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Soccer training load research mapping and trends: a bibliometric analysis
Mapeo y tendencias de la investigación sobre la carga de trabajo en el fútbol: análisis bibliométrico

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Abstract. In soccer, monitoring training load is crucial for performance enhancement, optimizing recovery, and preventing injury risks. The research trend in training load within soccer has been rapidly evolving, making this bibliometric study instrumental in understanding the direction of research focus in soccer training load. The objective of this study is to comprehend and explore the current state of research on soccer training load. This research analysis includes mapping contributions by country, publication years, authors, articles, and their respective citation counts. Findings indicate that research on training load in soccer commenced as early as 1976 and has gradually expanded with time, with a significant increase observed in 2019, marked by 109 articles addressing training load in soccer. The United Kingdom emerges as the top country in terms of scholarly publications and citation counts in this field.
Keywords: soccer, training load, bibiometric analysis.

Resumen. En el fútbol, el monitoreo de la carga de entrenamiento es crucial para mejorar el rendimiento, optimizar la recuperación y prevenir riesgos de lesiones. La tendencia de investigación en carga de entrenamiento en el fútbol ha evolucionado rápidamente, haciendo que este estudio bibliométrico sea fundamental para entender la dirección del enfoque investigativo en la carga de entrenamiento del fútbol. El objetivo de este estudio es comprender y explorar el estado actual de la investigación sobre la carga de entrenamiento en el fútbol. Este análisis de investigación incluye mapear las contribuciones por país, años de publicación, autores, artículos y sus respectivos recuentos de citas. Los hallazgos indican que la investigación sobre la carga de entrenamiento en el fútbol comenzó desde 1976 y ha crecido gradualmente con el tiempo, observándose un aumento significativo en 2019, marcado por 109 artículos que abordan la carga de entrenamiento en el fútbol. El Reino Unido emerge como el país líder en términos de publicaciones académicas y recuentos de citas en este campo.
Palabras clave: el fútbol, carga de entrenamiento, análisis bibliométrico.

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Introduction

Training load is defined as the total intensity, volume, and type of physical activity that athletes must perform during training and competition (Fitzgerald et al., 2019). Monitoring athlete load is fundamental in training to ensure athletic performance (Murray, 2017) as it is closely linked to injury risk and the imposed training load. As the level of sports activity increases, so does the intensity and complexity of movements, which in turn increases the risk of injury. Soccer, in particular, is a team sport that demands high levels of technical and tactical skills (Helgerud et al., 2011). In soccer, physical performance requires high levels of physical health and fitness parameters such as muscle strength, balance, jumping ability, running performance, flexibility, and agility (Sumartiningsih et al., 2022; Kariyawasam et al., 2019). As explained by Nédélec et al. (2012), soccer involves numerous physical demands such as sprints, rapid changes of direction, decelerations, accelerations, jumps, and various technical and tactical elements. During a 90-minute soccer match, players typically run about 10 km at an average intensity near the anaerobic threshold, around 80 to 90% of their maximum heart rate (Stølen et al., 2005). European professional teams usually play 50 to 80 matches per season over approximately 40 weeks, routinely playing two matches per week (Carling et al., 2011). This means that soccer players must cover long distances and perform high-intensity activities while repeatedly executing explosive movements. These demands stem from the dynamic nature of soccer, which requires high skill levels, thus necessitating exceptional physical and mental capabilities.

Training load can be adjusted at various times during the training cycle to either increase or decrease fatigue, depending on the training phases, such as the initial phase or the competition phase (Halson, 2014). Detecting patterns of changes in player fitness, on-field performance, or injury risk over time is crucial for coaches and sports practitioners. Monitoring acute and chronic training loads, along with their ratio, is considered an optimal method for evaluating the accumulation of training or competition loads (Buchheit, 2016). Acute training load refers to the physiological stress experienced by the athlete's body in response to a single training session, while chronic training load refers to the cumulative stress experienced by the athlete's body over a longer period (Zouhal et al., 2021). Zouhal et al. (2021) argue that an athlete's physical fitness improves effectively when the chronic training load increases gradually over time, with the acute training load being below, equal to, or slightly above the chronic training load (ACWR ranging from 0.8 to 1.3). Conversely, if the acute training load is frequently conducted and exceeds the chronic training load, the athlete is at risk of injury (ACWR $\geq$ 1.5) (Windt & Gabbett, 2016).

Several studies support a significant relationship between the Acute Chronic Workload Ratio (ACWR) and the risk of non-contact injuries in elite soccer players. In recent years, soccer coaches and sports scientists have focused particularly on monitoring training and competition loads in their players. Additionally, technological advancements have facilitated the measurement of training loads, such as

through GPS (Global Positioning System) and other microtechnologies (Clemente et al., 2020). For instance, research by Jiang et al. (2022) utilized GPS and weekly cumulative loads along with ACWR to investigate the relationship between training load and injury risk, involving variables such as total distance, sprint distance, and the number of accelerations and decelerations. To optimize performance and prevent injuries, players must carefully balance physical exertion with adequate recovery strategies, especially when facing competitions in quick succession (Fatouros et al., 2008). Team sports often carry risks of both contact and non-contact injuries (Ketut Yoda et al., 2024). In women's soccer, González et al. (2024) reported that 60% of injuries were muscle-related, while 20% were ligament injuries, the most common types. Each sport has its own injury risks, and injuries in sports have a direct physical impact on professional athletes and can often affect their economic situation.

