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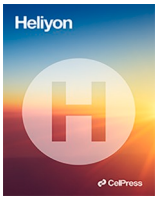

Research article

Global research trends in skiing from 1974 to 2023: A bibliometric analysis

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ABSTRACT

This study analyzes 1643 documents related to skiing from 1974 to 2023 using the Web of Science Core Collection database, employing CiteSpace and VOSviewer for quantitative analysis. Findings reveal a growing literature output, with the past five years contributing to 36.2 % of publications. Norway leads in total publications and collaboration intensity, with the University of Salzburg and the Norwegian University of Science and Technology as prominent institutions. The research spans a wide range of disciplines such as Sport Sciences, Physiology, etc., and interdisciplinary intersections with engineering, computer science, etc. have become a future research trend. The research focuses on the analysis of skiers' sports performance, the analysis of skiing-induced sports injuries, the biomechanical analysis of skiers' postures, and the analysis of skiing-induced respiratory diseases. The study highlights the evolution of research focus from skiing injuries to injury prevention and sports performance enhancement. This comprehensive overview aids scholars in understanding skiing research hotspots and future trends efficiently.

1. Introduction

Skiing is the use of skis or other equipment in the snow on a variety of skiing sports, mainly by the alpine skiing, freestyle skiing, snowboarding, ski jumping, cross-country skiing, Nordic two and ski mountaineering 7 projects. Skiing, as an important part of winter sports, is popular among people because of its challenging, entertaining, and ornamental qualities [1,2], and the annual average number of skiing trips in the world has been stable at more than 300 million from 2009 to 2020, making it a popular sport for the general public to choose in winter [3]. In addition, the Winter Olympics as the world's largest winter comprehensive games, skiing in the Winter Olympics program also has a pivotal position. Among the 15 sub-sports of the Winter Olympics, skiing sports account for 7 sports. Therefore, countries have also formulated relevant policies around the goal of winning gold in the Winter Olympics, such as the Own the Podium program implemented by Canada [4] and the Norwegian Olympic Top Sport Program implemented by Norway [5]. The large number of participants and the promulgation of favorable policies in many countries have greatly promoted the development of skiing. The rapid development of skiing is of great value in terms of enriching the variety of sports and improving the physical and mental health of participants.

At the same time, skiing-related research results have begun to emerge in large numbers. For example, from the biomechanical point of view of cross-country skiers' techniques and tactics, it was found that athletes with better performance would use the Double-

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Poling strategy with smaller joint angles and higher flexion speeds [6]; from the physiological point of view of the long-distance cross-country skier's risk of arrhythmia, it was found that the athlete's completion time, the number of races and the incidence of arrhythmia were positively correlated [7]; the training methods of biathletes were analyzed from an athletic training perspective, and it was found that plateau training could increase the hemoglobin mass and red blood cell volume of athletes, thus improving athletic performance [8]. a review of cross-country skiers' pacing strategies affecting their performance from a technical and tactical perspective showed that athletes should adopt an even pacing strategy in order to maintain their level of performance for a longer period of time [9]. For example, the current methodology used in research mainly on a single ski sport program or in the review of ski sport programs has certain shortcomings, such as the literature data of the systematic review mainly relies on the author's subjective screening and the number of literature included is small [10]; Meta-analysis usually focuses on specific research issues, and the vision is not broad enough to provide a comprehensive overview of research in the field of skiing when studying the hotspots and directions of research in the field of skiing [11]. Therefore, there is still a lack of studies in the field of skiing sports that systematically summarize and conclude the whole field from a quantitative perspective.

Bibliometrics refers to the cross-cutting science that analyzes all knowledge carriers quantitatively using mathematical and statistical methods. Its qualitative and quantitative analysis of a specific object can identify its research topics and predict future trends [12,13]. At the same time, bibliometrics also allows for a comprehensive analysis of the contributions of different countries/regions, institutions, and journals, and quantitatively analyze a specific field from multiple perspectives. Several sports have been analyzed using bibliometric methods, such as soccer [14], basketball [15], tai chi [16], and swimming [17], which provide important reference value for researchers to understand the development of these sports.

Skiing, as one of the major winter sports, understanding the developmental lineage of skiing is also important for research in the field of sports. Previously, bibliometrics has not been applied to research in the field of skiing sports. Therefore, this study takes the literature of web of Science core collection (WoSCC) database in the field of skiing sports as the object, and adopts bibliometric method to sort and summarize the field from the perspectives of temporal, spatial, disciplinary, and hotspot trends, to systematically assess the current status of research in the field of skiing sports, hotspots, and research fronts, and to provide valuable We hope that this study will provide valuable insights for the future development of skiing. We hope that this study will facilitate the academic exploration of scholars related to the field of skiing, and also serve as an effective reference for scientific research institutions in their scientific decision-making and research management, so as to promote the benign development of the field of skiing.

2. Data sources and research methodology

2.1. Data sources

In order to ensure the rigor of the data, this study will use the WoSCC's Science Citation Index Expanded (SCI-Expanded), Social Sciences Citation Index (SSCI), Emerging Sources Citation Index (ESCI), and Arts & Humanities Citation Index (A&HCI) as data sources for the search, and the search formula is TI = ("snow sports" or "skiing sports" or "sports on snow" or "Alpine Ski*" or "Freestyle Ski*" or "Snowboard*" or "Nordic Ski*" or "Cross-Country Ski*" or "Ski Jump*" or "Nordic Combined" or "biathlon" or "Ski mountaineering"). Two authors were involved in the literature search and data processing process. The results of this search formula revealed that there was no literature published in the field of skiing prior to 1974. Therefore, literature published between January 1, 1974 and October 8, 2023 was analyzed in this study. Inclusion and exclusion criteria were identified during the document search and data processing process.

Inclusion criteria: (1) studies addressing the field of skiing; (2) literature written in the language of English; (3) literature type limited to Article or Review Article.

Exclusion criteria: (1) Literature not consistent with research in the field of skiing and sports; (2) Literature written in languages other than English; (3) Exclusion of literature that was not of Article or Review Article type; (4) Duplicate literature.

After screening, a total of 1711 literatures were obtained. Subsequently, according to the content of the literature, two persons screened the above literature one by one, respectively, and excluded 68 documents that did not match the topic, and finally obtained 1643 documents (the first one was published in 1974), including 1576 research documents (95.9 %) and 67 (4.1 %) review documents.

Table 1
Data collection strategies in skiing.

Item	Content
Data source	SCI-Expanded、SSCI、ESCI、A&HCI
Search formula	TI = ("snow sports" or "skiing sports" or "sports on snow" or "Alpine Ski*" or "Freestyle Ski*" or "Snowboard*" or "Nordic Ski*" or "Cross-Country Ski*" or "Ski Jump*" or "Nordic Combined" or "biathlon" or "Ski mountaineering")
Time span	1974.1.1–2023.10.8
Language	English
Exclusion basis	document type: Proceeding Paper, Correction, Meeting Abstract, etc. were excluded, only Article, Review Article were retained.
Search results	1711
Refinement basis	Article Topic
Final result	1643

TI, title.

The specific search strategy is shown in Table 1.

