REVIEW ARTICLE
SCIENCE OF MARTIAL ARTS

A performance in martial arts: a bibliometric analysis

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Manuscript Preparation
E Funds Collection

Yrui Tropin [1ABCD], **Władysław Jagiełło** [2ACD], **Iryna Fediai** [1BDE], **Oksana Mashchenko** [3BDE]

[1] Kharkiv State Academy of Physical Culture, Kharkiv, Ukraine
[2] Gdansk University of Physical Education and Sports, Gdansk, Poland
[3] O.M. Beketov National University of Urban Economy in Kharkiv, Kharkiv, Ukraine

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Abstract

Background & Study Aim: The study of the indicators of competitive activity allows the coach to organize the training process more effectively; to timely identify deficiencies in the athlete's preparation and make certain adjustments to the training plan; to rationally select tactical options for the upcoming bout (combat, fight) considering the capabilities of the rival. The aim of this review is knowledge on competitive activity in martial arts based on the publications in the web database PubMed.

Material & Methods: Bibliometric analysis of PubMed database data was used to create a sample of studies as of 06/17/2023. The key phrase 'competitive activity in martial arts' was used for the search. 190 publications were found. The first publication was published in 1990. The software VOSviewer 1.6.19 was used for keyword analysis and direct citation analysis with the construction of bibliometric maps, visualization of the density of clusters, weights – citations.

Results: With the help of VOSviewer 1.6.19 software 76 journals from 36 countries were identified. The USA (23 journals), China (14 journals) and the UK (9 journals) are the unequivocal leaders among the countries. We analysed the publication activity of 782 authors whose link strength was more than 0. The authors were grouped into 137 clusters. They were characterized by the presence of 2249 links with total link strength of 2447. The number of items in the clusters did not have a significant difference; this can be explained by the popularity of all research areas. The highest number of publications is observed for Franchini Emerson (20), Chamari Karim (8), Chaabene Helme (5), Capranica Laaura (5), and Miarka Bianca (5) and 71 elements (keywords) were selected to visualize the network. The elements formed 6 clusters. The network includes 1257 links, and the total number was 6465. The most popular studies are highlighted. These studies include the following keywords: 'humans', 'martial arts', 'male', 'adult', 'young adult', 'female', 'athletes', 'adolescent'. Overlay visualization shows that most of the keywords with the newest publication dates are related to martial arts, while older publications compare the indicators of competitive activity in martial arts and in other sports (sports games).

Conclusions: The relevance of research on competitive activity in martial arts was confirmed. There has been a significant increase in publications in the last decade. The main array of publications is aimed at improving the methods of sports training for successful performance in competitions. A popular direction is the prevention of injuries in the process of preparation and performance at competitions. Modern technologies and the availability of big data open new opportunities for studying the competitive activities in martial arts (and neo gladiatorship).

Keywords: bibliometric mapping • competitive activity • martial arts • VOSviewer

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Author's address: Władysław Jagiełło, Department of Sport, Faculty of Physical Education, University of Physical Education and Sports, K. Gorskiego Str.1, 80-336 Gdansk, Poland; e-mail: wjagiello1@wp.pl

INTRODUCTION

The competitive activity fully reflects the advantages and disadvantages of the athlete's skill and the peculiarities of the sport [1-3].

Historically, sports science has brought to the forefront issues related to the theory of sports training, but often the solution of training problems was carried out without considering the specifics of competitive activity of athletes [4-6].

It is impossible not to agree with the authors who believe that the study of competitive activity, cognition of the regularities of this process enable to make a more significant contribution to the preparation of an athlete to the highest achievements than the approach to the training process on the basis of research [7, 8].

Many scientists in their studies have paid attention to the competitive activity of athletes in various types of martial arts: in jiu-jitsu [9], in wrestling [10], in judo [11], in taekwondo [12], in mixed martial arts (MMA – neo gladiatorism [13]; see glossary). In addition, the competitive activity of national teams in various types of martial arts has been analysed [14, 15].

Researchers who specialize in various types of martial arts have analysed competitive activity to determine the features of modern competitive activity [16]; to identify various indicators and the most frequently used technical and tactical actions [17]; to assess the strengths and weaknesses of athletes' preparedness [18]; to model the skills of stronger martial artists worldwide [19], identify injuries sustained during competitions [20], to predict future results in competitions [21], etc.

The study of the content of competitive activity allows the coach-teacher to organize the training process more effectively (the choice of means and methods of training, parameters of training loads, consideration of extra-training factors); to timely identify shortcomings in the athlete's preparedness and make certain adjustments to the training plan; to avoid injury; to rationally select tactical options for the upcoming bout (combat, fight), considering the capabilities of the rival [22-24].

All of the above makes it possible to assert that the chosen research direction is relevant. Researchers are faced with a vast amount of constantly updated information that needs to be analysed and summarized. A software called VOSviewer is available for thorough literature analysis. VOSviewer is a tool that helps create visual maps and visualize bibliographic data. Such maps can contain journal titles, authors' names, names of organizations where the research was conducted, and keywords. This software is able to systematize and group key terms into special semantic clusters that reflect the interest in a certain problem in a certain period of time [25].

The aim of this review is knowledge on competitive activity in martial arts based on the publications in the web database PubMed.

MATERIAL AND METHODS

Method of study

The study used a bibliometric method [26]. The software used was VOSviewer 1.6.19. VOSviewer is a software used to build and visualize bibliometric networks. These networks can, for example, include journals, researchers, or individual publications, and they are built based on citations, bibliographic links, co-citations, or co-authorship relationships [27].

