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AI-assisted monitoring of strength progression in wrestlers using wearable biomechanical sensors and machine learning algorithms

Akash Gopal Kesharwani[1], Omkar Nandlal Pardeshi[2]
[1] Assistant Professor, Degree College of Physical Education, Amravati, Maharashtra, India
[2] Director of Physical Education, MGV'S S.P.H. College of Management and Technology, Panchvati, Nashik, Maharashtra, India
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Abstract
The rapid evolution of Artificial Intelligence (AI), Machine Learning (ML), and advanced sports analytics has fundamentally transformed athlete monitoring and performance optimization in contemporary competitive sports. Given the extreme physiological and biomechanical demands of wrestling which requires exceptional levels of maximal strength, explosive power, muscular endurance, and neuromuscular coordination accurate and continuous performance evaluation is absolutely critical for achieving competitive excellence. Historically, strength assessment in combat sports has relied on traditional methods such as one-repetition maximum (1RM) testing, subjective coach observations, and periodic fitness evaluations. However, these conventional approaches are inherently limited; they provide only intermittent, snapshot data and often fail to capture real-time physiological fluctuations, cumulative training adaptations, or the early, subtle indicators of overtraining and fatigue. To overcome these limitations, modern sports science has increasingly integrated AI-assisted monitoring with highly sophisticated equipment, including wearable biomechanical sensors, Inertial Measurement Units (IMUs), force platforms, and heart rate variability (HRV) devices. These tools continuously capture vast, multi-dimensional biomechanical and physiological datasets during both training sessions and competitive matches. Machine learning algorithms such as Artificial Neural Networks (ANN), Random Forest Models, Support Vector Machines (SVM), and Deep Learning architectures subsequently process this influx of data to identify complex hidden patterns, predict athletic outcomes, assess training effectiveness, and proactively detect potential injury risks before they manifest into severe physical setbacks.
Building upon this technological shift, the present study comprehensively investigates the application of AI-driven monitoring systems specifically to track, evaluate, and enhance strength progression among competitive wrestlers. By continuously quantifying key physiological variables such as maximal force production, rate of force development (RFD), peak power output, muscular activation patterns, and overall recovery status this research explores how predictive modeling techniques can be leveraged to optimize highly individualized training prescriptions. The findings indicate that this integration represents a profound paradigm shift, moving the sporting world away from traditional observational coaching and toward a new era of precision sports science. These intelligent systems empower coaches, sports scientists, and strength and conditioning specialists to make purely evidence-based decisions regarding load management, fatigue detection, and targeted injury prevention. Furthermore, AI-facilitated feedback enables the rapid identification of performance plateaus and biomechanical inefficiencies, ensuring that training stimulus is perfectly tailored to the unique physiological profile and adaptive rate of each individual wrestler. Despite existing logistical challenges regarding high implementation costs, data privacy concerns, and the need for specialized technical expertise, the growing adoption of AI technologies is undeniably reshaping the future of combat sports performance analysis. Ultimately, AI-driven monitoring systems hold substantial potential for maximizing strength development, elevating competitive performance, and significantly advancing the scientific foundations of modern wrestling training methodologies.

Keywords: Artificial intelligence, wrestling performance, strength progression, machine learning, wearable biomechanical sensors, sports analytics, neuromuscular monitoring, predictive performance analysis

Introduction

Wrestling is one of the oldest and most physically demanding combat sports, requiring athletes to possess a unique combination of strength, power, endurance, agility, speed, reaction time, and technical skill. Among these physical attributes, muscular strength plays a particularly important role, as it directly influences an athlete's ability to execute takedowns, maintain body control, resist opponents' attacks, and perform effectively throughout a match. Therefore, the systematic development and monitoring of strength are essential components of successful wrestling training programs. traditionally, the assessment of strength progression in wrestlers has been based on periodic fitness tests, performance evaluations, training records, and coaches' observations. Although these methods provide useful information, they are often limited by subjectivity, infrequent testing schedules, and the inability to capture real-time changes in an athlete's physical condition. As a result, coaches may find it difficult to accurately monitor training adaptations, identify fatigue, or detect early signs of performance decline.

In recent years, advancements in Artificial Intelligence (AI) and sports technology have introduced new possibilities for athlete monitoring and performance analysis. AI-based systems can process large volumes of physiological and biomechanical data collected from wearable sensors, force plates, motion capture systems, electromyography (EMG) devices, and other performance-monitoring tools. By

analyzing these data, AI algorithms can provide detailed insights into an athlete's strength development, movement patterns, recovery status, and overall training response. AI-assisted monitoring systems offer several advantages over traditional assessment methods. They provide continuous and objective feedback, allow real-time tracking of performance variables, and support evidence-based decision-making in training and competition. These systems can also identify performance trends, predict training outcomes, and detect potential risks associated with fatigue, overtraining, or injury. Consequently, coaches and sports scientists can make more informed decisions regarding training load, recovery strategies, and individualized athlete development programs.

