



Concept of Computational Fluid Dynamics and Its Application in Sport Science: Bibliometric Analysis of Modelling Thermal Comfort in Sport Hall

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ARTICLE INFO

Article history:

Received 24 September 2023

Received in revised form 20 October 2023

Accepted 2 November 2023

Available online 5 December 2023

Keywords:

Bibliometric; Computational Fluid Dynamics; CFD; Sport science

ABSTRACT

Computational Fluid Dynamics (CFD) has become a very effective tool in modeling and analyzing various complex phenomena, including being an integral part of analyzing thermal comfort phenomena. Therefore, this research was carried out to identify developments in the scientific literature related to research on sports science to carry out initial identification of sports hall thermal comfort modeling using dynamic computing concepts, analyzing trends and research focus in this field through bibliometric. In addition, this research provides a comprehensive insight into the latest scientific contributions and developments in the field of sports science as an initial identification of sports hall thermal comfort modeling using a dynamic computing approach. Bibliometric analysis and theoretical analysis were chosen as research methods. This research also consists of five steps, namely (i) determining the theme and sources of research data; (ii) article data collection; (iii) data processing, (iv) bibliometric analysis, and (v) report preparation. "Computational Fluid Dynamics Design (CFD) in Sport Science" was used as a keyword in this research. Based on the search results, 823 documents were obtained from 1996 to 2023. Research on CFD in sports science will increase in 2022. Many countries, affiliates, and authors have contributed to increasing the number of publications on CFD in sports science, such as the United States with a total of 103 publications. With this research, it is hoped that it will provide insight to researchers, practitioners, and policymakers regarding research directions that may not have been fully explored in the application of CFD in the field of sports in particular, as well as other fields.

1. Introduction

Sports science is a multidisciplinary science that continues to develop and covers various aspects related to sports performance and athlete achievement [1]. Many reports about sport science have been well-developed [2-25].

In the modern era filled with technological developments, Computational Fluid Dynamics (CFD) has become an important tool in modeling and analyzing fluid flow phenomena which is complex in various contexts, including thermal regulation in the construction of a sports hall [26]. One aspect

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that is increasingly receiving attention is understanding temperature comfort in sports spaces, especially in indoor sports arenas (sports halls) [27]. When analyzed further, a better understanding and knowledge of the temperature inside a sports hall can have a significant impact on sports performance and athlete achievement. Comfortable room temperature is an important factor in creating an environment that supports optimal sports performance [28]. Temperature discomfort in a room can disrupt athletes' concentration, reduce their performance levels, and even potentially affect the outcome of a match [29]. Therefore, modeling and analyzing temperature comfort in sports halls is very important in improving sports experience and performance.

A specific understanding of how fluid flow and heat transfer interact within a sports hall can provide valuable insight into how to improve air quality, temperature distribution, and thermal comfort. CFD has become a very effective tool for modeling this phenomenon in detail [30]. In addition, CFD has become an integral part of modeling and analyzing thermal comfort phenomena. CFD also enables the development of predictive models that can be used to efficiently optimize sports facility design, temperature regulation, and thermal comfort management. Research on CFD applied in sports science has been carried out by many previous researchers, including regarding the effects of drafting in swimming using computational fluid dynamics [31], the future of CFD in 2025 and beyond [32], the concept of computational dynamics in cardiac computed tomography and noninvasive quantification of fractional flow reserve [33], CFD in retrospective sports [34], Computational studies of fluid names for propulsion due to the effect of the orientation of the swimmer's hands [34], CFD on particle technology [35] and the application of computational dynamics in modeling forces in swimming [36]. Based on several studies that have been mentioned, many have linked CFD (Computational Fluid Dynamics) in sports science, but it is still limited in the literature review. So, there has been no research linking CFD with sports science using bibliometric analysis to determine trends in CFD research in sports science combined with theoretical analysis to support and strengthen research.

Many previous studies have used bibliometric analysis to determine research trends [37-44]. Detailed information is shown in Table 1. However, there has been no bibliometric research analyzing CFD trends and their application in sports science. Based on the background, this research aims to carry out a bibliometric analysis of existing literature to identify the development of dynamic computing concepts and their application in sports science to provide an initial identification of thermal comfort modeling in sports halls. In more detail, this research aims to identify developments in the scientific literature related to research on sports science to carry out initial identification of thermal comfort modeling in sports halls using dynamic computing concepts, analyze trends, and focus on existing research in this field through bibliometric, and provide useful insights. comprehensive about the latest scientific contributions and developments in providing initial identification of Thermal Comfort modeling in sports halls using a dynamic computing approach.

Table 1
 Previous studies on bibliometric analysis

No	Title	Topic Discussion	Ref.
1	Dental suction aerosol: Bibliometric analysis.	This study examined the distribution of bibliometric maps and research trends using VOSviewer to describe how dental aerosol suction evolved.	[45]
2	A bibliometric analysis of Covid-19 researches using VOSViewer.	This study studied the development of research during the Covid-19 era using bibliometric methodology.	[46]
3	The latest report on the advantages and disadvantages of pure biodiesel (B100) on engine	This study reviewed the literature on the advantages and disadvantages of using pure biodiesel in engines.	[47]

