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ORIGINAL RESEARCH

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Available rehabilitation technology with the potential to be incorporated into the clinical practice of physiotherapists: A systematic review

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Abstract

Background: The development of prototypes capable of intervening in the area of rehabilitation in physical therapy clinical practice activities that were previously carried out in a traditional way, that is, manually, demonstrates how technology is having an impact on professional careers such as physiotherapy.

Objective: The purpose of this study is to present a comprehensive examination of various technologies employed in the facilitation of patient rehabilitation, with a focus on their potential integration within the clinical practice of physical therapists.

Methods: We conducted a systematic search in four electronic databases (CINAHL, Embase, PEDro, and PubMed) for research on rehabilitation technologies. The eligible studies should demonstrate a clear utilization of technology in various aspects of the clinical approach to the rehabilitation process and have been published between 2000 and 2021 in either Portuguese or English.

Results: A total of 18 articles that satisfied the selection criteria were included in the study. The studies were classified into four distinct categories of rehabilitation technologies, which were determined by the specific characteristics of the technology employed and its integration with the therapeutic approach to rehabilitation. These categories include digital technologies, artificial intelligence and/or robotics, virtual technologies, and hybrid technologies.

Implications on Physiotherapy Practice: Rehabilitation technologies possess the capacity to effectively facilitate clinical activities performed by physical therapy professionals, including injury prevention, movement monitoring, and coordination of rehabilitation programs, with minimal or negligible intervention from the physical therapist. Further research is required to ascertain the precise capabilities of various technologies in collaborating with physiotherapists to deliver comprehensive care for patients' physical well-being, encompassing both therapeutic and preventive approaches.

Trial Registration: PROSPERO registration number CRD42020222288

KEYWORDS
artificial intelligence, health technologies, physiotherapy, rehabilitation, technological rehabilitation

1 | INTRODUCTION

The integration of technologies into the everyday work routines of professionals has resulted in the development of tailored and flexible services that cater to the specific requirements of users across different age groups.[1] Consequently, health care professionals have integrated various software, such as Health Data Analysis Software, Health Education Software, Medical Imaging Software and Electronic Prescription Software that establish connections between patients and mobile devices, and robots into their everyday routines.[2]

Researchers have employed virtual reality (VR) technology to address post-traumatic stress disorder and aid in the rehabilitation of individuals afflicted with chronic pain or other incapacitating medical conditions.[3] The efficacy of employing interactive computer-generated simulations, which offer users the opportunity to actively engage in surroundings that closely emulate real-world scenarios, can be attributed to the method's achievements.[4]

Digital health technologies provide the capacity to offer fresh ways for health care practitioners to approach and administer health care, grounded in a concept of suitability that challenges established conventional health care practices.[5] The utilization of proactive equipment can facilitate a range of clinical activities, including consultations, examinations, follow-ups, diagnoses, and preventative interventions.[6] Rehabilitation technologies that fall under the category of specific interventions are primarily designed to enhance an individual's functionality and independence, promote active involvement, and enhance overall well-being.[4]

In response to the limited availability of health care resources, there is a growing inclination to employ Artificial Intelligence (AI) methodologies in the development of health care facilities and eldercare services. Within such settings, the utilization of robots and other advanced technologies can serve as an auxiliary group of proficient caregivers, doing tasks such as disease prognosis, aided diagnosis, therapy facilitation, and rehabilitation assistance.[7]

One of the most appealing aspects of implementing this technology in health care is its capacity to replicate independent practice at higher dosages than what can be achieved through conventional therapy.[8] Hence, these technologies share various similar properties, including increased repetition and intensity of training, as well as reduced duration of expert monitoring.[4]

It is anticipated that in the coming years, families will experience a rise in the presence of social robots designed to provide health care support.[6] It is our contention that there exists a dearth of research that categorizes rehabilitation technologies as having the capacity to intervene in the therapeutic duties of a physical rehabilitation program with minimal or negligible participation from a rehabilitation professional.

Therefore, the purpose of this study was to present a comprehensive survey of the many technologies employed in aiding patient rehabilitation and their potential integration into the clinical practice of physiotherapists.

2 | METHODS

2.1 | Research design

This review was influenced by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 declaration.[9] Using the International Prospective Register of Systematic Reviews, we were able to confirm that the study reported here was unpublished.We subsequently entered the procedure for this review (ID: "REDACTED") into a Center for Reviews and Dissemination database.

2.2 | Information sources

A thorough search of four electronic databases (CINAHL, Embase, PEDro, and PubMed) as well as an analysis of the bibliographies of papers that were included and interviews with rehabilitation technology experts (B. T. and A. L.) helped find pertinent articles. The database search took place in December 2020 and was repeated in April 2021. Initially, no search filters were applied to the study design. This procedure ensured that all articles were included for summary reading.

2.3 | Search strategy

In the Embase, PEDro, PubMed and CINAHL databases the search terms were specified: "Physiotherapy" OR "rehabilitation" AND "artificial intelligence" OR "technological rehabilitation" were utilized as the search approach. The search keywords were modified as needed to investigate more databases.

The database was searched in December 2020 and again in April 2021. The study's design did not initially have any search criteria. This process made sure that every article was available for summary reading. After the search algorithms were used, the studies that were located were exported to a Mendeley® file and subsequently compiled in a Prisma flowchart (Figure 1). By reading the whole papers and the keywords displayed in the electronic databases, the study design might be identified. AI, rehabilitation, physiotherapy, and technology rehabilitation were used as keywords.

2.4 | Eligibility criteria

Included were complete publications from randomized clinical trials that were conducted between 2000 and 2021, were written in Portuguese or English, and related to rehabilitation technology used in physiotherapists' daily practices. When there was no proof of efficacy despite the application of rehabilitation technologies, pilot studies were disregarded. We chose to take an inclusive strategy that was targeted at a hugely diverse audience with variances in demographics, age, and gender to get a more complete picture of how technologies are used.

Studies with clinical outcomes relating to the functionality of rehabilitation technologies that demonstrated a positive outcome regarding safety in the use of technology for the patient and the professional; maintaining patient engagement with the proposed intervention, efficiency of technology in prevention, evaluation, monitoring, and improvement of physical and functional capabilities after intervention were prioritized.

