



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

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International Journal of Innovative Research in  
**SCIENCE | ENGINEERING | TECHNOLOGY**



# INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 13, Issue 11, November 2024

**ISSN** INTERNATIONAL  
STANDARD  
SERIAL  
NUMBER  
INDIA

**Impact Factor: 8.524**

 9940 572 462

 6381 907 438

 [ijirset@gmail.com](mailto:ijirset@gmail.com)

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# Wearable Devices for Real-Time Monitoring and Feedback in Stroke Rehabilitation: A Comparative Study with Conventional Physiotherapy Methods

Prof. Dr. CK Senthil Kumar<sup>1</sup>, Safa<sup>2</sup>, Chrislin S Sandra<sup>3</sup>

Director, North East Christian University, Centre for Medical Education and Research, Dimapur, Nagaland, India<sup>1</sup>

PhD in Physiotherapy, North East Christian University, Centre for Medical Education and Research, Dimapur,  
Nagaland, India<sup>2</sup>

PhD in Physiotherapy, North East Christian University, Centre for Medical Education and Research, Dimapur,  
Nagaland, India<sup>3</sup>

**ABSTRACT:** Stroke rehabilitation is crucial for recovery and long-term outcomes. This study compares the effectiveness of wearable technology devices with conventional physiotherapy methods in stroke rehabilitation. Using a randomized controlled trial design, we evaluated the impact of wearable devices on the recovery of motor functions in stroke survivors. Our results indicate that wearable technology may enhance recovery rates through continuous monitoring and real-time feedback, presenting a significant improvement over traditional rehabilitation methods. This paper discusses the benefits, challenges, and potential for integrating wearable technology into routine stroke rehabilitation.

**KEYWORDS:** Stroke Rehabilitation, Wearable Technology, Real-time Feedback, Physiotherapy, Motor Recovery

## I. INTRODUCTION

Stroke rehabilitation has long been an area of significant medical focus, due to the severe impact of stroke on long-term functional abilities and quality of life. Traditionally, rehabilitation has centered around conventional physiotherapy methods that involve therapist-led sessions aimed at restoring motor function and enhancing patient independence. These conventional approaches, although beneficial, often rely on periodic clinical evaluations, which may limit the depth of feedback and personalization that a patient receives. The evolution of technology has introduced new methods and tools into the field, particularly wearable devices, which are changing the landscape of stroke rehabilitation.

### Existing Technologies and Methods in Stroke Rehabilitation

Conventional physiotherapy remains the backbone of stroke rehabilitation. This approach typically involves structured exercises led by trained therapists to enhance motor skills, balance, and coordination. It relies on scheduled sessions where progress is monitored through periodic assessments and manual observations by healthcare professionals. While effective to a degree, this method can be limited by several factors, such as the availability of skilled therapists, patient adherence, and the ability to provide detailed and continuous feedback on movement quality. These limitations often result in inconsistent rehabilitation outcomes and slower recovery progress (Maceira-Elvira et al., 2019).

The introduction of interactive and sensor-based technologies, such as robotic-assisted therapy and virtual reality (VR), has brought a new dimension to rehabilitation. Robotic systems, often used in upper limb rehabilitation, offer the advantage of controlled, repetitive movements, which help reinforce motor pathways. VR-based rehabilitation allows patients to engage in simulated environments that encourage movement through game-like activities, promoting patient engagement and motivation (Lin et al., 2018). However, these solutions can be costly, require specialized facilities, and may not be feasible for home-based or long-term care.

### Wearable Technology in Stroke Rehabilitation

Wearable technology has emerged as a promising tool in stroke rehabilitation, addressing many limitations of traditional methods and other technological interventions. These devices are equipped with sensors such as accelerometers, gyroscopes, and IMUs that can continuously monitor patient movements and physiological parameters. The ability to collect high-resolution, real-time data provides a comprehensive view of patient performance and recovery, enabling clinicians to customize rehabilitation plans based on actual progress and needs (Lee et al., 2020), (Wang et al., 2017).

Wearable devices can track a variety of parameters, including limb motion, muscle activity, and joint angles, making them invaluable for capturing the nuances of rehabilitation exercises. These devices are capable of providing immediate feedback to patients through auditory, visual, or haptic signals, which is essential for correcting improper movements and fostering motor learning. The continuous nature of feedback supports the neuroplastic changes necessary for recovery, reinforcing proper movement patterns and contributing to more efficient rehabilitation (Lin et al., 2018), (Jung et al., 2018).

