Chapter 6

The Evolution of Digital Rehabilitation: Next-Generation Technological Approaches in Occupational Therapy and Physiotherapy

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Abstract

Digital rehabilitation is reshaping occupational therapy and physiotherapy by coupling person-centred care with scalable technologies across telehealth, mobile applications, wearable sensors and inertial measurement units (IMUs), virtual and augmented reality, and clinical decision support systems. Evidence from neurological, musculoskeletal, pulmonary, and cardiac settings shows that digitally delivered or augmented interventions achieve outcomes comparable to conventional care while improving access, continuity, and adherence. Mechanistically, adaptive task practice and multimodal real-time feedback leverage neuroplasticity to drive motor and cognitive gains, and wearables extend assessment beyond clinics to enable objective, longitudinal monitoring and data-driven personalisation; IMUs demonstrate acceptable reliability and validity relative to laboratory motion capture. Clinical decision support can standardise protocols, tailor exercises, and deliver timely feedback at scale. Persistent challenges include usability and connectivity barriers, variable digital literacy among patients and clinicians, data integration and privacy concerns, reimbursement uncertainty, and alignment with clinical workflows. Equity remains central: without inclusive design and digital skill-building, digital health interventions risk widening existing access gaps. Overall, digital rehabilitation is shifting from adjunct to core service model; the priority for therapists is less about choosing a single tool than embedding adaptive feedback, objective monitoring, and person–environment fit into routine care. Future work should emphasise pragmatic trials, standardised outcomes, interoperable data pipelines, and implementation strategies that explicitly address the digital divide.

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1. The Rise of Digital Health and Rehabilitation

The advancement of digital health in rehabilitation marks a major shift in healthcare practice, emphasizing the integration of technology to enhance patient outcomes. Over the past decade, a growing body of research has demonstrated the effectiveness of digital health interventions (DHIs) across cardiac, pulmonary, and neurological rehabilitation. Digital health has increasingly been recognized as a pivotal component of rehabilitation, contributing to improved diagnosis, risk assessment, and recovery processes (Wang et al., 2023). The incorporation of mHealth platforms, wearable sensors, and virtual reality (VR) systems has enabled the development of personalized intervention strategies tailored to individual needs. Evidence from VR-based telerehabilitation programs highlights notable improvements in balance and motor function among stroke patients, demonstrating the clinical potential of immersive digital tools (Wang et al., 2023).

Findings from the AMOUNT study indicate that the integration of digital devices can substantially enhance rehabilitation outcomes for both inpatients and individuals in post-hospital recovery (Hassett et al., 2020). Similar outcomes have been observed in pulmonary rehabilitation, where the use of telehealth and VR technologies has helped address persistent barriers such as limited patient engagement and accessibility (Darabseh et al., 2025).

Advancements in cardiac rehabilitation further underscore the transformative role of digital health. Guidance from the American Heart Association highlights how digital components can support greater health equity and accessibility (Golbus et al., 2023). Moreover, telemonitoring systems and smartphone-based applications have been associated with higher levels of patient adherence and engagement, reflecting the value of connected technologies in sustained rehabilitation participation (Falter et al., 2020; Pearce et al., 2023).

Although the benefits of DHIs are increasingly evident, challenges remain in their practical implementation. Effective adoption requires adequate training and structured integration into existing clinical workflows (Hassett et al., 2020). In addition, user engagement and personalization emerge as critical factors influencing intervention success. Research points to a strong association between self-efficacy and treatment adherence, emphasizing that continuous digital monitoring and individualized feedback contribute to improved rehabilitation outcomes (Wiesmüller et al., 2025).

1.1. The Transformative Impact of Technology on Physiotherapy and Occupational Therapy

1.1.1. Telehealth and Remote Consultations

Telehealth has become one of the most influential developments in modern rehabilitation practice, particularly during the COVID-19 pandemic when face-to-face sessions were restricted. Within physiotherapy education, telehealth has been increasingly recognized as a sustainable and innovative model of service delivery that is likely to remain an integral component of future clinical practice (Davies et al., 2022). Remote assessments and consultations expand access to care, enabling therapists to maintain continuity of treatment for individuals who encounter geographical or mobility-related barriers. In occupational therapy, the growing integration of telehealth has underscored the importance of developing digital competencies to deliver effective, real-time interventions and monitor client progress more efficiently (Segal & Doyle, 2024). These developments have strengthened the therapeutic relationship by supporting engagement and adherence in remote rehabilitation settings.

1.1.2. Mobile Applications and Digital Tools

The rapid growth of mobile applications and digital tools designed for therapeutic use has introduced new dimensions to data collection, assessment, and communication in rehabilitation. Applications that facilitate digital documentation and progress tracking streamline the evaluation process, enhancing both the accuracy and efficiency of treatment planning (Svarre et al., 2022). In addition to supporting professional decision-making, these technologies foster ongoing communication and feedback between practitioners and clients. The use of customized digital platforms has also demonstrated potential in helping older adults sustain participation in meaningful daily activities, illustrating how technology can support individualized and context-sensitive rehabilitation approaches (Fischl et al., 2020).