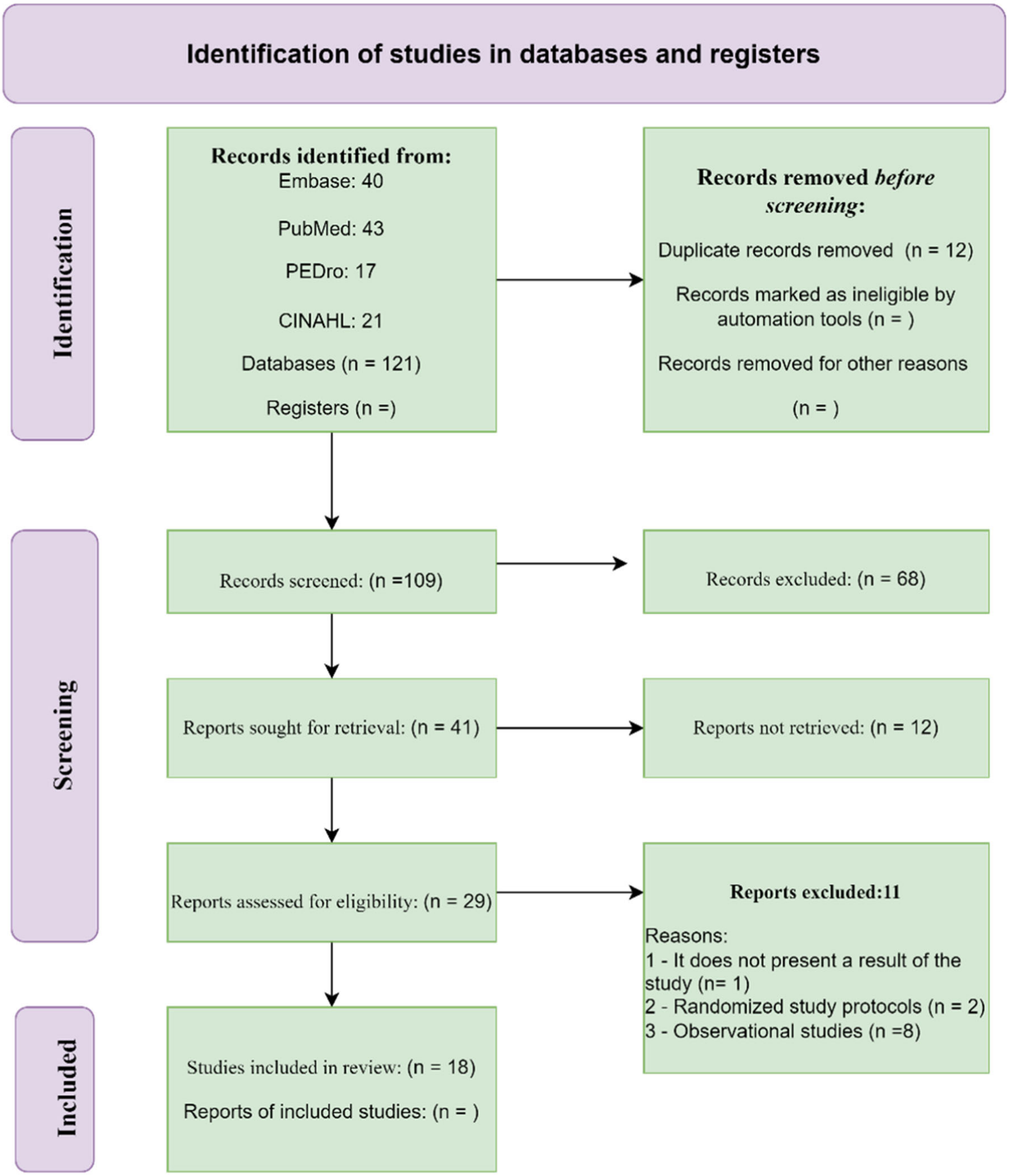

FIGURE 1 PRISMA 2020 flow diagram for new systematic reviews which included searches of databases and registers only. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

TABLE 1 Assessing risk of bias in randomized trials with the cochrane collaboration tool.

Evaluated studies	Domains and general risk assessment					
Author and Year	D-1	D-2	D-3	D-4	D-5	Overall
Aprile et al.[11]	⊖	⊖	⊖	⊖	⊖	⊖
Bickmore et al.[12]	⊖	⊖	⊖	⊖	⊖	⊖
Cecchi et al.[13]	⊖	⊖	✓	⊖	⊖	⊖
Chae et al.[14]	⊖	⊖	⊖	⊖	⊖	⊖
Fernández-González et al.[15]	⊖	⊖	⊖	⊖	⊖	⊖
Jirayucharoensak et al.[16]	⊖	⊖	✓	⊖	⊖	⊖
Kim et al.[17]	⊖	⊖	⊖	⊖	⊖	⊖
Lao et al.[18]	⊖	⊖	⊖	⊖	⊖	⊖
Padua et al.[19]	⊖	⊖	⊖	⊖	⊖	⊖
Park et al.[20]	✓	✓	⊖	✓	✓	✓
Park et al.[21]	⊖	⊖	⊖	⊖	⊖	⊖
Persell et al.[22]	⊖	⊖	⊖	⊖	⊖	⊖
Picelli et al.[23]	⊖	⊖	⊖	⊖	⊖	✓
Salarian et al.[24]	⊖	⊖	⊖	⊖	⊖	⊖
Tousignant et al.[25]	⊖	⊖	⊖	⊖	⊖	✓
Tramontano et al.[26]	⊖	⊖	✓	⊖	⊖	⊖
Yeh et al.[27]	⊖	⊖	⊖	⊖	⊖	⊖
Zhang et al.[28]	⊖	⊖	⊖	✓	⊖	⊖

Note: Overall risk-of-bias judgement: Low risk of bias = ⊖, Some concerns = ✓, High risk of bias = ®.

Abbreviations: D-1, Bias arising from the randomization process; D-2, Bias due to deviations from intended interventions; D-3, Bias due to missing outcome data; D-4, Bias in measurement of the outcome; D-5, Bias in selection of the reported result.

2.5 | Study selection

The process of study selection involved two reviewers (T. S. and J. S.) with expertise in physiotherapy and rehabilitation technologies. Both reviewers actively participated in the search strategy and the identification of relevant records to assess eligibility. The reviewers worked independently to screen each record and report retrieved. In cases where disagreements arose, consensus was achieved through discussion and mutual agreement. No automation tools were employed in this manual screening process, ensuring a comprehensive and thorough evaluation of each study against the inclusion criteria, as outlined in criterion 8 of the PRISMA checklist.

