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Avances en la investigación sobre el seguimiento de las cargas de entrenamiento en deportistas: análisis bibliométrico

Developments in research on monitoring training loads in athletes: bibliometric analysis

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Abstract. Monitoring training load can help improve performance, predict injury risk, determine athlete readiness, and keep track of health conditions. By using bibliometric analysis methods, one can evaluate publications from institutions or countries and track the growth or decline of a specific field. The purpose of this study is to compile a bibliography of works on the subject of training load monitoring that were published between 1979 and 2023. This study analyzes publications on training load monitoring and uses scientific mapping to describe the structure and trends. Contributions from countries, authors, cited articles, frequently appearing keywords, and keyword trends are all covered in this study. According to the findings, research was scarce during the first two decades and significantly increased in the next. While Australia has the most publications, the European continent dominates this research field. Most articles are published in and referenced from the International Journal of Sports Physiology and Performance. Furthermore, due to its high citation count, Halson's article had the greatest influence. Some keywords are related and appear in this study. This article presents a trend visualization that academics can use as a reference guide.
Keywords: monitoring, training load, bibiometric analysis.

Resumen. Monitorear la carga de entrenamiento puede ayudar a mejorar el rendimiento, predecir el riesgo de lesiones, determinar la preparación del atleta y realizar un seguimiento de las condiciones de salud. Al utilizar métodos de análisis bibliométrico, se pueden evaluar publicaciones de instituciones o países y rastrear el crecimiento o declive de un campo específico. El objetivo de este estudio es recopilar una bibliografía de trabajos sobre el tema del seguimiento de la carga de entrenamiento que se publicaron entre 1979 y 2023. Este estudio analiza las publicaciones sobre el seguimiento de la carga de entrenamiento y utiliza un mapeo científico para describir la estructura y las tendencias. En este estudio se tratan las contribuciones de países, autores, artículos citados, palabras clave que aparecen con frecuencia y tendencias de palabras clave. Según los hallazgos, la investigación fue escasa durante las dos primeras décadas y aumentó significativamente en las siguientes. Si bien Australia tiene la mayor cantidad de publicaciones, el continente europeo domina este campo de investigación. La mayoría de los artículos se publican y tienen referencias en el International Journal of Sports Physiology and Performance. Además, debido a su alto número de citas, el artículo de Halson tuvo la mayor influencia. Algunas palabras clave están relacionadas y aparecen en este estudio. Este artículo presenta una visualización de tendencias que los académicos pueden utilizar como guía de referencia.
Palabras clave: monitoreo, carga de entrenamiento, análisis bibliométrico.

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Introduction

To achieve optimal performance, an athlete must consistently enhance their performance during each workout. An objective, organized, and methodical training load is necessary, particularly when it comes to escalating the intensity, duration, and frequency of training sessions. Utilizing effective training load monitoring enables coaches and athletes to assess an athlete's ability to adjust to a training regimen and predict the likelihood of injury (Halson, 2014). Training adaptations can result in either beneficial or detrimental changes. Negative adaptation arises during the periods of detraining and overtraining, whereas positive adaptation occurs when performance is at its peak and the recovery period is adequate (Helwig et al., 2023).

Training load monitoring is typically categorized into two parameters: internal and external. Internal training load refers to the physiological response experienced by athletes during training or competition. It is assessed by monitoring factors such as heart rate, blood lactate levels, oxygen consumption, and ratings of perceived exertion (RPE) (Bourdon et al., 2017). External training load refers to the quantifiable assessment of an athlete's performance during training or competition. It is measured using various methods such as power output, speed, acceleration, time-motion analysis, global positioning system (GPS), and accelerometer-derived data (Bourdon et al., 2017).

Monitoring training load offers several advantages. It aids in mitigating a risk of injury and illness among athletes. Additionally, for athletes who engage in intense training and competition, it can reveal potential adverse effects, promote optimal physiological and psychological well-being, and prioritize athlete welfare (Halson, 2014). It is advisable for coaches to monitor training load, particularly by using the RPE method. This helps ensure that the training program is well-planned and allows for the measurement of psychophysiological responses to the training load. Additionally, RPE monitoring is relatively inexpensive and easy to use (Coyne et al., 2022).

Excessive or unsuitable training loads can heighten the likelihood of injury in athletes or individuals engaging in physical exercise. Effective surveillance is necessary to accurately determine the optimal training intensity and miti-

gate the risk of excessive training, which can lead to persistent exhaustion, diminished performance, and physical harm (Bourdon et al., 2017). Precise monitoring of training load can assist coaches and athletes in modifying training programs to attain optimal performance. By comprehending the specific reactions of individuals to training loads, it is possible to modify training programs in order to optimize physiological conditions and enhance performance (Halson, 2014).

