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Review Article

Resistance Training and Elite Athletes: A Systematic Bibliometric Analysis (2015–2023)

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

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Abstract

Objectives. This study aims to systematically map global research trends, influential contributors, and thematic evolution in resistance training (RT) research involving elite athletes from 2015 to 2023.

Materials and Methods. A systematic bibliometric analysis was conducted using the Scopus database. Study selection followed PRISMA 2020 guidelines and focused on RT interventions involving elite competitive populations. Duplicate records were removed, followed by title, abstract, and full-text screening conducted by independent reviewers. VOSviewer version 1.6.20 was used to generate bibliometric visualizations, including co-authorship, co-citation, and keyword co-occurrence networks. Key bibliometric indicators, such as publication trends, citation impact, collaboration networks, and thematic clustering, were evaluated.

Results. From an initial total of 2,710 records, 678 documents met the eligibility criteria. Global scientific productivity exhibited steady growth, with a marked acceleration after 2019. The United States demonstrated the highest citation impact, whereas Spain and Brazil emerged as central international collaboration hubs. Three major thematic clusters were identified: (1) performance optimization strategies, including velocity-based training and blood flow restriction; (2) neuromuscular adaptations and hypertrophy mechanisms; and (3) youth athlete development with increasing integration of digital and monitoring technologies.

Conclusions. Research on RT in elite athletes continues to expand, characterized by strong international collaboration and increasing methodological refinement. The findings emphasize the central role of RT in high-performance sport and provide directions for future research, particularly regarding gender inclusivity, advanced monitoring technologies, and standardized measurement approaches.

Keywords: resistance training; elite athletes; bibliometric analysis; hypertrophy; neuromuscular adaptation; performance enhancement.

Introduction

Resistance training (RT) is a fundamental component in elite athlete development programs, particularly due to its role in enhancing muscle strength, neuromuscular capacity, and injury resilience. Recent studies have shown that RT not only contributes to competitive performance but also has significant effects on metabolic health and body composition in athletes (Grgic & Schoenfeld, 2018; Schoenfeld & Grgic, 2018). At the elite level, the high intensity of competition requires science-based training approaches to achieve optimal physiological adaptations. This highlights that RT is not merely an auxiliary exercise but a primary strategy in supporting the long-term performance of athletes. Furthermore, the theoretical foundation of RT emphasizes the importance of progression, periodization, and individualization, which have long been recognized as key principles in exercise science (Kraemer & Ratamess, 2004; Moesgaard et al., 2022). Nevertheless, although RT has become a common practice, global research developments in this area still reveal disparities, particularly in the context of elite athletes from different regions of the world (Pedersen & Saltin, 2015; Makaruk et al., 2024).

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The increase in RT publications over the past decade indicates a growing scientific interest in this training method, especially in exploring its effects on muscle hypertrophy, maximal strength, and neural adaptations. (Morton et al., 2018) emphasized that combining RT with protein supplementation leads to significant improvements in muscle mass and strength performance. Moreover, new training methodologies such as velocity-based training (VBT) and blood flow restriction (BFR) have gained attention in recent studies, as they are considered effective in eliciting greater adaptive responses in elite athletes (Michał Włodarczyk et al., 2021; Centner et al., 2019). For instance, VBT allows coaches to monitor lifting intensity and movement velocity in real time, making training more objective and measurable (Nagatani et al., 2025; Weakley et al., 2021). These trends indicate that RT is evolving into an arena of methodological innovation, technological experimentation, and reinforcement of individualized training principles (Krzysztofik et al., 2019).

Despite the increasing number of studies on RT, there remains considerable variation in terms of research populations, methodologies, and reported outcomes. Most studies continue to focus on male athletes, while female and Paralympic athletes remain underrepresented (Franchi et al., 2023; Larsen et al., 2016). This lack of representation indicates that research findings cannot yet be fully generalized to all athlete populations. Recent studies have also highlighted the importance of examining psychosocial and hormonal factors specific to female athletes, as well as the unique needs of disabled athletes (Suchomel et al., 2018; Heather et al., 2021). Similarly, RT studies in Asia, Africa, and Latin America are relatively limited compared to those in Europe and North America (Faigenbaum, 2018; Baker et al., 2021). This imbalance restricts the applicability of research findings across different cultural, infrastructural, and athletic contexts (Peters & Klatt, 2023).

