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Editorial

Research on Biomechanics, Equipment Development, Motor Control and Learning of Human Movements

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1. Introduction

Human movement science has evolved from largely independent disciplinary traditions into an increasingly integrated research field. Biomechanics provides the mechanical foundation of movement analysis [1–6], and motor control and motor learning explain the neural and behavioral organization of skilled actions [7–11], while equipment development and wearable technologies increasingly enable the augmentation, monitoring, and optimization of human performance [12–16]. Recent advances in artificial intelligence (AI), wearable sensing, computational modeling, and real-time feedback systems have accelerated this convergence and expanded the translational potential of movement science across sport, ergonomics, rehabilitation, clinical, and aging applications [17–23].

At the same time, important challenges remain. Many complex motor behaviors still lack comprehensive biomechanical characterization [24–26]. Traditional ergonomic assessments often rely on static or simplified models that inadequately represent dynamic human movement [27,28]. Moreover, despite rapid technological progress, the integration of real-time biomechanical monitoring, adaptive intervention systems, and motor learning principles remains incomplete [16,29,30]. As a result, the field is increasingly shifting from descriptive analysis toward predictive, personalized, and ecologically valid approaches capable of operating in real-world environments.

This Special Issue, "Research on Biomechanics, Equipment Development, Motor Control and Learning of Human Movements", was organized to highlight emerging advances across these interconnected domains. The published studies collectively demonstrate how contemporary movement science is evolving toward interdisciplinary integration involving biomechanics, equipment efficiency, wearable technology, AI-assisted analysis, musculoskeletal simulation, cybernetic modeling, and adaptive human-centered systems. Rather than representing isolated contributions, the articles in this Special Issue reveal broader trends shaping the future direction of human movement research.

2. Major Contributions of the Special Issue

A central contribution of this Special Issue is the advancement of movement analysis beyond static and laboratory-constrained paradigms toward dynamic, real-time, and context-sensitive approaches. Yu et al. [31] developed a novel biomechanical framework for quantifying dynamic ergonomic risks during aircraft maintenance tasks, illustrating how motion capture and computational modeling can improve the assessment of complex occupational movements beyond traditional posture-based scoring systems. Similarly, Kos et al. [32] addressed a major technological bottleneck in real-time biomechanical

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feedback by developing a lightweight scheduler architecture capable of supporting high-frequency wearable sensing with minimal latency. Together, these studies demonstrate the growing feasibility of closed-loop movement monitoring systems for occupational, sport and rehabilitation settings.

The Special Issue also highlights the increasing importance of personalized and application-oriented equipment evaluation. Riedl et al. [33] demonstrated that carbon plate running shoes significantly improved running economy in amateur athletes, while simultaneously revealing substantial inter-individual variability in biomechanical responses. Their findings reinforce the growing recognition that optimal equipment solutions are highly individualized rather than universally transferable. In parallel, Ebenbichler et al. [34] advanced exoskeleton evaluation by integrating musculoskeletal simulation with joint loading analysis, illustrating the importance of assessing internal biomechanical consequences beyond surface-level muscular activity alone.

Another major theme emerging from this collection is the transition toward ecologically valid and ambulatory movement analysis. Swafford et al. [35] highlighted the potential of wearable technologies for studying circus biomechanics and physiology, an area historically constrained by the practical limitations of laboratory-based measurements. Similarly, Wang et al. [36] used noncontact millimeter-wave radar and machine learning for emotion recognition in closed cabins, demonstrating how occupational research is increasingly expanding into real-world environments and previously understudied populations.

The Special Issue further contributes to the conceptual understanding of motor control and coordination. Morasso [37] synthesized multiple control paradigms into a cybernetic framework for balance regulation, emphasizing the dynamic interaction between center of mass and center of pressure control mechanisms. Collectively, these contributions reflect a broader transition from isolated biomechanical measurements toward integrated systems-level interpretations of human movement involving neural control, environmental interaction, and adaptive feedback processes [38–41].

3. Emerging Trends Revealed by the Special Issue

Beyond the individual findings of each article, several broader disciplinary trends emerge from this Special Issue.