2.2. Research methodology

CiteSpace and VOSviewer are commonly used software for bibliometrics, CiteSpace can clearly outline the process of knowledge evolution and the historical span of literature in a certain field in the time dimension, and understand the scientific development trend and the latest developments in the field [18], The basic CiteSpace settings are as follows: Time Slicing is set to 1 year, Selection Criteria is set to TOP N 50, and the rest of the parameters are left as default; VOSviewer provides a variety of visualization views, and has the characteristics of easy mapping and beautiful images [19], The counting method is set to full counting; Origin is a professional software for data analysis and plotting, mainly used in scientific research, engineering analysis, data processing and other fields. In this study, we used CiteSpace 6.2.R4 to complete the journal overlay and keyword burst mapping; VOSviewer 1.6.18 to complete the national geographic visualization, institutional collaboration, keyword clustering and field overlay mapping; and Origin 2023 to carry out the trend of the number of documents, fit analysis, statistics of the number of publications in the country/region and the number of publications in the institution, and to The analysis was carried out according to the above obtained mapping. The specific analysis process is shown in Fig. 1.

3. Results

3.1. Time trend

3.1.1. Number of publications and type ratio

Changes in the number of publications directly reflect changes in the amount of scientific knowledge [20]. As shown in Fig. 2, the number of publications in the field of skiing and sports is in a continuous upward trend between 1974 and 2023. Using a polynomial function to fit the cumulative number of publications, it was found that the cumulative number of publications in the field satisfies the trinomial: $y = -73.71135 + 21.55891x - 1.07933x^2 + 0.0263x^3$; $R^2 = 0.995$. It is worth noting that the number of publications in the field of skiing and sports in the last ten years accounted for 54.9 % of the total number of publications (903). The ratio of research literature to review literature can reflect the maturity of the development of a field [21]. By plotting the ratio of annual publications between research literature and review literature (Fig. 2), it was found that the ratio of annual publications between the two types fluctuates widely, with an overall upward trend, and the type of published literature is mainly dominated by research literature.

3.2. Spatial trend

3.2.1. Countries/regions

The number of articles published by a country/region can reflect its research level and strength in this field. Statistics show that there are 58 countries/regions involved in the research in this field. Geographic visualization of the countries/regions (Fig. 3 A) shows that there is close cooperation between countries/regions in this field, and the output countries/regions are mostly concentrated in

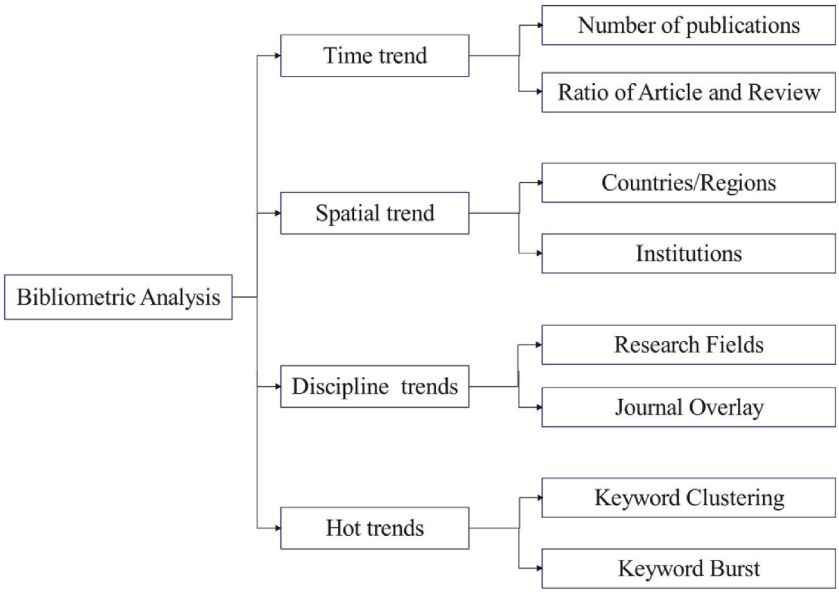


Fig. 1. Flow chart for the bibliometric analysis in skiing field.

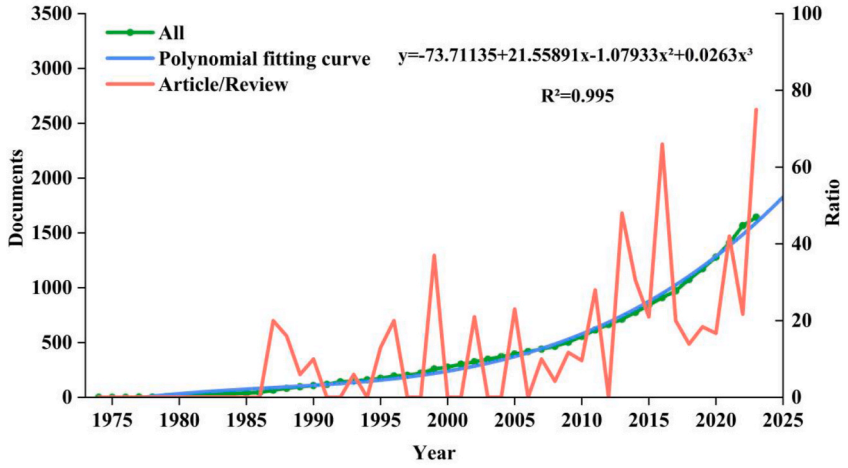


Fig. 2. Cumulative annual publications in skiing field from 1974 to 2023.

Europe and the United States, such as Norway, the United States and other European and American countries. A count of the top 10 countries/regions in terms of total number of articles and total connectivity strength (Fig. 3 B) reveals that there are large differences in the number of papers published by each country/region. In terms of the total number of publications, Norway leads with 286, followed by USA (261), and Austria (226). In terms of total link strength with other countries/regions Norway leads (strength = 208), followed by Sweden (strength = 207), and Austria (strength = 206). The only other country in the top ten in terms of publications in Asia is China (82), ranked eighth, with a total connectivity strength of 31.

3.2.2. Institutions

Institutional publication volume can reflect the differences in research strength of different institutions, while institutional collaboration mapping can reflect the collaborative relationship between institutions. Using VOSviewer to analyze the cooperation network of institutions, as shown in Fig. 4 A, there is a close cooperation between institutions in the field of skiing sports. The number of publications by institutions in the field of skiing sports is shown in Fig. 4 B. Salzburg University is in the first place with 130 publications, followed by Norwegian University of Science Technology Ntnu (110), and Mid Sweden University (104).

