2024, Retos, 56, 998-1008

Exploration of branches of physics for handling several cases in sports applications: A systematic literature review

Exploración de ramas de la física para el manejo de varios casos en aplicaciones deportivas: Una revisión sistemática de la literatura

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Abstract. The principles of physics have become a primary focus in the development of sensory technology and biomechanical analysis in the context of modern sports. This study aims to explore the contributions of physics in enhancing athlete performance and reducing injury risks. A systematic literature review (SLR) was conducted to identify relevant empirical studies highlighting the role of physics in sports. Data were analyzed from Scopus database sources with criteria as specified in the SLR study and with the PRISMA method. Search strategies using predefined keywords referring to the current topic were employed. The results of the literature review indicate that the application of sensory technology and biomechanical analysis has provided profound insights into human body movements in sports. Technologies such as motion capture and 3D analysis have enabled the identification of specific aspects of athlete techniques that require improvement. Furthermore, real-time feedback from sensor technology has assisted in direct adjustments during training, potentially enhancing the quality of athlete techniques and reducing injury risks. Integrating the principles of physics in sports not only enhances athlete performance but also constitutes an integral part of injury prevention efforts and effective care. Thus, understanding and applying the principles of physics in the context of sports can provide significant benefits to athletes, coaches, and sports health professionals in efforts to enhance athlete well-being and performance.
Keywords. Sports, biomechanics, kinematics, physics

Resumen. Los principios de la física se han convertido en un foco principal en el desarrollo de la tecnología sensorial y el análisis biomecánico en el contexto del deporte moderno. Este estudio tiene como objetivo explorar las contribuciones de la física en la mejora del rendimiento del atleta y la reducción de los riesgos de lesiones. Se realizó una revisión sistemática de la literatura (RSL) para identificar estudios empíricos relevantes que destacaran el papel de la física en el deporte. Los datos fueron analizados a partir de fuentes de la base de datos Scopus con los criterios especificados en el estudio de RSL y con el método PRISMA. Se emplearon estrategias de búsqueda utilizando palabras clave predefinidas que se refirieran al tema actual. Los resultados de la revisión de la literatura indican que la aplicación de la tecnología sensorial y el análisis biomecánico ha proporcionado una profunda comprensión de los movimientos del cuerpo humano en el deporte. Tecnologías como la captura de movimiento y el análisis 3D han permitido la identificación de aspectos específicos de las técnicas de los atletas que requieren mejoras. Además, la retroalimentación en tiempo real de la tecnología sensorial ha ayudado en ajustes directos durante el entrenamiento, potencialmente mejorando la calidad de las técnicas de los atletas y reduciendo los riesgos de lesiones. La integración de los principios de la física en el deporte no solo mejora el rendimiento del atleta, sino que también constituye una parte integral de los esfuerzos de prevención de lesiones y cuidado efectivo. Por lo tanto, comprender y aplicar los principios de la física en el contexto del deporte puede proporcionar beneficios significativos a los atletas, entrenadores y profesionales de la salud deportiva en los esfuerzos para mejorar el bienestar y el rendimiento del atleta.
Palabras clave. Deporte, biomecánica, cinemática, física

Fecha recepción: 02-03-23. Fecha de aceptación: 28-04-24
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Introduction

Sports science is a highly beneficial specialization field for both athletes and coaches. This field explores how the healthy human body operates during sports activities, as well as ways in which sports and physical activities can enhance overall health. However, in sports involving repetitive jumping and landing movements, there is a high prevalence of patellar tendinopathy and patellofemoral pain syndrome, most likely due to the cumulative impact forces associated with repetitive actions such as single or double-leg landings (Llombart et al., 2024; Heebner et al., 2017).

Physics plays a significant role in understanding the phenomena occurring in sports. Basic physics concepts such as force, motion, energy, and momentum have direct applications in various aspects of sports, including techniques, strategies, and athlete performance. Physics plays an important role in the development of new materials, is part of the technological equipment needed for data collection and analysis, and serves as the basis for biomechanical models that attempt to understand human performance. Therefore, many research institutions have been established, and their scientific findings are published in related journals (Mathelitsch, 2017).

