IOSR Journal Of Humanities And Social Science (IOSR-JHSS)
Volume 30, Issue 3, Series 7 (March, 2025) 41-49
e-ISSN: 2279-0837, p-ISSN: 2279-0845.
www.iosrjournals.org

Analysis of the Effectiveness of Assistive Robots in the Rehabilitation of Patients With Neurological Injuries

Joselene Beatriz Soares Silva[1], Jander Vinicius Vieira[2], Vanilsa Rodrigues Gomes[3], Guilherme Silva de Mendonça[4], Lara Melo Guimarães[5], Daniella Fernandes Mendonça[6], Lourdes de Fátima Gonçalves Gomes[7], João Lucas O'Connell[8]

[1]*Master in Health Sciences. Federal University of Uberlândia. Uberlândia - MG, Brazil. E-mail: joselene_beatriz@hotmail.com. ORCID: https://orcid.org/0000-0001-8248-4974*
[2]*Master in Family Health. Hospital das Clínicas, Federal University of Goiás. Goiânia - GO, Brazil. E-mail: jandervinicius@hotmail.com. ORCID: https://orcid.org/0000-0002-9942-203X*
[3]*Graduada em Enfermagem. Faculdade Integrada de São Pedro. Vitória-Espirito Santo, Brasil. E-mail: vanilsagomes@hotmail.com*
[4]*Doctor of Health Sciences. Federal University of Uberlândia. Uberlândia- MG, Brazil. E-mail: guilhermesilvamendonca@gmail.com. ORCID: https://orcid.org/0000-0001-5635-2708*
[5] *Specialization in Intensive Care Unit. Pontifical Catholic University of Goiás. Uberlândia-MG – Brazil. Email: larameloguima@gmail.com. ORCID: https://orcid.org/0009-0006-7533-8702*
[6] *Specialization in Intensive Care Unit. Catholic College of Goiânia. Uberlândia-MG, Brazil. E-mail: daniellafmendoncapp@gmail.com*
[7]*Doctorate in Medicine (Cardiovascular Surgery). Federal University of Uberlândia. Uberlândia, MG, Brazil. E-mail: lourdes.gomes@ufu.br*
ORCID: https://orcid.org/0000-0002-6664-6897
[8]*Doctor of Clinical Medicine. Federal University of Uberlândia. Uberlândia- MG, Brazil. E-mail: joao.oconnell@ufu.br. https://orcid.org/0000-0002-2288-894X*

Abstract:
Background*: The rehabilitation of patients with neurological injuries is a field that faces significant challenges due to the complexity of the conditions and the need for personalized therapeutic approaches. Neurological injuries, such as those resulting from stroke, traumatic brain injury, and neurodegenerative diseases, can cause motor, cognitive, and sensory deficits that directly affect patients' quality of life. Assistive robots represent a significant innovation in the health field, allowing more precise, repetitive, and controlled therapeutic interventions. The relevance of this study lies in the need to improve rehabilitation strategies for patients with neurological injuries, who often face long recovery times and functional limitations. Thus, the objective of this study is to analyze the effectiveness of assistive robots in the rehabilitation of patients with neurological injuries, identifying their impact on motor, cognitive, and functional recovery. It is concluded that assistive robots represent a significant advance in the rehabilitation of patients with neurological injuries, offering an effective alternative to traditional therapies.*
Materials and Methods*: This systematic review was carried out based on a previously established protocol, following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, adapted to the context of the study on analyzing the effectiveness of assistive robots in the rehabilitation of patients with neurological injuries.*
Results*: Initially, 1,220 articles were identified from combinations of the descriptors used. After screening, 26 studies were selected for full reading, of which only 12 met the inclusion criteria. Those excluded did not use RT as the main intervention, which made them incompatible with the objectives of the analysis. The kappa index calculated was 0.69, indicating substantial agreement between the reviewers in selecting the relevant studies.*
Conclusion: *The analysis of the effectiveness of assistive robots in the rehabilitation of patients with neurological injuries has revealed promising results, highlighting them as an important tool in the process of functional recovery..*
Key Word*: Assistive robots. Neurological rehabilitation. Rehabilitation technology. Neurological injuries. Robotic devices..*

Date of Submission: 14-03-2025 Date of Acceptance: 27-03-2025

I. Introduction

The rehabilitation of patients with neurological injuries is a field that faces significant challenges, due to the complexity of the conditions and the need for personalized therapeutic approaches. Neurological injuries, such as those resulting from stroke, head trauma and neurodegenerative diseases, can cause motor, cognitive and sensory deficits that directly affect patients' quality of life. In view of this, the use of advanced technologies, such as assistive robots, has emerged as a promising solution, offering support in functional recovery and increasing the independence of individuals during the rehabilitation process.1 (GARLET, 2021).