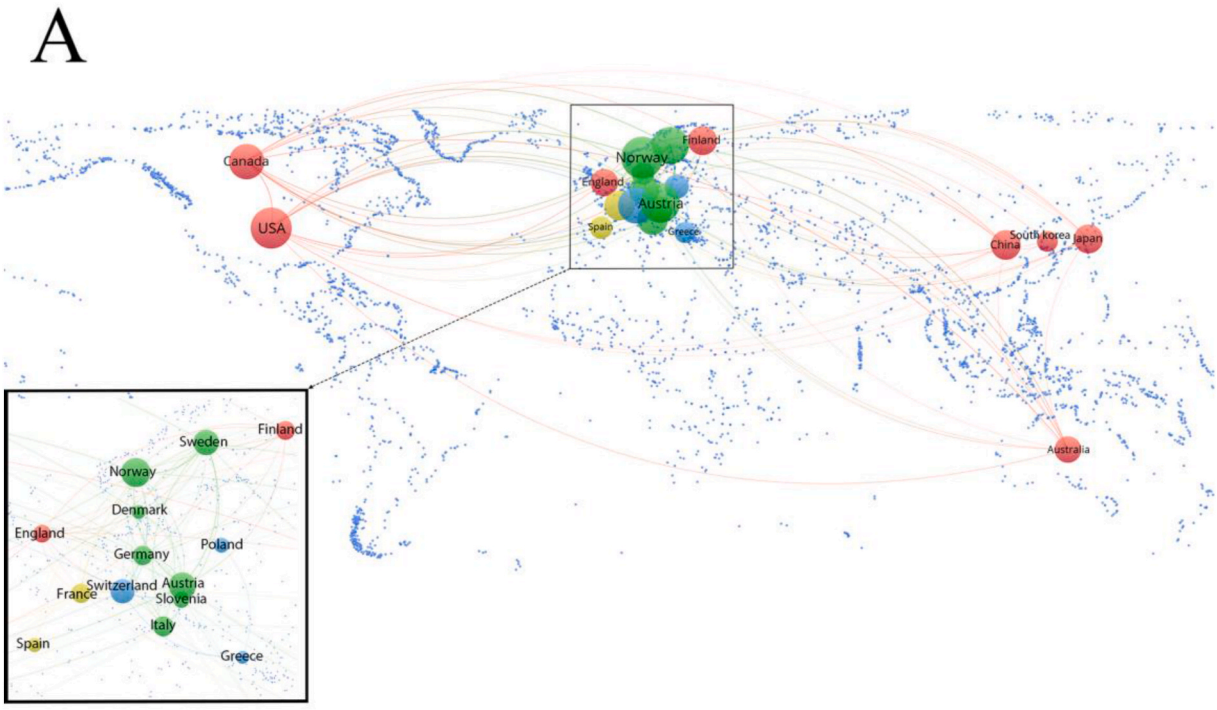
3.3. Discipline trends

3.3.1. Research fields

An analysis of the research fields provides insight into the distribution of disciplines in the skiing field. Through the analysis function of Web of Science, it can be seen that 1643 documents are distributed in 129 different disciplinary fields, and the top 3 fields in terms of the number of publications are Sport Sciences (956), Physiology (183), and Orthopedics (157). As shown in Fig. 5 A, the s discipline fields contained in the field of skiing were overlaid and analyzed by clustering them into five broad categories: cluster #1 Biology & Medicine, cluster #2 Biology & Medicine Psychology & Social Sciences, cluster #3 Chemistry & Physics cluster #4 Biology & Medicine Psychology & Social Sciences Ecology and Environmental Science & Technology, Cluster #5 Engineering & Mathematics. Subsequently, the statistics were performed according to the number of subfields contained in each cluster (Fig. 5 B). The top three subfields in terms of the number of publications in each cluster were as follows: Cluster #1 contained 39 fields, with the top three being Sport sciences (956), Physiology (183), and Orthopedics (157). Cluster #2 contains 32 domains with TOP3 being Hospitality Leisure Sport & Tourism (84), Public Environmental & Occupational Health (71), Psychology (27). Cluster #3 contains 18 fields, with the TOP 3 being Chemistry Analytical (42), Instruments & instrumentation (41), and Engineering Mechanical (38). Cluster #4 contains 21 fields, and the TOP3 fields are Environmental Sciences (33), Engineering civil (9), and Geosciences multidisciplinary (8). Cluster #5 contains 17 fields and the TOP3 are Engineering electrical & electronic (48), Engineering multidisciplinary (23), and Computer science information systems (15).

3.3.2. Journal overlay

The overlay analysis of journals visualizes the disciplinary relationship between the citing and cited literature in the field [22]. As shown in Fig. 6, within the field of skiing, the citing literature is mainly distributed in journals related to “Neurology, Sports, Ophthalmology”, and the cited literature is mainly concentrated in “Molecular, Biology, Genetics”, “Health, Nursing, Medicine”, and “Health, Nursing, Medicine”. Genetics”, “Health, nursing, medicine”, “Sports, rehabilitation, sport”, “Psychology, education, social".



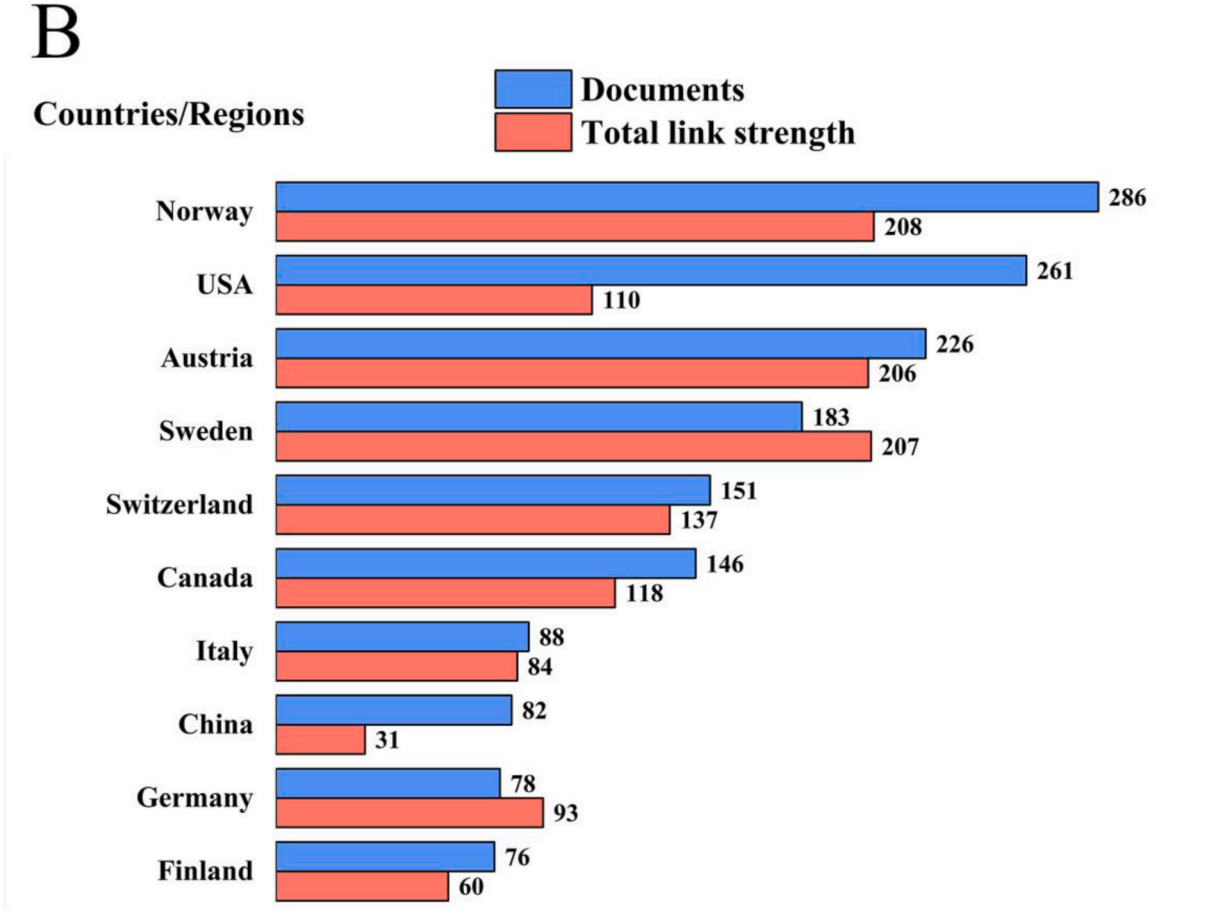


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Fig. 3. Geographical distribution and publications of countries/regions in skiing field. A. Countries/regions distribution mapping map (top 20); B. The top 10 institutions in terms of publications.

