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ORIGINAL ARTICLE

Analyzing the bibliometric progress of sustainable monitoring and analysis of sports training loads

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Abstract

Introduction and Objective. In recent years, load monitoring and analysis have become increasingly important in athletic training. The aim of this study was to provide a background for businesses and institutes to prepare for the implementation of load training and analysis in sports training, utilizing visual analysis of CiteSpace (CS) software.

Materials and method. A total of 169 original publications were obtained from Web of Science using a comprehensive list for analysis with the CS scientometrics program. The parameters included range (2012–2022), visualization (display of completely integrated networks), precise collection criteria (top 10%), node form (institution, author, area, reference cited; referenced author, key words, and journal), and trimming (pathfinder, slice network).

Results. Visual analysis of load monitoring and analysis for use in athletic training showed that 'questionnaire' was the most popular topic area in 2017 with 51 citations, while 'training programmes' emerged as a new area of study with 8 citations. In 2021 and 2022, the terms 'energy expenditure', 'responses', 'heart rate', and 'validity' gained popularity, increasing from a strength of 1.81 to 1.1. Liverpool John Moores University was the top institution, collaborating with 14 other organizations. The leading authors in this field were Close, Graeme L., and Gastin, Paul B. Most publications were found in the 'SPORTS MED' journal, with authors primarily based in the United Kingdom, the United States, and Australia.

Conclusions. The findings of the study highlight the potential frontiers of load training analysis in the research and management of sports, emphasizing the importance of preparing businesses and institutes for the implementation of load training, and analysis in athletic training.

Key words

CiteSpace, sustainability, sports, energy, load monitoring

Abbreviations

CS – CiteSpace; **WOS** – Web of Science; **WOSCC** – Web of Science Core Collections; **PCA** – Principal Component Analysis; **GPS** – Global Positioning System; **SPORTS MED** – Sports Medicine (Journal); **LLR** – Log-Likelihood Ratio; **MI** – Mutual Information; **VO(2)max** – Maximum Oxygen Uptake

INTRODUCTION

The analysis and tracking of training loads are crucial for athletes. To ensure that players are adequately pushed while reducing the risk of injury, it allows coaches and athletes to measure the physical demands of training and competition [1, 2]. Coaches can see trends and patterns in an athlete's performance over time by keeping track of training load, both exterior (such as distance traveled or weight lifted), and internal (such as heart rate and rating of perceived effort) [3]. They may then use this information to make educated decisions about whether to increase or reduce training intensity, how to modify the training programme to best meet the athletes needs, and what recuperation methods to put into place. Load analysis and monitoring can also help spot hazards before they cause injuries. This may be done with the use of objective data and athlete input, leading to better preventative strategy for injuries.

In addition to soccer and football, load monitoring and analysis may also be used in other performance-based sports. Monitoring an athlete's load can assist in gauging his or her fitness for training or competition, seeing red flags indicating a higher risk of injury, and crafting more effective workout plans. Athletes' physical and physiological capacities, and how they influence performance, may be better understood via load analysis [4].

Wearable technology has become more popular as a method of measuring and analyzing training loads in the field of sports. The training load of an athlete may be monitored in real time with the use of wearable technologies, e.g. activity trackers, heart rate monitors, and GPS-enabled gadgets. This information may be gathered in real time throughout training and tournaments, allowing coaches to modify an

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athlete's workout in reaction to their physiological state. In addition, enormous datasets created by load monitoring and analysis in sports training may be understood with the use of cutting-edge statistical approaches, such as principal component analysis (PCA), machine learning algorithms, and artificial neural networks. By using these techniques, coaches and sports scientists may better grasp the connection between training volume, output, and harm.

In conclusion, measuring and analyzing load is a potent method for bettering athletic performance [5]. It helps coaches anticipate injury risks and make well-informed judgments regarding training intensity, individual demands, and recovery procedures. Load monitoring and analysis may help athletes perform better and avoid injuries, although further study is needed to confirm this.

The long-term viability of monitoring and analyzing training loads is essential. Sustainable sports training prioritizes both the well-being of players and the survival of the sport in the long run [6]. Athlete tracking, wearable technology, and physiological monitoring can assist coaches and trainers improve the health and well-being of their athletes, while also maximizing their performance. From an ecological point of view, sustainability is also crucial [7]. The usage of energy, water, and equipment in sports training can have serious consequences for the natural world. Coaches and trainers may reduce the negative effects of sports training on the environment by using load monitoring and analysis to include sustainability concepts [8, 9].

There is a paucity of thorough bibliometric reviews that synthesize the research in the subject of load monitoring and analysis, despite the increasing popularity of the topic. Because of this void, it is essential to conduct a comprehensive literature assessment of the subject to identify research trends, significant contributors, and research needs. As such, this research aims to undertake a bibliometric study of the existing literature on the topic of load monitoring and analysis as it pertains to athletic preparation. This research uses a thorough search approach in Web of Science (WOS) to locate applicable papers. Load monitoring, athlete tracking, wearable technology, and related topics were all part of the search approach. The study also uses the social network analysis tool CiteSpace (CS) visualization to display and assess the research literature [10]. Using the CS tool [11–13], researchers may get useful insights into the research environment by identifying trends, notable authors, institutions, nations, and co-citation linkages between articles. The whole framework is shown in Figure 1.

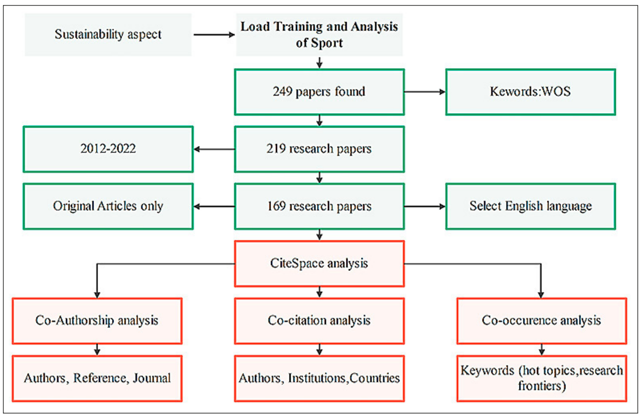

Figure 1. Flowchart demonstrating the activities for the current study

MATERIALS AND METHOD

Web of Science. When it comes to bibliometric research, the Web of Science (WOS) is often considered to be exceptional [14]. Therefore, data from the Web of Science Core Collections (WOSCC) was used for the research. The '11-year' data used in this analysis was collected on 20 December 2022. Multiple key words were explored to discover the most relevant papers in the field of load training and analysis in sports training. Examples of popular key word codes are shown in Table 1. Key words searched for in the records extraction procedure from WOS for conducting searches and retrieving data from WOS databases. List of key words used in the search: 'load measures', 'load monitoring', 'load analysis', 'training load', 'athlete tracking', 'wearable technology', 'physiological monitoring', 'performance analytics', 'data-driven coaching', 'injury prevention', 'load periodization', and 'soccer', 'football', 'sports training', 'performance assessment', 'athlete monitoring', 'sports performance', 'athlete optimization', 'training optimizatio', 'performance enhancement', and 'energy', 'cost', 'environment', 'sustainability', 'life cycle engineering', 'life cycle assessment', 'product quality', which means that available articles, and with such words found in the key words, titles, or abstracts, were downloaded. and found 249 articles. The authors found 219 articles (2012–2022) containing 219 articles, including 6 early access, 6 proceeding papers, 30 review articles, 1 editorial material, 1 meeting abstract, 2 chapters,1 book, and 1 book review. Next, 173 articles were selected from 173 articles The authors then selected English language and found 169 articles. A flow chart was devised depicting the arrangement of items used in the study (Fig. 2)

Table 1. Key words searched for in the records extraction procedure from WOS

No.	Key word Code	Result
1	'Load measures', 'load monitoring', 'load analysis', 'training load', 'athlete tracking', 'wearable technology', 'physiological monitoring', 'performance analytics', 'data-driven coaching', 'injury prevention', 'load periodization', and 'soccer', 'football', 'sports training', 'performance assessment', 'athlete monitoring', 'sports performance', 'athlete optimization', 'training optimization', 'performance enhancement', and 'energy', 'cost', 'environment', 'sustainability', 'life cycle engineering', 'life cycle assessment', 'product quality'.	249
2	Refine to the last 10 years – 2012–2022	219
3	After selection of only articles	173
4	Only English articles	169