1.1.3. Advanced Rehabilitation Technologies

Emerging technologies such as VR and wearable devices are increasingly shaping the future of rehabilitation environments. The incorporation of immersive systems has enhanced both safety and motivation during therapy sessions, allowing patients to practice functional skills within simulated, controlled settings that promote engagement and measurable progress (Kakaraparthi et al., 2024). These technologies contribute not only to

physical recovery but also to the psychological experience of rehabilitation, fostering a greater sense of autonomy and self-efficacy among users. However, the effective implementation of such innovations depends on appropriate professional training and ongoing digital literacy development, ensuring that practitioners can confidently integrate advanced tools into clinical workflows (McKinstry et al., 2020).

2. Theoretical Foundations of Digital Rehabilitation

2.1. Digital Rehabilitation Frameworks

Frameworks for digital rehabilitation focus on how technology can enhance therapeutic outcomes and promote equitable access to care. The model proposed by Reisdorf and DeCook emphasizes the importance of digital inclusivity, illustrating how access to technology and digital skill-building can support social reintegration and autonomy in diverse populations (Reisdorf & DeCook, 2022). When extended to rehabilitation contexts, this approach highlights that inclusive and accessible digital health interventions are essential to sustain engagement and optimize recovery. Similarly, person-centered frameworks that acknowledge differences in digital literacy are fundamental in developing tailored interventions. Research focusing on individuals living with chronic conditions such as HIV demonstrates that adapting digital platforms to varying user abilities can improve participation and overall treatment adherence (O'Brien et al., 2023). These principles reinforce the notion that digital rehabilitation must remain flexible and responsive to individual needs to achieve meaningful outcomes.

2.2. Remote and Hybrid Rehabilitation Models

The transition toward telehealth and hybrid rehabilitation models has been guided by theoretical perspectives emphasizing accessibility and patient-centered care. Analyses of digitally assisted physiotherapy environments reveal that remote and hybrid modalities can create opportunities for deeper engagement in therapeutic activities while maintaining convenience and continuity of care ((Sjögren & Korpi, 2024). This reflects a paradigm shift in which digital components are no longer supplementary but central to rehabilitation delivery. Studies exploring web-based rehabilitation interventions further demonstrate that technological interaction enhances both user experience and therapeutic outcomes. Evidence indicates that patients' acceptance of and satisfaction with digital modalities contribute to stronger adherence and overall success of rehabilitation programs (Busse et al., 2021). Together, these findings suggest that theoretical frameworks

of engagement and usability are vital for the effective implementation of remote rehabilitation practices.

2.3. Evidence-Based Practice and Implementation Frameworks

Evidence-based practice serves as a cornerstone for integrating digital technologies into rehabilitation. Implementation strategies discussed in the literature stress the importance of structured frameworks that ensure both clinical efficacy and long-term sustainability of digital health interventions (Pearce et al., 2023). These models guide clinicians and organizations in adopting new technologies through systematic evaluation, iterative design, and data-driven decision-making. Further contributions to this field highlight the need for comprehensive evaluation mechanisms to assess the quality and impact of digital interventions. Structured assessments are essential for understanding how users, technologies, and healthcare providers interact within digital rehabilitation environments, thereby informing continuous improvement and ethical implementation (Soobiah et al., 2020).

2.4. Addressing the Digital Divide

An integral component of the theoretical foundations of digital rehabilitation is the acknowledgment of the digital divide and its influence on accessibility and equity. While digital health interventions have expanded access for many, disparities in resource availability and technological literacy continue to limit participation among certain groups (Bayly et al., 2021). Understanding this duality is essential to ensure that digital rehabilitation promotes inclusion rather than reinforcing existing inequalities. At the professional level, varying degrees of readiness to adopt new technologies underscore the need for ongoing education and digital literacy training. The increased acceptance of telerehabilitation observed during the COVID-19 pandemic suggests that such training can gradually shift attitudes and normalize the use of digital tools within rehabilitation practice (Lau et al., 2022).

3. Neuroplasticity and Feedback Mechanisms in Digital Rehabilitation

3.1. The Role of Neuroplasticity in Digital Rehabilitation

Neuroplasticity constitutes a central theoretical foundation for most rehabilitation strategies, particularly within neurorehabilitation. Patient engagement has been identified as a crucial determinant in promoting neuroplastic changes and achieving functional gains, with digital platforms

offering flexible tools that adapt to individual performance levels and therapeutic needs (Matamala-Gomez et al., 2020). Such adaptability creates an enriched environment conducive to neural reorganization and behavioral recovery.

Evidence also indicates that digital and hybrid rehabilitation models can effectively modulate neuroplasticity through structured interventions. Improvements in both cognitive and motor functions have been observed in individuals with multiple sclerosis participating in digitally supported programs, suggesting that telehealth modalities can stimulate cortical reorganization comparable to in-person therapy (Petracca et al., 2024). Moreover, research exploring stroke rehabilitation demonstrates that integrating digital therapeutic interventions with neuroimaging feedback enables a deeper understanding of cortical activation patterns and their role in recovery (J. Kim et al., 2024). Collectively, these findings underscore the significance of incorporating neuroplastic principles into digital rehabilitation design.