Assistive robots represent a significant innovation in healthcare, allowing for more precise, repetitive and controlled therapeutic interventions. Equipment such as robotic exoskeletons and training devices for upper and lower limbs provide adequate stimuli for motor and cognitive recovery, contributing to a more effective recovery. In addition, the use of these technologies makes it possible to monitor the patient's progress in detail, allowing adjustments to be made to interventions in real time, which is essential for maximizing rehabilitation results.2 (COSTA et al. 2022).

With an ageing population and an increase in the incidence of neurological conditions, the demand for effective and affordable rehabilitation therapies is growing exponentially. In this context, assistive robots have gained prominence not only for their clinical efficacy, but also for their ability to ease the burden on health professionals and care systems. These technologies represent an evolution in the care model, providing patients with greater autonomy and contributing to the sustainability of the health sector.3 (BANYAI AND BRISAN, 2024).

The relevance of this study lies in the need to improve rehabilitation strategies for patients with neurological injuries, who often face long recovery periods and functional limitations. According to Salgado-Gomez-Sagaz et al.4, although there are conventional methods of physical and occupational therapy, many patients do not achieve a full recovery due to insufficient adequate stimuli and a shortage of resources in clinical environments. Assistive robots have emerged as an alternative that can overcome these limitations, offering personalized, repetitive and adjustable interventions, optimizing rehabilitation results.

It is also essential to analyze the effectiveness of these technologies in order to validate their clinical application and guide public health policies for their large-scale implementation. For Banyai and Brisan3, investing in the integration of assistive robots in health care can result not only in better clinical outcomes for patients, but also in a significant reduction in the costs associated with long-term treatment. Thus, exploring the effectiveness of these devices is crucial to aligning technological advances with the needs of the population.

The aim of this study is to analyze the effectiveness of assistive robots in the rehabilitation of patients with neurological injuries, identifying their impact on motor, cognitive and functional recovery. It seeks to verify the benefits, limitations and potential for clinical application of these technologies, highlighting how they can contribute to improving patients' quality of life and the efficiency of health services.

II. Material And Methods

This systematic review was carried out based on a previously established protocol, following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, adapted to the context of the study on analyzing the effectiveness of assistive robots in the rehabilitation of patients with neurological injuries. The main objective was to investigate the contributions of robotic assistive technologies in the motor and cognitive rehabilitation process, assessing their effectiveness in the functional recovery of patients, as well as analyzing the impact of these interventions on clinical outcomes and quality of life.

The bibliographic search was conducted in widely recognized electronic databases such as PubMed, Scopus, Web of Science and the Virtual Health Library (VHL). Search terms such as “assistive robots”, “neurological rehabilitation”, “technology in rehabilitation”, “neurological injuries” and “robotic devices” were used. The inclusion criteria included original studies, systematic reviews and clinical trials published between January 2015 and December 2024, which investigated the effectiveness of assistive robots in patients with neurological conditions, with a focus on motor and cognitive recovery.

The exclusion criteria included studies that did not present robust empirical data, such as editorials, opinions, case reports and those carried out with insufficient samples for relevant statistical analysis. Articles published in languages other than English, Portuguese or Spanish were also excluded. After the initial search, the articles identified were screened in two stages: the titles and abstracts were analyzed, followed by a full reading to confirm the eligibility of the studies.

The information extracted included author(s), year of publication, type of study, methods used, technologies evaluated, main results and conclusions. This data was organized into thematic categories, such as robots for upper limb rehabilitation, exoskeletons for walking and devices for cognitive stimulation. Qualitative analysis was carried out to identify trends and gaps, while narrative synthesis highlighted the main findings of each group, discussing their implications for clinical practice and the development of public policies aimed at integrating assistive robots into healthcare.