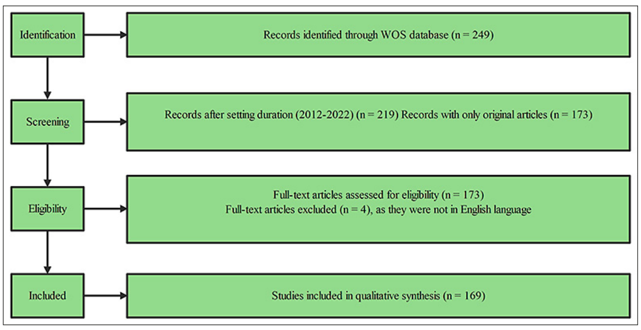

Figure 2. Flow chart showing the items used in study activity of the methodology section

CiteSpace Visualization. Research visualization in the area of social network analysis is an emerging subfield in bibliometrics [15]. The CS, invented by Chen Chaomei of Drexel University in Philadelphia, USA [16], is an open-source Java research software suite for the natural sciences. Its potent and well-respected qualities have led to its widespread adoption and acclaim on a global scale. Therefore, CS was utilized to display and assess the existing literature on load monitoring and analysis.

Data was collected and visually analyzed using the CS as the primary analytical procedure (6.1.R6). In the first step, the comprehensive WOS list was used to develop a proposed project for a 'load training & analysis project that referenced a simple CS text instruction. Due to a constraint in the CS programme, the authors were only able to employ WOSCC, despite their best efforts to use many research collections in tandem with WOSCC. Next, the range was defined from 2012–2022, with one-year slicing co-authorship, the visualization (showing the combined network), the specific assortment criteria (the top 10%), the node form (author, institution, section, reputable source cited; cited author, key words), pruning (such as the pathfinder and slicing network), and the selection process, which included the top 10%.

Co-authorship, co-citation, and assessment of co-occurrences with one or more occurrences were all integral to the CS's operation, as was the acquisition of a network and data displaying authors, organizations, and countries with multiple article publications, journal, and author cited twice or more. Data and networks were correlated for visualization of results of this study, which were then shown.

The current CS-based research can be highly useful for future research because it identifies the most relevant research topics, hotspots, and boundaries in load training research to develop sports technology in a range of applications.

Sustainability aspects. The measurement and analysis of training loads are fundamental practices in every sport. It helps coaches and players monitor and control the emotional and mental strains of competition. Technology advancements in load monitoring and analysis have transformed sports training by giving coaches and trainers access to real-time information on an athlete's physical condition, leading to more targeted workouts boosting performance and reducing risk of injury [17, 18]. However, the long-term viability of these innovations has been generally disregarded.

Sustainability considerations for advances in sports training load monitoring and analysis. The growth of electronic devices used to measure and analyse athlete performance is directly attributable to the development of load monitoring and analysis technology. There is a rising environmental concern caused by electronic trash, which can be exacerbated by the disposal of these gadgets after they reach the end of their useful life. It's important to urge coaches and athletes to discard or give their old gadgets to groups that can reuse or recycle them [19].

Sensors, computer programmes, and other hardware and software used in load analysis and monitoring systems use up a lot of power. It's important to encourage coaches and athletes to adopt low-power gadgets and programmes. In addition, gadgets and software should be made to be easily upgradable so that athletes and coaches may avoid repeated replacements and upgrades, which add to the energy consumption associated with the manufacture and disposal of electronic devices [20].

Components of load monitoring systems. Plastic, the material most commonly used in load monitoring sensors, is not biodegradable and can take hundreds of years to disintegrate in landfills. Load monitoring equipment used by coaches and players should be produced from environmentally friendly materials, such as bioplastics or recycled plastics [21].

Data privacy and security. Sports performance data is collected by load monitoring and analysis systems. The confidentiality of this information is of the utmost importance. There are threats to data privacy and security that coaches and athletes should be aware of and prepare for by utilizing secure communication channels and secure passwords [22].

Threats to human health and safety, despite the fact that load monitoring and analysis technologies have the potential to boost sports performance, also present some dangers to the users. Athletes and coaches should be aware of the dangers of employing load monitoring and analysis technology, including exposure to electromagnetic radiation, and take precautions to reduce such risks, such as using equipment with lower radiation levels and reducing exposure time.

Ethics Issues. There is a real danger that load monitoring and analysis technology might provide coaches and players with a major performance edge. However, there are ethical considerations that arise from the usage of these technologies, such as the possibility of coaches misusing data to gain an unfair advantage over their opponents, and the possibility of athletes having uneven access to these technology. The ethical implications of load monitoring and analysis technologies should not be ignored, and coaches and athletes should take steps to ensure that they are used in a responsible manner [23].

Load monitoring and analysis systems can be expensive, placing them out of reach for some sports teams and coaches. Open-source software and do-it-yourself load monitoring devices are two examples of low-cost alternatives that coaches and athletes might consider [24, 25].

RESULTS AND DISCUSSION

CiteSpace is a programme that helps researchers examine and visualize information found in scholarly journals. Bibliometric techniques are widely employed in the study of scientometrics, which aims to quantify and assess the progress made in the scientific and technical domains.

Co-authorship load monitoring and analysis research analysis. Load training via the analysis of enormous data sets is successful and most recognized example of scientific cooperation; this sort of activity requires cooperation on the institutional and national levels. Co-authorship studies in the field of load monitoring and analysis can shed light on the interdependencies between different authors and help researchers locate other experts in the field from all around the world [26].

