International Journal of Innovation and Industrial Revolution IJIREV
EISSN: 2637-0972
Volume 8 Issue 25 (June 2026) PP. 369-387

INTERNATIONAL JOURNAL OF INNOVATION AND INDUSTRIAL REVOLUTION (IJIREV)
www.gaexcellence.com/ijirev

GLOBAL ACADEMIC EXCELLENCE

OCCUPATIONAL BIOMECHANICS RESEARCH: A BIBLIOMETRIC ANALYSIS OF THEMATIC EVOLUTION AND MODELLING TRENDS

Khairul Hafezad Abdullah[1*]

[1]Occupational Safety and Health Management Program, School of Business Management, Universiti Utara Malaysia, Malaysia
hafezad@uum.edu.my
https://orcid.org/0000-0003-3759-6541
[*]Corresponding Author

Article Info:

Article history:
Received date: 04.05.2026
Revised date: 24.05.2026
Accepted date: 21.06.2026
Published date: 30.06.2026

To cite this document:

Abdullah, K. H. (2026). Occupational Biomechanics Research: A Bibliometric Analysis of Thematic Evolution and Modelling Trends. *International Journal of Innovation and Industrial Revolution, 8*(25), 369-387.

Abstract:

Occupational biomechanics has developed into a diverse and steadily expanding field. It is shaped not only by advances in kinematics and modelling but also by changing workplace demands and technological pressures. This study presents a bibliometric mapping of research published from 1990 to 2025. This study utilises Scopus and Web of Science (WoS) to examine publication trends, geographical patterns, thematic evolution, and the modelling approaches. A total of 128 publications formed the final dataset, which was analysed using ScientoPy to trace performance indicators and shifts in authors' keywords. The findings indicate a gradual increase in research activity, with significant growth after 2005. The United States emerges as the leading contributor, followed by Canada and the Netherlands, while several countries show emerging but modest contributions. Thematic patterns also change considerably over time, where early work emphasised biomechanical modelling and movement mechanics, while later periods introduced ergonomics, musculoskeletal disorders, manual handling, and, most recently, wearable sensors and integrated cognitive–physical ergonomics. This bibliometric analysis further reveals that biomechanical, musculoskeletal, skeletal, digital human, and response surface models each contribute distinct analytical strengths. The results indicate a shift in the field from laboratory-based modelling toward applied, technology-enabled, and context-sensitive inquiry. The study emphasised the need for deeper interdisciplinary engagement and future exploration of Artificial Intelligence (AI)-driven analytics in occupational biomechanics.

DOI: 10.35631/IJIREV.825023

Keyword:
Biomechanical Risk Modelling, Occupational Biomechanics, Predictive Safety Analytics, Science Mapping, Thematic Evolution

Introduction

Occupational biomechanics has long been an important field at the intersection of ergonomics, human factors, occupational health and workplace safety. Over several decades, the field has evolved from a relatively narrow focus on mechanical movement and physical loading. This is important for ensuring that this field aligns with a broader multidisciplinary domain concerned with understanding how workers interact with increasingly complex occupational environments. The human body's responses to repetitive movements, awkward postures, forceful exertions, and cumulative physical demands from work activities have been consistently studied by researchers (Dickerson et al., 2023; Erazo-Chamorro et al., 2023; Marras & Karwowski, 2021). Hence, occupational biomechanics is often portrayed as a technical discipline focused on kinematics, motion analysis, and tissue mechanics (LeVeau, 2024). Nevertheless, its evolution is closely linked to broader technological, organisational, and socio-economic changes that are reshaping modern workplaces (Anacleto Filho et al., 2024; Babangida et al., 2025).

Today's workplaces are characterised by instant technological change, ageing workforces, automation and ever-increasing productivity expectations. These developments have heightened concern about work-related musculoskeletal disorders (WMSDs), fatigue, repetitive strain injuries, and long-term biomechanical exposure among workers (Nguyen et al., 2025; Patel et al., 2022). These issues indicate that decades of attempts at occupational intervention have not eliminated ergonomic risks among workers. These conditions have renewed scholarly and industrial interest in occupational biomechanics as a key foundation for designing safer tasks, improving ergonomic systems, and strengthening strategies to prevent occupational injuries. In the meantime, the emergence of new technologies such as wearable sensors, motion capture systems, smart monitoring devices, and Artificial Intelligence (AI)-driven analytics is slowly changing the way biomechanical risks are identified, interpreted and managed in organisations (Anacleto Filho et al., 2024; Babangida et al., 2025).

Despite this growing relevance, research in occupational biomechanics remains highly fragmented across disciplines and publication outlets. Existing studies are distributed across journals associated with ergonomics, occupational medicine, biomechanics, sports science, engineering, and rehabilitation sciences, each adopting different conceptual assumptions and methodological orientations (Azghani et al., 2023; Nunes et al., 2012; Öhlin et al., 2025; Tasso & Menoni, 2025; Whyte et al., 2018). While this diversity reflects the field's interdisciplinary nature, it also poses challenges for researchers and practitioners seeking to understand the broader intellectual trajectory of occupational biomechanics. It becomes increasingly difficult

International Journal of Innovation and Industrial Revolution IJIREV
EISSN: 2637-0972
Volume 8 Issue 25 (June 2026) PP. 369-387
to identify dominant research themes, recognise emerging methodological trends, determine influential contributors, and understand how theoretical perspectives have shifted over time. Consequently, there is a growing need for a systematic synthesis that can map the development of this field in a structured and comprehensive manner. In this regard, bibliometric analysis offers a valuable methodological approach for identifying publication patterns, thematic evolution, influential research clusters, and emerging scientific directions (Abdullah et al., 2023).

Bibliometric analysis is more than the measurement of publication growth. It enables scholars to interpret the evolution of research priorities and conceptual orientations. Analysis of publication trends, keyword networks, and thematic shifts. This has highlighted how occupational biomechanics has transitioned from traditional laboratory-based modelling to more applied, systems-oriented, and technologically integrated forms of inquiry (Abdullah et al., 2023). Previous work has largely focused on task-specific biomechanical assessment and mechanical load estimation. In contrast, the current research is increasingly incorporating broader concerns such as worker fatigue, cognitive ergonomics, human-machine interface and predictive risk modelling (Abdullah & Sofyan, 2023). This change reflects a broader trend in occupational safety and health research, in which systems thinking, organisational dynamics, behavioural considerations, and technology integration are now recognised as significant influences on workplace safety outcomes (Griffin et al., 2016).

