being in constant feedback of non-immersive visual information through an avatar representing oneself, similarly, the authors in [30] implemented a Game Enjoyment Questionnaire (or GEQ) after the completion of the training sessions of their rehabilitation system with VR environments and an assistive robot to assess the level of users' enjoyment of their rehabilitation system with VR environments and an assistive robot: Game Engagement Questionnaire) after completion of training sessions of their rehabilitation system with VR environments and an assistive robot to assess the users' level of enjoyment.

Authors often seek to know the feasibility and effectiveness of different upper limb rehabilitation systems through VR, for this it is important to know the opinion of users with conditions that are sought to recover, as in the case of the authors in [48], where they implemented system usability scales (SUS) as well as goal achievement scales (GAS) to evaluate the perception of volunteer patients regarding the proposed system and their sense of satisfaction when fulfilling the proposed tasks.

The negative impact in the social sphere that a CNS condition can have on a person is quite high, which is why in the rehabilitation processes of these pathologies the psychological state of the patients is usually monitored, the authors in [11] implemented Customer Satisfaction Questionnaires (CSQ8), Fatigue Severity Scales (FSS) as well as Multiple Sclerosis Impact Scales (MSIS29) to evaluate the quality of service received, distinguish the presence or absence of fatigue and the physical and psychological well-being of MS patients during the wrist and elbow rehabilitation process with the help of VR environments and a *Leap Motion*® controller, obtaining positive results in each of them, on the other hand, the authors in [35] applied measures of functional independence (FIM), the Edmonton Symptom Assessment Scale (ESAS), among other measures to assess the level of independence from questions oriented to the consideration of activities of daily living (ADL) and the impact that different symptoms may have on these respectively, obtaining more favorable results in people included in the experimental group of rehabilitation with VR environments than in the control group with conventional methods of physical therapy.

4. Discussion

Assistive robots have a large number of applications in which they can be implemented, making them a flexible alternative that can be used by people in different types of tasks, such as rehabilitation and exercise. In general, similarities were found between the guidelines that assistive robotic systems should have during their design phase, which are:

- Highly robust control systems that guarantee user safety by regulating the movements and efforts applied by the user.
- High precision with the help of specialized sensors that allow obtaining relevant information of the user's dynamics in the rehabilitation process.
- Guarantee the maximum physical efforts recommended in a rehabilitation process with

due medical support, as well as the repetitiveness of the proposed exercises to avoid major injuries [53].

These exploratory studies have given way to other areas of study linked to rehabilitation processes, such as, training people, as proposed by the authors in [54] which is based on the kinematics of the joints of interest in the upper limbs, or on the other hand, the authors in [55] have conducted research projects based on multiple degrees of freedom, which are observed in flexion-extension, pronation-supination movements, among others. The implementation of VR environments for rehabilitation processes usually apply the essential "three I's" of any VR system (immersion, interaction and imagination) [51]. The consideration of the immersion level when designing VR environments oriented to rehabilitation processes applicable to assistive robotics systems opens a large number of possibilities to contribute to the recovery of motor functions in upper limbs. We have presented important literature focused on rehabilitation processes for conditions associated with the CNS or PNS, which tend to use more immersive technologies when the brain or spinal cord is involved than when only the locomotor system is involved [56].

Another good practice discussed in the literature is the evaluation of the VR rehabilitation system applicable to assistive robotics systems, since involving different joints either for ROM recovery or force generation applications can fall into the deviation of evaluating many performance parameters of the same (such as impact on motor functions, quality of technologies and models applied to patient monitoring, etc.), leaving aside the user experience during the rehabilitation process dismissing the level of feasibility, usability or acceptance of the affected population that is intended to help.

5. Conclusions

A literature review focused on the types of conditions covered in rehabilitation processes with VR environments applicable to assistive robotic systems has been presented, mentioning the trends that have been generated to provide feedback to the user as well as the technologies applied to define the level of immersion of each of these studies, Additionally, the types of evaluation implemented to quantify the level of acceptance of these proposals, based on the improvement in motor functions that they can provide or in the ability of the system to entertain and encourage the user to continue attending rehabilitation sessions, are presented.

Based on our review, we observed a preference in the proposal of upper limb rehabilitation systems through VR applicable to assistive robotics to medium to long term recovery processes, proof of this is in the large number of studies dedicated to CNS conditions compared to those of the PNS, For this reason, we recommend exploring to a greater extent the rehabilitation processes of PNS conditions, analyzing the possibilities of implementing systems with different levels of immersion without neglecting proprioception and the limitations that this type of lesions may impose on the design of upper limb rehabilitation systems.

Additionally, general guidelines found for the design of assistive robots for rehabilitation applications are mentioned, however we recommend additional literature reviews to find more determinant parameters in terms of mechanical design, resistive and assistive force limitations, control strategies and other parameters of interest in these systems.

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