Professional sports organizations, national and regional public-funded sports institutes, as well as private athletic training facilities, are increasing-ly investing in biomechanical feedback technology with the hope that the generated kinematic and kinetic data can be utilized to enhance sports performance by improving athletic techniques (Glazier, 2021; Valencia & Echavarria, 2022; Chaeroni et al., 2023).

Biomechanical studies indicate that individuals undergoing ACL reconstruc-tion may exhibit abnormal movement patterns or asymmetry. Numerous studies have been conducted during level walking demonstrating abnormal gait patterns in all three planes; sagittal, coronal, and transversal (Gokeler et al., 2013; Hart et al., 2016).

Despite the importance of directional changes for sports performance and their association with ACL injury risk, it is somewhat surprising that most studies on the biomechanics of change of direction investigate performance (Dos'Santos et al., 2017, 2020; Jones et al., 2017; Maloney et al., 2017; Marshall et al., 2014; Weir et al., 2019; Welch, Richter, Franklyn-Miller, et al., 2021; Welch, Richter, Moran, et al., 2021) and determinants of ACL injury risk (David et al., 2017; Donnelly et al., 2017; Jones et al., 2015, 2016b, 2016a; Kristianslund et al., 2014; Sigward et al., 2015; Yoshida et al., 2016) independently. From a performance pers-pective, greater braking and propulsive forces, as well as impulse during short GCT, are associated with faster change of direction speed (Dos'Santos et al., 2017, 2020; Havens & Sigward, 2015; Maloney et al., 2017; Spiteri et al., 2015; Welch, Richter, Franklyn-Miller, et al., 2021; Welch, Richter, Moran, et al., 2021).

Previous research also indicates that joint kinematics are crucial in quantifying the body's ability to modify and absorb high-impact forces during landing tasks that may lead to injury development (Chaeroni et al., 2024; De Ridder et al., 2015). Numerous studies have been conducted to examine the relationship between disturbed landing kinematics and acute lower extremity injuries (Leppänen et al., 2017; Saniah et al., 2024).

Furthermore, whole-body kinetics and kinematics such as greater ankle power, plantar flexion moment at the ankle, hip power and extensor moment, rapid knee and hip extension, wide lateral foot planting, body inclination and rotation, and low COM are also associated with faster cutting performance (Havens & Sigward, 2015; Marshall et al., 2014; Welch, Richter, Franklyn-Miller, et al., 2021); highlighting the importance of lower limb extensor musculature and body inclination towards the intended direction of travel. Conversely, from an injury risk perspective, change of direction techniques with wide lateral foot planting (Havens & Sigward, 2015; Jones et al., 2015; Kristianslund et al., 2014), greater hip abduction angle (Sigward & Powers, 2007; Weir et al., 2019), increased initial foot progression angle (Jones et al., 2016a; Sigward & Powers, 2007), increased initial hip internal rotation angle (Havens & Sigward, 2015; Sigward et al., 2015), greater lateral body inclination (Jones et al., 2015), smaller knee flexion angle (Weir et al., 2019), smaller knee flexion angle (Weir et al., 2019), and greater ground reaction forces (GRF) (Haugen et al., 2018; Jones et al., 2016b; Sigward et al., 2015; Wild et al., 2022). Their latest commercial solutions (not open-source), referred to as 3D, estimate the positions of various key points around the joints and then apply multi-body optimization techniques to handle inverse kinematics (Kanko, Laende, Davis, et al., 2021; Kanko, Laende, Selbie, et al., 2021). A study utilizing model-based 3D image matching techniques analyzed 10 sequences of high-quality videos of ACL injuries and observed that limited energy absorption occurs at the hip joint (Koga et al., 2018). Haralabidis et al. combined OpenPose results from a monocular video and two IMU outputs to solve upper body kinematics in OpenSim (an open-source 3D biomechanical analysis software) (Okilanda et al., 2024; Chaeroni et al., 2024; Seth et al., 2018).