	performance: Literature review and bibliometric analysis		
4	A bibliometric analysis of management bioenergy research using VOSviewer application	In this study, the topic of managing bioenergy was studied for research trends and advancements.	[48]
5	Oil palm empty fruit bunch waste pretreatment with benzotriazolium-based ionic liquids for cellulose conversion to glucose: Experiments with computational bibliometric analysis	This study investigated the usage of benzotriazole ionic salt liquid as a solvent for empty palm oil fruit bunches using bibliometric analysis and VOSviewer.	[49]
6	Biomass-based supercapacitors electrodes for electrical energy storage systems activated using chemical activation method: A literature review and bibliometric analysis.	A very effective supercapacitor that uses carbon derived from biomass as its electrode has the potential to provide extremely efficient current transmission in energy storage devices.	[50]
7	Bibliometric analysis of nano metal-organic frameworks synthesis research in medical science using VOSViewer	In this study, mapping analysis and VOSviewer software were used to examine the bibliometric analysis of nFs for medical science.	[51]
8	Past, current and future trends of salicylic acid and its derivatives: A bibliometric review of papers from the Scopus database published from 2000 to 2021.	This study's goal was to discuss scientometric studies of SA and its derivatives' organizational development and future possibilities.	[52]
9	Correlation between process engineering and special needs from bibliometric analysis perspectives.	In this study, the integration of mapping analysis utilizing the VOSviewer program was covered.	[53]
10	Bibliometric analysis for understanding the correlation between chemistry and special needs education using VOSviewer indexed by Google.	The use of VOSviewer in conjunction with mapping analysis was covered in this work.	[54]
11	Computing bibliometric analysis with mapping visualization using VOSviewer on "pharmacy" and "special needs" research data in 2017-2021.	The next five years (2017–2021) were examined in this study with regard to mapping visualization in research on pharmaceutical subjects and special requirements.	[55]
12	Nutritional research mapping for endurance sports: A bibliometric analysis.	The field of endurance sports nutrition was mapped out in this study.	[56]
13	Bibliometric and visualized analysis of scientific publications on geotechnics fields.	This study utilized bibliometric distribution maps from the VOSviewer program to assess the development of research in geotechnical engineering.	[57]
14	A bibliometric analysis of computational mapping on publishing teaching science engineering using VOSviewer application and correlation.	The description of research advancements in engineering and scientific education was studied in this study.	[58]
15	What is the correlation between chemical engineering and special needs education from the perspective of bibliometric analysis using VOSviewer indexed by Google Scholar?	In this study, "Special Needs of Chemical Engineering" are analyzed using the VOSviewer tool.	[59]
16	Counselling guidance in science education: Definition, literature review, and bibliometric analysis.	This study uses a literature review and bibliometric analysis to talk about the subject of guidance and counseling in science education.	[60]
17	Phytochemical profile and biological activities of ethylacetate extract of peanut (<i>Arachis hypogaea</i> L.) stems: In-vitro and in-silico studies with bibliometric analysis.	This study uses a literature review and bibliometric analysis to talk about the subject of guidance and counseling in science education.	[61]
18	A bibliometric analysis of materials research in Indonesian journal using VOSViewer	The current state of materials research was discussed in this paper.	[62]
19	Research trend on the use of mercury in gold mining: Literature review and bibliometric analysis	In this study, the use of mercury in gold mining was covered.	[63]

20	Bibliometric analysis of educational research in 2017 to 2021 using VOSViewer: Google Scholar indexed research.	This work explored the bibliometric analysis of Google Scholar-indexed works in the context of education.	[64]
21	Bibliometric analysis of special needs education keyword using VOSviewer indexed by Google Scholar	A bibliometric analysis of special education-related articles that were indexed by Google Scholar was included in this paper.	[65]
22	Sustainable development goals (SDGs) in science education: Definition, literature review, and bibliometric analysis.	This study examined the origins and trends in the literature on sustainable development objectives.	[66]
23	Computational bibliometric analysis of research on science and Islam with VOSViewer: Scopus database in 2012 to 2022.	This study examined the evolution of research in the disciplines of science and Islam using information from Scopus-indexed article data.	[67]
24	Resin matrix composition on the performance of brake pads made from durian seeds: From computational bibliometric literature analysis to experiment.	The results of this study's bibliometric analysis were used to discuss the effect of resin matrix composition on brake pad performance.	[68]
25	Bibliometric Analysis of Briquette Research Trends During the Covid-19 Pandemic.	The trends in briquette research during the Covid-19 outbreak were examined in this publication.	[69]
26	Computational Bibliometric Analysis on Publication of Techno-Economic Education.	This study used bibliometric analysis to look at how publications in the area of techno-economic education have changed over time.	[70]
27	How bibliographic dataset portrays decreasing number of scientific publications from Indonesia	This study looked into the best way to explain the drop in scientific publications in Indonesia using bibliographic datasets.	[71]
28	Research trends from the Scopus database using keyword water hyacinth and ecosystem: A bibliometric literature review	According to research trends on water hyacinths and ecosystems in the Scopus database, this paper was published.	[72]
29	Bibliometric analysis of high school keyword using VOSviewer indexed by google scholar	This study employed bibliometric analysis to look at studies on senior high school.	[73]
30	How to calculate bibliometric using VOSviewer with Publish or Perish (using Scopus data): Science education keywords	This study looked into the use of Publish or Perish and VOSviewer for bibliometric analysis.	[74]
31	Bibliometric analysis for understanding "science education" for "student with special needs" using VOSViewer	The bibliometric analysis of science education and children with special needs was examined in this study.	[75]
32	Bibliometric analysis of research development in sports science with VOSViewer.	This study looked into how sports science research has changed throughout time.	[76]
33	Bibliometric analysis of engineering research using VOSviewer indexed by Google Scholar	This study used data from papers that were indexed by Google Scholar along with VOSviewer to assess the development of research on technical subjects.	[77]
34	Bibliometric computational mapping analysis of publications on mechanical engineering education using VOSViewer	The development of research in the area of engineering education was the subject of this study.	[78]
35	Introducing ASEAN Journal of Science and Engineering: A Bibliometric Analysis Study	The impact and accomplishments of the ASEAN Journal of Science and Engineering on internationalization were evaluated and validated in this study.	[79]
36	Introducing ASEAN Journal of Science and Engineering Education: A Bibliometric Analysis Study for Understanding Internationalization	The influence and internationalization of the ASEAN Journal of Science and Engineering Education were investigated and validated in this study.	[80]
37	Exploring Iron Oxide's Role in Hydrogen Production: Bibliographic and Bibliometric Analysis	The Scopus database was used in this study's bibliometric analysis of scientific trends in metal oxide oxidation-reduction processes for energy storage systems. A survey of the literature on the most current theoretical advancements in iron-	[81]