Bibliometric analysis provides a relevant approach to understanding the global landscape of RT research. Through this method, researchers can identify publication trends, collaboration networks, and dominant research themes. Similar studies have been successfully applied in mapping other sport science domains, such as high-intensity interval training (HIIT) and sport tourism (Pham, 2024; Da Silva et al., 2020). Thus, bibliometric analysis in the context of RT offers a more comprehensive picture of research directions, knowledge gaps, and opportunities for cross-country collaboration (Chen, 2025). Furthermore, this approach is strengthened by the use of visual analytic tools such as VOSviewer, which has proven effective in mapping author collaborations and thematic clusters (Van Eck & Waltman, 2010; Du et al., 2024).

Based on this background, the present study aims to map global research trends on RT in elite athletes between 2015 and 2023. The main focus is directed toward patterns of publication, citation performance, the most influential articles, country distribution, collaboration networks, and the emergence of dominant keywords. The findings are expected to enrich understanding of RT development at the international level and open avenues for further research in underexplored regions and populations. In this way, the article seeks to provide a knowledge framework that can serve as a foundation for coaches, athletes, and sport scientists in designing evidence-based training strategies.

Materials and Methods

Data Source

The Scopus database was selected as the primary source for data retrieval due to its wide coverage, reliability, and relevance for bibliometric studies (Suhendar et al., 2024). Data collection was conducted in March 2024, ensuring that all available publications up to December 2023 were included. Boolean operators were applied to identify documents related to resistance training (RT) and elite athletes. Two main search strings were used: "resistance training" AND "elite athlete" and "resistance training" AND "muscle hypertrophy." To maintain focus on scientific contributions, filters were applied to restrict the dataset to articles and reviews published in peer-reviewed journals, written in English, and indexed in medicine, health, and social sciences subject areas.

Data Selected and Analysis

The initial search yielded 2,710 documents from Scopus. After duplicate removal using Scopus utilities and manual verification (n = 420), 2,290 records remained for title and abstract screening. A total of 1,412 records were excluded due to non-elite populations or irrelevance to resistance training. Full-text assessment was performed on 878 articles, and 200 were excluded based on eligibility criteria. Ultimately, 678 documents met all inclusion criteria and were retained for bibliometric analysis. Data were organized and validated prior to bibliometric mapping to ensure accuracy (Donthu et al., 2021; Hassan & Duarte, 2024).

Table 1. Search strategy

Item	Details
Database	Scopus
Date of search	January 2024 (includes publications up to 31 Dec 2023)
Time window	2015–2023
Fields searched	TITLE-ABS-KEY
Search string (primary)	TITLE-ABS-KEY(«resistance training» OR «strength training») AND TITLE-ABS-KEY(«elite athlete» OR «high-performance athlete» OR «professional athlete»)
Filters applied	Document type = Article OR Review; Language = English; Subject areas = Sport Sciences / Physiology / Rehabilitation / Medicine related
Export format	RIS / CSV (full metadata: authors, title, abstract, year, keywords, affiliations, citations)
Deduplication tools	Scopus built-in deduplication + manual verification in Zotero
Screening process	Title → Abstract → Full-text; two independent reviewers; disagreements resolved by third reviewer
Inclusion criteria summary	Studies on RT interventions / outcomes in elite/high-performance athletes; peer-reviewed; English; 2015–2023
Exclusion criteria summary	Recreational/non-elite populations; non-primary RT studies; conference abstracts, editorials, book chapters
Software for analysis	VOSviewer v1.6.20; Bibliometrix (R) for descriptive stats (if used)

Procedure

The analysis followed three main stages. First, descriptive statistics were generated to identify annual publication trends, most cited articles, productive authors, journals, and countries. Second, bibliometric mapping was performed using VOSviewer (version 1.6.20), enabling visualization of co-authorship networks, bibliographic coupling, and keyword co-occurrence. Thresholds were set at a minimum of five publications per author and ten citations per document to focus on influential contributions. Third, thematic clusters were identified to detect major research streams in the field of RT for elite athletes. This systematic approach ensured consistency and replicability in line with bibliometric research standards (Pamboris et al., 2024; Mi et al., 2023).