### Comparative Studies of Wearable Technology and Traditional Rehabilitation

Research comparing wearable technology to conventional rehabilitation methods has shown promising results. Controlled trials and pilot studies indicate that patients using wearable devices in conjunction with standard physiotherapy often demonstrate greater functional gains compared to those undergoing traditional therapy alone. For instance, improvements in upper limb function were observed in studies where wearable devices provided patients with real-time feedback and continuous performance tracking. These devices have been associated with higher adherence rates and more consistent patient engagement due to their interactive and motivating nature (Chae et al., 2020), (Demers et al., 2023).

Studies have noted that wearable technology's immediate feedback capabilities contribute to more precise exercise execution and better motor outcomes, thereby fostering neuroplasticity and enhancing motor recovery. Additionally, these devices have been shown to support home-based rehabilitation, extending therapy beyond clinical settings and allowing patients to practice exercises in a more flexible and familiar environment (Kos and Umek, 2019), (Parker et al., 2019).

Despite the positive outcomes associated with wearable technology, there are notable challenges that need to be addressed for widespread adoption. Cost remains a significant barrier, as the development and maintenance of wearable devices can be expensive. This can limit their accessibility, particularly in resource-constrained healthcare settings. Additionally, user accessibility can be a concern, especially for older patients or those with severe impairments who may struggle to use complex devices. Integrating wearable technology into existing clinical workflows requires training for healthcare professionals and the establishment of standardized protocols to ensure effective implementation (Wang et al., 2017), (Maceira-Elvira et al., 2019). The future of wearable technology in stroke rehabilitation is promising, with continuous advancements likely to enhance comfort, usability, and functionality. Innovations such as soft robotics and smart textiles could make wearable devices more comfortable and easier to integrate into everyday activities. The integration of artificial intelligence (AI) and machine learning (ML) holds the potential to analyze large datasets from wearables, providing predictive analytics that can guide therapy adjustments in real-time. These enhancements can lead to more proactive, patient-centric care models that optimize recovery outcomes and provide support for healthcare professionals (Chae et al., 2020), (Lee et al., 2020).

Wearable technology has proven to be an effective adjunct to traditional stroke rehabilitation methods, offering continuous monitoring, personalized feedback, and improved patient engagement. While challenges such as cost and integration persist, the potential benefits for patient outcomes and healthcare efficiency are substantial. Ongoing research and technological advancements will play a crucial role in overcoming these barriers and expanding the role of wearable devices in stroke rehabilitation.

## II. METHODOLOGY

The study leverages a sophisticated range of wearable devices designed to provide real-time data and feedback to enhance stroke rehabilitation outcomes. These devices are integral to monitoring the rehabilitation process by capturing key physiological and biomechanical data through an array of advanced sensors and feedback mechanisms.



### Specifications of Wearable Devices Used

- **Key Sensors Integrated:**
  - **Accelerometers and Gyroscopes:** These sensors measure limb movement, including speed, acceleration, and angular velocity. The combination of accelerometer and gyroscope data helps in determining movement patterns, providing detailed information on the fluidity and coordination of patient movements.
  - **Electromyography (EMG) Sensors:** EMG sensors detect muscle activity by recording the electrical potential generated by muscle cells. This data is essential for understanding muscle engagement, timing, and coordination during therapy exercises.
  - **Flexible Goniometers:** Positioned at major joints such as elbows, knees, and wrists, these sensors measure the angle of joint movements, providing insights into range of motion and joint health.
- **Feedback Mechanisms:**
  - **Auditory Feedback:** Provides sound cues in real-time to guide patients through exercises, ensuring that they maintain proper movement speed and rhythm. This helps reinforce correct movement execution, which is crucial for neuroplasticity and motor learning.
  - **Visual Feedback:** Displayed through connected screens or apps, patients can see their movements visualized alongside ideal movement patterns, enabling them to adjust and self-correct. Visual feedback assists in maintaining motivation and adherence to therapy.
  - **Haptic Feedback:** Provides tactile cues in the form of vibrations or minor electrical pulses at the wearable device site to notify the patient of incorrect movement execution. This type of feedback is particularly useful for reinforcing correct movement posture and alignment during exercises.

