

Use of artificial intelligence and machine learning in rehabilitation: A systematic review

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DECLARATIONS

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Abstract - Background and Purpose: In rehabilitation medicine, machine learning (ML) and artificial intelligence (AI) are two formidable technologies that have the potential to completely transform motor recovery. Research into the usefulness of AI and ML in rehabilitative medicine is still in its early phases. The purpose of this study is to present a thorough overview of the literature on the application of machine learning and artificial intelligence to rehabilitation. Many strategies have been put out in recent years to help intelligent support and remote monitoring in rehabilitation services.

Methods: The database exploration encompassed various search engines, such as Google Scholar and Pubmed, spanning from any date until December 31, 2023. All articles covering topics like artificial intelligence (AI), Machine Learning (ML), robotic features, motor rehabilitation, and AI technology were considered. Out of a total of 17,100 articles, only 17 met the specified inclusion criteria.

Discussion and Conclusion: The incorporation of motor learning and artificial intelligence (AI) in the context of rehabilitation initiates a comprehensive discourse on the revolutionary possibilities of this inventive combination. Artificial Intelligence (AI) and Motor learning (ML) enhances rehabilitation outcomes by enabling customized and flexible therapies using sophisticated

robotic devices and machine learning algorithms. By encouraging skill development and functional recovery, the integration of motor learning principles further augments the efficacy of these therapies.

INTRODUCTION

The process of AI is iterative, which means machines can perceive information, retain it as knowledge and use it to adapt their behaviour in an environment. In society, as well as in health care and research, AI methods are widely used. Machine learning is the study of algorithms which improve automatically with experience, a subset of artificial intelligence. (Anderson, 2019) Healthcare is one industry where machine learning is becoming more and more popular and widely used. Medical image analysis is gaining ground thanks to deep learning techniques, especially convolutional neural networks (CNNs), which have shown useful for a variety of tasks like object detection, feature extraction, and image segmentation. Specific techniques for creating algorithms that automatically get better with experience are referred to as machine learning (ML). (Chang et al., 2023)

Applications of artificial intelligence (AI) are thought to be crucial to the development and upkeep of a decentralized rehabilitation paradigm, wherein intelligently linked technologies would be used to support clinical decision-making and health outcomes monitoring. In order to address the future challenge of enabling assisted physical therapy and evaluations in a minimally supervised and decentralized manner, ideally at the patient's home, a number of AI-based methodologies and solutions have been presented recently. (Mennella et al., 2023) By combining patient-specific data with evidence-based recommendations, AI and ML can help create customized treatment strategies. The clinical data, functional abilities, and treatment history of a patient can all be analyzed by

these algorithms to produce suggestions for the best therapies, exercise regimens, and assistive devices.(Swarnakar & Yadav, 2023)

The computer emulation of human intelligence is known as artificial intelligence (AI). A computer algorithm uses machine learning (ML) to analyze data, find patterns, and then forecast correlations between those patterns. A kind of machine learning known as "deep learning" processes information through multiple layers of interconnected nodes (thus the term "deep") using an artificial neural network. In the realm of rehabilitative medicine, AI and ML have enormous potential for motor recovery. (Mennella et al., 2023)These tools can help with condition assessments, individualized treatment planning, progress tracking, and rehabilitation strategy optimization. Improving patient engagement, optimizing resource allocation, and improving rehabilitation outcomes are all possible with the integration of AI and ML in motor recovery. It's vital to remember, nevertheless, that medical practitioners are still required to interpret AI-generated insights, guarantee patient safety, and offer human knowledge during the rehabilitation process. Additionally, we would like to suggest that in the future, AI and ML be used in the fields of rehabilitation medicine for evaluation and diagnosis, predictive modeling, customized treatment planning, sensor-based movement analysis, and adaptive neurorehabilitation.(Swarnakar & Yadav, 2023)

AI technologies are currently being applied in diverse health care research sectors, and scientists are looking into the potential applications of these technologies. AI has been applied to rehabilitation to improve patient care by helping physical therapists (PTs) with a variety of tasks, such as performing a thorough examination, forecasting patients' performance, or making a diagnosis. More applications of AI in medical and rehabilitative settings, including problem-solving, x-ray diagnosis, treatment protocol design, and patient manipulation, have also been found through research. Core components of professional physical therapy practice are all these AI functions.(Alsobhi et al., 2022)

Today's most popular treatment for managing pain and ailments related to the bones is physiotherapy. Patients frequently experience excruciating pain as a result of accidents or abrupt jerks. For this reason, it is the magic drug that heals patients. Using AI and machine learning, we hope to create a framework that would

enable consumers to access a digitalized physiotherapy system. Recent approaches for computer-aided monitoring and performance lack robustness and variety, even though there are many different computer-aided assessment methods for physiotherapy rehabilitation. (Godse, 2019)

Taking into account the quick development of AI and ML applications in rehabilitation, this paper aims to give a thorough summary of their present use, advantages, and difficulties in enhancing patient outcomes. The goal is to produce a resource that educates researchers, policymakers, and healthcare practitioners by exploring the subtleties of how these technologies improve treatment protocols, customize rehabilitation plans, and increase overall healthcare efficiency.

