Review Article

A bibliometric analysis of publications on eccentric training or flywheel inertial training

Análisis bibliométrico de la literatura sobre entrenamiento excéntrico o también llamado entrenamiento con rueda de inercia

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ABSTRACT

The aim of this study was to conduct a bibliometric review focusing on training with inertial devices, which have gained popularity over time, initially utilized by astronauts and more recently adopted in sports such as soccer, volleyball, and

basketball. The methodology was developed collaboratively by the *Universidad Autónoma de Manizales* and the *Fundación Universitaria del Área Andina*. Three bibliometric dimensions were examined: 1) scientific production and dissemination, 2) scientific collaboration, and 3) bibliometric evaluation at the individual level (including Bradford's Law and the h-index). Data analysis was performed using Bibiometrix, an open-source tool programmed with R, allowing for a comprehensive analysis of scientific literature behavior. Among the findings, a total of 67 documents were identified, published across 30 indexed journals between 2003 and 2022. Of these, 55 (82%) were original articles and 7 (10.4%) were review articles. Inertial technology represents an emerging training methodology, offering significant benefits at anatomical, structural, physiological, and functional levels in high-performance sports. However, its widespread adoption necessitates the consolidation of concepts and high-quality research to establish evidence-based guidelines. This review underscores the importance of further research to support the advancement and standardization of training protocols using inertial devices.

Keywords: eccentric exercise; flywheel training; bibliometric analysis; sports performance; strength training.

RESUMEN

El objetivo de este estudio fue realizar una revisión bibliométrica centrada en el entrenamiento con dispositivos inerciales, que han ganado popularidad con el tiempo. Inicialmente se utilizaron por astronautas y se han adoptado en deportes como el fútbol, el voleibol y el baloncesto. La metodología fue desarrollada en colaboración entre la Universidad Autónoma de Manizales y la Fundación Universitaria del Área Andina. Se examinaron tres dimensiones bibliométricas: 1) producción y difusión científica, 2) colaboración científica, y 3) evaluación bibliométrica a nivel individual, incluyendo la Ley de Bradford y el índice h. El análisis de datos se realizó utilizando Bibiometrix, una herramienta de código abierto programada con R, lo que permitió un análisis exhaustivo del comportamiento de la literatura científica. Entre los hallazgos se identificó un total

de 67 documentos, publicados en 30 revistas indexadas entre 2003 y 2022. De estos, 55 (82 %) eran artículos originales y siete (10,4 %) artículos de revisión. La tecnología inercial representa una metodología de entrenamiento emergente, que ofrece beneficios significativos a nivel anatómico, estructural, fisiológico y funcional en deportes de alto rendimiento. Sin embargo, su adopción generalizada requiere la consolidación de conceptos y una investigación de alta calidad para establecer directrices basadas en la evidencia. Esta revisión subraya la importancia de una mayor investigación para apoyar el avance y la estandarización de los protocolos de entrenamiento utilizando dispositivos inerciales

Palabras clave: ejercicio excéntrico; entrenamiento inercial; análisis bibliométrico; rendimiento deportivo; entrenamiento de fuerza.

Received: 17/11/2023

Accepted: 21/04/2024

Introduction

Evidence suggests that in high-performance sport conditioning physical qualities are essential characteristics and improving them will lead to greater sports performance in athletes.[1] Suchomel *et al.*[2] suggests that muscle strength improves the ability to perform sport-specific tasks, such as running, jumping, accelerating, decelerating, and changing direction, thus determining a relationship between strength and physical-sport performance.[3] The foregoing can be explained because during all sports activities the muscles perform three different actions directly related to the ability to produce force: concentric action, which is defined as the ability to produce force overcoming external resistance and allowing shortening of the muscle fiber,[4] the eccentric action that is defined as the ability to produce force, however, and unlike the previous one, in this action

the muscle fiber lengthens and does not overcome external resistance[4,5], and, finally, isometric action, which is the ability to produce force without changing the length of the muscle fiber and without producing movement.[5]

