

# Inflammation biomarker and physical exercise: a bibliometric study

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**Abstract.** Physical exercise is widely recognized not only for its role in improving physical fitness and functional capacity, but also for its significant impact on various biological systems, including the immune response and inflammation. This study aims to determine research trends on inflammatory biomarkers and physical exercise over a 10-year period. Data collection was conducted based on the Scopus database. The database was then visualized using the VosViewer program. Based on a bibliometric analysis of 667 publications on inflammatory biomarkers and physical exercise from 2015 to 2025, the most research trends were found in 2024 with 84 publications, followed by 2018 with 79 publications and 2019 with 71 publications. Mapping the development of research publications based on keywords (co-occurrence) related to the relationship between physical activity and inflammation is in 8 clusters, while based on authors there are 6 author clusters consisting of 38 items. Co-citation analysis shows Cohen J and Statistical Power appear most prominently in the middle and are the brightest in color, indicating that these references are highly cited or have strong links with other sources. This research can be a consideration in determining research related to inflammatory biomarkers and physical activity.

## 1 Introduction

Physical exercise is a form of physical activity performed in a planned and structured manner with the goal of improving or maintaining physical fitness and overall health. There are various types of physical exercise, including aerobic exercise, strength training, and flexibility training. However, the intensity and duration of exercise can vary significantly between individuals, making assessing the effectiveness of an exercise program challenging.

Inflammation is triggered by the innate immune system after cells detect infection or tissue injury. Inflammation can be divided into acute and chronic, each characterized by distinct pathways. Acute inflammation is a temporary response of the body that is beneficial to the organism, while chronic inflammation is often associated with impaired function and tissue damage. The inflammatory response can be triggered by infection, physical injury, or exercise, and is under the control of the immune system. Physical activity acts as a form of physiological stress that can disrupt various body systems,

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including metabolic pathways, blood circulation, hormones, and body temperature regulation, causing imbalances or disruptions in homeostasis [1].

Exercise is known to cause small physiological damage to muscle tissue, known as 'microtrauma.' This damage triggers muscle repair and restructuring, allowing the muscle to adapt to increased workload. The result of this process is muscle growth (hypertrophy) and the formation of new blood vessels (angiogenesis).

After exercise, pro-inflammatory compounds and salivary IG-A decrease, while anti-inflammatory cytokines increase, suppressing immune function. Cortisol drives the immune response toward anti-inflammatory, reducing the number and activity of T cells, natural killer cells, macrophages, and granulocytes, and increasing the neutrophil/lymphocyte ratio. Leukocytes migrate to damaged muscle to clean and repair the tissue [2]. Cytokines are part of a complex signaling pathway and play a role in the interaction between the immune and endocrine systems in response to various forms of physiological stress, including exercise.

Regular moderate-intensity exercise (<70% VO<sub>2</sub> max) increases anti-inflammatory cytokines (IL-10, IL-1ra), which promote tissue growth, blood vessel formation, and improve mitochondrial function. Exercise also stimulates ROS, but it is unclear whether the positive immune effects stem from adaptation or stress reduction. Regular physical activity over several months improves resting immunity, as evidenced by an increase in CD4 Th cells and a decrease in neutrophils. Over the long term, this strengthens the immune system, balances the Th1/Th2 ratio, and reduces inflammation. Immune effectiveness is also increased, as evidenced by a better vaccine response in individuals who exercise regularly [2].

Moderate-intensity exercise tends to trigger an anti-inflammatory response, while high-intensity exercise can activate pro-inflammatory pathways through cytokine production. For example, pro-inflammatory cytokines such as IL-1 show significant increases during high-intensity physical activity compared to lighter exercise in humans. This response is part of the long-term adaptation process to physical exercise, which is influenced by various factors such as the type of exercise, intensity, duration, level of exercise habit, age, and the individual's clinical condition. Four weeks of moderate-intensity aerobic exercise has been shown to reduce tumor necrosis factor-alpha (TNF- $\alpha$ ) levels. Conversely, high-intensity physical exercise or competitive activity tends to trigger a pro-inflammatory response. Heavy, prolonged exercise can also cause a temporary decrease in immune system function, a phenomenon known as the "open window" theory [3]. Immune system activation is a response to physiological stress, aimed at restoring cellular balance (homeostasis). One possible mechanism involved is changes in the distribution of white blood cells (WBCs) between the peripheral and central circulation. Inflammation plays a crucial role in maintaining homeostasis, particularly as an active defense against various harmful stressors, such as neurotropic viral infections or traumatic injuries, supporting the recovery of cell and tissue function. Both the innate and adaptive immune systems serve as the body's primary line of defense against infection [1].