SEARCH STRATEGY

Inclusion and exclusion criteria

The review encompassed solely prospective, controlled, or uncontrolled intervention trials that were documented in academic journals. This review excludes retrospective study designs, case reports, case series, comments, letters to the editor, and expert opinions. In this study, language was not a hindrance. Studies on the application of AI and machine learning in rehabilitation must meet certain requirements in order to be included.

As said earlier, the search was conducted with the goal of encompassing all studies that looked at the application of machine learning and artificial intelligence in rehabilitation. Choosing not to participate in experiments if additional factors were allowed or delivered simultaneously. Only papers with a primary focus on AI and ML-assisted rehabilitation were included in the review. Research that were unable to demonstrate a connection between AI and ML in the context of rehabilitation were excluded. After analyzing the titles and abstracts, case studies in current trials, retrospective research, publications in other languages, and completely unrelated things were eliminated from consideration. The only studies that were considered in the review were those that were published in peer-reviewed journals and had full texts available in English. All research reports were accepted, regardless of the study design. Excluded from consideration were studies that were only published as abstracts or dissertations.

Searching Criteria

To find all relevant English articles, we conducted a comprehensive, methodical literature search using the following databases: Google Scholar, PubMed, and Elsevier using filters to search articles as English papers encompassing the time range from anytime until December 2023.

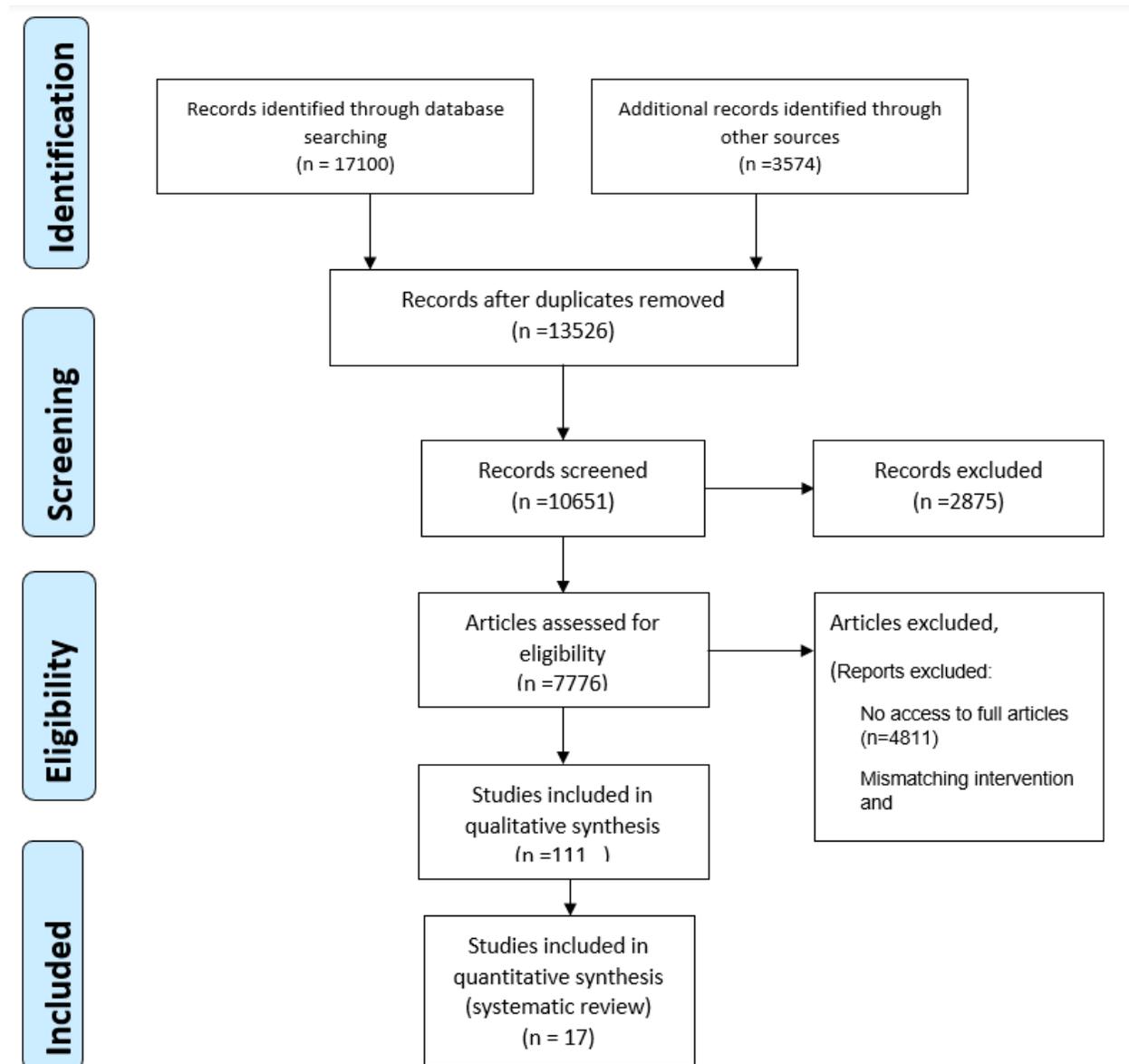
The strategy listed below was taken:

