2025 International Conference on Economics, Management and Education Technology (ICEMET 2025)

Article

Research on the Application Strategy of AI-Enabled Intelligent Management and Effectiveness Improvement in the Full Process of Sports Rehabilitation

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Abstract: This study investigates the application strategies of artificial intelligence (AI) in the full process of sports rehabilitation, with the goal of realizing intelligent management and measurable effectiveness improvement. Building on deep learning algorithms and data-driven decision-making, AI techniques are integrated into multiple rehabilitation stages, including initial assessment, program design, real-time monitoring, feedback adjustment, and outcome evaluation. By combining sensor-based motion capture, wearable devices, and clinical assessment data, the study constructs intelligent evaluation and treatment models capable of tracking patients' functional recovery trajectories and automatically updating individualized rehabilitation plans. Comparative experiments between AI-assisted and conventional rehabilitation approaches indicate that AI support can shorten functional recovery time, improve the precision of exercise prescription, and enhance patient adherence and satisfaction. Furthermore, AI-based systems facilitate more efficient allocation of medical and rehabilitation resources, support standardized yet personalized interventions, and provide clinicians with objective, continuous data for decision support. The findings demonstrate that AI enables comprehensive and refined management of sports rehabilitation processes, strengthens the scientific basis and targeting of interventions, and offers a scalable technical framework for future clinical practice. This work provides methodological references for integrating AI into rehabilitation management platforms and highlights key challenges such as data quality, model interpretability, and interdisciplinary collaboration that must be addressed to promote wider application.

Received: 05 February 2026
Revised: 25 March 2026
Accepted: 07 April 2026
Published: 11 April 2026

Keywords: artificial intelligence; sports rehabilitation; intelligent management; personalized medicine; clinical outcomes

1. Introduction

1.1. Research Background

The global aging population and the increasing prevalence of sports injuries have made sports rehabilitation a crucial approach to enhancing quality of life and restoring physical functions [1]. It is increasingly gaining attention across various sectors of society. Traditional sports rehabilitation methods often encounter challenges such as insufficient personalization, difficulty in quantifying rehabilitation outcomes, and inefficiencies in management throughout the process. These issues adversely affect patients' rehabilitation progress. In recent years, the rapid advancement of AI technology has introduced new opportunities for the field of sports rehabilitation. By enabling real-time monitoring and in-depth analysis of sports-related data, AI facilitates more precise assessments and tailored interventions, thereby significantly improving overall rehabilitation outcomes.

Utilizing machine learning and deep learning algorithms, AI can accurately identify patients' specific physical conditions, predict recovery trajectories, and assist therapists in designing scientifically sound rehabilitation plans. The integration of intelligent systems allows for automated management and visualization of relevant data, enhancing the efficiency of the entire rehabilitation process. In this context, the application of AI technology to comprehensive management and effectiveness enhancement in sports rehabilitation addresses the limitations of traditional methods, offers innovative solutions for improving healthcare service quality, and holds substantial practical significance and extensive application potential.

1.2. Research Significance

The significance of this study lies in the specific application of AI technology in sports rehabilitation, achieving intelligent management throughout the entire process and effectively improving patients' rehabilitation outcomes. By introducing AI algorithms, precise analysis of patients' exercise data can be performed, enabling the refinement of personalized rehabilitation plans and promoting faster recovery. This approach combines traditional experience-based judgment with scientific decision-making, enhancing the predictability and reliability of rehabilitation outcomes. The study emphasizes data collection and real-time monitoring during the rehabilitation process, which improves the timeliness and adaptability of treatment plans, provides scientific evidence for therapists, and reduces the likelihood of human error. The intelligent management system facilitates the integration and analysis of large-scale data, optimizing resource allocation and increasing the efficiency of rehabilitation healthcare services, while addressing the current shortage of medical resources. This research offers theoretical support and practical guidance for the future development of informatization and intelligence in sports rehabilitation, advancing medical technology and contributing significant academic and social value [2, 3].

