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Artificial Intelligence (AI) based data analysis methods in biomechanical movement assessments of musculoskeletal conditions discriminating between groups: A Scoping Review Protocol

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ADMINISTRATIVE INFORMATION

Support - DFG.

Review Stage at time of this submission - Piloting of the study selection process.

Conflicts of interest - None declared.

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Amendments - This protocol was registered with the International Platform of Registered Systematic Review and Meta-Analysis Protocols (INPLASY) on 25 April 2025 and was last updated on 25 April 2025.

INTRODUCTION

Review question / Objective Objective: The primary objective of this scoping review is to identify Artificial Intelligence (AI) based analysis methods for biomechanical time series data that can effectively distinguishing between groups of conditions. The secondary objective is to identify relevant parameters extracted from data captured through biomechanical measurement methods, such as Motion Capture or EMG. The review focuses on studies that provide performance measures of the methods applied and allow the distinction between groups.

Research question: The primary research question guiding this study, based on the PCC framework, is: „What AI analysis methods are used to discriminate groups in studies assessing human movement in individuals with musculoskeletal (MSK) conditions, using biomechanical measuring methods, such as Motion Capture or EMG?"
with the following definitions:
Population: Humans, any age, with MSK conditions
Concept: AI analysis methods capable of discriminating between groups
Context: Studies assessing human movement using biomechanical measuring methods such as Motion capture or EMG
To address this question, several sub-questions are posed:
1. "Which AI-based analysis methods show proven capabilities to distinguish or prepare the distinction between different groups in humans with musculoskeletal conditions?"
2. "What biomechanical parameters are relevant when assessing differences in movements between groups in humans with musculoskeletal conditions?"

Background This Scoping Review is part of a larger project, funded by the Deutsche Forschungsgesellschaft (DFG) investigating the development and aetiology of movement-related musculoskeletal (MSK) conditions in performing artists, particularly musicians. While performing artists' health is an emerging research field, gaining increasing scientific and clinical attention (Rodríguez-Gude et al. 2023), biomechanical research in this specific population remains limited. Advanced AI methods offer promising opportunities for analysing complex biomechanical data, by integrating high-dimensional, multi-parameter inputs. Since biomechanical research on performing artists and general MSK studies share core measurement technologies, analytical frameworks, and validation approaches, methods from general MSK research can be transferred to the study of performing artists. Expanding the review to the broader MSK population increases the available literature and strengthens the methodological basis for future research in both fields.

Biomechanical human movement analysis is widely used in clinical and research settings, from prevention to diagnosis and rehabilitation across various conditions. Commonly used measuring methods, such as marker-based - and more recently, marker less -motion capture systems, often produce high dimensional, heterogeneous data (Halilaj et al. 2018; Mündermann et al. 2006). This is especially true when combining different data sources, such as Inertial Measurement Units (IMUs), motion capture systems, force plates or electromyography (EMG). The integration of multiple measurement methods is common, as shown by Alzahrani and Ullah (2024) and Sakamoto et al. (2023) and provides a rich source of multimodal data for AI analysis.

Traditional statistical methods in biomechanics, such as parametric tests and linear regression, often require reducing continuous kinetic or kinematic data—like time series—to discrete summary metrics (e.g., mean or peak values) to meet their assumptions (Yona et al. 2024). While they provide interpretable results with well-established significance criteria (Halilaj et al. 2018), they are limited in handling complex, high-dimensional data. In contrast, machine learning (ML) techniques can capture non-linear relationships and process large datasets more efficiently. Although ML models often achieve higher predictive accuracy, they tend to be less interpretable, require extensive training data and can be prone to overfitting (Halilaj et al. 2018). In recent years, ML methods, such as Support Vector Machines and Artificial Neural Networks, have seen growing application in human movement studies. A wide range of algorithms is used, reflecting a growing need for an overview of their application, performance, and interpretability, data or parameters used to train these models.

One important use of these analytical methods, is to differentiate between different conditions, movement patterns, risk factors or other subgroups, as shown by e.g. (De et al. 2025; Liu et al. 2025; Senvaitis et al. 2025). Algorithms and methods that can classify these categories are essential for tailoring interventions and design prevention measures.

By focusing on analysis methods that enable group discrimination (e.g. healthy vs. ill or between subgroups) in biomechanical human movement research, this review provides a structured overview of existing approaches, their benefits, and limitations to carve out factors that influence the development of musculoskeletal condition. With the continuous development especially of ML methods, researchers are faced with an increasingly complex landscape of available methods, each with different assumptions, data requirements, and interpretability limitations (Halilaj et al. 2018). A comprehensive overview of these methods is essential to guide future studies in selecting the most appropriate analytical tools for distinguishing movement patterns, identifying risk and assessing MSK or other health conditions. This review, therefore, serves as a valuable reference to help navigate the expanding methodological field and ensure that emerging AI technologies are used effectively in biomechanical human movement research.