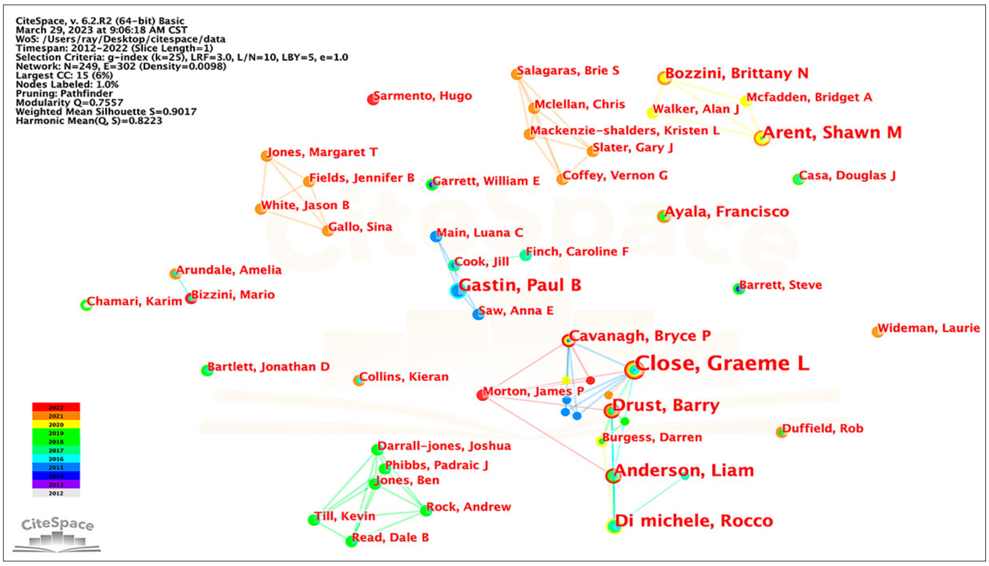

Figure 3. Author-co-authorship analysis in load monitoring and analysis research

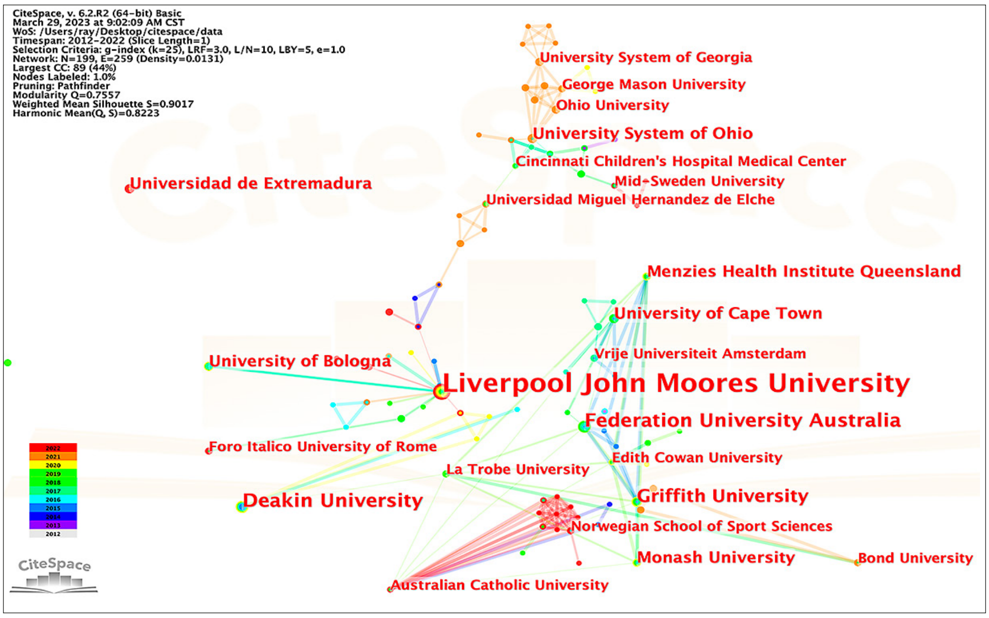

Figure 4. Institution co-authorship study in load monitoring and analysis research

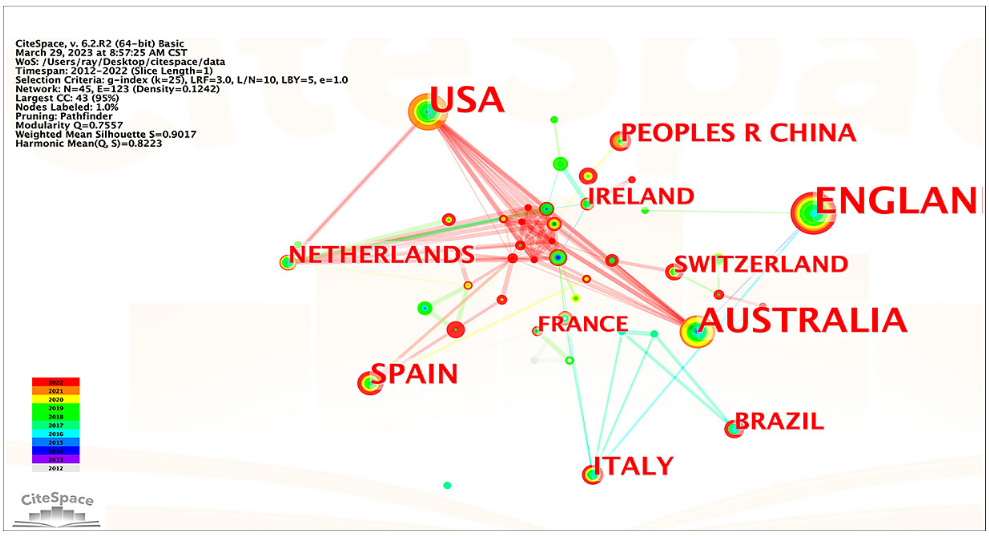

Figure 5. CS map of countries co-authorship in load monitoring and analysis research

Author co-authorship load monitoring and analysis research analysis. Figure 3 shows the results of a group of scholars who collaborated to produce a single academic work by agreeing on a suitable threshold and a suitable analytical unit. A node's size is proportional to the aggregate number of articles produced by its authors. When authors collaborate, the bonds between them grow stronger. For example, a blue background indicates an older publication, whereas a yellow background indicates a more recent one.

The most renowned intellectual panel under the guidance of Close and Graeme [27] is the biggest sub-network with six nodes, Anderson, in one of their article [30], reported on a study that compared the mental and physical demand of Division I collegiate men's soccer players during training and games. The research contrasted the internal and the external strains experienced by athletes during training and actual games. These findings provided useful indicators that might inform Division I collegiate soccer programmes' approaches to fitness and workload management during the season. Twenty-six male collegiate soccer players were tracked using a GPS and heart rate telemetry device for two full seasons. The author compared outdoor practice sessions with actual games.

The second largest group consists of four nodes, under the leadershipof Paul B. Gastin, and included Jill Cook in this group., In their paper, [31] they claimed that they intended to investigate whether there was any connection between levels of blood creatine kinase (CK), a proxy for muscle injury, and certain measures of match load in professional Australian football. Muscle injury from deceleration, acceleration, and collisions is a major problem in professional Australian Football. As a result of the Australian Football League, there was a surge in (CK) of between 129–152%. Muscle injury was most reliably predicted by characteristics related to high intensity running.

Table 2 displays the ten most prolific writers in terms of the number of publications to which they have contributed (Fig. 3). The Table additionally lists each author's total number of articles and the year of publication.

Table 2 Top 10 productive authors in the load monitoring and analysis research study obtained by CS analysis.

No.	Count	Year	Author
1	6	2015	Close, Graeme L
2	4	2015	Gastin, Paul B
3	4	2016	Di michele, Rocco
4	4	2016	Anderson, Liam
5	4	2019	Arent, Shawn M
6	4	2016	Drust, Barry
7	3	2018	Ayala, Francisco
8	3	2015	Cavanagh, Bryce P
9	3	2020	Bozzini, Brittany N
10	2	2015	Saw, Anna E

Institution co-authorship load monitoring and analysis research analysis. The author-co-authorship network of academic institutions engaged in load monitoring and analysis is depicted in Figure 4. Each university's node's size is relative to the number of articles it has published, and the thickness of each link indicates the degree to which institutions have worked together.

Figure 4 identifies the universities that have produced four or more papers. The cooperative network is supported by three major, geographically distributed subnetworks, and a handful of widely-dispersed institutions. John Moores University in Liverpool, UK, collaborated with a total of 14 institutions, some of which, however, are not shown in the figures above. Federation University in Mt Helen, Australia, has started collaborating with six institutions and has already established publication relations with Griffith University in Southport, Australia.

To better understand Figure 4, Table 3 gives a quick rundown of the ten most prestigious universities from a range of countries, arranged according to their total number of publications.

Table 3. Top 5 productive institutions in load monitoring and analysis research obtained by CS analysis.

No.	Count	Year	Institution
1	14	2015	John Moores University, UK
2	6	2015	Federation University, Australia
3	6	2015	Deakin University, Australia
4	5	2014	University of North Carolina, USA
5	5	2015	Griffith University, Australia AAuAustraliaAustraliaAustraliaAustralia
6	4	2016	University of Bologna, Italy
7	4	2015	University of Cape Town, South Africa
8	4	2017	University System of Ohio, USA
9	4	2015	Monash University, Australia
10	4	2015	Menzies Health Institute, Australia

Country co-authorship load monitoring and analysis research analysis. Figure 5 shows the global spread of research on load monitoring and analysis by examining the co-author networks of studies conducted in a single country. The diameters of the circles represent the total quantity of publications from each country. The density of links and proximity of nodes show the level of collaboration among countries. The size of the purple circle indicates the importance of the node. Three countries, each with three or more labels, are depicted in the diagram.

There are total of 45 networks in Figure 5. CS map of countries co-authorship in load monitoring and analysis research (density 0.12). The UK, USA, Australia, and Ireland are in Europe, North America, and Oceania, respectively. Spain and Italy are also in Europe, while the Peoples' Republic of China is in Asia; Brazil in South America, and Switzerland and Netherlands are in Europe. Based on a CS analysis, Table 4. Top 10 productive countries in load monitoring and analysis research obtained by CS analysis lists the top 10 nations in terms of research output related to load monitoring and analysis. The Table lists the number of scholarly articles published in the field for each country, together with the year in which the articles were published.