2. Current Application of AI-Enabled Intelligent Management and Effectiveness Improvement in Sports Rehabilitation

2.1. AI Technology Principles and Medical Rehabilitation Application Characteristics

The core principle of AI technology is to utilize algorithms such as machine learning, deep learning, and natural language processing to extract valuable information from large datasets, enabling self-learning and predictive capabilities. In the medical rehabilitation field, AI is primarily applied in the intelligent monitoring and evaluation of patients' physical conditions. Its features include precision, adaptability, and personalization. By collecting real-time data from sensors, wearable devices, and imaging systems, AI accurately analyzes patients' motion postures, physiological indicators, and recovery progress, providing tailored rehabilitation plans. The dynamic feedback mechanism allows treatment goals and strategies to be flexibly adjusted based on the patient's actual progress, ensuring optimal rehabilitation outcomes. Furthermore, AI's predictive capabilities can identify potential rehabilitation challenges using historical data and individual characteristics, enabling targeted interventions. Through an information management system, healthcare professionals can efficiently oversee the rehabilitation process, enhancing work efficiency, minimizing management risks, and promoting the effective allocation of medical resources. The extensive application of AI technology represents a significant advancement toward the intelligent and precise development of medical rehabilitation.

2.2. Application Scenario Analysis

2.2.1. Patient Profiling and Digital Health Records

Patient profiling and digital health record management are essential components of intelligent sports rehabilitation management. By conducting a comprehensive analysis of multidimensional data, a complete profile of the patient is established. This process

involves systematic collection and integration of data such as the patient's basic information, physiological state, athletic ability, and medical history, laying the foundation for developing personalized rehabilitation plans. Advanced data mining and machine learning technologies are utilized to analyze the patient's performance in various exercise scenarios, identify potential risk factors, and support decision-making for therapists. Digitalizing health records enhances data acquisition efficiency, ensures real-time updates and sharing of information, and facilitates access to comprehensive patient information for medical staff. Through a digital platform, patients can conveniently track their rehabilitation progress, communicate with healthcare providers, and receive timely guidance and feedback. Combining patient profiling with digital health record management fosters personalized and precise rehabilitation, optimizing overall treatment effectiveness and creating a user-friendly experience for patients during the rehabilitation process [4].

2.2.2. Personalized Rehabilitation Plan Generation and Precise Recommendation

The generation and precise implementation of personalized rehabilitation plans is a particularly critical part of the sports rehabilitation process supported by artificial intelligence [5, 6]. Through in-depth analysis of multifaceted information such as patients' health files, sports ability, injury types, and individual differences, personalized rehabilitation plans suitable for patients' characteristics can be constructed. This process includes the application of data mining, pattern recognition, and machine learning algorithms. At the same time, it can monitor the physiological state and motor performance of patients in real time. With the support of data, the intelligent system can accurately set rehabilitation goals and select the most suitable training programs and recovery strategies for patients through big data analysis, maximizing the efficiency and effectiveness of rehabilitation. The rehabilitator can make necessary adjustments to the system-generated plan to ensure that the implementation process aligns closely with the patient's feedback, effectively stimulating the patient's enthusiasm and compliance. The personalized plan can be dynamically adjusted based on constantly updated data to ensure that the rehabilitation plan responds promptly to changes in the patient's condition. This patient-centered intelligent management model not only improves rehabilitation outcomes but also revitalizes the traditional rehabilitation system, helping patients return to their optimal state of physical activity as quickly as possible.

2.2.3. Rehabilitation Cycle Management and Effectiveness Tracking Evaluation

Rehabilitation cycle management and efficacy tracking and evaluation are critical components for achieving intelligent control in sports rehabilitation. By regularly monitoring and evaluating patients' performance throughout all stages of the rehabilitation process, the effective implementation of rehabilitation plans is ensured. AI technology leverages sensors and wearable devices to collect patient-related exercise data, including metrics such as exercise intensity, frequency, and physiological responses. This data is intelligently analyzed and processed to develop a scientific rehabilitation cycle evaluation model, providing real-time insights into the patient's rehabilitation progress and changes in efficacy. Based on the analysis results, rehabilitation practitioners can promptly adjust rehabilitation plans to address the evolving needs of patients. A dynamic feedback mechanism enables patients to receive real-time guidance and suggestions during rehabilitation, enhancing their sense of participation and compliance. Regular evaluation reports offer doctors and patients a comprehensive overview of rehabilitation progress, supplying data support for subsequent research and practice. This systematic management and evaluation approach ensures precise and efficient control and optimization throughout the entire sports rehabilitation process, providing a robust foundation for improving overall rehabilitation outcomes [7].