The initial title abstract search in Scopus yielded 2,710 records. A multi-stage screening process was then applied using Scopus filtering tools. Records were sequentially refined based on publication year, subject area, document type, publication stage, keyword relevance, and language criteria. After these screening refinements, 678 records remained eligible for detailed evaluation.

Duplicate detection using Scopus utilities and manual verification removed 910 overlapping entries, resulting in 1,800 unique records for title and abstract screening. Two independent reviewers screened these records, with disagreements resolved through discussion and, when necessary, adjudication by a third reviewer. Of the 1,800 screened records, 1,122 were excluded based on topic irrelevance, leaving 678 records for full-text retrieval.

All 678 full-text articles were successfully retrieved and assessed. None were excluded at this stage, as all met the predetermined eligibility criteria. Thus, a total of 678 documents were included in the final dataset for the bibliometric analysis (2015–2023).

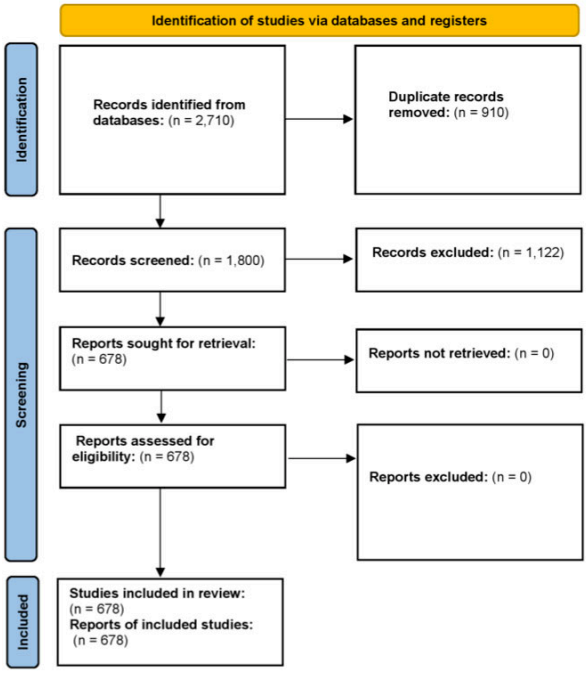

Fig. 1. PRISMA 2020 Flow Diagram.
Note: Data retrieved from Scopus (2015–2023). Screening, deduplication, and eligibility assessment followed PRISMA 2020 procedures. Diagram generated manually based on extracted records

Results

Publication Trends

The bibliometric search revealed a total of 678 documents published between 2015 and 2023 that focused on resistance training (RT) in the context of elite athletes. As illustrated in Figure 1, annual publication output showed a fluctuating pattern, with a notable increase from 2018 to 2020. The peak occurred in 2020 with 118 publications, followed by a slight decline in 2021 (110 documents) and a more modest output in 2023 (93 documents). This trend reflects the rapid expansion of interest in RT research before and during the COVID-19 pandemic, which likely influenced the volume of sport science publications worldwide. In terms of citation counts, the most cited works appeared in the earlier period of the dataset, indicating that impactful studies tend to accumulate citations over time.

