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A Systematic Literature Review on Wearable Technology in Sports Performance and Injury Prevention

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Abstract

With the rapid advancement of wearable technology, this innovation has become a central focus for enhancing athletic performance and preventing sports-related injuries. This study systematically examines the impact of wearable technologies on performance-related indicators and injury prevention among athletes by integrating and analyzing relevant literature from the past five years. The research highlights key functions such as heart rate monitoring, fatigue assessment, and recovery tracking, which assist coaches and athletes in optimizing training strategies. The findings suggest that wearable devices—such as heart rate monitors and motion capture systems—enable real-time monitoring of athletes' physiological conditions, thereby enhancing adaptability during high-intensity training and competition while significantly reducing injury incidence. Moreover, wearable technology contributes to the improvement of both physical and psychological attributes, supporting the development of individualized training programs. Real-time data feedback offers valuable insights for evidence-based coaching decisions and sports medicine interventions. Future research should address existing technological limitations and broaden the applicability of wearable technologies across diverse sports disciplines and athlete populations.

Keywords: wearable technology, artificial intelligence, sports biomechanics, training fatigue, recovery indicators

1. Introduction

With the rapid advancement of digital technologies, wearable devices, and data analytics, the field of sports science has been profoundly transformed, offering new pathways for athletes to achieve optimal performance. Modern wearable technologies—such as advanced heart rate variability monitors, high-precision GPS trackers, and inertial motion capture systems capable of recording subtle biomechanical movements—have become indispensable tools for athletes and coaches seeking comprehensive physiological and biomechanical insights [25] These data enable athletes to objectively interpret physiological fluctuations and support the design of tailored, precision-based training strategies [18]. The integration of artificial intelligence (AI) further strengthens this process by providing individualized, data-driven insights, multidimensional performance analyses, and real-time feedback, thereby enhancing athletes' ability to reflect on and dynamically adapt training strategies. This technological convergence underscores the substantial potential for optimizing performance through precisely modulated, individualized training interventions.

Traditionally, training strategies have relied heavily on coaches' experiential judgment and subjective observation. However, as modern sports evolve toward greater specialization and data dependency, empirical approaches alone are no longer sufficient to meet athletes' increasingly complex demands [41]. Breakthroughs in wearable technology—particularly in endurance and team sports—now enable accurate, real-time performance monitoring, transforming training decisions from intuition-based to evidence-driven [33]. This paradigm shift replaces periodic assessments with continuous, data-informed optimization, facilitating the customization of training programs that align with individual physiological profiles and maximize performance potential [2,35].

Despite rapid technological progress, empirical evidence substantiating the concrete impacts of wearable technology on athletic performance remains limited. Existing studies primarily address device functionality and innovation, whereas systematic evaluations of real-world effectiveness, sport-specific applications, and ethical implications remain underdeveloped [61]. This limitation contributes to ongoing skepticism regarding data accuracy, reliability, and contextual applicability [14]. For instance, environmental variables such as temperature, humidity, and terrain can distort physiological and positional data [24]. Consequently, translating wearable-derived data into actionable insights for fatigue monitoring, injury prevention, and adaptive training design remains a central challenge in contemporary sports science.

Sports injuries—particularly those occurring in high-intensity disciplines—pose significant threats to athletes' health, performance, and career longevity [9,59]. To address this issue, many coaches have adopted Internet of Things (IoT) platforms integrated with big data analytics to identify behavioral and physiological patterns predictive of injury risk. Wilkerson et al. (2018) found that continuous monitoring of heart rate and training load can reduce injury risk by approximately 30%, underscoring the critical role of wearable technology in athlete health management. Similarly, Chidambaram et al. [10] and Kamper and Moseley [27] confirmed the effectiveness of wearables in enhancing performance and reducing injury incidence. Doherty et al. [13] emphasized the importance of monitoring variables such as heart rate, distance, and velocity while employing heart rate variability analysis to predict overtraining. Moreover, athletes' and coaches' acceptance of wearable technologies depends heavily on perceptions of accuracy, usability, and trustworthiness, all of which influence their adoption and integration into training practices [45].