As the main method of data analysis using the VOSviewer software, a 'co-occurrence' method is chosen, which clusters keywords according to how often they occur together in the same paper. The keywords form thematic clusters. The clusters

Neo gladiatorship – the corresponding author of this publication is a signatory of 'Czestochowa Declaration 2015 HMA against MMA' and 'Gdansk 2nd HMA World Congress Resolution'**.** Both documents oblige experts in the science of martial arts not to promote MMA as a sport, but to call this phenomenon truthfully 'neo gladiatorship'. The other authors agree with this view.

Neo-gladiator – a person who trains mix martial arts (MMA) and similar forms of hand-to-hand fighting that do not meet the definition of sport according to the Olympic Charter, p. 18 [53, 54].

Czestochowa Declaration 2015 HMA against MMA: 'continuous improvement of health through martial arts as one of the most attractive form of physical activity for a human, accessible during entire life should constantly exist in public space, especially in electronic media, to balance permanent degradation of mental and social health by enhancing the promotion of mixed martial arts – contemporary, bloody gladiatorship, significant tool of education to aggression in a macro scale'.

Gdansk 2nd HMA World Congress Resolution – **Article 1** The white flag with five interlocking "Olympic rings" is the most recognizable symbol in the global public space. Neither did the resurrected idea of Olympia, "Citius, Altius, Fortius" save humanity from the horrors of two world wars, nor did the declared mission of the International Olympic Committee (IOC): "1. (...) the promotion of ethics and (...) ensuring that, in sport, the spirit of fair play prevails and violence is banned" (Olympic Charter, p. 18) stop the pathology of permanently educating contemporary man in

are labelled with different colours, the size of each keyword is determined by the 'total link strength' score, i.e., the link strength of a given keyword to all others, and the lines represent the links between two individual keywords [28].

Data extraction

After completing the article selection, the following data were extracted for visual and bibliometric analysis: author name, article title, journal of publication, keywords, organization, country of publication, and citation amount.

Research design

A sample of publications as of 06/17/2023 was created using bibliometric analysis of PubMed database data. The phrase 'competitive activity in martial arts' was used for the search. 190 publications were found. The first publication was published in 1990. There is a large increase in publications after 2011 (Figure 1). This is due to the popularization of many martial arts in the world. Researchers from 433 organizations studied competitive performance in different types of martial arts. All publications were written in English.

On the basis of the most cited sources, promising research directions in this category were identified. The results of the research are presented in bibliometric maps. Bibliometric mapping is a type of research built on the use of a formal assessment of information flows. Mapping enables researchers to navigate in the information space of large data sets and allows them to structure them for effective use. Data sources for mapping are usually information systems that include metadata of scientific publications: bibliographic and citation information. The units of analysis for scientific mapping are journals, publications themselves, references, authors, and the terms and keywords used. Terms as units of analysis can be selected from publication titles, abstracts, keyword lists, and from the text of publications. In scientific mapping, links between units of analysis are established when at least two units of analysis appear together in the same publication. The links between units of analysis can be represented in the form of a graph or network called a map, where the units of analysis (elements) are the nodes of the network and the links between them are the edges of the network. Thus, bibliometric maps are networks that describe the correlation between units of analysis [29]. This methodology of calculating the main indicators for analysing and selecting the most significant areas of research was used in the works of domestic [30, 31] and foreign authors [32, 33].

Bibliometric maps were created using VOSviewer 1.6.19 software. The analysis of these maps was aimed at identifying the trend of scientific research on the competitive activity in martial arts and highlighting priority areas.

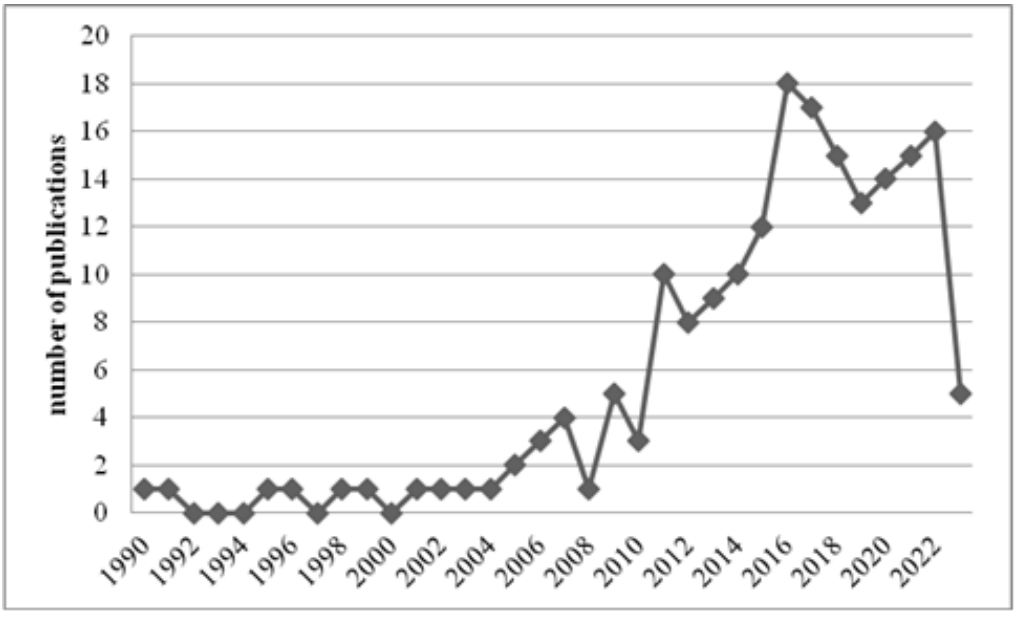

Figure 1. Dynamics of publications in the research period.

