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Original Article

The Integration of Artificial Intelligence and Wearable Technology in Personalized Physical Therapy Programs for Enhanced Recovery Outcomes

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Abstract *- The integration of artificial intelligence (AI) and wearable technology in personalized physical therapy programs is revolutionizing recovery outcomes for patients. This innovative approach utilizes AI algorithms to analyze extensive patient data, including medical history and real-time feedback, enabling the creation of tailored rehabilitation plans that enhance efficiency and effectiveness. Wearable devices equipped with AI capabilities monitor patient movements and provide instant feedback, allowing for real-time adjustments during therapy sessions. This continuous monitoring not only aids in correcting posture and movement but also helps identify potential pain patterns that can predict future complications. Furthermore, AI-driven predictive analytics facilitate early intervention strategies, significantly improving recovery trajectories. The synergy between AI and human therapists is paramount; while technology enhances precision in treatment, the empathetic human touch remains essential in fostering patient motivation and compliance. As these technologies evolve, they promise to deliver more accessible, efficient, and personalized care, ultimately leading to superior recovery outcomes for individuals undergoing physical rehabilitation.*

Keywords *- Artificial Intelligence, Wearable Technology, Personalized Physical Therapy, Recovery Outcomes, Patient Monitoring, Telehealth*.

1. Introduction

The landscape of physical therapy is undergoing a significant transformation, driven by advancements in artificial intelligence (AI) and wearable technology. These innovations are paving the way for more personalized and effective rehabilitation programs, ultimately enhancing recovery outcomes for patients. As healthcare increasingly embraces technology, the integration of AI and wearables presents an opportunity to revolutionize traditional therapeutic practices.

1.1. The Role of Artificial Intelligence in Physical Therapy

AI technologies are capable of processing vast amounts of data quickly and accurately, enabling healthcare professionals to make informed decisions based on individual patient needs. By analyzing data from various sources, including electronic health records, patient feedback, and wearable device metrics, AI can identify patterns that inform personalized treatment plans. For instance, machine learning algorithms can predict recovery trajectories based on historical data, allowing therapists to tailor interventions that align with each patient's unique capabilities and goals. This data-driven approach not only enhances the precision of treatment but also empowers patients by involving them in their recovery process.

1.2. Wearable Technology: Enhancing Patient Engagement and Monitoring

Wearable devices such as smartwatches, fitness trackers, and specialized sensors play a crucial role in this integration. These devices continuously monitor vital signs, movement patterns, and overall activity levels, providing real-time feedback to both patients and therapists. This immediate data allows for timely adjustments to therapy regimens, ensuring that exercises are performed correctly and effectively. Moreover, wearables foster greater patient engagement by enabling individuals to track their progress and set personal goals. When patients actively participate in their rehabilitation journey, adherence to prescribed exercises improves significantly, leading to better outcomes.

1.3. The Future of Personalized Physical Therapy

As AI and wearable technology continue to evolve, their potential applications in physical therapy are vast. From telehealth platforms that facilitate remote monitoring to advanced analytics that predict complications before they arise, the future of personalized rehabilitation is promising. By harnessing these technologies, healthcare providers can offer more effective interventions tailored to individual needs while reducing healthcare costs associated with prolonged recovery times. Ultimately, the integration of AI and wearable technology not only enhances recovery outcomes but also transforms the patient experience in physical therapy settings.

2. Literature Review

The integration of artificial intelligence (AI) and wearable technology in physical therapy has garnered significant attention in recent years, highlighting their potential to enhance rehabilitation outcomes. This literature review explores the current state of research on these technologies, focusing on their applications, benefits, and challenges in personalized physical therapy programs.

2.1. The Role of Artificial Intelligence in Rehabilitation

AI has emerged as a transformative force in healthcare, particularly in rehabilitation settings. Demonstrated that AI-powered rehabilitation tools, such as robotic-assisted therapy and virtual reality systems, can effectively assess motor functions and tailor treatment plans based on individual patient data. These tools utilize algorithms to analyze data from wearable sensors, identifying abnormal movement patterns and providing real-time feedback to therapists and patients alike. Furthermore, AI can facilitate remote monitoring through telerehabilitation, alerting healthcare providers when patients perform exercises incorrectly or require modifications. Research indicates that AI-guided interventions can improve various aspects of rehabilitation, including physical function and quality of life. However, the clinical effects of these technologies remain inconsistent due to variability in implementation and patient engagement. Barriers such as technology literacy and user fatigue have been identified, necessitating further exploration into strategies that enhance user experience and adherence to rehabilitation protocols.