Frequency, intensity, and duration all contribute to the overall effects of training (Campbell et al., 2017). Dupont et al. (2010) reported that a congested match schedule and inconsistent training intensity can lead to a decline in physical performance in soccer teams and even result in match losses. A study on injuries during competitions among 23 professional soccer clubs in Europe found an incidence of 28 injuries per 1,000 match hours (Ekstrand et al., 2011). This number is relatively low compared to the findings of Carling et al. (2011), which reported approximately 50 injuries per 1,000 match hours, indicating that soccer players generally have a high risk of injury during matches. Several studies recommend adopting strategies for calculating and monitoring both internal and external training loads, as these can directly measure and assess player fatigue and fitness levels (Scanlan et al., 2014; Akubat et al., 2014). Besides designing well-structured training programs, monitoring the impact of training and matches on players is equally important. Overtraining or undertraining can lead to a high risk of injury and decreased performance for both players and their teams (Eirale et al., 2013).

Sanders et al. (2017) argue that if training load is too low or lacks sufficient intensity, it can risk a decline in athletic performance. Conversely, if the training load is too high and recovery is inadequate, it can lead to overtraining and result in injury (Drew & Finch, 2016). Training load can be measured internally or externally. It is crucial to adopt an integrated approach to training load, utilizing both external and internal loads simultaneously to provide comprehensive insights into training stress (Bourdon et al., 2017; Soligard et al., 2016). Jiang et al. (2022) report in their literature review that there is a relationship between training load and injury risk in elite male soccer players. They note a correlation between high workloads and an increased risk of injuries, particularly to muscles and tendons. Several studies emphasize the importance of monitoring training loads across various sports (McLaren et al., 2018; Halson, 2014).

Examples of internal load measurements include blood lactate, heart rate, and RPE (rating of perceived exertion) (Bourdon et al., 2017). On the other hand, external training load is an objective measure of the work performed by athletes during training or competition, assessed independently of internal load (such as power output, speed, and distance) (Barry et al., 2022; Bourdon et al., 2017). Specific external load measurements depend on the type of training employed and are tailored to the sport, training goals, and athlete needs. Injuries can hinder athlete or team performance and are potentially linked to training loads, suggesting a preventive approach should be a responsibility of sports science and health teams to avoid performance declines (Gabbett, 2016). Additionally, monitoring athlete training loads has become common practice in elite sports and has gained increasing importance in sports performance (Coutts et al., 2018; Wing, 2018). This practice can determine athletes' adaptation to training programs, understand individual responses to training, assess fatigue related to recovery needs, and minimize the risk of overuse, injury, and illness (Bourdon et al., 2017; Halson, 2014).

Previous literature reviews have been conducted by Miguel et al. (2021), demonstrating various measurements of training load that can be utilized to monitor during both training and competition in soccer. Another study by Jiang et al. (2022) systematically reviewed the relationship between training load and injury. Their findings reported a significant association between training load and the risk of injury among professional male soccer players. While these studies provide valuable insights, there remains a gap in comprehensive bibliometric analysis depicting the development and trends in specific training load research within soccer. This study addresses this gap by presenting a bibliometric analysis focused on soccer, encompassing various aspects such as methods of training load measurement, its relationship with performance and injury, and its application across different levels of competition. The urgency of this research lies in its ability to identify underrepresented areas in soccer literature, highlight emerging methodological and conceptual trends, and provide directions for future research in this specific sports context. By gaining a deeper understanding of the research landscape on training load in soccer, practitioners, coaches, and researchers can optimize strategies for monitoring and managing training loads, ultimately enhancing player performance and reducing injury risks. Furthermore, this analysis can uncover potential interdisciplinary collaborations in soccer research, fostering innovation in scientific approaches to understanding and managing training loads in this sport. The specific focus on soccer is crucial given the popularity and complexity of the sport, as well as the ongoing need to improve training and monitoring methods in response to the high physical demands of modern competition.

Although research on soccer training load has become an increasingly popular and emerging topic, there remains a shortage of analyses on the relationship between the structure, evolution, collaboration of existing literature, and the clarification of potential research directions. Therefore, this

study adopts bibliometric analysis to comprehend and explore the current state of research on soccer training load. The findings of this research will assist sports scientists, researchers, decision-makers, and higher education institutions in identifying research hotspots and emerging trends in soccer training load, guiding their future research efforts. Specifically, this research aims to address the following research questions:

RQ 1: What are the publication trends regarding soccer training load?

RQ 2: Which countries are involved in advancing this field of knowledge?

RQ 3: Which journals are involved in the publication of soccer training load studies?

RQ 4: Who contributes the most, and how do authors contribute?

RQ 5: What are the most popular and relevant keywords in this field?