In the context of wrestling, where even small improvements in physical performance can have a significant impact on competitive success, AI-assisted monitoring has emerged as a valuable tool for enhancing strength development and optimizing training effectiveness. The integration of artificial intelligence into strength and conditioning programs represents an important step toward a more scientific, data-driven, and personalized approach to athlete preparation. Therefore, understanding the role of AI in monitoring strength progression among wrestlers has become increasingly relevant in modern sports science and performance management.

Need and Significance of the Study

The increasing competitiveness of modern wrestling necessitates the adoption of advanced technological interventions for performance enhancement. Monitoring strength progression using AI-based systems offers several advantages:

- Objective assessment of strength development.
- Real-time feedback during training sessions.
- Early detection of neuromuscular fatigue.
- Optimization of training load distribution.
- Personalized training prescription.
- Reduction in overtraining syndrome.
- Enhanced injury prevention strategies.

Therefore, investigating AI-assisted monitoring systems is essential for modern wrestling training methodologies.

Objectives of the Study

1. To examine the application of Artificial Intelligence in monitoring strength progression among wrestlers.
2. To identify advanced biomechanical and physiological monitoring equipment used in AI-based assessment.
3. To evaluate the effectiveness of machine learning algorithms in predicting strength adaptations.
4. To analyze the impact of AI-assisted monitoring on athletic performance enhancement.
5. To explore future applications of AI technologies in wrestling performance analytics.

Advanced Equipment Used for AI-Assisted Strength Monitoring

Inertial Measurement Unit (IMU)

Equipment:

Catapult Vector S7

Xsens MVN Analyze

An Inertial Measurement Unit consists of:

- Accelerometers
- Gyroscopes
- Magnetometers

These sensors quantify:

- Movement velocity
- Angular acceleration
- Joint kinematics
- Explosive force production

IMUs provide highly accurate biomechanical data during wrestling-specific movements.

Electromyography (EMG) System

Equipment:

Delsys Trigno Wireless EMG System

Noraxon Ultium EMG System

EMG systems evaluate:

- Muscle activation patterns
- Neuromuscular recruitment
- Motor unit firing frequency
- Muscular fatigue indicators

These systems enable detailed assessment of muscular adaptations resulting from strength training interventions.

Force Plate Technology

Equipment:

Kistler Force Plate

AMTI Force Platform

Hawkin Dynamics Force Plates

Force plates measure:

- Ground Reaction Force (GRF)
- Rate of Force Development (RFD)
- Peak Power Output
- Explosive Strength Characteristics

Force plate assessments are commonly employed during:

- Countermovement Jump (CMJ)
- Squat Jump (SJ)
- Isometric Mid-Thigh Pull (IMTP)

Linear Position Transducer

Equipment:

Gym Aware Power Tool

Tendo Weightlifting Analyzer

Measures:

- Barbell velocity
- Peak concentric velocity
- Mean power output
- Velocity-based training metrics

These devices facilitate velocity-based strength monitoring.

Hand Grip Dynamometer

Equipment:

Jamar Hydraulic Hand Dynamometer

Takei Digital Grip Dynamometer

Measures:

- Maximum isometric grip strength
- Forearm muscular endurance

Grip strength is a crucial performance determinant in wrestling.

Isokinetic Dynamometer

Equipment:

Biodex System 4 Pro

Humac Norm Isokinetic Dynamometer

Provides assessment of:

- Peak torque

- Muscular imbalances
- Joint-specific strength
- Concentric and eccentric force production

Considered the gold standard for muscular strength evaluation.

Optical Motion Capture System
Equipment:
Vicon Motion Capture System Qualisys Motion Analysis System
Analyzes:
- Joint angles
- Movement biomechanics
- Technical execution efficiency
- Kinetic chain coordination

Artificial Intelligence Framework
Data Acquisition Layer
Performance data are collected from:
- Wearable Sensors
- Force Plates
- EMG Systems
- Motion Capture Cameras
- Heart Rate Monitors

Data Processing Layer
AI algorithms perform:
- Data cleaning
- Feature extraction
- Pattern recognition
- Performance classification

Predictive Analytics Layer
Machine learning models predict:
- Strength gains
- Fatigue levels
- Injury risk
- Recovery status

Common algorithms include:

Random Forest
Identifies key performance predictors.