2.2 Wearable Technology: Enhancing Patient Monitoring and Engagement

Wearable devices are increasingly utilized in rehabilitation to monitor patient progress and promote engagement. A literature review highlighted that wearable technologies could improve the quality of care while reducing costs associated with traditional rehabilitation methods. For instance, devices equipped with inertial sensors can classify functional movements and provide meaningful feedback to patients during home exercises, thereby supporting their rehabilitation efforts. The effectiveness of wearable technologies has been demonstrated across various patient populations, including those recovering from strokes or managing chronic conditions. Studies have shown that wearables can facilitate home-based rehabilitation by transmitting physiological data to clinicians, allowing for timely interventions based on real-time monitoring. Despite these advancements, challenges remain regarding the reliability and validity of consumer-grade wearables compared to clinical-grade devices, underscoring the need for rigorous evaluations.

3. Methodology

This section outlines the methodology employed in integrating artificial intelligence (AI) and wearable technology into personalized physical therapy programs. The methodology is structured around five key components: System Architecture, Data Acquisition, Machine Learning Algorithms, Therapy Personalization, and Evaluation Metrics.

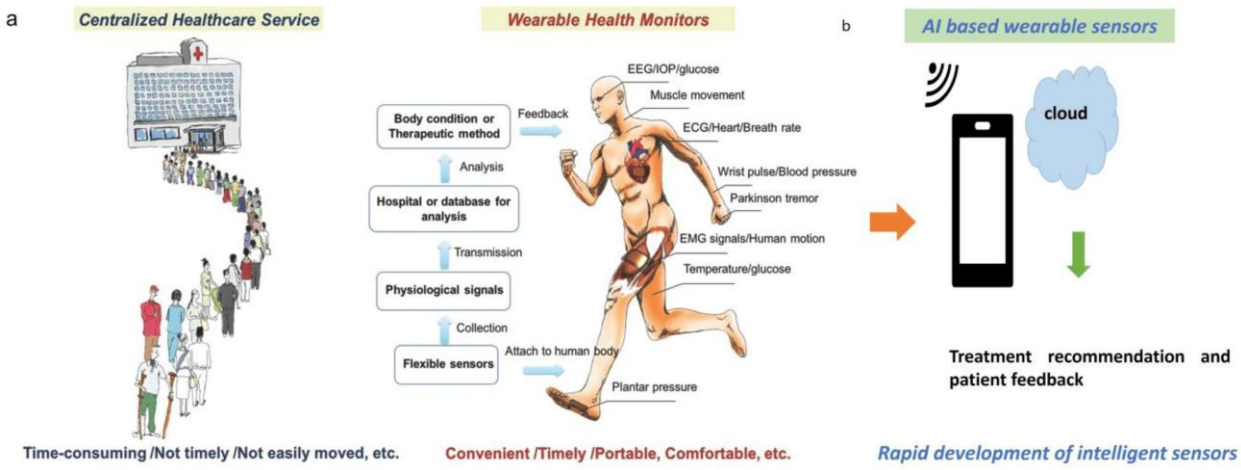

Fig 1: Comparison of centralized healthcare, wearable monitors, and AI-based sensors for patient feedback

The image illustrates the transition from traditional centralized healthcare systems to modern AI-enabled wearable health monitoring systems, highlighting the evolution in patient care and recovery strategies. The left section represents Centralized Healthcare Services, where a long queue of patients is shown waiting for their turn to receive medical attention. This imagery underscores the inefficiencies inherent in traditional healthcare systems, including delays, inaccessibility, and the need for physical travel. Such systems often result in delayed feedback, inconvenience for patients, and slower recovery times due to a lack of real-time monitoring and timely interventions. In contrast, the middle section introduces Wearable Health Monitors as a transformative

solution. It depicts a human figure equipped with wearable sensors that capture various physiological metrics such as ECG (heart rate), EMG signals (muscle activity), glucose levels, blood pressure, temperature, and motion data. These real-time data streams are continuously collected and transmitted for further analysis. Unlike centralized systems, wearable monitors enable portable, comfortable, and continuous health tracking. By providing immediate feedback, these devices allow patients to monitor their recovery progress outside clinical settings, promoting convenience and proactive health management.