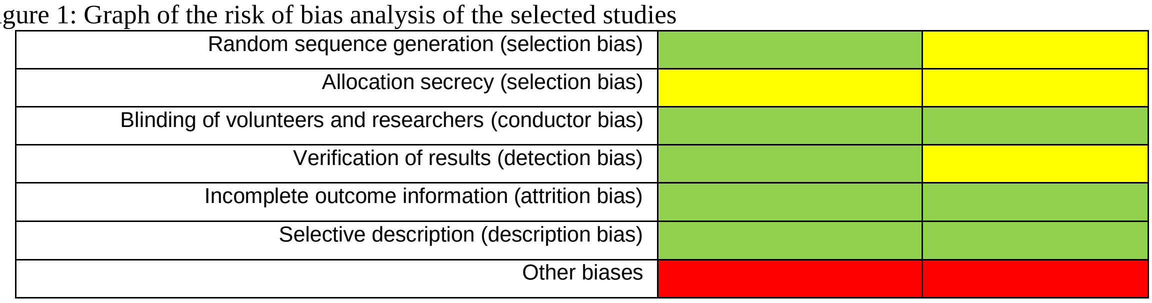
In addition, the reference lists of the selected articles were manually reviewed to identify relevant studies not captured in the initial search. Rigorous measures were adopted to minimize the risk of bias, including double-checking the screening and data extraction by different reviewers. Despite the limitations, such as the methodological heterogeneity of the included studies and the exclusion of non-indexed articles, the judicious approach adopted ensured the validity and reliability of the review, offering a comprehensive and up-to-date overview of the use of assistive robots in the rehabilitation of patients with neurological injuries.

Statistical analysis

After completing the systematic search, the kappa index was used to measure the degree of agreement between the studies selected for the qualitative analysis. The main methodological aspects were organized and described qualitatively, synthesizing information using tables and graphs that highlighted the characteristics of the samples, the interventions applied, the outcomes assessed and the main results of each study. The risk of bias was assessed based on the criteria of the Cochrane Collaboration tool, using RevMan software, which classified the risk into three categories: low, uncertain or high.

The results of the graphical analysis of the risk of bias, shown in Figure 1, indicated that the blinding of participants in the interventions was not possible in any of the studies analyzed, and that there was insufficient information on the blinding of researchers. As a result, the risk of bias was classified as uncertain in this domain. Other factors that compromised the methodological quality included the absence of adequate sample calculation, flaws in the randomization processes, lack of blinding of the evaluators and incomplete or inadequate presentation of the results, which negatively impacted the overall assessment of the studies included in the review.

Figure 1: Graph of the risk of bias analysis of the selected studies



Quantitative analysis

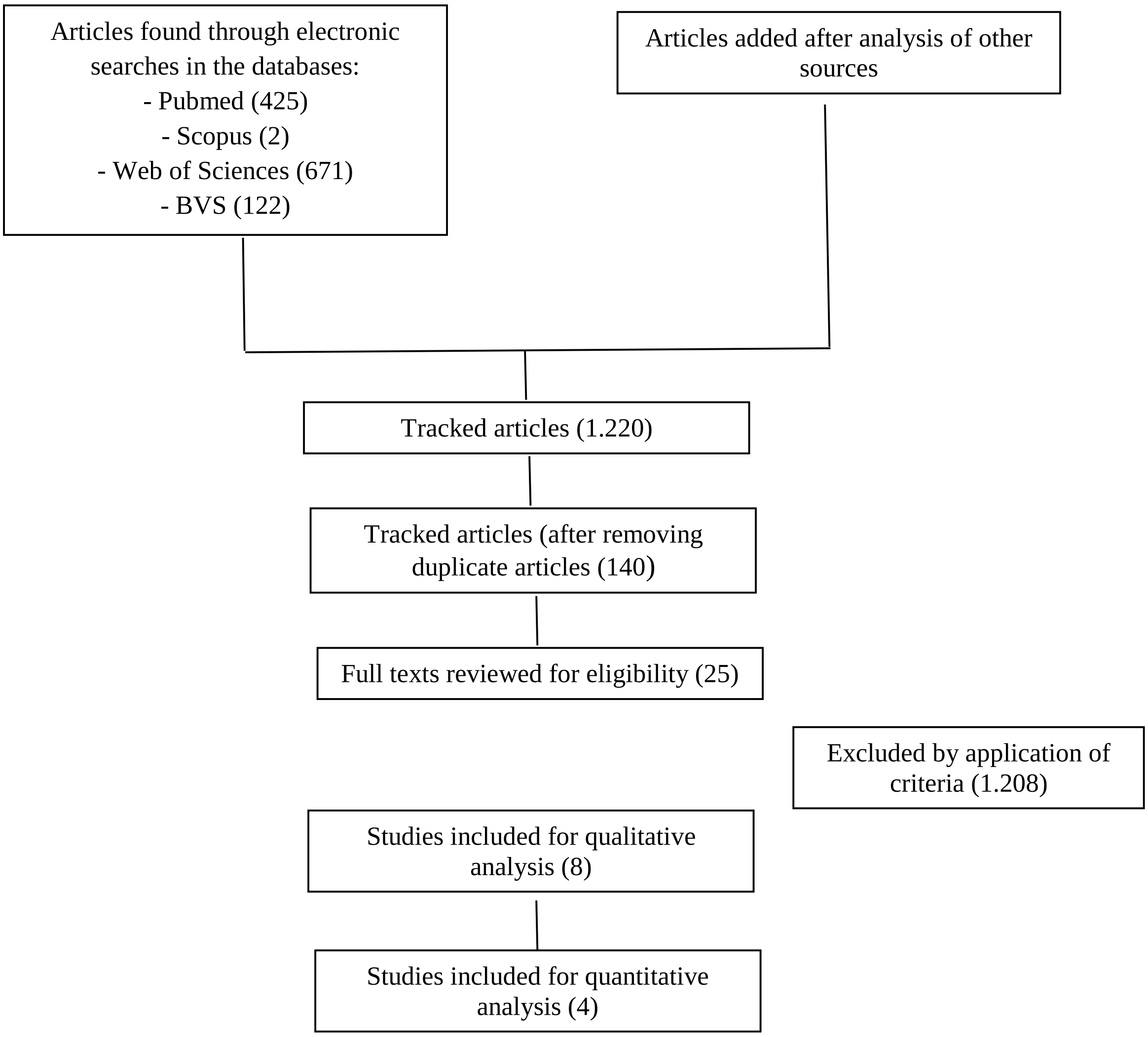
After completing the systematic search, the kappa index was calculated to measure the agreement between the studies included in the qualitative analysis. The most relevant methodological aspects were organized and described qualitatively, and summarized in tables and graphs detailing the characteristics of the samples, the interventions carried out, the outcomes assessed and the main results obtained in each study. The Cochrane Collaboration tool was used to analyze the risk of bias, supported by RevMan software, categorizing the studies as low, uncertain or high risk.