aggression. **Article 2** Likewise, symbols (a sword pointed downwards surrounded by five rings) and motto ("Friendship through Sport") of Conseil International du Sport Militaire (CISM) did not stop soldiers from killing each other and murdering people after 1948 (the year of establishing CISM, the second largest multi-sport discipline organization after the IOC, and also the year of the Universal Declaration of Human Rights). **Article 3** Although there are five identical combat sports in the Olympic Games and the Military World Games, their potential is still not used to meet the second of the Fundamental Principles of Olympism: "(...) to place sport at the service of the harmonious development of humankind, with a view to promoting a peaceful society concerned with the preservation of human dignity" (Olympic Charter, p. 13). **Article 4** Boxing and wrestling cultivate the traditions of ancient Olympism. Judo and taekwondo have given martial arts humanistic and health attractiveness. Fencing combines this tradition with modernity in the spirit of chivalry. Aiming dynamic offensive and defensive actions directly at the opponent's body (irrespective of the protectors used) in such a way as not to hurt is a measure of respecting those knightly rules. This rule harmonizes with the principle of respect for the opponent's as well as one's own corporeality and dignity over the vain victory at all costs. **Article 5** For the civilized individual and the society for whom human health and dignity are the common good, participation, in any role, in brutal shows of people massacring each other cannot be a standard of the quality of life. Neo gladiatorship camouflaged under the banner of martial arts or combat sports is a slight to the Fundamental Principles of Olympism, but also to the Universal Declaration of Human Rights. Therefore, this Resolution should inspire as many actors of Knowledge Society as possible jointly to oppose any deformations of the mission of Olympism and sport. The expansion of the pathology of unauthorized naming neo gladiators as combat sports athletes will soon turn the Fundamental Principles of Olympism into their own caricature

– objective indicators are a testament to the devastation of all dimensions of health by the practice of legal bloody pageants [55].

Physical activity – *noun* exercise and general movement that a person carries out as part of their day [56].

Skill – *noun* an ability to do perform an action well, acquired by training [56].

Tactics – *plural noun* the art of finding and implementing means to achieve immediate or short-neo [56].

Technique – *noun* a way of performing an action [56].

RESULTS

For the request "competitive activity in martial arts" using VOSviewer 1.6.19 software 76 journals from 36 countries were identified. The most productive countries are the USA (23 journals), China (14 journals) and the UK (9 journals).

Between 1990 and 17 June 2023, 190 publications were found. The sample was limited to a maximum of 25 co-authors to identify major links. The analysis included 782 authors whose link strength was greater than 0. Authors were grouped into 137 clusters. They were characterized by the presence of 2249 links with total link strength of 2447. The highest number of publications is observed for Franchini Emerson (20), Chamari Karim (8), Chaabene Helme (5), Capranica Laaura (5), Miarka Bianca (5), Cibelle Giuseppe (4), Falko Coral (4) – Figure 2.

The threshold of the minimum number of occurrences of keywords was 5, this threshold was suggested by the software. 71 elements (keyword) were selected. The elements formed 6 clusters. There are 1257 links in the network, total 6465 links. Each keyword is located in a circle. The larger the size of the circle, the greater the number of links to that keyword. The proximity of these circles on the map reflects the strength of correlation between the entities (Figure 3).

They are concentrated around the keywords: 'humans', 'martial arts', 'male', 'adult', 'young adult', 'female', 'athletes', 'adolescent'. The first cluster is the largest and is shown in red on the map. It includes 23 keywords. It contains the largest number of significant keywords. The cluster is conditionally called 'physical activity and sports'. Keywords of this cluster are sports, physical activities, age groups, the prevention of injuries and diseases. Occurrences, number of links and total link strength (TLS) in decreasing order are as follows: humans – occurrences 170, links 70, TLS 1316; martial arts – occurrences 167, links 70, TLS 1245; adult – occurrences 88, links 70, TLS 731; female – occurrences 69, links 68, TLS 601; adolescent – occurrences 59, links 67, TLS 546; athletic injuries – occurrences 23, links 41, TLS 199; child – occurrences 18, links 49, TLS 167; sports – occurrences 13, links 34, TLS 99; middle aged – occurrences 13, links 32, TLS 125; cross-sectional studies – occurrences 12,