In summary, this study aims to establish a comprehensive theoretical and practical foundation for optimizing wearable technology applications in sports science. Ongoing technological innovation continues to demonstrate the potential of wearable monitoring systems to reduce injury risks, capture sport-specific variations, and enhance the scientific precision of performance optimization strategies.

2. Literature Review

2.1 Wearable Technology (WT)

Wearable technology has become increasingly integral to the field of sports science. Through continuous data collection and analysis, these devices enable athletes to enhance performance while gaining deeper insights into training efficiency, recovery status, and overall health indicators [12]. However, realizing their full potential requires addressing persistent challenges related to data accuracy, user engagement, and ethical considerations. Devices such as inertial sensors, electromyography (EMG) sensors, and pressure sensors capture essential physiological variables—including heart rate, joint kinematics, and muscle activation—thereby improving the precision of athletic performance monitoring [1].

Wearable sensor devices (WSDs)—including pedometers, accelerometers, and GPS trackers—facilitate real-time monitoring of biomechanical movement, training load, and recovery status [24]. These technologies not only support injury prevention but also optimize training and rehabilitation by improving performance evaluation and enabling personalized training design [39]. In general, wearable technologies integrate monitoring, analytical, and data transmission functions aimed at enhancing athletic and health outcomes [58]. For instance, during the Tokyo 2020 Olympic Games, wearable systems were implemented to mitigate safety risks under extreme environmental conditions, allowing for real-time physiological monitoring and adaptive management of training intensity [18]. Specialized devices, such as smart gloves for runners, can monitor heart rate, oxygen saturation (SpO_2), and body temperature [51]. Nevertheless, endurance athletes continue to face difficulties in interpreting wearable data and integrating it with subjective training feedback [52]. Moreover, wearable technology facilitates post-injury recovery by guiding rehabilitation and supporting safe return-to-play protocols [39], thereby advancing both sports medicine and digital health through improved health management and reduced injury risk [46].

Recent innovations have expanded wearable technology beyond physiological monitoring. Baldassarri et al. [3] demonstrated that wristbands measuring electrodermal activity can infer emotional states and enhance motivation through music-based feedback. Zhao and You [60] proposed an IoT-based posture monitoring system that accurately tracks real-time movement for rehabilitation and performance assessment. Similarly, Liang et al. [31]

developed a wearable system capable of simultaneously measuring physiological indices and stimulating neural activity to improve endurance. Collectively, these advancements emphasize the transformative role of wearable technology in enhancing athletic performance through continuous physiological monitoring, individualized adaptation, and proactive injury prevention.

2.2 Sport Biomechanics (SB)

Sports biomechanics examines the mechanisms underlying athletic movement to optimize performance and minimize injury risk. It encompasses motion analysis, muscle function, joint kinematics, and the biological determinants of performance [38]. Traditionally, biomechanical studies were conducted in controlled laboratory environments to ensure measurement precision and minimize environmental variability [48]. However, the advent of wearable and mobile technologies has transformed data collection, allowing the acquisition of ecologically valid data in real-world training and competition contexts [25].

Contemporary biomechanics research increasingly employs wearable sensors—such as EMG and accelerometers—to analyze muscle activation patterns and movement dynamics [19]. Reinebo et al. (2024) demonstrated that wearable-derived metrics can quantify performance and assess the influence of psychological factors, facilitating the development of integrated performance models and improving injury prevention strategies. Smartwatches and fitness trackers further extend these capabilities by continuously monitoring physiological parameters, including heart rate, step count, movement distance, and posture, through advanced data analytics [15]. This real-time feedback enables athletes to adapt training strategies dynamically and improve performance outcomes.

As wearable technologies continue to evolve, sports biomechanics has advanced in both quantitative precision and qualitative insight [1,49]. Nevertheless, challenges remain in data interpretation and field application, particularly in accounting for individual physiological variability and environmental influences [23,37]. Personalized analyses are therefore essential for generating athlete-specific recommendations and advancing biomechanical understanding [54]. Moreover, coaches play a vital role in interpreting biomechanical data to support performance optimization and reduce injury risk [8,43].