Based on the scientific evidence found in current literature, there are numerous aspects of physics applied in sports. However, the existing systematic literature review does not clearly indicate the physical aspects. Therefore, this systematic literature review aims to revisit and explore the handling of several cases in sports using the principles of physics, thus providing a basis for further research to expand its application in the field of sports.

Methods and materials

This research utilized the Systematic Literature Review (SLR) method, an approach designed to identify, assess, and interpret all available and relevant information in the literature or references to comprehensively address research questions (Snyder, 2019; Xiao & Watson, 2019). SLR aids in providing a summary of current knowledge or topics related to research questions (Kurniati et al., 2022). Systematic reviews are valuable sources of information where authors need to summarize and evaluate reliable scien-tific literature using organized methods based on predefined objectives, thus making it usable for other researchers (Gopalakrishnan & Ganeshkumar, 2013).

To obtain information for this study, data sources were retrieved through searches in the Scopus database, which covers high-quality scientific literature in over 250 disciplines, including social sciences and humanities (Cretu & Morandau, 2020).

In this study, the chosen method is a literature review conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method (Page et al., 2021). The PRISMA method, introduced in 2009 (Moher et al., 2009), is one of the best methods available to assist authors in conducting systematic reviews and meta-analyses correctly and also aids authors in reviewing structures such as roadmaps. PRISMA is also the most frequently used method in articles such as literature reviews (Hutton et al., 2016; Moher et al., 2016; Shamseer et al., 2015; Stewart et al., 2015)

Table 1.
Inclusion and Exclusion Criteria

Inclusion criteria	Exclusion criteria
English Language	Articles written in other languages
Years 2020-2024	Before the year 2020
Type of empirical research articles indexed in Scopus 1st quartiles - 2nd quartiles (Q1-Q2)	Types of book chapters, theses, short reports, non-empirical studies, literature reviews, and not indexed in Scopus
Related to nanotechnology in sports equipment	Not related to nanotechnology in sports equipment

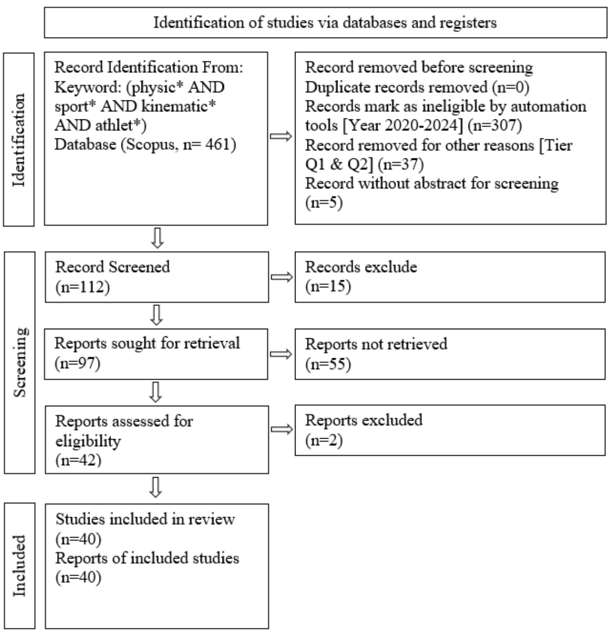

Figure 1. PRISMA Diagram including Scopus database articles

Furthermore, articles outside the Scopus-indexed Q1-Q2, beyond the last 5 years (2020-2024), and articles lacking clear abstracts were designated within the exclusion criteria. This resulted in 112 articles meeting the inclusion criteria, indicating that 349 articles were removed.