37 How Technology Can Change Educational Research? Definition, Factors for Improving Quality of Education and Computational Bibliometric Analysis	based catalysis for hydrogen production and energy storage systems was used to support this research. According to this study, strategies for developing and enhancing educational quality are developed in relation to communication, technology input (such as IT, ICT, AI, AR, and so forth), curriculum, educational level, and the connections between social studies, humanities, science, and industry, as well as management and facilities.	[82]
38 Is Universitas Pendidikan Indonesia Ready for Internationalization? A Bibliometric Analysis in The Science and Technology-Related Publications	The purpose of this study was to determine whether Universitas Pendidikan Indonesia (UPI) was prepared for internationalization by analyzing its publication statistics.	[83]
39 Social Impact and Internationalization of "Indonesian Journal of Science and Technology" the Best Journal in Indonesia: A Bibliometric Analysis	This study did bibliometric scopus data analysis from publications in the Indonesian Journal of Science and Technology (IJoST), the best journal in Indonesia (Q1 in scimagojr with the highest rank position), from 2016 to 2023 using VOSViewer and RStudio.	[84]
40 Mapping of nanotechnology research in animal science: Scientometric analysis	This essay examines animal science and the latest developments in that field.	[85]
41 How Language and Technology Can Improve Student Learning Quality in Engineering? Definition, Factors for Enhancing Students Comprehension, and Computational Bibliometric Analysis	Using Bibliometric Computation analysis, this study looks at how to increase students' understanding of engineering learning as well as language research trends for engineering learning.	[86]
42 How to Improve Student Comprehension in Learning Chemistry by Making Strategy in Language Education? Definition, Factors for Enhancing Students Comprehension, and Computational Bibliometric Analysis	In order to help students better grasp chemistry education, this study investigates bibliometric computational analysis trends and language research for chemistry learning.	[87]
43 Enhancing student understanding on the concept of carbon biochar production in islamic boarding school through collaborative practicum with experimental demonstration for supporting sustainable development goals (SDGs)	Students' understanding of the concept of creating biochar carbon in Islamic boarding schools is improved by this study.	[88]

2. Methodology

Bibliometric analysis is used as a method in this research to measure and analyze productivity, developments, trends, and the influence of scientific literature in a particular research field. Apart from bibliometric analysis, there is also theoretical analysis to support this research. This research consists of five steps as shown in Figure 1.

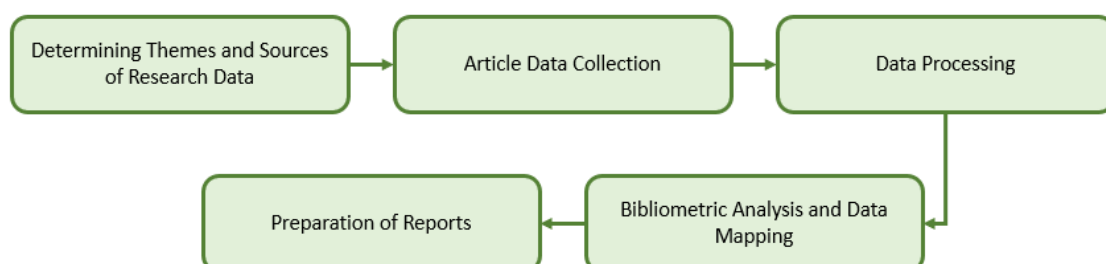


Fig. 1. The steps of research methods

2.1 Determining Themes and Sources of Research Data

The first step is to determine the research theme and data sources that will be used. The research theme is used as a reference in formulating data search keywords. So, from the predetermined theme, the term "Computational Fluid Dynamics Design (CFD) in Sports Science" was obtained which was used as a search keyword in this research. Meanwhile, the data source used in this research is a source that comes from a journal based on Scopus data.

2.2 Article Data Collection

The second step taken was collecting article data. Article data collection was carried out directly from the Scopus database (<https://scopus.com>). All relevant bibliographic data, including article title, author, journal, year of publication, citations, country, and affiliation were collected in this study.

2.3 Data Processing

The third step is to process the article data. The article data that has been collected in step two is saved in three formats, namely *.csv, *.ris, and *.bibTeX. Data processing is carried out with the help of Microsoft Excel, VOSviewer, and RStudio applications. Each format that has been prepared has its use. *.csv format is used for data processing using Ms. Excel, *.ris is used for data processing using VOSviewer, and *.bibTeX is used for data processing using RStudio.

2.4 Bibliometric Analysis and Data Mapping

The next step is to carry out bibliometric analysis. This stage was carried out to obtain the desired results by the objectives of this research. The type used for bibliometric analysis is the co-occurrence type based on keywords, country, and author with the help of the VOSviewer application. At this stage, visualization results are also obtained from the data that has been collected.

2.5 Preparation of Reports

The final step is preparing the report. At this stage, we create tables and graphs to support the research results. Apart from that, relevant references are also collected at this stage.

3. Theoretical Framework

3.1 Computational Fluid Dynamics Design (CFD)

Computational Fluid Dynamics (CFD) is a method of calculating, predicting, and approximating fluid flow numerically with the help of computers [89]. CFD approaches the numerical method and uses fluid equations [89]. CFD is a calculation method with control of dimensions, area, and volume by utilizing computer computing assistance to carry out calculations on each dividing element. CFDs have received widespread attention from the international community since the advent of digital computers. CFD has become an integral part of the engineering design and analysis environment in many companies due to its ability to predict the performance of a new design or process before it is produced or implemented. Table 2 shows several areas of application of CFD [90].

Table 2

Subject area of CFD application

Area	Subject
Industrial applications	Aerospace, Architecture, Automotive, Biomedical, Chemical and Process, Combustion, Electronics and computers, Glass manufacturing, HVAC (heat, ventilation, and cooling), Petroleum, Power, Marine, Mechanical, Metallurgical, Nuclear, Train design, Turbomachinery, and Water
Environmental applications	Atmospheric pollution, Climate calculations, Fire in buildings, and Oceanic flows Pollution of natural waters Safety
Physiological applications	Cardiovascular flows (heart, major vessels) and Flow in lungs and breathing passages

3.2 The Benefit of CFD

CFD has grown from a mathematical curiosity to an essential tool in almost every branch of fluid dynamics. Most CFD results will provide improved performance, better reliability, and more reliable scale increases [91]. CFD is also often used to analyze new systems before deciding which and how much validation testing needs to be performed. The advantages of CFD according to Xia & Sun [91] suggest that CFD provides a detailed understanding of flow distribution, weight loss, mass and heat transfer, as well as particulate separation, making it possible to evaluate geometry changes with much less time and cost compared to laboratory testing. In addition to these advantages, CFDs can answer many 'what if' questions in a short time. CFD can reduce scale-up problems because the models are based on fundamental physics and are scale-independent, it is very useful in simulating conditions where it is not possible to make detailed measurements such as high temperatures or dangerous environments in ovens, and CFD is a proactive analysis and design tool [92].

3.3 CFD Analysis Process

CFD analysis will state the problem and use scientific knowledge to express it mathematically. Then CFD software will put this knowledge into action and express the problem in scientific terms. Finally, the computer will perform the calculations determined by the CFD software and will check, and interpret the results. In principle, three different major tasks must be performed to perform a CFD simulation.