RQ 6: What are the latest keyword research trends in soccer training load?

Research Methods

Bibliographic review, also known as science mapping, aims to comprehensively analyze all published studies within a particular field by examining large-scale bibliographic data. This approach seeks to understand the structural and relational characteristics of the literature (Pan et al., 2022). Bibliometric reviews specifically focus on various bibliometric indicators such as keywords, authors, citations, and geographic locations. Rather than assessing the quality of individual studies, these reviews provide a broad overview of the knowledge base's features, thereby complementing, rather than replacing, other review methodologies (Hallinger & Kovacevic, 2021).

The initial step in conducting a bibliometric review involves selecting a specific and bounded topic. This review centers on literature related to workload within soccer contexts. The subsequent step is identifying the most suitable database for literature search. Scopus is the primary database typically used for bibliometric analysis. Following guidelines from previous reviews (Pham et al., 2021), we selected the Scopus index due to its extensive range of journals, advanced search capabilities, and the high quality of bibliometric data it provides. This study analyzes documents from 1976 to 2024, without limiting the search solely to published articles. The initial search yielded 1540 sources. We refined the search to include only article documents, excluding reviews, letters, errata, and other types. Furthermore, the analysis focuses exclusively on documents published in English-language journals, as these are recognized as certified bodies of knowledge and are generally expected to provide reliable results (Haleem et al., 2020). Consequently, 1271 documents were selected for review.

In this study, data for articles were retrieved directly from the Scopus database in July 2024 in CSV (comma-separated values) format, and the results were evaluated using Microsoft Excel 2013 and VOSviewer software (Van Eck & Waltman, 2020). The data were first cleaned using OpenRefine before analysis. Cleaning the data is crucial for obtaining reliable results. Although most bibliometric data are accurate, the cited references may contain numerous duplicates of the same article (Donthu et al., 2021). The research findings are presented in the form of graphs, tables, and network visualization maps. The bibliometric study was conducted based on the frequency of publications by country, journal, author, and the most cited articles. Additionally, keyword network analysis and density analysis were performed to determine the most critical research domains and the most popular themes (Haleem et al., 2020). VOSviewer was used to conduct a network analysis of the relationships between the article keywords. The findings are displayed as a network graph consisting of nodes (i.e., keywords) and the network lines connecting those nodes. The more frequently a keyword appears, the larger the node size. Close associations between keywords are shown by lines representing shared keyword citations, and the thickness of the network reflects the closeness of these relationships. Because the proximity or distance between nodes affects how frequently they are linked, the nodes can be in close proximity at any time. Nodes with a high density of relationships are distinguished by the color of the surrounding nodes (clusters). Subsequently, density analysis was performed among the identified primary study domains, allowing researchers to identify trending research subjects within the research topic.

Results

The research identified 1,271 documents sourced from over 230 distinct journals, involving a cumulative count of over 3,900 authors across 62 countries. The bibliometric investigation delineated annual research trends. The study specifically aims to pinpoint influential authors and their contributions, as well as frequently cited journals. It also assesses the countries actively engaged in research within this domain. Furthermore, the study conducts an analysis of impactful and highly cited publications, examines keyword usage, and explores evolving trends in themes and topics.

Yearly Publications

The evolution of research on training load monitoring spanning the past four decades (since the earliest documented publication in 1976) is illustrated in Figure 1.

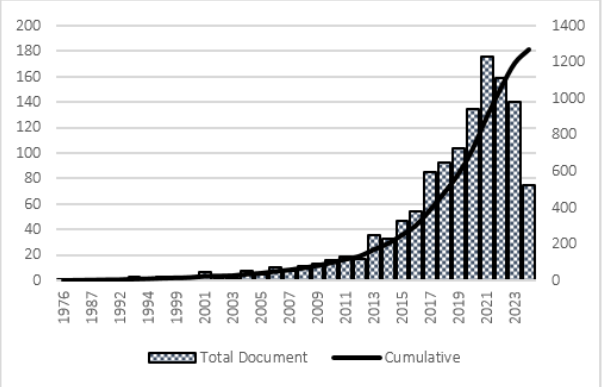

Figure 1. Yearly publication.

The research conducted by Reilly and Thomas (1976) represents an early investigation into training load monitoring. Less than twenty articles were published in the two decades starting from 1979. Significant advancements were expected to continue in the following decades, but the rate of growth slowed. A remarkable increase in annual publication occurred in 2001. Although there was a brief decline in publications, starting notably from the third decade, particularly in 2009, the number of articles steadily increased. From 2009 to the present, there has been a continuous rise in publications related to training load monitoring, with 2021 marking the highest number of published articles at 176. This trend indicates ongoing development in research that provides crucial insights and ideas related to sports performance.

During the period from 2017 to 2018, there was a surge in the use of wearable technology such as motion sensors, heart rate monitors, and activity monitoring devices in sports. Keeping pace with technological advancements, these technologies and methods are expected to become precise and effective tools for monitoring training load, thus driving further investigation in this field. In 2020-2021, despite the challenges posed by the COVID-19 pandemic, research publications continued to increase significantly, albeit showing a gradual decline in publications after 2021.