Article monitoring was conducted by investigating titles and abstracts based on the relevance of the articles to the topic under discussion. At this stage, irrelevant articles have been removed. Overall, 92 articles meet the inclusion criteria and are relevant to the purpose of this literature review. These articles were analyzed, and relevant information was organized considering several classifications and criteria that align with the information needs we are searching for. Data extraction was organized to categorize, evaluate, and summarize the articles that meet the predefined criteria. Through the process of analyzing the collected data, we were able to reach recommendations and findings relevant to the topic.

The analysis of articles that meet the inclusion criteria reveals key findings that will encompass aspects such as the type of research, population groups, and related aspects of physics. At least 40 articles are meeting the criteria for analysis (Akhmedova et al., 2021; Paul et al., 2021). Although selecting appropriate articles requires a considerable

The articles were examined by concluding the search on February 3, 2024, utilizing a keyword-based search strategy of physic* AND sport* AND kinematic* AND athlete*. Article selection was restricted to newly published articles within the last 5 years (Paul et al., 2021) from 2020 to 2024, preferably from journals indexed in the 1st to 2nd quartiles (Paul et al., 2021).

The eligibility criteria are necessary in selecting the appropriate articles (Ahmadi et al., 2018). Articles are screened based on inclusion and exclusion criteria as described in Table 1. According to the exclusion criteria, only articles that meet the requirements are selected, but for articles outside the specified years, such as book chapters, theses, short reports, non-empirical studies, and non-English articles, a total of 461 articles were excluded.
amount of time, structured methods like PRISMA (see Figure 1) ensure that the selected articles are the most rigorous and relevant for the subject of this literature review.

Results

Jumlah literatur yang relevan dengan topik berdasarkan strategi pencarian yang telah ditetapkan pada basis data Scopus mengalami tren yang positif hingga tahun 2023. Dari tren publikasi yang terlihat pada Gambar 2, kami meyakini akan berlanjut di akhir tahun 2024.

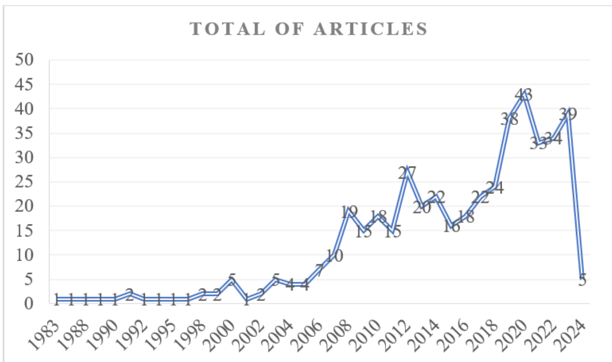

Figure 2. Graph showing the number of published articles over the years

After analysis, 40 relevant articles were found regarding the application of various branches of physics in addressing various sports-related issues and utilizing different study methods, as depicted in Table 2.

