

Identification of the Olympic Powers in History using a Methodology Based on *h*-index and *h*-core

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ABSTRACT

The Olympic Games were created in 1896, where 241 men competed in 10 modalities. Since then, new editions have been held every 4 years, with more athletes, more countries, and more modalities. Although there is no official ranking released by the International Olympic Committee (IOC), the media always elaborate rankings to evaluate the countries' participation using the lexicographic method. However, the lexicographic method is often criticized as it overvalues the gold medal and disregards that each modality distributes a different number of medals. We propose a methodology to analyse the performance of the countries, through the application of successive *h*-indexes and *h*-cores, where the goal is not to generate a final ranking, but to identify the Olympic Powers in the history of the Games. Olympic Powers are the countries that stand out in a great variety of modalities, so they can be considered the great champions in the general picture. The concept of Olympic Power considers the number of times that a country occupies the first places of the ranking of each modality (or of each edition). As a result, we identified six countries as the Olympic Powers of history: USA, USSR, Germany, UK, China and Russia. Finally, we compared the result of the proposed methodology with the lexicographic ranking.

Keywords: *H*-core, *H*-index, Olympic Games, Ranking, Sports.

Key Messages: Proposal of ranking based on calculation of successive *h*-indexes and *h*-cores; With this methodology we can identify potentials in different fields.

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Received: 06-08-2020

Revised: 21-02-2021

Accepted: 02-03-2021

DOI: 10.5530/jscores.10.1.11

INTRODUCTION

The Olympic Games are one of the biggest sporting competitions among countries in the world. Its editions have always been the scene of intense disputes, not only for the athletes, but also for the nations, who want to gain greater power and influence by winning more medals than the others. The Berlin edition of the Olympic Games, held in 1936, for example, were used by Hitler as a way of demonstrating the strength of the Nazi regime. Likewise, during the Cold War, the United States and Soviet Union struggled to see which country was the most imposing.^[1]

Even with this intense competition between countries, the International Olympic Committee (IOC), responsible for organizing the Games, has never released an official ranking of nations. The best-known medal table of the Olympics is elaborated by the media and uses the lexicographic method. This method considers the sum of the gold medals won by each country and, only in case of a tie, takes into account the silver and bronze medals.^[2]

The lexicographic method can be criticized because it overvalues the gold medal and disregards that each modality distributes a different number of medals. In this way, a country that performs well in a modality that has many competitions, such as Athletics, tends to have a better position when compared to a country that is strong in a team sport, like soccer, which distribute only two gold medals, one in the male category and another in the female category.

For this reason, we proposed a method that, unlike traditional rankings to identifies the Olympic Powers of history, a set of countries that are the highlight of the Olympics in its many editions until today. The proposed method uses successive *h*-indexes^[3] and *h*-cores,^[4] and has the characteristic of considering each modality equally.

First, we need to recognize the Olympic Powers by evaluating the countries participating in each edition of the Olympic Games. So, we calculated the *h*-index of each modality in that edition and the nations present in its *h*-core are considered as powers of that modality. Then the countries that make up the *h*-core of each modality are aggregated, and we can calculate the *h*-index again, this time for that edition of the Olympic Games. The countries present in its *h*-core are the Olympic Powers of this edition. Again, we aggregated the nations that make up the *h*-core of each edition and we calculated the *h*-index for the set of all Olympic Games. Finally, the nations

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present in this *h*-core are considered the Olympic Powers of history of the Olympic Games.

It should be noted that the main quality of the proposed methodology is that it is not necessary to define the number of Olympic Powers a priori. This quantity is determined by the properties of the *h*-index and the *h*-core, which contributes to eliminate any subjectivity in the method of choice. Some other advantages of this method are its simplicity and easy understanding, characteristics resulting from the *h*-index.

This study brings contributions to advance scientometric research and to sociology, since it proposes a new application of scientometric methods for the evaluation of sporting events, which can be treated as a social phenomena. In other hand, the study encourages the application of successive *h*-indexes and *h*-cores, which are generally used in traditional scientometric studies, to analyse the performance of the countries in the history of the Olympic Games, which can draw important insights of countries investments and policies, as pointed out in^[5] and^[6] or be used as a way to generate subjective well-being,^[7] articulate pride and stimulate national cohesion.^[8-10]

The present article is organized as follows: in section 2 in we present a brief review on the construction of rankings in sports competitions, in section 3 we present the concepts of *h*-index and *h*-core. We detail the proposed methodology in section 4, and in section 5 we analyse the results obtained. Finally, we describe in section 6 the conclusions of the study and some final considerations.