In 2014, the UK had the largest number of research articles in load monitoring and analysis, a total of 43, USA came second, and Australia third with 33 publications in 2013. With 15 publications in 2012, Spain ranked fourth, and Italy

Table 4. Top 10 productive countries in load monitoring and analysis research obtained by CS analysis

No.	Count	Year	Country
1	43	2014	UK
2	39	2013	USA
3	33	2013	Australia
4	15	2012	Spain
5	12	2013	Italy
6	11	2017	Peoples Republic of China
7	9	2015	Brazil
8	9	2013	The Netherlands
9	8	2017	Switzerland
10	8	2015	Ireland

Table 5. Top 10 productive journals in load monitoring and analysis research obtained by CS analysis

No.	Count	Year	Journal
1	117	2012	SPORTS MED
2	111	2012	MED SCI SPORT EXER
3	110	2012	BRIT J SPORT MED
4	108	2012	J STRENGTH COND RES
5	99	2012	J SPORT SCI
6	96	2012	J SCI MED SPORT
7	84	2012	INT J SPORT PHYSIOL
8	74	2012	INT J SPORTS MED
9	68	2013	SCAND J MED SCI SPOR
10	64	2013	AM J SPORT MED

ranked in fifth place with 12 works published in 2013. The People's Republic of China ranked sixth in terms of annual publishing output in 2017 with 11 total works, both Brazil and The Netherlands had nine publications in 2015, placing them sixth and eighth, respectively. In 2017 and 2015, Switzerland and Ireland tied for tenth place with eight publications each.

Co-citation load monitoring and analysis research analysis – Journal co-citation load monitoring and analysis research analysis. Figure 6. CS map of journal co-citation analysis in load monitoring and analysis research. shows the network of citation relationships between the various periodicals. There is also a correlation between the size of the node and the overall number of citations received by the article. The number of pages in the journal is proportional to the shortest path between any two nodes. The closer two journals are to one another, and the larger their individual nodes, the more often their articles are mentioned in one another's publications.

Table 5 presents the top ten journals with the highest productivity in load monitoring and analysis research, as obtained by CS analysis. The Table provides information on the count of research publications in the field for each journal, together with the corresponding year of data.

With 117 articles published in 2012, 'SPORTS MED' was the leading journal in load monitoring and analysis research. The second most prolific journal was 'MED SCI SPORT EXER', with 111 articles, while the third most prolific was 'BRIT J SPORT MED', with 110 articles. 'J STRENGTH COND RES' ranked fourth with 108 publications and 'J SPORT SCI' ranked fifth with 99.

Besides the 'J SCI MED SPORT', which had 96 publications in 2012, there were also many articles published in 'INT J SPORT PHYSIOL' (84), and 'INT J SPORTS MED' (74). In 2013, 'SCAND J MED SCI SPOR' ranked ninth with 68 articles, and 'AM J SPORT MED' ranked tenth with 64 publications.

The significant number of articles published in these journals is evidence of their importance in spreading research in the subject of load monitoring and analysis. These journals publish the most recent findings on the subject, which makes them valuable sources for academics and professionals interested in load monitoring and analysis.

Document co-citation load monitoring and analysis research analysis. The cited publications are the main source of data, as demonstrated by the presence of a co-citation. In order to identify the structure and development path of a domain using training analysis literature review of a paper as a ground for load training and analysis in sports training, it is essential to choose some typical studies, merely as a topic of analysis to an article's co-citation link. Nodes representing the various data sources were utilized to construct Figure 7. CS map of document co-citation analysis in load monitoring and analysis research in CS. All sources cited four times or more have their first author and publication year listed. In addition, the arrows depicting connections between nodes signify sources that are cited by one another.

The findings by SAW Ae [4] proposed that an average wellness score may be effective in spotting over-reaching; nevertheless, despite the widespread adoption of wellness in monitoring systems, these measures have shown only a modest ability to distinguish between periodic variations in load.

Figure 7 can be better understood in connection with Table 6. Top 7 productive documents in load monitoring and analysis research obtained by CS analysis, which lists the seven most-cited publications, together with such information as the total number of citations, the year of publication, and the corresponding reference.

Table 6. Top 7 productive documents in load monitoring and analysis research obtained by CS analysis

No.	Count	Year	Document	Reference
1	11	2016	Saw AE, 2016, BRIT J SPORT MED, V50, P281, DOI 10.1136/bjsports-2015-094758	[4]
2	10	2017	Bourdon PC, 2017, INT J SPORT PHYSIOL, V12, P161, DOI 10.1123/IJSPP.2017-0208	[32]
3	9	2016	Akenhead R, 2016, INT J SPORT PHYSIOL, V11, P587, DOI 10.1123/ijspp.2015-0331	[33]
4	7	2014	Halson SL, 2014, SPORTS MED, V44, P13, DOI 10.1007/s40279-014–0147-0	[34]
5	7	2015	Buchheit M, 2015, INT J SPORTS MED, V36, P1149, DOI 10.1055/s-0035-1555927	[35]
6	7	2017	Bartlett JD, 2017, INT J SPORT PHYSIOL, V12, P230, DOI 10.1123/ijspp.2015-0791	[36]
7	6	2017	Anderson L, 2017, INT J SPORT NUTR EXE, V27, P228, DOI 10.1123/ijsnem.2016-0259	[37]

Source: Author co-citation analysis

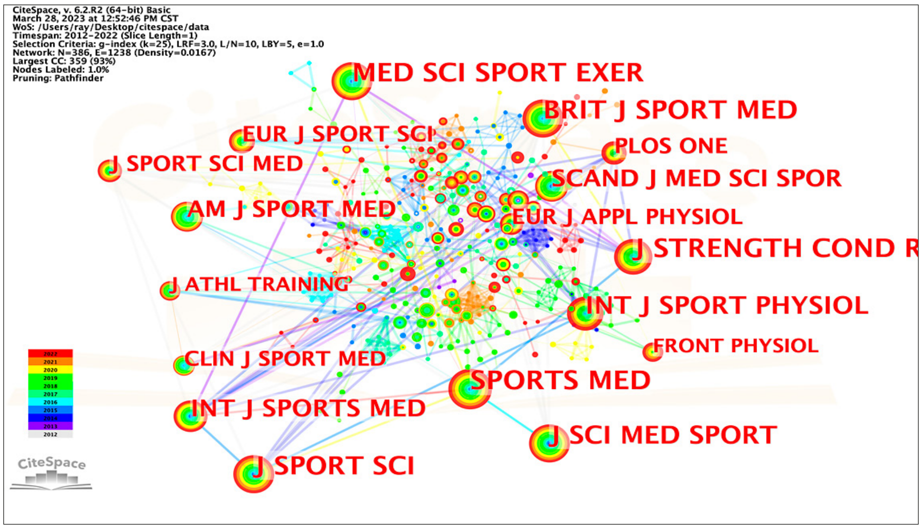

Figure 6. CS map of journal co-citation analysis in load monitoring and analysis research.

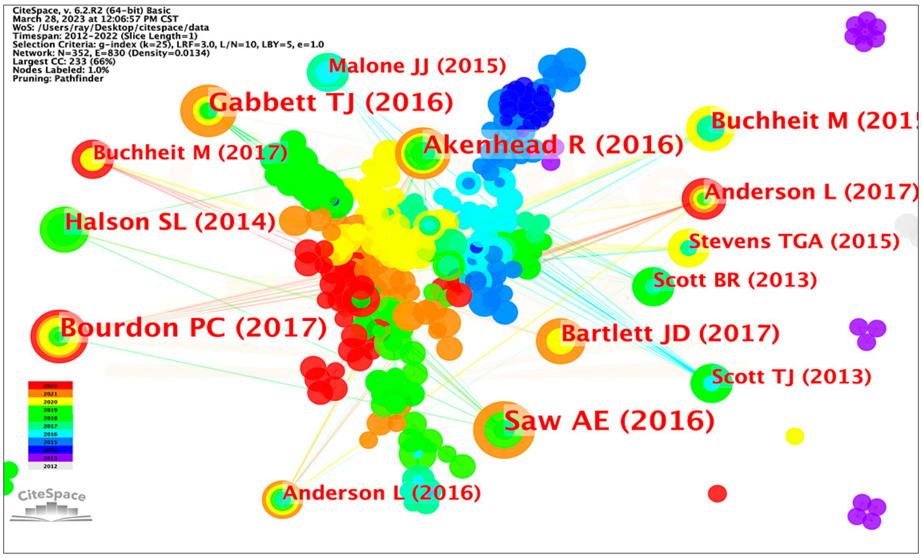

Figure 7. CS map of document co-citation analysis in load monitoring and analysis research