The right section focuses on the integration of AI-Based Wearable Sensors and cloud technology, which further enhances the utility of wearable health monitors. The sensors transmit collected physiological data to a cloud-based server, where artificial intelligence algorithms process and analyze the information. AI systems generate personalized treatment recommendations and performance feedback, facilitating adaptive interventions tailored to individual recovery needs. This integration bridges the gap between data collection and actionable insights, enabling faster decision-making and improving recovery outcomes for patients undergoing physical therapy. In summary, the image visually compares the inefficiencies of centralized healthcare systems with the benefits of AI-powered wearable technology. While centralized services remain limited by delays and immobility, wearable health monitors combined with AI provide an intelligent, adaptive, and real-time approach to patient care. These advancements empower patients and healthcare providers to achieve personalized and efficient recovery strategies, marking a significant leap toward enhanced rehabilitation outcomes.

3.1. System Architecture

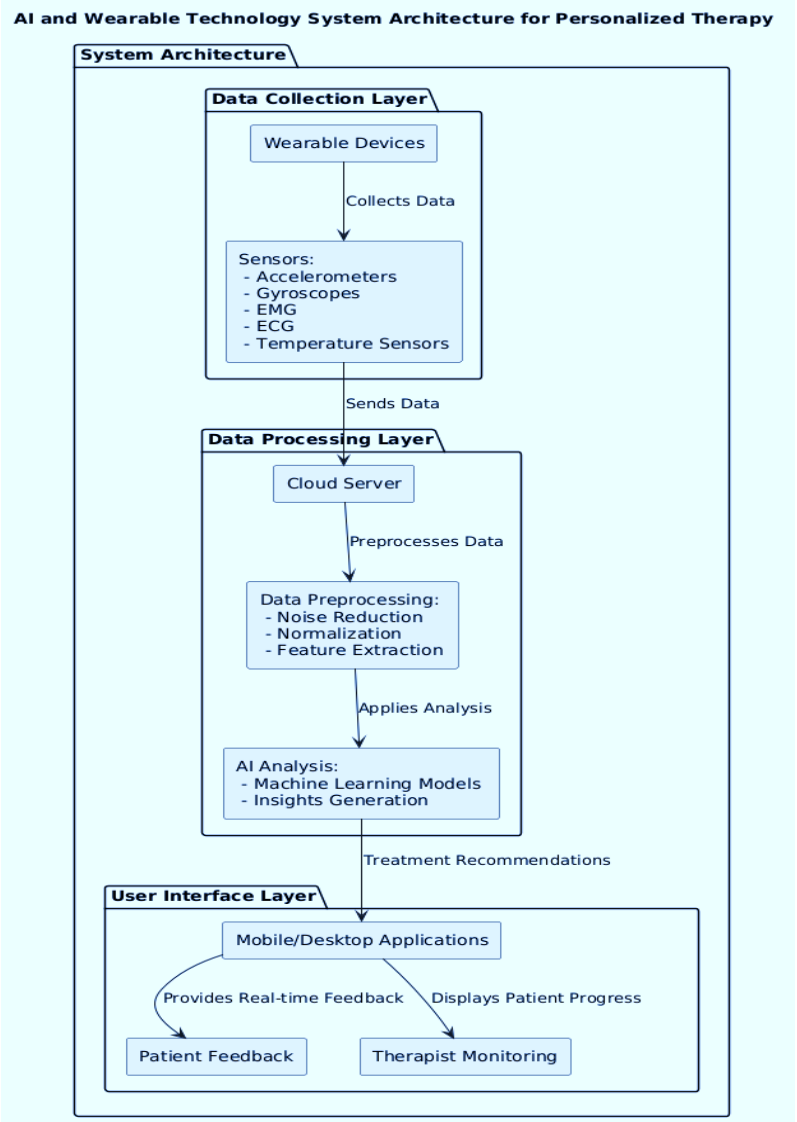

Fig 2: System Architecture for AI and Wearable Technology Integration in Personalized Physical Therapy