3.3.1 Pre-processing

Pre-processing is all tasks carried out before the numerical solution process in CFD analysis. The pre-processing stage involves thinking about the problem, connecting, and creating a computational model. Problem thinking is the first stage in using CFD. At the problem-thinking stage, an analyst should consider the problem flow and try to understand it as much as possible. The second stage is meshing. At this stage, the analyst must create a problem domain that needs to be analyzed. Then the problem domain is further divided into cells, also known as volumes and elements. As an example, Figure 2 shows the presented boundary conditions. On the top and bottom walls, the velocity values in both coordinates are considered zero. The bottom wall represents the bottom of the swimming pool and the top wall represents the top of the pool. Meanwhile, Figure 3 shows an example of the meshing structure of a net with a distance of 0.05 in a drafting swim with a distance between swimmers equal to 0.5 m [31]. Once the meshing is complete, the boundaries of the problem domain can be found and the necessary boundary conditions, determined in the initial stage must be applied. These conditions along with several fluid parameters and physical properties

determine the actual flow problem to be solved. Advanced CFD software packages have programs to perform the following operations: defining a grid of points, as well as volumes or elements, defining geometric boundaries, applying boundary conditions, defining initial conditions, setting fluid properties, and setting numerical values of control parameters.

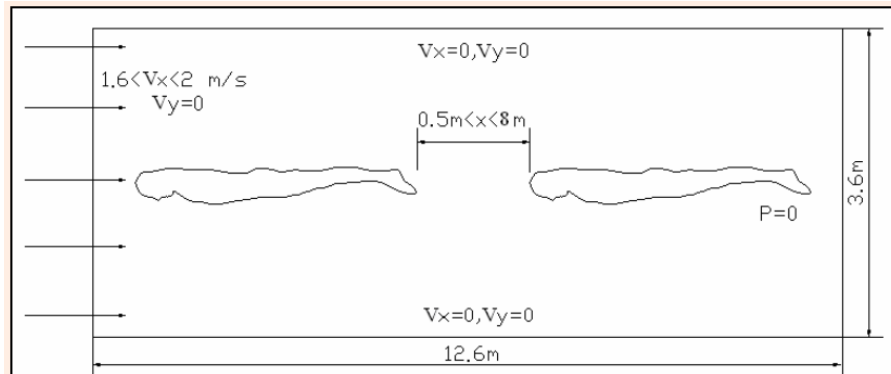


Fig. 2. Boundary Condition (Silva *et al.*, [30])

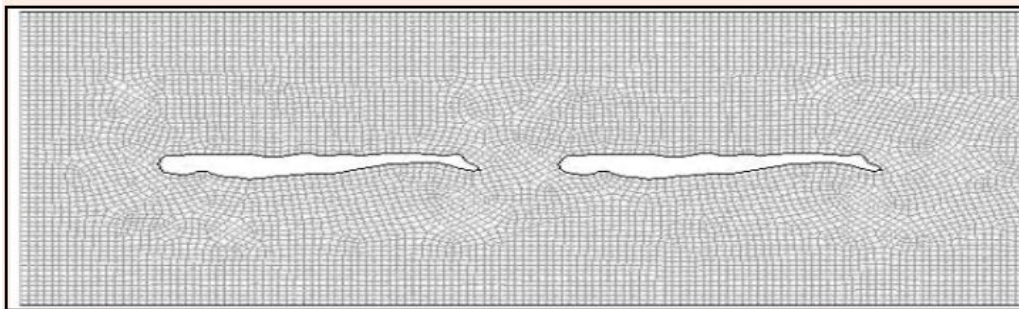


Fig. 3. Mesh structure Net with a distance of 0.05 in the drafting pool. The distance between swimmers is equal to 0.5 m (Silva *et al.*, [30])

3.3.2 Post-processing

The post-processing program is used to evaluate the data produced by CFD analysis. When the model has been completed, the results can be analyzed both numerically and graphically. Figure 4 provides an example of the swimmer's speed vector shown in Figure 3. Figure 4 shows the conditions inherent in the lead swimmer in contrast to the conditions verified in the rear swimmer [31]. When some results have been obtained, they must be analyzed, first to check whether the solution is satisfactory and then to determine the actual flow data required from the simulation.

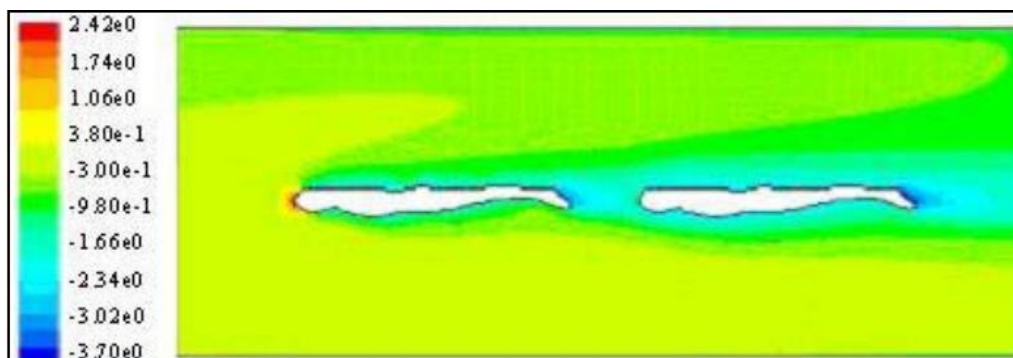


Fig. 4. Pressure profile in swimming preparation. The distance between swimmers is equal to 0.5 m. The flow velocity is equal to 2.0 m·s⁻¹ (Silva *et al.*, [30])

4. Results and Discussion

4.1 Trend in Number of Publications and Citations per Year Articles

Figure 5 shows the publication history of the number of articles regarding Computational Fluid Dynamics Design (CFD) in Sport Science. Based on the results of research data searches, it is known that the trend of research publications regarding CFD in sports science was first carried out in 1996. In the 27 years of publication data, an annual research report was obtained which shows that the development of publications regarding CFD in sports science has been fluctuating, and has experienced increased publications in 2019-2022. The number of publications increased significantly from the number of publications in 1996 with 1 publication to 63 publications in 2022. However, in 2023 the number of publications decreased to 45 publications. The year with the highest number of publication productivity occurred in 2022, namely 63 publications. Meanwhile, the year with the lowest number of publication productivity occurred in 1996 - 2005 with the number of publications not exceeding 5. The description of the number of publications each year was based on the number of documents found, namely in 1997, 1998, 1999, and 2001 no published documents were found. In 1996, 2000, 2003, 2004, and 2003 1 published document was found. In 2002 and 2005, 3 published documents were found. In 2006 there were 10 publications and in 2007 7 published documents were found. In 2008 – 2023 the number of publications increased significantly with the number of publications already exceeding 20 (>20). However, in 2011-2012 it decreased again to 19 and 13 publications respectively.