2.6 | Data collection process

One reviewer (J. S.) tested a data extraction form on three randomly chosen publications to summarize the evidence. Data extraction was checked by a second reviewer (T. S.), and any discrepancies were worked out through conversation. This tactic enhanced the accuracy of data extraction and the detection of additional items that needed to be gathered. Despite being integrated with other papers, the entire published characteristics of each study were taken into account in data extraction to prevent discrepancies and restrictions.

2.7 | Data items

No assumptions were made when an article lacked the necessary information. The review team did not get in touch with the authors to get a confirmation or more details. Reporting data that was readily accessible to end users was our main concern. Data extraction was coded for applicable publications. The information gathered is summarized in Tables 3, 4, and 5, which include information like the author and year of publication, methodological details, technological instrument(s) used that may be incorporated into the physiotherapist's routine clinical practices (evaluate, treat, or monitor the rehabilitation routine), and the key findings of each study.

2.8 | Risk of bias

The assessment of the risk of bias in the studies included in this review adhered to the Cochrane RoB-2 method, a specialized tool for scrutinizing bias in reviews encompassing studies from randomized clinical trials. Each of the 18 included studies underwent individual analysis across the five domains of the RoB-2 tool, namely: bias arising from the randomization process; bias due to deviations from intended interventions; bias due to missing outcome data; bias in outcome measurement; and bias in the selection of the reported outcome.[10]

Two reviewers, T. S. and J. S., with expertise in physiotherapy and rehabilitation technologies, conducted the assessments. In the evaluation of seven of the 18 studies, minor concerns were identified, detailed in Table 1 of the Risk of Bias assessment. Importantly, these concerns did not compromise the overall classification of the studies, which maintained a low risk of bias.

3 | RESULTS

3.1 | Study selection

The initial search turned up 121 studies, 12 of which were duplicates and were eliminated before screening. A total of 109 studies were found and screened; the results are displayed in (Figure 1). In the initial round of screening, we found that 33 studies lacked a title and/or abstract that was appropriate for the review's goal, and another 35 studies lacked a proposal that was appropriate for the rehabilitation techniques used by the physiotherapist. We eliminated 12 more studies during a second round of screening, including 3 studies without full texts and 9 review studies.

After the two screening phases, we examined the 29 studies' eligibility. A complete analysis was conducted before a decision to exclude was reached. We found 1 study with ambiguous findings, 2 studies with unfulfilled randomized study protocols, and 8 studies that were observational. After doing the final screening analysis, we eliminated 11 more studies. The screening produced 103 exclusions and 18 additions of studies that were appropriate for review.

The most pertinent information of the analysis was presented in tables that show the particulars and summary of the study results to ensure a better understanding of the objective of this review and better comprehend how included studies fit into the framework of rehabilitation technologies.

3.2 | Study details

The data reported in Table 2—Categorization of Rehabilitation Technologies—was the most pertinent data for this investigation. There were 18 randomized studies in total that were looked at. The technologies found in the reviewed research were first categorized, taking into account the type of technology and its applicability in physical rehabilitation with the potential to be included into the work routine of physiotherapists in areas of professional importance. Based on the attributes of the technologies, a classification is shown in Table 2 below.

3.3 | Synthesis of results

With regard to the abilities and capabilities of the physiotherapy professional, four categories of rehabilitation technologies were recognized. Robotics, VR, assistive technology, and smartphone applications are just a few of the many technologies that could be used in the rehabilitation process.

The key information about the papers examined in this review is presented in three tables. Table 3 shows the technology used, the goal of the research, and the applications of each study. Table 4 gives an overview of the countries that conducted research in the area of technologically aided rehabilitation as well as a description of the types of patients who benefited from these interventions. Table 5, our last table, offers details regarding the interventions and the most important findings.

TABLE 2 Categorization of rehabilitation technologies.

Rehabilitation technologies				
Technology Type	Digital: telerehabilitation and mobile applications.	AI/R - Artificial Intelligence and/or Robotics: robots, software and intelligent devices.	Virtual: serious games and immersive and nonimmersive virtual reality.	Hybrid: technology made up of more than one of the above components.
Applicability of Technology in the Physiotherapist's Routine.	Prevention and monitoring: action that aims to avoid physical and systemic disabilities or reduce complications from pre-existing problems in the patient.	Assessment: clinical activity to identify physical and systemic disorders that support the treatment plan.	Intervention: approach focused on carrying out rehabilitation.	Hybrid: performs more than one activity in the rehabilitation process.

TABLE 3 Technologies and applicability.

Author	Type of technology	Objectives	Applicability
Aprile et al.[11]	Bipodalic platform (Prokin, Technobody, Italy).	Evaluate technological proprioceptive rehabilitation compared to conventional rehabilitation in patients after lasty total hip arthritis (THA).	Treatment: to improve proprioception in orthopedic patients after hip arthroplasty.
Bickmore et al.[12]	Software for simulated conversations with users on their home computers and pedometer steps.	An automated health counselor agent was designed to promote both physical activity and fruit and vegetable consumption through a series of simulated conversations with users on their home computers.	Automated health behavior changes interventions.
Cecchi et al.[13]	A set of robotic sensor-based devices (Motore, Humanware; and Amadeo, Diego and Pablo, from Tyromotion).	The present study aimed to identify baseline patient characteristics that may predict response to robotic or physiotherapy-based treatment in our RCT, and to verify whether, in our sample, specific subgroups of patients may be more responsive to either intervention.	Upper extremity (UE) recovery after stroke.
Chae et al.[14]	Smartwatch (watch style W270, LG,) that can be connected to a personal smartphone after installing a custom-programmed app.	This study aimed to (1) develop a home-based rehabilitation (HBR) system that can recognize and record the type and frequency of rehabilitation exercises conducted by the user using a smartwatch and smartphone app equipped with a ML algorithm and (2) evaluate the efficacy of the home-based rehabilitation system through a prospective comparative study with chronic stroke survivors.	Home Rehabilitation System (HBR) Determine the most accurate way to detect the type of exercise at home as a cost-effective tool for home care for stroke survivors.
Fernández-González et al.[15]	LMC Non-immersive video games system used with serious games.	The primary aim of the present study was to evaluate the effectiveness of the LMC system using serious games designed for improving UL grip muscle strength, coordination, speed of movements and fine and gross dexterity. Furthermore, we sought to assess satisfaction and compliance levels among those in mild-to-moderate stages of the disease.	Technological rehabilitation for individuals with PD
Jirayucharoensak et al.[16]	A game-based neurofeedback training system.	The main aim of this study was to examine whether a newly developed game-based neurofeedback training (NFT) system may enhance neurocognitive performance in healthy elderly subjects and patients with amnestic mild cognitive impairment aMCI.	Improve cognitive performance in patients with mild amnestic cognitive impairment (aMCI) and healthy elderly.
Kim et al.[17]	E-RAGT and BWST	The purpose of this study was to compare, in individuals with hemiparetic stroke, the effects of E-RAGT versus BWST on cortical activation and clinical outcomes, including lower limb motor function and gait speed.	Locomotor neurorehabilitation after hemiparetic stroke