In order to maximize performance and reduce the risk and impact of injury, coaches and athletes are frequently under pressure from management, supporters, and the media (Impellizzeri et al., 2020). Not only are physiological reactions, suitable training schedules, and injury risk prediction the goals of training load monitoring. Athletes' sense of empowerment, sense of ownership, and sense of involvement in the training program can all be increased through monitoring their training load and the communication that results between them, coaches, and management (Halson, 2014).

Maintaining proper recovery in between training sessions requires close observation of the training load. Athletes who do not receive adequate recovery may accumulate fatigue, which raises their risk of injury or decreased performance (Kellmann et al., 2018; Sumartiningsih et al., 2022; Susanto et al., 2023). Every person has distinct genetic, psychological, and physiological traits. In order to maximize the intended outcomes, training programs can be individually tailored to each person's unique needs and responses with the aid of training load monitoring (Impellizzeri et al., 2019). Monitoring has been shown to be useful in identifying functional limitations and asymmetries (Šćepanović T et al., 2020).

Subsequent research is required to comprehend the optimal utilization of emerging technologies, including wearable devices and monitoring applications, along with increasingly complex data analysis techniques, for training load monitoring. Additionally, our preliminary analysis of the literature on training load monitoring in athletes reveals that this field of study is still in its infancy and that no systematic study has examined the evolution of the field. This research is very important to conduct because it can provide an overview of the development of exercise monitoring, the benefits of monitoring for improving performance, detecting the risk of injury and evaluating exercise programs. In light of this, bibliometric analysis is extremely relevant since it can be used to assess publications from organizations or nations, as well as determine the growth and decline of a specific field (Prieto et al., 2015). Thus, through bibliometric analysis, research into the evolution of training load monitoring in athletes aims to comprehend the scientific structure and dynamics of training load monitoring.

Research methods

Bibliometric analysis describes, evaluates, and tracks published research using a quantitative approach. The quality of reviews may be enhanced if this method were to implement a systematic, transparent, and reproducible review procedure. Before reading a single word of literature, bibliometric approaches can help researchers find the most important works and create an objective field map (Zupic and Cater, 2015). According to Cobo et al. (2011), there are two primary applications of bibliometric methods: science mapping and performance analysis. In the former, researchers and organizations are examined for their performance in terms of research and publishing. The second one aims to learn about the workings of the studied scientific area (Zupic and Cater, 2015).

A bibliometric analysis was conducted using bibliometric indicators, which are the tools employed to analyze and interpret the collected data (Regalado-Pezúa & Estares, 2024). The obtained results were subsequently graphically represented through the utilization of a similarity visualization program (VOSviewer) to process the data. The results assessed the level of advancement and the primary patterns in terms of impact, prominent publications, studies, subject matters, authors, institutions, and nations. Analyzing and visually representing data are crucial in order to enhance the comprehension of research findings in the area of monitoring training load among academics and professionals (Cavalcante et al., 2021). Figure 1 shows a full breakdown of the research's details.