A review of sports ranking

As previously mentioned, the International Olympic Committee, responsible for organizing the Olympic Games, has never published an official ranking of participating countries. However, the media usually publishes an unofficial ranking using the lexicographic method.^[2]

In this method, countries are ranked according to the total amount of gold medals obtained, and only in the case of a tie, silver and bronze medals are taken into consideration. As pointed out by Lins *et al.*^[2] this method has the disadvantage to overvalue the gold medal. In other words, countries that win a high number of silver and bronze medals but none of gold are ranked below countries that have won a single gold medal. In addition, the method privileges countries that are better in certain modalities that have many categories and distribute many medals, such as athletics and swimming. For these and other reasons, this ranking, although widespread, is not unanimous, and several other methods of ranking have been proposed, both for the Olympic Games and for other multimodal competitions.

For example, Lins *et al.*^[2] proposed a ranking based on Data Envelopment Analysis (DEA) to examine the results of

Sidney 2000 Olympic Games. They considered the number of all types of medals won by each country as outputs and the population and Gross Domestic Product of that country as the resources to win those medals. The zero-sum gains DEA model (ZSG-DEA) was required because the total number of medals to be won is constant. Several other authors have used the concepts of DEA to elaborate rankings.^[11-14]

Moreover, many studies using Multicriteria Decision Support to elaborate rankings can be found in the literature^[15-17] and several other methodologies for elaboration of fairer rankings.^[18,19]

Wittkowski *et al.*^[20] highlighted that in many sport competitions athletes, teams, or countries are evaluated based on several variables, and the strong assumptions underlying traditional 'linear weight' scoring systems (that the relative importance, interactions, and linearizing transformations of the variables are known) can often not be justified on theoretical grounds. Therefore, they used μ -scores that allows integrating information of several variables even if the variables have different scales and unknown interactions or if the events counted are not directly comparable.

In another aspect, Daud *et al.*^[21] relied on the *h*-index and PageRank to propose a ranking method to evaluate cricket teams. Reis *et al.*^[22] also relied on the *h*-index to build a simple and objective ranking in competitions involving several countries. It is noteworthy that the methodology developed in this study was based on this article.

Some remarks about *h*-index and *h*-core:

Developed by Hirsch,^[3] the *h*-index aims to evaluate the scientific production of researchers and considers the number of citations that an author's publications received. We can calculate the *h*-index by identifying the *h* publications of an author who received at least *h* citations.^[3] The higher the *h*-index of a researcher, the greater the impact of their work and the greater their productivity.^[23]

The *h* index has always been the subject of much discussion. Many authors have even proposed alternative indexes to complement or replace it.^[24-26] In a recent study, Brandão and Soares de Mello^[27] have studied the *h*-index considering the multi-criteria fundamental axioms of coherence and pointed that the number of publications and citations alone are not a coherent criteria family. However, many platforms like SCOPUS and Web of Science use the *h*-index in its original function to measure the academic productivity of each author.

In addition, in the literature there are several studies using the concepts of *h*-index for other applications, for example, in education, without the focus of the evaluation of the researchers,^[28,29] in paper review and journal rankings,^[30,31] in business and management field,^[32,33] in molecular science,^[34] in graphs,^[35] in transport^[36] and in sports.^[21,22]

Related to *h*-index is the concept of *h*-core. In the *h*-core are the main publications of an author and it consist of the *h* most cited publications of that author. It can be said that the *h*-core delimits the choice of the main items of a list. In general, the *h*-core is made up of *h* items. However, in case of ties, i.e., more than one publication with the same number of citations, the number of items in the *h*-core may be more than *h* items. Some authors proposed methods to define which publications should remain at the *h*-core,^[37] whereas others, such as Burrell,^[38] defend cases in which all items are considered *h*-core components.

Schubert^[39] introduced the concept of successive *h*-indexes, whose main parameter is to calculate an *h*-index of a set of *h*-indexes. In the literature, some authors have already performed the calculation of successive *h*-indexes such as^[40] and,^[37] however, the applications did not consider the successive *h*-core obtained.

METHODOLOGY

An Olympic Power is a nation that stands out in various modalities of the Olympics. In addition, an Olympic Power in the history of the Olympics is a country that performs well in multiple modalities in various editions of the Olympics.