3. Challenges Faced by AI-Enabled Intelligent Management and Effectiveness Improvement in the Full Process of Sports Rehabilitation

3.1. Technical Challenges

3.1.1. Multi-Source Heterogeneous Data Silos and Integration Difficulties

In the sports rehabilitation process, multi-source heterogeneous data silos and integration difficulties present a significant technical challenge. The various data sources involved in rehabilitation include physiological data collected by wearable devices, medical imaging data, exercise records, self-reported patient data, and environmental data, among others [8]. These data originate from different devices and platforms, utilizing different formats, standards, and protocols, which creates fragmented data that is difficult to integrate effectively. The data silo phenomenon prevents rehabilitation teams from obtaining a comprehensive and accurate picture of the patient's health condition and rehabilitation progress, limiting the formulation and implementation of personalized plans. Data integration involves complex data processing, cleaning, and transformation methods, making it urgent to establish unified data standards and sharing mechanisms.

3.1.2. Inaccuracy of Assisted Diagnosis and Reliability of Prognosis Prediction

In the field of sports rehabilitation, AI is utilized for auxiliary diagnosis and prognosis prediction, yet challenges related to accuracy and reliability remain significant technical issues. While intelligent algorithms analyze extensive datasets and identify potential patterns, their predictive capabilities are often constrained under specific circumstances, such as cases involving complex sports injuries or coexisting medical conditions. This limitation introduces uncertainty in diagnostic outcomes. Algorithmic models are typically trained on historical data, and factors such as data bias, insufficient sample sizes, or non-representative datasets can weaken the generalization ability of these models, thereby impacting the accuracy of prognostic predictions [9]. Additionally, AI systems often operate as "black box" models, lacking transparency in their decision-making processes. This reduces the trust of medical professionals in the model's outputs, making it difficult for these systems to serve as the sole basis for clinical decision-making.

3.2. Challenges Arising from Rehabilitation Business Characteristics

3.2.1. Large Individual Differences Among Patients and Complex Rehabilitation Scenarios

Patients exhibit significant individual differences, and the rehabilitation scenario is inherently complex. These two factors present notable challenges in the field of sports rehabilitation. Each patient demonstrates distinct physiological characteristics, psychological states, medical histories, and athletic abilities. Consequently, formulating an effective personalized rehabilitation plan becomes particularly crucial. Individual differences directly influence the outcomes of rehabilitation treatments, underscoring the need for flexible and targeted plans. The complexity of rehabilitation scenarios is reflected in the variety of sports injuries, rehabilitation goals, and the diverse environments in which patients undergo treatment. Different types of injuries require entirely distinct rehabilitation strategies. Furthermore, the treatment process involves considerable variation in terms of location, equipment, and the composition of the rehabilitation team. This inherent complexity significantly increases the difficulty of designing an intelligent management system.

3.2.2. Attribution of Intervention Effects and Difficulty in Quantifying Clinical Efficacy

The difficulty in attributing intervention effects and quantifying clinical efficacy presents a significant challenge in the application of AI strategies within sports rehabilitation. Rehabilitation outcomes are influenced by numerous factors, including the type of condition, treatment methods, psychological state of the patient, lifestyle habits, and social support systems. These complex interactions make it challenging to isolate and define the specific contribution of individual interventions to rehabilitation outcomes. Additionally, quantifying clinical efficacy is problematic, as traditional evaluation

methods often rely on subjective judgments, which may lack the support of objective data and lead to potential inaccuracies in assessing effectiveness. While AI offers numerous quantifiable metrics through data analysis, the integration and scientific evaluation of diverse data in scenarios where multiple factors interact across various dimensions remain a considerable challenge [10].