One of the mechanisms involved Another factor contributing to the observed changes in cytokine levels is the effect of regular exercise on reducing body fat. Fat cells (adipocytes) are known to be a major source of pro-inflammatory cytokines, such as TNF-

$\alpha$  and IL-6. However, decreased cytokine levels can also occur even without weight loss or changes in body composition, suggesting other mechanisms are at play, including the possible direct anti-inflammatory effects of exercise on immune cells.

While exercise carries certain risks, including immunodepression, increased inflammation, or even more severe complications, these risks tend to occur only with excessive or irregular exercise. When performed in moderation, these risks are virtually nonexistent, while the benefits are clear and undeniable. The benefits of physical exercise are well-known and widely accepted in the scientific world. Several studies have recognized the anti-inflammatory properties of exercise, particularly in the elderly population, and underscore the importance of practicing some form of exercise program, even at an advanced age.

Research has shown that resistance training can lower CRP levels in patients with type 2 diabetes (T2DM). Factors such as age, comorbidities, duration of intervention, and blood glucose levels do not significantly influence CRP reduction, except for baseline HbA1c levels, which, if high, can reduce the anti-inflammatory effects of exercise [4]. A single exercise session causes significant changes in the number and composition of blood leukocytes that can persist well into the post-exercise recovery period. All major leukocyte subpopulations tend to increase in number during exercise as a result of hemodynamic shear stress and/or catecholamines acting on leukocyte  $\beta$ 2-adrenergic receptors. The post-exercise recovery period is characterized by opposing effects on blood neutrophil and lymphocyte counts. Neutrophil counts (and, consequently, total leukocyte counts) often continue to increase well into the recovery period (up to 6 hours after cessation of exercise), especially if the exercise session is extended beyond 2 hours.

Through this approach, researchers can evaluate the literature in a field of study to understand the conceptual structure and identify the development of research themes. This study aims to identify research trends in the field of inflammation and physical activity through a bibliometric approach. By analyzing published publications, this study attempts to observe the development patterns of scientific studies over time and map topics that have been widely studied and those that have not been addressed. It is hoped that the results of this study will provide a comprehensive overview of research directions in this field and open up opportunities for exploring potential, under-researched topics in the future.

## 2 Method

The research data used were sourced from the Scopus database. The data collection date was August 9, 2025, and a total of 667 articles were retrieved from 2015-2025, using the keywords "biomarkers of inflammation" and "physical exercise." This study employed a bibliometric analysis related to physical activity and inflammation, limited to human research. The research data used were sourced from the Scopus database. The data collection date was August 9, 2025, and a total of 667 articles were retrieved from 2015-2025, using the keywords "biomarkers of inflammation" and "physical exercise." The data were obtained using the Scopus database and stored in comma-separated values (CSV) format. The collected data will then be visualized in VosViewer software to view data

related to co-authorship, co-occurrence, and citations, using three visualization categories: network visualization, overlay visualization, and density visualization.