We will use the lexicographic method to elaborate the ranking of each sport, instead of all sports grouped together. As we evaluate the sports separately, each sport will have the same weight in our method. Thus, we avoided that the difference between the numbers of medals distributed by each modality generates an influence in the final ranking. In this way, we want to eliminate the advantage of a country that performs well in a modality that has many competitions, such as Athletics. In the usual ranking, a country tends to have a better position when compared to a country that is strong in a team sport, like soccer, which distribute only two gold medals, one in the male category and another in the female category.

In order to identify the Olympic Powers of each modality, or Olympic Games, we should determine how many nations, among the best ranked, deserve this appointment. As this decision may be different for each decision maker, we will use the concepts of *h*-index and *h*-core to avoid subjectivity to identify the Olympic Powers.

The method will consist of two steps, which will be carried out in succession in three phases to achieve the objective of the study. In the first phase, we will identify the sporting powers of each modality of the Olympics. In the second phase, we will find the Olympic Powers of each edition, and in the third phase, we will obtain the Olympic Powers of history.

We can make an analogy with the calculation of the *h*-index and the *h*-core in the traditional way (for the evaluation of

researchers). In the present study, each country represents an article. In addition, in the first phase, when evaluating each modality, we can relate the number of gold medals to the number of citations. In the second phase, the evaluation is made for each edition of the Olympic Games and the number of citations is the number of times a country has been in the *h*-core of each modality. In the last phase, the Olympic Games in general (all the editions together) are evaluated, being the number of citations the amount of times that a country is in the *h*-core of an edition of Olympic Games.

We summarized the phases and steps in the Figure 1. In the first phase of the method, we obtain the countries that are the powers of each modality for each edition of the Olympics. We must follow the two steps of first phase for each modality in each edition of the Olympic Games to obtain the Sporting Powers of each modality. Then, we must execute the second phase. In the second phase, we obtain the Olympic Powers of each edition of the Olympic Games. We must follow the two steps of second phase for each edition of the Games to obtain the Olympic Powers of each edition. Finally, we must perform the third phase in which we obtain the Olympic Powers of history. For that, we need to execute the same two steps in third phase.

We can note that there is a pattern of repetition of the method, that is, the *h*-index and the *h*-core are calculated successively. First, to identify the sporting powers, then for the achievement of the Olympic Powers of each edition, and finally to find the countries that are the historical powers of the Olympics.

In all phases of the methodology, if the number of countries in an *h*-core is greater than the value of the *h*-index (this can possibly occur when there are ties between countries that have exactly the analyzed value equal to the *h*-index), all these countries will be considered as powers.

It is worth mentioning that we can use the same methodology to identify potentials in different fields, besides sports. For

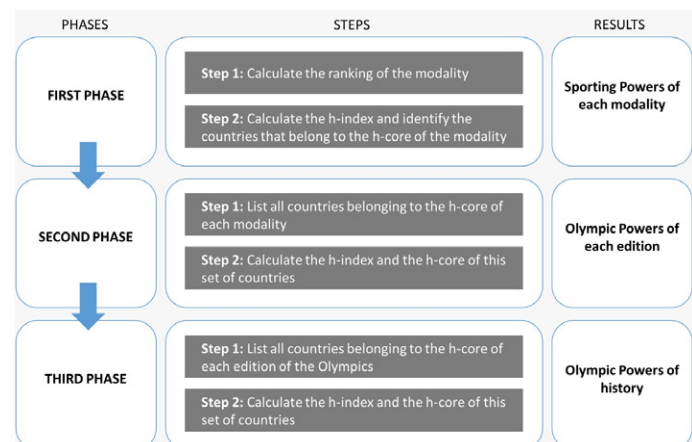


Figure 1: Phases and steps of the methodology.

example, we can identify those authors who are references in a group of journals or in a certain area of knowledge.

Case Study

The first edition of the Olympic Games took place in Athens in 1896, where only 241 men competed in 10 different modalities. Since then, every four years new editions have been made, each of which is based in a city. In 1916, 1940 and 1944, the Games did not occur because of World War I and World War II.

The last edition of the Summer Olympic Games took place in Rio de Janeiro in 2016, where 11,237 athletes competed for 306 gold medals in 39 different modalities. We can notice that the Olympics gained a lot of prestige over the years, with more athletes and more countries competing, and more modalities to be played.

Among the different modalities, only athletics, swimming, fencing and artistic gymnastics, were present in all editions of the Olympics. Some sports came first as a demonstration, to become Olympic, like Volleyball. Whereas other sports were considered Olympic and later, they were withdrawn of the program, case of Tug of War and the Croquet, disputed in Paris 1900.