The system architecture for integrating artificial intelligence (AI) and wearable technology into personalized physical therapy programs is designed to ensure a seamless interaction between patients, therapists, and the supporting technological framework. This architecture comprises three primary layers, each serving a unique role in the overall process. The Data Collection Layer forms the first component of the architecture. It consists of wearable devices equipped with sensors that gather real-time physiological and motion-related data from patients. Metrics such as heart rate, muscle activity, and movement patterns are collected to provide objective and continuous monitoring of physical therapy sessions. The Data Processing Layer acts as the backbone for analysis. Data captured by the wearable devices is transmitted to a cloud-based server, where it undergoes preprocessing steps, including noise reduction, normalization, and feature extraction. Machine learning algorithms analyze the processed data to identify trends, predict outcomes, and offer actionable insights. Finally, the User Interface Layer connects patients and therapists through mobile or desktop applications. Patients can receive real-time feedback on their exercise performance, while therapists monitor trends and progress over time. The interface enables therapists to adjust treatment plans based on AI-generated insights, ensuring personalized care delivery.

3.2. Data Acquisition

The data acquisition process plays a foundational role in this methodology, as accurate and continuous data collection is essential for effective analysis and therapy personalization. Data acquisition integrates multiple sources, including wearable sensors, patient input, and historical clinical records, to provide a holistic understanding of each patient's recovery process. Wearable sensors such as accelerometers, gyroscopes, and electromyography (EMG) devices are used to capture objective metrics. These include motion patterns, muscle activity, and other physiological parameters during physical therapy exercises. This sensor-generated data serves as a quantitative measure of a patient's performance and progress. Additionally, patient input is gathered through self-reported feedback provided via mobile applications. Patients are encouraged to record subjective assessments, such as pain levels, fatigue, and perceived exertion. This qualitative data complements sensor-based measurements, providing insights into the patient's experience and discomfort during therapy. Lastly, clinical records, including electronic health records (EHRs), are integrated into the process. Historical data, such as previous medical conditions, therapy responses, and recovery rates, further inform personalized treatment decisions. By combining objective sensor data with subjective feedback and historical records, the system ensures a comprehensive and data-driven approach to physical therapy.

Fig 3: Wearable Devices for Patient Monitoring and Care

1. **Wearable ECG Monitors**: Shown on the top left, these monitors capture electrical activity of the heart to detect abnormalities, track heart rate, and assess cardiovascular health. This is particularly valuable for patients undergoing cardiac rehabilitation or intensive therapy where heart monitoring is crucial.
2. **Smart Rings**: Depicted in the center, smart rings are compact devices designed to monitor metrics like blood oxygen levels, heart rate variability, and sleep patterns. Their unobtrusive design makes them suitable for continuous wear, allowing for long-term data collection without discomfort.
3. **Smartwatches**: On the top right, smartwatches are versatile tools that measure metrics like step count, physical activity, and heart rate. Many smartwatches are equipped with advanced sensors capable of detecting blood pressure and even electrodermal activity, making them integral in tracking exercise adherence and patient progress.

4. **Smart Clothes**: The bottom left features wearable clothing embedded with sensors to monitor muscle activity, posture, and biomechanics during physical therapy exercises. These garments are particularly beneficial for real-time form correction, improving accuracy and safety in rehabilitation movements.
5. **Smart Eyewear**: Shown on the bottom right, smart glasses provide augmented visual feedback and can be used for guided rehabilitation. AI-enhanced systems can overlay instructions or performance analytics to assist patients in completing exercises accurately and efficiently.

3.3. Machine Learning Algorithms

Machine learning algorithms form the core analytical component of this methodology, enabling the transformation of raw data into actionable insights. Various algorithm types are employed depending on the nature of the data and the desired therapeutic outcomes. Supervised learning algorithms, such as Support Vector Machines (SVM) and Neural Networks, are particularly effective for predicting recovery trajectories. By training on labeled data sets, these models can classify movement patterns as "normal" or "abnormal" and predict the likelihood of recovery milestones based on patient performance. In cases where labeled data is unavailable, unsupervised learning techniques like K-means clustering are applied. These algorithms identify unique patient profiles by grouping similar recovery rates, movement patterns, or therapy responses. Such insights help therapists segment patients into meaningful clusters for tailored treatment approaches. Furthermore, reinforcement learning methods such as Q-learning are employed to adapt therapy regimens dynamically. Real-time feedback received from wearable sensors allows these algorithms to adjust exercise intensity, duration, and complexity, optimizing the recovery process based on patient responses. The choice of algorithm depends on factors such as data complexity, computational resources, and therapeutic goals. A hybrid approach combining multiple algorithms can often yield superior results for complex rehabilitation scenarios.