3.2. Feedback Mechanisms and Their Impact

Feedback plays a pivotal role in enhancing learning and performance during rehabilitation. In digital environments, feedback is delivered through various sensory modalities visual, auditory, and haptic each contributing to motor learning and engagement (Banh et al., 2021). Robot-assisted systems exemplify this principle by adjusting resistance, movement range, or task difficulty in response to real-time performance data, allowing individualized progression and optimized outcomes.

VR technologies further extend the feedback dimension by immersing patients in interactive environments where real-time performance cues foster motivation and repetitive skill practice, both essential for neuroplastic adaptation (Naro & Calabrò, 2021). Similarly, in cognitive rehabilitation, structured and adaptive feedback has been shown to enhance functions such as attention, memory, and language recovery, reinforcing the role of targeted feedback in improving cognitive outcomes (Xiao & Cui, 2025).

3.3. Integration of Neuroplasticity and Feedback Mechanisms

The integration of neuroplasticity principles with responsive feedback mechanisms establishes an optimal environment for recovery in digital rehabilitation. Combining engaging, adaptive digital applications with immediate feedback promotes consistent participation and accelerates functional improvement. Interactive systems that translate motor performance

into dynamic feedback have been shown to strengthen motivation and adherence, key drivers of neuroplastic reorganization (Golota et al., 2025).

Virtual rehabilitation environments capable of adjusting sensory inputs and task complexity in response to user performance further amplify these effects. Such adaptive systems facilitate continuous motor learning and maximize neuroplastic potential by individualizing therapy intensity and feedback patterns (Nizamis et al., 2021). Through this synergy of neural adaptability and technological responsiveness, digital rehabilitation emerges as a powerful modality for promoting long-term functional recovery.

Table 1. Advantages and Limitations of Technology-Based Rehabilitation Programs

Aspect	Advantages	Limitations
Patient Engagement and Motivation	Interactive and immersive virtual environments increase engagement and adherence. Gamified features transform repetitive exercises into motivating experiences (Petrova et al., 2023; Sahai et al., 2024).	Some patients may experience frustration or anxiety when using digital tools, reducing motivation and long-term engagement (Glavare et al., 2021; Ovchinnikov et al., 2024).
Personalization and Adaptability	AI-driven and adaptive systems enable individualized rehabilitation strategies that adjust difficulty based on real-time performance, enhancing learning and recovery (Khalid et al., 2024; Quintana et al., 2022).	Unequal access to technology and varying digital literacy levels can limit effective personalization, especially in older or socioeconomically disadvantaged populations (Khalid et al., 2024).
Remote Monitoring and Accessibility	Remote systems allow patients to continue therapy from home, improving access for those with mobility or geographic limitations. Continuous monitoring supports timely clinical feedback (Lyapina et al., 2022).	Dependence on stable internet and device availability poses barriers in underserved regions. Connectivity issues can disrupt remote therapy sessions.
Neuroplasticity Facilitation	Virtual and simulated environments enhance neuroplasticity by promoting motor and cognitive retraining through repetitive, engaging tasks (Lv & Guo, 2022; Shirolapov, 2025).	Limited evidence in certain clinical populations regarding the long-term neural impact of virtual and augmented interventions.

Cost-Effectiveness	Digital systems reduce overall rehabilitation costs by minimizing in-person sessions and optimizing clinician time (Afridi et al., 2022; Petrova et al., 2023).	High initial costs for hardware, software, and system integration challenge implementation, particularly in low-resource settings (Mann, 2025).
Professional Expertise	Clinicians can leverage advanced tools to deliver efficient and data-driven interventions once trained (Quintana et al., 2022).	Lack of professional training and technical familiarity may reduce program efficacy and patient trust (Afridi et al., 2022).
Data Management and Security	Digital systems enable efficient collection and analysis of patient data for evidence-based decision-making.	Privacy and data protection issues remain critical concerns; patients may be reluctant to share personal health data (Mann, 2025).

4. Wearable Sensors in the Assessment of Motor Function in Rehabilitation

4.1. Continuous and Objective Monitoring

One of the most significant advantages of wearable sensors is their ability to provide continuous monitoring, offering clinicians valuable insights into a patient's motor behavior beyond the confines of clinical environments. Continuous data acquisition enables a detailed understanding of how patients perform daily activities, move within their homes, and maintain postural control, thereby supporting more accurate assessments of functional independence (Gakhar et al., 2025; Woelfle et al., 2023). Wearable systems have proven particularly effective in conditions such as Parkinson's disease, where they can quantify spatio-temporal gait features and balance across both clinical and real-life settings (Sotirakis et al., 2023). These data-driven insights allow therapists to adapt rehabilitation programs dynamically, enhancing personalization and therapeutic precision.