Research on monitoring is expected to evolve alongside future technological advancements. These studies have utilized simple measurements that can assist researchers in further exploring training load monitoring. Moreover, they contribute to a better understanding of the relationship between training load and various critical variables in soccer. A total of 1,271 articles were published from 1976 to 2024, indicating a growing trend in research on training load monitoring in soccer, with new discoveries aimed at supporting coaches, experts, and sports scientists in enhancing athletes' performance.

Author distribution

From Table 1, it is evident that there are 20 top authors in terms of article publications, with the top position held by Tim J. Gabbett, boasting the highest h-index score of 79. These leading authors have collectively produced a total of 372 publications related to training load monitoring in soccer. This indicates extensive reporting by these authors on both the number of articles successfully published and the number of citations received.

Table 1.
The top 20 author

No	Author	Affiliation	D	TC	AC	h-index
1	Gabbett, Tim J.	Gabbett Performance Solutions, Australia	21	2484	118	79
2	Impellizzeri, Franco M.	University of Technology Sydney, Australia	12	2332	194	66
3	Rampinini, Ermanno	MAPEI Sport Research Center, Italy	8	1820	228	40
4	Coutts, Aaron J.	University of Technology Sydney, Australia	9	1727	192	71
5	Drust, Barry	University of Birmingham, UK	25	1562	62	55
6	Clemente, Filipe Manuel	Instituto Politécnico de Viana do Castelo, Portugal	71	1386	20	14
7	Mendes, Bruno	Universidade de Lisboa, Portugal	23	1128	49	13
8	Casamichana, David	Real Sociedad Sports Performance Department, Spain	13	1032	79	27
9	Gregson, Warren	Liverpool John Moores University, UK	12	893	74	42
10	Morton, James P.	Liverpool John Moores University, UK	12	892	74	51
11	Castellano, Julen	Universidad del Pais Vasco, Spain	15	885	59	38
12	Castagna, Carlo	Università degli Studi di Urbino Carlo Bo, Italy	16	867	54	66
13	Dupont, Gregory	Liverpool John Moores University, UK	12	848	71	42
14	Mccall, Alan	Football Australia, Australia	14	843	60	35
15	Malone, Shane	Technological University Dublin, Ireland	11	795	72	21
16	Nobari, Hadi	University of Mohaghegh Ardabili, Iran	54	745	14	20
17	Morgans, Ryland	Cardiff Metropolitan University, UK	13	734	56	18
18	Di Michele, Rocco	Alma Mater Studiorum Università di Bologna, Italy	6	690	115	20
19	Owen, Adam	Claude Bernard University Sport Science, France	10	612	61	28
20	Weston, Matthew	College of Arts, Humanities and Social Sciences, UK	15	567	38	38

D, number of documents; TC, total citations; AC, average number of citations per document

Among the top 20 authors, Clemente, Filipe Manuel affiliated with Universidad del Pais Vasco, Spain, has the highest number of published documents, totaling 71 articles. Following closely is Nobari, Hadi, with a total of 54 published documents.

In terms of citation numbers, Tim J. Gabbett's articles received the highest citations among these 20 authors, totaling 2,484 citations. This is followed by Franco Impellizzeri, whose publications garnered 2,332 citations. Gabbett's research focus spans across various sports disciplines, emphasizing training load monitoring rather than being confined to a single sport. He holds a PhD in human physiology and completed a second PhD in applied sports science.

Undoubtedly, his expertise lies in physical demands, injury prevention, and skill acquisition related to training load monitoring in sports. He also developed the Acute Chronic Workloojj"ad Ratio (ACWR) method to assist coaches, experts, and sports scientists in monitoring athlete performance development.

Franco Impellizzeri, ranked second in citations according to the aforementioned table, is a professor at the School of Sport, Exercise, and Rehabilitation Sciences at the University of Technology Sydney, Australia. He began his research career in the private sector in 1997. From 2012 to 2016, Impellizzeri served as the physical coach for the Swiss fencing team in preparation for the Olympic Games in Rio de Janeiro. He completed his PhD studies at the University of Science and Technology in Norway, focusing on high-intensity training in soccer. Impellizzeri has authored over 200 scientific publications and books in the fields of sports science and orthopedics.

Journal distribution

The number of articles presented evaluates the academic journal ranking based on the frequency of citations received by these articles. This helps ascertain the impact of the articles within a research field. Generally, these scientific publications discuss the monitoring of training loads concerning various performance variables in soccer, published in various prestigious academic journals. Table 3 lists the top 10 journals ranked by the highest number of citations. The Journal of Strength and Conditioning Research tops the list with 5,643 citations among the 166 scientific documents related to training load monitoring that have been successfully published.

According to Table 2, the International Journal of Sports Physiology and Performance ranks second with 111 documents and 4,370 citations. Metrics are also evident in Table 3 to assess the productivity and impact of several journals publishing scientific articles. Additionally, the highest h-Index value among the top 10 most cited journals, at 435, is held by PloS One, with a total of 620 citations, although it has published a relatively small number of scientific articles related to training monitoring, approximately 28 documents. Medicine and Science in Sports and Exercise holds the second highest h-Index value at 261, and the third highest h-Index value, at 224, is held by the British Journal of Sports Sciences.