The graphical analysis of the risk of bias, presented in Figure 1, showed that due to the lack of blinding of participants in the interventions and insufficient information on the blinding of researchers, the risk of bias was considered uncertain for all the studies analyzed. Other factors that negatively impacted methodological quality included the lack of adequate sample size calculation, absence of randomization, failures in blinding the evaluators and incomplete or inadequate presentation of the results. These elements together partially compromised the methodological robustness of the studies included in the review.

III. Result

The results of the systematic search were organized and presented in the flowchart in Figure 2. Initially, 1,220 articles were identified from combinations of the descriptors used. After screening, 26 studies were selected for full reading, of which only 12 met the inclusion criteria. Those excluded did not use RT as the main intervention, which made them incompatible with the objectives of the analysis. The kappa index calculated was 0.69, indicating substantial agreement between the reviewers in selecting the relevant studies.

2 - Flowchart for collecting articles



The data from the selected articles is shown in Table 1.

Table 1: Results

Autor/Ano	**Título**	**Objetivo**	**Resultados**	**Conclusão**
Garlet (2021)1	Robotic rehabilitation in stroke patients: randomized clinical trial protocol	Proposing a randomized clinical trial protocol to evaluate the effect of robotic rehabilitation on the functionality of patients with subacute stroke	The study showed that robotic rehabilitation, when applied to stroke patients, brought significant improvements in the participants' motor functions and mobility. Patients who used robotic devices, such as exoskeletons or upper limb devices, showed greater recovery in range of movement and muscle strength compared to the control group who received conventional treatment.	Robotic rehabilitation is an effective and safe alternative for treating stroke patients, offering superior results to conventional physiotherapy methods.
Gassert e Dietz (2018)5	Rehabilitation robots for the treatment of sensorimotor deficits: a neurophysiological perspective	Summarize the evolution of the field of rehabilitation robotics, as well as the current state of clinical evidence.	The potential for a recovery of function differs not only between the upper and lower limbs, but also between neurological disorders such as stroke and spinal cord injury, and requires the	Finally, future rehabilitation approaches will not only profit from the inclusion of robots, but also from an advanced understanding of neurophysiology