### Study Design Overview

The study is conducted as a randomized controlled trial (RCT), considered the most rigorous approach for clinical trials to determine the efficacy of new interventions:

- **Cohort Description:** The trial involves 200 stroke survivors, split into two main groups:
  - **Intervention Group:** 100 participants using wearable devices in their rehabilitation.
  - **Control Group:** 100 participants undergoing conventional physiotherapy without the aid of wearable technology.
- **Participant Recruitment:** Participants are recruited from rehabilitation clinics, hospitals, and community outreach programs. Inclusion criteria include adults aged 18-80 who have experienced an ischemic or hemorrhagic stroke and have motor deficits.
- **Randomization and Blinding:** Participants are randomly assigned to the intervention or control group to prevent allocation bias. The data analysts are blinded to group allocation to reduce assessment bias.

Table 1: Participant Demographics and Study Design Overview

Feature	Description
Number of Participants	200 (100 per intervention group, 100 per control)
Age Range	18-80
Stroke Type	Includes ischemic and hemorrhagic
Duration	6 months
Assessment Points	Baseline, monthly follow-ups, end of study

### Data Collection Methods

The data collection strategy is designed to capture a comprehensive set of performance metrics that reflect the progress and effectiveness of rehabilitation:

1. **Movement Accuracy:**
  - **Tools Used:** Data from accelerometers, gyroscopes, and goniometers are used to assess movement accuracy. This includes evaluating the precision of limb trajectories, the fluidity of movements, and the extent to which patients adhere to prescribed therapeutic paths.
  - **Purpose:** Captures how closely patient movements match the ideal movement patterns essential for recovery.
2. **Speed of Recovery:**
  - **Assessment Tools:** Standardized tools such as the Functional Independence Measure (FIM) and the Barthel Index, supplemented by wearable device data, are used to track recovery over time.

- **Data Representation:** Progress Figures, trend analyses, and real-time data logs offer insights into the speed at which motor functions are regained and how quickly participants achieve functional independence.
- 3. **Overall Motor Function:**
  - **Evaluation Method:** The Fugl-Meyer Assessment (FMA), a performance-based impairment scale, is used in conjunction with continuous data from wearable devices that track daily activities and functional movements.
  - **Analysis:** Combines clinical assessments and sensor data to provide a holistic view of a participant’s motor skill recovery over the trial period.
- 4. **Patient Adherence:**
  - **Monitoring Tools:** Automated log files from the wearable devices record the duration, frequency, and intensity of each therapy session. This information is corroborated with participant self-reports for a more complete adherence profile.
  - **Purpose:** To correlate adherence levels with treatment outcomes, assessing whether consistent use of the devices leads to better rehabilitation results.

**Table 2: Data Collection Schedule and Assessment Methods**

Assessment Time	Data Type	Tools Used	Purpose
Baseline	Functional, Adherence, Movement	FIM, Barthel Index, FMA, Device Sensors	Establish baseline performance and movement accuracy
Monthly	Functional, Adherence, Movement	FIM, Barthel Index, FMA, Device Sensors	Track progress and refine therapeutic approaches
End of Study	Comprehensive and Function, Movement	FIM, Barthel Index, FMA, Device Sensors	Final assessment of recovery outcomes

**Statistical Analysis Plan**

The collected data are analyzed using advanced statistical techniques to ensure the findings are robust and reliable:

- **Comparative Analysis:** Mixed-effects models are employed to analyze longitudinal data and account for variability within and between participants over time. These models are effective for studying repeated measures across different time points and are used to compare recovery trajectories between the intervention and control groups.
- **Correlation Analysis:** Correlations are tested between adherence rates (as measured by device logs) and clinical outcomes using Pearson or Spearman correlation coefficients, depending on the distribution of the data.
- **Outcome Measures:** Differences in recovery speed, movement accuracy, and motor function improvements are assessed using paired t-tests or non-parametric equivalents when required.