At the same time, practical pressures in the workplace continue to influence the direction of research in occupational biomechanics. While workplace safety programmes have made progress, manufacturing plants, logistics centres, healthcare facilities, and agricultural industries continue to report high levels of ergonomic exposure and musculoskeletal strain (Loske et al., 2021; Mishra et al., 2024). The emergence of Industry 4.0 technologies has further stimulated interest in real-time monitoring, predictive analytics, digital human modelling, and intelligent ergonomic systems that enable proactive risk management (George, 2024; Zong & Guan, 2025). Nonetheless, these technologies raise new concerns about worker privacy, data ethics, sensor reliability, algorithmic transparency, and employee acceptance of monitoring systems. Such development shows that the occupational biomechanics is not restricted to mechanical assessment only. Instead, it is becoming a more integrated field that brings together engineering, ergonomics, occupational health, behavioural science and intelligent technologies in increasingly complex work environments.

The current study aims to address the growing demand for a systematic, integrated understanding of advances in occupational biomechanics research from 1990 to 2025. The study specifically aims to examine the growth patterns of publications, leading geographical contributors, thematic transitions across different periods, and the modelling approaches that have shaped the field over time. In addition, the study aims to provide a more complete analytical interpretation of the evolution of occupational biomechanics, from the traditional biomechanical modelling to the more intelligent, technology-assisted, and context-sensitive applications in occupational safety and health.

This bibliometric study offers descriptive and analytical perspectives on the evolution of occupational biomechanics research, incorporating performance analysis, country-level assessment, thematic evolution analysis, and methodological profiling. More importantly, the study contributes to improving our understanding of how evolving biomechanical knowledge continues to inform ergonomic risk assessment, injury prevention strategies, workplace design, and decision-making processes in modern occupational environments, which are characterised by technological transformation and increasing organisational complexity.

The four research questions guiding this study are outlined as follows:

1. How has research on occupational biomechanics evolved?
2. Which countries have contributed most to occupational biomechanics research?
3. How have research themes transitioned across periods?
4. What research models have been used in occupational biomechanics between 1990 and 2025?

Methodology

Data Collection

This study used two well-established databases, Scopus and the Web of Science (WoS), to search for relevant publications. The data retrieval was performed in December 2025. The selection of these databases was based on their reputation for reliability and comprehensiveness as sources of scholarly literature across multidisciplinary research fields (Nora et al., 2025). Furthermore, Scopus and WoS are characterised by broad journal coverage, stringent indexing processes, and extensive citation metadata, which are particularly valuable for bibliometric and science-mapping analysis (Abdullah & Sofyan, 2023).

The search strategy to retrieve publications on occupational biomechanics included the keywords “occupational biomechanics”, “workplace biomechanics”, “manual handling biomechanics”, and “postural biomechanics”. Systematic searches for these terms were performed across the title, abstract, and keyword sections of the databases. No restrictions on publication language were imposed at the initial search stage in order to maximise coverage of relevant studies. However, the analysis was limited to the period from 1990 to 2025 to reflect the field’s long-term evolution. Retrieved records were exported, screened and refined before bibliometric analysis. Next, the cleaned dataset was analysed with the help of ScientoPy, which allowed us to analyse the growth of publications, the evolution of themes, the evolution of keywords and the transitions of research trends over the selected period of time.

Data Cleaning and Preprocessing

The initial search in Scopus and Web of Science (WoS) databases yielded 214 records (see Table 1). During the first screening phase, 14 publications were excluded because they did not meet the predetermined document type criteria for this study. Therefore, only journal articles, conference papers and proceedings were analysed, yielding a final data set of 200 publications. From these records, 114 publications were indexed in Scopus, and 86 came from WoS. The relatively broader journal and conference coverage in Scopus for the occupational biomechanics research domain might explain the greater number of records retrieved from Scopus.

A duplicate check found 72 shared records, all from the Scopus set. However, no duplicates were found in the WoS records. After eliminating duplicates, the final dataset included 128 unique publications: 86 (67.2%) from WoS and 42 (32.8%) from Scopus. For a reliable bibliometric analysis, a dataset with more than 100 records is generally enough. However,

International Journal of Innovation and Industrial Revolution
IJIREV
EISSN: 2637-0972
Volume 8 Issue 25 (June 2026) PP. 369-387

narrative or scoping reviews are typically more suited to smaller datasets with fewer than 100 records (Abdullah, 2023).

Table 1: Data Cleaning and Preprocessing Summary

Information	Number	Percentage (%)
Loaded papers from Scopus and WoS	214	
Omitted papers by document type (kept only journal articles, conference papers, and proceedings)	14	6.50
Total papers after omitted papers removed	200	
Loaded papers from WoS	86	43.00
Loaded papers from Scopus	114	57.00
Duplicated papers found	72	36.00
Removed duplicated papers from WoS	0	0.00
Removed duplicated papers from Scopus	72	63.20
Total papers after duplicates removed	128	
Papers from WoS (final dataset)	86	67.20
Papers from Scopus (final dataset)	42	32.80

Performance Analysis

A performance analysis was carried out in this study to address the first two research questions regarding the growth trajectory and distribution patterns of occupational biomechanics research. To answer RQ1, the annual publication data from Scopus and WoS were analysed and visualised to examine the trend in research output over time. This technique allowed the identification of productivity variation, periods of increased publication output, and new trends in the field (Sofyan et al., 2022). For RQ2, the analysis focused on country-wise scholarly contributions by categorising publications by authors' institutional affiliations (Abdullah, 2021). The dominant contributing countries were visualised using the country trend analysis functions in ScientoPy, differentiating established contributors from emerging research participants. It examined changes in global research engagement in the selected period.

Science Mapping Analysis

The second part of the analysis focused on the intellectual structure and methodological development of occupational biomechanics research. To answer RQ3, a thematic evolution analysis was conducted on keywords extracted from the selected publications. To maintain analytical consistency, the study period was divided into four discrete timeframes: 1990-1999, 2000-2009, 2010-2019, and 2020-2025. These time periods were chosen to coincide with the evolution of research themes over decades, including the emergence of new themes, the endurance of established themes, and the decline of less significant areas. Keyword frequency distributions were generated for each period using ScientoPy. Next, the ten most frequent keywords in each interval were analysed to reveal thematic shifts and changing research priorities within occupational biomechanics.

Based on the previous section, the study also developed a conceptual overview of the modelling approaches used across the occupational biomechanics literature to answer RQ4. In this process, concepts and terms related to modelling were first identified from the dataset and then systematically linked to the corresponding studies. Then, a classification table was developed to summarise the main objective of each model, its key findings and its applications. Overall, this mapping provides a more complete picture of the evolution of modelling preferences, analytical techniques and methodological orientations in occupational biomechanics research between 1990 and 2025.