Please refer to the "Eligibility Criteria" section for the reference list of all cited sources.

Rationale Given the increasing attention to the health of performing artists and the limited research in this specific field, there is a need to integrate findings from general MSK research to provide a stronger methodological basis. Biomechanical analysis of human movement provides valuable tools for understanding movement-related conditions, but the complexity and heterogeneity of biomechanical data pose significant challenges in selecting appropriate analysis methods. While traditional statistical approaches are still widely used, they often cannot fully capture the complex, high-dimensional nature of human movement data, creating a need for the use of more advanced techniques such as ML.

Despite the increasing use of ML, researchers in the field of biomechanical movement analyses face an increasingly complex methodological landscape, with limited structured guidance on the most appropriate techniques for group and subgroup discrimination. As methods for distinguishing movement patterns, identifying risk, and assessing health conditions are essential in research and clinical practice, a comprehensive overview of available approaches is needed. This scoping review addresses this gap by systematically mapping the biomechanical analysis methods used for group discrimination, assessing their benefits and limitations, and providing a structured reference for future research. This review aims to enhance the informed and effective application of analysis methods in biomechanical research, benefiting both MSK and performing artists' health domains

Focus of the study: This review focuses on AI methods that are used to distinguish between groups in biomechanical research. The primary goal is to better understand musculoskeletal conditions in humans through analysing human movement data that originate from contrasting groups either in research or clinical settings. These groups may include individuals with different musculoskeletal conditions, varying movement patterns, distinct risk factors, or other features of subgroups relevant to human movement. The review focuses on studies that provide measures of evaluation for the used methods, such as accuracy, sensitivity or specificity metrics, in either research or clinical settings.

METHODS

Strategy of data synthesis Literature research is conducted on MEDLINE, CINAHL, Web of Science, Embase and APA PsycINFO to ensure a comprehensive literature search that captures a wide range of perspectives and methodologies in human movement analysis and MSK research. MEDLINE covers a broad spectrum of biomedical research, with over 25 million records, making it ideal for finding studies on MSK conditions and movement analysis. MEDLINE also frequently includes studies on the application of AI in healthcare, such as ML algorithms for diagnostics or data analysis, making it also a useful database for exploring how AI methods are employed in movement-related contexts. CINAHL focuses on nursing and allied health literature, with almost 6 million records, especially valuable for finding studies related to rehabilitation and clinical applications of movement analysis. Web of Science includes a wide range of multidisciplinary research, that includes studies on e.g. AI applications in various fields, including healthcare, making it a valuable source for identifying research on AI methodologies and their use in movement analysis. APA PsycInfo extensively covers psychometric properties, which are crucial for evaluating the reliability and validity of assessment tools and outcome measures used in movement analysis studies. It therefore provides access to literature on methodological studies and statistical analyses, essential for understanding and critically appraising the methods employed in human movement research.

An extensive literature search is conducted first in MEDLINE and then translated into the other databases.

The search will be conducted using English keywords only, as prior research indicates that the majority of high-impact studies in MSK research and AI-based movement analysis are published in English. Additionally, resource constraints prevent systematic translation of non-English material. However, the potential impact of language limitations on study inclusion will be considered in the final review.

The search strategy of this review is carefully designed, with the help of a librarian, to effectively capture the extensive literature in the field, while ensuring the relevance of the results It is based on five main categories of search terms: population, data analysis method, measurement method, group differences and evaluation justification. These categories include combinations of search terms and subject headings, where they existed and are linked using search operators “AND” to increase specificity of the search. Within each category, terms are connected by the search operators “OR” or “adj” (or the corresponding linguistic equivalent in the respective database) to optimize sensitivity. In some cases, more complex combinations of terms are used to capture specific concepts more precisely. This multidimensional search strategy allows for a comprehensive literature search while maximizing the precision of the results, which is essential given the broad field of research and the complexity of the research question. For the majority of search terms, a Title/Abstract/Keyword search (or the corresponding equivalent of the database) was conducted. Where applicable, controlled vocabulary terms such as MeSH (Medical Subject Headings) in MEDLINE and equivalent indexing terms in other databases are incorporated to improve search precision. The resulting search will be provided in the final review.

Eligibility criteria The review focuses on studies published since 2010. This timeframe ensures that the most recent developments and innovations in the field are accurately represented, providing a current and relevant overview of the methodologies used. In particular, advances in AI-based approaches, particularly ML methods, have seen significant growth in both application and theoretical development over the past decade. By focusing on the most recent literature, this review highlights state-of-the-art techniques while reflecting the rapid technological advances that have fundamentally changed the field in recent years.