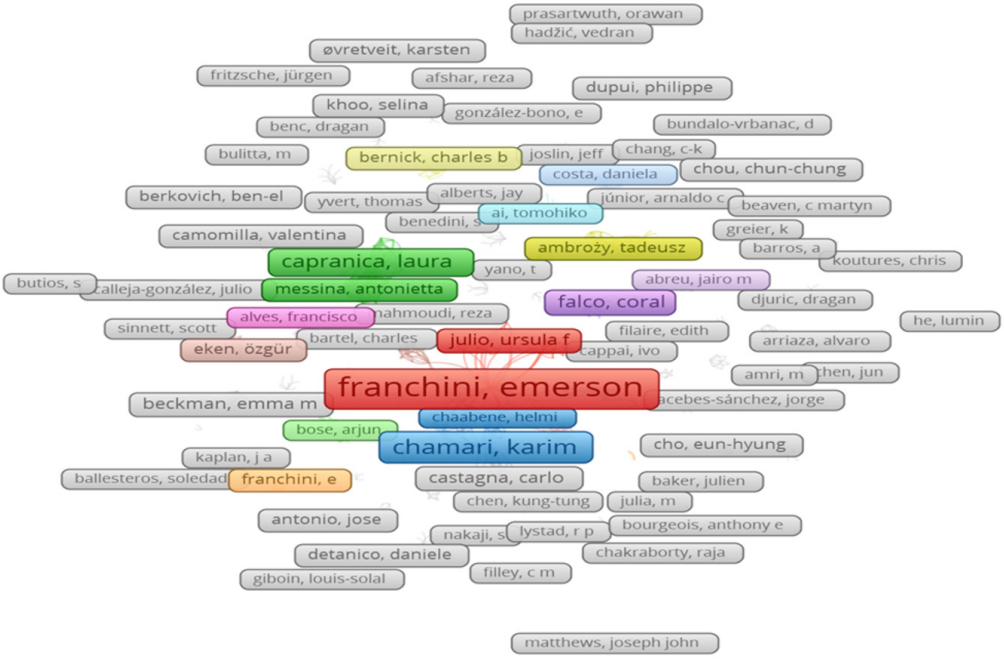

Figure 2. Bibliometric map of authors of publications that studied competitive performance in martial arts.
Source: own study based on data obtained from PubMed and analysed with VOSviewer

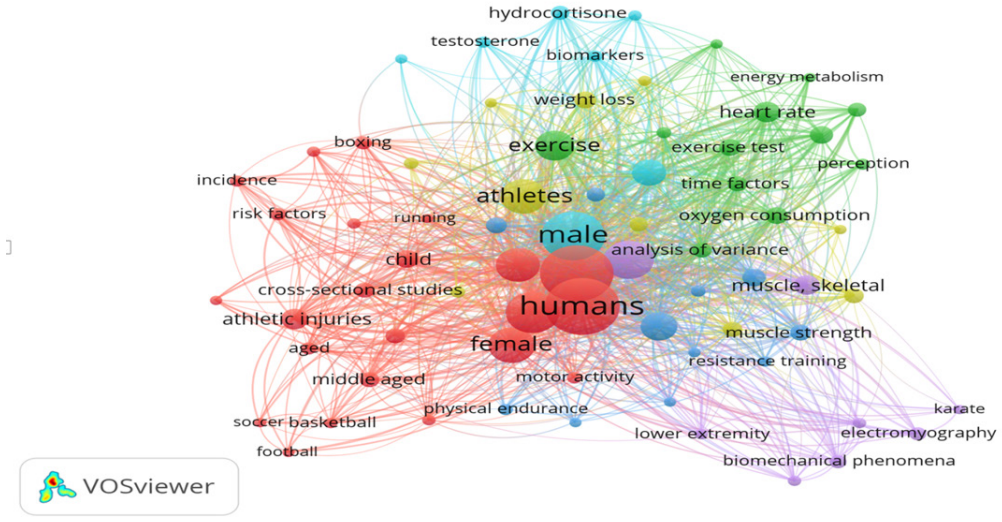

Figure 3. Bibliometric map of the main keywords in publications on competitive performance in martial arts, network visualization.

Source: own study based on data obtained from PubMed and analysed with VOSviewer.

links 36, TLS 115; boxing – occurrences 9, links 30, TLS 67; aged – occurrences 8, links 25, TLS 79; risk factors – occurrences 8, links 30, TLS 73; motor activity – occurrences 7, links 32, TLS 60; incidence – occurrences 7, links 20, TLS 56; age factors – occurrences 6, links 30, TLS 55; prospective studies – occurrences 6, links 27, TLS 58; retrospective studies – occurrences 6, links 26, TLS 54; basketball – occurrences 6, links 21, TLS 48; running – occurrences 5, links 26, TLS 50; treatment outcome – occurrences 5, links 16, TLS 35; soccer – occurrences 5, links 15, TLS 32; football – occurrences 5, links 14, TLS 32.

The second cluster includes 12 keywords. It is highlighted in green on the map. The cluster is conditionally called 'biomedical research'. The keywords of this cluster characterize: recovery, the body's reaction to physical load, and physiological and biochemical processes in the body during sports activity. Occurrences and number of references in decreasing order are as follows: exercise – occurrences 47, links 57, TLS 343; heart rate – occurrences 22, links 39, TLS 210; lactic acid – occurrences 17, links 37, TLS 163; exercise test – occurrences 16, links 50, TLS 123; oxygen consumption – occurrences 15, links 38, TLS 143; time factors – occurrences 13, links 48, TLS 138; analysis of variance – occurrences 13, links 43, TLS 118; physical exertion – occurrences 11, links 31, TLS 106; Brazil – occurrences 7, links 33, TLS 72; perception – occurrences 7, links 29, TLS 76; energy metabolism – occurrences 5, links 26, TLS 56; anaerobic threshold – occurrences 5, links 24, TLS 48.

The third cluster includes 11 keywords. It is marked on the map in blue. The conventional name of this cluster is 'athletic performance'. This is the most significant keyword in this cluster. It occurs 43 times, has 57 links with other keywords in the map, and the total link strength is 371. Next, occurrences and number of links in decreasing order are as follows: combat sports – occurrences 18, links 44, TLS 155; physical fitness – occurrences 14, links 42, TLS 116; muscle strength – occurrences 14, links 39, TLS 140; physical conditioning, human – occurrences 11, links 38, TLS 105; time and motion studies – occurrences 7, links 30, TLS 64; physical endurance – occurrences 7, links 27, TLS 57; Resistance training – occurrences 6, links 27, TLS 55; performance – occurrences 5, links 28, TLS 53; Sex factors – occurrences 5, links 26, TLS 52; physical education and training – occurrences 5, links 23, TLS 46. The key words of this cluster characterize: strength qualities, sports training, and factors that influence the results.