TABLE 3 (Continued)

Author	Type of technology	Objectives	Applicability
Lao et al.[18]	Sports Smart Bracelet	The purpose of this study is to study the effectiveness of the combined use of sports smart bracelets and multi-sports training programs on the motivation for the elderly in the Macau community.	Increase the motivation and participation of the elderly in exercises.
Padua et al.[19]	A robotic device	The aim was to assess if CR can influence the outcome of motor rehabilitation in stroke patients and if CR could provide information to direct the patient to robotic or conventional rehabilitation.	Upper limb rehabilitation after stroke.
Park et al.[20]	Walkbot-assisted locomotor training (WLT).	The present study aimed to compare the effects of WLT with CLT on balance and gait, cardiopulmonary and psychological functions and fall confidence in acute hemiparetic stroke.	locomotor training on balance and gait, cardiopulmonary and psychological functions and confidence in the fall in acute hemiparetic stroke.
Park et al.[21]	Park et al.[21]	The purpose of this study was to examine the effect of a 6-month SASMP on self-care behavior in people with COPD. Secondary outcomes included exercise capacity, exercise, physical activity, symptoms, HRQOL, and health care use.	Self-management for people with COPD based on smartphone app.
Persell et al.[22]	Smartphone coaching app plus an HBPM	To investigate the effect of an artificial intelligence smartphone coaching app to promote home monitoring and hypertension-related behaviors on systolic blood pressure level compared with a blood pressure tracking app.	Home monitoring of blood pressure.
Picelli et al.[23]	Robot-assisted gait	The main aim of this pilot study was to evaluate the combined effects of RAGT and BoNT-A on spastic equinus foot in patients with chronic stroke as measured by changes in the grade of resistance to rapid passive muscle stretch on the MAS.	Gait training in patients with chronic stroke.
Salarian et al.[24]	The proposed measurement system is based on three inertial Sensors attached to body parts.	The main goal of this study was to design a new method for the ambulatory monitoring of physical activity in PD patients during their daily activities by classifying basic posture allocations including sitting, standing,	Monitoring of physical activities in patients with PD.
Tousignant et al.[25]	Telerehabilitation	The purpose of this study was to investigate the satisfaction of patients and health professionals within-home teletreatmentas an alternative to face-to-face therapy for individuals at home following discharge from an acute care hospital after TKA	Home telerehabilitation as an alternative to conventional rehabilitation after discharge from total knee arthroplasty surgery.

(Continues)

TABLE 3 (Continued)

Author	Type of technology	Objectives	Applicability
Tramontano et al.[26]	Robotic-trained motor rehabilitation performed with PABLO®-Tyromotion.	The aim was to investigate the effects of a robotic-trained motor rehabilitation performed with PABLO®-Tyromotion on upper limbs' functions in MS patients.	Neuromotor rehabilitation of people with Multiple Sclerosis (MS), and upper limb function limitations.
Yeh et al.[27]	Virtual reality (VR) rehabilitative games adopted from Cawthorne–Cooksey exercises	The objectives of this study are to validate a VR system that can be used for imbalance patients rehabilitation.	Therapeutic effect
Zhang et al.[28]	Intelligent stretching device	The objectives of this paper were: 1) to develop a stretching device with intelligent control to stretch ankle joints with spasticity and/or contracture safely and efficiently throughout the ankle ROM to reduce spasticity and/or contracture; 2) to assess the feasibility of the stretching device based on a small sample of stroke patients.	Ankle joint stretching with contracture/ spasticity in neurologically impaired patients

Abbreviations: aMCI, amnestic mild cognitive impairment; BoNT-A, Botulinum toxin type; BWST, bodyweight-supported treadmill training; CLT, conventional locomotor training; COPD, chronic obstructive pulmonary disease; CR, cognitive reserve; E-RAGT, end-effector robot-assisted gait training; EU, upper extremity; HBR, home-based rehabilitation; HBPM, home blood pressure monitor; HRKOL, health-related quality of life; LMC, Leap Motion Controller; MAS, modified Ashworth scale; ML, machine learning; MS, Multiple Sclerosis; NFT, neurofeedback training; PD, Parkinson's disease; RCT, randomized-controlled trial; SASMP, smartphone app-based, self-management program; TKA, total knee arthroplasty; UL, upper limb; VR, Virtual reality; WLT, Walkbot-assisted locomotor training.

4 | DISCUSSION

This review looked for scientific proof of technology that could assist in the rehabilitation process in a complementary or alternative fashion to traditional methods. We made the decision to construct a study that focuses on several technologies because the majority of the studies we identified give support for particular rehabilitation technology tools. There is a dearth of literature connecting the peculiarities of technological intervention with the clinical skills that physiotherapists need to approach the process of physical rehabilitation.

Robotic equipment make up the biggest percentage of technological gadgets that could be used in a rehabilitation program, as shown in Table 3.[13,17,19,21,23] Second to robotic equipment, assistive technologies that are compatible with mobile gadgets like tablets, cell phone applications, or smart watches started to appear.[12,14,18,21,22,25] Finally, we saw both immersive and non-immersive VR gaming devices in clinical settings.[15,16,27]

An overarching theme in the majority of the included research is the quest for scientific evidence regarding the efficacy of the investigated technologies in aiding the rehabilitation of patients facing motor deficits resulting from neurological disorders such as stroke, Parkinson's disease, and Multiple Sclerosis.[14,15,17,19,20,23,24,26,28] Notably, these technologies have demonstrated potential benefits in diverse clinical contexts, including the rehabilitation of motor abnormalities arising from fractures, post-orthopedic surgeries, or as a result of systemic diseases such as cardiac and respiratory disorders.[20,22]

The technologies under study have broad applicability and meet the primary goals and skills of clinical practice for a rehabilitation professional, especially preventive skills as a motivator for a balanced diet and regular exercise.[12,18] Technology can also support assessment abilities with attention to memory and care for systemic problems like high blood pressure.[16,18] In addition to technology that can treat physical dysfunctions such orthopedic and respiratory conditions, as well as balance and gait issues.[11,21,27]

With regard to country representation, it is clear from the demographic and sample statistics presented in Table 4 that Italy and South Korea stand out, each having five of the 18 studies that are included and evaluate technology in the context of rehabilitation. If we look at the continents as a whole, Asia has had the most research done with eight, one more than Europe and four more than the US and Canada.