These data demonstrate the impact of journals on other research, although the number of documents published does not determine the extent of their influence on other research. All top 10 journals have total citations exceeding 600. Medicine and Science in Sports and Exercise, despite publishing fewer scientific articles related to training load monitoring in soccer, has a total of 1,151 citations. There are still many opportunities for researchers to engage in scientific publications on training load monitoring in soccer and other sports. These studies typically address measurement of training loads, the relationship between training load and injuries, and other variables that support soccer performance. It is hoped that these findings will prove beneficial and provide ideas, insights, and learning for practitioners and academics in the field of sports performance

Table 2.
The top 10 most-cited journals

No	Journal	D	TC	AC	h-index	Publisher
1	Journal of Strength and Conditioning Research	166	5643	34	161	NSCA
2	International Journal of Sports Physiology and Performance	111	4370	39	94	Human Kinetics Publishers Inc.
3	Journal of Sports Sciences	54	4236	78	163	Routledge
4	Journal of Science and Medicine in Sport	38	2431	64	125	Elsevier
5	International Journal of Sports Medicine	31	1795	58	124	Georg Thieme Verlag
6	British Journal of Sports Medicine	19	1730	91	224	BMJ Publishing Group
7	Medicine and Science in Sports and Exercise	5	1151	230	261	Lippincott Williams and Wilkins Ltd.
8	International Journal of Environmental Research and Public Health	52	835	16	198	MDPI
9	Science and Medicine in Football	35	775	22	27	Taylor and Francis Ltd.
10	PloS One	28	620	22	435	Public Library of Science

D, number of documents; TC, total citations; AC, average number of citations per document; h-index, Hirsch index; IF, impact factor

Country distribution

Twenty countries actively engage in the practice of training load monitoring in soccer. In the table 3, the United Kingdom emerges as the most active country in publications related to training load monitoring in soccer, with a total of 310 documents published and the highest number of citations at 11,887. The United Kingdom is unquestionably synonymous with soccer, serving not only as a sport of excellence and community but also as a national identity deeply rooted in its culture. Spain follows as the second country with the highest number of scientific publications related to training load monitoring in soccer, totaling 255 documents. In the realm of soccer, Spain maintains a strong and proud tradition of soccer achievements, contributing significantly to its national identity. Australia, not to be outdone in Europe, also contributes to the study of training load monitoring in soccer, with a total of 169 published documents and 8,107 citations. Soccer enjoys popularity not only across Europe but also in Australia. In Asia, Iran conducts studies on training load monitoring in soccer, with a total of 71 scientific articles published. While Qatar is also involved in soccer studies, with 47 scientific publications, it falls behind Iran. Soccer in Iran serves as a national passion and pride for its citizens, with its development continuing to advance with time. The tangible contributions of researchers, practitioners, and countries serve as exemplary models for other nations to actively engage in advancing scientific knowledge in sports for their respective countries. This active involvement allows them to contribute to the development of sports performance, particularly in the field

of training load monitoring in soccer. Soccer involves complex movements, demanding physiological, mental, and physical skills from its players, necessitating various methods to minimize negative impacts, especially in professional sports.

Table 3.
The top 20 country

No	Country	D	TC	AC
1	United Kingdom	310	11887	38
2	Australia	169	8107	48
3	Italy	146	5862	40
4	Spain	255	5571	22
5	Portugal	209	3590	17
6	France	92	3339	36
7	United States	147	3264	22
8	Qatar	47	2195	47
9	Brazil	118	2082	18
10	Switzerland	46	1809	39
11	Belgium	21	1485	71
12	Ireland	48	1303	27
13	Norway	41	1301	32
14	New Zealand	31	1175	38
15	Tunisia	41	1151	28
16	Netherlands	29	1096	38
17	Iran	71	948	13
18	Sweden	18	834	46
19	Poland	53	822	16
20	Germany	49	756	15

D, number of documents; TC, total citations; AC, average number of citations per document

Analysis of article by citations

The table below presents a list of the most cited scientific articles. At the top of the list is the scientific article titled "Use of RPE-based training load in soccer," which has the highest number of citations totaling 911. This article, authored by Impellizzeri et al. (2004), is highly impactful as it significantly contributes to the development and monitoring of training load in soccer. The study focuses on developing and validating the RPE-based method for measuring training load, providing a simple and valid tool for practitioners and academic researchers in assessing training loads to mitigate the risk of increased injuries.

Another influential study, authored by Philippaerts et al. (2006), ranks second in citation impact with a total of 514 citations. Titled "The relationship between peak height velocity and physical performance in youth soccer players," the article investigates the correlation between peak height velocity and physical performance in young soccer players, where peak height velocity serves as a critical indicator of individual physical maturity. Players with higher peak height velocity tend to exhibit better physical performance, aiding sports practitioners in identifying talented soccer players.