4.2. Comprehensive Data Collection

Wearable technologies facilitate the collection of diverse kinematic parameters, including speed, range of motion, and activity level, offering a multifaceted perspective on motor performance. Evidence from systematic reviews indicates that inertial sensors are effective in capturing everyday motor activities, helping to refine individualized rehabilitation strategies according to patient-specific impairments and goals (Rast & Labruyère, 2020). Additionally, functional monitoring of locomotor and upper-limb

movements provides timely feedback that informs treatment adjustments and encourages active patient participation (Demers et al., 2023). This comprehensive data collection approach bridges the gap between subjective clinical observation and objective performance measurement.

4.3. Integration with Machine Learning and Data Analytics

The integration of wearable sensor data with machine learning algorithms has significantly expanded their clinical potential. Analytical models can detect subtle changes in movement patterns, correlate them with progress or decline, and predict outcomes more accurately, thereby improving decision-making in ongoing rehabilitation (S. Wei & Wu, 2023). Longitudinal analyses of sensor data have also proven valuable in tracking disease progression, as seen in studies involving amyotrophic lateral sclerosis (ALS), where objective motor metrics derived from wearable devices provide early indicators of functional decline (Johnson et al., 2023). These developments highlight the emerging role of predictive analytics in optimizing rehabilitation pathways and preventing complications.

4.4. User-Centric Design and Acceptance

The success of wearable technology in rehabilitation depends heavily on its usability and patient acceptance. Devices must be comfortable, discreet, and easy to operate, particularly for older adults or individuals with physical limitations (Miller et al., 2025). Positive patient perceptions regarding comfort and aesthetics enhance adherence, which is critical for consistent data collection and therapeutic benefit. Understanding user perspectives, therefore, remains a central consideration in the design and clinical adoption of wearable devices.

4.5. Limitations and Challenges

Despite their clinical promise, wearable sensors present several challenges. Data privacy and security concerns continue to pose ethical considerations, while variations in sensor placement and calibration can affect measurement accuracy (García et al., 2022; Rast & Labruyère, 2020). Interpreting sensor-derived data requires technical expertise, and inconsistent data processing methods across devices can limit interoperability. Moreover, some patients may struggle to adapt to digital technologies, which can reduce engagement and compromise adherence to rehabilitation programs.

5. Inertial Measurement Units (IMUs) in Physiotherapy and Motor Function Assessment

5.1. Reliability of IMUs

Inertial Measurement Units (IMUs) have been consistently shown to be reliable instruments for measuring kinematic parameters in clinical populations. High levels of reliability have been reported in studies assessing lower-limb kinematics during dynamic activities such as running, where IMUs accurately capture angular velocity and acceleration—parameters crucial for evaluating movement efficiency and recovery progress (Zeng et al., 2022). Comprehensive reviews also confirm that IMUs demonstrate consistent reliability across diverse rehabilitation contexts, including post-operative monitoring and gait retraining (Alarcón-Aldana et al., 2020). This consistency strengthens confidence in IMU-derived data, enabling clinicians to base therapeutic decisions on objective and reproducible metrics.

5.2. Validity of IMUs

The validity of IMUs is a key consideration for their clinical application. Studies correlating IMU-based measurements with established clinical assessment tools, such as the Fugl-Meyer Assessment and other standardized motor function tests, indicate strong agreement between the two (Chen et al., 2021). This alignment supports the use of IMUs as accurate indicators of upper-limb performance and motor recovery, particularly in stroke rehabilitation. In Parkinson's disease, IMUs have also demonstrated high validity in quantifying motor performance and detecting subtle changes in movement transitions, offering clinicians a reliable method for monitoring disease progression and intervention efficacy (Y. Kim et al., 2024).

5.3. Comparative Performance with Gold Standards

Comparative analyses between IMUs and high-precision optical systems, such as Vicon and OptiTrack, suggest that IMUs deliver comparable accuracy in capturing movement dynamics (Alarcón-Aldana et al., 2020). Although optical systems remain the gold standard for laboratory-based motion analysis, IMUs provide a more accessible and cost-efficient alternative, suitable for both clinical and real-world rehabilitation settings. Their portability and ease of deployment allow for broader clinical use without sacrificing analytical quality, facilitating objective motion analysis in environments where advanced motion capture infrastructure is unavailable.

5.4. Applications in Specific Rehabilitation Contexts

The versatility of IMUs has been demonstrated across multiple rehabilitation domains. Evidence supports their use in tracking motor progression in Parkinson's disease, where sensor data provide quantitative insights into gait, balance, and tremor characteristics that reflect disease stage and treatment response (Sotirakis et al., 2023). Similarly, research has shown strong correlations between IMU-derived kinematic parameters and clinical scales such as the Fugl-Meyer Assessment (FMA) and the Wolf Motor Function Test (WMFT), confirming their diagnostic value in assessing upper-limb function post-stroke (S. I. Lee et al., 2024). Collectively, these findings highlight the role of IMUs as a valid and responsive tool for continuous monitoring in both neurological and orthopedic rehabilitation.