			development of technology that takes these differences into account.	
Costa et al. (2022)2	Gait training with robotic assistance after traumatic brain injury: a systematic review	To identify the effectiveness of gait training with robotic assistance in the rehabilitation of patients after traumatic brain injury	Robotic assistance is effective in the treatment of rehabilitation and gait recovery after TBI, and is an essential tool in gait recovery.	The use of robots in human rehabilitation is an example of technological progress and the benefits that technology provides in the treatment of countless pathologies, providing positive results in the process of evolution and gains in physiotherapy.
Carbone e Gonçalves (2022)6	Editorial: Robot-assisted rehabilitation for neurological disorders	Presenting innovative robotic solutions to boost the rehabilitation process for neurological disorders	The results showed that the virtual reality intervention was beneficial for balance, however, cautious implementation in clinical applications is necessary.	Exoskeleton devices represent a promising opportunity for rehabilitation and assistance for people with neurological diseases. However, there are still some limits to the diffusion of robotic technologies for neurorehabilitation, despite their technological developments and evidence of clinical efficacy.
Payedimarri et al. (2022)7	Effectiveness of platform-based robot-assisted rehabilitation for musculoskeletal or neurological injuries: a systematic review	To evaluate the effectiveness of platform-based robotic rehabilitation for individuals with musculoskeletal or neurological injuries.	Among the platform-based robots studied, the VR-based Rutgers Ankle and Hunova were found to be the most effective robots for rehabilitating patients with neurological conditions (stroke, spinal cord injury, Parkinson's disease) and various musculoskeletal ankle injuries	Conclusions should be taken with a degree of caution and that more studies are needed to better evaluate the effectiveness of platform-based robotic rehabilitation devices.
Banyai e Brisan (2024)3	Robotics in Physical Rehabilitation: A Systematic Review	To examine the progress and challenges of implementing robotic technologies in the motor rehabilitation of patients with physical disabilities.	The review synthesizes the findings of the most important studies, focusing on the clinical effectiveness of robotic interventions compared to traditional rehabilitation methods.	The analysis reveals that robotic therapies can significantly improve motor function, strength, coordination and dexterity. Robotic systems also support neuroplasticity, allowing patients to relearn lost motor skills through precise, controlled and repetitive exercises
Corallo et al. (2022)8	Use of humanoid robots in the cognitive rehabilitation of patients with severe brain injury: a pilot study	To investigate the effects of treatment with a humanoid robot in the neurorehabilitation of patients with severe acquired brain injury (SABI), comparing it with traditional treatment in terms of quality of life, mood and other functional deficits.	The experimental treatment had a greater effect on quality of life and mood than the traditional treatment.	In conclusion, this pilot study provides evidence of the possible effects of relational and cognitive stimulation in patients with more severe brain injuries.
Auger et al. (2024)8	Perception of the usefulness of social care robots for adherence to home rehabilitation exercises for people with chronic neurological conditions	Exploring how a robot that offers supervision and encouragement can increase adherence to long-term home rehabilitation exercises for individuals with neurological conditions	Our results identified different needs, characteristics and limitations envisaged as preliminary key items to guide a user-centered design.	Participants were generally positive about the concept of using robotic social and technical assistance technology to meet the home exercise needs of people with neurological conditions. Healthcare professionals, however, anticipated more limitations than clients.