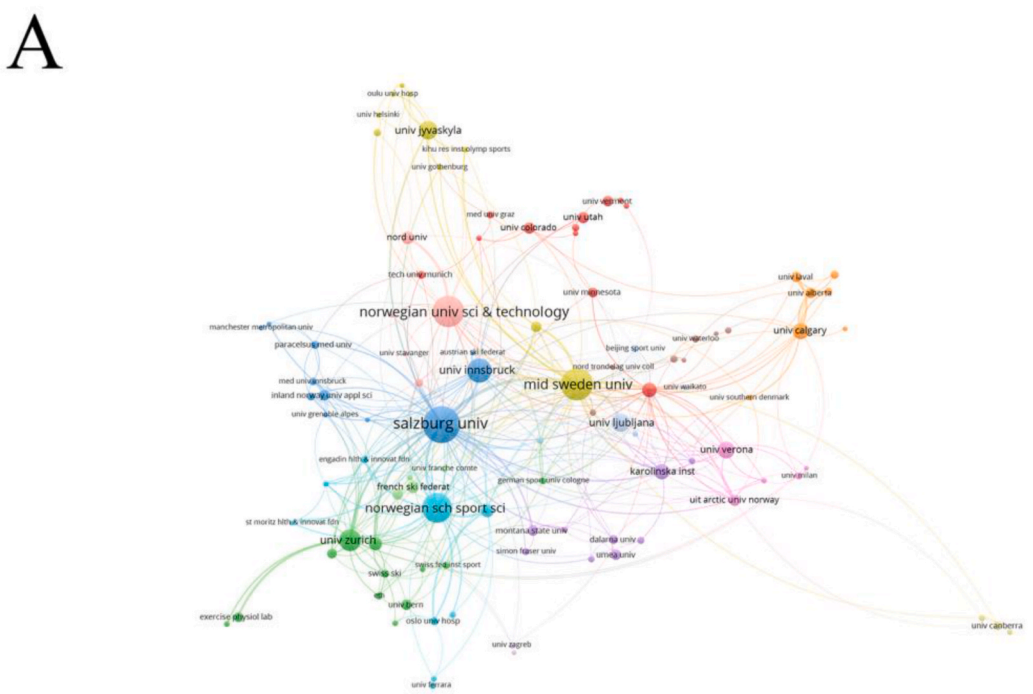


Fig. 4. Institutional cooperation and publications in skiing field. A. Institutional cooperation map (N ≥ 5); B. The top 10 institutions in terms of publications.

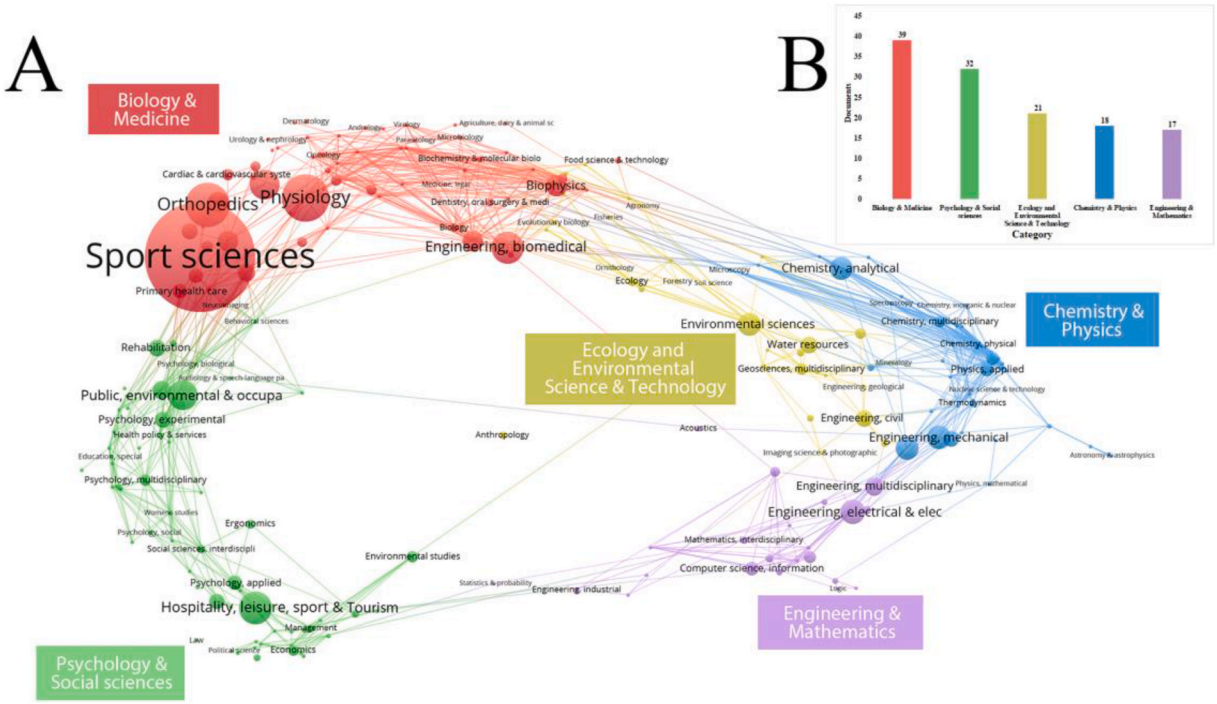


Fig. 5. Overlapping clustering of skiing literature. A. Field overlay map; B. Number of subfield clusters.

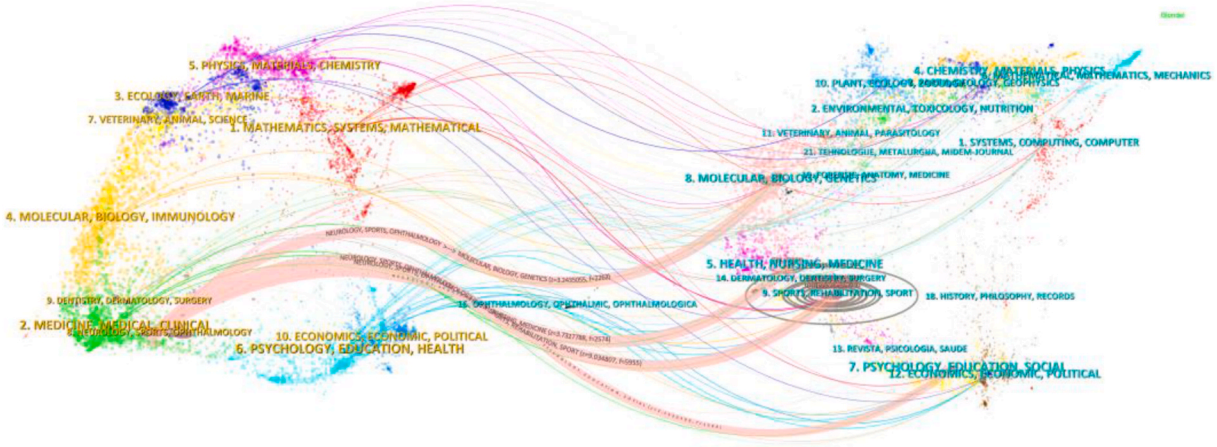


Fig. 6. Journal overlay map in skiing field.