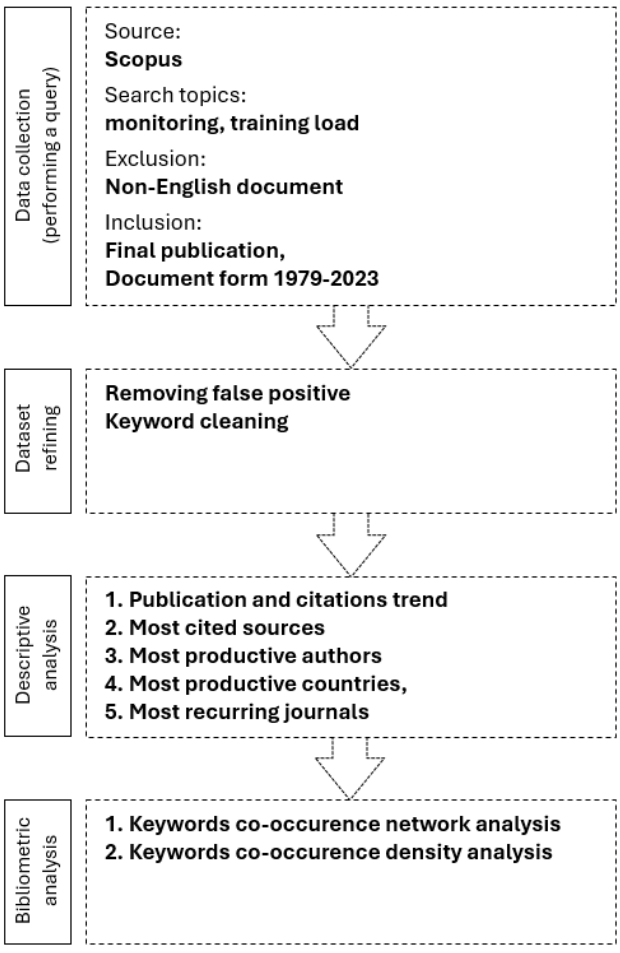

Figure 1. Research methodology

For the current study, Scopus was chosen because it offers the most extensive collection of peer-reviewed research related to the subject matter (Anglada-Tort and Sanfilippo, 2019). Following a series of experiments, the following title, abstract, and keyword search string was executed to locate studies pertaining to training load monitoring: ("monitoring" AND "training load"). The data retrieval occurred in February 2024. Initially, 1,206 items were found that fulfilled the criteria that were entered. However, this research only included items that were final papers and had a publication date up until 2023. Further, the search does not include documents that are not in English. Thus, 1,099 articles and reviews were considered for this analysis.

Table 1.
Type of document on monitoring training load research

Document type	Total document	Proportion
Article	934	85.0
Review	109	9.9
Conference Paper	28	2.5
Note	10	0.9
Book Chapter	9	0.8
Editorial	5	0.5
Short Survey	3	0.3
Erratum	1	0.1
TOTAL	1,099	100

Results and discussion

The study found 1,099 documents discovered, which were published in over 200 different journal sources. These documents had a combined total of more than 3,000 authors and originated from 69 different nations. The bibliometric analysis produced the yearly research patterns. The study focuses on identifying the writers who have made the most impact and exerted the most influence, as well as the most often cited journals. It also examines the countries that are actively conducting research in the field. Additionally, the study analyzes the most impactful and highly cited publications, conducts keyword analysis, and examines trends in themes and topics.

Publication by Year

Trends in training load monitoring research over the last 40 years (the first identified document was published in 1979) can be seen in Figure 2.

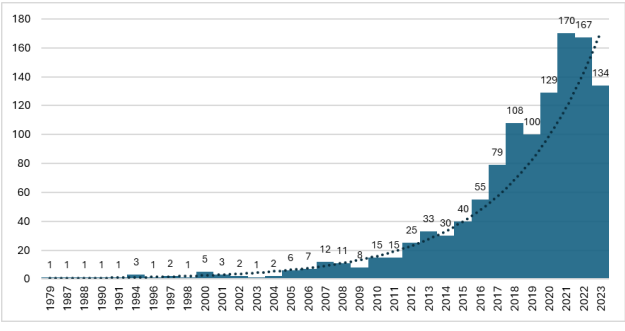

Figure 2. Research trend

The research conducted by Spadaccini et al. (1979) was the initial investigation relevant to the monitoring of training load. Less than twenty articles were published in the two decades beginning in 1979. Significant progress are expected in the upcoming decade, however the rate of growth continues to be sluggish. An extraordinary rise in the annual publication of articles can be noted starting from the third decade, specifically in 2009, when the number of articles continued to rise.

During the 2017-2018 period of time, there was a growth in the utilization of wearable technology, such as motion sensors, heart rate monitors, and activity monitoring devices, in the realm of sports. This method enables precise and immediate monitoring of training load, hence promoting further investigation in the subject. Nevertheless, there has been a noticeable decline in the number of publications compared to the subsequent years, specifically in 2019 and 2023. Amidst the COVID-19 epidemic in 2020-2021, numerous athletes and coaches encountered difficulties in tracking and managing their training intensity because of the limitations and shutdowns of sports facilities. Consequently, there was a decline in the number of research conducted on this subject. This also promotes research into investigating alternate and virtual monitoring techniques that might be employed in restricted circumstances.

Afterwards, in the period of 2022-2023, there would be a decrease in the quantity of research compared to previous years due to the lack of any novel methodologies or instruments introduced during that time period. Research on monitoring will inevitably progress in conjunction with technological developments in the future. Previous studies have established a correlation between age and training load in adolescents during their growth and development. These studies have utilized simple measures that might help researchers in further investigating training load monitoring (Dudley et al., 2023).