3.3. Ethical and Legal Dilemmas

3.3.1. Patient Privacy Protection and Medical Data Security

In the context of AI supporting sports rehabilitation, the focus on patient privacy protection and medical data security has significantly increased. Throughout the sports rehabilitation process, a substantial amount of personal health information is collected and analyzed, including physiological data, activity records, and medical history. Due to the sensitive nature of this data, medical institutions must strictly adhere to relevant laws and regulations during data processing to ensure that patient privacy is not compromised in any way. To effectively safeguard personal data, medical institutions should implement encryption technologies and access control measures, ensuring that only authorized personnel can access and utilize the information. Data anonymization serves as a critical method for protecting patient privacy.

3.3.2. Algorithm Bias and Liability Risks

Algorithm bias and liability risks are critical issues that must be addressed when applying AI to sports rehabilitation [11]. Algorithm bias can result from flaws or imbalances in training data, leading intelligent systems to process information in a way that disadvantages certain patients, thereby affecting rehabilitation plans and treatment outcomes. If specific groups are underrepresented in the training data, the system may fail to adequately address their unique needs, increasing the likelihood of treatment inefficacy. This could result in patients receiving inequitable treatment, potentially worsening their health conditions. Liability risks pertain to the determination of legal accountability when AI-driven recommendations or decisions result in suboptimal rehabilitation outcomes. It is essential to clearly define the legal responsibilities of rehabilitation therapists, technology developers, and medical institutions, particularly in cases where system errors or failures occur.

4. Optimization Strategies for AI-Enabled Intelligent Management and Effectiveness Improvement in Sports Rehabilitation

4.1. Technical Optimization Pathways

4.1.1. Establishing a Unified Medical Rehabilitation Data Platform and Governance System

Building a unified medical rehabilitation data platform and governance system is essential for achieving AI-enabled intelligent management in sports rehabilitation. The data platform should integrate medical data from various sources, including patient basic information, exercise records, diagnosis and treatment data, and rehabilitation feedback, ensuring the standardization and unification of data structures [6, 12]. Efficient data processing and analysis tools should be developed to enable clinicians to quickly access the necessary information and use it to create personalized rehabilitation plans. Establishing a comprehensive data governance system is crucial. This system should include standards and processes for data collection, storage, use, and sharing to ensure data accuracy and security. By implementing strict data management policies, access permissions can be properly controlled, ensuring the full protection of patient privacy. Regular data quality assessments and training should be conducted to enhance healthcare staff's ability to utilize data effectively and facilitate its application in clinical decision-making.

4.1.2. Deepening the Application of Deep Learning and Computer Vision Models

Deepening the application of deep learning and computer vision models in sports rehabilitation plays a significant role in enhancing intelligent control and therapeutic outcomes. By incorporating deep learning algorithms, large-scale exercise data can be efficiently processed and analyzed, enabling the precise identification and evaluation of a patient's movement status. This provides a scientific foundation for developing personalized rehabilitation plans. In this domain, the use of computer vision technology is particularly essential. Through video analysis and image recognition, it becomes possible to monitor a patient's movement posture, movement quality, and physiological responses in real time. This technology can accurately detect subtle changes during movement and identify potential risks of sports injuries in advance. Leveraging the adaptive capabilities of deep learning, the system can automatically adjust training intensity and modes based on the patient's recovery progress, thereby optimizing rehabilitation outcomes. To enhance the effectiveness of these models, it is crucial to focus on the diversity and high-quality annotation of training data while promoting continuous optimization and iterative updates of the models to ensure their adaptability and reliability across various rehabilitation scenarios.

4.2. Business Operation Improvement Strategies

4.2.1. Achieving Full-Process Rehabilitation Reach and Interaction Online and Offline

Achieving full-process rehabilitation reach and interaction both online and offline is a key measure for enhancing the operational efficiency of sports rehabilitation. By developing a comprehensive intelligent rehabilitation platform, online and offline services can be seamlessly integrated to provide patients with flexible and efficient rehabilitation plans. The online component, including mobile applications and remote monitoring systems, allows patients to perform basic exercises at home and submit exercise statistics in real-time. Medical professionals and therapists can then review these submissions and provide remote guidance, ensuring the effectiveness of personalized rehabilitation plans. The online platform also offers patients access to educational materials related to rehabilitation, enabling them to learn exercise methods, safety precautions, and improve their engagement and initiative. Offline rehabilitation centers complement this by offering face-to-face professional guidance and treatment, ensuring adherence to professional standards and the safety of exercises.