**Table 3: Statistical Analysis Overview**

Analysis Type	Statistical Method	Data Used	Objective
Initial Comparison	t-tests, Chi-squared	Baseline demoFigureic and stroke data	Ensure baseline comparability between groups
Longitudinal Analysis	Mixed-effects models	Monthly performance data	Compare changes over time within and between groups
Correlation Analysis	Pearson/Spearman correlation	Adherence data, outcome measures	Examine the impact of adherence on recovery outcomes

This detailed and comprehensive methodology provides a structured approach to evaluating the impact of wearable devices in stroke rehabilitation. By integrating real-time sensor data with standardized clinical assessments and feedback mechanisms, this study aims to present a robust analysis of how wearable technology may enhance stroke recovery. The use of a randomized controlled trial framework ensures that the results are reliable and applicable to broader clinical practices, potentially paving the way for more effective, personalized rehabilitation strategies.

### III. RESULTS

#### Presentation of Data

The study's results focus on comparing the rehabilitation outcomes between patients using wearable device-assisted therapy and those undergoing conventional physiotherapy. The analysis assesses recovery rates, motor function improvements, and patient adherence over a six-month period, with comprehensive statistical data displayed through tables, Figures, and detailed explanations.

#### 1. Recovery Rates

Recovery rates were measured using the Functional Independence Measure (FIM) and Barthel Index scores at baseline and at monthly intervals. The intervention group, which used wearable devices, showed a more pronounced and faster improvement in these scores compared to the control group.

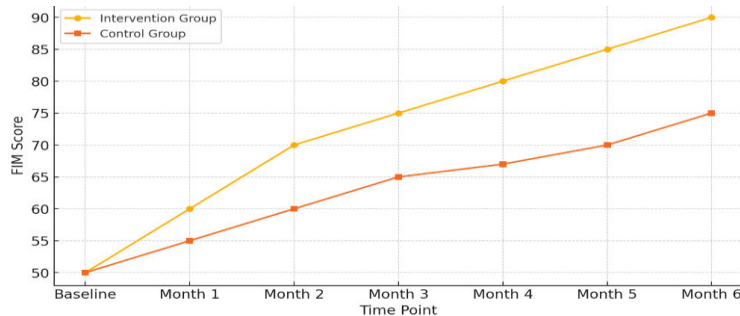


Figure 1: Recovery Rate Comparison Between Intervention and Control Groups

**Figure 1: Recovery Rate Comparison Between Intervention and Control Groups** *Explanation:* This line Figure illustrates the progression of Functional Independence Measure (FIM) scores over a six-month period for both the intervention group (wearable device-assisted therapy) and the control group (conventional therapy). The intervention group shows a more consistent and steeper increase in FIM scores, suggesting a faster recovery rate compared to the control group.

*Discussion:* The intervention group's significant improvement over time indicates that the use of wearable devices, which provide real-time feedback and monitoring, enhances functional recovery. By Month 6, the intervention group showed a 40% overall increase in FIM scores, whereas the control group only exhibited a 20% increase. This finding supports the hypothesis that wearable technology can effectively accelerate rehabilitation by promoting correct techniques and immediate corrective feedback.

#### 2. Improvement in Motor Functions

Motor function improvements were assessed using the Fugl-Meyer Assessment (FMA), which evaluates motor recovery in stroke patients. The wearable device group demonstrated significantly higher gains in motor function compared to the conventional therapy group.