According to Donthu et al. [5], several steps are taken in bibliometric analysis, including:

1. Determining the purpose and scope of bibliometrics to uncover the research's content and breadth of material. Publications ranging from five hundred to thousands of papers are considered extensive, while publications ranging from tens to three hundred are considered small and therefore do not warrant the use of bibliometric analysis.
2. Choosing a technique for bibliometric analysis: analytical or descriptive. Descriptive analysis provides information regarding the number of publications and citations. Analytical analysis presents data by interpreting the meaning and implications of the database used. A combination of both is possible.
3. Paying attention to the scope of data collection, aiming for a broad yet relevant scope, such as titles, abstracts, and keywords for co-word analysis. Unavailable data should be reviewed to avoid bias. The use of specific databases (e.g., Scopus or Web of Science) is recommended to avoid errors in data consolidation.
4. Conduct bibliometric analysis and report the results in an academic paper. The analysis and writing process should be treated as an integrated activity, as network visualization and cluster identification not only support the scientific narrative but can also evolve along with the needs of the article. Writing up the results should not be limited to presenting a data summary but should also include visualizations in the form of graphs and tables, as well as interpretive and contextual analysis, to produce a discussion that is not merely descriptive but also conceptually meaningful.

To identify the most frequently occurring keywords, co-occurrence analysis is used by first setting a minimum frequency threshold for keyword occurrence. In this study, VOSviewer software was used to conduct bibliometric analysis, encompassing co-authorship, co-occurrence, citation, bibliographic coupling, co-citation, and theme mapping. VOSviewer was also used for data exploration and network visualization. Keywords and countries are indicated by colored circles, where the circle size reflects the frequency of occurrence of the word or entity. The higher the frequency, the larger the size of the label and circle.

### 3 Results and Discussion

#### a. Annual Publication

Trends Research related to inflammation and physical exercise in Scopus-indexed journals yielded 667 documents. To obtain specific results, non-human studies were excluded.

Year	Publication	Percentage
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2015	41	6%
2016	40	6%
2017	51	8%
2018	79	12%
2019	71	11%
2020	68	10%
2021	65	10%
2022	54	8%
2023	59	9%
2024	84	13%
2025	55	8%

Table 1.1 Number of Inflammatory and Exercise Biomarker Studies Published in 2015  
Source: Scopus

Table 1.1 shows the trend in the number of publications from 2015 to 2025. There was a significant increase from 2016 (40 publications) to a peak in 2024 (84 publications). An increase was also seen in 2018 (79 publications), marking an initial surge. Although there were fluctuations in the following years, the general trend shows an increase in the number of publications compared to the beginning of the period. A decline occurred again in 2025 (55 publications), but it remained higher than in the earlier years. This finding indicates that interest in and productivity of publications is growing, although not consistently so each year.

b. Development of publications by author (co-authorship)

Selected	Author	Documents	Citations	Total link strength
<input checked="" type="checkbox"/>	bherer, louis	2	49	44
<input checked="" type="checkbox"/>	d'alicandro, giovanni	3	22	43
<input checked="" type="checkbox"/>	erickson, kirk i.	3	23	43
<input checked="" type="checkbox"/>	friso, giulia	3	22	43
<input checked="" type="checkbox"/>	gentile, luca	3	22	43
<input checked="" type="checkbox"/>	lombardo, barbara	3	22	43
<input checked="" type="checkbox"/>	mennitti, cristina	3	22	43
<input checked="" type="checkbox"/>	pero, raffaella	3	22	43
<input checked="" type="checkbox"/>	scudiero, olga	3	22	43
<input checked="" type="checkbox"/>	masquo, deborah cristina landi	5	94	42
<input checked="" type="checkbox"/>	mota, jorge	5	92	37
<input checked="" type="checkbox"/>	tock, ilan	4	90	37
<input checked="" type="checkbox"/>	corella, dolores	2	32	36
<input checked="" type="checkbox"/>	estruch, ramón	2	32	36
<input checked="" type="checkbox"/>	guinan, emer m.	2	105	36
<input checked="" type="checkbox"/>	martinez, j. alfredo	2	32	36
<input checked="" type="checkbox"/>	pintó, xavier	2	32	36
<input checked="" type="checkbox"/>	salas-salvadó, jordi	2	32	36
<input checked="" type="checkbox"/>	schröder, helmuth	2	32	36
<input checked="" type="checkbox"/>	serra-maiem, lluis	2	32	36

Figure 1. List of authors of research on inflammation and physical exercise in Scopus