4.2.2. Constructing a Dynamic Rehabilitation Treatment Strategy Matrix

Constructing a dynamic rehabilitation treatment strategy matrix is a crucial step in achieving intelligent management within sports rehabilitation. By establishing a systematic rehabilitation framework, treatment plans can be flexibly adjusted based on individual patient differences and real-time feedback [1]. The matrix should incorporate multi-dimensional information, including patients' basic physiological characteristics, exercise ability assessments, injury types, rehabilitation stages, and psychological states. Initial assessments classify patients into distinct treatment strategy modules, facilitating the development of personalized treatment plans. Rehabilitation progress is monitored through real-time data collection and analysis, enabling rapid identification of changes in treatment effectiveness and dynamic adjustments to ensure optimal outcomes. The dynamic strategy matrix should integrate AI algorithms, utilizing data mining and intelligence to recommend the most effective intervention measures based on historical successful cases.

4.3. Ethical and Legal Safeguards

4.3.1. Improving Patient Data Authorization and Privacy Protection Mechanisms

Enhancing patient data authorization and privacy protection mechanisms is essential for the safe application of AI in sports rehabilitation. Medical institutions should establish clear policies regarding the collection, use, and sharing of patient data, ensuring that patients fully understand how their personal information will be utilized and processed prior to treatment, and obtaining explicit informed consent. Transparent data usage processes should be implemented to promote patient participation and provide them with the autonomy to make decisions about data authorization. Advanced data encryption and anonymization technologies must be employed to safeguard sensitive patient information, minimizing the risk of data breaches during transmission and storage [13]. Strict access control mechanisms should be enforced to ensure that only authorized personnel can access and manage patient data, thereby maintaining information security. Regular data security training should be conducted to enhance healthcare staff's awareness of data protection and privacy. Additionally, emergency response plans should be developed to address potential data breach incidents, mitigating their impact on patient privacy.

4.3.2. Establishing Algorithm Transparency and Clinical Review Standards

Establishing algorithm transparency and clinical review standards is a key measure to ensure the safe and effective use of AI in sports rehabilitation. Algorithm transparency requires developers to manage the AI system in a way that ensures its decision-making process remains clear, explaining the model's working principles and the basis for its output results to medical staff and patients. During rehabilitation treatment, doctors need to understand the contents of model reports to communicate effectively with patients, thereby increasing trust and compliance with the treatment plan. Clinical review standards should focus on how algorithms perform in real-world clinical cases, where they must undergo adequate validation and trials to determine their applicability and effectiveness [14]. A multidisciplinary expert committee should be established for regular reviews, auditing every phase of data collection, model creation, and result interpretation to minimize potential biases and safety risks.

5. Conclusion

This study on AI-enabled intelligent management and effectiveness improvement in the full process of sports rehabilitation has yielded several significant findings. The integration of artificial intelligence technology into sports rehabilitation enhances the personalization and precision of treatment plans, enabling real-time monitoring and dynamic adjustments to improve patient recovery efficiency. By establishing a unified data platform and a dynamic treatment strategy matrix, the research addresses the challenge of integrating multi-source heterogeneous data, thereby optimizing treatment outcomes. Additionally, the implementation of robust privacy protection and data security mechanisms, along with the development of algorithm interpretability and clinical review standards, fosters greater trust in intelligent technologies among patients and promotes their compliance with these advancements. Addressing ethical and legal challenges through proactive measures, including a comprehensive data authorization process and a clear responsibility recognition system, lays a solid foundation for the broader application of artificial intelligence in sports rehabilitation. As technology continues to evolve, artificial intelligence holds the potential to drive the intelligent transformation of the industry, deliver higher-quality rehabilitation services, and contribute to the overall improvement of public health.

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