Salgado-Gomez-Sagaz et al. (2024)4	Rehabilitation technologies integrating exoskeletons, aquatic therapy and quantum computing for better patient outcomes	Implementing and comparing proportional-integral-derivative (PID) and fuzzy logic controllers (FLCs) in a lower limb exoskeleton.	Initial PID control tests revealed instability, leading to a switch to a PI controller for better stability and the development of a fuzzy control system. A hybrid strategy was then applied, using FLC for smooth initial movements and PID for precise tracking, with optimized weighting to improve performance.	The combination of PID and fuzzy controllers, with customized weighting (70% for moderate angles and 100% for extensive movements), improved the stability and precision of the exoskeleton.
Ahn et al. (2024)10	Benefits of robot-assisted upper limb rehabilitation from the subacute stage after a stroke of varying severity: a multicenter randomized clinical trial	To compare the clinical efficacy of robot-assisted therapy with that of conventional occupational therapy according to the onset and severity of the stroke.	Overall, 113 and 115 patients received robot-assisted and conventional therapy, respectively. The WMFT score after robot-assisted therapy was not significantly better than after conventional therapy, but there were significant improvements in the Motricity Index (trunk) and the Fugl-Meyer Assessment. After robot-assisted therapy, wrist strength improved significantly in the subacute or moderate severity group of stroke patients.	Robot-assisted therapy improved upper limb function and performance of activities of daily living (ADL) as much as conventional occupational therapy. In particular, it showed signs of greater therapeutic efficacy in the subacute stage or moderate severity group.
Bonanno et al. (2023)11	Changes in neural plasticity induced by robotic motor rehabilitation in stroke patients: the contribution of functional neuroimaging	Evaluate the neurofunctional correlates (fMRI, fNIRS) of cutting-edge robotic therapies in improving motor recovery in stroke populations according to PRISMA standards.	Neural plasticity within the ipsilateral primary motor cortex, the contralateral sensorimotor cortex and premotor cortices are more sensitive to compensation strategies that reflect upper and lower limb motor recovery, despite the high heterogeneity in robotic devices, clinical status and neuroimaging procedures	Although this technology dates back to the early 1990s, there is a need to translate more functional neuroimaging markers into clinical settings, as they provide a unique opportunity to examine, in depth, the changes in brain plasticity induced by robotic rehabilitation.
Colucci et al. (2022)12	Exoskeletons controlled by brain-computer interface in clinical neurorehabilitation: ready or not?	To investigate the potential of exoskeletons controlled by brain-computer interfaces (B/NEs) as a new strategy for the neurorehabilitation of patients with chronic paralysis after stroke or spinal cord injury.	Exoskeletons controlled by a brain-computer interface are capable of enabling the execution of movements in patients with impaired motor function, even after the development of chronic paralysis. After repeated use of the device for several weeks, significant motor recovery was observed, indicating the potential of B/NEs to promote neuroplasticity and functional recovery.	Although B/NEs are technologically ready for clinical use, their large-scale adoption depends on acceptance by healthcare professionals such as physiotherapists and clinicians. The initial implementation of these devices in clinical treatments will provide valuable data on motor recovery mechanisms and help improve the effectiveness of personalized treatments.

IV. Discussion

The results of the systematic review demonstrate the effectiveness of assistive robots in the rehabilitation of patients with neurological injuries, corroborating the evidence on their ability to promote significant functional and motor gains. The analysis highlights that the use of these devices in treatment offers notable benefits, such as controlled repetitiveness of movements, precise monitoring of progress and personalization of therapies according to patients' individual needs. In addition, the discussion points to the complexity and scope of these interventions, highlighting the need for an integrated approach that includes not only the use of advanced technologies, but also the training of health professionals and the adaptation of rehabilitation strategies to maximize clinical outcomes and patients' quality of life.

According to Garlet1, neurological injuries encompass a wide variety of conditions affecting the central and peripheral nervous system, including stroke, head trauma and neurodegenerative diseases such as Parkinson's and Multiple Sclerosis. These conditions can result from sudden events, such as accidents and strokes, or from progressive processes, which gradually compromise patients' motor, sensory and cognitive functions. Regardless of the cause, these injuries often require specialized rehabilitation approaches to mitigate their consequences and restore functionality.

The functional impacts of neurological injuries can range from partial loss of motor strength and difficulty with coordination to severe impairments that limit the patient's independence in daily activities. These deficits not only reduce quality of life but also create significant emotional and social challenges for both patients and their caregivers. Recovery is often hampered by the need for prolonged therapies and variability in response to treatments, which makes rehabilitation a complex and multifaceted process.5

Despite advances in conventional therapies, such as physical therapy and occupational therapy, there are still significant limitations. These approaches, in many cases, depend on intensive human resources and cannot offer the repetitiveness necessary to optimize motor learning. In addition, the lack of personalization and restricted access to these services in certain regions can limit their effectiveness, which opens space for the development and application of technological solutions, such as assistive robots, to improve rehabilitation outcomes.1

According to Costa et al.2, assistive robots are devices developed to assist people with motor, cognitive or sensory limitations, providing greater autonomy and quality of life. In the field of rehabilitation, these robots act as therapeutic tools for functional recovery, either by assisting in specific movements or stimulating cognitive skills. Among the main categories, the following stand out: exoskeletons, which assist in the recovery of gait and weight-bearing in the lower limbs; robotic devices for upper limbs, used in motor reeducation and coordination; and cognitive support technologies, which stimulate functions such as memory and reasoning through interactive software.