Table 2.
The application of physics in every article

Author	Study type	Population	Physics utilized
(Kim et al., 2021)	Observational	Elite archers with disabilities	Time analysis and 3D motion analysis.
(Webster et al., 2021)	Prospective longitudinal	Patients after ACL reconstruction surgery with an average age of 26 (±6) years.	3D motion analysis, ground reaction force data calculation of kinematic and kinetic variables
(Tai et al., 2021)	Experimental	15 male adolescent athletes with an average age of 14.7 (±0.9) years	Collection of kinematic and kinetic data, calculation of take-off angles, impulse, joint moments, and power
(Biró et al., 2023)	Observational	19 regular and injury-free runners	Use of Inertial Measurement Unit (IMUs) to monitor kinematic patterns in athletes
(Menzel & Potthast, 2021)	Experimental	Individuals with various levels of experience in boxing	Use of force sensing resistors and inertial sensors, determining 3D orientation.
(Rivadulla et al., 2020)	Exploratory cross-sectional	Male athletes aged 18-35 years, including groin athletic athletes (AGP) and healthy athletes	Motion capture technology, force platforms, kinematic and kinetic analysis, inverse dynamics
(Dong et al., 2022)	Biomechanical analysis	15 athletes from competitive Taijiquan teams, including 10 males and 5 females	Analysis of action amplitude changes, deceleration, and braking capacity. Focusing on biomechanical aspects of arm manipulation
(Dos'Santos et al., 2021)	Cross-sectional	Male multi-directional sports athletes (soccer, rugby, cricket, and field hockey) with an average age of 20.7 years	Biomechanical analysis of center of mass velocity, propulsive force, ground contact time, braking force, range of motion, knee flexion moment, inner leg motion angle, knee abduction moment, and internal rotation moment.
(Quittmann et al., 2020)	Observational cross-sectional	Competitive healthy male triathlon athletes. Specific age, height, and weight characteristics	Measurement of crankshaft torque, kinematic calculations
(Jamaludin et al., 2020)	Comparative or correlational observational	University athletes aged 19-25 years. Normal BMI and normal dynamic knee valgus range during vertical jump (DVJ)	Biomechanical factors related to dynamics, knee kinematics range of motion
(Wild et al., 2022)	Observational	29 professional male rugby union players	Analysis of whole-body sprint kinematic distribution
(Paterno et al., 2022)	Observational cohort	Individuals aged 13-27 years undergoing primary ACLR, following rehabilitation, cleared to return to pivoting/cutting sports by doctors and rehabilitation specialists	Isokinetic dynamometer
(Melo et al., 2020)	Experimental	8 males and 5 females amateur trained local community runners, with an average age of 36 years, weight of 70 kg, height of 170 cm, and maximum oxygen uptake (VO2 max) of 64.4 ml/kg/min.	Biomechanical assessment such as running speed, kinematic asymmetry, kinetic asymmetry, and step time
(Ma & Ma, 2022)	Observational	Urban residents in city Y who frequently engage in physical exercise in the research area	Motion sensor principles, kinematic analysis, and energy consumption monitoring.
(Decker et al., 2020)	Computational modeling	Individuals involved in American football at various levels	Stress-strain response and force response analysis.
(Lee et al., 2020)	Comparative study	Taekwondo demonstration athletes with functional ankle instability	3D motion analysis, kinematic and kinetic parameters, measuring ground reaction forces and determining pressure centers.
(Petrovic et al., 2020)	Controlled laboratory study	Pre-teen athletes aged 9-12 years, particularly those playing soccer and handball	3D motion analysis for normalizing force variables, assessing peak external knee moments
(Hribernik & Kos, 2023)	Exploratory	Professional swimmers	Biomechanical feedback modalities
(Torres-Banduc et al., 2021)	Cross-sectional	Amateur female volleyball players	Biomechanical considerations
(Elfmark et al., 2022)	Observational	Male and female ski jumpers) with various performance levels (junior to World Cup)	Measuring parameters related to position, velocity, and acceleration
(Santos et al., 2020)	Observational	Healthy swimmers and physically disabled swimmers each comprising 20 individuals	Analysis of motion pattern changes, punch length, punch speed, and velocity
(Letafatkar et al., 2020)	Experimental	49 healthy male runners	Kinematic and kinetic data analysis to assess biomechanics, as well as vertical loading rate and acceleration analysis, 3D motion analysis
(Carus & Mamaqi-Kapllani, 2023)	Observational, cross-sectional	Recreational skiers and snowboarders at four ski resorts	Kinetic energy impact and high-speed influence
(Huang et al., 2023)	Methodological	8 professional male jumpers	Inverse dynamics measurement, estimating takeoff reaction forces, and calculating aerodynamic forces based on object kinematics and computational fluid dynamics simulation
(Pimentel et al., 2020)	Observational	Female artistic gymnasts aged 8-18 years, competing in US Junior Olympic Gymnastics Program level 5 or higher	Measurement of ground reaction forces and inverse dynamics
(Mancha-Triguero et al., 2020)	Comparative cross-sectional and evolutionary	103 boys and 46 girls basketball players from different training categories (U'14, U'16, and U'18) affiliated with the same club and participating in national championships	Inertial devices
(Briley et al., 2020)	Observational	Manual wheelchair users (MWU) both athletic and non-athletic	Collecting 3D kinematics, measuring strike frequency, kinetics from force and speed data