2.3 Training Fatigue (TF)

Excessive fatigue adversely affects athletic performance, often leading to non-functional overreaching and maladaptive responses [5]. It compromises muscular efficiency, induces psychological strain, and impairs focus and decision-making. Therefore, understanding recovery demands supports the prevention of fatigue accumulation and the optimization of recovery processes [20,22]. Evidence-based recovery strategies—including rest, active recovery, nutritional support, and psychological interventions—enhance both physiological and psychological resilience [17,47].

Mental fatigue (MF) negatively impacts physical, technical, tactical, and cognitive performance dimensions while elevating injury risk [28,32,44,50]. Key contributors to training-induced fatigue include overtraining syndrome, which manifests as chronic fatigue, reduced performance, and increased susceptibility to illness [6,34]. Both central and peripheral fatigue can shorten athletic longevity, with physiological manifestations varying across disciplines: endurance athletes often exhibit elevated heart rate and decreased efficiency, whereas strength athletes demonstrate reduced power output and impaired coordination. Wearable technologies, such as heart rate monitors and activity trackers, enable objective quantification of fatigue-related physiological markers. Future research should explore how these monitoring tools can inform fatigue prevention strategies and support individualized recovery planning.

2.4 Recovery Index (RI)

Physiological assessment is essential for evaluating recovery status, with key indices—such as maximal isometric grip strength, forearm swelling, perceived pain, fatigue level, and readiness to train—providing insight into distinct recovery patterns. For example, elite climbers may require up to 60 hours for complete recovery [16]. Biochemical markers, including creatine kinase (CK) and inflammatory mediators, are instrumental in assessing muscle damage and post-exercise recovery, thereby guiding training load adjustments [4].

Wearable technologies, such as heart rate monitors and activity trackers, facilitate continuous monitoring of recovery-related indicators. For instance, individualized markers like urea and CK levels improve load monitoring accuracy [21]. Additional recovery metrics—such as hydration status, inflammatory responses, and injury risk—further support recovery management [30]. Sleep quality also represents a critical factor, as overtrained athletes frequently exhibit sleep disturbances that impair cognitive, emotional, and physical recovery [29]. Wearable sleep trackers provide objective data that enhance recovery monitoring.

Heart rate recovery (HRR) reflects autonomic function and training status, with improvements indicating enhanced conditioning, while deviations may signal overtraining [7,11]. Other performance-based indicators—including blood lactate clearance [40], repeated sprint ability (RSA), countermovement jump (CMJ) performance, and delayed onset muscle soreness (DOMS)—offer valuable insights into fatigue and recovery following high-intensity training [56].

In summary, integrating physiological biomarkers with self-reported wellness measures provides a comprehensive understanding of recovery processes, enabling precise monitoring of physical condition fluctuations and informing the design of optimized training and recovery protocols.

3. Data Collection

3.1 Literature Search Method

This study systematically identified research on wearable technologies in sports science by searching three core databases: Web of Science, SciSpace, and PubMed. Titles, abstracts, and author keywords were queried using three keyword sets: “wearable technology," "wearable device," and "wearable sensor." The initial search yielded 2,164 records. Duplicate records were removed, and the titles and abstracts of the remaining 1,132 studies were screened, excluding 471 unrelated studies. Abstracts of the 561 remaining papers were further reviewed to confirm relevance and methodological appropriateness, resulting in 423 studies retained for full-text assessment.