Most contributing and most influential authors

Table 2 demonstrates that the authors of the articles have extensively investigated the quantity of articles published as well as the number of citations performed. The author's productivity and impact as a writer can be inferred from the quantity of articles published and the number of citations received (Dzikowski, 2018). Among the authors, Filipe Manuel and Aaron J. Coutts stood out as the most productive contributors, with 38 and 27 published articles, respectively. According to the citation number the articles authored by Aaron J. Coutts and Tim J. Gabbet received the highest number of citations. Aaron J. Coutts' articles received 3,408 citations, while Tim J. Gabbet's articles received 2,583 citations, as indicated in table 2. Aaron J. Coutts, a professor in the field of sport and exercise science, serves as the head of the School of Sport, Exercise & Rehabilitation at the University of Technology Sydney. He is renowned for his research, which centers around

creating data-driven approaches to enhance athlete training, health, and performance. He is unquestionably the most influential writer. Tim J. Gabbet is a prominent figure in the field of training load monitoring. He is credited with developing the Chronic Corkload Ratio (ACWR) method, which is used to assess acute training load. Gabbet's research has been extensively published in highly regarded journals including the Journal of Strength and Conditioning, British Journal of Sports Medicine, and Journal of Athletic Training. Filipe Manuel Clemente holds the record for having written the highest number of articles among all writers. Filipe Manuel Clemente is an assistant professor at the Instituto Politécnico de Viana do Castelo. His research focuses on physical ability, training load monitoring, performance analysis, match analysis, physical activity, health, and sports medicine. His extensive background in these areas has made him the author with the highest number of articles.

Table 2.
An author who made significant contributions

Author	Affiliation	h-index	Citation	Document
Buchheit, Martin	Performance Research Intelligence Initiative	67	1,556	8
Clemente, Filipe Manuel	Instituto Politécnico de Viana do Castelo	40	709	38
Coutts, Aaron J.	University of Technology Sydney	70	3,408	27
Foster, Carl	University of Wisconsin-La Crosse	68	1,485	21
Gabbett, Tim J.	Gabbett Performance Solutions	78	2,583	16
Gleeson, Michael	Loughborough University	63	1,156	5
Gregson, Warren	Liverpool John Moores University	41	1,155	8
Impellizzeri, Franco M.	University of Technology Sydney	64	1,391	9
Jones, Ben	Leeds Beckett University	36	265	13
Kellmann, Michael	Ruhr-Universitat Bochum	34	1,031	10
Lyons, Mark	University of Limerick	27	192	13
Meeusen, Romain	Vrije Universiteit Brussel	71	1,034	6
Moreira, Alexandre	Universidade de São Paulo	32	691	22
Nobari, Hadi	University of Mohaghegh Ardabili	19	219	18
Raftery, Martin	Barts Health NHS Trust	31	1,010	3

Note: Authors displayed are those who have authored more than 10 documents or have accumulated more than 1000 citations.

Analysis of journals by citations

The quantity of research articles published by a journal and the number of citations it receives are indicative of the journal's productivity. The majority of research publications on training load monitoring were published in prestigious journals. According to the data in Table 3, the International Journal of Sports Physiology and Performance has the highest ranking based on the total number of citations, with 5,513 citations in published articles. Biology of Sport ranks first in terms of average citation score per article, with a score of 269.6. It is followed by Sports, which has an average citation score of 203.8 per article. The data obtained demonstrates the journal's significant impact, as it revealed a smaller number of published documents but a substantial number of citations. Out of a total of 225 journals, only 18 have received more than 100 citations. This demonstrates the involvement of researchers from diverse disciplines in studies related to monitoring training load. These studies aim to enhance athletic performance, mitigate injury risks, optimize training programs, and analyze athlete health. This highlights the significance of the present study. All the aforementioned journals belong to the highest category. Academics and practitioners worldwide refer to these journals. This demonstrates the direct correlation between research on exercise monitoring and its practical application in the field.

Table 3.
Most frequently cited journals

Journal Title	Number of Citation	Number of Document	Average Citation
International Journal of Sports Physiology and Performance	5,513	143	38.6
Sports Medicine	3,719	27	27.6
British Journal of Sports Medicine	3,668	18	37.3
Journal of Strength and Conditioning Research	3,230	117	12.5
Medicine and Science in Sports and Exercise	2,426	9	14.4
Frontiers in Physiology	1,490	40	31.2
Journal of Science and Medicine in Sport	1,385	22	137.7
International Journal of Sports Medicine	1,230	23	14.7
Journal of Sports Sciences	906	29	53.5
International Journal of Environmental Research and Public Health	499	40	63.0
Sports	488	34	203.8
Biology of Sport	353	24	269.6