Evolutionary Trends in Occupational Biomechanics Research

Figure 1 shows the trend in research publications in occupational biomechanics from 1990 to 2025. Based on the figure, the number of publications increased slowly over time, although the pattern was not completely consistent. In the 1990s, only a small number of publications per year were reported, indicating that the field was still in its early stages of development. After 2005, the research activity increased more noticeably, with a stronger increase in WoS than in Scopus. WoS had the highest number of publications in 2012, with 10. Since 2016, publication activity has stabilised, and WoS publishes 3-7 papers per year. Scopus, while having fewer publications overall, did show some growth, especially in 2023, which had five publications, the highest for any year. The field continued to attract research interest between 2020 and 2025, although publication patterns in both databases remained somewhat fluctuating.

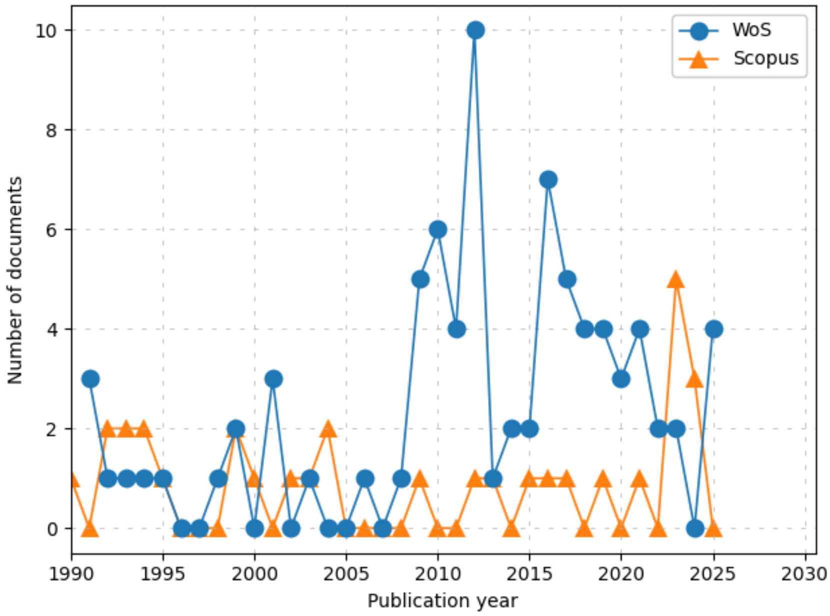

Figure 1: Growth of Occupational Biomechanics Research

Country Contributions to Occupational Biomechanics Research

Figure 2 shows country-level trends in the number of publications on occupational biomechanics research from 1990 to 2025. The results show that the U.S. is the main contributor and that publication output has increased steadily throughout the period. The next most active contributors are Canada and the Netherlands, both of which have shown steady growth and consistent research activity, especially over the last decade. Meanwhile, countries such as Brazil, Taiwan, Denmark, Iran, Hungary, and Thailand show smaller but increasing publication trends, indicating emerging research participation in the field of occupational biomechanics.

International Journal of Innovation and Industrial Revolution
IJIREV
EISSN: 2637-0972
Volume 8 Issue 25 (June 2026) PP. 369-387

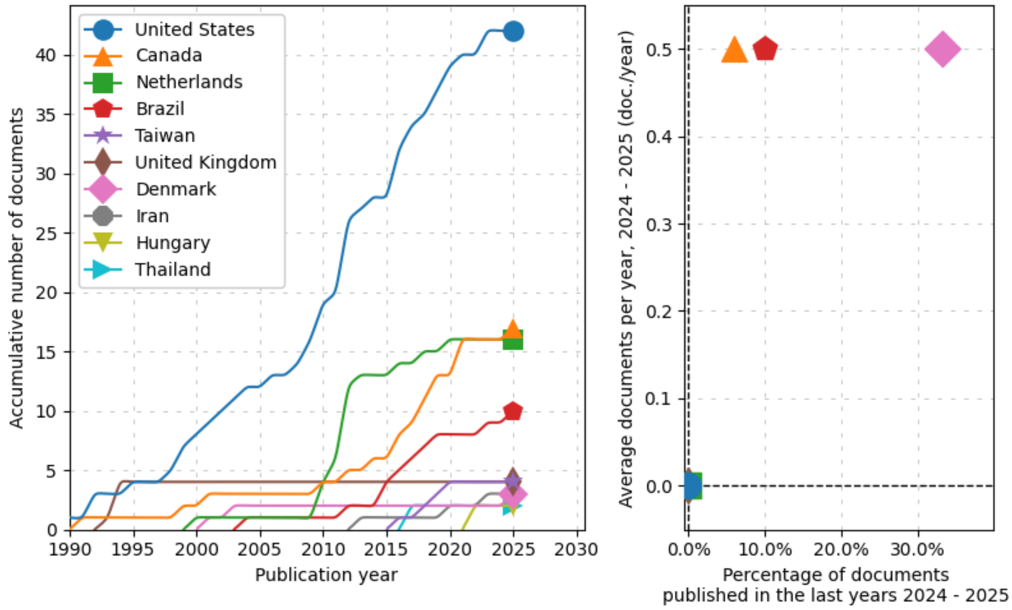

Figure 2: Country-level Analysis

The recent-year impact analysis (2024 and 2025) further highlights Canada, Brazil, and Denmark as active contributors, each producing an average of around 0.5 documents per year during this period. Their higher publication rate in the final two years indicates ongoing engagement and sustained research momentum. In contrast, several countries show negligible output in the most recent period, suggesting limited or declining activity.

Research Themes Transitioned from 1990 to 2025

Figure 3 shows the main research themes in occupational biomechanics during 1990-1999. The era was characterised by a predominant interest in biomechanical modelling, biomechanics and kinematics. There was an evident favour for the classical physical and mathematical approaches. Research efforts have often been aimed at analysing the mechanics of human movement (Conlan et al., 1995), estimating joint loading (Ayoub, 1998) and creating computational models of tasks associated with work (Wright & Brown, 1993; 1994). There were also several smaller themes, such as computer-aided instruction and computer systems, that showed an early interest in digital technologies. However, these were still somewhat limited in the field (Washington et al., 1999). Moreover, Electromyography (EMG) highlights the early development of studies of laboratory-based muscle activity, but on a smaller scale (Bloswick & Chaffin, 1990).

The early 2000s seem to have witnessed an expansion of the research landscape (see Figure 4). Keywords like ergonomics, joint discomfort, musculoskeletal disorders and posture are now in the spotlight. This transition reflects a change in occupational biomechanics from pure modelling towards understanding the epidemiology of musculoskeletal disorders (MSDs) (Laursen et al., 2003) and the ergonomic risk factors that impact workers' health (Marras et al., 2009). The presence of biomechanics suggests continuity with the previous period, but its co-occurrence with discomfort, MSDs, and assessment techniques indicates a shift towards workplace-centred applications. It was the decade when 'applied biomechanics' became firmly embedded in discussions of occupational safety and health (OSH) (Elliott & Satterberg, 2004). This time also reflects a growing interdisciplinary dialogue, and crossover with biomedical engineering, for example, in biomedical signal processing, would indicate an increase in the sophistication of measurement techniques (Cifrek et al., 2009).