Only five studies were found in which the average age stated in the data was clearly below 60 years. The majority of studies were focused on the elderly population. In eight studies, there were more men than women; in two studies, the sex of the participants in the randomized groups was not stated; and in one study, the number of men and women who participated in the study was equal.

TABLE 4 Population and sample.

Author	Country	General sample (n)	Sample per group	Gender	Ages and/or Middle Ages
Aprile et al.[11]	Italy	n = 64	CVG: 28 TG:36	CVG: 10 males and 18 females; TG: 10 males and 26 females	CVG: (age: 63.9 ± 15.2)TG: (age: 68.4 ± 10.5).
Bickmore et al.[12]	USA	n = 122	CG:31; EXG:31; FVG: 30; FVE: 30	Male/Female 39% males/61% female	Age: 21–69 years old.(mean 33.0 ± 12.6)
Cecchi et al.[13]	Italy	n = 224	CVG: 113; RG: 111	CVG: Man 64 (56.6%) Woman 49 (43.4%) RG: Man 63 (56.8%) Woman 48 (43.2%)	age between 40- and 85-years ageCVG: 68,5 and RG: 69,5
Chae et al.[14]	South Korea	n = 23	CG: 6 EG–"HBR" 17	–	age: 40 to 70mean age: –
Fernández-González et al.[15]	Spain	n = 23	CG: 11 EG:12	Male/Female 11/12	age: 45 to 79 years (mean age 66.65 ± 10.14 years)
Jirayucharoensak et al.[16]	Thailand	n = 119	NFT-IG: 58 ETG:36 CAU: 25	119 women	Mean age: NFT 71.7 (6.5); mean age: 73.9 (6.2) and CAU 70.9 (5.1).
Kim et al.[17]	South Korea	n = 28	E-RAGT: 14 BWST: 14	E-RAGT: 11 male; 3 female/BWST: 12 male; 2 female.	mean age ± standard deviation, 54 ± 11 years)
Lao et al.[18]	China	n = 60	EWB: 20 EXG: 20 CG: 20	1 man and 19 women per group.	Age (years): 80.00 ± 5.38; 78.40 ± 6.75; 76.75 10.64Age range (y/o) 67–90; 68–97; 68–92.
Padua et al.[19]	Italy	n = 75	CVG: 39 RG: 36	CVG: Male 25 (64.1%) and Female 14 (35.9%) RG: male 24 (66.7%) and female 12 (33.3%).	Age (years): CVG 65 ± 12/RG 66 ± 10
Park et al.[20]	South Korea	n = 14	CLT: 7 WLT:7	CLT: 4 men and 3 women WLT 5 men and 2 women	Age (years): CLT 69.86; WCLT 76.29 mean age = 72.8 ± 9.9
Park et al.[21]	South Korea	n = 42	EG: 22 CG: 20	EG: men 19 (86.4%) women 3/CG: men 14 (70.0%) women 6.	Mean age: 67.88 ± 10.49(45–87)/EG: 70.45 ± 9.40/CG 65.06 ± 11.12
Persell et al.[22]	USA	n = 297	EG:144 CG:153	(61.3%) were women EG: Female 91 (63.2) CG: 91 (59.5)	Age, mean EG 59.6 (12.4)/CG 58.3 (13.2)
Picelli et al.[23]	Italy	n = 22	EG: 11 CG: 11	Male/Female EG: 7/4 CG: 9/2	Mean age EG 62.4 (9.5)/CG 65.1 (3.4).
Salarian et al.[24]	Switzerland	n = 20	PD: 10 CG: 10	Male/Female DP: 5/5 CG: 5/5	PD: ages 61.5 7.8 years; CG: ages 63.6 10.5 years.
Tousignant et al.[25]	Canada	n = 42	EG: 22 CG: 20	–	mean age: EG 66.4–10.1/CG 66.4–13.3

(Continues)

TABLE 4 (Continued)

Author	Country	General sample (n)	Sample per group	Gender	Ages and/or Middle Ages
Tramontano et al.[26]	Italy	$n = 30$	EG:14 CG: 16	Male/Female EG: 6/8 CG: 6/10	mean age: EG 46.7 ± 10.4/CG 52.3 ± 5.4
Yeh et al.[27]	Taiwan	$n = 84$	EG:48 CG:36	Male/Female EG: 25/23 CG: 20/16	mean age: EG 64 ± 16/CG 22 ± 4
Zhang et al.[28]	USA	$n = 9$	EG: 4 CG: 5	9 men	EG: (53.2 ± 7.9 years old)CG: (36.8 ± 12.8 years old)

Abbreviations: BWST, bodyweight-supported treadmill training; CAU, care as usual; CG, Control Group; CLT, conventional locomotor training; CVG, Conventional Group; EG, experimental group; E-RAGT, end-effector robot-assiste gait training; ETC, Exergame treatment group; EWB, Exercising Wearing the Bracelet; EXG, Exercise Group; FVE, Fruit, vegetable; and exercise group; FVG, Fruit and vegetable group; HBR, home-based rehabilitation; IG, intervention group; NFT, neurofeedback training; PD, Parkinson's disease; RG, Robotic group; WLT, Walkbot-assisted locomotor training; TG, Technological group.

Regarding the clinical intervention findings shown in Table 4, all studies showed a substantial outcome of their individual technology-supported intervention suggestions. These findings bolster the body of scientific data showing physiotherapists and other rehabilitation specialists can use these technologies.