- Artificial intelligence
- Machine learning
- Motor rehabilitation
- Telerehabilitation

- Human robot interaction in rehabilitation
- Motor recovery
- Future technology in rehabilitation

Using this method to eliminate duplicate records, we were able to extract 13526 records from the searches. No additional records from other sources could be located. After reading the titles and abstracts of case studies in current trials, retrospective research, publications in other languages, and items that were completely irrelevant, we excluded 13509 entries. After additional evaluation, a total of 17 papers were found to match the review inclusion criteria.

PRISMA FLOWCHART



Level and quality of evidence supporting use of AI and ML in rehabilitation															
Author	Sackett Level of Evidence	PEDro scoring											SCORING		
		0	1	2	3	4	5	6	7	8	9	10		11	
CIRO MENNELLA.et.al (2022) 3	II	1	1			1					1	1	1	1	6
Raktim Swamakar.et.al (2023) 4	V											1	1	1	3
Mashaeh Alsobhi.et.al (2022) 6	II	1	1	1	1	1	1	1	1	1	1	1	1	1	10
Jennifer Sumner.et.al (2023) 7	I	1	1		1	1	1		1	1	1	1			8
Abolfazl Mohebbi.et.al (2020) 8	II	1	1		1	1	1		1	1	1	1			8
Tijana J. DimkiT TomiT.et.al (2017) 11	II	1	1	1	1	1	1	1	1	1	1	1	1	1	10
Shabnam Sadeghi Esfahlani.Et.Al (2019)12	V	1									1	1	1	1	4
Sang Hoon Chae.et.al (2020) 13	III	1	1	1	1	1	1	1	1	1	1	1	1	1	10
Tomomi Anan.et.al(2021) 14	II	1	1	1	1		1	1		1	1	1	1		9
Satit Thiengwittayaporn.et.al(2021) 15	II	1	1	1	1	1	1	1	1	1	1	1	1	1	10
David Ben-Israel.et.al(2020) 16	II	1	1	1	1		1	1		1		1	1		8
Javier Conte Alcaraz.et.al (2018) 17	III	1		1	1	1	1	1	1				1	1	8