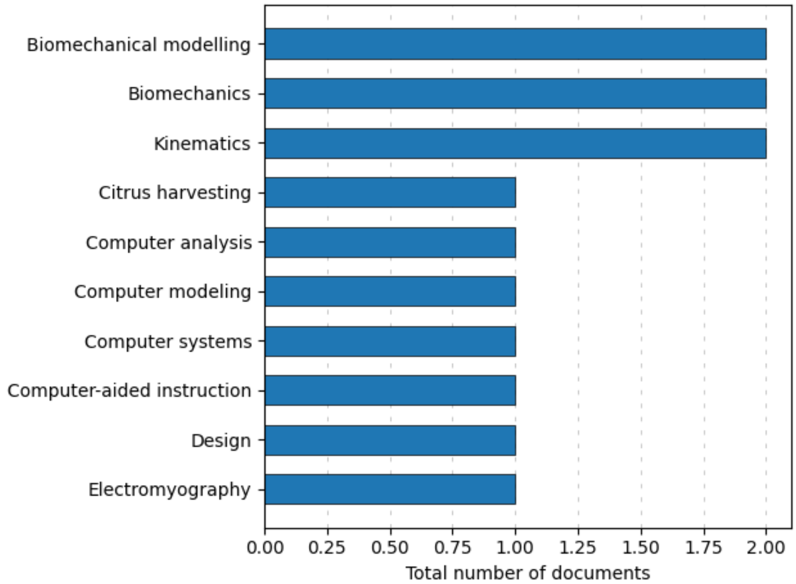

Figure 3: Overview of Research Themes from 1990 to 1999

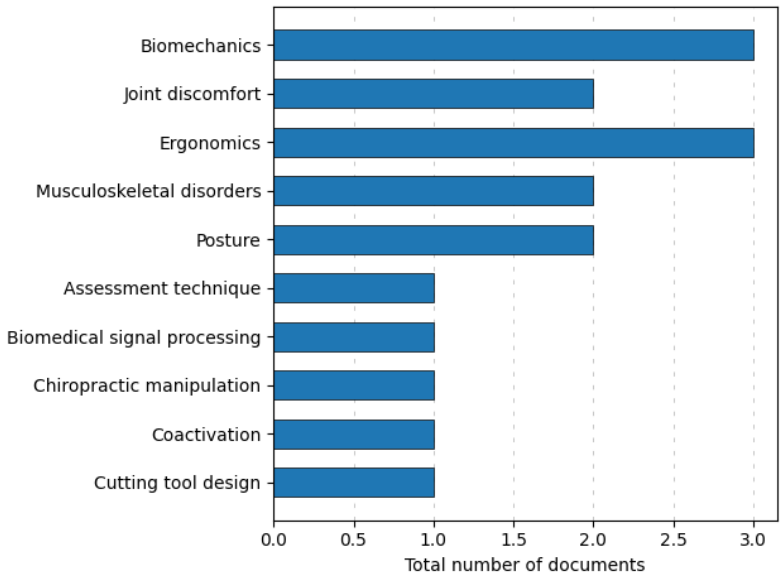

Figure 4: Overview of Research Themes from 2000 to 2010

The period from 2010 to 2019, shown in Figure 5, shows the field maturing and expanding significantly. Dominant themes are ergonomics, manual materials handling, low-back pain, lifting, spine and human motion prediction. This suggests a growing emphasis on real-world occupational tasks, especially those involving lifting and repetitive physical workloads. EMG, kinematics, and spine-related terms persisted, showing continuity with previous periods and now forming part of a broader discourse on ergonomics. The rise of ambulatory measurement is a sign of a move from laboratory-based to field-based measurement (Faber et al., 2013) and is enabled by using portable sensors and wearable devices. In terms of themes, it is a time of

International Journal of Innovation and Industrial Revolution
IJIREV
EISSN: 2637-0972
Volume 8 Issue 25 (June 2026) PP. 369-387

consolidation, translation, and expansion, where basic biomechanical principles are being applied to complex workplace problems in a more systematic, technology-assisted manner.

The last period, as shown in Figure 6, shows a definitive move towards modern, technology-enhanced biomechanics. Keywords such as wearable sensors, physical ergonomics, muscle fatigue, postural control, and cognitive theories point to a more comprehensive understanding of worker performance. The continuing rise in biomechanics is not surprising, but the simultaneous rise in sensor-based assessment indicates a methodological shift (Faber et al., 2020). The joint consideration of cognitive and physical ergonomics suggests a growing awareness that biomechanical risk cannot be reduced solely to mechanical and cognitive loads (Yang et al., 2021). One likely reason is that fatigue and task complexity matter, too. This period also saw increased interest in integrated systems. This is due to our ability to understand how body mechanics, worker perception, sensor data and job design interact to impact risk. In brief, 2020–2025 marks the rise of next-generation occupational biomechanics, where real-time monitoring, AI-ready datasets and multi-dimensional ergonomics frameworks complement traditional modelling approaches (Anacleto Filho et al., 2024).