In general, all the technologies discovered in the studies examined in this review have the potential to bring about advantages like improved access to health services, quick access to low-cost professional activities, and high efficacy in the rehabilitation process, ensuring universal coverage of this service.[11] The use of technology-assisted rehabilitation has an impact on the frequency of appointments with rehabilitation specialists and helps ease the pressure on health systems that house reference facilities for the treatment of physical-motor diseases.[12]

Furthermore, the adoption of web-based tools, such as mobile phone applications, for monitoring activities in rehabilitation facilities holds promise in easing patient monitoring, particularly when physical presence is challenging for professionals. However, it is crucial to address the ongoing need for robust assessment methods and research to validate the effectiveness of technological treatments. Notably, potential challenges, including the instability of electrical energy supply systems and internet connectivity, must be considered, given their pivotal role in the operation of many contemporary technologies that hold promise for technological interventions in rehabilitation.

4.1 | Limitations of this study

While striving to comprehensively review rehabilitation technologies in clinical practice and physiotherapy training, limitations include potential language bias from primarily English sources, a temporal bias due to rapid technological advancements, and challenges in meta-analysis due to heterogeneity in study designs. Despite these, the review aims to provide valuable insights into the current state of rehabilitation technologies, emphasizing the need for ongoing research in this evolving field.

5 | IMPLICATIONS ON PHYSIOTHERAPY PRACTICE

With little to no involvement from the physiotherapist, rehabilitation technologies have the potential to effectively intervene in physical rehabilitation in a variety of clinical activities carried out by professionals like physiotherapists. These clinical activities include injury prevention, movement monitoring, and coordination of rehabilitation programs. Given the quick modernization that ensures increasingly higher autonomy for existing equipment, new research that examine the effects of rehabilitation performed or monitored by digital technologies, AI, and robotics continue to be essential.

TABLE 5 Intervention and results.

Author	Intervention	Result
Aprile et al.[11]	5 times week/4 weeks: Both groups of patients performed postoperative conventional rehabilitation treatment, consisting of 20 daily 45-min sessions for 4 weeks (5 times/week). Patients included in the CVG underwent group treatment sessions (3 or 4 patients) lasting 45 min, 5 times per week. The treatment included techniques to improve joint range of motion, muscle force, ability to adopt different postures and proprioceptive exercises.	All scales improved significantly in both groups after treatment ($p < 0.05$). Static balance improved in both groups, but there were greater improvements in the TG than in the CVG. All dynamic balance indexes showed significant improvements only in the TG after treatment.
Bickmore et al.[12]	Once a day/for two months: Subjects in the intervention groups accessed the system remotely over the Internet from their home computers daily during the 2-month intervention period.	Participants in the physical activity intervention increased their walking on average compared to the control group, while those in the fruit and vegetable intervention and combined intervention decreased walking. Participants in the fruit and vegetable intervention group consumed significantly more servings per day compared to those in the control group, and those in the combined intervention reported consuming more compared to those in the control group.
Cecchi et al.[13]	5 times/week; 30 sessions or 6 weeks: In both groups, treatment was performed daily for 45 min, 5 days/week, for 30 sessions. All patients also underwent individual conventional physical therapy (6 times/week), lasting 45 min, focusing on the lower limbs, sitting, and standing training, balance and walking.	A sample of 190 patients was evaluated after the treatment; 121 were responders. Age, baseline impairment, and neglect were significantly associated with worse response to the treatment. Age was the only independently associated variable (OR 0.967, $p = 0.023$). Considering separately the two interventions, age remained negatively associated with recovery (OR 0.948, $p = 0.013$) in the conventional group, while none of the variables previously identified were significantly associated with the response to treatment in the robotic group
Chae et al.[14]	12 Weeks: We selected four exercise tasks based on bilateral movement therapy, which is called bilateral arm training rehabilitation: (1) bilateral shoulder flexion with both hands interlocked; (2) wall push exercise; (3) active scapular exercise; and (4) towel slide exercise. All patients in the control group received personal education about the four exercise tasks for 30 min at the beginning of study enrollment. CG: In the control group, the participants received a printed handout to remind them about how to perform the four exercise tasks. In contrast, participants EG: in the HBR group received the same education and were given a smartwatch, and the HBR apps were installed on their own smartphones on the first day of the meeting.	The ML model created with personal data involving accelerometer combined with gyroscope data (5590/5601, 99.80%) was the most accurate compared with accelerometer (5496/5601, 98.13%) or gyroscope data (5381/5601, 96.07%). In the comparative study, the drop-out rates in the control and HBR groups were 40% (4/10) and 22% (5/22) at 12 weeks and 100% (10/10) and 45% (10/22) at 18 weeks, respectively. The HBR group ($n = 17$) showed a significant improvement in the mean WMFT score ($p = 0.02$) and ROM of flexion ($p = 0.004$) and internal rotation ($p = 0.001$). The control group ($n = 6$) showed a significant change only in shoulder internal rotation ($p = 0.03$).
Fernández-González et al.[15]	Six Week: Both the experimental group and the control group received two 30 min sessions per week over a six-week period (a total of 12 sessions for each group).	Within the experimental group, significant improvements were observed in all posttreatment assessments, except for Box and Blocks test for the less affected side. Clinical improvements were observed for all assessments in the control group. Statistical intergroup analysis showed significant improvements in coordination, speed of movements and fine motor dexterity scores on the more affected side of patients in the experimental group.
Jirayucharoensak et al.[16]	20 intervention sessions 30 min/time and 2-3 times/ weekThe baseline (pretreatment) neurocognitive functioning was measured using the CANTAB tests. Subsequently, subjects in both active intervention	NFT significantly improved rapid visual processing and spatial working memory (SWM), including strategy, when compared with exergame training and no active treatment. aMCI was characterized by impairments in

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TABLE 5 (Continued)