Table 6.
Most cited papers

Author	Title	Pub. Source	Number of Citation
Impellizzeri et al. (2004)	Use of RPE-based training load in soccer	Medicine and Science in Sports and Exercise	911
Philippaerts et al. (2006)	The relationship between peak height velocity and physical performance in youth soccer players	Journal of Sports Sciences	514
Impellizzeri et al. (2006)	Physiological and performance effects of generic versus specific aerobic training in soccer players	International Journal of Sports Medicine	498
Impellizzeri et al. (2005)	Physiological assessment of aerobic training in soccer	Journal of Sports Sciences	462
Reilly & Thomas (1976)	A motion analysis of work rate in different positional roles in professional football match play	J.HUM.MOVEMENT STUD.	420
Akenhead & Nassis (2016)	Training load and player monitoring in high-level football: Current practice and perceptions	International Journal of Sports Physiology and Performance	369
Casamichana & Castellano (2010)	Time-motion, heart rate, perceptual and motor behavior demands in small-sides soccer games: Effects of pitch size	Journal of Sports Sciences	369
Dupont et al. (2010)	Effect of 2 soccer matches in a week on physical performance and injury rate	American Journal of Sports Medicine	319

Keyword analysis

In this section, we conduct an analysis of content focusing on keyword distribution. This includes an interactive co-occurrence map, identification of the top 5 keywords in publications on soccer training load, visualization of keyword density, and a timeline view of keyword trends. Co-occurrence of keywords serves as an effective method to identify research focal points within a specific discipline, thereby enhancing the support for scholarly investigations. This methodology is commonly utilized to gauge the relevance of publications based on citation relationships or semantic connections within texts. The VOSviewer software was utilized to generate a co-occurrence network of keywords related to soccer training load (refer to Figure 2), analyzing a dataset comprising 1748 keywords extracted from all 1271 publications. The visualization highlights 76 keywords that appear in at least ten documents, representing significant themes in the field.

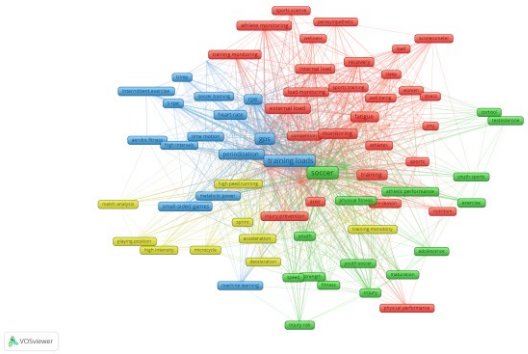

Figure 2. Keywords network visualization.

Among the key terms frequently observed in studies on soccer training load, "soccer" emerged as the most prevalent, appearing 440 times, followed by "training loads" at 280 instances, and "GPS" with 202 mentions. Other notable keywords include "team sports" (167 occurrences), "performance" (133 occurrences), "RPE" (105 occurrences), "monitoring" (81 occurrences), "fatigue" (80 occurrences), "workloads" (77 occurrences), "periodization" (75 occurrences), "training" (73 occurrences), "external load" (72 occurrences), and "heart rate" (63 occurrences). These terms collectively delineate the primary domains of inquiry within soccer training load research. Notably, "performance" and "monitoring" also exhibit substantial frequency in the broader context of sports nutrition research, indicating their critical role in understanding athletic development and optimizing performance outcomes. The frequency of co-occurrence between these keywords underscores their interconnectedness and relevance in shaping the research landscape of soccer training load studies.

Trend analysis of themes and topic

Figure 3 depicts a topic network map based on the usage of keywords, where darker colors denote earlier average publication years and lighter shades indicate more recent averages. Keywords such as "ACWR", "training monotony", "high intensity", "training strain", and "machine learning", shown in darker hues primarily from 2020 to 2021, signify recent advancements in soccer training load research. These terms reflect an increasing focus on employing advanced metrics and methodologies to effectively assess and manage training intensity and strain (Tenan et al., 2021).

Research centered on "injury risk", "playing position", "muscle damage", and "monitoring", depicted in moderately saturated colors around 2020, underscores the significance of tailored training protocols and position-specific strategies to reduce injury risks and optimize player performance across a season (Silva et al., 2020). The integration of GPS, accelerometers, and other technologies in monitoring physical fitness and deceleration patterns has become standard practice, providing precise, data-driven insights into athlete preparation and recovery strategies (Gonçalves et al., 2020).

Recent developments, including "football", "external load", and "injury prevention", reflect ongoing efforts to incorporate new technologies and methodologies into training programs to improve effectiveness and athlete well-being. This evolution in research not only advances scientific knowledge but also informs practical applications in optimizing training loads and performance outcomes in soccer and other team sports.