3.4. Hot trends

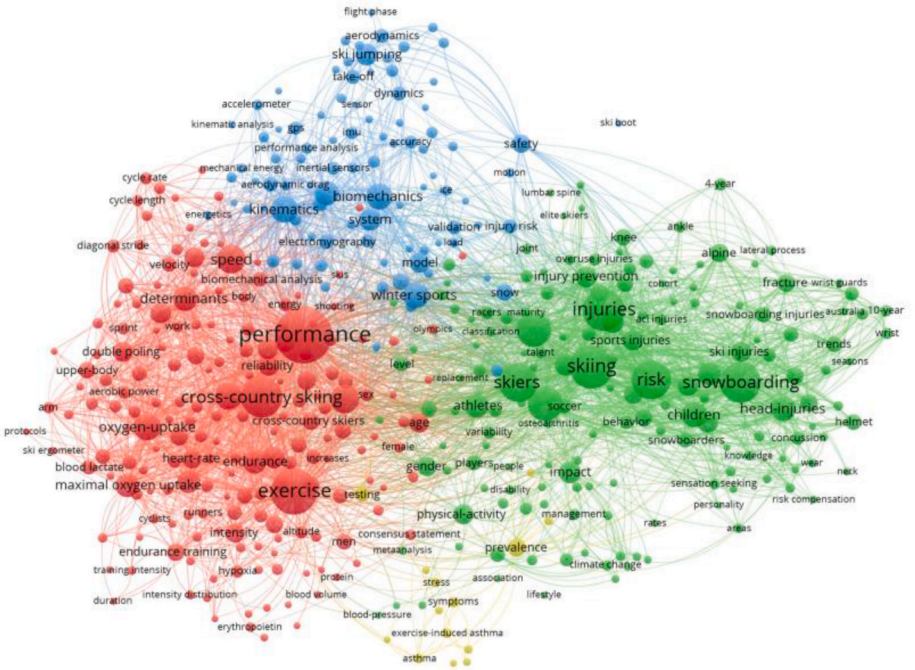
3.4.1. Keyword clustering

Keyword clustering visualizes the research hotspots in the field. Utilizing VOSviewer to cluster the keywords, as shown in Fig. 7 A, a total of four clusters were obtained. The top 10 keywords in each cluster are selected and summarized as shown in Fig. 7 B. Cluster #1 is dominated by the keywords “performance”, “exercise”, “cross-country skiing”, “speed”, “strength”, etc. Cluster #2 is dominated by the keywords “skiing”, " injuries”, “snowboarding”, “risk”, “skiers” , etc. Cluster #3 is dominated by the keywords “kinematics”, “biomechanics”, “winter sports”, “force”, “ski jumping”, etc. Cluster #4 is dominated by the keywords “prevalence”, “testing”, “symptoms”, “asthma”, “exercise-induced asthma”. induced asthma", etc.

3.4.2. Keyword burst

Keyword burst analysis can visualize the research hotspots and evolutionary trends of the field in different time periods. CiteSpace was utilized for keyword emergence detection, as shown in Fig. 8, and a total of 44 burst words were obtained. The earliest year in

A



B

Cluster	Color	Label (Top 10)
1		performance; exercise; cross-country skiing; speed; strength; power; oxygen-uptake; determinants; maximal oxygen uptake; endurance
2		skiing; injuries; snowboarding; risk; skiers; alpine skiing; sport; children; head-injuries; athletes; risk-factors
3		kinematics; biomechanics; winter sports; force; ski jumping; system; model; safety; snow; balance
4		prevalence; testing; symptoms; asthma; exercise-induced asthma; stress; bronchial hyperresponsiveness; sports medicine ; binding; induced bronchoconstriction

Fig. 7. Clustering map of keywords and Keyword clustering information in skiing. A. clustering map of keywords (N $\geq$ 5); B. High-frequency keyword information in cluster.

which the burst words were generated in this study was 1998. This is due to the fact that there were too few articles in the early years or the literature format was not standardized, which resulted in no burst mapping during the period of 1974–1997. Therefore, Fig. 8 shows the keywords with high-frequency bursts in the skiing field in different periods from 1998 to 2023. The top three keywords in terms of burst intensity are “capacity”, “determinants”, and “strength".

4. Discussion

Bibliometrics is the quantitative analysis of the current status and future trends of research in a field through the use of mathematical and statistical methods. This study uses bibliometrics to analyze the literature related to the field of skiing and sports, and conducts an in-depth analysis of the field of skiing and sports from the perspectives of time, space, discipline and hotspot, so as to provide valuable insights into the future direction of the field of skiing and sports.

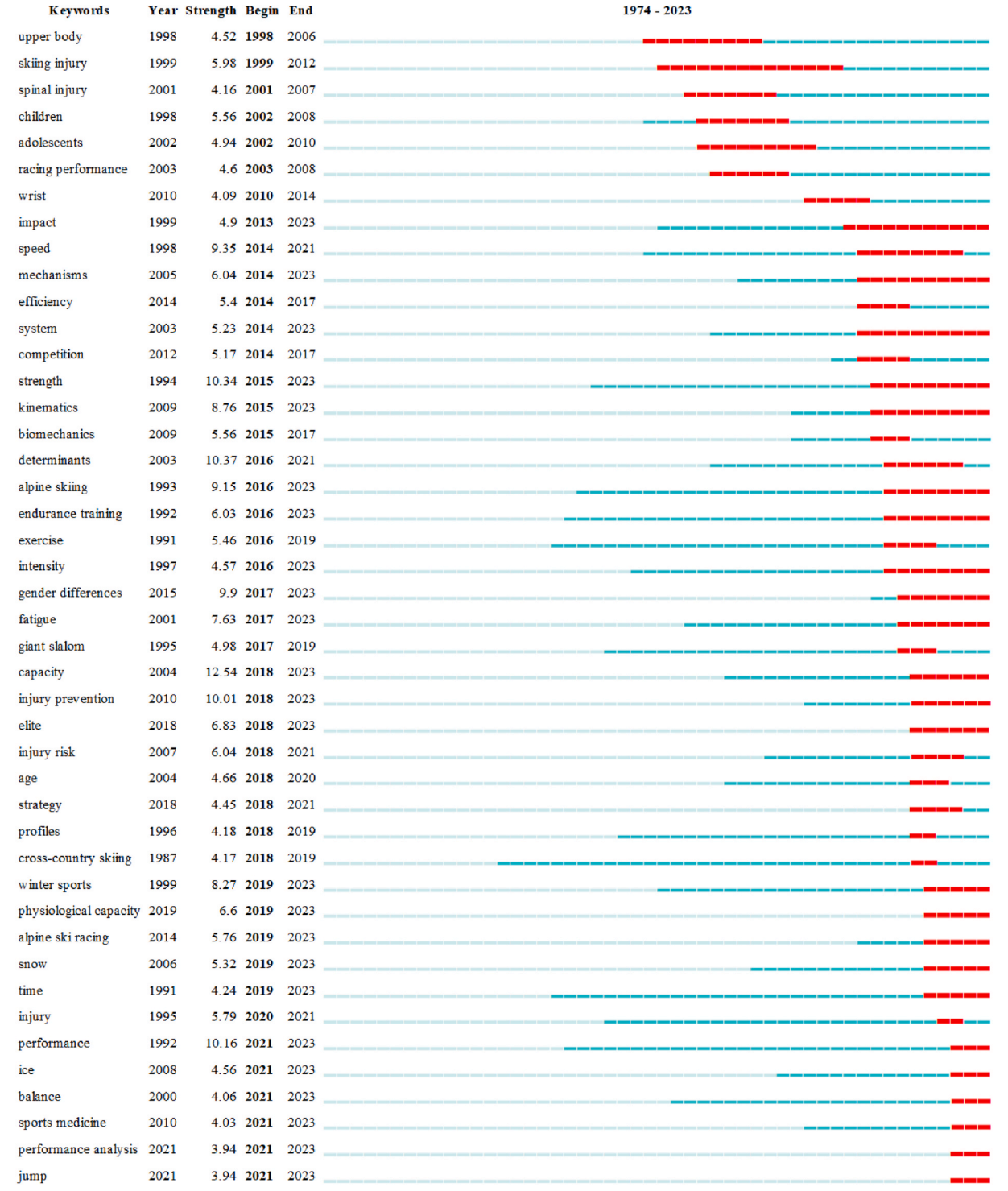


Fig. 8. Keyword burst map of skiing.