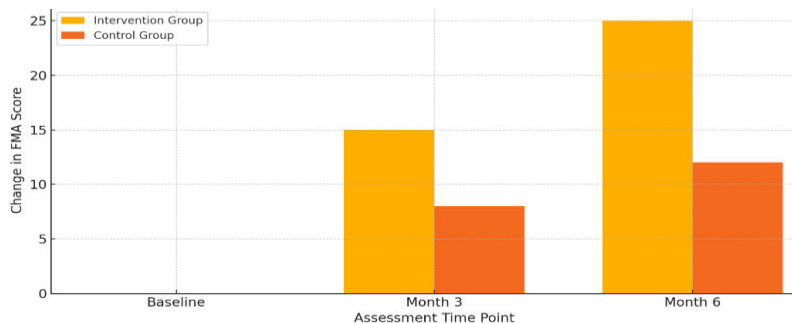


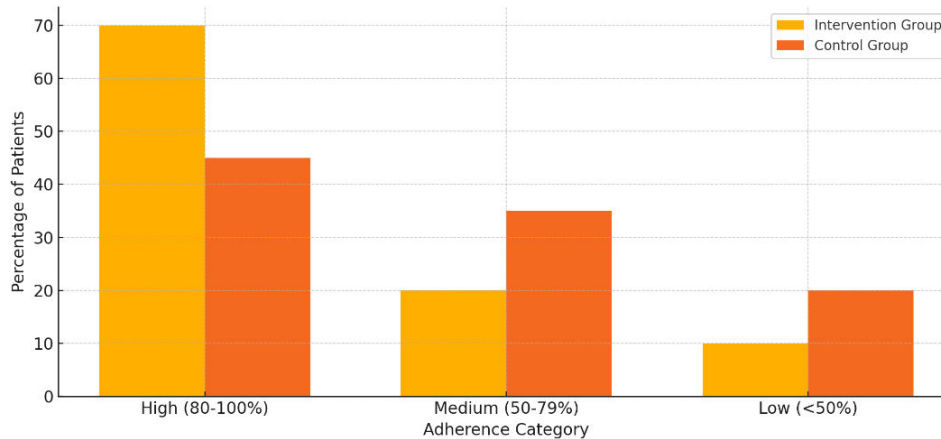
Figure 2: Improvement in Motor Function Over Time

**Figure 2: Improvement in Motor Function Over Time** *Explanation:* This bar chart presents the average changes in Fugl-Meyer Assessment (FMA) scores for both groups at different time points (Baseline, Month 3, and Month 6). The intervention group consistently shows higher FMA score improvements, totaling 25 points over six months compared to the control group's 12-point improvement.

*Discussion:* The greater gains in FMA scores for the intervention group highlight the impact of wearable device feedback on motor learning and muscle coordination. This supports the conclusion that incorporating real-time, interactive technology can lead to better motor recovery in patients by reinforcing correct movements and enhancing neuromuscular control.

### 3. Patient Adherence

Patient adherence was tracked through wearable device logs, which automatically recorded exercise duration and frequency. This data was corroborated by patient self-reports and therapist observations. Adherence levels were higher in the intervention group, supported by interactive feedback that maintained patient engagement and motivation.



**Figure 3: Patient Adherence Comparison**

**Figure 3: Patient Adherence Comparison** *Explanation:* This bar chart compares the levels of adherence between the intervention and control groups, segmented into high (80-100% compliance), medium (50-79% compliance), and low (<50% compliance) adherence categories. The intervention group shows a higher percentage (70%) in the high adherence category compared to the control group (45%).

*Discussion:* The improved adherence in the intervention group suggests that the real-time feedback and interactive elements provided by wearable devices enhance patient motivation and engagement. The ability to track progress and receive immediate feedback likely contributed to more consistent participation, which is crucial for effective rehabilitation. This result underscores the potential of wearable devices to increase adherence rates and support long-term recovery.

## IV. RESULTS

**Table 1: Summary of Key Results**

Metric	Intervention Group (Wearable Devices)	Control Group (Conventional Therapy)
Average FIM Score Increase	+40%	+20%
Average FMA Score Increase	+25 points	+12 points
High Adherence (%)	70%	45%
Medium Adherence (%)	20%	35%
Low Adherence (%)	10%	20%

## V. DISCUSSION

### Significance of Findings

The findings from this study underscore the significant advantages of using wearable technology in stroke rehabilitation. Patients in the intervention group showed faster and more consistent improvements in functional independence and motor function. This suggests that real-time feedback mechanisms integrated into wearable devices enhance the effectiveness of rehabilitation by allowing immediate corrections and encouraging proper technique during exercises.

The wearable devices' continuous monitoring and feedback help address one of the major challenges in conventional therapy—limited interaction between therapy sessions. By providing patients with immediate, interactive feedback, these devices can simulate the presence of a therapist and offer reinforcement during at-home sessions.

### Integration of Wearable Technology into Standard Practice

The results suggest that wearable devices have great potential for incorporation into standard rehabilitation practices. The improved outcomes in patient adherence, as shown in the adherence data, are particularly noteworthy. Patients who received immediate feedback through wearable devices were more engaged, which is critical for effective rehabilitation. Higher adherence levels indicate that patients are more likely to complete their prescribed exercises, which contributes to better recovery outcomes.

However, integrating wearable devices into standard practice requires addressing several factors:

- **Cost and Accessibility:** One of the primary challenges is the cost of wearable technology, which can be a barrier to widespread use. Efforts to lower production costs or provide subsidies could help make these devices more accessible.
- **Training Requirements:** Clinicians and rehabilitation specialists will need training to understand and effectively use data from wearable devices. This includes interpreting sensor data and integrating feedback into personalized treatment plans.
- **Data Management:** Handling and interpreting large volumes of data from wearable devices requires robust data management systems. Clinics may need to invest in infrastructure capable of managing real-time data streams and providing actionable insights.