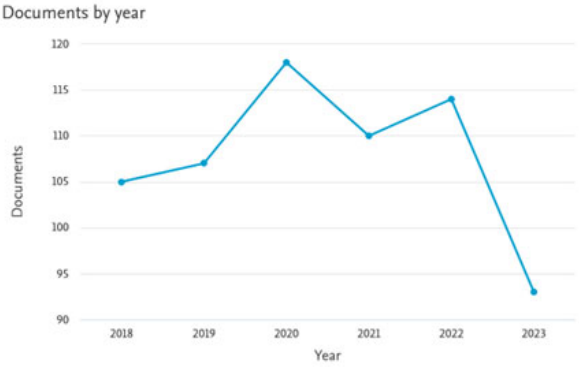

Fig. 2. Annual Distribution of Publications.
Note: Publication data extracted from Scopus for the period 2015–2023. The initial trend visualization was generated using Scopus analytical tools

Most Cited Articles

Table 2 presents the top 10 most cited articles in the dataset. The study by (Morton et al., 2018) emerged as the most influential, with 612 citations, emphasizing the importance of protein supplementation in enhancing the outcomes of RT. This is consistent with the broader literature highlighting the synergistic role of nutrition and exercise in muscle hypertrophy and strength development (Deldicque, 2023). Other highly cited works include (Izquierdo et al., 2021)ubiquitous and inevitable. Every physiological function is being continuously diminished. There is a range between two distinct phenotypes of ageing, shaped by patterns of living - experiences and behaviours, and in particular by the presence or absence of physical activity (PA, which addressed evidence-based exercise recommendations for older populations, and (Franchi et al., 2018), which investigated methods for accurately measuring hypertrophy. Collectively, these findings demonstrate that the most impactful studies focus on methodological rigor and practical implications for training interventions.

Tabel 2. Ten articles with the most citations based on Scopus

No	Document Title	Author and year	Total citations
1	A systematic review, meta-analysis and meta-regression of the effect of protein supplementation on resistance training-induced gains in muscle mass and strength in healthy adults	Morton, Robert W et al., 2018	612
2	International Exercise Recommendations in Older Adults (ICFSR): Expert Consensus Guidelines	Izquierdo, M et al., 2021	345
3	Muscle thickness correlates to muscle cross-sectional area in the assessment of strength training-induced hypertrophy	Franchi, Martino V et al., 2018	175
4	Effects of Blood Flow Restriction Training on Muscular Strength and Hypertrophy in Older Individuals: A Systematic Review and Meta-Analysis	Centner, Christoph M et al., 2019	168
5	Resistance Training Volume Enhances Muscle Hypertrophy but Not Strength in Trained Men	Schoenfeld, Brad Jon et al., 2019	159
6	Time-restricted feeding plus resistance training in active females: A randomized trial	Tinsley, Grant M et al., 2019	125
7	Comparing the Effectiveness of Blood Flow Restriction and Traditional Heavy Load Resistance Training in the Post-Surgery Rehabilitation of Anterior Cruciate Ligament Reconstruction Patients: A UK National Health Service Randomised Controlled Trial	Hughes, Luke et al., 2019	122
8	Volume for Muscle Hypertrophy and Health Outcomes: The Most Effective Variable in Resistance Training	Casagrande Figueiredo, Vandré Casagrande et al., 2018	102
9	Effects of different intensities of resistance training with equated volume load on muscle strength and hypertrophy	Lasevicius, Thiago et al., 2018	94
10	Loading Recommendations for Muscle Strength, Hypertrophy, and Local Endurance: A Re-Examination of the Repetition Continuum	Schoenfeld, Brad Jon et al., 2021	92

Country and Institutional Contributions

Analysis of country-level productivity revealed that the United States dominated the field, producing 254 documents and accumulating 4,681 citations. Brazil (2,307 citations) and Australia (1,732 citations) followed, reflecting strong contributions from South America and Oceania. European countries, particularly the United Kingdom, Spain, and Germany, also ranked among the most productive nations, with citation counts exceeding 1,200 each (see Table 2). Asian contributions, particularly from Japan (988 citations) and China (832 citations), were relatively limited, highlighting a geographic imbalance in the research landscape. This trend aligns with previous bibliometric analyses in sport science, where North America and Europe consistently appear as dominant contributors (Cruz, 2022). Institutional analysis showed that collaborations were often concentrated within established universities and research centers, suggesting that institutional reputation and funding resources strongly influence publication output.