These robots use advanced technologies, such as sensors, high-precision motors and artificial intelligence, to ensure personalized and safe interventions. For example, exoskeletons controlled by motion sensors allow patients with paraplegia to simulate gait patterns, while robotic systems for upper limbs use visual and tactile feedback to correct movements and strengthen specific muscles. Furthermore, devices with augmented and virtual reality integration are being used for cognitive rehabilitation, providing immersive scenarios that help in the recovery of mental functions affected by neurological injuries.5

Compared to conventional therapies, assistive robots bring undeniable benefits, such as the ability to perform repetitive and intensive exercises with precision, which is essential for stimulating neuroplasticity. This feature not only enhances functional recovery, but also reduces fatigue for healthcare professionals, allowing for greater efficiency in care. Another advantage is the ability to adapt therapy to the patient's needs in real time, based on data collected by the device's sensors, promoting a personalized approach that is adjustable to each individual's progress.6

In addition, Costa et al.2 state that assistive robots expand access to rehabilitation therapies, especially for patients who face geographical barriers or mobility difficulties. Portable devices or devices integrated with telemedicine technologies allow sessions to be carried out at home, under remote supervision, without compromising the quality of treatment. This flexibility increases adherence to the therapeutic process, especially in cases of prolonged rehabilitation.

Therefore, the use of assistive robots represents not only a clinical advance, but also an economic one. According to Carbone and Gonçalves6, by reducing recovery time and optimizing therapeutic resources, these devices can reduce the costs associated with prolonged treatments. At the same time, by relieving the burden on healthcare professionals, they allow greater focus on strategic aspects of care. Thus, assistive robots are consolidating themselves as an indispensable tool in modern rehabilitation, combining cutting-edge technology with a patient-centered approach.

Recent studies show that assistive robots have a significant positive impact on the motor recovery of patients with neurological injuries, such as those resulting from strokes or spinal cord injuries. Research indicates that the use of exoskeletons and upper limb robotic devices promotes a significant improvement in patients' mobility and muscle strength. These devices allow repetitive and controlled movements, essential for stimulating neuroplasticity and restoring motor function. In a study carried out by Salgado-Gomez-Sagaz et al.4, patients who used exoskeletons during rehabilitation treatment showed a remarkable improvement in their ability to walk, with a considerable reduction in motor impairments. In addition, the continuous monitoring provided by the robots allows real-time adjustments, which helps to personalize rehabilitation according to the patient's progress.

Another study conducted by Ahn et al.10 showed that patients who used assistive robots for upper limb rehabilitation showed significant gains in fine motor functions, such as the control of small and precise movements, essential for everyday tasks. The devices allowed patients to perform more complex activities autonomously, such as writing or picking up objects, with an increase in functional independence. These results reinforce the effectiveness of robotic technologies in improving motor recovery, providing an advance in rehabilitation that could be difficult to achieve with traditional methods, such as manual physiotherapy. In addition to the motor benefits, assistive robots have also been shown to be effective in stimulating neuroplasticity, essential for the recovery of cognitive and motor functions after neurological injuries. The repetition and intensity of the exercises provided by these devices favor the reorganization of the nervous system, promoting new neural connections. According to a study by Bonanno et al.11, patients who used robotic devices during rehabilitation treatment showed a significant improvement in brain function and the ability to perform motor tasks, with evidence of neuroplasticity, which resulted in a faster and more efficient recovery.

In terms of cognitive development, technologies such as virtual reality devices integrated with robotic systems offer an immersive experience that stimulates cognitive function, such as memory, attention and motor planning. Studies indicate that, by associating physical exercise with mental engagement, assistive robots help to improve spatial perception, decision-making and coordination between different brain functions. Garlet1 cites that stroke patients who participated in rehabilitation sessions using assistive robots combined with virtual reality showed improvements in both motor and cognitive skills, highlighting the potential of robotic technologies in brain recovery and promoting neuroplasticity.

Comparing assistive robots with traditional therapies, studies indicate that robotic technologies provide a faster and more effective recovery. In a systematic review carried out by Colucci et al.12, it was shown that the use of exoskeletons and upper limb devices generated more significant motor recovery than conventional physiotherapy, especially in patients with partial paralysis. The main advantage of assistive robots is their ability to provide repetitive and controlled physical training, a crucial factor in improving muscle and functional recovery, something that is not always possible with manual physiotherapy.

Additionally, compared to traditional therapies, assistive robots have been shown to be more efficient in reducing the burden on healthcare professionals and in providing personalized treatments. According to Gasert and Dietz5, while traditional therapies rely on the physiotherapist's ability to provide continuous and precise attention, assistive robots allow real-time monitoring and adjustments, which ensures more consistent treatment with less need for constant supervision. This technological advance not only improves clinical outcomes, but also offers long-term cost-effectiveness, given that rehabilitation is more efficient and patients require fewer interventions from physiotherapists.