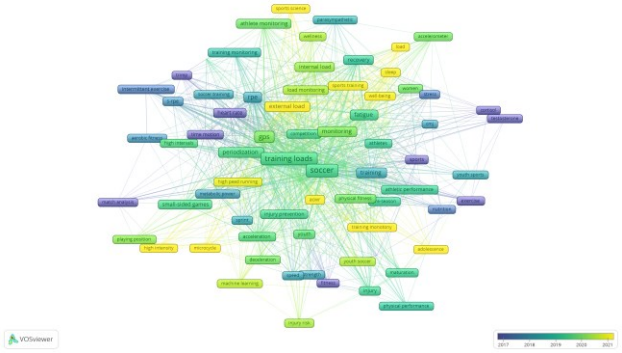

Figure 3. Keyword trends by publishing year.

iscussion

Keywords "team sports", "performance", and "monitoring" reflects a primary focus on optimizing performance through systematic monitoring in team sports contexts. The interconnection between various keywords indicates a holistic approach in contemporary research, integrating multiple aspects of athlete preparation. Impellizzeri et al. (2019) emphasize the importance of a comprehensive understanding of internal and external training loads to enhance performance, while Kellmann et al. (2018) highlight the critical balance between training stress and recovery. The concept of injury prevention, underscored by Gabbett (2016), emerges as a central theme linking training load management to injury risk reduction. Saw et al. (2016) emphasize the importance of integrating subjective measures into athlete monitoring, expanding focus beyond physiological parameters alone. The diverse methodologies for measuring training load, as discussed by Bourdon et al. (2017), demonstrate the complexity in quantifying and interpreting athlete data. Halson (2014) underscores the relationship between monitoring training load and understanding fatigue, while Malone et al. (2015) illustrate variability in training loads across different phases of the competitive season. The interdisciplinary approach advocated by Coutts et al. (2018) emphasizes the convergence of sports science, nutrition, and related disciplines in a holistic understanding of athlete preparation. Additionally, research by Datson et al. (2014) on women's soccer physiology highlights gender-specific considerations in training load management. The synthesis of keywords and literature portrays a dynamic and evolving research landscape aimed at optimizing athlete performance while maintaining their health and fitness through rigorous, evidence-based training load monitoring and management.

"Soccer", "workloads", and "injury" reflects a primary focus on optimizing performance and injury prevention through meticulous training load management in the context of soccer (Bowen et al., 2017). Keywords like "youth", "adolescence", and "maturation" indicate specific attention to young athletes, emphasizing the importance of understanding physiological differences and adaptations to training loads during critical developmental stages (Lloyd et al., 2014). Emphasis on "athletic performance" and "physical fitness" underscores the primary goal of training load management, which is to enhance overall athlete performance (Malone et al., 2015). Keywords such as "speed", "strength", and "body composition" depict various aspects of physical performance targeted in soccer training programs (Hammami et al., 2013). The presence of "testosterone" and "cortisol" as keywords indicates a focus on the endocrine aspects of training adaptation and stress response, particularly relevant in the context of developing young athletes (Hammami et al., 2018). Integrating "exercise" and "fitness" with other keywords emphasizes a holistic approach to athlete development, encompassing diverse training modalities to enhance comprehensive fitness (Faude et al., 2014). Keywords like "injury risk" and its relation to "workloads" describe the focus on balancing performance enhancement with injury prevention, a primary concern in youth athlete development (Gabbett et al., 2016). This synthesis of keywords portrays a complex and multifaceted research landscape in soccer, particularly concerning young athletes. This approach reflects efforts to optimize athletic performance while considering unique developmental, physiological, and safety factors in this population. The integration of these aspects aims to develop effective and safe training strategies that can enhance young athletes' performance while minimizing injury and overtraining risks.

Keywords "training loads", "GPS", and "RPE" reflects a primary focus on measuring and monitoring training loads using objective technologies and subjective perception methods (Bourdon et al., 2017). Integrating GPS with "time motion" and "metabolic power" indicates advancements in understanding specific physical demands of soccer, enabling detailed analysis of player activities during training and matches (Osgnach et al., 2010). The keyword "periodization" underscores the importance of structured and varied training loads to optimize adaptation and performance (Malone et al., 2015). Its connection to "small-sided games" and "high intervals" illustrates specific training strategies used to manipulate training intensity and develop aerobic fitness (Impellizzeri et al., 2006). "Heart rate" and "s-RPE" (session-RPE) represent traditional methods for monitoring internal training intensity, while "TRIMP" (Training Impulse) combines duration and intensity for quantifying training load (Akubat et al., 2012). Focus on "intermittent exercise" and "aerobic fitness" reflects the specific physiological nature of soccer demands and the importance of developing these capacities through targeted training (Bangsbo et al., 2006). "Performance analysis" links training load monitoring with match performance evaluation, providing essential context for interpreting training data (Carling et al., 2008). The presence of "machine learning" as a keyword indicates a new trend in training load data analysis, enabling processing and interpretation of larger and more complex datasets for deeper insights into the relationship between training load, performance, or injury risk (Rossi et al., 2018). This synthesis of keywords portrays a dynamic and multifaceted research landscape in soccer training load monitoring and management. This approach reflects efforts to integrate various measurement methods, training strategies, and advanced analysis techniques to optimize athlete performance and prevent injuries. This complexity underscores ongoing evolution in scientific understanding of training load in soccer, aiming ultimately to enhance training program effectiveness and competitive performance.