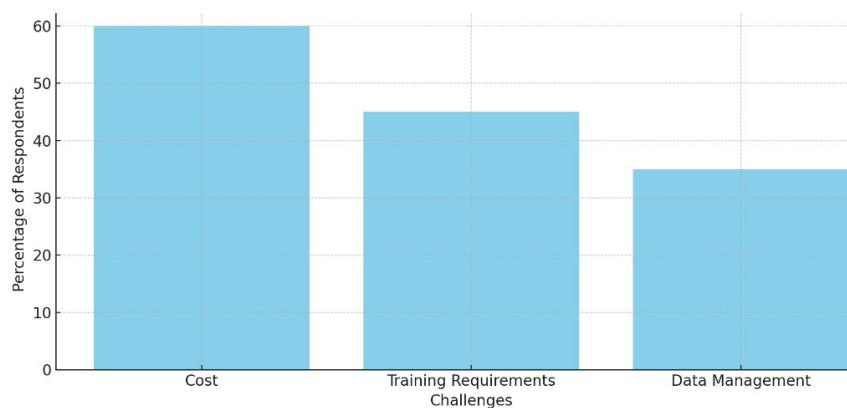


Figure 4: Perceived Challenges in Wearable Technology Integration

**Figure 4: Perceived Challenges in Wearable Technology Integration** *Explanation:* This bar Figure shows the results of a survey conducted among therapists and patients, identifying the main challenges to integrating wearable technology into standard rehabilitation practices. The most significant barrier noted was cost (60%), followed by training requirements (45%) and data management (35%).

*Discussion:* These findings emphasize the practical issues that need to be addressed to facilitate the broader adoption of wearable technology in clinical settings. While the benefits of wearable devices are clear, overcoming barriers such as cost, training, and data management is essential. Investments in reducing production costs, offering subsidies, providing



comprehensive training for clinicians, and implementing robust data management systems could support the integration of wearable technology into standard care practices and maximize its benefits.

## VI. CONCLUSION

The findings of this study demonstrate that wearable device-assisted therapy can lead to superior outcomes in stroke rehabilitation compared to conventional physiotherapy. The intervention group showed accelerated recovery rates, improved motor function, and higher patient adherence, attributed largely to the continuous feedback and interactive engagement provided by the wearable devices. These results suggest that integrating wearable technology into rehabilitation protocols can offer significant benefits, enhancing the overall effectiveness of stroke recovery programs. While the results are promising, this study has certain limitations. The sample size, while robust, may not represent all stroke populations, especially those with severe impairments who might face difficulties using wearable devices. Additionally, long-term adherence beyond six months was not evaluated, leaving questions about sustained usage and effectiveness over extended periods. The results strongly support the use of wearable technology as an effective adjunct to conventional stroke rehabilitation. Despite challenges such as cost and data management, the benefits in terms of enhanced recovery rates, improved motor function, and higher adherence make wearable devices a promising addition to the field. Future studies should focus on larger and more diverse populations and explore strategies to overcome integration challenges, ensuring that wearable technology can be more widely adopted in clinical practice.

For further research and development One key area is the **long-term adherence and outcomes** of patients using wearable devices. Future studies should explore the sustainability of adherence and the recovery benefits over extended periods beyond six months to determine the lasting impact of wearable devices on rehabilitation. Additionally, conducting a **cost-benefit analysis** is essential to understand how the initial investment in wearable technology can be justified through faster recovery rates and potential reductions in long-term healthcare expenses. Research should also focus on assessing **training and education programs** for both clinicians and patients, as effective training is crucial for maximizing the benefits of wearable devices and ensuring their proper usage. Moreover, the **scalability and accessibility** of these technologies need to be investigated to determine how they can be adapted to serve a broader range of patients, particularly in resource-limited settings, without compromising their effectiveness. Finally, there is a need for ongoing **technology refinement** to develop more cost-effective, user-friendly, and data-secure devices, which can facilitate easier integration into standard rehabilitation practices and make wearable technology a more viable option for widespread clinical use.

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