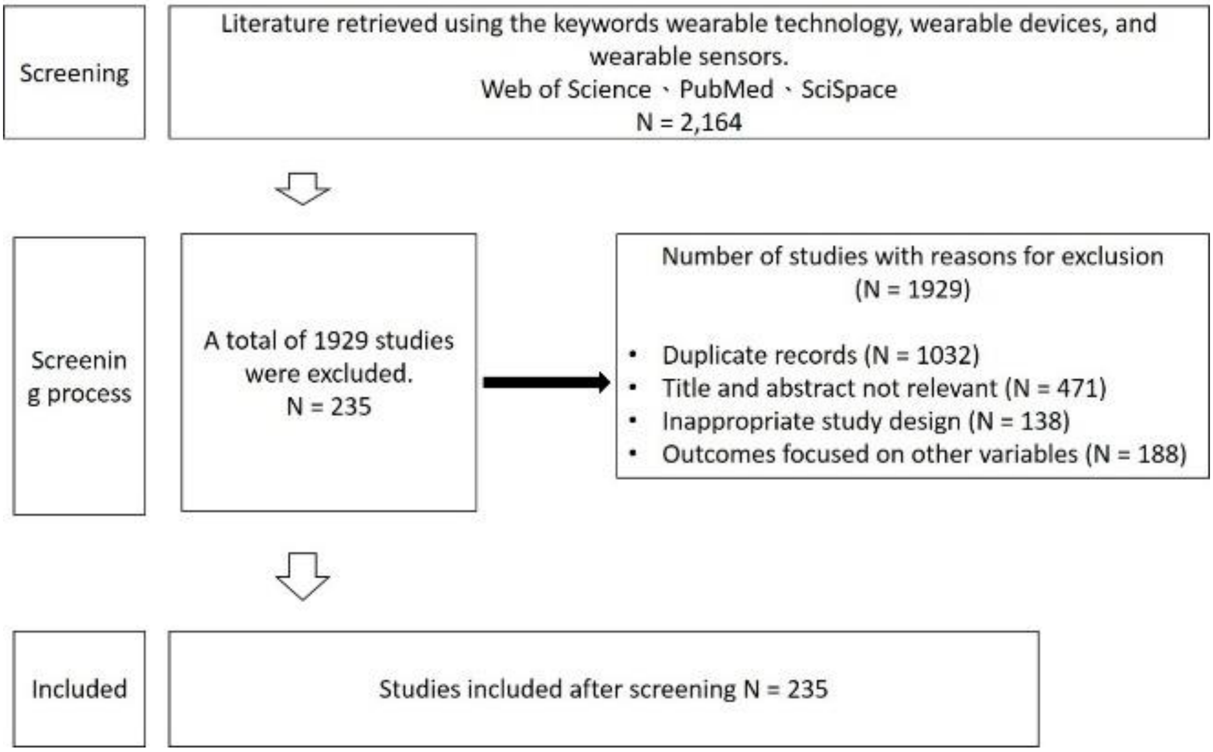

Figure 1. Literature screening process

3.2 Data Extraction

Full-text reviews of the 423 retained studies were conducted to ensure alignment with the research focus on wearable technologies in sports science. Explicit inclusion and exclusion criteria guided the selection process to ensure transparency and rigor. Data were extracted systematically from all eligible publications, resulting in 235 studies that met all criteria and were incorporated into the final analysis. This process ensured a comprehensive and objective synthesis of current research trends and applications.

4. Application Directions of Wearable Technology in Sports Science

With rapid technological advancement and ongoing innovation by manufacturers, wearable devices have increasingly diversified in function and design. Research suggests that single sensors are insufficient to capture the complex dynamics of physical activity; therefore, multidimensional data acquisition requires integrated sensor systems [55]. Beyond traditional Inertial Measurement Units (IMUs), contemporary applications include smart wristbands, sensor-embedded socks, intelligent sportswear, smartwatches, and Force-

Sensitive Resistors (FSRs). Over the past decade, these technologies have demonstrated notable progress in miniaturization, low-power operation, and measurement precision.

To examine research trends and focal areas, this study systematically reviewed and thematically classified recent literature on wearable technology in sports science. Findings indicate that applications can be broadly categorized into three primary domains. First, fatigue monitoring and prevention accounted for 612 instances (45%), reflecting the academic emphasis on physiological load management and exercise safety. Second, personalized training program design appeared in 479 instances (35%), underscoring the focus on individualized performance optimization. Third, recovery monitoring and enhancement occurred in 272 instances (20%), indicating its growing importance despite being a relatively early-stage research area. These distributions highlight the multi-dimensional development of wearable technology in sports applications and identify current research priorities and emerging directions. They also provide a structured framework for future investigations into exercise monitoring, performance optimization, and athlete management using wearable devices.