Studies are included if they are relevant to the research topic and if they are primary studies, that involve the analysis of raw or minimally processed data, that aims to generate new insights and is original, not a summary of previous findings. Participants in these studies must be alive, human individuals with MSK conditions. While there may be multiple participant groups, at least one of them must have an MSK condition, and this condition needs to be the main focus of the study. The measuring methods considered involve the use of at least one biomechanical measuring method, that collects time series data. Time series data is defined as a chronological sequence of data points, collected at regular intervals over time. Examples of these measuring methods are motion capture systems, electromyography (EMG) or Force Plate (FP) measurements. The resulting data should be able to capture changes over time, allowing for the analysis of trends, patterns, and temporal dynamics within that timeframe. Analysis methods included in this review should effectively discriminate between groups and are categorized as either statistical or AI-based approaches in a wide sense encompassing shallow (including statistical methods) and deep AI methods. These methods are used to analyse kinematic or kinetic parameters (such as joint angles, acceleration, velocity), movement quality or functional performance. Methods that can discriminate between groups, in this context, are able to identify and classify individuals into distinct categories based on specific health characteristics (e.g. disease or MSK conditions), movement patterns, or risk factors. This discrimination may take several forms, for example:

1. Distinguishing between individuals with a disease or condition and healthy controls
2. Distinguishing between individuals with different diseases or conditions
3. Identifying different stages of disease or condition within a population
4. Identifying different levels of risk of a disease or condition in individuals

The discriminative feature of the method does not refer to distinguishing between different movements of the same individual or between different muscle groups within a single individual. Rather, the focus is on inter-individual differences. To be eligible, studies must provide an evaluation of the applied analysis methods, such as classification accuracy, sensitivity, specificity, or other validation metrics.
Studies that use AI-based methods for data preprocessing, such as pattern recognition or dimension reduction, to prepare for group discrimination, are also of interest and will be included in this review.
Studies are excluded from this review if they do not involve human participants (e.g., movement analysis in robots), if they only analyse single-point measurements (e.g. Goniometer Measurements), only use non-biomechanical measuring methods (e.g. Questionnaires or observations), if they focus on participants with specific non-MSK diseases or conditions(e.g. internal or neurological disorders like diabetes or Parkinsons Disease), or if the analysis method cannot be used to distinguish between groups or does not provide an evaluation of the applied analysis methods.

The eligibility criteria and background information were built up on these references:
Alzahrani, Abdullah; Ullah, Arif (2024): Advanced biomechanical analytics: Wearable technologies for precision health monitoring in sports performance. In: Digital health 10, 20552076241256745. DOI: 10.1177/20552076241256745.
De, Sagnik; Mukherjee, Prithwijit; Roy, Anisha Halder (2025): GLEAM: A multimodal deep learning framework for chronic lower back pain detection using EEG and sEMG signals. In: Computers in biology and medicine 189, S. 109928. DOI: 10.1016/j.compbiomed.2025.109928.
Halilaj, Eni; Rajagopal, Apoorva; Fiterau, Madalina; Hicks, Jennifer L.; Hastie, Trevor J.; Delp, Scott L. (2018): Machine learning in human movement biomechanics: Best practices, common pitfalls, and new opportunities. In: Journal of biomechanics 81, S. 1–11. DOI: 10.1016/j.jbiomech.2018.09.009.
Liu, Yanyan; Chen, Jun; Liu, Ruiping; Chen, Chunyan; Wan, Xinzhu; Yu, Wanqi et al. (2025): High risk of falling in elderly with hallux valgus evaluated by muscle and kinematic synergistic analysis. In: Gait & posture 118, S. 33–38. DOI: 10.1016/j.gaitpost.2025.01.025.
Mündermann, Lars; Corazza, Stefano; Andriacchi, Thomas P. (2006): The evolution of methods for the capture of human movement leading to markerless motion capture for biomechanical applications. In: Journal of neuroengineering and rehabilitation 3, S. 6. DOI: 10.1186/1743-0003-3-6.
Phinyomark, Angkoon; Petri, Giovanni; Ibáñez-Marcelo, Esther; Osis, Sean T.; Ferber, Reed (2018): Analysis of Big Data in Gait Biomechanics: Current Trends and Future Directions. In: Journal of medical and biological engineering 38 (2), S. 244–260. DOI: 10.1007/s40846-017-0297-2.
Rodríguez-Gude, Clara; Taboada-Iglesias, Yaiza; Pino-Juste, Margarita (2023): Musculoskeletal pain in musicians: prevalence and risk factors - a systematic review. In: International journal of occupational safety and ergonomics : JOSE 29 (2),