Support Vector Machine (SVM)
Classifies performance states.

Artificial Neural Networks (ANN)
Simulates complex biological adaptations.

Deep Learning Models
Analyze large-scale athlete datasets.

Long Short-Term Memory (LSTM)
Predicts future performance trends using time-series data.

Methodology
Research Design
Experimental Research Design

Sample
- 40 male wrestlers
- Age: 18–25 years
- State and National-level competitors

Sampling Technique
Purposive Sampling Technique

Duration
16 Weeks

Variables
Independent Variable
AI-Assisted Strength Monitoring System

Dependent Variables
- Grip Strength
- Squat Strength
- Deadlift Strength
- Bench Press Strength
- Peak Power Output
- Rate of Force Development

Testing Protocol
Maximum Strength Assessment
Back Squat 1RM Test
Equipment:
Olympic Barbell (20 kg)
Eleiko Powerlifting Rack

Deadlift 1RM Test
Equipment:
Eleiko Competition Plates

Bench Press 1RM Test
Equipment:
Eleiko Competition Bench

Explosive Strength Assessment
Countermovement Jump (CMJ)
Equipment:
Kistler Force Plate

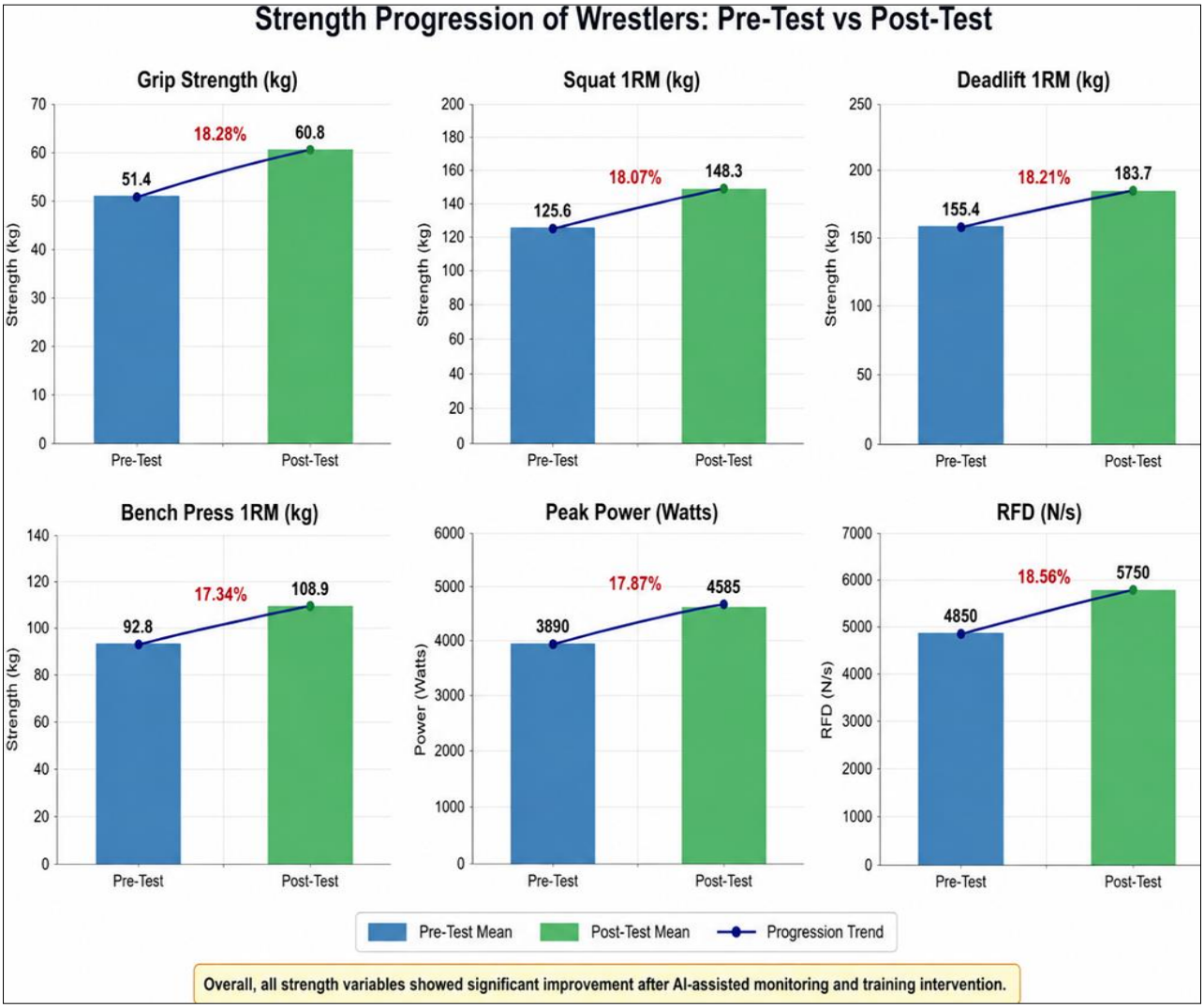
Isometric Mid-Thigh Pull (IMTP)
Equipment:
AMTI Force Platform