The total annual publications on CFD research in sports science as shown in Figure 5 come from the distribution of various types of documents, including articles (420 documents), conference papers (81 documents), book chapters (13 documents), reviews (46 documents), conference reviews (1 document), book (13 documents), and short survey (1 document). The distribution of document types analyzed in this research is shown in Figure 6. The document types most often found in research publications regarding CFD in sports science are articles at 73.04% and conference papers at 14.08%. Meanwhile, the types of documents that have the lowest total are short surveys and conference reviews with a percentage of 0.17% each.

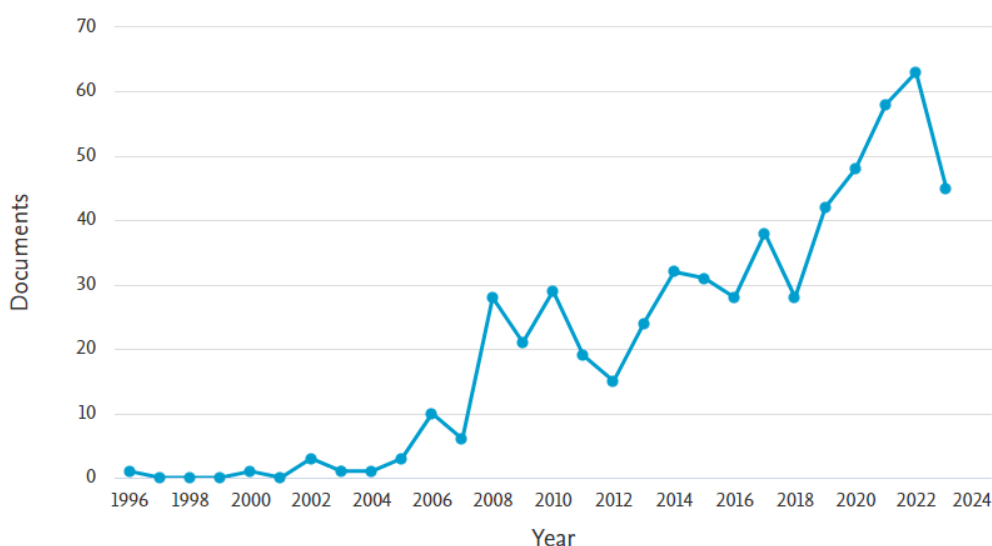


Fig. 5. Number of publications per year

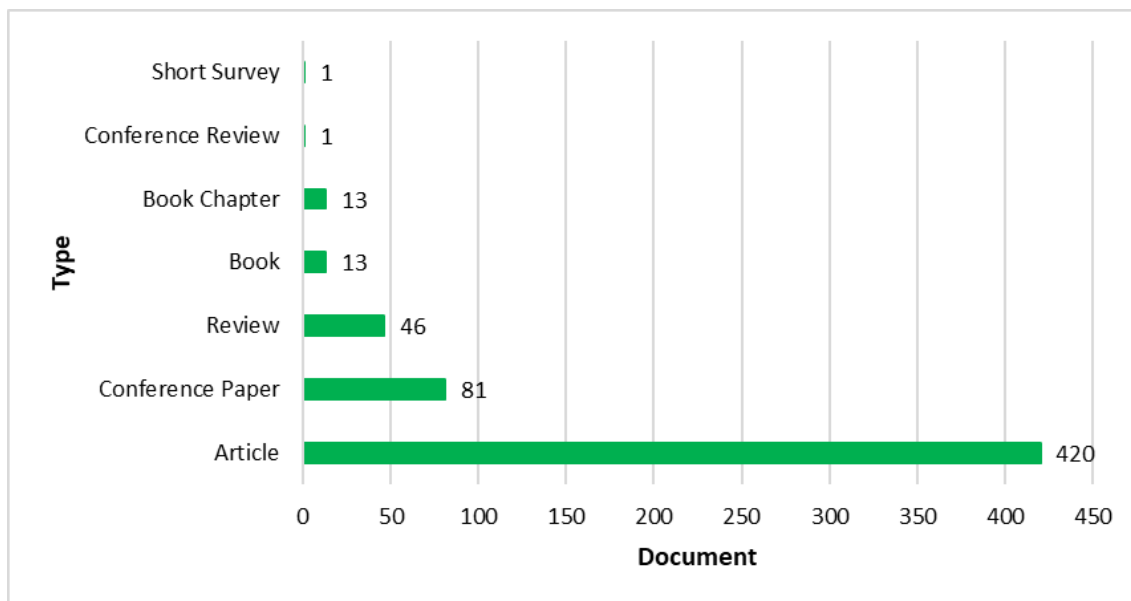


Fig. 6. Distribution of document types

Table 3 shows details of publication trends and the number of citations for articles regarding CFD in sports science published in Scopus-indexed journals. Table 3 shows the average total document citations per year. Citations in academic writing provide recognition to the author, support research arguments, and help build a strong foundation for writing a scientific work. The development of citation ranking lists highlights published works that have the potential to influence future patterns of clinical practice and research. Publication and citation trends can be shown through the number of articles per year and the average total (MeanTperYear) of citations per year [93]. Based on the data in Table 3, it is known that the number of citations to published articles regarding CFD in sports science is quite high. The article that has been cited the most is the article published in 2000 with a total of 1204 citations. The article is entitled "How Animals Move: An Integrative View" written by "Dickinson *et al.*, [94]. Another article that has the highest number of citations is the article the title "Aerodynamics of low Reynolds Number Flyers" written by Ansari. Aerodynamics of low Reynolds number flyers is a book-type written work.