The fourth cluster is marked in yellow on the map and includes 10 keywords. The conditional name of the cluster is 'anthropometry and

morphofunctional research'. The keywords of this cluster characterize the follows: weight loss, height-weight characteristics of a person, energy consumption, and consumption of the body, questionnaire survey. Occurrences and number of references in decreasing order are as follows: athletes – occurrences 63, links 66, TLS 504; weight loss – occurrences 16, links 37, TLS 146; body composition – occurrences 13, links 32, TLS 110; anthropometry – occurrences 12, links 42, TLS 123; body weight – occurrences 11, links 37, TLS 110; surveys and questionnaires – occurrences 7, links 30, TLS 80; judo – occurrences 7, links 27, TLS 56; energy intake – occurrences 6, links 28, TLS 63; hand strength – occurrences 5, links 25, TLS 50; dehydration – occurrences 5, links 23, TLS 57.

The fifth cluster includes 8 keywords and is highlighted in purple on the map. The conditional name of this cluster is 'young adult'. This is the most significant keyword in this cluster. It occurs 78 times, has 68 links with other keywords in the map, and the total link strength is 707. Next, the occurrence and number of links in decreasing order are as follows: muscle, skeletal – occurrences 21, links 49, TLS 195; biomechanical phenomena – occurrences 10, links 22, TLS 77; electromyography – occurrences 9, links 21, TLS 68; lower extremity – occurrences 6, links 30, TLS 64; reaction time – occurrences 6, links 24, TLS 59; range of motion, articular – occurrences 6, links 21, TLS 56; karate – occurrences 5, links 14, TLS 22. The key words of this cluster characterize the follows: biomechanics of movement, human anatomy, quickness, young athlete. This is a fundamental difference between this cluster and the previous one, which includes studies of the states of mainly experienced athletes.

The sixth cluster is marked in light blue on the map and includes 7 keywords. The conditional name of this cluster is 'male'. This is the most significant keyword in this cluster. It occurs 127 times, has 70 links with other keywords in the map, and the total link strength is 1061. Next, occurrences and number of links in decreasing order are as follows: competitive behaviour – occurrences 38, links 59, TLS 368; biomarkers – occurrences 7, links 29, TLS 66; hydrocortisone – occurrences 11, links 31, TLS 98; testosterone – occurrences 7, links 29, TLS 60; saliva – occurrences 6, links 25, TLS 58; mixed martial arts – occurrences 5, links 13, TLS 19. The key words of this cluster characterize: peculiarities of the endocrine system state of male combatants, their influence on sports activity, medical control, and mixed martial arts.

The overlay visualization function of VOSviewer 1.6.19 enables researchers to assign scores to the items and sort them according to the given score. We used this function to identify emerging topics in the research field. We assigned the date of publication as a score to each of the items taken for analysis, and then with VOSviewer 1.6.19 we generated a map visualizing the average publication year of high-frequency keywords (Figure 4). In the map, the colours range from blue (which corresponds to the lowest value of the score, i.e. the earliest average date of publication) through green to yellow (showing the keywords of the highest value, i.e. the most up-to-date average year of publication).

Overlay visualization shows that most of the keywords with the newest publication dates (shown in yellow) are related to martial arts, while older publications (shown in blue) reflect sports games. This is explained by the fact that the new publications investigated competitive performance specifically in martial arts, while the old publications compared the indicators of competitive performance in martial arts and in other sports (sports games).

Figure 5 shows the visualization of density. The interpretation of the results in this figure is: the more important the topic, the larger and brighter the circle, and the larger the font size. According to Figure 5 the most popular research topics can be identified. The research topics include (in descending order of importance): 'human', 'martial arts', 'male', 'adult', 'young adult', 'female', 'athletes', 'adolescent'.

DISCUSSION

This study presents the results of bibliometric analysis of PubMed database using VOSviewer software. This tool can significantly facilitate the work of the researcher in analysing and structuring the information obtained based on bibliographic data. More scientists use this software to analyse various databases: Scopus [33, 31]; Web of Science [27, 25]; PubMed [34, 35]; Google Scholar [36]. Some authors use the analysis of several databases at once to write articles.

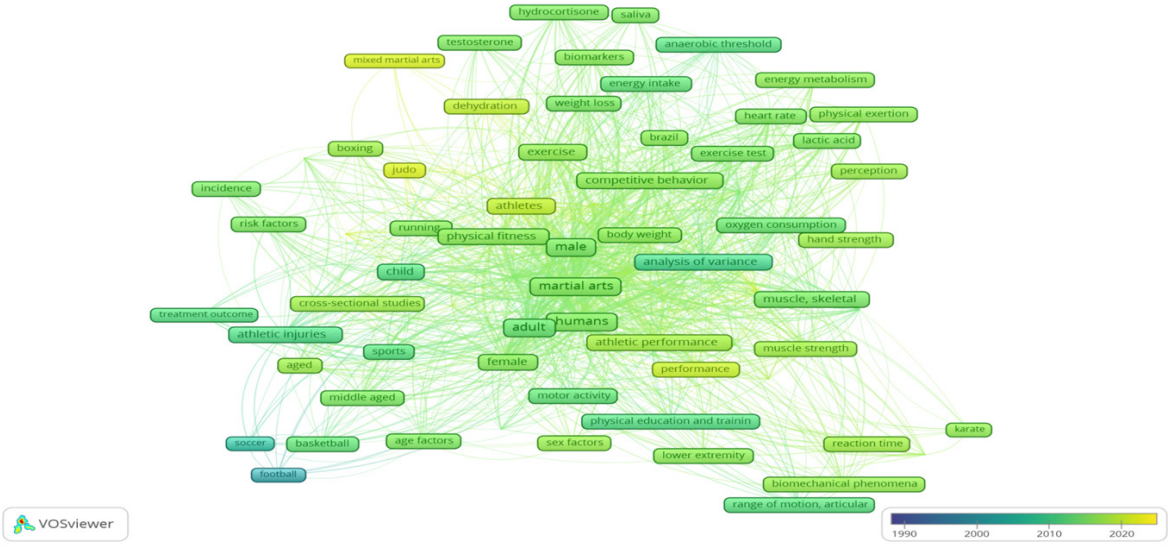

Figure 4. The average date of the publication of high-frequency keywords in competitive activity in martial art research field.
Source: own study based on data obtained from PubMed and analysed with VOSviewer.