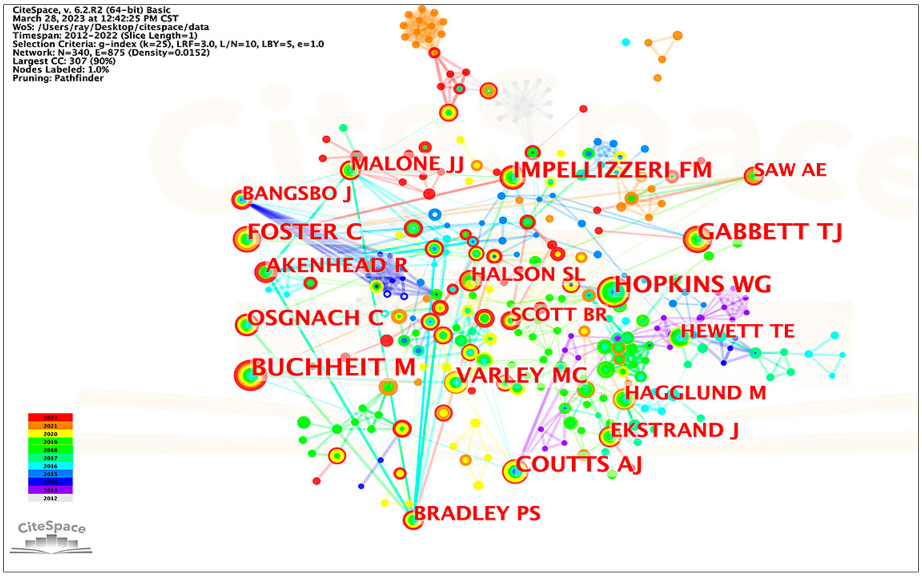

Figure 8. CS map of co-cited authors analysis in load monitoring and analysis research

Analysis of the author's co-citations may also reveal the research areas of similar authors in the field, and the distribution of their themes via a co-citation network. It also makes it easier to track how often certain authors and researchers are cited in the field's literature.

In Figure 8, each node represents a different author, and the line between any two authors shows their co-citation connection, and additionally shows the authors who have seven or more citations to their name. According to the results of the CS study, Table 7 lists the 13 most prolific co-cited authors in the subject of load monitoring and analysis. The prevalence of citations attributed to these authors in the literature attests the importance of the work they have produced. Leading the group in 2012 with 41 citations is BUCHHEIT M, followed by HOPKINS WG' in 2014 with 33 citations. Among the other authors on the list, GABBETT TJ' stands out with 29 citations in 2015, while FOSTER C' receives 27 and 'IMPELLIZZERI FM receives 26. COUTTS AJ, OSGNACH C, VARLEY MC, AKENHEAD R, EKSTRAND J, MALONE JJ, BRADLEY PS, and HALSON SL are also on the list because of the great number of times their works have been cited.

Table 7. Top 13 productive co-cited authors in load monitoring and analysis research obtained by Citespace analysis

No.	Count	Year	Name of cited Author
1	41	2012	BUCHHEIT M
2	33	2014	HOPKINS WG
3	29	2015	GABBETT TJ
4	27	2015	FOSTER C
5	26	2015	IMPELLIZZERI FM
6	24	2013	COUTTS AJ
7	22	2015	OSGNACH C
8	22	2015	VARLEY MC
9	20	2015	AKENHEAD R
10	18	2017	EKSTRAND J
11	17	2016	MALONE JJ
12	17	2016	BRADLEY PS
13	16	2015	HALSON SL

These co-authors are widely recognized as having made significant contributions to the development of the area of load monitoring and analysis. The Table summarizes the contributions of the most prominent researchers whose work has been frequently cited within the literature on the topic of load monitoring and analysis. The authors listed on this Table have all made significant contributions to the field of load monitoring and analysis, and their work quoted extensively.

Co-occurrence load monitoring and analysis research analysis – key words co-occurrence load monitoring and analysis research analysis. Search phrases may help reveal the primary themes of the articles. Trending topics can be deduced from search terms – repeatedly used key words – and a knowledge map of keyword co-occurrence [38]. Figure 9. CS map of analysis of key words in load monitoring and analysis research. was constructed with CS software, and each node represents a separate phrase with a line showing how often they occur together. CS analysis also yielded the top 15 prolific key words in research on load monitoring and analysis (Tab. 8). The term 'training load' appeared 41 times across the studies, with its prevalence peaking in 2015. Other frequently used terms included 'reliability' (21 instances in 2013) and 'injury prevention' (25 times in 2017 and 18 occurrences in 2013), 'players' (17 times in 2017) and 'validity' (17 times in 2016). There was also a high frequency of discussion surrounding such topics as 'athlete monitoring' (16 times in 2013), 'sports' (16 times in 2017), and 'injury risk' (14 times in 2017), 'soccer' (14 occurrences in 2014), 'weariness' (15 in 2015), 'football' (13 in 2013), 'exercise' (15 in 2015), 'heart rate' (13 in 2014), and 'team sports', are a few more noteworthy terms (12 in 2015).

Table 8. Top 15 productive key words in load monitoring and analysis research obtained by CS analysis

No.	Count	Year	Key word
1	41	2015	training load
2	25	2017	performance
3	21	2013	reliability
4	18	2013	injury prevention
5	17	2017	players
6	17	2016	validity
7	16	2013	athlete monitoring
8	16	2017	sports
9	14	2017	injury risk
10	14	2014	soccer
11	13	2015	fatigue
12	13	2013	football
13	13	2015	exercise
14	13	2014	heart rate
15	12	2015	team sports

Training load management, performance evaluation, injury prevention, and athlete monitoring are only some of the important themes and areas of interest in research on load monitoring and analysis, which are reflected by the terms mentioned above. The overall meaning of these terms within the context of load monitoring and analysis can be better understood with this information. According to data collected from CS, the year of occurrence reveals how often certain terms were used in that year.

Novel frontiers clusters. The best N=50 slicing method was chosen to produce the present status of CS research. When top N=50 is used, the 50 most frequently-occurring words and references are chosen from each paper. Figure 10 presents the whole bibliographic setting for the load training reference network. Connected nodes represent interconnected references. The Log-Likelihood Ratio (LLR) and Mutual Information Method is used to determine cluster labels (MI). LLR is considered as the gold standard since, after many iterations, it always provides the best result of a practical application. Clusters are shown one-by-one in Table 9.

Figure 10 shows the concentration of papers, with the size of the each cluster proportional to the number of publications within it. Without a doubt, the most cutting-edge academic discipline is the study of questionnaires. Each feasible cluster

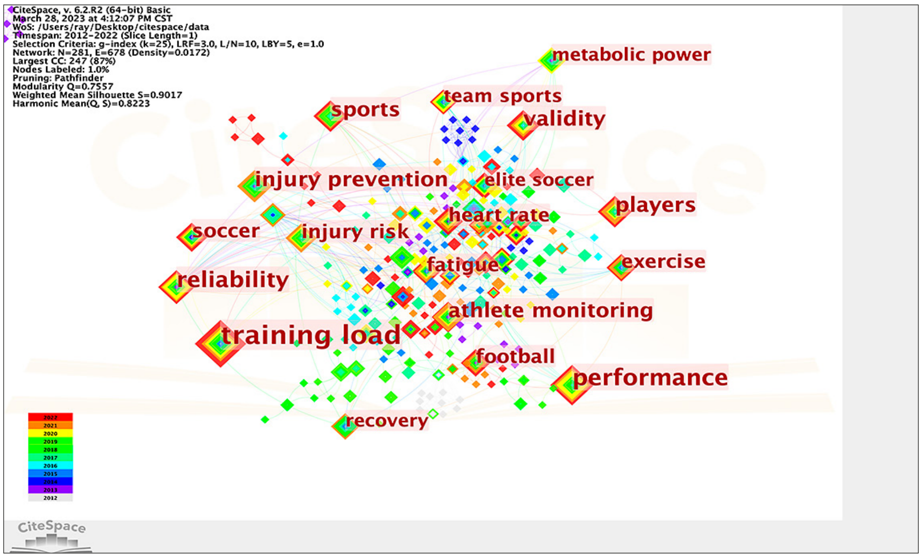

Figure 9. CS map of analysis of key words in load monitoring and analysis research