5.5. Limitations and Challenges

Despite their promise, IMUs are subject to several technical and methodological limitations. Measurement accuracy can be affected by sensor placement, calibration errors, and variations in patient movement patterns. External factors such as environmental interference and signal drift may also impact data quality (Monje et al., 2021). Ensuring proper calibration, standardizing sensor placement protocols, and enhancing clinician training are essential steps to maintain data reliability and validity in practice. Continued refinement of algorithms for noise reduction and movement segmentation will further strengthen the clinical applicability of IMU-based assessments.

6. Wearable Technologies and Patient Engagement in Rehabilitation (Revised Version)

6.1. Real-Time Feedback and Monitoring

One of the key benefits of wearable devices is their capacity to deliver real-time feedback on physical activity, empowering patients to monitor progress continuously. Personalized alerts and reminders promote self-management of health conditions, improving motivation and accountability throughout rehabilitation (Alzghaibi, 2025). In addition, wearable technologies can unobtrusively capture functional movement data within real-life contexts, allowing patients to integrate therapeutic exercises into daily routines. This seamless incorporation of monitoring functions supports sustained participation and long-term engagement in rehabilitation activities (Demers et al., 2023).

6.2. Personalized Health Management

Wearable technologies enable highly individualized rehabilitation experiences through goal setting and adaptive feedback. Integrating smartphone applications with accelerometer sensors provides customized feedback that motivates patients after surgery and strengthens adherence to prescribed activities (Dijk-Huisman et al., 2020). Health metrics derived from wearables can be adjusted based on a patient's progress, enabling rehabilitation plans to evolve alongside individual recovery trajectories (Ranganathan et al., 2020). This adaptability makes rehabilitation more relevant and engaging, fostering deeper patient commitment to the process.

6.3. Improved Self-Efficacy and Autonomy

Wearable devices enhance patients' self-efficacy by granting them greater control over their health management. The ability to independently track and interpret health data promotes autonomy and empowers individuals to take an active role in recovery (Alzghaibi, 2025). Feedback that visualizes progress over time further reinforces motivation and confidence. Evidence suggests that self-monitoring supported by wearable feedback strengthens belief in one's ability to achieve rehabilitation goals, ultimately increasing exercise adherence and engagement (Ho et al., 2022).

6.4. Remote Monitoring and Support

Wearable technologies play an essential role in extending rehabilitation beyond traditional clinical environments through remote monitoring. Continuous data transmission allows clinicians to observe patient progress, make timely adjustments, and provide ongoing support without requiring frequent in-person visits (Babaei et al., 2022). Accurate, continuous monitoring of activity performance through wearable sensors contributes to better goal tracking and sustained motivation, ensuring that patients remain connected to their rehabilitation process even outside clinical supervision (Miller et al., 2025).

6.5. Challenges in Integration and Adoption

Despite their clear benefits, the adoption of wearable technologies in rehabilitation faces several challenges. The digital divide continues to limit equitable access, as individuals from disadvantaged socioeconomic backgrounds may lack the resources or connectivity required to benefit from such technologies (Ranganathan et al., 2020). Furthermore, disparities in digital literacy particularly among older adults or those unfamiliar with

technology can reduce engagement and confidence in using wearable devices (Demers et al., 2023). Addressing these barriers through inclusive design, education, and professional support is essential to ensure that wearable technologies achieve their full potential in enhancing rehabilitation participation.

7. The Evidence Supporting the Effectiveness of Tele-Rehabilitation

7.1. Improved Clinical Outcomes

Tele-rehabilitation has demonstrated strong clinical effectiveness across a wide range of conditions. Findings indicate that outcomes achieved through remote rehabilitation are comparable to those of conventional, in-person approaches (Baigi, Mousavi, et al., 2022; Zhao et al., 2023). For example, tele-physical therapy has shown efficacy in post-surgical recovery, allowing for interventions tailored to patients' home environments (Zhao et al., 2023). Further evidence supports tele-rehabilitation in oncology, where remote interventions have led to improved quality of life and functional outcomes for cancer patients (Longacre et al., 2020). Collectively, these studies underscore that tele-rehabilitation can provide equivalent—if not superior—results to traditional modalities while expanding accessibility.

7.2. Cost-Effectiveness

Economic evaluations highlight tele-rehabilitation as a financially viable approach to healthcare delivery. Lower operational costs, reduced transportation needs, and minimal facility use contribute to its affordability (Fatoye et al., 2020; Niewada et al., 2021). These factors make tele-rehabilitation a scalable and sustainable model, particularly in health systems seeking to balance cost and quality of care.

7.3. Enhanced Patient Engagement and Satisfaction

Tele-rehabilitation consistently yields high levels of patient satisfaction and engagement. Home-based rehabilitation programs have been associated with increased comfort, flexibility, and adherence to therapeutic routines (Islam et al., 2022; Nambi et al., 2023). Evidence suggests that patients value the convenience of integrating rehabilitation into their daily lives, often reporting satisfaction rates comparable to traditional care (Bell et al., 2020). This alignment between convenience and therapeutic benefit reinforces tele-rehabilitation's role as a patient-centered model of care.