Tabel 2. Source: Scopus Database, Country Distribution by Citations

Rank	Country By Citation	Citation
1	United States	4681
2	Brazil	2307
3	Australia	1732
4	United Kingdom	1340
5	Japan	988
6	Canada	916
7	New Zealand	891
8	Italy	865
9	Spain	799
10	Germany	788

Co-Authorship and Collaboration Networks

The co-authorship analysis generated five major clusters of researchers, reflecting international collaboration patterns (Figure 2). The largest cluster linked authors from the United States, Brazil, and Canada, while another prominent cluster connected researchers from Spain, Germany, and the United Kingdom. These networks suggest that RT research is increasingly multidisciplinary, involving experts in physiology, nutrition, biomechanics, and sports medicine. However, collaboration between developed and developing countries remains limited, which may contribute to disparities in global knowledge production. Strengthening international partnerships could enhance both the quality and applicability of RT research across diverse populations and athletic contexts.

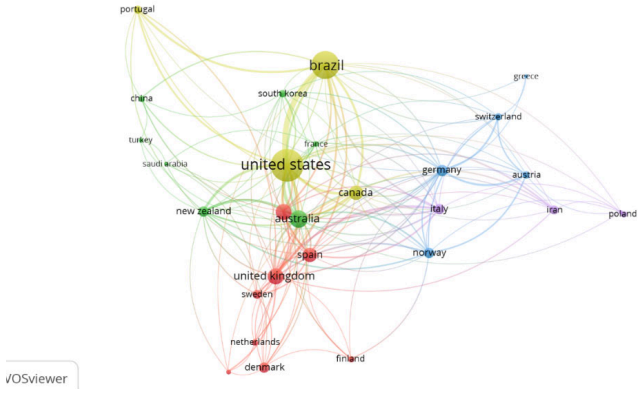

Fig. 3. Citation Network by Country
Note: Based on Scopus citation data (2015–2023). Network visualization created using VOSviewer 1.6.20 with full counting method

Fig. 4. Keyword Co-occurrence Network
Note: Data sourced from Scopus (2015–2023). Keyword co-occurrence map produced using VOSviewer 1.6.20 with minimum threshold of 5 occurrences per keyword

Keyword Co-occurrence Analysis

The keyword analysis revealed seven thematic clusters, represented in Figure 3. The most dominant cluster centered on "hypertrophy," "protein supplementation," and "muscle growth," confirming the critical role of nutrition-exercise interactions in RT research. Another strong cluster focused on "neuromuscular adaptation," "muscle fibers," and "strength," highlighting the physiological mechanisms underlying training outcomes. A third cluster was associated with "training volume," "intensity," and "endurance," reflecting ongoing debates about the optimization of RT variables. Emerging terms such as "velocity-based training," "blood flow restriction," and "individualization" indicate the incorporation of innovative methods in recent years (Çetin et al., 2022). These thematic groupings demonstrate both continuity in established areas and expansion into novel research directions.

Discussion

This bibliometric analysis (2015–2023) demonstrates substantial growth in resistance-training (RT) research in elite athletes, with a publication peak in 2020. This increase aligns with the shift toward controlled or remote training studies during early COVID-19 restrictions (Gentil et al., 2020), followed by a decline linked to funding challenges and limited athlete access (Jukic et al., 2020; Adrian et al., 2022). These patterns mirror disruptions across performance sciences during the pandemic, where many laboratory studies were halted (Poteko et al., 2023).

The prominence of (Morton et al., 2018) among the most cited works emphasizes the established importance of nutrition training interactions in maximizing hypertrophy and strength. This is consistent with systematic reviews showing synergistic effects of protein supplementation and resistance training (Lin et al., 2021; Grgic et al., 2022). Similarly, continued interest in program variables such as volume, intensity, and progression highlights sustained focus on optimizing neuromuscular adaptation (Franchi et al., 2018; Centner et al., 2019). Ongoing debates on the repetition continuum and load distribution further illustrate methodological evolution within RT research (Ralston et al., 2018; Schoenfeld et al., 2017). Emerging work on movement velocity, autoregulation, and fatigue monitoring signals increasing adoption of individualized prescription models (Weakley et al., 2021; Pareja-Blanco et al., 2016; Carvalho et al., 2022).