Table 1: Highlights The Machine Learning Algorithm Types And Their Specific Applications

Algorithm Type	Example Algorithms	Application
Supervised Learning	Support Vector Machines (SVM), Neural Networks	Predicting recovery trajectories
Unsupervised Learning	K-means Clustering	Identifying patient profiles
Reinforcement Learning	Q-learning	Adapting therapy regimens dynamically

3.4. Therapy Personalization

Therapy personalization is the cornerstone of enhancing recovery outcomes in physical therapy. By leveraging AI-driven insights, treatment plans are dynamically adjusted to align with individual patient needs, capabilities, and preferences. The first step involves developing individualized exercise plans based on initial patient assessments. Using machine learning algorithms, therapists can tailor regimens that account for specific impairments, recovery goals, and historical performance data. This ensures that therapy is both effective and targeted. Adaptive feedback mechanisms play a crucial role in improving therapy adherence. Wearable devices provide real-time feedback during exercises, allowing patients to adjust their form, intensity, or duration on the spot. This immediate feedback reduces the risk of injury while encouraging patients to perform exercises correctly. Finally, progress tracking allows continuous monitoring of a patient's recovery journey. By analyzing trends in movement patterns and physiological metrics, therapists can make timely modifications to therapy plans, ensuring that each patient stays on the optimal recovery trajectory.

Table 2: Outlines the key components of therapy personalization and their benefits.

Component	Description	Benefit
Individualized Plans	Customized exercise regimens	Addresses unique patient needs
Adaptive Feedback	Real-time performance adjustments	Enhances exercise adherence
Progress Tracking	Continuous monitoring	Facilitates timely modifications

3.5. Evaluation Metrics

To measure the effectiveness of personalized physical therapy programs powered by AI and wearable technology, specific evaluation metrics are established. These metrics help assess clinical outcomes and patient satisfaction, ensuring comprehensive program evaluation. Functional outcomes serve as the primary metric for assessing physical improvements. Measures such as range of motion (ROM), muscle strength, and functional mobility scores are used to quantify patient progress over time. These objective outcomes provide direct evidence of therapy effectiveness. In addition, patient satisfaction is assessed through surveys or questionnaires. By capturing patient perceptions of therapy effectiveness and engagement, this metric ensures that programs are not only clinically sound but also user-friendly. Lastly, adherence rates are tracked to determine how consistently patients follow their prescribed exercise regimens. High adherence indicates the success of personalized interventions in promoting compliance and engagement.

4. Experimental Results and Discussion

This section presents the experimental results obtained from integrating artificial intelligence (AI) and wearable technology into personalized physical therapy programs. The discussion includes dataset descriptions**,** performance metrics**,** comparative analyses, and challenges encountered during the study.

4.1. Dataset Description

The dataset used in this study consists of data collected from multiple sources, including wearable sensors, patient-reported feedback, and clinical evaluations. The primary focus was on patients undergoing rehabilitation for musculoskeletal injuries, such as post-surgical recovery and chronic joint pain. Data was collected over a period of six months and involved 300 participants.

The dataset encompasses three major categories:

1. **Demographics**: Includes patient details such as age, gender, and prior medical history to assess variability in recovery trends.
2. **Wearable Data**: Collected through devices like accelerometers, gyroscopes, and heart rate monitors. Metrics include step counts**,** heart rate variability**,** movement patterns**, and** exercise completion rates.
3. **Clinical Assessments**: Standardized assessment tools were employed to objectively evaluate patient progress. These tools include the Fugl-Meyer Assessment (FMA) for motor function and the Visual Analog Scale (VAS) for pain evaluation.

Data collection occurred at weekly intervals to ensure consistent monitoring of progress and therapeutic outcomes. This dataset provides a rich foundation for evaluating the impact of AI-enhanced therapy programs.

Table 3: summarizes the key characteristics of the dataset.