7.4. Addressing Barriers to Access

Tele-rehabilitation reduces logistical and geographical barriers by enabling therapy delivery directly within patients' home settings (Zhao et al., 2023). This expanded reach benefits individuals with mobility limitations or those residing in underserved regions, promoting equity and continuity of care. The ability to extend clinical support beyond institutional boundaries also strengthens long-term engagement in rehabilitation programs.

7.5. Applicability Across Conditions

The flexibility of tele-rehabilitation allows it to be effectively adapted to a variety of medical and rehabilitation contexts, including chronic obstructive pulmonary disease (COPD), diabetes management, and orthopedic postoperative care (Baigi, Sarbaz, et al., 2022; Yuan et al., 2024). This adaptability supports individualized, condition-specific care pathways while maintaining clinical rigor across diverse populations.

7.6. Limitations and Future Considerations

Although the benefits of tele-rehabilitation are well established, several structural and clinical challenges remain. The absence of standardized treatment protocols for remote interventions can lead to inconsistencies in therapeutic delivery and outcome measurement (S. I. Lee et al., 2024). Moreover, ensuring data integration between digital platforms and existing clinical record systems continues to be a critical need for cohesive care coordination. From a therapeutic perspective, the reduced physical presence of clinicians may alter the traditional dynamics of patient–therapist interaction, requiring new communication and empathy-building strategies in virtual environments (Sidelil et al., 2021). Finally, while issues of digital literacy and infrastructure persist globally, future research should emphasize the development of adaptable tele-rehabilitation frameworks that address cultural, cognitive, and technological diversity rather than focusing solely on access limitations.

8. Clinical Decision Support Systems (CDSS) in Remote Rehabilitation

8.1. Personalized Care and Tailored Interventions

CDSS enable the delivery of highly individualized rehabilitation by analyzing patient data to generate intervention recommendations aligned with each patient's functional abilities, preferences, and recovery progress. Method-agnostic systems have demonstrated the capacity to support remote

muscular function assessment in stroke survivors, allowing clinicians to design rehabilitation programs that adapt to patient-specific trajectories and needs (Joe et al., 2023). Similarly, the Smart-system for remote rehabilitation support developed by Palagin et al. applies intelligent analytical methods and large-scale statistical processing to continuously personalize therapy (Палагин et al., 2022) . This transdisciplinary, data-driven approach ensures that interventions remain responsive to dynamic patient conditions, enhancing the precision and effectiveness of remote rehabilitation.

8.2. Data Management and Analysis

Efficient management and interpretation of health data are central to the role of CDSS in remote rehabilitation. By integrating modern information systems, CDSS can guide patients through home-based exercises while minimizing the need for direct supervision (Cao et al., 2024). These systems consolidate clinical information from multiple sources, enabling healthcare professionals to access comprehensive, real-time data for informed decision-making. Hybrid e-rehabilitation models further demonstrate how analytics derived from CDSS can track longitudinal progress and automatically adjust therapeutic intensity based on performance metrics, ensuring that care remains both individualized and evidence-based (Catalán et al., 2021).

8.3. Timely Feedback and Monitoring

Timely feedback mechanisms embedded within CDSS strengthen communication between patients and therapists while promoting adherence to rehabilitation protocols. Automated feedback systems deliver personalized insights and reminders, helping patients maintain consistency in home-based exercises. Real-time monitoring enhances clinician responsiveness, allowing for immediate intervention when performance deviations or difficulties are detected (Xin et al., 2024). Advanced tele-rehabilitation platforms that employ CDSS have also demonstrated success in delivering instant performance indicators and motivational feedback, maintaining patient engagement and accountability throughout therapy (Mora-Traverso et al., 2022).

8.4. Accessibility and Increased Reach

CDSS contribute significantly to expanding the reach of rehabilitation services, particularly in rural or underserved regions. By integrating into tele-rehabilitation infrastructures, these systems provide continuity of care for patients who face barriers to accessing in-person therapy (Ortiz-Piña et al., 2021). This enhanced accessibility supports equitable service delivery and fosters consistent patient compliance in remote rehabilitation settings.

8.5. Evidence-Based Guidelines and Protocols

CDSS integrate evidence-based guidelines directly into clinical workflows, supporting standardized rehabilitation practices across diverse settings. The implementation of structured, protocol-driven tele-rehabilitation models ensures consistency and safety in patient management while enhancing clinician confidence in decision-making (Remsik et al., 2022). This systematization not only improves the quality of care but also promotes adherence to clinical best practices, ultimately strengthening the overall reliability and scalability of remote rehabilitation programs.