## Network visualization of authorship

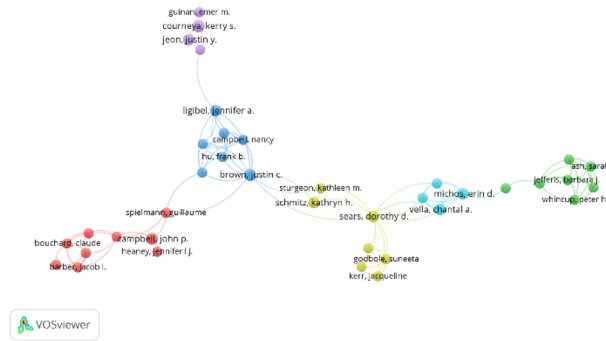


Figure 2. List of authors of research on inflammation and physical exercise in Scopus. Figure 1 shows a dataset of authors obtained by setting a minimum number of documents for each author of two. Figure 2 shows a network visualization of co-authorship, characterized by nodes (circles) representing the authors, and edges (networks) representing relationships between authors [6]. A collection of nodes with edges indicates a correlation or relationship between researchers in a study. Bibliometric analysis based on researchers or authors is shown in six clusters consisting of 38 items, including:

- Blue Cluster: Led by authors such as: Brown, Justin C., Hu, Frank B., Ligibel, Jennifer. This cluster serves as a link to many other clusters, including yellow, red, and purple.
- Red Cluster: Led by: Bouchard, Claude, Barber, Jacob. There is a thin connection to the blue cluster via Spielmann and Guillaume.
- Green Cluster: Ash, Sarah, Whincup, Peter H., Jefferis, Barbara J. shows minimal cross-cluster collaboration.
- Yellow Cluster: Sears, Dorothy D., Godbole, Suneeta, Kerr, Jacqueline, acts as a bridge between several clusters, including the blue and green clusters. This suggests that this group plays a significant role in connecting collaboration between groups.
- Purple Cluster: Guinan, Emer M., Jeon, Justin Y., consists of several authors and has limited connections, only through Ligibel and Jennifer A.
- Young / Cyan (around the center): Authors: Michos, Erin D., Vella, Chantal A., connected to the yellow and blue clusters, demonstrating cross-group collaboration.

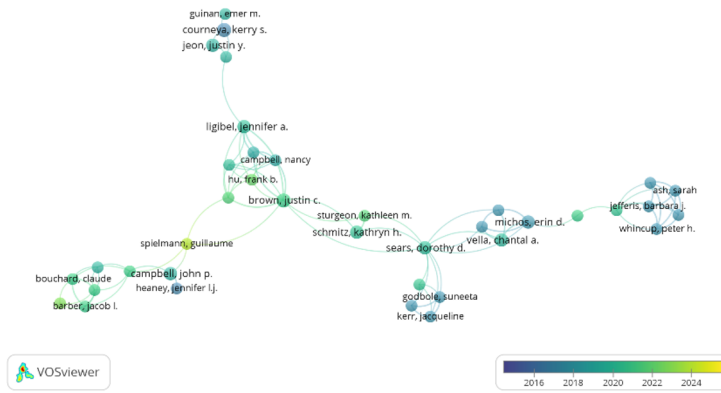


Figure 3. Overlay visualization of co-authorship

Overlay visualization depicting the historical trail of collaboration between authors in research on inflammation and exercise. This visualization is characterized by the presence of nodes of varying colors and connecting lines (edges) representing collaborative relationships between researchers. The color of the nodes indicates the time span of research activity, with darker colors reflecting involvement in earlier years, while lighter colors indicate more recent involvement. Authors such as Heaney, Jennifer L.J. and Spielmann, Guillaume are located in lighter (yellow) nodes, indicating their relatively recent involvement or increased involvement in recent years (2024). Conversely, authors such as Barber, Jacob L., Bouchard, Claude, and Jefferis, Barbara J. are located in darker nodes, indicating their activity earlier in the analysis period.