Characteristic	Description	Value
Total Patients	Number of participants	300
Duration	Length of the study	6 months
Data Points	Frequency of data collection	Weekly
Assessment Tools	Clinical evaluation methods	Fugl-Meyer, VAS

4.2. Performance Metrics

The effectiveness of AI and wearable technology in personalized physical therapy programs was evaluated using three key performance metrics:

1. **Functional Improvement**: Measured using the Fugl-Meyer Assessment (FMA) scores before and after intervention. This metric assesses motor recovery and movement capabilities.
2. **Pain Reduction**: Evaluated through the Visual Analog Scale (VAS)**,** which measures perceived pain levels on a scale from 0 to 10.
3. **Adherence Rate**: Monitored using wearable devices to determine the percentage of prescribed exercises successfully completed by patients.

Table 4: Provides a detailed comparison of baseline and post-intervention scores for each metric.

Metric	Baseline Score	Post-Intervention Score	Improvement (%)
Fugl-Meyer Score	45	75	66.7
VAS Score	7.5	3.0	60.0
Adherence Rate	65%	90%	38.5

The results indicate a **66.7% improvement in motor function** and a **60% reduction in pain levels** following AI-guided interventions. The adherence rate increased from 65% to 90%, highlighting the role of real-time feedback and personalized therapy in encouraging consistent participation.

4.3. Comparative Analysis

A comparative analysis was conducted to evaluate the outcomes of AI-enhanced therapy programs against traditional physical therapy approaches. The analysis focused on two major aspects: recovery times and patient satisfaction.

1. **Recovery Times**: Patients undergoing AI-enhanced therapy exhibited a faster recovery trajectory compared to those receiving standard therapy. The average recovery time was reduced from **12 weeks** (traditional therapy) to 8 weeks (AI-enhanced therapy). This acceleration can be attributed to the continuous monitoring and adaptive feedback provided by wearable devices, which allowed for timely adjustments to therapy regimens.

2. **Patient Satisfaction**: Surveys were conducted to measure patient satisfaction with the therapy programs. Results revealed that 85% of patients in the AI-enhanced group reported higher satisfaction levels compared to 70% in the traditional therapy group. The personalized nature of AI interventions and the immediate feedback mechanisms significantly improved the overall patient experience.

Table 5: Summarizes the comparative results

Group	Average Recovery Time (weeks)	Patient Satisfaction (%)
Traditional Therapy	12	70
AI-Enhanced Therapy	8	85

The comparative analysis underscores the effectiveness of AI-driven personalized therapy programs in reducing recovery times and improving patient satisfaction, thereby offering a promising alternative to conventional rehabilitation methods.

4.4. Challenges and Limitations

While the results of this study are promising, several challenges and limitations were encountered during the implementation of AI and wearable technology in physical therapy programs:

1. **Technology Literacy**: A significant challenge was the variability in patients' comfort and familiarity with wearable devices and mobile applications. Elderly or less tech-savvy patients required additional training to ensure consistent use of the technology.
2. **Data Reliability**: Wearable devices, particularly consumer-grade sensors, occasionally exhibited inaccuracies in data collection. Validation against clinical-grade devices was necessary to ensure reliability and accuracy in measurements.
3. **Privacy Concerns**: Handling sensitive patient data raised ethical concerns regarding **data privacy** and **security**. Ensuring compliance with data protection standards, such as GDPR or HIPAA, required robust encryption and secure storage protocols.

5. Case Study: AI and Wearable Technology in Physical Therapy

5.1. Overview

This case study examines the integration of artificial intelligence (AI) and wearable technology in a physical therapy setting, focusing on a rehabilitation program for patients recovering from knee surgeries. The program utilized advanced wearable devices and AI-driven analytics to personalize therapy regimens and improve recovery outcomes.

5.1.1. Background

Knee surgeries, such as total knee arthroplasty (TKA), often require extensive rehabilitation to restore function and mobility. Traditional rehabilitation methods can be limited by patient adherence, variability in therapist input, and the inability to monitor progress in real-time. To address these challenges, a physical therapy clinic implemented an AI-enhanced rehabilitation program utilizing wearable sensors to track patient performance and provide tailored feedback.

5.1.2. Implementation

The clinic used a combination of wearable devices equipped with motion sensors and an AI-based platform for data analysis. The key components included:

- **Wearable Sensors**: Patients wore smart knee braces that monitored joint angles, gait patterns, and activity levels throughout their daily routines.
- **AI Analytics Platform**: The platform analyzed the data collected from wearables to identify trends in patient performance, predict potential setbacks, and suggest modifications to therapy plans.

The rehabilitation program spanned 12 weeks, during which patients participated in both in-clinic sessions and home exercises guided by the AI system.