Previous investigations[6,7,8] reported that eccentric training programs could elicit larger neuromuscular adaptations compared to traditional resistance training; highlighting this, Clark *et al.*[9] reported that a 4-week eccentric resistance training intervention produces favorable neuromuscular adaptations. Therefore, Strength, Power, and Speed appear to be exceptionally responsive to eccentric stimuli and, due to possible adaptations to this particular type of training, has become an increasingly popular component of strength programs. and conditioning.[9]

The flywheel inertial training (FIT) is a training strategy to improve eccentric capacity, this methodology was used for the first time in astronauts who are constantly exposed to environments without gravity.[10] However, in the last decade the practice of this training methodology has grown considerably in amateur and semi-professional athletes as a means to improve sports performance.[11,12]

The mechanism of the FIT devices is produced by the rotation of the flywheel of the device, which begins with an eccentric action of the muscle that winds the flywheel strap. This is followed by a concentric muscular action which unwinds the belt from the shuttlecock. The force applied in the eccentric action to stop the flywheel will depend on the kinetic energy generated during the concentric action.[13]

A significant increase in strength and speed has been reported in male soccer players after an eccentric overload intervention using the FIT training methodology for 10 weeks, subjects performed two weekly sessions using an inertial device specifically on the hamstrings.[12] This agrees with the findings of Maroto-Izquierdo *et al.*,[14] who reported positive effects on strength, speed, and power in male handball players after 6 weeks of eccentric overload training with FIT.

In today's context, delving into this particular training methodology is crucial. To achieve this, conducting a critical analysis via bibliometric review, including an assessment of study quality, becomes imperative given its increasing application.

Thus, considering the aforementioned factors, this study aims to conduct a bibliometric review of existing literature.

Methods

The methodology used was developed by the Autonomous University of Manizales and the Pereira sectional Andean Area University Foundation. Three bibliometric dimensions were observed: 1) dimension of scientific production and delivery (number of articles published per year, journals, countries, citations and authors), 2) dimension of scientific collaboration (national and international collaboration and articles without collaboration), and 3) the dimension of the bibliometric evaluation at the individual level (Bradford's Law and h-index)

The total number of journals related to the subject indexed in Web of Science (WOS) was used as the population due to the high range of bibliographic sources and its complete structure of bibliometric variables of interest; The scientific production worldwide was extracted without limiting the search time or the language.

As a search strategy, "eccentric overload (Title) OR flywheel inertial training (Title)" was used in the WOS database without limiting the search process. The database exploration date was December 4, 2022. Gray literature documents, notes and short surveys were excluded.

Analysis of data

The data analysis was carried out with Bibiometrix, which is an open source tool programmed with R that allows a complete analysis of the behavior of the scientific literature.[15]

Descriptive statistics were used to summarize the analyzed data set, later, multidimensional scaling, mapping and data reduction techniques were used, which are available in the bibliometrix tool.[15]

Results

Within the analysis of scientific production, a total of 67 documents published in 30 indexed journals were determined. Table 1 summarizes the general characteristics of the documents included in the analysis; however, the years of publication are highlighted, which vary between 2003 and 2022, the type of document, of which 55 are original articles (82%) and 7 (10.4%) are review articles, in addition a total of 254 authors, 1671 references and 185 keywords were determined.

Table 1 - Characteristics of the studies

Description	Results
Timespan	2003:2022
Sources (Journals)	30
Documents	67
Average years from publication	4.88
Average citations per documents	35.73
Average citations per year per doc	4.939
References	1671
Document Types	
Article	55
Article; early access	1
Letter	2
Meeting abstract	2
Review	7
Document Contents	
Keywords Plus (ID)	277
Author's Keywords (DE)	185

Authors	
Authors	254
Author Appearances	343
Authors Collaboration	
Documents per Author	0.264
Authors per Document	3.79
Co-Authors per Documents	5.12
Collaboration Index	3.79

Figure 1 shows the behavior of the annual scientific production, evidencing a growing behavior in the subject of study, highlighting the considerable increase in publications from the year 2012, with the years of greatest production being 2018 and 2020 with an average publication. of 10 documents per year. When pondering the total behavior of the data, it is possible to show an annual growth of 4.7%.