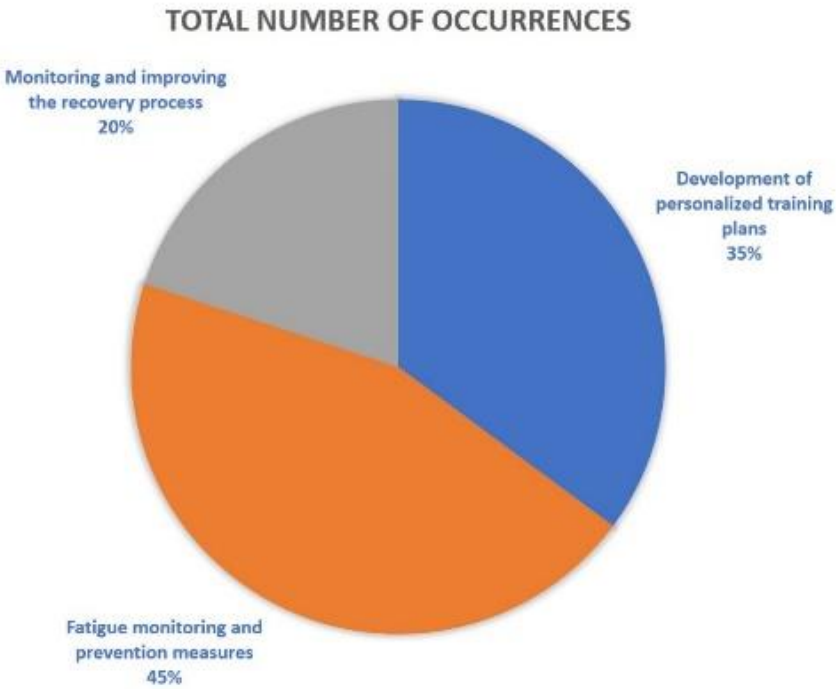

Figure 2. Application distribution of wearable devices

4.1 Development of Personalized Training Programs

With continued advancements in sports science, the development of personalized training programs has become a key strategy for optimizing athletic performance. Literature screening revealed that this topic appeared 479 times (35%) within wearable technology research, indicating its prominence as a research focus. Studies suggest that athletes' training efficiency, recovery status, and health indicators must be comprehensively assessed to design individualized training plans [12]. Tailored programs enhance overall performance and promote health outcomes by addressing each athlete's unique physiological and performance characteristics.

Training programs should incorporate diverse exercise modalities aligned with the specific demands of different sports disciplines. This aligns with Rössler et al. [43], who emphasized that diversified training enhances adaptability and improves performance. Comprehensive programs integrating aerobic, strength, and flexibility training promote overall physical development, consistent with the findings of Sun et al. [51] and Toner et al. [52].

Ensuring program effectiveness requires continuous assessment and dynamic adjustments based on athlete progress. Wearable technologies facilitate real-time monitoring of physiological states and training outcomes, enabling timely modifications. This integration enhances the efficiency of personalized training, strengthens performance, increases engagement, and improves athletes' overall quality of life.

4.2 Fatigue Monitoring and Preventive Measures

Fatigue significantly impacts both athletic performance and health. This study identified fatigue monitoring and prevention as the most prominent research domain, appearing 612 times (45%), reflecting a strong academic consensus on the importance of fatigue management. Establishing a systematic fatigue monitoring framework supports recovery efficiency and helps maintain consistent performance [5].

Such systems enable early detection of fatigue and adjustment of training loads to improve performance and reduce injury risk. Preventive strategies complement monitoring by facilitating precise training load management, mitigating overtraining, and improving overall performance [30,50]. Athletes and coaches can utilize real-time fatigue data to regulate training intensity, while recovery strategies—such as active recovery (light exercise) and passive recovery (sleep and nutrition)—restore physiological balance and reduce stress [17,28,44,47]. Integrating real-time monitoring, proactive prevention, and tailored recovery strategies enables athletes to manage fatigue effectively, enhance performance, and sustain long-term adaptation in competitive environments.

4.3 Monitoring and Improvement of the Recovery Process

Recovery is a fundamental component of training and competition, facilitating fatigue reduction and enhancing physiological and psychological adaptability. Research on recovery monitoring and improvement appeared 272 times (20%) within wearable technology studies, underscoring its importance despite being less frequently examined than fatigue monitoring or personalized training.