Table 3
Most cited articles

Document Title	Author	Source	Year	Citations
How animals move: An integrative view	Dickinson <i>et al.</i> , [94]	Science, 288(5463), pp. 100–106	2000	1204
Aerodynamics of low Reynolds number flyers	Ansari, S., [95]	Aerodynamics Of Low Reynolds Number Flyers, 9780521882781, pp. 1–193	2007	599
Energetics and biomechanics as determining factors of swimming performance: Updating the state of the art	Barbosa <i>et al.</i> , [96]	Journal of Science and Medicine in Sport, 13(2), pp. 262–269	2010	200
The importance of body stiffness in undulatory propulsion	Long <i>et al.</i> , [97]	American Zoologist, 36(6), pp. 678–694	1996	175
A review on locomotion robophysics: The study of movement at the intersection of robotics, soft matter, and dynamical systems	Aguilar <i>et al.</i> , [98]	Reports on Progress in Physics, 79(11), 110001	2016	152
Mechanical models of sandfish locomotion reveal principles of high-performance subsurface sand-swimming	Maladen <i>et al.</i> , [99]	Journal of the Royal Society Interface, 8(62), pp. 1332–1345	2011	133
Aerodynamic study of different cyclist positions: CFD analysis and full-scale wind-tunnel tests	Defraeye <i>et al.</i> , [100]	Journal of Biomechanics, 43(7), pp. 1262–1268	2010	129
Aerodynamic drag in cycling pelotons: new insights by CFD simulation and wind tunnel testing	Blocken <i>et al.</i> , [101]	Journal of Wind Engineering and Industrial Aerodynamics, 179, pp. 319–337	2018	103
On validation of multibody musculoskeletal models	Lund <i>et al.</i> , [102]	Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine, 226(2), pp. 82–94	2012	99
Exercise and Coronary Vascular Remodeling in the Healthy Heart	Brown, M.D. [103]	Experimental Physiology, 88(5), pp. 645–658	2003	97

4.2 Trends in Subjects and Research Topics

Figure 7 shows the distribution of previous research subject areas regarding CFD in sports science based on the Scopus database. Research publications regarding CFD in sport science are grouped into 24 different subject areas, namely engineering (268 documents), medicine (254 documents), Biochemistry (125 documents), health professions (122 documents), chemical engineering (73 documents), computer science (73 documents), mathematics (53 documents), physics and astronomy (52 documents), material science (46 documents), environmental science (28 documents), social science (26 documents), agricultural and biological science (24 documents), earth and planetary sciences (19 documents), energy (19 documents), multidisciplinary (19 documents), immunology and microbiology (9 documents), psychology (9 documents), business, management, and accounting (7 documents), chemistry (7 documents), neuroscience (7 documents), pharmacology, toxicology and pharmaceuticals (4 documents), nursing (2 documents), decision sciences (1 document), and economics, econometrics, and finance (1 document). The subject area with the highest number of research publications regarding CFD in sports science is engineering with 268 documents. The subject area with the least number of research documents regarding CFD in sports science is economics, econometrics, and finance with a total of 1 document.

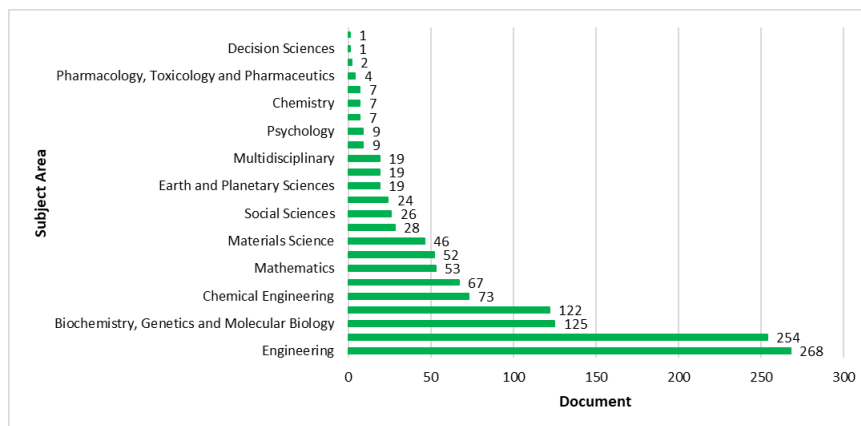


Fig. 7. Distribution of research area subjects

Analysis of subject area data mapping by looking at co-occurrence based on keywords. This data mapping was carried out to ensure that all keywords in this research topic are connected. Figure 8 shows a network visualization of terms in published articles regarding CFD in sports science. This network visualization depicts the connection between terms and displays the strength of the connection between these terms based on the link strength value [104]. The nodes in the visualization network have the meaning of showing that the larger the size of the node is directly proportional to the larger the value of its appearance [104]. Meanwhile, Figure 9 shows a VOSviewer overlay visualization of CFD research in sports science. The VOSviewer visualization overlay shows the novelty of research on related terms [104].

Figure 8 shows that the keywords that are most accurate and have the highest number of appearances are in one year of publication, namely 2023. The visualization network in this research has the condition that the keywords are found at least 2 times and the keywords used are included in the 100% most accurate keywords. Keywords found in the network visualization mapping analysis using VOSviewer are divided into 3 clusters. Cluster 1 is shown by a red node and has 9 items/keywords, namely CFD, CFD simulation, computational fluid dynamics, decade, difference, investigation, patient, software, and time. Cluster 2 with green nodes has 9 items/keywords, namely computational fluid dynamics, condition, effect, evaluation, pressure, simulation, speed, study, and work. Meanwhile, cluster 3 with blue nodes has 7 items/keywords, namely addition, application, exercise, experiment, model, multiple position, and position.