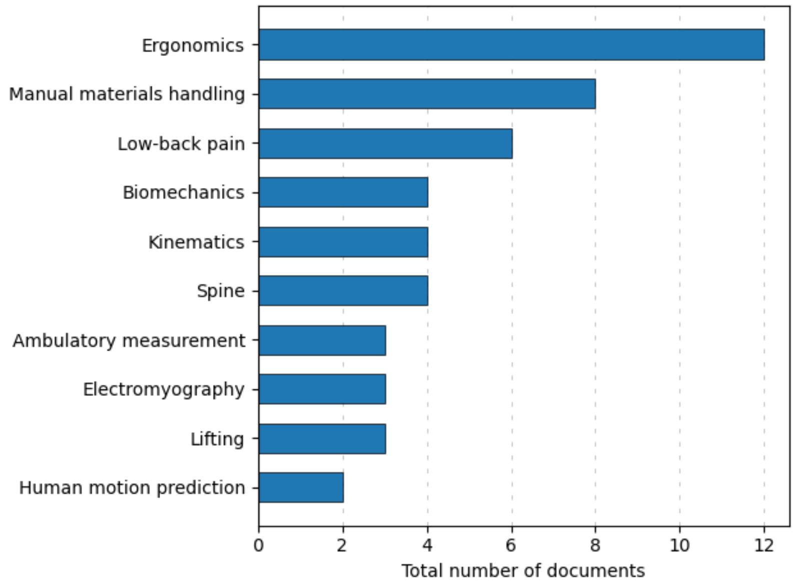

Figure 5: Overview of Research Themes from 2010 to 2019

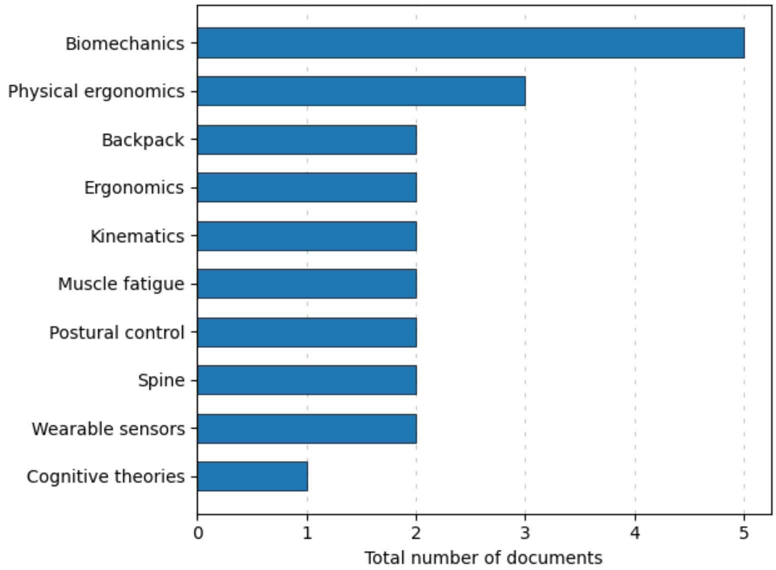

Figure 6: Overview of Research Themes from 2020 to 2025

Research Models Identified Across Occupational Biomechanics Studies

Figure 7 displays the distribution of modelling methods in occupational biomechanics research from 1990 to 2025. The most salient term, biomechanical modelling, reflects its centrality as the dominant analytical framework throughout the period. These studies also often used musculoskeletal and skeletal models. This is consistent with the work on estimating joint loads, muscle forces, and spinal mechanics during occupational tasks. The presence of digital human models indicates the growing use of simulation-based tools to predict posture and movement in ergonomic assessments. A minor but important contribution is the response surface model, mainly used for optimisation and predictive analysis.

Figure 7: Word Cloud of Modelling Approaches in Occupational Biomechanics

The studies related to the modelling approaches identified in the word cloud in Figure 7 are presented in Table 2. The earliest contributions in this set are by Wright and Brown (1993, 1994), who were experimenting with computer-based biomechanical models when such

International Journal of Innovation and Industrial Revolution
IJIREV
EISSN: 2637-0972
Volume 8 Issue 25 (June 2026) PP. 369-387
techniques were still unconventional in product design. They began in rehabilitation engineering; their work aimed at capturing the subtle ways people interact with tools and household devices. Their simulations produced more than a technical demonstration. The models showed design features that quietly imposed strain, especially on older users or those with physical constraints. These studies, in their own humble way, indicated the potential of computational modelling to guide the design of safer products.

Table 2: Modelling Approaches from 1990 to 2025

Model Type	Sources	Model Purpose	Key Findings
Biomechanical modelling	Wright & Brown (1993)	To introduce a system emphasising user–product mechanical interaction using anthropometric and mechanical analysis	Demonstrated feasibility of a computer-based design-analysis framework for ergonomics and occupational biomechanics
	Wright & Brown (1994)	To refine a computer-based modelling system for analysing biomechanical interaction between users and products	Modelling identified inappropriate product design features; case studies demonstrated the need to adjust models for elderly and special-population users.
	Pranav et al. (2023)	To quantify joint loads during railway inspection and hammering tasks using OpenSim	Identified hip, lumbar, and shoulder as peak-load sites; age and weight significantly predicted WMSD pain patterns
Skeletal models	Chumacero & Yang (2016)	To review skeletal-based prediction methods (OBMG and CBMG) for STS and lifting	Identified two main biomechanical prediction approaches; highlighted relevance for tasks linked to low-back pain
Digital human models	Chaffin (2009)	To explore simulation models in predicting overexertion injury risk	Demonstrated that digital human models support proactive ergonomic design by identifying injury-related biomechanical stressors
Musculoskeletal model	Ataei et al. (2020)	To evaluate how a wearable lift-assist vest affects muscle loading during squat lifting	EMG and optimisation modelling showed that the device reduced erector spinae forces by 45.38% and 42.03%.
Response surface model	Azghani et al. (2023)	To model trunk torques across multiple postural angles using second-order RSM	RSM accurately predicted extension, bending, and rotational torques; recommended as a tool for ergonomic risk assessment.

The study by Pranav et al. (2023) illustrates the progress in the field of occupational biomechanics. They used OpenSim software to model the physically demanding routines of railway gangmen who walk long distances carrying tools weighing close to 18 kilograms. The model showed significant loadings for the hip, lumbar and shoulder regions and age and body weight were found to be significant predictors of reported pain in the subsequent regression analysis. The value of biomechanical modelling is more tangible. It gives shape to the hidden effort within routine tasks, turning workers' descriptions of discomfort into quantifiable mechanical patterns.

The review by Chumacero and Yang (2016) shows a trend towards skeletal modelling. Their work focused on sit-to-stand and lifting tasks, two seemingly mundane movements that nonetheless place complex demands on the body's stability and torque. In this review, we clarify how the Optimisation-based motion generation (OBMG) and Control-based motion generation (CBMG) approaches, two main predictive approaches, approximate motion and where they succeed or struggle. The wider implications become more apparent when viewed alongside Chaffin's (2009) research on digital human models, which positioned simulation as a tool to anticipate overexertion and inform proactive ergonomics programmes.

Ataei et al. (2020) used a combination of musculoskeletal modelling and muscle electromyography (EMG) data to evaluate a wearable lift-assist vest. Their findings show significant reductions in erector spinae muscle forces and provide a glimpse of how modelling can be used to assess not only human effort but also technological interventions designed to reduce it. The latest example presented in Table 2 is the response surface model (RSM) developed by Azghani et al. (2023). By estimating trunk torques across different postures, their model provides an efficient way to predict loading patterns that are difficult to measure experimentally. This is a reminder that, over time, the modelling has matured into a practical tool for examining capacity limits and predicting injury risk in occupational settings.

Discussion

This study aimed to investigate the evolution of occupational biomechanics research, identify thematic changes across different time periods, and analyse the modelling approaches that have shaped the field. The general trend of publications from 1990 to 2025 shows the development of occupational biomechanics from a relatively narrow area of study into a broader, more applied research domain. Although publication activity was sparse in the first years, the field has grown significantly since the mid-2000s. This trend reflects a growing recognition in both academia and industry of the biomechanical hazards associated with occupational tasks, particularly those involving repetitive motions, awkward postures, and strenuous physical activity (Brambilla et al., 2023).