Most influential countries

A total of 69 countries are actively involved in conducting research on training load monitoring. Australia has the highest number of documents, with 243 articles published, followed by the United Kingdom with 206 articles and the United States with 191 articles. Research on training load monitoring is primarily conducted by European countries, although countries in Latin America, particularly Brazil and other developing nations, also contribute significantly to this field of research. This may be attributed to the fact that these countries possess robust sporting traditions and well-established research infrastructure, enabling them to make significant contributions to the field of training load monitoring research. In addition, research productivity can be impacted by substantial funding and investment in sports research from governmental bodies, research institutions, or private sponsors, with the aim of promoting an increase in publications within these advanced nations. Collaboration and extensive international research networks enable the exchange of knowledge and the increase in publication. Countries that possess robust research traditions and well-established international networks tend to exhibit higher levels of productivity. Countries that have a strong passion for specific sports, like football in Brazil, tend to engage in more research and publications focused on monitoring training load to enhance athlete performance.

Research on training load monitoring is an important

topic in an athlete's performance. This research has also been extensively conducted by Asian countries such as China, Qatar, and Iran. The economic growth and increased investment in scientific research and technology in countries such as China, Qatar, and Iran are driving more publications in the field of monitoring training load. In Figure 3, we present the distribution of articles published worldwide. The countries with the top 5 article counts are represented by darker colors compared to other countries, as seen in Australia, the United Kingdom, the United States, Spain, and Brazil.

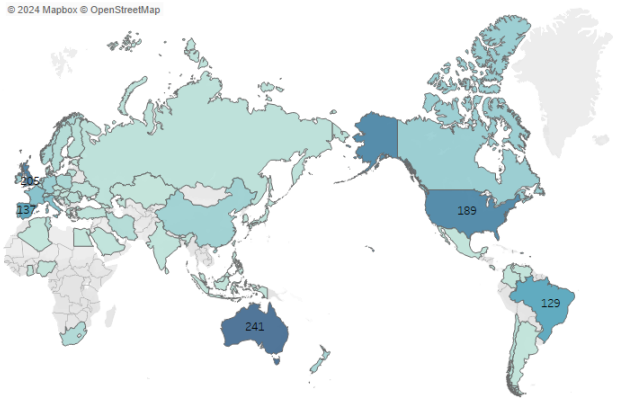

Figure 3. Geographical representation of document distribution by country.

Analysis of article by citations

Furthermore, the 10 most cited articles can be seen in Table 3, which is sorted based on the number of citations. The table indicates that the article published in 2014 by Halson (2014) titled "Monitoring Training Load to Understand Fatigue in Athletes" is the most cited article by practitioners and academics, with a total of 1,063 citations. The article is highly impactful as it contributes to the development of training load monitoring with the effect of fatigue on athletes. Additionally, it is published in a prestigious journal and is listed as one of the top two journals in Table 2. The next article with the highest number of citations is the work by Gabbett (2016). This article discusses ACWR as a method for monitoring exercise for injury risk, which has been cited 918 times. The ACWR method developed by Gabbett has been proven to have a significant impact on the wider community. The next article with the highest number of citations is Foster's (1998) work, which serves as the foundation for the development of the training load monitoring method. This article ranks among the top 3 with 898 citations and has become a key reference for the development of methods and tools in the field of training load monitoring up to the present day.

Table 4.
Most cited papers

Author	Title	Pub. Source	Number of Citation
Halson (2014)	Monitoring Training Load to Understand Fatigue in Athletes	Sports Medicine	1,063
Gabbett (2016)	The training-injury prevention paradox: Should athletes be training smarter and harder?	British Journal of Sports Medicine	918
Foster (1998)	Monitoring training in athletes with reference to overtraining syndrome	Medicine and Science in Sports and Exercise	898
Impellizzeri et al. (2004)	Use of RPE-based training load in soccer	Medicine and Science in Sports and Exercise	897
Bourdon et al. (2017)	Monitoring athlete training loads: Consensus statement	International Journal of Sports Physiology and Performance	641
Soligard et al. (2016)	How much is too much? (Part 1) International Olympic Committee consensus statement on load in sport and risk of injury	British Journal of Sports Medicine	619
Brancaccio et al. (2007)	Creatine kinase monitoring in sport medicine	British Medical Bulletin	598
Buchheit (2014)	Monitoring training status with HR measures: Do all roads lead to Rome?	Frontiers in Physiology	582
Saw et al. (2016)	Monitoring the athlete training response: Subjective self-reported measures trump commonly used objective measures: A systematic review	British Journal of Sports Medicine	528
Borresen & Lambert (2009)	The quantification of training load, the training response and the effect on performance	Sports Medicine	470

Keyword analysis

To proceed to the data analysis phase, the data set had to be cleaned. This process consisted of homogenizing keywords used in the articles (e.g. using only a plural or singular form). As a result, all the keywords that indicated the same topic were replaced with a unique word. An analysis was conducted on a subset of sixty keywords out of a total of 1,376 that fulfilled the criterion of appearing in at least ten documents within the database.