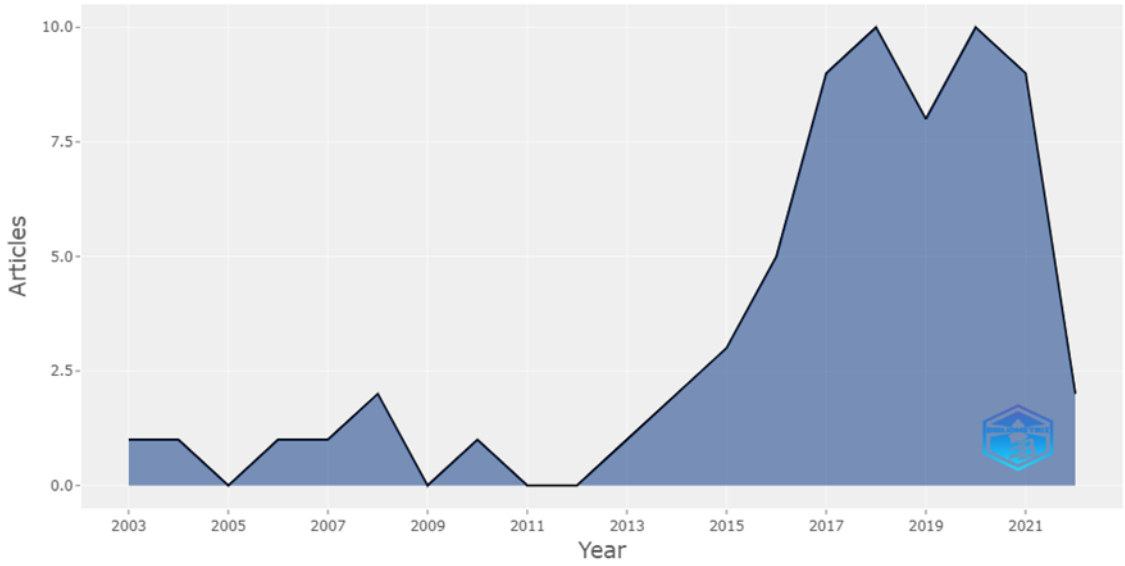


Fig. 1 – Annual scientific production.

Figure 2a describes the institutional affiliations of the publications included in the analysis, a total of 20 institutions are reported, among which the Karolinska Institute in Stockholm stands out with 14 documents, followed by the University of San Jorge in Spain and the University of Suffolk from the United States with 12 articles each. Figure 2b shows the behavior over time of the production of the 20 most important authors, highlighting Gonzalo-Fernández, who presents 7 articles published between 2014 and 2019, as well as Gonzalo-Skok, who has 7 articles, but published between 2016 and 2021. Figure 2c shows the 15 most cited countries, highlighting Spain and Switzerland with 968 and 855 citations, respectively.

Source: Authors.

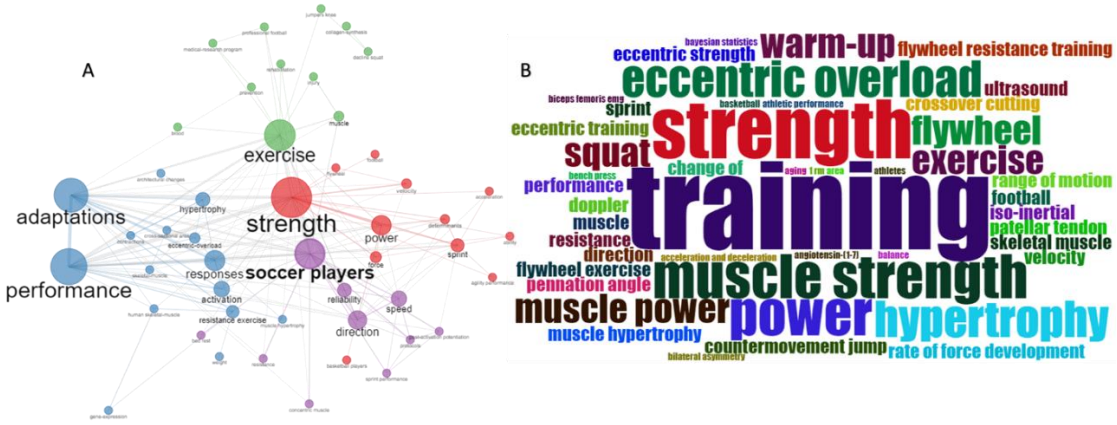
Fig. 2 – Bibliometric analysis by affiliation and authors. A: Most relevant affiliations; B: Scientific production of authors over time; C: Countries with the most citations.