The rise in publications after 2005 also reflects broader developments within occupational safety, ergonomics and technological innovation. During this time, issues concerning ageing workers, musculoskeletal disorders, and workplace productivity became increasingly prominent across sectors (Nygaard et al., 2022; Valentim et al., 2025). Meanwhile, advances in wearable technologies, sensor systems, and biomechanical measurement tools have enhanced researchers' ability to study workplace movement and physical exposure accurately (Babangida et al., 2025). Hence, occupational biomechanics research has progressively shifted from purely theoretical modelling to practical applications assisting in injury prevention and ergonomic interventions in actual working settings (Panariello et al., 2022). The increased publication growth in WoS may also reflect the greater visibility of the ergonomics and applied occupational health journals included in the database during this period.

The country-level results further show that occupational biomechanics research remains concentrated in highly industrialised countries, particularly the United States, Canada, and the Netherlands. These countries have sustained strong publication activity over time, perhaps explained by their well-developed research infrastructure, improved occupational health policies, and sustained investment in ergonomics and workplace safety research (Frank et al., 2023). Emerging contributions from countries such as Brazil, Taiwan, Denmark and Thailand suggest that the interest in occupational biomechanics is slowly spreading beyond traditional research centres. Nevertheless, publication activity in many developing countries remains relatively low. Differences in research funding, access to advanced technologies, interdisciplinary collaboration, and technical expertise may continue to shape global participation in this field.

The analysis of thematic evolution shows that occupational biomechanics research has undergone significant conceptual changes over the last three decades. The research themes in the 1990s were mainly related to mechanical modelling, kinematics, and fundamental movement analysis, with a clear focus on laboratory-based biomechanical investigations. The next decade saw the field begin to concentrate more on ergonomics, discomfort, posture and musculoskeletal disorders. This reflected growing concern about workplace-related health problems. During the 2010s, there was an increasing focus on issues such as manual materials handling, lifting tasks, spine loading, and human motion prediction, which was encouraged by advances in motion analysis technologies and portable measurement systems. More recently, research interest has expanded to wearable sensors, fatigue assessment, postural control, and the integration of cognitive and physical ergonomics. These thematic shifts indicate that occupational biomechanics is becoming increasingly interdisciplinary, incorporating elements of engineering, ergonomics, occupational health, behavioural science, and intelligent technologies. This aligns with broader trends in technical and engineering fields, where solving practical, context-oriented problems is becoming increasingly central to contemporary work environments (Wolff, 2020).

The results also highlight the growing heterogeneity of modelling approaches used in the research of occupational biomechanics. The field continues to focus primarily on biomechanical modelling, but other methods, such as musculoskeletal, skeletal, digital human, and response surface models, are increasingly important for supporting ergonomic analysis and injury prediction. Earlier modelling approaches were generally limited by the availability of computer power and the size of data sets, and the main focus was on estimating physical loads and identifying biomechanical strain. In contrast, modern modelling systems can incorporate electromyography (EMG), wearable sensors, optimisation techniques, and digital simulation tools to study complex human movements and workplace interactions (Ataei et al., 2020; Faber et al., 2013). The increasing applications of OpenSim, wearable-integrated systems, and predictive modelling tools also indicate a shift in occupational biomechanics toward more intelligent, technology-assisted, and data-driven approaches (Pranav et al., 2023). Moreover, the development of response surface models shows the ongoing efforts to improve the efficiency, predictive accuracy, and practical applicability of the methods used for ergonomic risk assessment (Azghani et al., 2023).

Conclusion

The bibliometric analysis of the occupational biomechanics research from 1990 to 2025 shows that the field has transformed from a laboratory-based, mechanically focused discipline to a more applied, technology-driven and interdisciplinary area of study. Over the three decades, publication activity rose steadily, research themes diversified, and modelling approaches evolved considerably, enabling more effective analysis of workplace tasks and biomechanical risks. The results also indicate that occupational biomechanics is playing an increasingly important role in the field of occupational health and safety, especially in promoting ergonomic workplace design, identifying musculoskeletal hazards, and guiding preventive actions. Beyond this, the field is gradually moving towards intelligent, data-driven and integrated ergonomic systems for proactive evidence-based workplace safety management.

Practical Implications

The findings underscore a growing need for organisations to integrate biomechanical insights into everyday OSH decision-making. Wearable sensors, musculoskeletal modelling and digital human simulations provide opportunities to design safer tasks, evaluate high-risk postures and support ageing or vulnerable workers. For practitioners, this means developing the capacity to interpret biomechanical data, translate it into actionable recommendations, and to balance technological advances with human-centred considerations such as comfort, fatigue, and job autonomy. The growing evidence base can also be used by policymakers to develop more transparent ergonomic standards and facilitate proactive risk management.

Limitations and Future Research Directions

The study has some limitations due to its reliance on Scopus and WoS databases, which do not include all regional publications, industry reports, and sector-specific studies on occupational biomechanics. Moreover, the consistency and quality of the authors' keywords are critical for the thematic analysis, which can influence the interpretation of research trends. Clear publication patterns were identified; however, the relatively small number of studies in some periods may limit more detailed quantitative analysis of thematic transitions over time.

Future research should expand database coverage to include local and industry-specific sources, especially from underrepresented regions. There is also increasing potential to explore the roles of Artificial Intelligence (AI), machine learning, and advanced sensing technologies in improving predictive biomechanics and ergonomic risk assessment, especially in high-risk, dynamic work settings. Comparison studies across industries can provide additional insights into the challenges and opportunities in implementing biomechanical tools. Also, more interdisciplinary collaboration among ergonomists, psychologists, designers, and data scientists could help us better understand the interplay among cognitive, organisational, and biomechanical factors impacting worker safety and wellbeing.

Acknowledgements:	The author would like to thank the reviewers for their valuable comments and constructive feedback, which helped improve the quality of this paper. The author also sincerely appreciates Perpustakaan Sultanah Bahiyah, Universiti Utara Malaysia, for providing access to the Scopus and Web of Science (WoS) databases used in this study.
Funding Statement:	No Funding.
Conflict of Interest Statement:	The author declares that there is no conflict of interest regarding the publication of this paper. The author confirms full responsibility for the preparation, writing, and approval of the final version of the manuscript submitted to the International Journal of Innovation and Industrial Revolution (IJIREV).
Ethics Statement:	This study did not involve human participants, animals, or sensitive data requiring ethical approval. The author confirms that the research was conducted in accordance with accepted academic integrity principles and ethical publication standards.
Author Contribution Statement:	The author was solely responsible for the conceptualisation, methodology, data collection, analysis, interpretation of findings, and preparation of the manuscript. The author also reviewed and approved the final version of the manuscript prior to submission.

