



# The Use of AI and Machine Learning in Injury Risk Predictions and Analyzing Movements – A Narrative Review

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**Abstract:** Injury risk and movement inefficiencies pose ongoing challenges across sports, rehabilitation, and occupational health, often disrupting careers, delaying recovery, and reducing quality of life. As technology advances, the integration of Artificial Intelligence (AI) and Machine Learning (ML) into injury prediction and movement analysis has opened new avenues for proactive, data-driven care. This review summarizes insights from 17 key studies published between 2016 and 2025, exploring how AI and ML are applied to injury prediction and movement analysis in sports, rehab, and workplace health. We examine the algorithms most commonly used, such as decision trees, neural networks, and support vector machines, and their application to biomechanical data like joint kinematics, EMG, and gait patterns. From predicting ACL injuries in athletes to identifying ergonomic risks in workplaces, these models offer nuanced insights into human movement. The review also highlights the growing use of wearable sensors, motion capture systems, and real-time video analysis as data sources for training predictive models. Despite the promise, challenges persist—ethical concerns, data privacy, model transparency, and high implementation costs remain barriers to wide adoption. Still, with trends like multimodal data integration, edge computing, and interpretable AI, the future looks bright. AI and ML are no longer distant technologies; they are becoming essential tools in optimizing performance, enhancing safety, and supporting recovery—helping people move better, train smarter, and live healthier lives.

**Keywords:** Artificial intelligence, Injury prediction, Wearable sensors, Machine learning

## INTRODUCTION

Injuries related to physical activity present significant challenges across sports, rehabilitation, and occupational health. They can derail athletic careers, prolong recovery in clinical settings, and reduce productivity in workplaces.<sup>1,2</sup> Advances in data collection technologies—such as wearable sensors, motion capture systems, and electronic health records—have produced large datasets that are ideal for in-depth movement analysis and injury risk modeling.

Artificial Intelligence (AI) and Machine Learning (ML) are increasingly being applied to these datasets to detect subtle patterns that may indicate injury risk.<sup>3</sup> Their ability to model complex, nonlinear relationships makes them powerful tools for injury prevention, rehabilitation support, and performance optimization.<sup>4</sup> This review explores current uses of AI and ML in injury risk prediction and movement analysis, highlighting algorithm types, targeted injury categories, benefits, limitations, and future directions.

## METHODOLOGY

This narrative review explored how Artificial Intelligence (AI) and Machine Learning (ML) are used in injury risk prediction and movement analysis across sports, rehabilitation, and occupational health. A structured search was conducted across PubMed, Scopus, Web of Science, and Google Scholar for articles published between 2016 and 2025, focusing on recent advancements.

Out of an initial pool of identified studies, 17 articles were selected based on relevance, methodological clarity, and contribution to the topic. These included peer-reviewed journal articles and reputable reviews that addressed AI/ML in the context of sports science, rehabilitation, or occupational health.

## THE ROLE OF AI AND MACHINE LEARNING IN INJURY RISK PREDICTION

### OVERVIEW OF ALGORITHMS USED

Tree-based models like Random Forest and XGBoost have shown strong performance in injury prediction tasks, offering robust handling of non-linear data and interactions.<sup>5</sup> Logistic regression, despite being a more traditional method, continues to compete closely with ML approaches, sometimes outperforming them when datasets are small or well-structured.<sup>6</sup>

Neural networks, including Artificial Neural Networks (ANNs), Convolutional Neural Networks (CNNs), and Recurrent Neural Networks (RNNs), have expanded the field further by enabling analysis of time-series and sensor-based motion data.<sup>7</sup> CNNs, for example, are used to analyze joint kinematics and gait patterns, while RNNs excel in modeling longitudinal training loads and physiological trends.<sup>8</sup>

Other methods such as Support Vector Machines (SVM), Decision Trees, and dimensionality reduction techniques like PCA are also employed, especially when feature selection and interpretability are key concerns.<sup>9,10</sup>

### EFFECTIVENESS AND LIMITATIONS

While some studies report high prediction accuracy—sometimes with AUC scores above 0.9—the generalizability of these models remains a challenge.<sup>11</sup> Variations in dataset size, injury definitions, and feature selection contribute to inconsistent findings across the literature. Furthermore, class imbalance (i.e., many more non-injury than injury cases) can reduce model effectiveness, despite countermeasures like oversampling.