Country-level analyses demonstrate dominant contributions from the USA, Brazil, and Australia regions with established sport science infrastructures. Conversely, Africa and Southeast Asia remain underrepresented, reflecting resource constraints and limited access to elite athlete samples. These imbalances align with broader inequities in global sport science output (Paleti et al., 2025; Wang et al., 2015; Riot et al., 2020) and reinforce calls for more geographically inclusive athlete data (Goyal, 2024).

Co-authorship mapping shows concentrated collaboration among leading institutions in North America, South America, and Europe. While such clustering supports strong thematic specialization, it may also restrict global dissemination of methodological innovations. Encouraging trends include increased adoption of open-access practices, digital collaboration tools, and shared data repositories, which can expand participation from emerging research regions (Beukelaar & Mantini, 2023; Yan & Girard, 2023; Krüger et al., 2023).

Keyword co-occurrence patterns reveal both established and emerging themes. Classical focuses such as hypertrophy, strength, and protein supplementation remain central, while newer approaches such as blood-flow restriction and velocity-based training reflect innovation in individualized load management (Moore & Dorrell, 2020). The increasing presence of terms related to wearable technology, athlete monitoring, and artificial intelligence indicates a shift toward data-driven training models (Mateus et al., 2024). These developments align with growing interest in machine-learning applications for athlete profiling, performance prediction, and injury prevention (Pisaniello, 2024; Claudino et al., 2017; Worsey et al., 2021).

Collectively, these findings show that RT research in elite athletes is simultaneously mature supported by foundational work on training variables and adaptation and evolving through methodological diversification sand technology integration. Persistent challenges include geographic bias, limited representation of female, youth, and Paralympic athletes, and slow adoption of advanced monitoring tools. Addressing these gaps will improve the breadth, precision, and applicability of RT research in high-performance environments (Granacher et al., 2016; Halperin et al., 2017; Behringer et al., 2023).

Analytical Synthesis: Methodological and Practical Implications

The integration of keyword, author, and citation networks reveals several methodological tendencies shaping contemporary RT research in elite athletes. Five dominant clusters hypertrophy and protein supplementation, neuromuscular monitoring, volume–intensity prescription, velocity-based training (VBT), and blood-flow restriction

(BFR) indicate a clear shift toward individualized and technology-supported programming. Highly cited studies (e.g., Morton et al., 2018) continue to reinforce the importance of optimizing load, intensity, and recovery strategies.

Author and country networks highlight concentrated contributions from the USA, Brazil, and Australia, creating methodological bias and limiting external validity for underrepresented populations. Citation clusters further reveal the dominance of short-term experimental studies, with limited long-term monitoring, female athlete research, and in-season intervention trials. These patterns point to the need for more diverse sampling strategies and longitudinal research designs.

Practically, these clusters underscore the value of integrating nutritional strategies, real-time load monitoring, athlete readiness assessment, and individualized progression models into elite RT programming. The growing presence of VBT and neuromuscular monitoring also suggests increased emphasis on fatigue management and precision training. Meanwhile, interest in BFR highlights its relevance for maintaining muscle qualities during congested schedules or post-injury scenarios.

Future Research

Future research on resistance training (RT) in elite athletes should address several critical gaps. Geographic disparities especially limited contributions from Asia, Africa, and parts of South America necessitate broader international collaboration and targeted funding (Fon, 2023; Steele et al., 2023). Open-access publishing and data-sharing platforms can further support inclusivity and enhance global research visibility (Murphy et al., 2023).

Specific athlete groups remain underexamined, including female, youth, and Paralympic athletes, each requiring population-appropriate training models (Franchi, Longo, et al., 2018; Faigenbaum & McFarland, 2023; Rodr et al., 2022). Increasing representation of these groups will improve the ecological validity of RT recommendations. Most RT studies still focus on short-term interventions, underscoring the need for longitudinal designs that capture in-season adaptation, chronic fatigue, and interactions with sport-specific demands (Townsend, 2022).