The frequently occurring keywords are "performance" and "team sport". Subsequently, the frequently encountered keywords include "workload", "fatigue", and "heart rate". Figure 4 displays a visual representation of the correlation between keywords.

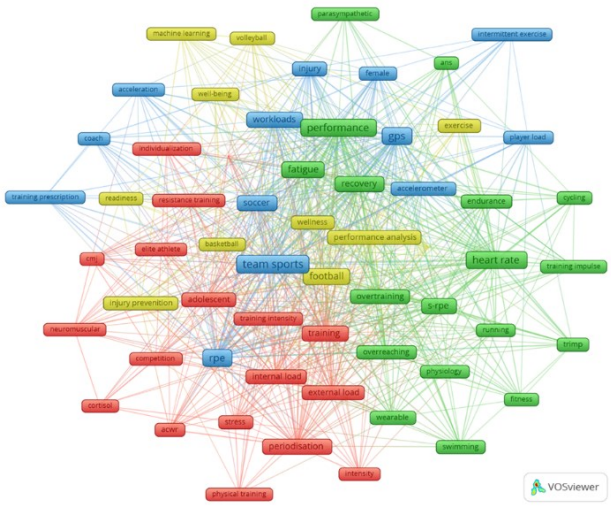

Figure 4. Keywords network visualization.

Red cluster: The key terms in this cluster pertain to the concepts, factors, or aspects associated with monitoring the training load in athletes. Periodization, training, and training intensity pertain to the organization and scheduling of training programs, as well as the level of exertion imposed on athletes during training. Monitoring training load is crucial for ensuring appropriate periodization and achieving optimal training intensity (Bourdon et al., 2017 and Impellizzeri et al., 2019). Adolescents and elite athletes share similar characteristics when it comes to being the focus of training load monitoring. When monitoring training load, it is important to take into account the athlete's developmental phase, such as teenagers, as well as their skill level, such as elite athletes. Additionally, it is crucial to individualize the training program based on the unique characteristics of each athlete. Monitoring training load is crucial in young athletes to prevent overtraining or excessive training load, which can impede normal growth and development (Bergeron, 2015). Prior studies have demonstrated that excessive training loads during early stages of development can heighten the likelihood of injury and burnout (DiFiori, 2014). Adolescence is a period characterized by substantial physiological and endocrine transformations in the body. Monitoring the training load in adolescent athletes is beneficial for optimizing training programs based on individual development and preventing issues like growth-related injuries (Malina, 2004). Monitoring training load in adult athletes aims to optimize performance and minimize the risk of overtraining or injuries caused by excessive training. Precise monitoring techniques are crucial for optimizing physiological adjustment and guaranteeing sufficient recuperation (Halson, 2014). Masters athletes encounter difficulties associated with the process of aging and the decrease in physiological capabilities. Monitoring the training load in master athletes enables the adjustment of training programs based on individual capacity, thereby reducing the risk of injury or overtraining. This, in turn, can extend the sports careers of master athletes (Tanaka, 2003). Individualization pertains to tailoring the training program to suit the unique characteristics and training load tolerance of each athlete. To prevent injuries resulting from excessive or insufficient training loads, training programs can be customized by closely monitoring and adjusting the training loads for each individual (Impellizzeri, 2019). Training load monitoring can assist in identifying high-risk phases or periods in a competition season or training program where the likelihood of injury is elevated. Coaches can utilize this information to make appropriate modifications to the training program, either by decreasing the intensity of training or enhancing the recovery process, during these critical phases where the risk is high (de Leeuw et al., 2022). Metrics and indicators such as internal load, external load, stress, ACWR, CMJ (countermovement jump), and cortisol are utilized for monitoring training load. Training load is measured using internal load, which includes physiological response and perception of effort, as well as external load, which includes factors like distance traveled or number of repetitions (Impellizzeri et al., 2019). Metrics such as ACWR (Hulin et al., 2016), CMJ (Rago et al., 2018), and cortisol (Cadegiani & Kater 2017) are employed to evaluate the level of training stress and the potential for injury or overtraining. The relationship between resistance training, competition, neuromuscular function, and physical performance is determined by the specific type of training, competitive circumstances, and the aspects of performance that are monitored during training load monitoring. Monitoring resistance training, competition, neuromuscular factors, and physical performance is crucial for optimizing athlete performance (Gabbett, 2016 and Halson, 2014).