The 10 most cited articles are listed in table 2. The documents were published between 2008 and 2017, most of these are clinical trials and/or cohort studies conducted largely in the athlete or physically active population, however, one of the 10 most cited documents correspond to a systematic review with meta-analysis performed on healthy subjects.

Table 2 - Most Cited Articles

Document	DOI	Year	Local Citations	Global Citations	LC/GC Ratio (%)
Norrbrand, *Eur J Appl Physiol*	https://doi.org/10.1007/s00421-007-0583-8	2008	34	157	21,66
Fernández-Gonzalo, *Eur J Appl Physiol*	https://doi.org/10.1007/s00421-014-2836-7	2014	18	77	23,38
De Hoyo, *Int J Sports Med*	https://doi.org/10.1055/s-0034-1395521	2015	15	44	34,09
Maroto-Izquierdo, *J Sci Med Sport*	https://doi.org/10.1016/j.jsams.2017.03.004	2017	15	90	16,67
Martinez-Aranda, *J Strength Cond Res*	https://doi.org/10.1519/JSC.0000000000001635	2017	12	49	24,49
Gual, *J Strength Cond Res*	https://doi.org/10.1519/JSC.0000000000001286	2016	11	44	25,00
Onambele, *J Biomech*	https://doi.org/10.1016/j.jbiomech.2008.09.004	2008	10	70	14,29
Friedmann-Bette, *Eur J Appl Physiol*	https://doi.org/10.1007/s00421-009-1292-2	2010	10	80	12,50
De Hoyo, *J Hum Kinet*	https://doi.org/10.1515/hukin-2015-0071	2015	9	32	28,13
Tesch, *Front Physiol*	https://doi.org/10.3389/fphys.2017.00241	2017	9	63	14,29

The bibliometric analysis of the keywords was carried out with the index terms automatically generated from the titles of the most cited articles (Keywords Plus). Of 277 keywords, 46 were included in the analysis, of which 4 clusters were formed. The words with the greatest relevance betweenness centrality strength (betweenness centrality) were the words strength, adaptations, exercise and soccer players main words the clusters found (fig. 3a). A word cloud was also created to show the frequency of the keywords. It was indicated that "Strength" was the most frequent followed by "performance", "adaptations" and "exercise" coinciding with the co-occurrence analysis (fig. 2b).