Crucially, algorithm complexity does not guarantee better outcomes. In some cases, simpler models outperform complex neural networks, depending on the context and data structure.<sup>6</sup> This reinforces the importance of aligning model choice with data characteristics and intended applications.

### TYPES OF INJURIES PREDICTED

AI and ML tools are being applied to predict various injuries, including hamstring strains, ACL tears, ankle injuries, and concussions.<sup>5,12</sup> In endurance sports, models often focus on overuse injuries, while in occupational health, the emphasis is on musculoskeletal disorders.<sup>10</sup> Some tools attempt to forecast next-season injury risk or cumulative injury likelihood without specifying injury type, based on longitudinal training data.<sup>5</sup>

Emerging approaches, like time-series image encoding combined with deep learning, show promise in improving prediction accuracy by capturing subtle biomechanical deviations over time.<sup>13</sup>

## BIOMECHANICAL MOVEMENT ANALYSIS USING AI AND MACHINE LEARNING

### AI/ML TECHNIQUES FOR MOVEMENT ANALYSIS

Deep learning methods, especially Convolutional Neural Networks (CNNs), are widely used for video-based movement analysis, athlete identification, posture assessment, and skill evaluation. CNNs also facilitate gait analysis by extracting detailed spatiotemporal features from video or sensor data. Recurrent Neural Networks (RNNs) are particularly suited for analyzing movement sequences, capturing temporal dependencies critical for dynamic motion tracking.<sup>3</sup>

Traditional machine learning methods continue to play a key role in classifying movement patterns and detecting abnormalities. Supervised learning algorithms such as Support Vector Machines (SVMs) and k-Nearest Neighbors (KNN) are commonly used for movement classification, while unsupervised techniques like clustering help discover hidden patterns in gait or posture data.<sup>6</sup> Dimensionality reduction techniques such as Principal Component Analysis (PCA) simplify high-dimensional datasets, allowing researchers to identify essential biomechanical features more efficiently.<sup>6</sup>

### BIOMECHANICAL DATA ANALYZED

AI/ML models analyze a variety of biomechanical data, including:

- **Kinematics:** Joint angles, acceleration, velocity, and displacement.
- **Kinetics:** Ground reaction forces, joint moments, and power.
- **Electromyography (EMG):** Muscle activation patterns.
- **IMUs and Wearable Sensors:** Real-time monitoring of acceleration, angular velocity, and estimated joint forces.
- **Motion Capture Systems:** High-resolution kinematic and kinetic measurements.

- **Gait Parameters:** Cadence, stride length, and walking symmetry.
- **Video and Image Data:** Pose recognition, performance evaluation.<sup>6,7</sup>

## APPLICATIONS IN MOVEMENT ANALYSIS AND INJURY RISK PREDICTION

AI/ML supports a wide range of applications, including:

- **Performance Enhancement:** Identifying inefficiencies in technique and providing actionable feedback.
- **Injury Prevention:** Detecting risky movement patterns that contribute to overuse or acute injuries.<sup>7</sup>
- **Rehabilitation:** Objectively tracking recovery progress and quality of movement.<sup>8</sup>
- **Gait Analysis:** Differentiating normal and abnormal gait patterns, identifying individuals by their movement signatures.<sup>6</sup>
- **Athlete Monitoring:** Tracking fatigue and readiness by analyzing movement trends.<sup>8</sup>
- **Occupational Ergonomics:** Identifying high-risk workplace motions and suggesting safer alternatives.<sup>2</sup>

## DATA SOURCES FOR TRAINING AI/ML MODELS

1. **Motion Capture Systems:** Provide accurate 3D motion data but are expensive and lab-dependent.<sup>6</sup>
2. **Wearable Sensors (e.g., IMUs, GPS, HR monitors):** Enable real-world biomechanical and physiological data collection at scale.<sup>1,9</sup>
3. **Medical Records and Injury History:** Include valuable data on prior injuries and recovery, though privacy regulations like GDPR and HIPAA must be followed.<sup>9</sup>
4. **Training Logs and Performance Metrics:** Track load, intensity, and progress to predict overtraining or insufficient recovery.<sup>3</sup>
5. **Other Data Sources:** Include psychological factors, environmental variables, self-reported wellness scores, and biological markers. Integrating these multimodal inputs enhances prediction accuracy.<sup>3,10</sup>