According to the IOC, for a modality to be considered Olympic, it must be organized by an International Federation, must comply with the Olympic Charter, apply the World Anti-Doping Code and be widely practiced in the world.^[41] At the next Olympics to be held in Tokyo, five new modes have been added: surfing, baseball, skateboarding, karate and climbing.

RESULTS AND DISCUSSION

We applied the methodology described in section 3 to the Olympic Games to identify the Olympic Powers of the Olympics' history. Thus, we separated the achievements of the countries in each edition of the Olympics by modalities. We decided to use the classification of modalities according to the IOC.

Firstly, we applied the first phase, where the sports powers were found and then the second phase, which highlighted the Olympic Powers of each edition of the Games.

Thus, the Table 1 shows the Olympic Powers of each Olympics, as well as the *h*-index of each edition. We can note from the results shown in Table 1 that the *h*-index tended to grow over the years, varying from 2 to 5. This was because the number of modalities increased, so a country today has greater chances of be a power in some sports than it used to be.

The Olympics of Moscow 1980 and Los Angeles 1984 stand out for their low value of *h*-index that does not follow the

highlighted tendency. These cases are justified by political boycotts of the countries due to the Cold War, which has made a smaller number of countries participate in competitions in these editions.^[1]

We can also note in Table 1 that some editions of the Olympics had more nations in the *h*-core than the value of the *h*-index of the edition. It is the case of Athens 1896, Melbourne/Stockholm 1956, and Montreal 1976. This happened because there was more than one country in each of these positions on the *h*-index cut line, so all tied countries were considered Olympic Powers.

An interesting feature to be analysed is home advantage. There are many papers that study the impact of home advantage on the Olympic games, such as.^[42,43,6] In 20 of the 28 editions, we identify the host country as an Olympic Power of that Olympics, which shows signs of home advantage. In addition, when countries discover that they will host the Games, they tend to invest more in sports, which also can justify the best performance.

The third and last phase of the methodology aims to find the countries that are the Olympic Powers of all the Olympics. Table 2 describes the results.

According to the method, the countries designated as Olympic Powers in the history of the Olympics are: USA, USSR, Germany, United Kingdom, China and Russia, as they were the six countries that were Olympic Powers in at least 6 editions of the Games.

It is important to note that, between the years 1896 and 2016, we can observe several geopolitical changes, such as the division and later reunification of Germany, and the creation and subsequent fragmentation of the Soviet Union. In this study, we decided to group the countries according to the understanding of the time in which they won the medals. Thus, we considered separately Russia, USSR and Unified Team (team created in the 1992 Games with former members of the USSR) and Germany, East Germany and West Germany.

However, this did not prevent the USSR, Germany and Russia from being named Olympic Powers. Even though they did not participate in many of the editions, the dominance of these nations was remarkable. For example, research indicates that Russians love the Olympic Games, because they are nationalists and because of their tradition.^[44] This tradition emerged after the Second World War, with the desire of the USSR to become an Olympic power.^[45] As a result, since 1952, the USSR or Russia have been Olympic powers in all editions of the Olympic Games, except in 1984 and 1992.

Table 1: Olympic Powers of each Olympics.

City	Year	H-index	Olympic Powers (h-core)
Rio de Janeiro	2016	5	United Kingdom, USA, China, Russia and Germany
London	2012	5	USA, United Kingdom, China, Russia and France
Beijing	2008	4	China, USA, Russia and Germany
Athens	2004	4	Russia, USA, China and Germany
Sidney	2000	4	Russia, USA, China and Australia
Atlanta	1996	4	USA, Russia, Germany and China
Barcelona	1992	4	Germany, Unified Team, USA and China
Seoul	1988	4	USSR, USA, West Germany and South Korea
Los Angeles	1984	3	USA, West Germany and Romania
Moscow	1980	2	USSR and East Germany
Montreal	1976	4	USSR, USA, West Germany, East Germany and Japan
Munich	1972	4	USSR, USA, West Germany and East Germany
Mexico City	1968	3	USSR, USA and Hungary
Tokyo	1964	4	USSR, USA, Hungary and Japan
Rome	1960	3	USSR, USA and Italy
Melbourne/ Stockholm	1956	3	USSR, USA, Hungary and Sweden
Helsinki	1952	3	USA, Hungary and USSR
London	1948	3	USA, Sweden and France
Berlim	1936	3	Germany, USA and Hungary
Los Angeles	1932	3	USA, Italy and France
Amsterdam	1928	2	USA and Germany
Paris	1924	3	USA, France and Switzerland
Antwerp	1920	3	United Kingdom, Sweden and USA
Stockholm	1912	2	Sweden and United Kingdom
London	1908	2	United Kingdom and USA
St Louis	1904	2	USA and Canada
Paris	1900	2	France and United Kingdom
Athens	1896	2	Greece, USA, Germany and United Kingdom

Table 2: Olympic Powers of history.