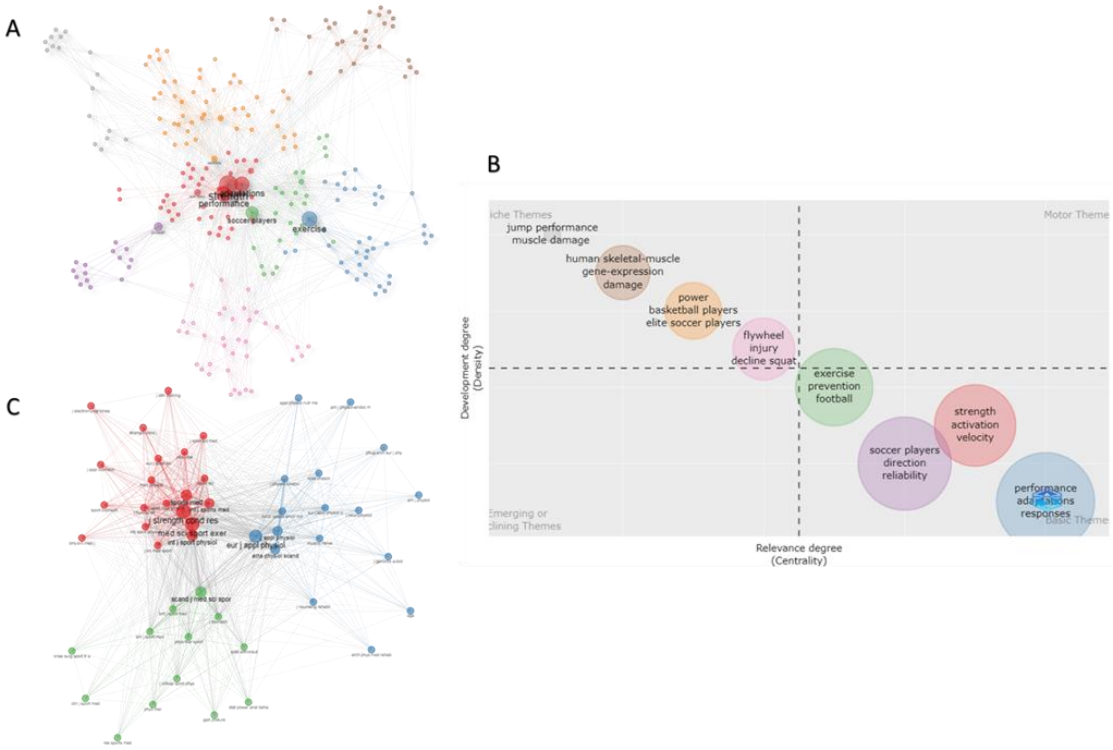


Legend: A: Co-occurrence of keywords. The size of the nodes indicates the frequency of occurrence. The curves between the nodes represent their co-occurrence in the same publication. The smaller the distance between two nodes, the higher the number of co-occurrences of the two keywords; B: Word cloud. 50 keywords were registered. The font size represents the frequency of occurrence. Key words such as “strength”, “performance”, “adaptations” and “exercise” were the most common. The words “Aquilian tendinopathy”, “agility performance” and “acceleration” were the least frequent.

Fig. 3 – Bibliometric analysis of the keywords plus.

The bibliographic coupling map of documents and sources is shown in figure 4 a,b. From the analysis, eight clusters were obtained that group the different thematic areas. Group 1 includes 11 items and the area of investigation is force (shown in red). Groups 2 and 3 add up to 23 items and include study areas related to the practice of exercise and soccer players (shown in blue and green). Finally, when analyzing the bibliographic behavior of the journals, it is possible to show that the

journals Medicine and Science in Sports and Exercise and The Journal of Strength and Conditioning Research are the most relevant within the set of bibliometric data analyzed (fig. 4c).