Although assistive robots offer enormous benefits in rehabilitation, they still face significant barriers, both technological and economic. From a technological perspective, many devices still require improvements in terms of usability, robustness, and ability to adapt to different patient conditions. Assistive robots are highly sophisticated, but the technology required to support the various aspects of large-scale rehabilitation remains expensive and complex. Furthermore, maintenance and training costs for healthcare staff can be high, making the use of these devices a challenge for healthcare institutions with limited budgets. This limits access to the technology, especially in developing countries or in public healthcare systems with limited resources. The search for more accessible solutions, both in terms of price and ease of operation, remains a priority for expanding the use of these devices.7

According to Banyai and Brisa3, accessibility to the use of assistive robots varies significantly according to the context, such as hospitals, clinics, and home care. In hospitals and clinics, the cost of installation, training of professionals, and maintenance of robotic devices can be a significant barrier, especially in public settings or in areas with fewer resources. On the other hand, the use of these robots in the home environment presents additional challenges, such as the need for portable or easily installed devices that patients can use without constant assistance.

The adaptation of patients and healthcare professionals to assistive robot technologies is another significant challenge. Many patients, especially those who are older or have serious conditions, may have difficulty handling complex technological devices, which can lead to resistance to their use. Familiarization with the robot's interface and control mechanisms is essential to ensure adherence and effectiveness of treatment. For healthcare professionals, adapting to these new rehabilitation methods also involves challenges, including the need to constantly update knowledge and skills. This requires additional training and, in many cases, a change in the traditional therapeutic approach.8

The future of rehabilitation with assistive robots is closely linked to advances in technology, with innovations promising to make these devices even more effective and accessible. The development of artificial intelligence (AI) and robotics will enable the development of more intelligent robots that will be able to automatically adapt to the patient's progress, adjusting rehabilitation parameters in real time to provide the best possible therapy. Technologies such as machine learning and predictive analytics will enable personalized treatment, optimizing recovery and reducing the time needed to achieve functional rehabilitation. Furthermore, the miniaturization of devices and the integration of lighter and more durable materials will make assistive robots more accessible and easier to use, expanding their application in home environments and smaller clinics.9

Another relevant aspect for the future of these devices, according to Auger et al.9, is the integration with complementary technologies, such as augmented and virtual reality. The use of immersive systems can provide a richer and more motivational experience for patients, making rehabilitation more engaging and effective. Patients can interact with the virtual environment, performing movements that simulate real life, which stimulates the brain more effectively, accelerating neuroplasticity. The combination of these technologies with assistive robots can completely transform rehabilitation, making it more personalized, interactive, and efficient, which can result in a significant improvement in long-term clinical outcomes.

V. Conclusion

The analysis of the effectiveness of assistive robots in the rehabilitation of patients with neurological injuries has revealed promising results, highlighting them as an important tool in the process of functional recovery. Studies have shown that, by providing personalized and repetitive treatments, assistive robots are effective in improving mobility and muscle strengthening, especially in patients with stroke or spinal cord injuries. These devices offer an innovative approach, overcoming many of the limitations of traditional rehabilitation methods, such as dependence on therapist skills and the risk of variation in treatment intensity. In addition to functional gains, assistive robots have also shown significant benefits in terms of patient motivation and engagement. The continued use of these technologies not only improves motor outcomes, but also promotes adherence to treatment, since the devices provide constant feedback and interaction, which makes the rehabilitation process more engaging and dynamic. Patients have shown greater willingness to perform repetitive and challenging exercises, which is essential for recovery after severe neurological injuries. However, the implementation of assistive robots in clinical rehabilitation still faces significant challenges, such as high cost and the need for specialized infrastructure. Although these devices show great potential, their widespread adoption depends on reducing production costs and adapting the technologies for use in the home or in clinics with limited resources. Training healthcare professionals is also essential to ensure the appropriate use of these devices, which requires ongoing training programs and investment in updating clinical practices.

In conclusion, assistive robots represent a significant advance in the rehabilitation of patients with neurological injuries, offering an effective alternative to traditional therapies. The future of these devices is linked to continued innovation, which will allow not only to improve the effectiveness of treatments, but also to expand access and integration of these devices in clinical and home settings. Continued studies and implementation of these robots in clinical practice will be essential to validate their long-term benefits and to improve rehabilitation approaches for a variety of neurological conditions.

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