(González-frutos et al., 2022)	Correlational cross-sectional	13 elite female field hockey players, average age 24.9 years, height 1.67 m, weight 58.7 kg participating in the study during the ninth week of the 2018/2019 season.	Kinematic analysis, speed-force (FVP) relationships and RSA performance, and analysis of correlations between running time, step frequency, and step length
(Carvalho et al., 2021)	Cross-sectional	Female volleyball players aged 15-21 years, with minimum three years of sports training experience, without lower limb pain complaints for more than six months	2D kinematic analysis of landing movements
(Maestroni et al., 2023)	Experimental	Professional male soccer players who have undergone ACL reconstruction and are in the late rehabilitation stage	Isokinetic measurement, kinematics from 3D inertial measurement unit systems, mechanics of force plates
(Edwards et al., 2023)	Observational cross-sectional	Australian junior soccer players at various competition levels (state level U'18, state level U'16, local U'18, local U'15, and local U'14. Total participants 162	Speed-time data analysis, speed-force (Fv)
(Kotsifaki et al., 2022)	Observational with case-control comparative analysis	Male athletes who have undergone ACL reconstruction and healthy male athletes as controls	Biomechanical analysis of triple hop for distance
(Xu et al., 2020)	Observational	45 young male amateur athletes engaging in various physical exercises (basketball, volleyball, and soccer)	Biomechanical principles (joint angles and energy absorption during landing)
(Zimmerman et al., 2023)	Observational	American professional soccer players who experienced head impact resulting in loss of consciousness, dystonic posture	Predicting strain patterns and strain rates, loading models with linear and rotational accelerations
(Amara et al., 2021)	Experimental	Competitive male swimmers, average age around 16 years, minimum 6 years of national swimming competition experience, more than 6 years of water endurance training and 4 years of land endurance training	Application of forces, influencing speed and punch speed
(Janowski et al., 2020)	Observational	Trained taekwondo athletes, particularly 15 elite athletes aged 16-25 years, including male and female athletes	Collecting kinematic data
(Wolfsperger et al., 2021)	Observational	Composed of three skiers and three snowboarders, with specific physical characteristics and qualifications	Forces governing speed, explaining coefficient of friction variations
(Rossi et al., 2021)	Prospective cohort	Elite young female and male floorball and basketball players from Finland, average age 15.7 (± 1.8) years	Analisis biomechanical analysis, motion capture technology , teknologi penangkapan gerak
(Weich et al., 2020)	Cross-sectional	30 athletes both male and female participants, with varying age ranges, training experience, running performance, and weekly training hours	Collection of 3D acceleration data using MEM sensors, describing human cyclic motion kinematics
(Giménez-egido et al., 2020)	Descriptive observational	20 junior tennis players under the age of 10, with an average age of 9.46 years.	Measuring ball speed, impact location, and spin

Discussion

This systematic literature review reveals the application of physics principles in the field of sports. Among them, the implementation of sensor technology and biomechanical analysis to enhance techniques and strategies in the sports domain. This can help identify areas that need improvement and reduce the potential risk of injury. Motion capture technology and 3D analysis play a crucial role in understanding athlete biomechanics and movement dynamics, which in turn can optimize training techniques and strategies (Janowski et al., 2020; Rossi et al., 2021; Wolfsperger et al., 2021).