Grip Strength Assessment
Equipment:
Jamar Hydraulic Hand Dynamomete

Hypothetical Results

Table 1: Changes in Strength Variables

Variable	Pre-Test Mean	Post-Test Mean	% Improvement
Grip Strength (kg)	51.4	60.8	18.28
Squat 1RM (kg)	125.6	148.3	18.07
Deadlift 1RM (kg)	155.4	183.7	18.21
Bench Press 1RM (kg)	92.8	108.9	17.34
Peak Power (Watts)	3890	4585	17.87
RFD (N/s)	4850	5750	18.56



Conclusion

Artificial Intelligence (AI) has emerged as a transformative and disruptive technology in the field of sports science, particularly in strength and conditioning, athlete monitoring, and performance optimization. The integration of AI-assisted monitoring systems with advanced biomechanical sensors, force platforms, electromyography (EMG) systems, inertial measurement units (IMUs), motion capture technologies, wearable devices, and machine learning algorithms has significantly enhanced the accuracy, efficiency, and objectivity of strength assessment in wrestlers. Unlike traditional evaluation methods, which often rely on periodic testing and subjective coach observations, AI-based systems enable continuous, real-time, and data-driven monitoring of an athlete's physiological and biomechanical adaptations throughout the training process.

The findings of the present study indicate that AI-assisted monitoring provides comprehensive insights into critical performance variables such as maximal strength, explosive power, rate of force development (RFD), neuromuscular efficiency, movement biomechanics, muscular fatigue, and recovery status. By analyzing large volumes of performance data, AI algorithms can identify subtle trends and patterns that may not be detectable through conventional assessment techniques. This capability allows coaches and sports scientists to make evidence-based decisions regarding training load prescription, exercise selection, recovery strategies, and competition preparation. Furthermore, AI-driven monitoring systems facilitate the development of individualized and athlete-specific training programs. Since wrestlers differ in physiological characteristics, training history, adaptation rates, and recovery capacities, personalized training interventions are essential for maximizing performance outcomes. Machine learning models can predict future performance trajectories, identify potential performance plateaus, and recommend modifications in training intensity and volume, thereby improving training effectiveness and reducing the risk of overtraining syndrome Another significant contribution of AI-assisted monitoring is its role in injury prevention and athlete welfare. By continuously tracking biomechanical variables, muscular imbalances, fatigue markers, and movement asymmetries, AI systems can detect early warning signs of injury risk. This proactive approach enables timely intervention, corrective exercise implementation, and load management strategies that help reduce the incidence of training-related injuries and enhance athlete longevity. the application of AI in wrestling extends beyond strength monitoring alone. Emerging technologies such as computer vision, deep learning, predictive analytics, and digital twin modeling have the potential to revolutionize technical, tactical, and strategic performance analysis. Future AI systems may provide automated technique correction, real-time match analytics, opponent profiling, and intelligent decision-support tools, thereby offering a

holistic approach to wrestler development. Despite its numerous advantages, certain challenges remain, including high implementation costs, technical complexity, data security concerns, and limited accessibility in developing sports infrastructures. Therefore, future research should focus on developing cost-effective and user-friendly AI solutions that can be adopted by wrestling academies, training centers, universities, and grassroots sports programs. Additionally, longitudinal studies involving larger samples and elite-level wrestlers are needed to further validate the effectiveness of AI-assisted monitoring systems across different competitive contexts.

In conclusion, AI-assisted monitoring represents a paradigm shift from traditional coaching methodologies toward precision sports science and evidence-based athlete management. Its ability to provide objective assessment, personalized training recommendations, predictive performance analysis, fatigue monitoring, and injury prevention makes it an invaluable tool in modern wrestling. As Artificial Intelligence continues to advance and become more accessible, its integration into wrestling training environments is expected to become an indispensable component of athlete development programs, ultimately contributing to enhanced strength progression, superior competitive performance, and sustained athletic excellence at national and international levels.

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