Country	Number of times that it appears in a h-core of an Olympics	Proposed Ranking
USA	25	1
USSR	9	2
Germany	8	3
United Kingdom	7	4
China	7	4
Russia	6	6
France	5	7
Hungary	5	7
Sweden	4	9
West Germany	4	9
East Germany	3	11
Italy	2	12
Japan	2	12
Greece	1	14
Unified Team	1	14
Canada	1	14
Romania	1	14
Switzerland	1	14
Australia	1	14
South Korea	1	14

Table 3: Comparison between the proposed and the lexicographic method.

Proposed Ranking		Lexicographic Ranking	
1	USA	1	USA
2	USSR	2	USSR
3	Germany	3	United Kingdom
4	United Kingdom	4	China
4	China	5	France
6	Russia	6	Italy
7	France	7	Germany
7	Hungary	8	Hungary
9	Sweden	9	West Germany
9	West Germany	10	Russia

Also noteworthy in Table 2 is the great performance of the USA, which were Olympic Power of 25 of the 28 editions of the Olympics.

Although the goal of the proposed methodology is not to generate a final ranking but to identify the Olympic Powers in the history of the Games, the Table 3 shows a comparison between the ranking generated by the proposed and by the Lexicographic method for the top ten positions.

We can note that comparing the two methods, the first two positions of the ranking remain the same: first USA, followed by USSR. This means that historically these nations won a large amount of gold medals, 1022 and 395, respectively, but

have also been successful in a wide variety of sports, which is why they are considered the great champions in the general scenario.

However, Germany that was identified as an Olympic Power by the proposed method, being the 3rd nation of all Summer Olympic Games, in the lexicographic ranking appears only in the 7th position. And Russia, also a member of the h core and classified as an Olympic Power, appeared only in the 10th position of the Lexicographic ranking.

On the other hand, France and Italy (5th and 6th position, respectively, in the Lexicographic ranking), which have many medals won, have not been able to be an Olympic Power in many Olympics, possibly because they invest only in certain modalities that guarantee many victories and do not diversify as much as the United Kingdom, Germany and Russia. Italy does not even appear in the list of the top ten generated by the proposed method.

CONCLUSION

In this study, we aimed to identify the Olympic Powers in the history of the Olympic Games, that is, the countries that can be considered the greatest champions in the overall panorama. For this purpose, we developed a methodology based on the application of successive calculations of *h*-indexes and *h*-cores. The main quality of the proposed methodology is that it is not necessary to define the number of Olympic Powers a priori. The properties of the *h*-index and the *h*-core determine this quantity, which contributes to eliminate any subjectivity in the choice of countries that deserve to be classified as Olympic Powers.

At the end of the study, we named six countries as the Olympic Powers of history by the proposed method, they are: USA, USSR, Germany, UK, China and Russia.

One feature of the proposed method is that it equates the outstanding countries in sports that distribute many gold medals to countries that win medals in team sports, in which a single medal rewards a group of athletes. In addition, it also benefits nations investing in various distinct modalities, such as the United Kingdom, Germany and Russia.

Note that, for a country to be considered an Olympic Power it must have good representatives in various sports and stand out in various modalities; it is not enough to specialize in a single sport. Similarly, an Olympic Power in history is that country that consistently works well in various editions of the Games. Thus, to be considered a power, the nation must be consistent in its investments and sports programs to present consistent results over the years.

As a study limitation, we can identify the difficulty of defining which sports correspond to a modality, since this analysis is subjective. In addition, for similar studies, data collection may be difficult. As improvements, we suggest the application of other successive bibliometric indices to find powers, such as the *g*-index^[24] and the *R*-index.^[25]

A great advantage of the method is its simplicity, since the calculation of the *h*-index and the *h*-core is easy and can be easily understood by all. It is also important to highlight that we can use the same methodology to identify potentials in different fields, besides sports. For example, it is possible to

identify the greatest authors in each field of study, such as Sociology. In this case, the authors would be the countries, their publications their medals, and each journal an edition of the Olympic Games. Another option would be to identify the greatest universities in relation to their publications. In this case, each department would be a country, its publications would correspond to their medals and each university would be an edition of the Olympic Games.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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