Finally, emerging technologies including wearables, artificial intelligence, and machine learning offer promising avenues for advancing monitoring precision and individualized programming (José et al., 2022; Mateus et al., 2024). Molecular and imaging methods also provide opportunities to investigate adaptation mechanisms at deeper biological levels (Bersiner & Kirill, 2023).

Conclusions

This bibliometric study (2015–2023) reveals that resistance training (RT) remains a highly active research field for elite athletes, with consistent scientific output, a publication peak in 2020, and a clear geographic imbalance dominated by established countries while developing regions are underrepresented. Core research themes continue to focus on hypertrophy, neuromuscular adaptations, and training volume, alongside growing interest in innovative methods such as velocity-based training, blood flow restriction, and technology-assisted monitoring. In conclusion, RT is a fundamental pillar of elite athlete development, but future progress requires greater inclusion of diverse populations, enhanced international collaboration, and deeper integration of technology to strengthen both the scientific evidence base and practical application in optimizing elite sports performance.

Ethics Approval

Ethical approval was not required for this study because it is a narrative/systematic review based exclusively on previously published and publicly available sources and does not involve human participants or animals.

Informed Consent

Not applicable.

Data Availability Statement

No new data were generated in this study. All information analyzed is derived from publicly available sources cited in the reference list.

AI Transparency Statement

AI-assisted tools were used exclusively for language editing, stylistic refinement, and text structuring, based on content prepared by the authors. AI was not used for literature selection, data extraction, data analysis, interpretation of findings, or generation of scientific conclusions.

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Conflict of Interest

The author declares no conflict of interest.

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Тренування з опором і елітні спортсмени: систематичний бібліометричний аналіз (2015–2023)

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 10 с., 3 табл., 4 рис., 73 джерела.

Мета. Це дослідження має на меті систематично відобразити глобальні дослідницькі тенденції, впливових авторів і тематичну еволюцію досліджень тренувань з опором (RT), що стосуються елітних спортсменів, у період з 2015 по 2023 рік.

Матеріали і методи. Було проведено систематичний бібліометричний аналіз із використанням бази даних Scopus. Відбір досліджень здійснювався відповідно до настанов PRISMA 2020 та був зосереджений на інтервенціях із тренуванням з опором за участю елітних спортивних популяцій. Дублікати було вилучено, після чого незалежні рецензенти виконали скринінг за назвами, анотаціями та повними текстами. Для побудови бібліометричних візуалізацій, зокрема мереж співавторства, співав цитування та співзустрічальності ключових слів, використовувалося програмне забезпечення VOSviewer версії 1.6.20. Оцінювалися ключові бібліометричні показники, зокрема динаміка публікацій, цитованість, мережі наукової співпраці та тематичне кластерування.

Результати. Із початкової сукупності 2 710 записів 678 документів відповідали критеріям включення. Світова наукова продуктивність демонструвала стабільне зростання з помітним прискоренням після 2019 року. Сполучені Штати Америки продемонстрували найвищий рівень цитованості, тоді як Іспанія та Бразилія сформувалися як ключові міжнародні центри наукової співпраці. Було ідентифіковано три основні тематичні кластери: (1) стратегії оптимізації спортивних результатів, зокрема тренування, засновані на швидкості виконання, та обмеження кровотоку; (2) нейром'язові адаптації та механізми гіпертрофії; (3) розвиток юних спортсменів із дедалі ширшою інтеграцією цифрових і моніторингових технологій.

Висновки. Дослідження тренувань з опором у елітних спортсменів продовжують активно розширюватися, характеризуючись високим рівнем міжнародної співпраці та зростанням методологічної виваженості. Отримані результати підкреслюють центральну роль тренувань з опором у спорті вищих досягнень і окреслюють напрями майбутніх досліджень, зокрема щодо гендерної інклюзивності, використання передових технологій моніторингу та стандартизованих підходів до вимірювання.

Ключові слова: тренування з опором, елітні спортсмени, бібліометричний аналіз, гіпертрофія,нейром'язова адаптація, підвищення спортивної результативності.

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