Green cluster: The body's physiological response to training loads is associated with heart rate, fatigue, overtraining, overreaching, and parasympathetic activity. Heart rate, fatigue level, overtraining, overreaching, and parasympathetic nervous system activity are crucial factors for evaluating training intensity and the recovery status of athletes (Bourdon et al., 2017, Halson, 2014, and Meeusen, 2013). Performance, endurance, swimming, running, cycling, and fitness are all aspects that pertain to the specific sport or physical activity being monitored for training load. Performance, endurance, swimming, running, cycling, and fitness are commonly assessed in different sports to ensure the most effective training intensity (Black et al., 2016; Mujika, 2017). Recovery, s-RPE (Session rating of perceived exertion), TRIMP (training impulse), and wearable devices are all associated with the techniques and technology employed in tracking and measuring training loads. Recovery, s-RPE (session rating of perceived exertion), TRIMP (training impulse), and wearable devices are commonly employed tools and metrics for assessing and tracking the training load and recovery status of athletes (Bourdon et al., 2017; Impellizzeri et al., 2019). Physiology and the Autonomic Nervous System (ANS) are relevant to the physiological factors associated with monitoring training load. The understanding and monitoring of body physiology and the autonomic nervous system (ANS) are crucial in relation to training load. This is emphasized by Helson (2014) and Lucini et al. (2017) in the context of training load monitoring. Utilizing training load monitoring enables coaches and medical personnel to detect instances of excessive training load or overtraining in athletes. Excessive training load can heighten the likelihood of injury due to the amplified physical strain it places on the body and the diminished capacity for recovery (Bourdon, 2017). Monitoring the training load can assist in identifying discrepancies between the intensity of training and the subsequent recovery. Inadequate recovery time for athletes can impede their body's complete recuperation, potentially resulting in fatigue-induced injuries (Soligard, 2016).

Blue Cluster: Team sports, soccer, and intermittent exercise are related to the types of sports that are the focus in monitoring training load. Team sports like football require monitoring of training load due to their intermittent nature, which involves a stop-start pattern of training and matches

(Fanchini et al., 2018; Malone et al., 2018). Workloads, injuries, player load, and acceleration are all factors that are considered when monitoring training load in team sports. These factors are measured using metrics and indicators. Monitoring workloads, injury risks, player load, and acceleration is crucial for optimizing performance and preventing injuries (Hulin et al., 2016; Impellizzeri et al., 2020). RPE, GPS, accelerometer, and coach pertain to the techniques and technologies employed for monitoring training load in team sports. The accurate and effective monitoring of training load requires the inclusion of RPE (Rating of Perceived Exertion), GPS (Global Positioning System), accelerometer, and the active involvement of the coach (Bourdon et al., 2017; Maddison & Ni, 2007). The relationship between female athletes and training prescription is based on athlete characteristics and the utilization of training load monitoring outcomes. Special considerations may be necessary when monitoring training load in female athletes (Bourdon et al., 2017). Training prescription, also known as training perception, is determined by monitoring training load and can be utilized to develop optimal training programs (de Leeuw et al., 2022).

Yellow Cluster: Football, volleyball, basketball, and sports training pertain to distinct athletic activities that are the primary subjects of training load monitoring. Football, volleyball, and basketball are widely popular sports that frequently serve as the focus of research and training load monitoring practices within the realm of sports training (Bahr & Holme 2003; Impellizzeri et al., 2019). The primary goals of monitoring training load in sports are directly linked to performance analysis, injury prevention, and exercise. Training load monitoring is crucial in the sports environment due to its significant role in performance analysis, injury prevention, and training optimization (Bourdon et al., 2017; de Leeuw et al., 2022; Gabbett, 2016). Wellness, well-being, and readiness pertain to various aspects of an athlete's health and preparedness that require monitoring in relation to the intensity of their training. The adequate training load and recovery of an athlete have a significant impact on their well-being, health, and preparedness (Kellmann et al., 2018; Saw et al., 2016). Machine learning pertains to novel techniques and technologies employed in the monitoring of training loads. Machine learning is a method that is being increasingly investigated for analyzing training load monitoring data in order to enhance accuracy and predictions (Bourdon et al., 2017).

Trend analysis of themes and topic

Figure 5 displays the topic network map based on the utilized keywords. Keywords displayed in a darker color indicate an average year of publication, while lighter colors indicate a more recent average year of publication. The presence of the keywords "training", "overtraining", "overreaching", "training intensity", and "fitness" displayed in a dark color indicates that these keywords have been the subject of research since 2017. The training load conducted is determined by the quantity and timing of the exercises. Engaging in physical exercise can lead to strain on the tissues and musculoskeletal system. Consequently, closely monitoring the intensity of training can help predict how the body will adapt to this strain (Vanrenterghem et al., 2017). Monitoring training load enables the tracking of changes in fatigue and readiness to train both mentally and physically. This monitoring is necessary to prevent functional overreaching in athletes (Ten et al., 2017).