## BENEFITS IN SPORTS, REHABILITATION, AND OCCUPATIONAL SETTINGS

- **Sports:** AI/ML enables early injury detection, personalized training plans, real-time feedback, return-to-play decisions, and continuous monitoring via wearables.<sup>3,9,11</sup>
- **Rehabilitation:** Supports customized programs, remote monitoring, virtual rehab tools, and improved adherence through feedback-driven interventions.<sup>10,12</sup>
- **Occupational Settings:** Enhances safety via ergonomic risk assessments, smart wearables, and AI-driven hazard alerts. Smart systems also optimize building environments and support safer workflows.<sup>1,2</sup>

## CHALLENGES AND LIMITATIONS

- **Privacy and Ethics:** Sensitive data must be handled responsibly, complying with privacy regulations and ensuring informed consent.<sup>9</sup>
- **Model Interpretability:** Many AI models function as "black boxes," making clinical adoption difficult. Tools like SHAP improve transparency.<sup>5</sup>
- **Data Standardization and Quality:** Variability in data formats and small sample sizes can hinder model generalizability.<sup>1,13</sup>
- **Overfitting and Context Dependency:** Models trained on narrow datasets may not transfer to new populations or settings.<sup>13</sup>
- **Technical and Financial Barriers:** High-quality data collection and AI deployment often require significant investment.<sup>14</sup>

## EXAMPLES OF EXISTING AI-POWERED SYSTEMS AND PLATFORMS

System/Platform Name	Application Area	Key Functionalities
Catapult	Sports	Wearable tracking, load monitoring, performance dashboards.
Zone7	Sports	Integrates wearables and medical data to predict injuries and personalize plans.

<b>Hudl / Dartfish</b>	Sports	AI-enhanced video analysis for movement and performance feedback.
<b>Kitman Labs / Sparta Science</b>	Sports	Machine learning tools for injury risk profiling based on biomechanics and workload.
<b>Inner Balance (HeartMath)</b>	Sports	Stress tracking and mental readiness through physiological sensors.
<b>AI Imaging Tools</b>	Sports	Improved diagnostic accuracy for musculoskeletal injuries via MRI/CT enhancement.
<b>MedBridge Pathways</b>	Rehabilitation	Motion capture and AI for remote care, program compliance, and outcome tracking.
<b>Virtual Rehab Platforms</b>	Rehabilitation	Real-time movement feedback, gamified rehab programs.
<b>Smart Building Systems</b>	Occupational	AI-driven energy and comfort optimization.
<b>AI Wearables &amp; CCTV</b>	Occupational	Real-time monitoring of hazards, fatigue, and policy compliance.

## FUTURE TRENDS AND ADVANCEMENTS

AI/ML will continue evolving through:

- **Model Interpretability:** More transparent models using SHAP, LIME, and attention mechanisms.<sup>5</sup>
- **Generative AI:** Used for synthetic datasets and intervention design.<sup>3</sup>
- **Multimodal AI Integration:** Combining movement, audio, physiological, and environmental data for holistic modeling.<sup>17</sup>
- **Real-Time, On-Device Processing:** Enabling immediate analysis and intervention via edge computing.<sup>9</sup>
- **Accessible Tools:** Low-code platforms democratizing AI use for clinicians, coaches, and therapists.<sup>16</sup>
- **Privacy-Preserving Techniques:** Including federated learning to allow secure, collaborative model training across institutions.<sup>9</sup>

## CONCLUSION

AI and machine learning are transforming the landscape of injury risk prediction and biomechanical movement analysis. By enabling early detection, personalized feedback, and continuous monitoring, these tools enhance outcomes across sports, rehabilitation, and occupational domains. Despite existing challenges—such as privacy, interpretability, and generalizability—the rapid evolution of AI-driven systems offers promising opportunities. Future research should focus on ethical development, interdisciplinary collaboration, and broader accessibility to fully realize the potential of AI/ML in optimizing human health and performance.

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