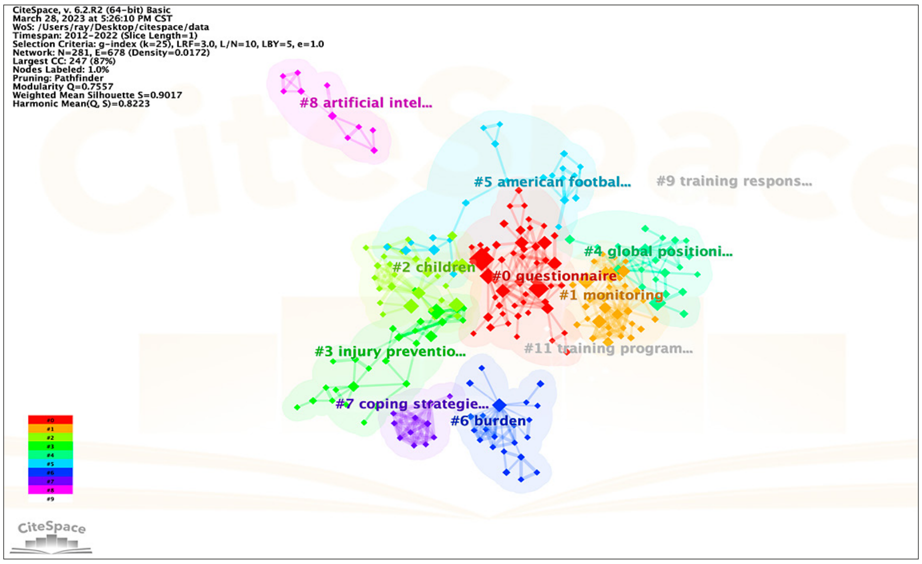

Figure 10. Top 11 co-cited reference clusters of load monitoring and analysis research related research

configuration is represented by a different number for the silhouette, ranging from 0–1. The silhouette's ability to cluster is dependent on its importance. The year listed for a cluster is the typical year of publishing of the articles contained within that cluster. Emerging trends within a cluster may be reflected in the centre of a cluster analysis, constructed on the most recent data.

Cluster-ID 0 is the most active cluster, 51 light-years across, with a silhouette score of 0.851, and a mean age of 2017 Analysis of loads placed on athletes is the focus of the studies that make up this group. With a label LLR of 8.35 at the 0.005 level, 'questionnaire' is the most prominent label associated with this cluster, followed by 'athlete monitoring' (LLR: 5.58; 0.05 level), 'pre-season' (LLR: 5.55; 0.05 level), 'well-being' (LLR: 5.55; 0.05 level), and 'training diary' (LLR: 5.55; 0.05 level). Furthermore, 'adaptation', 'effort perception', and 'sleep' were the MI labels most strongly related with this cluster, each with a value of 0.99.

Based on this grouping, it appears that in 2017 researchers interested in load monitoring and analysis in sports performance paid particular attention to questionnaires, athlete monitoring, preseason preparation, well-being evaluation, and training diaries. Load monitoring and analysis is strongly linked to adaptability, effort perception, and sleep, as shown by this study. Research into these areas might help fill gaps in our understanding of how to best track and analyze athletic performance. When applied to the realm of sports performance, this cluster emphasizes the significance of knowing numerous elements connected to load monitoring and analysis in order to maximize training and enhance players' health. Therefore, further investigation into these areas may provide fresh insights and practical uses in the future.

Research into the 'iot platform and unified health algorithm' (5.4.2) is a relatively new area of study.

Cluster-ID 11 is a new cluster with a size of 8, a silhouette score of 0.974, and a 2019 association. Training programmes, VO(2)max (maximum oxygen uptake), multisport, VO(2) max time, and the swimming flume are some of the most studied concepts in this cluster. Training programmes (6.38, 0.05) and vo(2)max (6.38, 0.05) are the most relevant and important research topics in this cluster, as shown by their

Table 9. A brief summary of the top 11 clusters

Cluster-ID	Size	Silhouette	Mean (Year)	Label (LLR)	Label (MI)
0	51	0.851	2017	questionnaire (8.35, 0.005); athlete monitoring (5.58, 0.05); pre-season (5.55, 0.05); well-being (5.55, 0.05); training diary (5.55, 0.05)	adaptation (0.99); effort perception (0.99); sleep
1	34	0.852	2016	monitoring (11.24, 0.001); perceived exertion (7.47, 0.01); metabolic power (5.17, 0.05); heart rate (5.17, 0.05); energy cost (3.99, 0.05)	time-motion analysis (0.53); trimp (0.53); stiffness
2	28	0.983	2017	children (7.21, 0.01); health (7.21, 0.01); anterior cruciate ligament (6.7, 0.01); injury risk (3.75, 0.1); biomechanics (3.75, 0.1)	load monitoring (0.58); adolescents (0.58); fronta
3	26	0.917	2016	injury prevention (20.86, 1.0E-4); neuromuscular (5.18, 0.05); first aid (5.18, 0.05); knee injuries (5.18, 0.05); movement patterns (5.18, 0.05)	neuromuscular (0.21); first aid (0.21); knee injury
4	23	0.879	2018	global positioning system (8.75, 0.005); periodization (8.75, 0.005); external load (5.17, 0.05); speed zones (4.36, 0.05); physiological response (4.36, 0.05)	speed zones (0.35); physiological response (0.35);
5	23	0.903	2017	American football (11.03, 0.001); video analysis (5.48, 0.05); functional movement screen (5.48, 0.05); ankle injuries (5.48, 0.05); lean body mass (5.48, 0.05)	video analysis (0.17); functional movement screen
6	23	0.855	2018	burden (6.43, 0.05); training monotony (5.02, 0.05); impact (5.02, 0.05); Australia (5.02, 0.05); adult (5.02, 0.05)	training monotony (0.23); impact (0.23); Australia
7	12	0.972	2012	coping strategies (9.82, 0.005); time-of-day (9.82, 0.005); athletic performance (7.06, 0.01); training (6.03, 0.05); athlete monitoring (0.17, 1.0)	coping strategies (0.02); time of day (0.02)
8	10	0.996	2020	artificial intelligence (7.82, 0.01); atmospheric fine particles (7.82, 0.01); research developments (7.82, 0.01); deep learning (7.82, 0.01); lung function (7.82, 0.01)	artificial intelligence (0.04)
9	9	0.992	2014	training response (8.29, 0.005); progressive statistics (8.29, 0.005); assessing changes (8.29, 0.005); heart rate recovery (8.29, 0.005); endurance sports (8.29, 0.005)	training response (0.03); progressive statistics
11	8	0.974	2019	training programmes (6.38, 0.05); vo(2)max (6.38, 0.05); multisport (6.38, 0.05); time at vo(2)max (6.38, 0.05); swimming flume (6.38, 0.05)	programmes (0.09); vo(2)max (0.09)

high mean label likelihood ratio (LLR) ratings. Multisport (6.38, 0.05), VO(2)max time (6.38, 0.05), and swimming flume (6.38, 0.05) are other important areas of study in this group (6.38, 0.05). The mutual information (MI) ratings of 0.09 and 0.09, respectively, for the most prominent labels in this cluster further demonstrate the significance of these terms to the studies conducted here. In general, this new community is interested in studying training regimens, vo(2)max, and associated themes within the frameworks of multi-sport, VO(2)max testing over time, and swimming flume studies.

To fully grasp the findings and consequences of this new area of research, it may be necessary, however, to do more analysis and examination of the research papers contained within this cluster. In conclusion, this grouping reflects the most recent and significant research tendencies in the field of load monitoring and analysis, particularly as they relate to training programs and vo(2)max. Considerable future progress may be expected in our knowledge of load monitoring and analysis from the study into this cluster as a whole. New discoveries, approaches, and practical applications may emerge from more study in this area.