International Journal of Innovation and Industrial Revolution
IJIREV
EISSN: 2637-0972
Volume 8 Issue 25 (June 2026) PP. 369-387

References

Abdullah, K. H. (2021). Four decades research on higher vocational education: A bibliometric review. *Journal of Vocational Education Studies*, *4*(2), 173-187. https://doi.org/10.12928/joves.v4i2.4297

Abdullah, K. H. (2023). An analysis of publications on climate change communication using a bibliometric lens. *Fronteira: Journal of Social, Technological and Environmental Science*, *12*(3), 354-371. https://doi.org/10.21664/2238-8869.2023v12i3.p354-371

Abdullah, K. H., & Sofyan, D. (2023). Machine learning in safety and health research: A scientometric analysis. *International Journal of Information Science and Management*, *21*(1), 17-37. https://doi.org/10.22034/ijism.2022.1977763.0

Abdullah, K. H., Roslan, M. F., Ishak, N. S., Ilias, M., & Dani, R. (2023). Unearthing hidden research opportunities through bibliometric analysis: A review. *Asian Journal of Research in Education and Social Sciences*, *5*(1), 251-262. https://doi.org/10.55057/ajress.2023.5.1.23

Anacleto Filho, P. C., Colim, A., Jesus, C., Lopes, S. I., & Carneiro, P. (2024). Digital and virtual technologies for work-related biomechanical risk assessment: A scoping review. *Safety*, *10*(3), 79. https://doi.org/10.3390/safety10030079

Ataei, G., Abedi, R., Mohammadi, Y., & Fatouraee, N. (2020). Analysing the effect of wearable lift-assist vest in squat lifting task using back muscle EMG data and musculoskeletal model. *Physical and Engineering Sciences in Medicine*, *43*(2), 651-658. https://doi.org/10.1007/s13246-020-00872-5

Ayoub, M. M. (1998). A 2-D simulation model for lifting activities. *Computers & industrial engineering*, *35*(3-4), 619-622. https://doi.org/10.1016/S0360-8352(98)00173-9

Azghani, M. R., Kian-Bostanabad, S., Meghdari, A., Parnianpour, M., & Farahmand, F. (2023). Normative database of response surface method for human trunk extension in isometric mode. *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine*, *237*(7), 855-868. https://doi.org/10.1177/09544119231177564

Babangida, A. A., Caraballo-Arias, Y., Decataldo, F., & Violante, F. S. (2025). Advancing occupational medicine through wearable technology: A review of sensor systems for biomechanical risk assessment and work-related musculoskeletal disorder prevention. *ACS Sensors*, *10*(8), 5410-5432. https://doi.org/10.1021/acssensors.5c01578

Bloswick, D. S., & Chaffin, D. B. (1990). An ergonomic analysis of the ladder climbing activity. *International Journal of Industrial Ergonomics*, *6*(1), 17-27. https://doi.org/10.1016/0169-8141(90)90047-6

Brambilla, C., Lavit Nicora, M., Storm, F., Reni, G., Malosio, M., & Scano, A. (2023). Biomechanical assessments of the upper limb for determining fatigue, strain and effort from the laboratory to the industrial working place: a systematic review. *Bioengineering*, *10*(4), 445. https://doi.org/10.3390/bioengineering10040445

Chaffin, D. B. (2009). The evolving role of biomechanics in prevention of overexertion injuries. *Ergonomics*, *52*(1), 3-14. https://doi.org/10.1080/00140130802479812

Chumacero-Polanco, E. A., & Yang, J. (2016, August). A review on human motion prediction in sit to stand and lifting tasks. In *International Design Engineering Technical Conferences and Computers and Information in Engineering Conference* (Vol. 50077, p. V01AT02A066). American Society of Mechanical Engineers. https://doi.org/10.1115/DETC2016-59891

Cifrek, M., Medved, V., Tonković, S., & Ostojić, S. (2009). Surface EMG based muscle fatigue evaluation in biomechanics. *Clinical Biomechanics*, *24*(4), 327-340. https://doi.org/10.1016/j.clinbiomech.2009.01.010

Conlan, T. M., Miles, J. A., & Steinke, W. E. (1995). Static lower back stress analysis in citrus harvesting. *Transactions of the ASAE*, *38*(3), 929-936.

Dickerson, C. R., McDonald, A. C., & Chopp-Hurley, J. N. (2023). Between two rocks and in a hard place: Reflecting on the biomechanical basis of shoulder occupational musculoskeletal disorders. *Human Factors*, *65*(5), 879-890. https://doi.org/10.1177/0018720819896191

Elliott, R., & Satterberg, J. (2004). State of the Art Work Measurement Systems: Linking Standard Data, Ergonomics, and Lean Concepts. In *IISE Annual Conference. Proceedings* (p. 1). Institute of Industrial and Systems Engineers (IISE).

Erazo-Chamorro, V. C., Arciniega-Rocha, R. P., & Szabo, G. (2023). Safety workplace: From of point of view of ergonomics and occupational biomechanics. *Acta Technica Napocensis-Series: Applied Mathematics, Mechanics, and Engineering*, *65*(3S), 669-676.

Faber, G. S., Chang, C. C., Kingma, I., & Dennerlein, J. T. (2013). Estimating dynamic external hand forces during manual materials handling based on ground reaction forces and body segment accelerations. *Journal of Biomechanics*, *46*(15), 2736-2740. https://doi.org/10.1016/j.jbiomech.2013.07.030

Faber, G. S., Kingma, I., Chang, C. C., Dennerlein, J. T., & Van Dieen, J. H. (2020). Validation of a wearable system for 3D ambulatory L5/S1 moment assessment during manual lifting using instrumented shoes and an inertial sensor suit. *Journal of Biomechanics*, *102*, 109671. https://doi.org/10.1016/j.jbiomech.2020.109671

Frank, J., Mustard, C., Smith, P., Siddiqi, A., Cheng, Y., Burdorf, A., & Rugulies, R. (2023). Work as a social determinant of health in high-income countries: Past, present, and future. *The Lancet*, *402*(10410), 1357-1367.

