News and Perspectives

AI-Powered Robotics Are Personalizing Rehabilitation

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Abstract

Rehabilitation is crucial for making a full recovery from surgery or managing a chronic physical disability, but it can be resource-intensive and highly individual in treatment response. In this *News and Perspectives* article, JMIR Correspondent Benedette Cuffari reports on robotics in rehabilitation and how AI is helping to make it more personalized, efficient, and effective.

Key Takeaways:

- The rapid development and widespread deployment of AI in health care have improved the capabilities and adoption of robotics in rehabilitation.
- AI-enabled rehabilitation robotics support personalized, data-driven therapy by continuously monitoring patient performance and providing objective feedback during the recovery process.

Advances in emergency and acute medical care have transformed the management of conditions like stroke and traumatic brain injury, enabling more people to survive these life-threatening events. Concurrently, a growing number of individuals live with chronic physical disabilities that require long-term rehabilitation, with current estimates indicating that about 16% of the global population is affected by a physical disability resulting from neurological injury or disease. These disabilities can severely impact an individual's quality of life by preventing them from performing daily tasks like walking, bathing, eating, and dressing.

Patient recovery depends on frequent and repetitive exercises to help the nervous system adapt and regain function, but most medical systems are not financially or logistically equipped to provide continuous rehabilitation. As a result, rehabilitation services are chronically delivered at a lower intensity and frequency than recommended by evidence-based clinical practice guidelines. This prevents patients from receiving sufficient guided practice needed to maximize recovery.

"This is where robotics can be useful," explains Dylan Edwards, PhD, Director of Rehabilitation Medicine at Thomas Jefferson University. "It can tirelessly retrain movement at scale, which was previously a limiting factor." In practice, this translates into more movement repetitions, with the RATULS trial reporting 1075-1090 movement attempts during a single session of robot-assisted therapy. This is comparable to observational studies of stroke rehabilitation, during which conventional upper-limb therapy often produces only tens of functional movements during each session.

Robotics in Rehabilitation

Rehabilitation robotics (RRs) have emerged, in part, to address this gap and ensure that patients receive the optimal level of assistance and challenge throughout rehabilitation sessions. Assistive RRs are widely used to support daily activities related to mobility, feeding, dressing, and handling objects; therapeutic systems are designed to help patients do exercises and tasks for recovery, while continuously monitoring their progress and adjusting assistance throughout therapy sessions.

Early RRs represented a major advance in delivering high-intensity treatment, but were traditionally limited to preprogrammed movements and control algorithms. More modern robotic systems are often integrated with sensors, actuators, and control algorithms that further improve patients' ability to regain mobility. Material science innovations have also increased how portable and comfortable RRs are to use, expanding utilization and improving treatment adherence in both home and outpatient facilities.

RRs are not the right fit for every patient, and determining suitability can be challenging. "Understanding the responders and patient selection could be facilitated by a data-driven approach that helps us understand who this is most suitable for," Edwards continues. AI is increasingly being explored as a clinical decision-support tool, as AI models can combine data from clinical assessments, wearable sensors, and imaging results to help identify whether and how patients might benefit from this kind of approach.

From Programmable Machines to Intelligent Rehabilitation

Various AI approaches have been integrated in the design and development of RRs, some of which include human-machine interaction (HMI), virtual reality (VR), natural language processing, machine learning (ML), and computer vision. Compared to conventional RRs that primarily deliver predefined movement patterns based on fixed goals, AI-enabled RRs continuously learn from updated patient-specific data in real time to adapt the difficulty of movements while providing personalized feedback.

For example, ML algorithms in robotic systems analyze joint movements, muscle activity, gait patterns, and force measurements during sessions to identify when the patient is getting fatigued or compensating with incorrect movements. By identifying these patterns, AI-enabled RRs can maximize the intensity and effectiveness of rehabilitation while providing clinicians with objective data to guide treatment decisions.

HMI enables patients to have more efficient interactions with robotic systems and ultimately accelerate their recovery. These feedback mechanisms are evident in the upper limb Armeo®Spring exoskeleton, a medical device that provides personalized therapy for both children and adults. During therapy, embedded motor and grip-force sensors within this system continuously record patient movements to create a detailed digital record. This record is then analyzed by AI algorithms to identify movement deficits, monitor patient recovery, and personalize future treatment protocols.

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VR is used to augment these robotic systems, immersing patients in interactive therapeutic environments while adjusting the intensity and frequency of exercises in real time using visual and auditory feedback. In addition to head-mounted displays, interactive VR gloves can support tactile manipulation of virtual objects and support the targeted rehabilitation of specific hand exercises. Together, VR and AI-driven robotic systems can increase patients’ motivation and engagement by transforming otherwise repetitive exercises into activities that more closely resemble real-world tasks and that feel more meaningful and purposeful in the moment.

According to Edwards, AI-driven robotic adjustments can make all the difference in delivering real-time, personalized care. “Having a whole team of coaches watching and providing updates has the ability to use much more information and do it in a faster, more accurate, and systematic manner,” he says. Future systems are likely to become more personalized, adaptive, and accessible across a wide range of care settings.

Challenges and Future Directions

Conventional RRs are widely used and available in clinical practice; however, their availability is often limited by cost, training requirements, and infrastructure challenges. The integration of AI into modern RRs used in specialized rehabilitation centers remains investigational, with current studies evaluating their safety, effectiveness, and ability to improve treatment delivery while increasing patient participation. Greater adherence and recovery may reduce health care costs by lowering reliance on long-term rehabilitation services and hospital readmission.

However, the novelty of AI in this field is reflected by the lack of large-scale clinical trials, which would normally establish harmonized rules for how to monitor the safety and efficacy of medical devices like AI-enabled RRs. Without this information, clinicians may be reluctant to incorporate these technologies into routine rehabilitation practice.

Adding AI capabilities to RRs also introduces important ethical concerns that require more extensive regulatory oversight. For example, developers must ensure that any patient information that is used to train and operate these systems remains private and secure. As a result, the approval process becomes even more time-consuming and expensive.

By addressing these challenges through continued research and collaboration, AI-driven RRs may become valuable tools for improving the future of rehabilitation care.

Keywords: robot-assisted rehabilitation; rehabilitation robotics; artificial intelligence; stroke recovery; virtual reality; wearable sensors; AI

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