In the context of training programmes and vo(2)max, this cluster may be of particular relevance to researchers and practitioners interested in load monitoring and analysis. Possible applications of this growing cluster include developing more effective training plans, increasing performance, and improving the health of athletes and others who regularly engage in physical exercise. As a whole, this new group of researchers sheds light on the cutting edge of load monitoring and analysis, and may help guide future efforts in this area. Researchers and practitioners alike need to keep abreast of these developing trends in the area if they intend continuing to play a leading role in its development. (0.09); vo(2)max (0.09).

LLR and MI are statistical measures used to evaluate the significance of the relationship between two study subjects within a cluster. The strength of the connection between the two subjects is measured by the LLR and MI scores. When referring to a specific study topic in the cluster, the values in parenthesis (e.g., 6.38, 0.05) indicate the average LLR or MI score and the matching significance level (p-value). The greater the average LLR or MI score, the more important the topic is to study within the cluster. The likelihood of generating a score as severe as, or more extreme than, the observed score by chance alone is represented by the significance level (p-value), with a lower p-value (e.g., 0.05) indicating a higher degree of significance. It is essential to consider the research field and the articles included in the analysis when attempting to make sense of the LLR and MI scores. It may be essential to perform additional analysis and interpretation of the cluster results before any relevant conclusions or implications may be drawn. For the most complete and accurate picture of the study, readers should always return to the primary sources.

Novel research frontiers of load monitoring and analysis for future research. Emerging trends in load monitoring and analysis are illuminated by the studies characterized with the burst key words. Table 10 shows the leading 27 load monitoring and analysis key words expected to have substantial increase between 2012–2022. The blue line represents the total time, and the red line represents duration of the burst.

Table 10. Top 27 key words with the Citation Bursts

Key words	Year	Strength	Begin	End	2012–2022
basketball	2013	1.17	2013	2014	
anterior cruciate ligament	2014	1.99	2014	2017	
injury	2014	1.79	2014	2015	
aerobic fitness variables	2014	1.04	2014	2016	
energy cost	2013	2.38	2015	2016	
costs	2015	1.11	2015	2016	
children	2016	0.9	2016	2017	
balance	2016	0.9	2016	2017	
elite soccer	2015	0.28	2016	2017	
recovery	2015	2.19	2017	2018	
risk factors	2017	1.94	2017	2019	
metabolic power	2013	1.51	2017	2020	
clinical assessment tool	2017	0.9	2017	2018	
team sports	2015	0.53	2017	2018	
soccer players	2015	2.55	2018	2019	
injury risk	2017	1.24	2018	2019	
burden	2018	0.87	2018	2019	
burnout	2018	0.87	2018	2019	
football	2013	0.79	2018	2019	
epidemiology	2017	1.29	2019	2020	
reliability	2013	1.03	2019	2020	
energy expenditure	2020	1.8	2020	2022	
responses	2015	1.41	2020	2022	
heart rate	2014	1.26	2020	2022	
validity	2016	1.11	2020	2022	
distance	2020	0.9	2020	2022	
coaches	2020	0.9	2020	2022	

The following are the major research frontiers in load monitoring and analysis with a strength of 1.8–1.02 for 2021 and 2022.

Energy expenditure. The goal of studying athletes' energy expenditure is to gain insight into the relationship between the amount of energy used during various activities and the subsequent effects on performance and recuperation. Wearable devices or metabolic carts are two examples of innovative methods for measuring energy expenditure that could be explored in the future, together with studies examining the effects of varying training loads on energy expenditure in different populations, such as elite athletes, recreational athletes, and special populations [39, 40].

Responses. Learning how athletes adapt to varying training loads is another major step forward in load monitoring and analysis. Research in this area looks at the physiological, psychological, and behavioural effects of various training loads on athletes. In the future, researchers may be able to use individual differences in response to training loads to pinpoint possible biomarkers or signs of exhaustion or over-reaching. There is room for investigation into how varying training loads affect performance, recuperation and health over time [41, 42].

Heart rate. In sports science and exercise physiology, measuring heart rate (HR) has been standard practice for decades. The intricate connection between HR and workload is currently poorly understood. Improved methods for monitoring HR, such as heart rate variability analysis or non-invasive measurements of cardiac function, might be a subject for future study. Heart rate responses to training loads are important for optimizing performance and avoiding injury; further study might examine how hydration, nutrition, and sleep affect these responses [18, 43, 44].

Validity. The load monitoring and validity of analysis is also very important. The validity of load measurement tools, such as accelerometers, GPS trackers, and self-report questionnaires, relates to their precision and dependability [45]. The accuracy and reliability of various load monitoring systems in various sports, demographics, and training environments, might be investigated in future studies. The potential for mistake or bias in load monitoring systems might also be studied, with the aim of developing solutions to address these issues [46].

SUMMARY AND FUTURE RESEARCH

This bibliometric study set out to assess the state of knowledge about the use of massive datasets in epidemic management. In recent years, there has been a great deal of interest in the application of load monitoring and analysis to the realm of sports training. With the use of CiteSpace (CS) visual analysis, this study was able to identify emerging patterns in the field of load training research, which may be used by academics to direct future studies, and by businesses to provide the groundwork for accommodating the field's expected expansion.

The results of the visual analysis of load monitoring and analysis in sports training were provided, based on the analysis of 169 original publications acquired from the Web of Science (WOS) employing CS factors, including range, visualization, selection criteria, node shape, and pruning. With 51 citations, 'questionnaire' was the most popular topic of study in 2017, while 'training programmes' was a new area of inquiry. In 2021 and 2022, 'energy expenditure', 'responses', 'heart rate' and 'validity' were 1.61-to-1.1-strength emerging key words. John Moores University in Liverpool, UK, was found to have the most partnerships in this area – 14, while Close, Graeme and Gastin were found to be the most prominent authors. Articles on this subject originated mostly from the UK, USA and Australia, and were published in 'SPORTS MED' magazine. Additional study in this area may help progress the field of sports science and lead to better overall athletic performance.

The visual results provide fresh perspectives and insights that may be informative for future research, policies, and choices in the field of load monitoring. The authors' familiarity with the data and its context was much improved by the visualizations which, in turn, facilitated analysis and comprehension of the results. This helped gain insight into the data and select meaningful patterns and correlations. The data is depicted graphically, providing a clear and concise image of the information that will help the reader understand the key findings of the study and the relevance of those findings in the real world. Although the findings pleased the research community and the medical business. To obtain the CS research articles for analysis, the authors relied solely on the WOSCC. It is suggested that this should be extended to include more research libraries, such as Scopus, PubMed, etc.