George, A. S. (2024). The fourth industrial revolution: A primer on industry 4.0 and its transformative impact. *Partners Universal Innovative Research Publication*, *2*(1), 16-40. https://doi.org/10.5281/zenodo.10671872

Griffin, M. A., Cordery, J., & Soo, C. (2016). Dynamic safety capability: How organisations proactively change core safety systems. *Organisational Psychology Review*, *6*(3), 248-272. https://doi.org/10.1177/2041386615590679

Laursen, B., Søgaard, K., & Sjøgaard, G. (2003). Biomechanical model predicting electromyographic activity in three shoulder muscles from 3D kinematics and external forces during cleaning work. *Clinical Biomechanics*, *18*(4), 287-295. https://doi.org/10.1016/S0268-0033(03)00004-4

LeVeau, B. (2024). *Biomechanics of human motion: basics and beyond for the health professions*. Routledge. https://doi.org/10.4324/9781003522775

Loske, D., Klumpp, M., Keil, M., & Neukirchen, T. (2021). Logistics work, ergonomics and social sustainability: Empirical musculoskeletal system strain assessment in retail intralogistics. *Logistics*, *5*(4), 89. https://doi.org/10.3390/logistics5040089

Marras, W. S., & Karwowski, W. (2021). Basic biomechanics and workplace design. *Handbook of Human Factors and Ergonomics*, 303-357. https://doi.org/10.1002/9781119636113.ch12

Marras, W. S., Knapik, G. G., & Ferguson, S. (2009). Loading along the lumbar spine as influence by speed, control, load magnitude, and handle height during pushing. *Clinical Biomechanics*, *24*(2), 155-163. https://doi.org/10.1016/j.clinbiomech.2008.10.007

Mishra, S., Bhagat, D., & Borah, S. (2024). Ergonomic studies on occupational health of women workers involved in agricultural industries: A systematic review. *Research on World Agricultural Economy*, *5*(4), 110-127.

Nguyen, A., Lee, P., Rodriguez, E. K., Chahal, K., Freedman, B. R., & Nazarian, A. (2025). Addressing the growing burden of musculoskeletal diseases in the ageing US population: challenges and innovations. *The Lancet Healthy Longevity*, *6*(5), 1-9.

Nora, S., Kuswardani, R. A., Mawardi, S., & Abdullah, K. H. (2025). Research trends on arabica coffee: A bibliometric analysis. *Coffee Science*, *20*, e202388. https://doi.org/10.25186/.v20i.2388

Nunes, N., Carnide, F., Batista, N., Arajo, T., Martins, G., Vieira, F., ... & Gamboa, H. (2012). Wireless platform for ergonomics evaluation of occupational biomechanical exposure. *Journal of Biomechanics*, *45*(1), 506. https://doi.org/10.1016/S0021-9290(12)70507-9

Nygaard, N. P. B., Thomsen, G. F., Rasmussen, J., Skadhauge, L. R., & Gram, B. (2022). Ergonomic and individual risk factors for musculoskeletal pain in the ageing workforce. *BMC Public Health*, *22*(1), 1975. https://doi.org/10.1186/s12889-022-14386-0

Öhlin, J., Stjernbrandt, A., Andersson, M., Järvholm, B., Lewis, C., Slunga Järvholm, L., ... & Liv, P. (2025). Occupational physical activity and stroke mortality in male Swedish construction workers between 1971 and 2015. *Occupational Medicine*, 75(7), 412–417. https://doi.org/10.1093/occmed/kqaf031

Panariello, D., Grazioso, S., Caporaso, T., Palomba, A., Di Gironimo, G., & Lanzotti, A. (2022). Biomechanical analysis of the upper body during overhead industrial tasks using electromyography and motion capture integrated with digital human models. *International Journal on Interactive Design and Manufacturing (IJIDeM)*, *16*(2), 733-752. https://doi.org/10.1007/s12008-022-00862-9

Patel, V., Chesmore, A., Legner, C. M., & Pandey, S. (2022). Trends in workplace wearable technologies and connected-worker solutions for next-generation occupational safety, health, and productivity. *Advanced Intelligent Systems*, *4*(1), 1-30. https://doi.org/10.1002/aisy.202100099

Pranav, T., Krishnan, A. A., Mahesh, R., Jithu, J., & Sajeesh, P. (2023). Biomechanical analysis of railway workers during loaded walking and keyman hammering. *Research on Biomedical Engineering*, *39*(3), 587-595. https://doi.org/10.1007/s42600-023-00290-y

Sofyan, D., Abdullah, K. H., & Hafiar, H. (2022). The philosophy of sport and physical education: Four decade publication trends via scientometric evaluation. *Physical Education Theory and Methodology*, *22*(3), 437-449. https://doi.org/10.17309/tmfv.2022.3.20

Tasso, M., & Menoni, O. (2025). REBA integrated with organisational analysis to assess the risk of biomechanical overload in physiotherapists. *Ergonomics*, 1-14. https://doi.org/10.1080/00140139.2025.2575065

Valentim, D. P., Comper, M. L. C., Sandy Medeiros Rodrigues Cirino, L., da Silva, P. R., Padilha Alonso Gomes, M., Martins da Silva, A., & Padula, R. S. (2025). Observational methods for the analysis of biomechanical exposure in the workplace: a systematic review. *Ergonomics*, *68*(10), 1561-1582. https://doi.org/10.1080/00140139.2024.2427864

Washington, N., Parnianpour, M., & Fraser, J. (1999). Development of a computer-aided instruction tutorial software for use in an occupational biomechanics and ergonomics undergraduate class. *Yixué gongchéng. Applications, Basis, Communications*, *11*(6), 305-314.

Whyte, E. F., Richter, C., O'connor, S., & Moran, K. A. (2018). The effect of high intensity exercise and anticipation on trunk and lower limb biomechanics during a crossover cutting manoeuvre. *Journal of Sports Sciences*, *36*(8), 889-900. https://doi.org/10.1080/02640414.2017.1346270

Wolff, K. (2020). Researching the engineering theory-practice divide in industrial problem solving. *European Journal of Engineering Education*, *45*(2), 181-195. https://doi.org/10.1080/03043797.2018.1516738

Wright, D. K., & Brown, R. (1993). A computer modelling system for the biomechanical interaction in product design. *Biomedical Sciences Instrumentation*, *29*, 129-134.

Wright, D. K., & Brown, R. (1994). Recent applications of a computer based modelling system for biomechanical interactions. *Biomedical Sciences Instrumentation*, *30*, 163-167.

Yang, J., Howard, B., & Baus, J. (2021). A collision avoidance algorithm for human motion prediction based on perceived risk of collision: part 1-model development. *IISE Transactions on Occupational Ergonomics and Human Factors*, *9*(3-4), 199-210. https://doi.org/10.1080/24725838.2021.1973613

Zong, Z., & Guan, Y. (2025). AI-driven intelligent data analytics and predictive analysis in Industry 4.0: Transforming knowledge, innovation, and efficiency. *Journal of the Knowledge Economy*, *16*(1), 864-903. https://doi.org/10.1007/s13132-024-02001-z