Effective recovery strategies are individualized and supported by wearable technologies and advanced data analytics, which provide accurate, real-time physiological feedback [4,16,30,40,56].

Integrating physiological and psychological recovery—through practices such as meditation, relaxation, and mindfulness—further improves performance readiness and long-term stability [11,29].

In summary, recovery monitoring requires a comprehensive approach encompassing both physiological and psychological dimensions. Wearable technologies significantly enhance real-time monitoring and intervention, supporting the implementation of optimized recovery protocols. Future research should continue evaluating the effectiveness of recovery strategies and develop more precise, individualized monitoring tools to further improve athlete health and performance outcomes.

5. Conclusion

This study examined the impact of wearable technologies on athletic performance and injury prevention, emphasizing their critical role in contemporary sports science. Devices such as heart rate monitors, activity trackers, and physiological sensors provide real-time, accurate data, enabling athletes to monitor and adjust training based on their physiological states. Through these technologies, athletes can effectively manage training intensity, detect early signs of fatigue, and implement preventive measures to minimize injury risk. Findings from this study further indicate that continuous monitoring and analysis of physiological data significantly enhance performance, underscoring the practical value of wearable technologies. Nonetheless, the accuracy of these devices and the reliability of data under varying environmental conditions remain critical factors influencing their effectiveness and the generalizability of research outcomes.

From a practical perspective, it is recommended that athletes and coaching teams routinely employ wearable devices for physiological monitoring and establish systematic frameworks for data analysis, including database management, analytical tool selection, and result interpretation. Such frameworks enhance athletes' self-monitoring capabilities and support coaches in making evidence-based training decisions. In particular, adjustments to training intensity should integrate real-time physiological indicators to design optimal recovery and high-intensity cycles, ensuring both effectiveness and safety. Effective communication between athletes and coaches is also essential to facilitate feedback on perceived physical conditions, thereby improving training outcomes and reducing injury risk. Ethical considerations, including data privacy and informed consent, must be rigorously addressed through clear governance and ethical protocols.

Future research should investigate sport-specific applications of wearable technologies, focusing on variations in physiological demands among disciplines with similar movement patterns. Attention should also be directed toward the adaptability of these devices for adolescent athletes, whose adoption may be influenced by psychological factors, perceived usefulness, and trust. Interdisciplinary collaboration is necessary to improve the design, functionality, and usability of wearable technologies to address the diverse needs of athletes. Furthermore, integrating AI into data processing can enable more precise, individualized training guidance, improving performance while reducing injury risk and advancing sports science. Additional research should explore the potential of wearable devices for monitoring psychological states and broadening their application across different sports disciplines and populations.

Author Contributions

Conceptualization: Chao-Zheng Zheng and Jia-An Li; Research methodology: Chao-Zheng Zheng; Data collection: Jia-An Li; Drafting, Chao-Zheng Zheng, Jia-An Li, and Keng-Yu Lin; Writing and editing: Keng-Yu Lin. All authors approved this version of the manuscript for submission.

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穿戴式科技在運動表現與訓練傷害預防之系統性文獻回顧研究

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摘要

隨著穿戴式科技的迅速發展，該技術已成為提高運動員表現和預防運動傷害的重要焦點。本研究旨在系統性地探討穿戴式科技對運動員表現相關指標及運動傷害預防的效果，並綜合分析近五年來的相關文獻。研究重點集中在心率監測、疲勞評估及恢復指標等功能，以期協助教練與運動員最佳化訓練計畫。結果顯示，穿戴式裝置，如心率監測器與動作捕捉系統，可即時監控運動員的生理狀態，從而增強其在高強度訓練及比賽中的適應能力，並顯著降低運動傷害的發生率。此外，穿戴式科技還有助於增強運動員的體能及心理素質，提供個別化訓練的參考依據。即時的資料回饋對於教練的訓練策略和運動醫學介入具有重要價值。未來的研究可進一步探討如何克服現有技術限制，並擴充其在不同運動領域及族群中的應用。

關鍵字：穿戴式科技、人工智能、運動生物力學、訓練疲勞、恢復指標