Bibliometric analysis was conducted using network, overlay, and density map visualizations to identify bibliometric relationships between articles or online publications based on collected metadata. This bibliometric network consists of nodes in the form of circles representing keywords, while edges depict the relationship between two nodes. The mapping and clustering processes in this analysis used the complementary VOSviewer software. Clustering also serves to provide an overview of the grouping patterns in the bibliometric data [7]. There were eight clusters: Cluster 1, consisting of 250 items, dominated by abdominal obesity, accelerometry, acetylsalicylic acid, adolescent obesity, and age. Cluster 2, consisting of 196 items, dominated by three categories: nitrotyrosene, adaptation, adaptation physiological, adult, and adverse event. Cluster 3 consists of 188 items) dominated by activities of daily living, African American, African Americans, amino terminal pro brain natriuretic peptide, angiogenesis. Cluster 4 consists of 170 items, dominated by adipose tissue, aged, aged, 80 and over, aging, aging. Cluster 5 consists of 77 items, dominated by absorptiometry, photon, adolescent, age factors, anthropometry. Cluster 6 consists of 62 items dominated by adiponectin, aerobic exercise, antidiabetic agent, antineoplastic agent, arterial wall thickness. Cluster 7 consists of 55 items consisting of acute phase protein, acute-phase proteins, adipocytokine, adipokines, adipoq protein, human. Cluster 8 consists of mental stress and psychological stress.

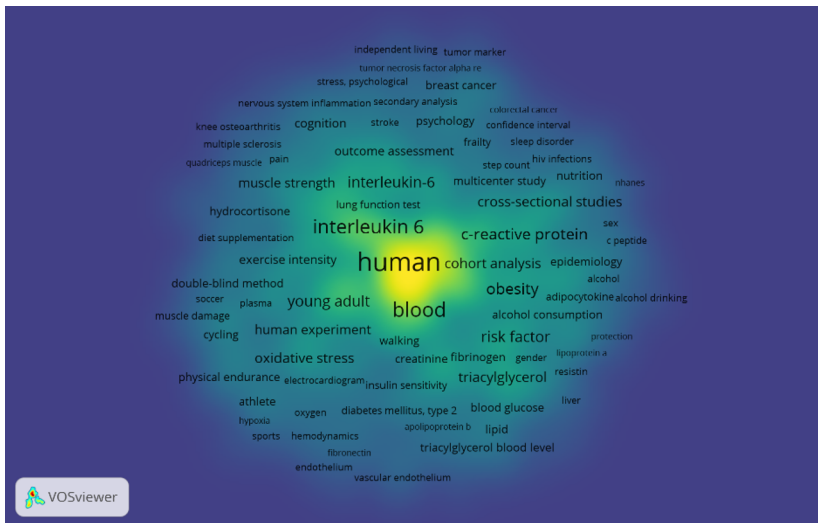


Figure 6. Density visualization of co-occurrence

The bibliometric analysis utilized density visualization. Based on the visualization results displayed in Figure 6, areas with high density between nodes can be identified. The yellow color, which appears as an indicator of saturation, indicates that these areas represent topics that have been extensively explored and indexed in Scopus, for example, the keywords human, blood, and interleukin 6. Bibliometric analysis using density visualization revealed a sparse distribution and low intensity of connections, indicating that studies on the gastrocnemius muscle are still relatively limited. This suggests that

this topic still has ample room for exploration in research related to inflammation and physical exercise.

d. Co-citation

Co-citation analysis is a method used to measure the relationships and connections between articles by calculating the frequency with which two articles are cited simultaneously by other articles.