4.1. Trend of increasing number of literature outputs over time

Under this search formula, the first document in the field of skiing was Nordic Ski Touring for the Visually Handicapped [23] published in Education of the Visually Handicapped in 1974. Over the next 30 years, the number of publications in the field of skiing was 370, or 22.5 % of the total literature, with an average of 12.3 publications per year. The small number of people participating in

skiing and the lack of national attention to the sport were the main reasons for the slow development of the skiing sector during this period. With the promotion of skiing, the number of people participating in skiing programs has increased, and governments have also continuously increased investment in skiing programs, which has driven the rapid development of the field. During the last ten years (2013–2022), the cumulative number of articles in the field of skiing sports was 903, accounting for 54.9 % of the total literature, with an average annual number of 90.3 articles. In addition to external factors such as the increase in the number of skiing participants and favorable national policies, another important reason for the rapid development of this field is that the accumulation of research in the field of skiing has greatly shortened the cycle of scientific research output, especially in recent years, the depth of inter-disciplinary crossover has led to the richness and diversity of its research content. Using a trinomial model ($R2 = 0.995$) to fit the cumulative number of publications in the field of skiing and sports, it is predicted that the cumulative number of publications in this field in 2034 will be more than double the cumulative number of publications in 2022. It is worth noting that the type of literature published in the field of skiing sports is dominated by research literature. This indicates that the field of skiing sports is still in a period of rapid development and has not yet formed a stable internal structure, and the focus of research is still on exploratory research, with fewer scholars reflecting on and summarizing its internal aspects [21].

4.2. Literature output is concentrated in Europe and the United States, and there is closer cooperation between countries/regions

There is a significant imbalance in the distribution of countries/regions to which the research literature in the field of skiing belongs, mainly in Europe and North America. This phenomenon is influenced by the economic strength of the country, the scientific research strength of university institutions, the geographical location of the country and whether it has hosted the Winter Olympics [24,25]. As a sport with high economic requirements, the popularization of skiing cannot be separated from national economic support. The top 10 European and American countries in terms of the number of publications are mostly developed countries, which have a huge economic base and play an important role in promoting the development of skiing. For example, the Own the Podium Program implemented by Canada and the Norwegian Olympic Top Sport Program implemented by Norway have made good progress because of national economic support. As shown in Fig. 4 B, the top ten institutions in terms of publications within the field of skiing are all universities. The top-ranked institution, Salzburg University, is located in Austria, which alone accounts for 57.5 % of the total number of Austrian publications in the field of skiing. In Norway, the country with the highest number of publications in the field of skiing, the Norwegian University of Science Technology Ntnu and the Norwegian School of Sport Sciences alone account for 71 % of the total number of publications in the country. Universities, as important places for academic research, produce research results that play a crucial role in promoting the development of the skiing field. Benefiting from their geographic location, countries such as Switzerland, Austria, Canada and the United States have high-quality snow resources in their countries all year round, which provides an important external environment for their development in the field of skiing. Hosting the Winter Olympics also promotes the development of the skiing sports sector in the host country. The United States has hosted four Winter Olympics, and Austria, Norway, and Canada have all hosted two Winter Olympics, and all of these countries rank high in terms of the number of articles published in the field of skiing. Since China's successful bid to host the 2022 Winter Olympics in 2015, the country has enacted a series of policies to promote the development of winter sports, and research related to the field of skiing has begun to increase, with 90 % of China's scientific research in the field of skiing focusing on the output after 2015. Hosting the Winter Olympics will be a milestone in promoting the development of China's skiing sector.

With the increasing flow of knowledge worldwide, research cooperation between countries is increasingly becoming an important way of scientific and technological exchange between countries [26]. As can be seen from Fig. 3 A, Norway has the highest total number of publications and the closest cooperation with other countries/regions. Norway, as the birthplace of modern skiing, is the first country in the world to advocate the addition of skiing to physical education, while focusing on youth sports training to achieve scientific and standardized, strictly in accordance with the law of youth development, which is conducive to the selection of skiing sports to provide a high specification of the reserve force [27]. Longer and more mature reserve personnel training experience so that more scholars from other countries/regions to carry out exchanges and cooperation with Norwegian scholars. It is worth noting that the United States ranks second in terms of the number of publications, but the total link strength is low compared to other countries/regions that are also highly productive in terms of scientific output. This is due to the fact that the U.S. has developed a better scientific research system within the country, At the same time, the high degree of development of biomechanics, physiology, engineering and other disciplines closely related to skiing in its country has contributed to the maturity of the research system in the field of skiing in its country, attracting more scholars in the field of skiing to come to the United States to conduct research exchanges.

4.3. Involving a wide range of disciplines, cross-trend is obvious

Skiing encompasses 129 of the 225 existing subject field classifications [28], a proportion that is already more than half, indicating that the field of skiing is widely studied and applied. "Biology and Medicine" is the cluster with the highest scientific output in the field of skiing, where "Sport Science", "Physiology" and "Orthopedics" are also the main disciplinary focuses of research in the field of skiing. "Sport Science" and "Physiology" focus on research to improve the performance of skiers. "Sport Science" focuses on improving the performance of skiers through the study of ski equipment, techniques and tactics. For example, when cross-country skiers increased the length of their ski poles by 10 cm from the self-selected pole length, usually 82%–85 % of their height [29], the cost of oxygen consumed at low and moderate gradients decreased by 2 % and 4 %, respectively [30]. The aerodynamic resistance of a ski jumper in a full squat stance is 7.85N less than that in a half squat stance, which effectively reduces the aerodynamic resistance of the athlete in the air [31]; "Physiology" focuses on the study of the enhancement of physical function to improve the athletic performance of skiers. For

example, alpine skiers can increase their maximal oxygen uptake by 6 % after 11 days of block training periodization [32]. "Orthopedics" focuses on the mechanisms of injury caused by skiing. For example, head injuries in skiers are mainly caused by individual technical and tactical errors that lead to sideways and backwards falls [33]. In addition, the cluster "Psychology & Social Sciences" in the Hospitality Leisure Sport Tourism is also the skiing field research literature distribution of the subject area, which focuses on the development of the ski industry related research. For example, dynamic pricing strategies in the alpine skiing industry can increase revenues by 0.5%–7.5 % [34]. In summary, research in the field of skiing covers a wide range of disciplines, with "Sport Science", "Physiology" and "Hospitality Leisure Sport Tourism" being the main disciplines in terms of scientific output.

The journal overlay mapping clearly illustrates the linkages and diffusion of knowledge within the field of skiing. The citing shows the current research in the field of skiing in journals related to "Neurology, Sports, and Ophthalmology", which contributes to the improvement of knowledge about skiing in the fields of sports and medicine. The cited literature represents the disciplinary base of the skiing field mainly based on journals related to "Molecular, Biology, Genetics", "Health, nursing, medicine", "Sports, rehabilitation, sport", "Psychology, education, social". Research in the field of skiing and sports is based on the four most important clusters mentioned above, and its development is influenced by them. "Molecular, Biology, Genetics" is the basic discipline of skiing research, which mainly constructs the underlying theoretical foundation of the skiing field; "Health, nursing, medicine" and "Sports, rehabilitation, sport" mainly investigate the mechanism of skiing-induced injuries and the subsequent rehabilitation treatment; "Psychology, education, social" reveals the impact of skiing on the mental health of participants. In addition, the progress of materials science has made more emerging materials used in ski equipment, thus promoting the output of related literature, "Physics, Materials, Chemistry" related journals of the ellipse of the aspect ratio is gradually expanding, and has slowly become a new branch of research in the field of skiing sports. In conclusion, the distribution of disciplines in the field of skiing sports is characterized by diversified development, and the integration of multiple disciplines has become an important direction for the present and future development of skiing sports.