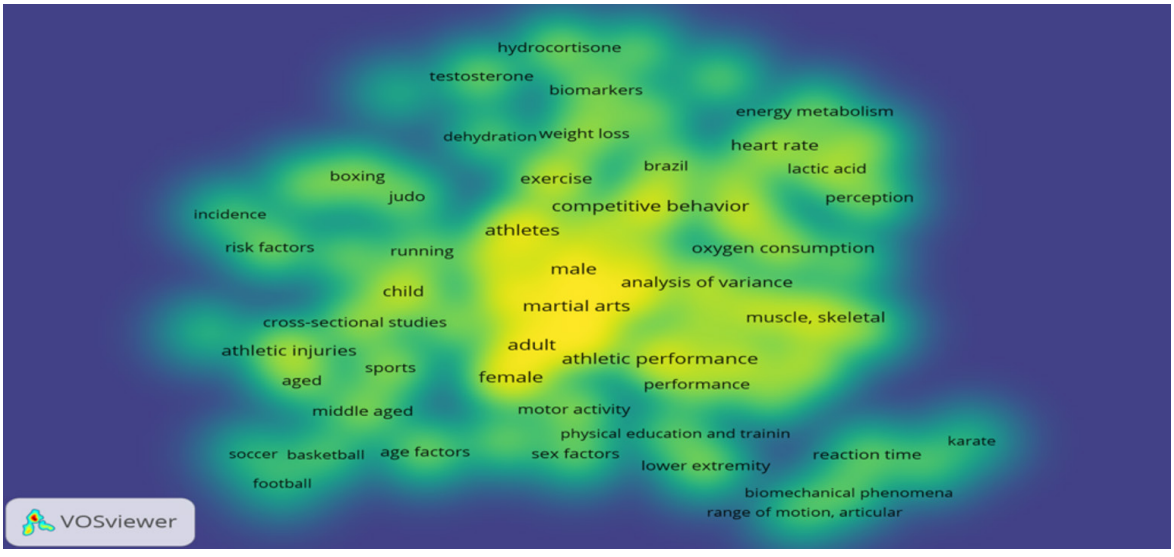

Figure 5. Bibliometric map aimed at research publications on competitive performance in martial arts (direct citation analysis, the visualization of cluster density, weight – citations), network visualization.
Source: own study based on data obtained from PubMed and analysed with VOSviewer.

Ai et al. [37] used bibliometric analysis in Web of Science, PubMed, and Scopus databases to explore the hotshots and trends in the field of exercise therapy of college students with depression from 2002 to 2022. Krzysztofik et al. [38] searched for all studies investigating the effect of unilateral conditioning activity on the effect of PAPE in Scopus, MEDLINE, SPORTDiscus, and Google Scholar databases. Makaruk et al. [39] analysed the effects of weight training on speed, strength, and endurance in athletes using a computerized literature search in Scopus, Web of Science, SPORTDiscus, and MEDLINE databases. Andreato et al. [40] analysed the literature in Scopus, PubMed, ISI Web of Knowledge, and SportDiscus databases to study the physiological

and physical profiles of Brazilian jiu-jitsu athletes. Kwok et al. [41] analysed the literature in Web of Science, PubMed, SPORTDiscus, and EBCSOhost databases to compile a biomechanical assessment of the effectiveness of strength and conditioning training programs in breaststroke crawl swimming. Redman et al. [42] conducted a systematic literature search using Web of Science, PubMed, MEDLINE, and SPORTDiscus to determine the magnitude of changes in muscle strength and power in athletes at different stages of an elite rugby league season.

The analysis of Figure 1 makes it possible to assert that the study of competitive activity in martial arts is a relevant topic for research, and its popularity has been increasing in the last decade. Studies on this topic have been conducted in many types of martial arts. Tropin et al. [13] identified the structure and model characteristics of modern competitive performance of elite female mixed martial arts MMA gladiators for each weight category. The obtained model characteristics can be used for planning the training process of qualified female athletes and for solving the issues of managing their preparation for competitions.

Latyshev et al. [10] determined the influence of relative age on the achievement of successes by elite wrestlers in competitions. The results showed that the relative age effect does not affect the achievement of success in wrestling and is levelled at the adult stage. However, it was found that the greatest effect of relative age on athletes was found at the cadet level.

Strelchuk et al. [8] developed and experimentally substantiated the structure of annual training of taekwondo athletes at the stage of specialized basic training, which was built considering the individual style of conducting a competitive fight, the manifestation of physical qualities, and the calendar of competitions. At the end of the experiment, there was an improvement in the level of physical fitness, better performance of complex technical and tactical actions, and higher efficiency of indicators of competitive activity in taekwondo athletes of the experimental group.