Author	Intervention	Result
	groups (CAU + NFT and CAU + Exergame) underwent 20 intervention sessions, 2–3 sessions a week, and then underwent a second cognitive evaluation using the CANTAB. Subjects in the control group had a second neurocognitive test after the same period of time (3 months).	SWM (including strategy), pattern recognition memory, and delayed matching to samples
Kim et al.[17]	30 min/day, 5 times/week: The E-RAGT group received end-effector-based RAGT and the BWST group received treadmill gait training with partial bodyweight support 30 min/day, 5 times a week, for 4 weeks, for a total of 20 sessions25,26. E-RAGT was performed using the G-EO System Evolution (Reha Technology, Olten, Switzerland). The harness secured to the participants on two-foot plates, whose trajectories could be programmed to approximate a normal gait. During training, the participants received real-time visual feedback from the pressure plates regarding the weight distribution on their feet. They were also provided with verbal cues to help them ensure that their nucleus and trunk were centered, and their movements were symmetrical.	Clinical outcomes, including the Fugl-Meyer assessment (FMA), timed up and go test, and 10-m walk test scores, improved after training in both groups, with significantly better FMA scores in the E-RAGT group than in the BWST group. These findings suggest that E-RAGT effectively improves neuroplastic outcomes in hemiparetic stroke, although its superiority over conventional training remains unclear. This may have clinical implications and provides insight for clinicians interested in locomotor neurorehabilitation after hemiparetic stroke.
Lao et al.[18]	12 weeks: The progress e intervention phase involved wearing sports smart bracelets during the 12 weeks of prescription exercise, which involved exercising three times a week for 1 h at a time (including warm-up and strain relaxation). The exercise only group (25 people) were involved in 12 weeks of elderly prescription exercise, which was the same as for the group exercising while wearing the bracelet. The control group (25 people) involved in the progress e for 12 weeks did not do any exercise, nor were they equipped with any sort of sports smart bracelets and products.	After 12 weeks of multi-sport exercise training, the evaluation scores on the EMS increased significantly in the group wearing exercise bracelets and those taking part in the multi-component exercise program, and the degree of progress each a statistically significant level, but the control group did not show any statistically significant difference. The influence of the combination of sports smart bracelets and multi-sport training programs on elders' motivation is clearer.
Padua et al.[19]	6 Weeks; 45 min/time, 5 times/week, All patients underwent a global conventional rehabilitative protocol f six sessions per week, each lasting 45 min, focused on postural changes, re-education and recovery of gait and balance. The CG performed exercises for hand, arm and shoulder oriented to sensor-motor re-programming, inhibition of the hypertonus, functional improvement and task-oriented exercises. In the RG, patients' upper limbs were treated by using the following devices: (a) a robotic device that allowed passive, active and active-assistive planar movements of the shoulder and elbow joints; (b) a robotic device that allowed passive, active and active-assistive finger flexion and extension movements; (c) a sensor-based device that allowed three-dimensional movements of shoulder, elbow and wrist joint, both unimanual and bimanual, without mechanical support; and (d) na electromechanical system that allowed three-dimensional, unimanual and bimanual, movements of the shoulder joint.	Considering all patients, a weak correlation was found between the CRI related to leisure time and MI evolution ($r = 0.276$; $p = 0.02$). Amongst the patients who performed a robotic rehabilitation, a moderate correlation emerged between the CRI related to working activities and MI evolution ($r = 0.422$; $p = 0.02$.
Park et al.[20]	Both groups received 30 additional minutes of therapy everyday, 7 days/week for 2 weeks. The CLT group received the usual inpatient care, including at least one 60 min physical therapy session per day, and an additional 30 min standard physical therapy session focused on pre-gait and/or gait training activities. The WLT group received the usual inpatient therapy, including at least one 60 min physical therapy session and an additional 30 min WLT session	ANCOVA showed that WLT showed superior effects, compared to CLT, on FAC, HR, BRPE, BDI-II, and ABC scale ($p < 0.05$), but not on BBS ($p = 0.0061$).

TABLE 5 (Continued)

Author	Intervention	Result
Park et al.[21]	The experimental group received the SASMP; the control group did not. At the first education session, participants in the experimental group received instruction on how to use each feature of the smartphone app. Four group exercise sessions were also offered during the first month of the 6-month intervention period for both groups. Each session, taught by an exercise expert who majored in exercise physiology, lasted about an hour and included stretching, main exercise, and stretching, in that order. The exercise expert helped the participants of both groups set an individualized goal for weekly exercise and physical activity, based on their personal exercise or physical activity status. For the experimental group, a video clip of each posture and motion, which was taught in the group exercise session, was included in the smartphone app's directory under exercise.	After randomization, the experimental group numbered 22, the control group numbered 20, and 2 participants dropped out. Significant differences between groups were found in change score for self-care behavior, total activity count per wear time, and percent time spent in moderate-to-vigorous physical activity over 6 months.
Persell et al.[22]	Control participants received an HBPM (7 Series Wireless Upper Arm Blood Pressure Monitor Model BP761N, Omron; or global Model HEM-7320T, Omron Health care Co Ltd), were instructed how to perform self-monitoring, and were asked to demonstrate use of the device. Intervention group participants received all interventions provided to the control group except the Omron smartphone app. Instead, they installed the HPCP coaching app.	At 6 months, self-confidence in controlling blood pressure was greater in the intervention group (0.36 point on a 5-point scale; 95% CI, 0.18 point to 0.54 point; $p <$ 0.001). There were no significant differences between the 2 groups in other secondary outcomes. The adjusted difference in self-reported physical activity was 26.7 min per week (95% CI, −5.4 min per week to 58.8 min per week; p = 0.10). Subgroup analysis raised the possibility that intervention effects differed by age.
Picelli et al.[23]	All participants were injected with Abobotulinumtoxin A (Ipsen Pharma, Boulogne-Billancourt, France) into the spastic triceps surae muscle of the affected lower limb. all patients included in this study received a 60-min session of electrical stimulation of the injected muscles (rectangular current pulses, 4 Hz, 0.2 ms, intensity adjusted to elicit visible muscle contraction).25 No other physical therapy, casting, taping or stretching procedures were done during the study period. In addition, patients allocated to the Group 1 underwent RAGT for 30 min a day for five consecutive days, beginning the day after BoNT-A injection. Robotic gait training was carried out on the G-EO System Evolution (Reha Technology, Olten, Switzerland)	No difference was found between groups as to the modified Ashworth scale and the Tardieu scale measured at the affected ankle 1 month after botulinum toxin injection. A significant difference in the 6-min walking test was noted between groups at the post-treatment evaluation (p = 0.045).
Salarian et al.[24]	A 45-min protocol was used that included typical daily tasks: quiet sitting and standing, eating, writing, talking while seated, walking inside the room, brushing the teeth, combing hair, walking in a 20-m pathway, climbing up and down the stairs, and lying on a bed. Participants carried the measurement system during the protocol and the measurement period was recorded on vídeo.	For the detection of posture transitions, compared to video recordings used as a reference system, the proposed algorithm demonstrated a sensitivity [true-positives divided by true-positives plus false-negatives) of 94.4% and a positive predictive value (PPV): true-positives divided by true-positives plus false-positives] of 96.9% for the controls (n = 232), and a sensitivity of 83.8% and a PPV of 87.0% for the PD patients (n = 272). In the classification of basic activities, i.e., walking, standing, sitting, and lying, the algorithm had a sensitivity of 99.1%, 96.1%, 99.5%, and 100%, respectively, for the control group and 98.5%, 83.6%, 86.3%, and 91.8%, respectively, for the PD patients. The specificity (true-negatives divided by true-negatives plus false-positives) of the algorithm for these basic activities for the control group was 99.8%, 97.9%, 99.8%, and 100%, respectively, and 97.8%, 96.5%, 98.0%, and 99.8%, respectively, for PD patients.