9. User Experience Challenges in Tele-Rehabilitation Platforms

9.1. Technological Barriers

Technological limitations remain one of the most significant obstacles to effective tele-rehabilitation. Insufficient digital infrastructure and unstable internet connections are frequently cited as barriers, particularly in regions with limited technological development (Padmavathi et al., 2023). Interruptions in connectivity or inadequate hardware can disrupt rehabilitation sessions, leading to frustration, decreased motivation, and eventual disengagement. Even when technical resources are available, the usability of tele-rehabilitation platforms may present difficulties. Although many patients express overall satisfaction with digital rehabilitation systems, the introduction of unfamiliar devices or complex interfaces can complicate the experience, especially for users with limited technical competence (Cerfoglio et al., 2024). These challenges underscore the importance of user-friendly design and ongoing technical support in ensuring accessibility.

9.2. User Familiarity and Training

Digital literacy is a critical determinant of user engagement in tele-rehabilitation. Many patients—particularly older adults—struggle to navigate online platforms without prior experience or structured guidance. Reports indicate that patients often require specific training to effectively use smartphones or tablets during rehabilitation (Padmavathi et al., 2023). The absence of targeted education programs can result in poor interaction with digital tools, ultimately limiting therapeutic impact. This challenge is particularly evident in dementia care, where maintaining consistent remote contact with healthcare professionals is crucial, yet limited digital proficiency continues to hinder participation and motivation (Lorito et al., 2020). Enhancing digital literacy among patients and caregivers is therefore essential for improving both engagement and rehabilitation outcomes.

9.3. Psychological Factors and Acceptance

Psychological readiness plays an equally important role in shaping patients' engagement with tele-rehabilitation. Factors such as anxiety, limited motivation, or cognitive overload can negatively affect users' willingness to participate. Patients who are not mentally prepared for digital interaction may find the transition from in-person to virtual therapy challenging, impacting overall adherence (Vitali et al., 2025). Therapists thus face the dual responsibility of not only delivering interventions but also nurturing a supportive virtual environment that fosters motivation and emotional stability. Evidence suggests that hybrid models combining online sessions with occasional in-person consultations can enhance confidence and trust in the rehabilitation process while reducing feelings of isolation (Khatib & Hlayisi, 2022).

9.4. Systemic Issues and Provider Preparedness

Systemic challenges also shape user experience by influencing the capacity of healthcare providers to deliver quality remote care. Many clinicians report inadequate training and unfamiliarity with digital platforms, particularly during the rapid shift to online modalities during the COVID-19 pandemic (Gefen et al., 2021). This lack of preparedness can compromise treatment continuity and diminish patient confidence in digital rehabilitation.

In addition, policy-level barriers such as unclear reimbursement structures and limited institutional support discourage widespread adoption of tele-rehabilitation (Dham et al., 2020). The absence of standardized compensation frameworks and regulatory guidance creates uncertainty for practitioners, reducing motivation to integrate digital services into regular clinical practice. Addressing these systemic gaps through structured training, institutional policy development, and regulatory clarity is therefore crucial for optimizing both provider and patient experiences in tele-rehabilitation.

10. Virtual Reality (VR) and Augmented Reality (AR) Interventions in Neurorehabilitation

10.1. Enhanced Patient Engagement and Motivation

VR and AR interventions substantially increase patient motivation and adherence by offering immersive, interactive experiences that transform traditional rehabilitation into an engaging process. Immersion alters patients' perception of their motor abilities, which plays a crucial role in facilitating neuroplastic adaptation and motor re-learning (Toledo-Peral et al., 2022).

In musculoskeletal rehabilitation, the use of immersive technologies has been linked to improved adherence and long-term participation, suggesting that VR and AR experiences foster sustained involvement and commitment to therapeutic goals (Plavoukou et al., 2025). By making therapy sessions more enjoyable and rewarding, these technologies promote consistency in rehabilitation routines.

10.2. Facilitation of Neuroplasticity

A key advantage of VR and AR lies in their capacity to support neuroplasticity the brain's ability to reorganize neural pathways following injury. Through multisensory feedback and interactive simulation, these systems reinforce neural learning processes essential for functional recovery. Research has shown that VR-based rehabilitation enhances motor performance and can even reduce rehospitalization rates compared with conventional approaches (Gazendam et al., 2022). Similarly, the use of interactive, adaptive environments stimulates both cognitive and physical domains, supporting faster and more comprehensive recovery outcomes (Yang et al., 2022).

10.3. Improvement in Cognitive and Motor Recovery

Growing evidence indicates that VR and AR interventions improve both cognitive and motor functions across various neurological conditions. Integrating complex kinesiological programs within immersive technologies enhances neural connectivity and promotes post-stroke motor recovery (Dvurechenskaya et al., 2024). Systematic reviews have further demonstrated that VR significantly improves upper-limb function and overall daily performance in patients with neurological impairments (Liscano, 2025). The ability to simulate real-life challenges in controlled virtual settings allows patients to safely practice meaningful tasks, accelerating both cognitive rehabilitation and functional independence.

10.4. Personalized and Adaptive Therapies

The adaptability of VR and AR systems enables the design of personalized rehabilitation experiences tailored to individual patient needs and performance levels. Adjustable difficulty levels, real-time feedback, and data-driven insights ensure that therapy remains engaging and appropriately challenging throughout recovery. Although developed in other contexts, adaptive VR frameworks have demonstrated potential for enhancing personalized rehabilitation experiences within occupational and physical therapy (Cha et al., 2024). Likewise, AR platforms can dynamically modify

task parameters based on user responses and therapist input, providing a collaborative and patient-centered model of care (Q. Wei et al., 2024).