S. 883–901. DOI: 10.1080/10803548.2022.2086742.
Sakamoto, Sei-Ichi; Hutabarat, Yonatan; Owaki, Dai; Hayashibe, Mitsuhiro (2023): Ground Reaction Force and Moment Estimation through EMG Sensing Using Long Short-Term Memory Network during Posture Coordination. In: Cyborg and bionic systems (Washington, D.C.) 4, S. 16. DOI: 10.34133/cbsystems.0016.
Senvaitis, Karolis; Adomavičienė, Aušra; Daunoravičienė, Kristina (2025): Framework Using Multicriteria Analysis for Evaluating the Risk of Musculoskeletal Disorders. In: Sensors (Basel, Switzerland) 25 (2). DOI: 10.3390/s25020444.
Yona, Tomer; Kamel, Netanel; Cohen-Eick, Galya; Ovadia, Inbar; Fischer, Arielle (2024): One-dimension statistical parametric mapping in lower limb biomechanical analysis: A systematic scoping review. In: Gait & posture 109, S. 133–146. DOI: 10.1016/j.gaitpost.2024.01.018.

Source of evidence screening and selection

Software Tool:
Covidence is used as the primary tool for screening and data extraction.
Search Strategy:
A systematic three-step search strategy is employed to ensure comprehensive literature coverage. Three reviewers are involved in the screening and extraction process.
In the first step, a preliminary search using predefined terms is conducted by one researcher across two databases.
In the second step, the final search strategy is developed iteratively, including a bibliographic co-occurrence network for a comprehensive bibliographic analysis to visualize relations between search terms. This helps to identify relevant terms based on frequent co-occurrence in the literature, ensuring that the search strategy is effective in capturing relevant studies. A librarian then helps to refine the final search strategy. Pre-identified relevant papers are cross-checked to ensure they are included in the search. The search is first conducted in MEDLINE and then translated and applied to the other databases. One reviewer develops these translations, which are then checked by the other two.
In the third step, the reference lists of the studies included in the final review are searched for additional sources.
Evidence Screening:
A pilot title/abstract screening is conducted on 25 randomly selected title/abstracts. All three reviewers screen these samples based on the eligibility criteria. Discrepancies are discussed among the team, and necessary modifications to the criteria are made. Title and abstract screening begins once at least 75% agreement is reached.
Before screening, duplicates are removed, prioritizing records with abstracts. Records without abstracts are excluded. During title/abstract screening, each study is independently reviewed by at least two reviewers. Inclusion/exclusion is based on the eligibility criteria, decisions are made blindly by the researchers. Disagreements are resolved through consensus, or if needed by the third reviewer. Studies marked as “Yes” or “Maybe” by at least two reviewers proceed to full-text screening.
Full texts are automatically retrieved via Covidence or obtained through databases, contains author contact, or ZBmed Cologne if necessary.
A pilot full-text screening is conducted on five randomly selected studies, based on the eligibility criteria. All reviewers independently assess the sample studies. Discrepancies are discussed and necessary modifications to the criteria are made.
In full-text screening each study is assessed by at least two reviewers. Inclusion/exclusion decisions are made blindly, and disagreements are resolved through consensus, by a third reviewer if needed. Studies included by at least two reviewers are selected for final inclusion.
Following this, a pilot data extraction is carried out to test the draft extraction table. All three reviewers extract data from two randomly selected studies, that are selected for final inclusion. Any inconsistencies in extraction are discussed, and the table is revised as needed before proceeding full extraction.
Studies agreed upon for final inclusion will be subject to data extraction. Disagreements between two reviewers will be resolved through consensus, or the third reviewer if needed. The results of the search and the study selection process will be documented in the final scoping review and presented visually in the PRISMA ScR flow chart.

Data management PRISMA-ScR guidelines and instruments are used as references for the review ensure methodological rigor.
A draft charting table is developed to systematically record extracted information, capturing the key information such as:
• General information (e.g. title, authors, year of publication, study design)
• Population and sample size (e.g. health conditions, number of groups)
• Assessed movement(s)
• Measuring Method(s) (e.g. what method, location of sensors/markers, measured parameters)
• Analysis Method(s) (Preprocessing & Analysis)
• Evaluation Method (how was the analysis method evaluated).

Reporting results / Analysis of the evidence The review employs qualitative content analysis to systematically summarize the AI-based methods used to discriminate between groups from biomechanical movement assessments in humans with MSK conditions and the various preprocessing techniques involved, as well as their methodological benefits.

Presentation of the results Tables and figures will present the extracted data for each extraction category, followed by detailed descriptive analysis.

Language restriction Search will be limited to sources in English, because of the costs and time involved in translating material from foreign languages.

Country(ies) involved Germany; Canada.

Keywords Artificial Intelligence; Human Movement analysis; Musculoskeletal; Group discrimination; Motion capture; EMG; Machine learning; Artificial Intelligence; Biomechanics.

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