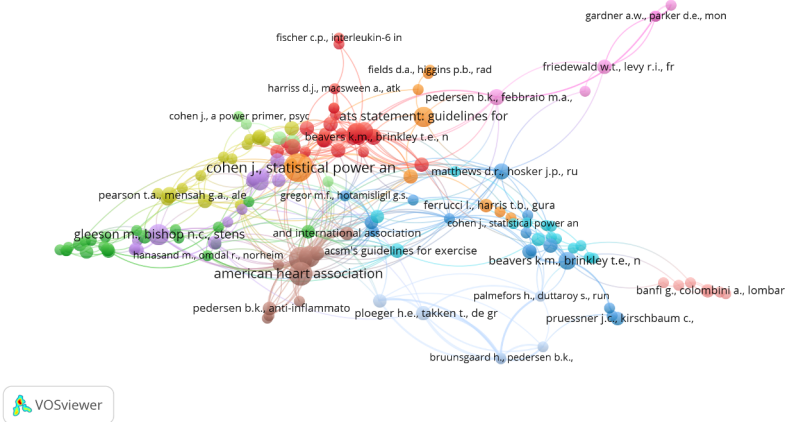


Figure 7. Network visualization of co-citation

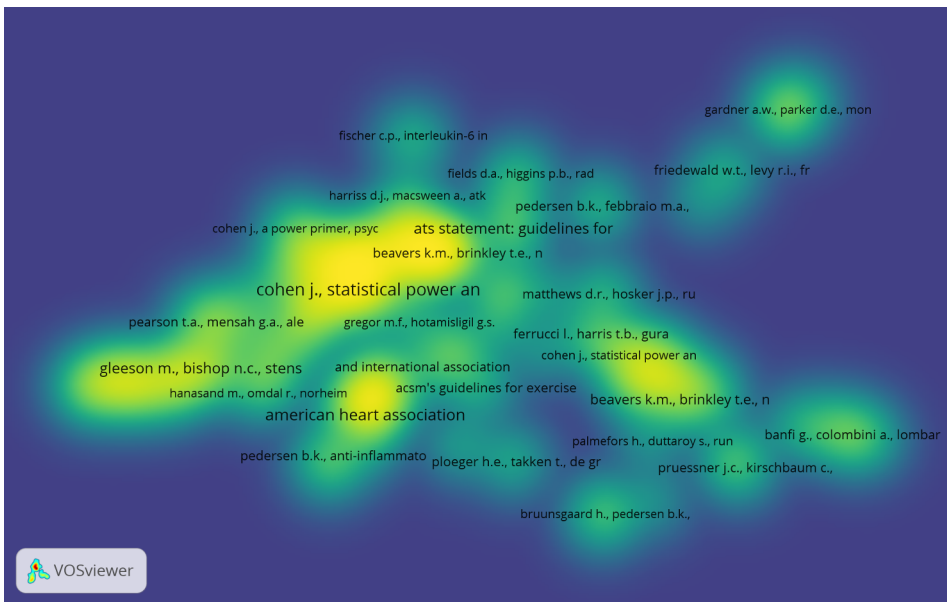


Figure 8. Density visualization of co-citation

Bright yellow indicates areas with high density (many citations or linked references). Green to dark blue indicate areas with lower density. The name "Cohen J., Statistical Power an" appears most prominently in the center and is the brightest in color, indicating that this reference is highly cited or has strong connections to other sources. Other names that are also quite central and frequently appear include: Gleeson M., Bishop N.C. Beavers K.M., Brinkley T.E. American Heart Association ATS Statement: Guidelines and Pedersen B.K.

## 4 Conclusion

This research shows that the application of Artificial Intelligence (AI) in Physical Education (PE) has continued to grow over the past five years, with primary applications being physical activity monitoring, motor skill evaluation, personalized learning, and gamification. Overall, AI has been shown to increase student motivation, strengthen assessment objectivity, and enable more adaptive and inclusive learning. However, infrastructure limitations, lack of teacher preparedness, and ethical and data privacy issues remain key barriers that require attention.

The practical implications of this research emphasize the importance of improving PE teachers' digital literacy and pedagogical competence, providing infrastructure support and clear policies regarding data privacy, and further research to explore the long-term impact of AI on motivation, participation, and physical education learning outcomes. With these steps, the use of AI in physical education can be more optimal and have a tangible impact on learning quality.

From a theoretical perspective, this research expands the literature on AI integration in education by emphasizing the role of technology as an agent of pedagogical transformation, not simply as a technical aid. These findings support a constructivist perspective that emphasizes the importance of adaptive feedback, interactivity, and personalization in learning, and open up space for the development of new conceptual frameworks related to technology-based physical education.

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