Level and quality of evidence supporting use of AI and ML in rehabilitation

RESULT

Author /Year	Type of Study	Aim of Study	Participants	Outcome Measures	Result
Tijana J. DimkiT TomiT.et.al/2017	RCT	This pilot study compared the effectiveness of matched traditional arm training with ArmAssist (AA) robotic training in subacute stroke participants with moderate-to-severe upper limb disability.	For this investigation, 26 hemiparetic subacute stroke patients were enrolled. Using SAS software, a table of random numbers was used to assign participants to either the Arm Assisted group (n = 13) or the Control group (n = 13).	The Wolf Motor Function Test-Functional Ability Scale (WMFT-FAS) and Barthel index (BI) were the secondary outcomes, while the Fugl-Meyer Assessment-Upper Extremity (FMA-UE) motor score served as the major outcome measure.	After three weeks of treatment, the FMA-UE score (18.0 ± 9.4 versus 7.5 ± 5.5, p = 0.002) and WMFT-FAS score (14.1 ± 7.9 versus 6.7 ± 7.8, p = 0.025) increased significantly more in the AA group than in the Control group, but the increase in BI was not statistically significant (21.2 ± 24.8 versus 13.1 ± 10.7, p = 0.292).
Javier Conte Alcaraz .et.al/2018	An Experimental Study	The study's objective is to demonstrate how wearable technology (WT) in conjunction with real-time acoustic feedback (RTAF) can provide a fantastic rehabilitation option.	Two volunteer patient groups were chosen: the experimental group (height: 173 ± 5 cm, age: 63 ± 10 years) and the control group (height: 176 ± 4 cm, age: 61 ± 8 years).	Although the gait rehabilitation exercises and sessions were the same for all groups, the experimental group received additional help from the RTAF. There were ten patients in each group.	The rehabilitation sessions show a positive association in both circumstances, but the experimental individuals' grades rise more quickly, most likely as a result of the acoustic feedback's beneficial effects. For the grade in the experimental group, improvements of up to 16% are possible to see.
Satit Thiengwittayaporn .et.al /2021	RCT	This study's main goal was to determine whether, in comparison to traditional educational handouts, the use of interactive mobile applications that are not for profit may enhance the accuracy of knee OA patients' rehabilitation..	Patients (n=82) who were randomized to the handout group (H-group) and the mobile application group (M-group) participated in a single-blinded study. Age, gender, BMI, degree of disease, beginning of pain, education, and occupation were all controlled for in the patient groups.	Three recommended knee exercises (catch-bend-down, stretch-touch-feet, and sit-stretch-hold) were performed accurately, and this accuracy was assessed. Using the KOOS and KSS scores, clinical results were compared before and after the 4-week	After the trial was finished, the M-group (76.2%) completed the exercises with significantly higher overall accuracy than the H-group (52.5%). Following the 4-week regimen, the M-group showed significantly greater improvement in daily activities, quality of life, ability to participate in sports, and leisure

				program to measure quality of life, physical activity, pain, symptoms, and range of motion.	activities than the H-group (p=.001).
Tomomi Anan.et.al/2021	RCT	This study sought to assess the effects of an exercise-based, artificial intelligence (AI)-assisted interactive health promotion system that runs via a mobile messaging app (the AI-assisted health program) on the musculoskeletal symptoms of workers with low back pain and neck/shoulder stiffness/pain.	Using computer-generated random numbers, all 121 participants were divided into two groups and stratified into age groups of ten. The age groups were then allocated at a 1:1 ratio.	To avoid stiff shoulders and back pain, the control group completed their daily exercise regimen for approximately three minutes during the company-provided break time. AI intervention group: Every day, the participants could complete their exercise in one minute. Three things made up the program's exercise: stretching, maintaining proper posture, and mindfulness.	When compared to individuals in the control group, the intervention group's participants exhibited statistically significant improvements in the degree of low back pain and neck/shoulder discomfort/stiffness. 36 (75%) out of 48 subjects reported a subjective reduction in pain or stiffness after 12 weeks.
Mashaal Alsobhi.et.al/2022	A cross sectional study	The purpose of this study was to examine, using a variety of explanatory variables, the knowledge and attitudes of PTs toward the use of AI in rehabilitation.	317 PTs in all freely took part in the study; Google Forms (Google LLC) was used to produce the survey link.	The ethical ramifications of using AI and the participants' willingness to learn more about the area were covered in the final portion. A 5-point Likert scale, spanning from strongly agree to strongly disagree, was used to evaluate the survey respondents' responses to yes/no questions.	discovered that the PTs' knowledge of AI applications in the field of rehabilitation varied statistically significantly depending on their sex (odds ratio x (odds ratio [OR] 2.43, 95% CI 1.53-3.87; P<.001) Furthermore, it was strongly agree that knowledge of AI applications was significantly predicted by experience (OR 1.79, 95% CI 1.11-2.87; P=.02) and educational background (OR 1.68, 95% CI 1.05-2.70; P=.03).

DISCUSSION

The study's primary goal was to gain a quick overview of PTs' general views and opinions about AI and machine learning in healthcare and rehabilitation.