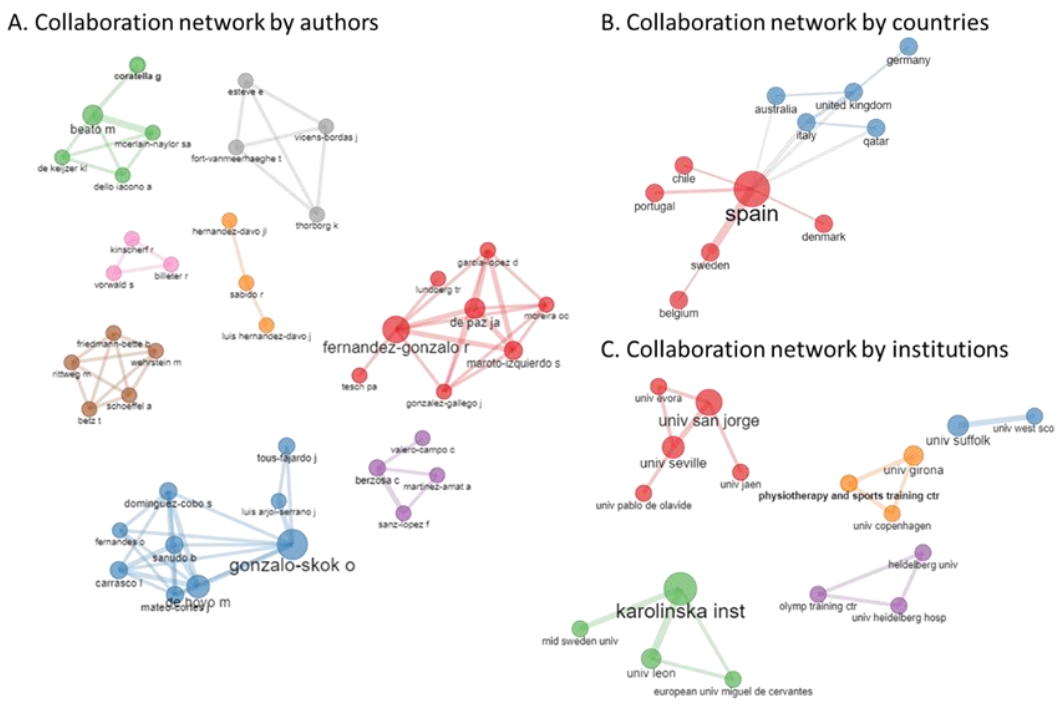


Legend: A: Bibliographic coupling of documents; B: Thematic map; C: Conjoint analysis of sources. A different color indicates different research areas. The size of the circles represents the cocitation counts. The distance between the two circles indicates their correlation.

Fig. 4 – Bibliometric analysis of bibliographic coupling and cocitation.

The bibliometric analysis of scientific collaboration by authors, cities and institutions is shown in figure 5, in general, a high prevalence of scientific collaboration is evident. The analysis by authors (fig. 5a) determined four clusters or collaborative work groups where authors such as Fernández-Gonzalo, Gonzalo Skok, Beato, Vicens-Bordas, among others, stand out. The analysis of scientific collaboration by countries yielded two clusters where Spain stands out, which presents a considerably high collaborative network. Finally, the analysis of scientific collaboration by institutions determined 5 clusters of collaborative work

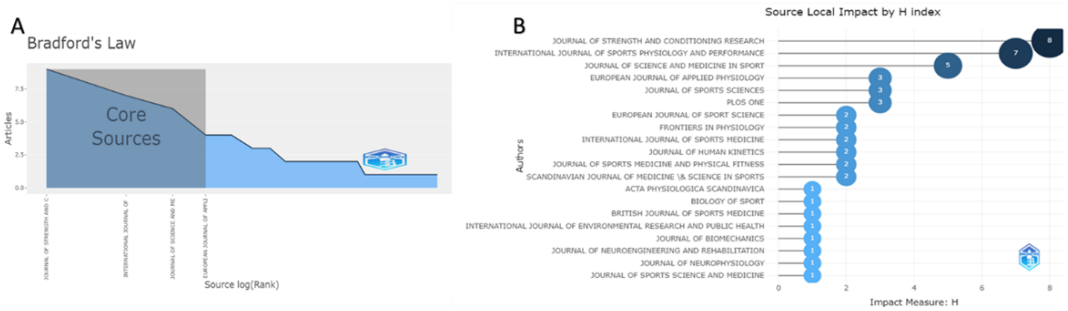
where the Karolinska Institute, the San Jorge University, the University of Girona, among others, stand out.



Legend: A: Collaboration network by authors; B: Collaboration network by countries; C: Collaboration network by institutions. A different color indicates different research areas. The size of the circles represents the cocitation counts. The distance between the two circles indicates their correlation

Fig. 5 – Analysis of scientific collaboration.

Figure 6 shows the relationship between the H index and the behavior of the publications according to Bradford's law of the 20 most important journals within the data set analyzed. It can be highlighted that the journal with the greatest impact and representativeness in the subject of study is the *Journal of Strength and Conditioning Research* followed by the *International Journal of Sports Physiology and Performance.*



Legend: A: Bradfords Law; B: Source local impact by H index.

Fig. 6 – Impact bibliometric analysis.

Discussion

Over the past decade, the utilization of FIT (Inertial Device Training) in both amateur and professional sports has experienced a remarkable surge, driven by its perceived myriad benefits across anatomical, physiological, structural, and functional dimensions.[16,17] These adaptations encompass an array of improvements, including enhanced muscle fiber quantity and size, reduced metabolic expenditure leading to increased resistance to fatigue, improved energy absorption and storage efficiency, and advancements in the sarcomere-genesis process, Such adaptations extend to muscle fiber length, area, and cross-section, culminating in heightened peak force production, consequently amplifying performance metrics such as jumping ability, acceleration, deceleration, and agility.[18] Moreover, this adaptation to eccentric load has shown promise in mitigating the incidence of muscle injuries.[8,19,20]