"Acceleration", "high-speed running", and "sprint" reflects the importance of explosive activities in modern soccer performance (Carling et al., 2008). Integrating these with "deceleration" and "high intensity" indicates a nuanced understanding of physical demands in soccer, involving not only the ability to generate high speeds but also to change direction and intensity rapidly (Akenhead et al., 2013). The keyword "match analysis" connects these performance components with match contexts, enhancing understanding of the frequency, duration, and significance of high-intensity activities during competition (Bradley et al., 2009). Its association with "playing position" acknowledges variations in physical demands based on players' tactical roles on the field, implicating individualized training strategies (Di Salvo et al., 2009). "Microcycle", "training monotony", and "training strain" emphasize the focus on short-term training load structure and variation, aiming to optimize high-intensity training periodization while managing fatigue and injury risks (Impellizzeri et al., 2004). Integrating these concepts with high-intensity performance components reflects a holistic approach to athlete development, aiming to enhance sprint and acceleration capacities while maintaining appropriate training load balance. This synthesis of keywords depicts a research landscape focused on optimizing high-intensity performance in soccer through in-depth analysis of match demands and careful periodization strategies. This approach reflects ongoing evolution in understanding the importance of explosive activities in modern soccer and efforts to integrate these insights into training practices and performance analysis. This complexity highlights the need for highly specific and individualized training strategies, considering position demands, microcycle structure, and training load management to optimize athlete performance in speed and acceleration while minimizing overtraining and injury risks.

The trend in research keywords related to training load monitoring highlights ACWR as having the most recent publication average. ACWR, or Acute to Chronic Workload Ratio, quantitatively measures the acute training load,

which reflects the immediate training load over a brief period, in relation to the chronic training load, representing the average load sustained over a longer timeframe, typically 4 weeks or more.

Studies have indicated that elevated ACWR values, where the acute load significantly exceeds the chronic load, are associated with a higher risk of injury among athletes. Conversely, a low ACWR value can also increase injury risk due to insufficient training load (Hulin, 2016). Coaches utilize ACWR as a tool to optimize athletes' training loads, adjusting training programs based on ACWR monitoring to ensure gradual and safe increases in load (Gabbett, 2016).

Each athlete responds uniquely to training intensity, making ACWR valuable for tailoring training programs by adjusting the acute-to-chronic load ratio according to individual athlete characteristics. Further research could explore alternative metrics for training load and ACWR monitoring to enhance accuracy and specificity for different sports or training types (Impellizzeri, 2019).

Winther et al. (2024) describe athletes' training load patterns such as pyramid or inverted pyramid, where training load gradually increases to a peak mid-period and decreases towards the end. However, their study did not find a significant correlation between training load and performance in elite female soccer athletes.

Michailidis (2024) reported varied ACWR values across different indices, highlighting challenges in establishing injury risk thresholds. These indices include GPS (Global Positioning System) metrics such as total distance, high-speed running distance, acceleration, deceleration, and RPE (Rating of Perceived Exertion). RPE is noted for its simplicity and is recommended to be combined with other indices for more accurate assessments (Michailidis, 2024).

Conclusion

Findings from this study demonstrate that monitoring training loads in soccer has gained popularity in the United Kingdom, followed by several other countries including Australia, Italy, Spain, and Portugal, based on their impact on other research. Prominent researchers in the field of training load monitoring include Gabbett, Tim J., and Franco Impellizzeri, with their publications garnering the highest citations in scientific literature. Their educational backgrounds and extensive experience significantly contribute to influencing other researchers. As time, technology, research, and knowledge advance regarding training loads, ideas for application and further development by future researchers are fostered. Utilizing various research methodologies to implement training load monitoring in soccer, this study extracted 1271 documents from an online database (Scopus) using specific keywords. Research on soccer training loads began as early as 1976 and has shown gradual increases annually, with a notable rapid rise in 2019, reaching 104 documents.

On average, the studies discovered new methods, applied existing methodologies, and integrated training load monitoring with other variables. Whether exploring the relationship between training load or its combined effects with other related variables, these findings represent new discoveries in soccer research. This report can influence training load monitoring and serve as a reference to aid sports scientists, researchers, decision-makers, and higher education institutions in identifying research hotspots and emerging trends in soccer training loads, guiding their future research efforts.

Limitation and recommendations

The bibliometric approach offers a structured method for analyzing the knowledge base; however, it comes with inherent limitations. In this research, we selected Scopus as our database of choice due to its extensive coverage of scholarly publications compared to Web of Science. Nonetheless, since most journals indexed in Scopus publish articles primarily in English, our study may not capture the complete breadth of the teacher leadership literature. Furthermore, co-citation analysis serves as a tool to delineate the intellectual landscape of an academic discipline. Researchers with a deep understanding of the literature can better interpret the analytical outcomes. In our study, we leveraged our leadership expertise and consulted relevant literature to enhance our understanding of the reviewed papers. Despite these efforts, it's important to acknowledge the constraints of our research and provide recommendations for future studies.

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