Ambroży et al. [9] established a correlation between special training and indicators of technical and tactical skills of elite jiu-jitsu athletes. The research showed that athletes with higher physical fitness were more active and effective in attacking in competitions. Indicators of special effectiveness showed a high correlation with technical and tactical indicators. It follows that jiu-jitsu athletes should develop during the training period and then maintain an optimal level of aerobic capacity during the competitive season, which should have a direct impact on their competitive performance.

The results of bibliometric analysis show that the number of authors who created the most influential papers is limited. Only 10 (5.3%) papers were written by a single author, and 180 (94.7%) papers were co-authored, indicating a high level of collaboration between authors on the topic (Figure 2). Most of the publications are open access, resulting in rapid and wide dissemination of contributions and multiple authors as the field develops

A bibliometric review of the literature on competitive performance in martial arts using the VOSviewer 1.6.19 software identified six keyword clusters (Figure 3). Each cluster includes more than six keywords, which makes it possible to establish the main directions of publications.

The subject matter of the first cluster characterizes physical activity and sport. The authors devoted their research types of sports, physical exercise, age groups, injury, and disease prevention. For example, Molanorouzi et al. [43] studied the motives for engaging in physical activity in athletes of different sports. The results of the study showed that strong and important motives for participating in physical activity differed by activity type, age, and gender. Understanding the motives that influence physical activity participation is critical for developing interventions to promote higher levels of involvement.

Petrisor et al. [20] described injuries sustained during training and competition in Brazilian jiu-jitsu (BJJ). The prevalence of injuries in BJJ is very high, with 9 out of 10 athletes sustaining at least 1 injury. 91% of participants were injured in training and 60% of athletes were injured in competition. Injuries were primarily sprains and strains to the fingers, upper extremity, and neck. Potential participants in BJJ should be informed regarding the significant risk of injury and instructed regarding appropriate precautions and safety protocols.

Miarka et al. [2] identified potential risk factors by analysing the technical and tactical injury profiles of sanctioned mixed martial arts fights over 12 years. Results of the study showed that the leading cause of injury in clinician stoppage situations was facial injuries (>90%), with 87.1% occurring after striking during the second round. Lacerations were the leading injury type, occurring at 80% frequency. The higher values of strike attempts with 2 main orientations, namely the head (on the ground and in stand-up actions) and body (in stand-up actions), may provide important information regarding the technical knockout and when it can be called by officials supervising mixed martial arts bouts.

The second cluster is dedicated to medical control. Its main research topics are recovery, body response to exercise, and physiological and biochemical processes in the body. López-Laval et al. [44] conducted a literature review regarding recovery strategies in combat sports. They determined that to optimize in combat sports performance, adequate recovery is required during training and competition processes. Traditional ergo-nutritional supplementation of carbohydrates and proteins combined. Besides, the consumption of evidence-supported supplementation (green tea, beetroot gels, creatine or alkaline water) improved recovery processes. Further methods of recovery including physical (cold-water immersion, massage or photobiomodulation) and physiological (types of active recovery, sleep and rest) therapies have also been shown to be useful.

Chernozub et al. [6] studied the peculiarities of changes in functional and body composition indicators of MMA neo gladiators of striking style and some blood biochemical indicators during two months of training load regimes of different intensity. We have determined the optimal complexes of criteria for the evaluation of adaptation-compensatory changes in fighters neo gladiators of MMA striking style. These complexes will allow in the shortest possible time to adjust the of the training load regime to accelerate the functional capabilities of the organism in the process of special strength training.

Kostorz et al. [22] analysed the prevalence of dependence on physical activity among those engaged in martial arts and combat sports. Exercise Dependence Scale-EDS was used. The regression coefficient indicates that the higher respondent's age, the lower the total score she/he will achieve in the EDS. The findings have practical implications for identifying subjects at-risk for exercise dependence symptoms and may aid coaches and individuals in the implementation of a prevention program to seek suitable support.

The third cluster is centred around the keyword 'athletic performance' and characterizes more professional sports activities, focusing on: strength, athletic training, and factors that influence performance. Chaabène et al. [45] paid attention to the most important physical and physiological characteristics of karate athletes. Top-level male karate athletes are typified by low body fat and mesomorphic-ectomorphic somatotype characteristics. Aerobic capacity plays a major role in karate performance. It prevents fatigue during training and ensures the recovery processes during rest periods between two subsequent bouts of fighting activity within a fight and between two consecutive matches.

The explosive power of the upper and lower limb muscles plays an important role in the ability of karate athletes to perform at high-level competitions. Reaction time is a crucial element in karate because high-level performance is essentially based on explosive technique. Reaction time is a crucial element in karate because high-level performance is based essentially on explosive techniques.

Monks et al. [4] determined the effect of high-intensity interval training (HIIT) on athletes' performances in taekwondo. The results of the study showed that the effectiveness of eleven sessions of HIIT improves the anaerobic capacity of athletes. This improvement has a positive effect on successful performance in taekwondo competitions.

James et al. [17] determined performance measures that have the greatest impact on the classification outcome at the elite level of mixed martial arts neo gladiators. They determined that wrestling activity and technique accuracy are of particular importance in achieving victory in mixed martial arts competition in elite fighters.

The conditional name of the fourth cluster is "anthropometry and morphofunctional studies". The main research topics in this cluster are the follows: weight loss, height-weight characteristics

of a person, energy expenditure and consumption of the body, and questionnaire surveys. Matthews & Nicholas [46] quantified the magnitude and identified rapid weight loss (RWL) and rapid weight gain (RWG) methods in MMA neo gladiators preparing for competition. Athletes reported using harmful dehydration-based RWL strategies, including sauna (43%) and training in plastic suits (43%). The results of the study showed that RWG was higher than RWL. The observed RWL and the strategies used are comparable to those that have previously resulted in fatalities. The regulations that make RWL impractical should be modified to ensure the health, safety and well-being of participants.