On average in 2018, research focused on keywords denoted by moderately saturated colors, such as "heart rate", "periodisation", "rpe", and others. During this period, the practice of monitoring training loads using ratings of perceived exertion (RPE) and heart rate monitors was widespread. The Rating of Perceived Exertion (RPE) is a dependable assessment tool for categorizing training intensities. However, it is most suitable to employ RPE with athletes who possess prior experience (Carvalho et al., 2018).

The predominant instances of "performance", "team sport", "injury prevention", and "recovery" denoted by slightly paler hues are primarily found in the 2019 average. During performance optimization, the training load progressively increases throughout a season, resulting in a heightened risk of injury due to overtraining (Pullinger et al., 2019).
The recent events, such as "football", "acwr", "injury", and "external load", have been updated with the latest information. Alternative colors for investigation pertain to years preceding 2017.

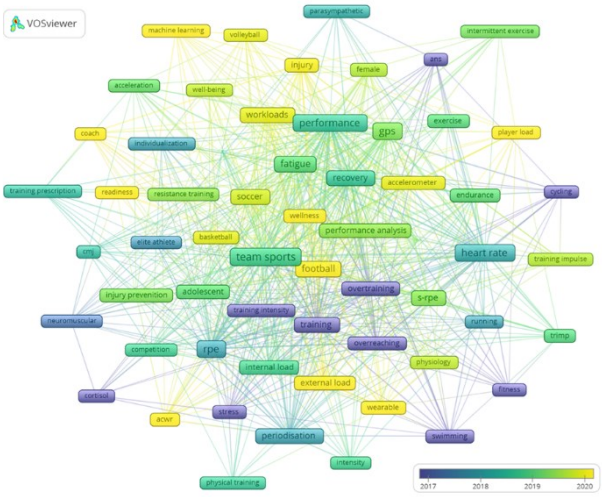

Figure 5. Keyword trends by publishing year.

From the trend of research keywords related to training load monitoring, there is the keyword ACWR which has the most recent publication average. ACWR is a quantitative measure employed to assess the acute training load, which refers to the training load experienced in a brief timeframe, in relation to the chronic training load, which represents the average training load sustained over a longer duration, typically spanning 4 weeks or more. Research has demonstrated that elevated ACWR values (where the acute training load significantly surpasses the chronic training load) are linked to a higher likelihood of injury in athletes.

Conversely, a low ACWR value can also heighten the risk of injury because of insufficient training load (Hulin, 2016). The ACWR (Acute to Chronic Workload Ratio) can serve as a tool to enhance an athlete's training load. Coaches can modify training programs by monitoring ACWR values to ensure that athletes undergo gradual and secure increments in training load (Gabbett, 2016). Every athlete possesses a unique capacity and reaction to the intensity of training. ACWR enables coaches to customize training programs by modifying the ratio of acute to chronic loads based on the specific attributes of the athlete. Additional research can be conducted to investigate alternative metrics for training load and ACWR monitoring that may offer greater accuracy or specificity for specific sports or types of training (Impellizzeri, 2019).

Conclusion

Finding the direction of future development is made possible by the knowledge and research advancements in training load monitoring. The findings of this study indicate that the practice of tracking the intensity of training in athletes has emerged as a widespread area of research worldwide. Using the methodology employed in this study, a total of 1,099 documents were extracted from the Scopus database by utilizing specific keywords. The research on training load monitoring originated in 1979 and has since undergone a substantial increase from 2010 to the present. Australia has published the highest number of research articles, specifically 243, on the topic of monitoring. However, when it comes to overall research on this subject, the European continent takes the lead. Australia conducted the most influential research on this topic, as indicated by the country of origin of the article writer. Halson's article from 2014 received the highest number of citations, totaling 1,063. The topic of training load monitoring frequently involves the keywords "performance", "team sport", and "heart rate".

The results of this study have implications for the field of training load monitoring and can provide guidance for future research. This research can assist academics, coaches, and researchers in discovering crucial information pertaining to the monitoring of training load.

Limitation and Recommendations

The study we performed had a number of limitations. Although additional research may be available in other databases pertaining to this field, we have limited ourselves to using the Scopus database for our study. Secondly, author thresholds determined through VOSViewer analysis can only regulate, not fully reflect, needs.

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