4.4. Research hotspot clustering

After clustering the keywords in the field of skiing, a total of 4 clusters were obtained (Fig. 7), combining the keywords of clustering and the content of the literature, the topics of the 4 clusters were named as follows: cluster #1 analysis of skiers' sports performance, cluster #2 analysis of skiing-induced sports injuries, cluster #3 biomechanical analysis of skiers' postures and cluster #4 analysis of skiing-induced respiratory diseases.

Cluster #1 Analysis of skiers' sports performance. This clustering focuses on the effect of maximal oxygen uptake on the athletic performance of skiers. Maximum oxygen uptake is an important factor limiting the athletic performance of skiers [35], especially for endurance skiing sports such as cross-country skiing and ski mountaineering. For example, the maximal oxygen uptake capacity of cross-country skiers is an important determinant of their performance in the second half of the race (uphill and flat segments) [36]. Competition performance in ski mountaineering is also affected by maximal oxygen uptake capacity, and athletes with higher maximal oxygen uptake capacity have better performance [37]. Therefore, increasing maximal oxygen uptake is crucial for athletes to improve their athletic performance. In terms of training methods to improve athletes' maximal oxygen uptake capacity, prolonged aerobic high-intensity interval training improves athletes' endurance performance and oxygen uptake more than short-duration high-intensity interval training [38]. Also, training at moderate altitude living and low altitude close to sea level significantly increased maximal oxygen uptake and erythrocyte mass in adolescent athletes [39]. In addition, without increasing total high-intensity aerobic interval-training (HIT) volume, double-poling HIT can Improving Utilization of Maximal Oxygen Uptake and Work Economy [40]. It is worth noting that maximal oxygen uptake is an important reference for the prediction of athletic performance in endurance skiing events, but the prediction of skill-based events such as alpine skiing revealed that the correlation between maximal oxygen uptake and their sport performance was not significant [41]. Compared with endurance skiing, which requires high maximal oxygen uptake capacity, the performance of athletes in skill skiing may be more influenced by their technique and tactics. Additionally, the impact of lifestyle factors such as physical activity, nutrition, and sleep on skiing performance is critical for a holistic understanding of athlete performance. Recent studies have highlighted the significant roles these factors play in sports performance. the interplay between physical activity and immune function has been shown to influence athletic performance [42]. Adequate nutrition provides the necessary energy and nutrients for optimal performance and recovery [43,44]. Proper sleep is essential for physical and mental recovery, as well as improved cognitive function [45,46].

Cluster #2 Analysis of skiing-induced sports injuries. This clustering focuses on head injuries due to skiing. Head injuries are more common in both recreational skiing and professional competition. Among recreational skiers, the incidence of head injuries accounts for 38 % of all injuries [47]; in high-level competitions such as the International Ski Federation World Cup, the number of people requiring medical treatment for head and face injuries ranges from 10 % to 13 % of the total [48–50]. As the most important part of the human body, head injuries are the leading cause of death among skiers [51]. In alpine skiing, freestyle skiing, and snowboarding, the main cause of head injury is the fall caused by the athlete's technical and tactical errors, and the order of fall is the athlete's first impact with the ski on the snow surface, followed by the upper limb or the lower limb, the hips/pelvis, the back, and finally the head. As a result of this crash sequence, impacts to the rear and side of the helmet dominated [33]. While wearing a helmet reduces the risk of head injuries for skiers [52,53], but recent findings suggest that the incidence of head injuries has not decreased despite a gradual increase in helmet use [54], which may be due to the reduced ability of skiers to perceive risk after wearing a helmet, and their subjective belief that their head is in a safe position to engage in more risky behaviors. It is worth noting that, in addition to head injuries, injuries to the knee and wrist areas, although not as lethal as head injuries, are also areas where skiers are prone to injuries [49,55,56], and also require more attention.

Cluster #3 Biomechanical analysis of skiers' postures. This clustering mainly investigates the effect of changes in body posture on

sports performance of skiers during skiing from the biomechanical point of view. In ski jumping, keeping the shoulder-ankle joint line at a smaller angle to the horizontal axis in the range of 0–1.4s after leaving the stage in the early flight phase can effectively improve the flight distance [57]. In ski mountaineering events, choosing a larger slope minimizes energy expenditure to reach longer distances [58]. In alpine skiing events, air resistance accounts for 80–90 % of the total resistance experienced by skiers [59], and reducing the effects of air resistance can significantly improve performance. After measuring and calculating the ski curl position, it was found that reducing the torso angle and thigh angle could significantly reduce the air resistance [60]. In addition, analyzing skiing postures from a biomechanical point of view is also useful for exploring the causes of injuries. In an injury risk analysis of the giant slalom event in alpine skiing, it was found that the athletes' incorrect movements and postures resulted in a smaller turning radius and required a greater turning force, which resulted in injuries due to greater loads on the athletes' muscles and joints [61]. Analyzing skiing sports from a biomechanical perspective can not only effectively improve athletes' performance, but also deeply analyze the mechanism of athletes' injuries in sports.

Cluster #4 Analysis of skiing-induced respiratory diseases. This clustering focuses on the relationship between skiing sports programs and asthma. Asthma is a common chronic respiratory disease with clinical manifestations of wheezing and breath with or without cough and chest tightness. Studies have shown that the prevalence of asthma is higher in people who participate in skiing than in the general population, with 21 % of people who participate in cross-country skiing compared to 10 % in the general population [62]. Prolonged strenuous exercise in cold temperatures is the main reason why skiers are prone to develop asthma [63,64]. The absolute humidity of the air is very low in low temperatures, and athletes training and competing in that environment for long periods of time need to inhale large quantities of dry, cold air, which increases the water loss from the epithelial lining fluid that covers the airway mucosa, leaving it in a state of high osmolarity. Inflammatory cells located in the airways secrete inflammatory mediators under high osmotic pressure, which not only trigger airway obstruction in asthmatics, but also irritate the airways of healthy people, thus triggering asthma. Asthma can usually be controlled with medication. For example, inhalation of A fixed combination of inhaled corticosteroids + long-acting β2-agonist can effectively control skiing-induced asthma [65,66]. However, whether the use of asthma medications in competition affects skier performance has been a controversial topic. It has been demonstrated that inhalation of normal doses of β2-agonists, such as salbutamol or salmeterol, alone does not improve athletes' performance [67,68]. However, oral administration of high doses of β2-agonists or combined inhaled β2-agonists, significantly improved sprinting ability or maximal strength [69,70]. Whether these strength improvements affect final sprint performance in healthy cross-country skiers remains to be investigated.

In summary, skier sport performance is primarily related to the athlete's physical functioning, technique and lifestyle. Athletes can take targeted training to improve their physical function to meet the demands of the program according to the program they participate in. In addition, maintaining a good lifestyle is also conducive to improving sport performance. A biomechanical study of skiing can explore more efficient and safer skiing postures in different sports, which not only improves athletic performance but also prevents injuries caused by incorrect movements. The use of medication can effectively control skiing-induced asthma, but may have an impact on athletes' performance.

4.5. Evolution of research hotspots

By summarizing the time points and themes of keyword emergence in the field of skiing, the research in this field can be divided into two stages: the budding stage (1998–2013) and the development stage (2014–2023). This study analyzes the hot keywords in different phases in order to explore the research hotspots and evolution trends of skiing in different periods.