REFERENCES

1. Jiménez-García M, Ruiz-Chico J, Peña-Sánchez AR, et al. A Bibliometric Analysis of Sports Tourism and Sustainability (2002–2019). Sustainability [Internet]. 2020;12. Available from: https://www.mdpi.com/2071-1050/12/7/2840.
2. Hu K-H, Chen F-H, Tzeng G-H. Evaluating the Improvement of Sustainability of Sports Industry Policy Based on MADM. Sustainability [Internet]. 2016;8. Available from: https://www.mdpi.com/2071-1050/8/7/606.
3. Ryan S, Kempton T, Impellizzeri FM, et al. Training monitoring in professional Australian football: theoretical basis and recommendations for coaches and scientists. Sci Med Football. 2020;4:52–58.
4. Saw AE, Main LC, Gastin PB. Impact of Sport Context and Support on the Use of a Self-Report Measure for Athlete Monitoring. J Sports Sci Med. 2015;14:732–739.
5. Song H. Application of embedded wearable devices in football training injury prevention. Microprocess Microsyst. 2021;82:103915.
6. Sousa H, Gouveia ER, Marques A, et al. The Influence of Small-Sided Football Games with Numerical Variability in External Training Load. Sustainability. 2022;14:1000.
7. Neupert E, Gupta L, Holder T, et al. Athlete monitoring practices in elite sport in the United Kingdom. J Sports Sci. 2022;40:1450–1457.
8. Piras A, Raffi M, Atmatzidis C, et al. The Energy Cost of Running with the Ball in Soccer. Int J Sports Med. 2017;38:877–882.
9. Hannon MP, Parker LJF, Carney DJ, et al. Energy Requirements of Male Academy Soccer Players from the English Premier League. Med Sci Sports Exerc. 2021;53:200–210.
10. Wang Y, Mushtaq RT, Ahmed A, et al. Additive manufacturing is sustainable technology: citespace based bibliometric investigations of fused deposition modeling approach. Rapid Prototyp J [Internet]. 2022;28:654–675.
11. Wang Y, Ahmed A, Azam A, et al. Applications of additive manufacturing (AM) in sustainable energy generation and battle against COVID-19 pandemic: The knowledge evolution of 3D printing. J Manuf Syst. 2021;60:709–733.
12. Mushtaq RT, Iqbal A, Wang Y, et al. Parametric Effects of Fused Filament Fabrication Approach on Surface Roughness of Acrylonitrile Butadiene Styrene and Nylon-6 Polymer. Materials [Internet]. 2022;15:5206.
13. Ahmed A, Azam A, Wang Y, et al. Additively manufactured nano-mechanical energy harvesting systems: advancements, potential applications, challenges and future perspectives. Nano Converg [Internet]. 2021;8:37.
14. Azam A, Ahmed A, Wang H, et al. Knowledge structure and research progress in wind power generation (WPG) from 2005 to 2020 using CiteSpace based scientometric analysis. J Clean Prod. 2021;126496.
15. Puce L, Trabelsi K, Trompetto C, et al. A Bibliometrics-Enhanced, PAGER-Compliant Scoping Review of the Literature on Paralympic Powerlifting: Insights for Practices and Future Research. Healthcare [Internet]. 2022;10.
16. Chen C. CiteSpace II: Detecting and visualizing emerging trends and transient patterns in scientific literature. J Am Socr Infor Sci TechnoL. [Internet]. 2006;57:359–377.
17. Morehen JC, Rosimus C, Cavanagh BP, et al. Energy Expenditure of Female International Standard Soccer Players: A Doubly Labeled Water Investigation. Med Sci Sports Exerc. 2022;54:769–779.
18. Colosio AL, Pedrinolla A, Da Lozzo G, et al. Heart Rate-Index Estimates Oxygen Uptake, Energy Expenditure and Aerobic Fitness in Rugby Players. J Sports Sci Med. 2018;17:633–639.
19. Clubb J, McGuigan M. Developing Cost-Effective, Evidence-Based Load Monitoring Systems in Strength and Conditioning Practice. Strength Cond J. 2018;40:75–81.
20. Salagaras BS, Mackenzie-Shalders KL, Nelson MJ, et al. Comparisons of Daily Energy Intake vs. Expenditure Using the GeneActiv Accelerometer in Elite Australian Football Athletes. J Strength Cond Res. 2021;35:1273–1278.
21. Roe M, Blake C, Gissane C, et al. Injury Scheme Claims in Gaelic Games: A Review of 2007–2014. J Athl Train. 2016;51:303–308.
22. Zhang S, Mao H. Optimization Analysis of Tennis Players' Physical Fitness Index Based on Data Mining and Mobile Computing. Wirel Commun Mob Comput. 2021;2021.
23. Xie R, Xie Y, Lopez-Barron CR, et al. Ultra-stretchable conductive iono-elastomer and motion strain sensor system developed therefrom. Technol Innov. 2018;19:613–626.
24. Van Reijen M, Vriend I, van Mechelen W, et al. Preventing recurrent ankle sprains: Is the use of an App more cost-effective than a printed Booklet? Results of a RCT. Scand J Med Sci Sports. 2018;28:641–648.
25. Nouni-Garcia R, Rosario Asensio-Garcia M, Orozco-Beltran D, et al. The FIFA 11 programme reduces the costs associated with ankle and hamstring injuries in amateur Spanish football players: A retrospective cohort study. Eur J Sport Sci. 2019;19:1150–1156.
26. Zhang J, Liu J, Chen Y, et al. Knowledge Mapping of Machine Learning Approaches Applied in Agricultural Management – A Scientometric Review with CiteSpace. 2021.
27. Bradley WJ, Cavanagh BP, Douglas W, et al. Quantification of training load, energy intake, and physiological adaptations during a rugby preseason: a case study from an elite European rugby union squad. J Strength Cond Res. 2015;29:534–544.
28. Beato M, Drust B. Acceleration intensity is an important contributor to the external and internal training load demands of repeated sprint exercises in soccer players. Res Sports Med. 2021;29:67–76.
29. Anderson L, Drust B, Close GL, et al. Physical loading in professional soccer players: Implications for contemporary guidelines to encompass carbohydrate periodization. J Sports Sci. 2022;40:1000–1019.
30. Anderson T, Adams WM, Martin KJ, et al. Examining Internal and External Physical Workloads Between Training and Competitive Matches Within Collegiate Division I Men's Soccer. J Strength Cond Res. 2021;35:3440–3447.
31. Gastin PB, Hunkin SL, Fahrner B, et al. Deceleration, acceleration, and impacts are strong contributors to muscle damage in professional Australian football. J Strength Cond Res. 2019;33:3374–3383.
32. Bourdon PC, Cardinale M, Murray A, et al. Monitoring Athlete Training Loads: Consensus Statement. Int J Sports Physiol Perform. 2017;12:S2161–S2170.
33. Akenhead R, Nassis GP. Training load and player monitoring in high-level football: Current practice and perceptions. Int J Sports Physiol Perform. 2016;11:587–593.
34. Halson SL. Sleep in elite athletes and nutritional interventions to enhance sleep. Sports Med. 2014;44:13–23.
35. Buchheit M, Manouvrier C, Cassirame J, et al. Monitoring Locomotor Load in Soccer: Is Metabolic Power, Powerful? Int J Sports Med. 2015;36:1149–1155.
36. Bartlett JD, O'connor F, Pitchford N, et al. "Relationships Between Internal and External Training Load in Team Sport Athletes: Evidence for an Individualised Approach" by Bartlett JD et al. International Journal of Sports Physiology and Performance Section: Original Investigation Article. Journal: International Journal of Sports Physiology and Performance [Internet]. 2016; Available from: http://dx.doi.org/10.1123/ijspp.2015-0791.
37. Anderson L, Orme P, Naughton RJ, et al. Energy Intake and Expenditure of Professional Soccer Players of the English Premier League: Evidence of Carbohydrate Periodization. Int J Sport Nutr Exerc Metab. 2017;27:228–238.
38. Yu D, Xu Z, Pedrycz W, et al. Information sciences 1968–2016: A retrospective analysis with text mining and bibliometric. Inf Sci (NY). 2017;418–419:619–634.
39. Salagaras BS, Mackenzie-Shalders KL, Slater GJ, et al. Increased carbohydrate availability effects energy and nutrient periodisation of professional male athletes from the Australian Football League. Appl Physiol Nutrition Metab. 2021;46:1510–1516.
40. Highton J, Mullen T, Norris J, et al. The Unsuitability of Energy Expenditure Derived From Microtechnology for Assessing Internal Load in Collision-Based Activities. Int J Sports Physiol Perform. 2017;12:264–267.
41. Hebert-Losier K, Yin NS, Beaven CM, et al. Physiological, kinematic, and electromyographic responses to kinesiology-type patella tape in elite cyclists. J Electromyography Kinesiol. 2019;44:36–45.
42. Looney DP, Santee WR, Blanchard LA, et al. Cardiorespiratory responses to heavy military load carriage over complex terrain. Appl Ergon. 2018;73:194–198.
43. Rabbani A, Clemente FM, Kargarfard M, et al. Match Fatigue Time-Course Assessment Over Four Days: Usefulness of the Hooper Index and Heart Rate Variability in Professional Soccer Players. Front Physiol. 2019;10.
44. García-Ceberino JM, Gamero MG, Ibáñez SJ, et al. Are Subjective Intensities Indicators of Player Load and Heart Rate in Physical Education? Healthcare. 2022;10:3: 428.
45. Lee JWY, Li C, Yung PSH, et al. The reliability and validity of a video-based method for assessing hamstring strength in football players. J Exerc Sci Fit. 2017;15:18–21.
46. Akubat I, Barrett S, Sagarra ML, et al. The Validity of External: Internal Training Load Ratios in Rested and Fatigued Soccer Players. Sports. 2018;6:44.