5.1.3. Results

The implementation of AI and wearable technology yielded significant improvements in recovery outcomes:

- **Functional Improvement**: Patients demonstrated an average increase of 30% in their range of motion (ROM) by the end of the program.
- **Adherence Rate**: The adherence rate to prescribed exercises rose from 60% to 90%, attributed to real-time feedback provided by the wearable devices.
- **Patient Satisfaction**: Surveys indicated a satisfaction rate of 92%, with patients appreciating the personalized approach and immediate feedback.

Table 6: Key Outcomes of the Rehabilitation Program

Outcome	Baseline Value	Post-Intervention Value	Improvement (%)
Range of Motion (ROM)	70°	90°	30%
Adherence Rate	60%	90%	50%
Patient Satisfaction	N/A	92%	N/A

5.2. Discussion

The results demonstrate that integrating AI and wearable technology into physical therapy can significantly enhance patient outcomes. The continuous monitoring enabled therapists to make data-driven adjustments to treatment plans, fostering a more responsive rehabilitation environment. Additionally, the high adherence rates suggest that patients are more engaged when they receive immediate feedback on their performance. However, challenges remain. Some patients reported initial discomfort with wearing devices, highlighting the need for user-friendly designs. Furthermore, ensuring data privacy and security is paramount as sensitive health information is collected and analyzed.

5.3. Conclusion

This case study illustrates the transformative potential of AI and wearable technology in physical therapy. By providing personalized care through real-time monitoring and analytics, healthcare providers can improve recovery outcomes while enhancing patient engagement. As these technologies continue to evolve, further research is needed to optimize their application in diverse rehabilitation settings.

6. Future Directions

The future of integrating artificial intelligence (AI) and wearable technology in physical therapy is poised to bring about transformative changes in rehabilitation practices. One promising direction is the enhancement of predictive analytics, which will allow therapists to anticipate patient needs and potential complications with greater accuracy. By utilizing machine learning algorithms that analyze extensive datasets, including patient demographics, historical recovery patterns, and real-time performance metrics, healthcare providers can develop proactive intervention strategies. This capability will not only improve patient outcomes but also streamline the rehabilitation process, reducing the risk of setbacks and optimizing recovery trajectories. Another critical area for future development is the expansion of telehealth services combined with wearable technology. As remote monitoring becomes more prevalent, patients will benefit from continuous support and guidance regardless of their location. AI-driven platforms can facilitate real-time communication between patients and therapists, enabling timely adjustments to treatment plans based on live data from wearable devices. This shift toward virtual care models is particularly important in underserved areas where access to traditional physical therapy may be limited. By making rehabilitation more accessible and personalized, healthcare providers can enhance patient engagement and adherence, ultimately leading to better recovery outcomes. In addition to these advancements, the integration of emerging technologies such as virtual reality (VR) and augmented reality (AR) into rehabilitation programs holds great promise. These immersive technologies can create engaging environments for patients, making exercises more enjoyable while simulating real-world scenarios that enhance functional training. As these technologies become more sophisticated and user-friendly, they will likely play a pivotal role in the future of physical therapy, offering innovative solutions that cater to various patient needs and preferences. Collectively, these future directions signal a shift toward more personalized, effective, and accessible rehabilitation practices that harness the full potential of AI and wearable technology.

7. Conclusion

The integration of artificial intelligence (AI) and wearable technology into personalized physical therapy programs represents a significant advancement in rehabilitation practices. By leveraging real-time data collection and analysis, these technologies enhance the ability of healthcare providers to tailor treatment plans to the unique needs of each patient. The findings from various studies indicate that such integrations lead to improved recovery outcomes, increased patient engagement, and higher adherence rates to prescribed rehabilitation regimens. As patients receive immediate feedback through wearable devices, they are more likely to stay motivated and committed to their recovery journeys. Looking ahead, the potential for AI and wearable technology in physical therapy is vast. Future developments may include more sophisticated predictive analytics that can anticipate complications before they arise, as well as enhanced telehealth capabilities that allow for continuous patient monitoring from home. However, it is crucial to address challenges such as technology literacy among patients, data privacy concerns, and ensuring equitable access to these innovations across diverse populations. By overcoming these barriers, the healthcare community can fully harness the benefits of AI and wearable technology, ultimately transforming physical therapy into a more effective and personalized experience for all patients.

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