10.5. Addressing Practical Barriers to Rehabilitation

VR and AR technologies have also proven invaluable in overcoming logistical and environmental barriers to care. Their integration into telehealth frameworks during the COVID-19 pandemic enabled continuity of rehabilitation while minimizing physical contact and travel requirements (Yang et al., 2022). This flexibility underscores their long-term potential to expand access to therapy for individuals in remote or underserved areas, ensuring inclusivity in neurorehabilitation practices.

Table 2. Motivational Mechanisms of Immersive Rehabilitation Technologies

Mechanism	Description	Motivational Impact
Enhanced Engagement and Interaction (Jo et al., 2024)	Immersive environments create multisensory and interactive experiences that increase attention and participation in therapy activities.	Promotes active involvement, sustained interest, and sense of ownership in the rehabilitation process.
Tailored and Adaptive Experiences (Maggio et al., 2024)	VR/AR systems can be customized to match patients' functional abilities, preferences, and progress.	Ensures relevance and challenge balance, maintaining long-term motivation and engagement.
Gamification and Reward Systems (Wiskerke et al., 2024)	Incorporation of game elements such as levels, scores, and positive feedback into rehabilitation programs.	Enhances intrinsic motivation, persistence, and enjoyment of therapy sessions.
Real-Time Feedback and Progress Monitoring (Hao et al., 2022)	Immediate performance indicators and feedback loops inform patients of progress and reinforce effort.	Builds self-efficacy, strengthens engagement, and promotes accountability.
Reduction of Therapy Barriers (Padmavathi et al., 2023)	Remote accessibility and flexible use of immersive systems reduce physical, geographical, and logistical limitations.	Increases autonomy and participation by making rehabilitation more accessible and convenient.
Improved Psychological and Emotional Well-being (Micheluzzi et al., 2024)	Immersive experiences support emotional health by reducing anxiety and promoting positive affect during therapy.	Improves mood, confidence, and motivation to continue rehabilitation.

10.6. The Use of Virtual Reality (VR) to Simulate Daily Living Tasks in Occupational Therapy

10.6.1. Creating Realistic Scenarios

VR technologies allow the creation of highly realistic and immersive environments where patients can safely practice complex daily living tasks such as cooking, grocery shopping, personal care, and mobility challenges. These environments simulate real-world situations while minimizing risk, thereby encouraging patients to engage more confidently in task-oriented activities (Oliveira et al., 2021). By replicating the sensory and contextual elements of everyday experiences, VR enables skill generalization from therapy settings to daily life, enhancing the ecological validity of rehabilitation interventions.

10.6.2. Enhancing Motor and Cognitive Skills

Task-specific training within VR environments has been shown to improve both motor and cognitive functions. Repetitive, goal-directed activities strengthen neural pathways associated with movement and coordination, supporting neuroplastic recovery. A systematic review of post-stroke rehabilitation demonstrated that VR interventions can improve functional outcomes by enabling repetitive, task-specific practice of daily living activities (Landim et al., 2024). Furthermore, VR-based therapy promotes cognitive engagement by requiring sustained attention, problem-solving, and planning during task execution. Evidence shows that stroke survivors participating in VR programs exhibited improvements not only in motor abilities but also in executive functions such as attention and sequencing (L. Lee et al., 2023). This dual impact supports a holistic approach to rehabilitation.

10.6.3. Personalization and Adaptability

A distinctive strength of VR in occupational therapy lies in its capacity for personalization. Therapists can modify the complexity, duration, or goals of virtual tasks according to each patient's abilities and progress. Adjustable parameters, such as task difficulty and environmental stimuli, allow for individualized intervention planning and incremental skill development (Lagos et al., 2022). This adaptability ensures that rehabilitation remains both achievable and stimulating, fostering sustained engagement and optimizing therapeutic outcomes.

10.6.4. Gamified Approaches to Therapy

Gamification has become a powerful motivational component in VR-based rehabilitation. By incorporating elements such as scoring systems, rewards, and progression levels, VR transforms repetitive exercises into enjoyable and purposeful experiences. Gamified environments promote sustained engagement, reducing the monotony often associated with traditional therapy (Rojo et al., 2022). Through structured challenges and immediate feedback, patients are encouraged to set and achieve personal goals, which reinforces both intrinsic motivation and functional performance.

10.6.5. Comprehensive Feedback Mechanisms

Instant feedback is a defining feature of VR systems that supports self-correction and learning. Real-time visual, auditory, or haptic feedback allows patients to recognize successful actions and identify errors during task performance. Such feedback loops strengthen motor learning and accelerate functional recovery (Baker et al., 2025). Moreover, detailed performance analytics such as movement accuracy, speed, and task completion rates can guide therapists in refining interventions, ensuring that therapy remains data-informed and outcome-oriented.

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