Bartel et al. [47] measured physiological demands, mainly energy expenditure, in taekwondo-specific high-intensity intermittent exercise (HIIE). Athletes performed a taekwondo-specific test. The test consisted of 3 rounds of 2 min each, with 1 min rest between rounds. The results of the test were recorded in three different HIIE protocols on different days. It was determined that the mean of the three rounds for 35:5 and 15:10:5 presented similar absolute and relative contributions of aerobic and galactic metabolisms, whereas the TKDtest100 showed predominantly aerobic activity. We emphasize that aerobic metabolism was predominant from the second round in the 15:10:5 and 100%TKDtest protocols and in the last round of the 35:5 protocol.

Slankamenac et al. [48] identified differences between karate athletes in five male and five female weight categories in various anthropometric measurements and determined the somatotypes profiles of the athletes. The results of the study showed that anthropometric parameters were highest in karate athletes of the heaviest weight categories. All male subjects were endomorphic mesomorphs, except for the category <84 kg, which was endomorphic ectomorphs. Somatotype analysis of male categories found a difference between the <75 kg and <84 kg in endomorph. In mesomorph, there is no difference between categories. Perceiving ectomorph, there is a significant difference between the first category and >84 kg. Profiling female athletes, three different types of somatotypes were obtained concerning the weight category. The lightest weight category was predominantly endomorphic ectomorphs, and two weight categories were ectomorphic endomorphs (<61 kg and <68 kg), and the other two weight categories were endomorphic mesomorphs (<55 kg and >68 kg). Somatotype differences in female karate athletes were observed only in the ectomorph components, between <50 kg and <61 kg.

The fifth cluster focuses around the keyword phrase 'young adult'. The authors of this cluster studied: biomechanics of movement, human anatomy, speed, and young athletes. Berkovich et al. [11] determined the prevalence of rapid weight loss (RWL) among adolescents practicing judo. Two-thirds of the athletes indicated that their coaches were the most influential figure in their decision to lose weight before competition. RWL is widespread among adolescent judo athletes. The methods used by these athletes can lead to significant health risks, including impaired nutritional status, reduced physical performance, and impaired growth and development.

Moreira et al. [49] compared the kinematic and neuromuscular indicators of *bandal chagui* leg kicks in elite and subelite taekwondo athletes. The selected biomechanical indicators of *bandal chagui* were found to be useful for monitoring the training status of the kick and determining the training goal for black belt athletes. Contraction indices and angular velocity during knee extension, foot and knee linear velocity, and horizontal ground reaction forces were significantly higher in elite than in sub elite athletes.

Kamali et al. [50] studied the effects of neurostimulation in potentiating motor and cognitive functions in elite taekwondo athletes. We determined that the present dual-mode neurostimulation could potentially improve motor functions through the effect of tsDCS (transcutaneous spinal direct current stimulation) over the spinal interneurons and tDCS (transcranial Direct Current Stimulation) over the primary motor cortex. This research provides an opportunity to develop neurostimulation protocols to improve the performance of professional martial artists, including their accuracy and reaction speed.

The sixth cluster centres around the keyword "male" and characterizes: males, medical control, mixed martial arts. Jansen et al. [16] characterized impact exposure during training and competition among male and female athletes participating in boxing and MMA neo gladiators using an instrumented custom-fit Impact Monitoring Mouthguard (IMM). They found that MMA neo

gladiators impacts produced significantly higher peak angular acceleration than boxing impacts ($p<0.001$) and were more varied in impact location on the head during competitions. In terms of sex, men experienced a greater number of impacts than women per practice session. However, there was no significant difference between men and women in terms of impact magnitude.

Curran-Sills [51] analysed the circumstances that led to MMA neo gladiator fights being cancelled by doctors at the Calgary ring during the pre-fight inspection period. He determined that cancelled fights during pre-fight inspection periods accounted for 5.4% of all MMA fights. A total of 25 reasons led to fight cancellations. The author recommended the follows: the creation of guidelines regarding pre – and post-bout neuroimaging, the implementation of industry-wide minimum medical screening standards, the adoption of a longitudinal approach to weight monitoring, the development of competent ringside physician groups, and active oversight by the Combative Sports Commission during the matchmaking process.

Esagoff et al. [24] explored regional brain volumes associated with sparring in MMA neo gladiators. We found that a higher number of weekly sparring rounds during training was significantly associated with larger left and right caudate volumes. Sparring was not significantly associated with left or right thalamus, putamen, hippocampus, or amygdala volumes.

It was recommended to conduct a medical examination of fighters after sparring.

The analysis of visualization allows us to conclude that more studies of competitive activity are conducted in popular martial arts: taekwondo, wrestling, karate, judo, MMA neo gladiatorism, and jiu-jitsu. The popularity of these sports (and neo gladiatorism) is growing every year, which significantly affects the number of publications (Figure 4). These data are confirmed with previously obtained results [14, 5, 52, 21].

The results of density visualization (Figure 5) actually repeat the results of network visualization. This should be regarded as a confirmation of the correctness of the assumptions made.

CONCLUSIONS

The relevance of research on competitive activity in martial arts was confirmed. There has been a significant increase in publications in the last decade. The main array of publications is aimed at improving the methods of sports training for successful performance in competitions. Also, the reduction of injuries in the process of preparation and performance at competitions. Modern technologies and the availability of large amounts of data open new opportunities for the study of competitive activity in martial arts.

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