While the advantages of FIT technology in high-performance sports are widely acknowledged, our bibliometric analysis reveals a pertinent gap: despite its burgeoning popularity, there remains a dearth of robust scientific evidence in premier international journals. This underscores the urgency for rigorous research endeavors to substantiate the efficacy of FIT technology in various domains such as rehabilitation, training, and sports readaptation.[21]

However, research must be carried out that can manage and develop the importance of the use of FIT technology based on high-impact scientific evidence such as RCTs, Meta-analysis and systematic reviews that allow the development of standardized protocols, injury reduction studies, improvements in variables that enhance sports performance, effects on specific injuries at the ligament, tendon, bone and muscle level, comparisons with conventional training methodologies. Additionally, it is the responsibility of all professionals who work in high-performance sports with access to this type of technology to develop research and publish the results to demonstrate specific work models under the reliability and validity of a scientific model in sport and break paradigms and stereotypes. of dogmas or pseudoscience's used in this branch.

To contextualize these findings, recent studies by Buosenso *et al.*[22] further support the efficacy of FIT technology in enhancing athletic performance across diverse sports disciplines. Their research underscores flywheel training as a promising strategy for performance improvement, offering variability in training methods and bolstering athletes' adherence. However, further investigations are warranted to establish comprehensive guidelines regarding training modalities, weekly frequency, volume, and inertia load. Moreover, limited research has directly applied the flywheel device to overload specific multidirectional movements at various joint angles, indicating an area ripe for exploration and innovation. In a similar vein, the systematic review by Chabeene *et al.*[23] concludes that flywheel resistance training (FRT) appears to be more effective than traditional resistance training (TRT) in enhancing Change of Direction (CoD) performance in male athletes.

In conclusion, the proliferation of FIT technology heralds a paradigm shift in the realm of sports training, offering a multifaceted approach to enhancing athletic performance and mitigating the risk of injuries. While empirical evidence continues to underscore its efficacy, there remains a pressing need for further research to elucidate optimal protocols, refine methodologies, and address knowledge gaps. By embracing a rigorous scientific approach and fostering collaboration between researchers, practitioners, and industry stakeholders, we can unlock the full potential of FIT technology and usher in a new era of evidence-based practice in

high-performance sports. Through continued innovation and exploration, we stand poised to revolutionize training methodologies, optimize athlete performance, and elevate the standards of sports excellence on a global scale.

The adoption of inertial technology (FIT) represents an emerging training methodology gaining momentum in high-performance sports. Despite its relative novelty, FIT has quickly garnered attention for its potential to revolutionize training methodologies and enhance athletic performance across multiple dimensions. Its application extends beyond traditional resistance training, offering a dynamic and adaptable approach that addresses the intricacies of human biomechanics and physiology.

FIT leverages the principles of inertia to provide variable resistance throughout a range of motion, challenging muscles in a manner that closely mimics real-world athletic movements. This nuanced approach holds promise for athletes seeking to optimize their performance, targeting muscle strength, power, proprioception, neuromuscular coordination, and movement efficiency. By engaging muscles in a more functional manner, FIT bridges the gap between traditional strength training and the dynamic demands of sports performance.

Research indicates that FIT induces adaptations across physiological systems, leading to increases in muscle fiber size and quantity, improvements in metabolic efficiency, and enhancements in neuromuscular function. It has been associated with greater gains in muscle strength, power, and endurance compared to traditional resistance training methods. These adaptations translate into tangible improvements in athletic performance, including greater explosiveness, agility, and resilience to fatigue.

However, gaps remain in our understanding of FIT's optimal implementation and application. High-quality research and systematic analysis are crucial to delineate effective training protocols, including frequency, volume, intensity, and mode of training. Real-world studies exploring FIT's practical applications across diverse sports and athletic populations are essential to provide insights into its efficacy and feasibility.

Moreover, FIT holds promise as a rehabilitation tool for individuals recovering from injury or managing chronic conditions. Exploring its therapeutic applications can expand its utility beyond sports performance into preventive and rehabilitative medicine.

The present bibliometric analysis provides a roadmap for future research endeavors and serves as a catalyst for standardizing concepts and methodologies worldwide. Through dissemination of high-quality research and development of evidence-based guidelines, we can unlock FIT's full potential and usher in a new era of athletic training and performance enhancement.

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Conflicts of interest

The authors declare no conflict of interest.