A major goal of health systems as the population ages is to maintain independence. Rehabilitation services must adapt to promote access while maximising efficiency in light of resource constraints as the burden of disease and disability rises. Advances in rehabilitative care can only come from one direction: health technology, particularly AI systems. But the nature of therapeutically useful technology and the obstacles to its adoption are still unknown.(Sumner et al., 2023)

In addition to offering financial advantages, the advancement of intelligent technologies in rehabilitation and healthcare in general holds promise for raising treatment standards. Because of the volume of health-related data that can be gathered to evaluate patient outcomes, these technologies have the potential to enhance overall quality of treatment. (Luxton & Riek, 2019)The application of AI technologies in healthcare and rehabilitation is expanding quickly. In order to provide competent patient care facilities, it is necessary to raise PTs' awareness of the many applications of AI in rehabilitation. The study's results also underscored the need of encouraging PTs to translate evidence-based information, especially when it comes to AI

technology. However, more study on physical therapy practitioners and patient expectations is needed in order to properly apply AI in the rehabilitation area.(Alsobhi et al., 2022)

The field of AI-supported physical rehabilitation is expanding and has the potential to enhance services by providing more individualized care, more accessibility, and increased efficiency.(Sumner et al., 2023)The utilization of intelligent technologies in the fields of rehabilitation and healthcare might yield substantial financial advantages for both service providers and patients.(Luxton & Riek, 2019)

Patients are typically provided with feedback regarding their workout regimen and the advancement of their therapies through the use of monitors, virtual reality headsets, haptic feedback devices, and neurostimulation. Calabro et al. investigated the impact of providing MS patients with walking impairments with a virtual reality (VR) system combined with robot-assisted gait training. They demonstrated that training several brain regions related to motor planning and learning is one of the main benefits of using a virtual reality environment. By combining a virtual reality platform, neuromuscular electrical stimulation (NMES), and an upper limb rehabilitation robot, Archambault et al. presented a rehabilitation intervention for the upper extremities.(Ciccarelli et al., 2023) Berezny et al. used tactile feedback and virtual reality to enhance user engagement in the development of a lower limb rehabilitation robot for acute, bedridden patients.(Mohebbi, 2020a) Ocampo et al. integrated an augmented reality (AR) game environment into an upper limb robotic rehabilitation system to provide colocation between visual and haptic feedback.(Mohebbi, 2020b)

Therefore, AI's function in clinical practice should be to provide embedded algorithms that analyze and process data provided by digital technologies online, combining medical, psychological, and technical knowledge. Artificial Intelligence is anticipated to be of great significance in the areas of therapeutic decision-making, online therapy exercise adaptation, and progress tracking via the extraction of validated evaluation scores. (Tomić et al., 2017)

Artificial intelligence (AI) and machine learning (ML) have the potential to revolutionize the field of rehabilitation by combining these two cutting-edge technologies to improve and personalize patient care.

As we advance, AI systems will comb through the enormous amount of patient data, figuring out complex relationships and patterns to create extremely customized rehabilitation plans.(Sadeghi Esfahlani et al., 2019) The individual physiological and psychological traits of the patient will be taken into account in addition to the particular medical issues. It will be customary to monitor in real-time using wearable technology and sensors, enabling ongoing progress evaluation and dynamic rehabilitation regimen modification. AI integration into virtual worlds and games for rehabilitation will also make the process more pleasurable and offer adaptable challenges, ensuring that workouts stay engaging and in line with each patient's developing capabilities. (Thiengwittayaporn et al., 2023)The future is full of opportunities to transform rehabilitation—making it more effective, interesting, and, ultimately, conducive to greater results for people pursuing recovery.(Anan et al., 2021)

The application of machine learning (ML) and artificial intelligence (AI) in rehabilitation has significant limits, despite encouraging developments. One major obstacle is the interpretability of AI-driven models, which makes it challenging to understand the reasoning behind their judgments.(Ben-Israel et al., 2020)Particularly in medical contexts where knowing the rationale behind treatment recommendations is critical, this lack of transparency is concerning. Large datasets may not accurately reflect the variety of patients and circumstances seen in actual rehabilitation scenarios, which means that using them to train these algorithms may also create biases.(Falces-Prieto et al., 2021) A further obstacle to the broad adoption of AI and ML solutions is their high implementation costs and the requirement for specialist knowledge in handling and comprehending the technology. To avoid misuse or unauthorized access to sensitive health information, strict rules are required due to ethical considerations around patient privacy and data security. To guarantee that new technologies genuinely improve patient outcomes while maintaining ethical norms and accessibility, it will be crucial to overcome these limits as we negotiate the integration of AI and ML in rehabilitation.

CONCLUSION

In conclusion, the field of integrating motor learning and artificial intelligence (AI) in rehabilitation is one that is full of promise for both changing the way rehabilitation is done now and offering significant improvements in patient outcomes. A customized and adaptable approach that is suited to each patient's demands is provided by the synergistic fusion of motor learning principles with AI technologies, such as robotic systems and machine learning algorithms. It also makes therapy more accurate and data-driven. All of these benefits contribute to the effectiveness of rehabilitation programs.

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