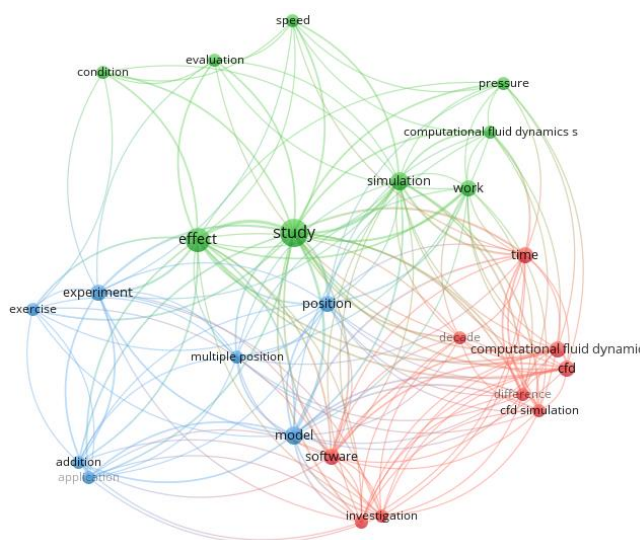


Fig. 8. Network visualization of research on CFD in sports science

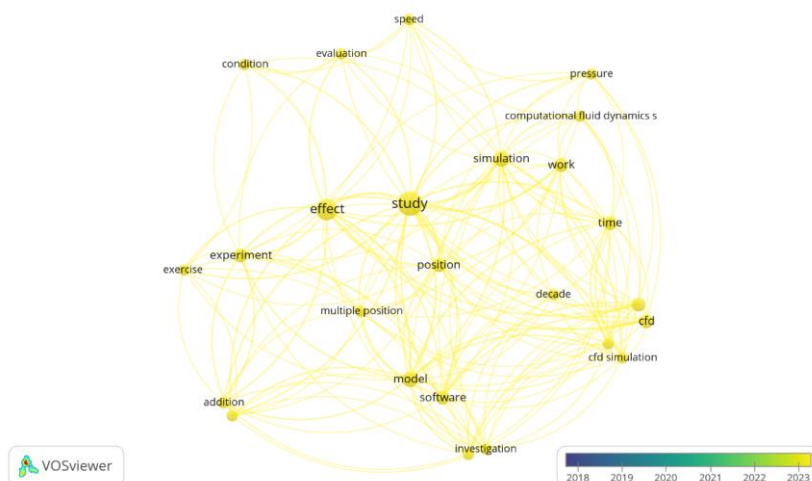


Fig. 9. Overlay visualization of research on CFD in sports science

4.3 Analysis of Research Author Contributions

In research publications regarding CFD in sports science, 159 scientists or researchers have contributed. Figure 10 shows the 15 authors who have contributed the most articles to CFD research publications in sports science. Marinho, D. A. is the author who has the highest number of published articles on CFD in sports science, namely 50 articles. Meanwhile, of the 15 authors listed in Figure 10, Gonjo, T. ranks last, namely 15 with a total of 11 articles published.

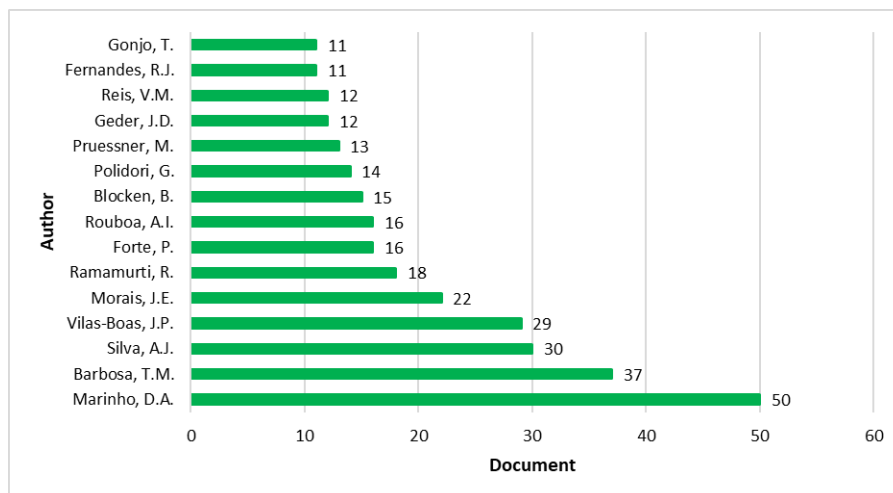


Fig. 10. Authors with the highest contributions

4.4 Analysis of Affiliate and Country Research Contributions

This research analyzes affiliates and countries that have contributed to the publication of CFD research in sports science. Figure 11 shows the distribution of author affiliations in the top 15 with the highest number of publications. Nanyang Technological University is the affiliate with the highest total CFD in sports science publications, namely 15 documents, followed by the U.S. Naval Research Laboratory as many as 18 documents. Technische Universiteit Eindhoven as many as 19 documents. KU Leuven with 21 documents, University of Tsukuba with 22 documents, Universidade do Porto with 37 documents, Instituto Politecnico de Braganca with 40 documents, University of Trás-os-Montes

and Alto Douro with 44 documents, Universidade da Beira Interior with 55 documents, and Centro de Investigação em Desporto, Saúde e Desenvolvimento Humano totaling 64 documents.

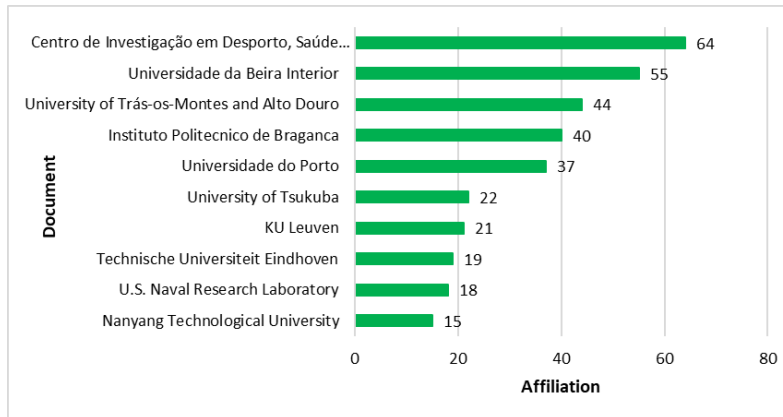


Fig. 11. Affiliate contributions

Figure 12 shows the country's contribution to writing articles with the theme CFD in sports science. 59 countries have contributed to research on CFD in sports science. However, Figure 12 shows the 14 countries with the highest number of article contributions < 19 documents. Countries that have contributed to CFD research in sports science are United States, Portugal, United Kingdom, China, Japan, Australia, France, Belgium, Netherlands, Italy, Spain, Germany, Canada, Singapore, Switzerland, Brazil, Norway, India, Greece, New Zealand, Ireland, South Korea, Austria, Hong Kong, Malaysia, Sweden, Iran, Lithuania, Thailand, Czech Republic, Hungary, Poland, Taiwan, Colombia, Cuba, Denmark, Georgia, Mexico, Morocco, Qatar, Russian Federation, Saudi Arabia, Serbia, Slovenia, Argentina, Bulgaria, Costa Rica, Cyprus, Finland, Israel, Lebanon, Pakistan, Romania, Sri Lanka, Syrian Arab Republic, Tunisia, Uganda, United Arab Emirates, Viet Nam. The United States is the country with the highest number of research publication contributions regarding CFD in sports science with 103 documents found. India with 20 documents, China with 16 documents, and the United States with 16 documents are the countries in the top 5 with the most contributions. This distribution of countries shows that CFD research in sports science does not only occur or focus on one region but has been carried out by researchers from the continents of Asia, Europe, America, Australia, and Africa.