In the budding stage (1998–2013) "skiing injury", "children", and "adolescents" are the keywords that appear with high frequency. keywords. During this period, skiing became popular in various countries, which led to more people getting involved in the sport. with the dramatic increase in the number of skiers, the incidence of injuries caused by skiing is also increasing [71,72]. Children and adolescents are more likely to be at risk and more susceptible to injuries in skiing due to their underdeveloped physiology and motor skills, which are not compatible with the ability requirements of skiing [73]. McLoughlin R J et al. [74] and Polites S F et al. [75] conducted a statistical study on the injury sites of children and adolescents participating in snowboarding and showed that the most susceptible injury sites were those of the children and adolescents. The results showed that the most vulnerable areas were the head and neck, upper limbs and trunk. Moreover, it was found that the incidence of head and neck injuries in the adolescent population showed an increasing trend during the period 1995–1999 [76]. "Spinal injury" is also a key word that appears frequently at this stage. The spine is critical to maintaining stability and health, and injuries can have a serious impact on body function. Franz T et al. [77] found that nearly one-third of skiers with severe spinal injuries experienced fatal central nervous system damage and transient or persistent neurological symptoms. Snowboarders with spinal injuries characteristically presented were more often with cervical fractures than skiers. Cervical fractures were present in 44 % of snowboarder-related spinal injuries as compared to 16 % of skier-related spinal injuries [51].

During the development stage (2014–2023) the amount of literature published in the field of skiing began to skyrocket, "Strength", "determinants", "capacity", "performance", "performance analysis" are the most frequently occurring keywords. performance", "performance analysis" are the key words that appear with high frequency. In terms of keyword bursting, there are more research directions in this phase, and the directions of injury prevention and sports performance analysis are still the cutting-edge hotspots of research in this field. The keywords "strength", "determinants" and "capacity" are the first high-frequency keywords appearing in this stage. The Winter Olympics is the world's highest-level winter sports event, which attracts many countries to participate because of its significance in improving the international image of participating countries and promoting international cooperation and friendship. In 2010, there were already more than 80 countries participating in the Winter Olympics, and in 2014, the number of participating

countries reached 88. And the Winter Olympics represents the highest level of ice and snow sports competition within the scope of the athletes to achieve excellent results can not only improve the country's sports reputation, but also inspire the domestic masses of sports enthusiasm. Therefore, a large number of scholars have studied how to improve sports performance, and a large number of related studies have emerged. The keyword "injury prevention" is also a keyword that appears with high intensity in this phase. With the rapid development of skiing, the number of injuries caused by skiing has also increased. Although some studies have shown that alpine skiers can increase their maximal oxygen uptake by 2.5 ml/min/kg after 10 sessions of high-intensity interval training [78], over-training can increase the injury rate of athletes [79]. Therefore, it is important to enhance injury prevention. Studies have shown that imbalance of strength between the legs may be responsible for ACL injuries in alpine skiers, so maintaining a balance of strength between the legs can prevent injuries [80]. Moreover, good quality and adequate sleep are also essential to maintaining good health and preventing sports injuries [81–83].The keywords "performance" and "performance analysis" have a high intensity of bursting from 2021 until now. As multidisciplinary cross-fertilization becomes the trend of research development in skiing, more scientific methods are applied to skiing to improve athletes' performance, such as musculoskeletal simulation combining the principles of biomechanics, computer simulation, and engineering is used to analyze the muscular functions and activities in the take-off phase of ski jumping athletes [84], which can promote researchers' understanding of the role of the muscles in the take-off phase of ski jumping, and help coaches to guide athletes' training to improve their performance in the jump phase. It is worth noting that during the COVID-19 epidemic, quarantine measures restricted athletes' access to sports venues, and as a sport that needs to be played outdoors, skiers were more affected. How to maintain the training hours of the athletes so that they can better maintain their sports status was an urgent problem at that time. Virtual reality technology based on the integrated application of intelligent hardware technology and computer graphics technology can effectively solve the problem of limited sports venues [85], and the data collected during sports can be scientifically analyzed using computer technology to help athletes improve their sports performance. Therefore, in the post-COVID-19 era, the combination of more scientific technologies and methods may become a new direction for future research and development in the field of skiing.

This study utilizes bibliometric techniques to systematically quantitatively analyze the research in the field of skiing and sports, providing a guide for academic exploration of scholars related to this field. Two bibliometric tools, including widely used tools such as VOSviewer and CiteSpace, were also jointly used in the study to enhance the objectivity of our data analysis process. Bibliometric analysis provides a more comprehensive understanding of research hotspots and frontiers than traditional literature reviews. However, this study also has some limitations. First, the data were selected from the WoSCC while ignoring relevant studies existing in other databases; Irregularities in the formatting of earlier literature may have resulted in literature published before 1974 not being included in the database. Second, we only selected English publications, and some excellent publications with non-English papers may have been excluded. In addition, some recently published high-quality literature may have fewer citations due to shorter publication time, which may lead to some discrepancies between the research results and the actual situation. Therefore, more bibliometric data updates are needed to further clarify the scientific trends and hotspots in research in the field of skiing.

5. Conclusion and outlook

Bibliometric analysis is an effective tool to study the hotspot evolution and development trend and time evolution in the field of skiing sports. This study analyzes the literature related to the field of skiing and sports based on this method, and draws the following main conclusions: (1) The field of skiing and sports has a small amount of publications in the early days, and has been given a period of development in the last decade or so, especially in the last 3–5 years, the field of skiing and sports has made a high speed development. (2) Europe and the United States contribute a lot to the field of skiing sports, led by the University of Salzburg, a number of institutions, the development of the field of skiing sports has played an important role in promoting the development of the field of skiing sports, and most of the countries/regions are more closely cooperating with each other. (3) The distribution of research fields and journals shows that the research in the field of skiing and sports spans multiple disciplinary fields, and multidisciplinary cross-fertilization has become the future development orientation of the field of skiing and sports. (4) The clustering of keywords indicates that the analysis of skiers' sports performance, the analysis of skiing-induced sports injuries, the biomechanical analysis of skiers' postures, and the analysis of skiing-induced respiratory diseases are the hot spots of research. The keyword bursts further predicted the development direction of the skiing sports field, mainly focusing on the prevention of sports injuries, and the improvement of sports performance in a scientific and standardized way.

To summarize, the field of skiing is currently in a period of rapid development, and the further strengthening of cooperation and exchange between countries/regions will help to promote cutting-edge research in the field of skiing. The future development of skiing should follow the trend of multidisciplinary intersection, through the cross-fertilization with computer science and electronic engineering, in-depth analysis of the factors affecting the performance of skiing, such as the impact of different sports postures on the performance of the skier, and from the biomechanical point of view to design the optimal sports postures under the premise of conforming to the structure of the human body in order to improve the performance of the skier; Through cross-fertilization with engineering and sports medicine, we can develop preventive solutions to the mechanisms of skiing injuries, such as designing more ergonomic ski protective gear and suggesting exercise recommendations for different ski populations in order to minimize injuries caused by skiing.

Data availability statement

No data were deposited in any publicly available repositories. Data will be made available on request.

Ethics statement

Review and/or approval by an ethics committee was not needed for this study because this article did not involve any animal or human experiments.

CRediT authorship contribution statement

Wenlong Hou: Investigation, Data curation, Software, Writing – original draft. **Xiaoliang Li:** Formal analysis. **Yan Wen:** Supervision. **Xincheng Du:** Writing – original draft, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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