Firstly, the integration of biomechanics with AI and computational modeling is becoming increasingly central to movement science. Recent developments in machine learning, predictive modeling, and simulation-based analysis are enabling researchers to move beyond descriptive biomechanics toward individualized prediction, adaptive intervention, and human-in-the-loop optimization [19,20,42,43]. The studies included in this Special Issue illustrate how biomechanical data are increasingly being integrated with intelligent analytical systems capable of supporting real-time decision making.

Secondly, the field is progressively shifting from laboratory-centered experimentation toward ecologically valid monitoring in real-world settings. Advances in wearable sensing, mobile computing, and wireless communication technologies now allow researchers to investigate movement behaviors in natural environments ranging from athletic performance to occupational tasks and daily living [16,44–46]. This transition represents a major methodological evolution in movement science, enabling the study of complex behaviors that cannot be fully reproduced under laboratory constraints.

Thirdly, the articles in this Special Issue reinforce the growing importance of personalization in both training and equipment design. Individual variability in motor strategies, biomechanical responses, fatigue adaptation, and injury risk has become increasingly recognized across motor learning, sports biomechanics, rehabilitation, and ergonomics research [47–49]. Consequently, future systems are likely to rely more heavily on individu-

alized biomechanical profiling and adaptive intervention strategies rather than generalized population-based approaches.

Finally, the convergence of biomechanics, motor control, motor learning, and assistive technologies suggests that movement science is entering a more integrative and translational phase. Rather than functioning as isolated sub-disciplines, these areas are increasingly interconnected through shared analytical tools, wearable technologies, computational methods, and feedback-driven intervention systems [17–19,50–52]. The studies published in this Special Issue collectively illustrate this broader transformation.

4. Future Directions

The findings presented in this Special Issue point toward several important future research directions.

One major priority involves the development of fully integrated closed-loop systems capable of combining real-time sensing, biomechanical analysis, and adaptive intervention. Although wearable technologies and high-frequency sensing architectures have advanced substantially [35], future systems must further integrate AI-driven movement classification, fatigue prediction, motor learning principles, and personalized feedback strategies [20,52,53]. Such systems may ultimately support real-time optimization in sport performance, rehabilitation, occupational ergonomics, and assistive device control.

Another critical direction concerns ecological validity and longitudinal monitoring. Future movement research should increasingly investigate human behavior within realistic environments and over extended time periods rather than relying exclusively on short-duration laboratory assessments [31,35,54]. Advances in wearable sensing, ambient monitoring, and mobile biomechanical technologies are expected to play an essential role in this transition.

The continued development of personalized equipment and assistive technologies also represents an important frontier. The variability observed in responses to running shoes [33] and exoskeleton systems [32] highlights the need for individualized optimization approaches integrating biomechanics, computational modeling, and motor adaptation processes [6–9]. Future systems may increasingly adapt dynamically to individual users based on biomechanical and physiological feedback.

Finally, future research should continue expanding toward inclusive and diverse populations. Although this Special Issue included studies involving occupational workers, rehabilitation contexts, and unique performer groups [31,32,35,36], substantial opportunities remain for research involving clinical populations, aging individuals, individuals with disabilities, and nontraditional movement environments [21–23,55]. Broadening the ecological and demographic scope of movement science will be essential for improving the translational impact of the field.

5. Conclusions

The studies published in this Special Issue demonstrate that contemporary human movement science is undergoing a significant transformation driven by the convergence of biomechanics, motor control, motor learning, wearable technology, computational modeling, and AI-assisted analysis. Collectively, the contributions move the field beyond isolated descriptive measurements toward more integrated, adaptive, and ecologically valid approaches capable of addressing complex challenges in sport, rehabilitation, occupational ergonomics, and human performance.

Importantly, the Special Issue highlights not only technological advances, but also a broader conceptual shift toward a systems-level understanding of human movement. Real-time feedback architectures, wearable sensing systems, musculoskeletal simula-

tions, cybernetic control models, and personalized equipment evaluation collectively illustrate how interdisciplinary integration is reshaping both research methodology and practical application.

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