The implementation of sensor technology and inertial devices in sports training allows coaches and athletes to receive real-time feedback that can be used to improve techniques and prevent injuries (Rossi et al., 2021; Weich et al., 2020). On the other hand, it is also shown how sensor technology and motion analysis can be used to enhance training and injury prevention strategies (Decker et al., 2020; Lee et al., 2020; Petrovic et al., 2020; Xu et al., 2020; Padli et al., 2023). Research conducted by Carus & Mamaqi-Kapllani (2023), focuses on the use of sensor technology in improving athletic technique and performance, highlighting the importance of real-time feedback in sports training. Exploring the use of advanced tools and analysis methods can also be utilized to understand and enhance athletic performance through biomechanical physics principles (Elfmark et al., 2022; Hribernik & Kos, 2023; Santos et al., 2020; Torres-Banduc et al., 2021)

The development of methodologies to measure and improve biomechanical efficiency and sports performance is crucial. The dynamics of motion and its relationship with mechanical efficiency provide insight into how biomechanical aspects can be manipulated for performance enhancement and injury risk reduction (Amara et al., 2021; Giménez-egido et al., 2020; Janowski et al., 2020; Zimmerman et al., 2023).

Biomechanics can influence sports performance, with a focus on aspects such as speed, strength, movement efficiency (Carvalho et al., 2021; González-frutos et al., 2022; Maestroni et al., 2023; Wild et al., 2022), long jump (Huang et al., 2023) as well as muscle strength, kinematics, and movement dynamics (Melo et al., 2020; Paterno et al., 2022). Meanwhile, biomechanical principles such as kinematic and kinetic asymmetries, as well as step timing, can enhance performance and reduce injury risk (Dos'Santos et al., 2021; Jamaludin et al., 2020; Quittmann et al., 2020). The application of biomechanical analysis and inverse dynamics in specific sports contexts can evaluate ground reaction forces and kinematics during physical activities (Briley et al., 2020; Mancha-Triguero et al., 2020; Pimentel et al., 2020; Maidawilis et al., 2022).

The importance of kinematic and kinetic analysis in understanding sports biomechanics, with a focus on the impact of training on performance and potential injury risk (Dong et al., 2022; Menzel & Potthast, 2021; Rivadulla et al., 2020), through specific exercises, such as plyometrics, can influence athletes' biomechanics, including their landing techniques and energy utilization during physical activities (Edwards et al., 2023; Kotsifaki et al., 2022; Letafatkar et al., 2020; Welis et al., 2022; Pranoto et al., 2023; Gusril et al., 2022). In their research, Ma & Ma (2022) contribute to the development and validation of algorithms for biomechanical analysis, demonstrating how data-driven approaches can enhance our understanding of athletic performance and training interventions.

The results of this systematic review provide insights into the application of various branches of physics to address several aspects of injury management and performance in sports. However, it is important to conduct additional SLR research using more consistent designs and samples that encompass greater diversity to strengthen the reliability of the results and expand their potential application in a broader sports context. On the other hand, this SLR still predominantly focuses on the branch of physics, namely biomechanics. The limited inclusion of other physics aspects in this SLR demonstrates the vast opportunities for exploration of various branches of physics applied as alternative interventions in sports activities.

Conclusions

This systematic literature review underscores the crucial role of physics principles in the development and enhancement of athletic performance, as well as injury management across various sports disciplines. Through the application of sensor technology and biomechanical analysis, this research demonstrates that a profound understanding of human body movement in sports can be attained. Technologies such as motion capture and 3D analysis enable the identification of specific aspects in athletes' techniques that need improvement, while also aiding in reducing the risk of injuries. Real-time feedback obtained from sensor technology and inertial devices provides opportunities for coaches and athletes to make immediate adjustments in their training, which, in turn, can enhance the quality of techniques and prevent potentially harmful injuries. Therefore, the integration of physics principles in sports not only optimizes athlete performance but also forms an integral part of effective injury prevention and care efforts.

Acknowledgments

Thanks to the Indonesian Collaborative Research Team (RKI) from the Institute for Research and Community Service (LPPM) of three universities in Indonesia, namely Surabaya State University; Indonesian Education University and especially Padang State University for funding research with Decree Number 1162/UN35.15/LT/2024. Then to the entire research team and participants.

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