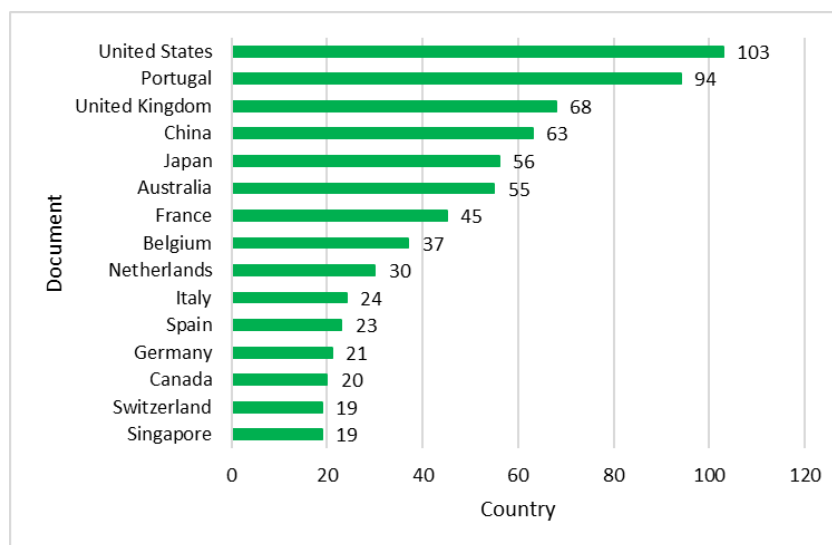


Fig. 12. Country contributions

4.5 Analysis of Publication Source

Several articles analyzed in this research were published by several international publication sources indexed by Scopus. Therefore, we conducted a publication source analysis. Data resulting from analysis of publication sources can be used by future researchers as a reference source for choosing a place to publish their work. Figure 13 shows 15 research publication sources that have the highest number of documents. The 12 research publication sources that have the highest number of documents are the Journal of Biomechanics (33 documents), Proceedings of the Institute of Mechanical Engineering (21 documents), and so on. For greater brevity, the Journal of Biomechanics is the source with the largest number of documents. Meanwhile, the Journal of the Royal Society Interface, Frontiers in Physiology, and Computer Methods in Biomechanics and Biomedical Engineering are 3 sources with a small number of publications compared to sources ranked 15 and above. The number of publications from these three sources is 7 publications each.

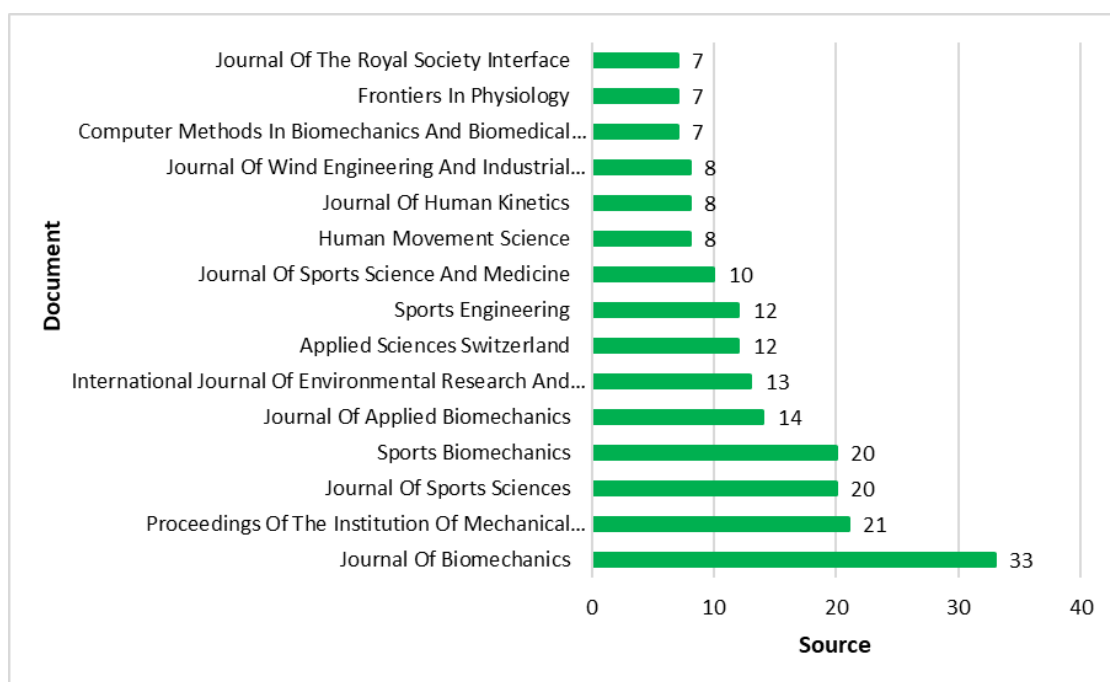


Fig. 13. Most contribution publication source

5. Conclusions

Computational Fluid Dynamics (CFD) is a technology used to test product designs through computer simulations of fluid flow around the product. The use of technology in various fields such as sports science is very important to understand, train, and improve performance in various aspects. The results of the publication search found that the development of these publications occurred fluctuatingly, and experienced an increase in 2022. The year with the highest number of publication productivity occurred in 2022, namely 63 publications. Meanwhile, the years with the lowest number of publication productivity occurred in 1997, 1998, 1999, and 2001. Research publications regarding CFD in sports science were grouped into 24 different subject areas. The subject area with the highest number of research publications regarding CFD in sports science is engineering with 268 documents, while the fewest are Economics, Econometrics, and Finance with a total of 1 document. Contributions to this research consisted of 159 authors, 10 affiliates, and 60 countries. Nanyang Technological University is the affiliate with the most total CFD publications in sports science, namely 15

documents. CFD research in sports science does not only occur or focus on one region but has been carried out by researchers from countries from all over the world, such as countries from the continents of Asia, Africa, America, and Europe.

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