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TABLE 5 (Continued)

Author	Intervention	Result
Tousignant et al.[25]	Both interventions (teletreatment and home care/outpatient clinic) focused on functional rehabilitation. The mean duration of each therapy session was about 1 h of treatment (including treatment assessment and recommendations between treatments). The teletreatments were delivered to the participants at a rate of two sessions per week for 8 weeks (total of 16 sessions). The home visit/outpatient clinic treatments were delivered as usual over a period of 2 months on average, and the number of sessions was not controlled by research procedures but took place as usual in-home care/outpatient clinic services. No change was made in frequency, duration, or exercises.	Both groups of patients (Tele and Comparison) were satisfied with the services received and no significant difference wasobserved between them. Moreover, the physiotherapists' satisfaction with regard to goal achievement, patient–therapist relationship, overall session satisfaction, and quality and performance of the technological platform was high.
Tramontano et al.[26]	Both groups performed the training three times a week for 4 weeks. Each session lasted 40 min and was performed in addition to the conventional neurorehabilitation. Both rehabilitation programs were carried out by a physiotherapist with experience in neurorehabilitation. Experimental group's intervention TYRg performed twelve sessions of upper limb training with PABLO®-Tyromotion. For each session, the training consisted in interactive games based on virtual reality which allowed a taskoriented approach and neurocognitive feedback. Control group's intervention CTRLg performed twelve sessions of upper limb sensory-motor training, without robotic support. Subjects performed specific exercises aimed to recover global upper limb functions, to control hand grasp and to improve hand's fine movements.	The within-subject analysis showed a statistically significant improvement in both groups, in the Modified BarthelIndex and in the Rivermead Mobility Index scores and a significant improvement in Multiple Sclerosis Quality of Life-54 in the experimental. The analysis of effectiveness revealed that, compared with baseline (T0), the improvement percentage in all clinical scale scores was greater in the experimental group than the control group.
Yeh et al.[27]	The patients were given a standard 6-training session protocol. The training tasks and the balance test were conducted by currently practicing licensed physical or occupational therapists. The patients in the experimental group were divided into 3 groups: before treatment, undergoing treatment, and after treatment. Therapists were requested to conduct a Wii Fit balance test before and after each training session. Upon completion, all subjects were invited to join our survey, which focused on analyzing the sufficiency of gaming instructions, game appearance, system usefulness/playfulness, motivation promotion, and the ease-of-use of all game types. In addition, the subjects' personal information and their type of dizziness were recorded.	Analyzing the balance indices, in the patients who completed the training process, it was evidenced that they progressed and the difference between normal and patients is perceptible.
Zhang et al.[28]	The beginning of the experiment, the subject was examined for spasticity and contracture using the Ashworth scale (0–4), tendon reflex scale (0–4) and joint range of motionBefore the subject's ankle was exercised passively or actively, tendon reflexes were evaluated quantitatively by tapping the Achilles tendon with an instrumented reflex hammer and measuring the reflex responses. Before stretching, the joint stretching device was rotated manually by the operator to the extreme dorsiflexion and plantar flexion to set the extreme position limits (θp and θn). After the operator chose the Mp, Mn and θd values and entered them into the computer (default values and proper ranges were prespecified), the stretching device flexed the ankle throughout its ROM, with the DSP controller controlling the stretching velocity based on the resistance torque.	The relationship between the ankle dorsiflexion and external dorsiflexion torque (plantar flexor muscle resistance torque) during the strenuous stretching was quite different between healthy subjects and patients with spastic/contracted ankles. The passive ROM of the ankle joint increased considerably after the stretching treatment of spastic ankle, evaluated at comparable levels of stretching torque. For a representative case, dorsiflexion range increased from 11.9 to 16.5 at the same level of terminal torque (10 N·m) after a stretching session of 30 min. Similarly, plantar flexion range increased from 32.1 to 35.5 at a 10 N·m torque. Over multiple patients, the increase in ankle ROM was consistently observed in both dorsiflexion and plantar flexion, making the passive ROM closer to that of the healthy subjects.

TABLE 5 (Continued)

Author	Intervention	Result
	The patient was asked to relax and not to react to the stretch (if they reacted to the stretch, it would simply make the stretching device reverse its rotation before reaching to the extreme positions). The typical stretching velocity and peak resistance torque were chosen based on practice of experienced physical therapists.	

Abbreviations: ABC, activities-specific balance confidence scale; aMCI, amnestic mild cognitive impairment; ANCOVA, analysis of covariance; BBS, berg balance scale; BDI-II, Beck depression inventory-II; BRPE, Borg rating of perceived exertion; BWST, bodyweight-supported treadmill training; CANTAB, Cambridge Neuropsychological Test Automated Battery; CAU, care as usual; CG/CTRL, Control Group; CLT, conventional locomotor training; CRI, Cognitive Reserve Index; CVG, control group; DSP, digital signal processor; EMS, exercise motivation scale; E-RAGT, end-effector robot-assiste gait training; FAC, functional ambulation category; FMA, Fugl-Meyer assessment; HBPM, home blood pressure monitor; HBR, home-based rehabilitation; HR, heart rate; MI, Motricity Index; ML, Machine Learning; NFT, neurofeedback training; PD, Parkinson's disease; RAGT, Robot-assisted gait training; ROM, range of motion; SASMP, smartphone app-based, self-management program; SWM, spatial working memory; TG, Technological group; TYR, Tyromotion; WLT, Walkbot-assisted locomotor training; WMFT, Wolf Motor Function Test.

AUTHOR CONTRIBUTIONS

Tarciano Batista e Siqueira: Conceptualization; formal analysis; investigation; methodology; project administration; writing—original draft. **José Parraça**: Funding acquisition; supervision; validation. **João Paulo Sousa**: Funding acquisition; supervision; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

On reasonable request, the corresponding author will provide the information supporting the study's conclusions.

TRANSPARENCY STATEMENT

The lead author Tarciano Batista e Siqueira affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

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