İnönü Üniversitesi, Beden Eğitimi ve Spor Bilimleri Dergisi (İÜBESBD), 2025, 12(2), 82-94
Inonu University, Journal of Physical Education and Sport Sciences (IUJPESS), 2025, 12(2), 82-94 e-ISSN: 2148-6786

THE INTERACTION BETWEEN ACUTE EXERCISE AND GUT MICROBIOTA: A BIBLIOMETRIC ANALYSIS

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ABSTRACT

In recent years, microbiota has emerged as a pivotal component in human health, intersecting dynamically with the field of exercise science. Despite the rapid development of this research area, comprehensive analyses regarding the thematic distribution of studies, prominent concepts, influential researchers, and institutions remain limited in the literature. However, identifying the current state and developmental trends of the field holds strategic importance for guiding future research. Accordingly, the aim of this study is to examine the relationship between exercise and microbiota through a bibliometric approach and to reveal multidimensional trends in the literature. The research was conducted within the framework of qualitative methods, specifically document analysis; the Web of Science database was solely used for data collection. The bibliographic data obtained (n=12) were analyzed using VOSviewer software. Three main bibliometric analyses were performed: (1) Keyword co-occurrence analysis was used to identify thematic foci and trends; (2) Institutional collaboration networks were analyzed to evaluate prominent universities and partnerships; (3) Author collaboration networks were used to assess the productivity and interactions of individual researchers. The findings indicate that studies in this field predominantly focus on endurance exercise and underlying biological mechanisms, while collaborations tend to be limited and fragmented. Although certain researchers and institutions stand out, there is a need for more international and multi-center studies in the field.

Keywords: Exercise, Microbiota, Microbiome, Bibliometric Analysis, Endurance Exercise

AKUT EGZERSİZ VE BAĞIRSAK MİKROBİYOTA ARASINDAKİ ETKİLEŞİM: BİBLİYOMETRİK BİR İNCELEME

ÖZET

Son yıllarda insan sağlığı üzerindeki belirleyici rolü giderek daha iyi anlaşılan mikrobiyota, egzersiz bilimiyle kesişen yeni ve dinamik bir araştırma alanı oluşturmaktadır. Ancak bu alan hızla gelişmesine rağmen, literatürdeki çalışmaların tematik dağılımı, öne çıkan kavramlar, etkili araştırmacılar ve kurumlar hakkında kapsamlı analizler sınırlı sayıdadır. Oysa alanın mevcut durumunu ve gelişim eğilimlerini ortaya koymak, gelecekteki araştırmaların planlanması açısından stratejik önem taşımaktadır. Bu doğrultuda, çalışmanın amacı egzersiz ve mikrobiyota ilişkisini bibliyometrik yaklaşımla inceleyerek literatürdeki eğilimleri çok boyutlu biçimde ortaya koymaktır. Araştırma, nitel yöntemlerden doküman incelemesi çerçevesinde yürütülmüş; veri toplama sürecinde yalnızca Web of Science veri tabanı kullanılmıştır. Elde edilen bibliyografik veriler (n=12) VOSviewer yazılımı ile analiz edilmiştir. Üç temel bibliyometrik analiz gerçekleştirilmiştir: (1) Anahtar kelime eşbirliği ile tematik odaklar ve eğilimler belirlenmiş; (2) Kurumsal işbirliği ağı ile öne çıkan üniversiteler ve işbirlikleri değerlendirilmiş; (3) Yazar işbirliği ağı ile bireysel araştırmacıların üretkenlik düzeyi ve etkileşimleri analiz edilmiştir. Bulgular, alandaki çalışmaların dayanıklılık egzersizleri ve biyolojik mekanizmalara yöneldiğini; işbirliklerinin ise genellikle sınırlı ve dağınık olduğunu göstermektedir. Bazı araştırmacılar ve kurumlar öne çıkmakla birlikte, alanda daha fazla uluslararası ve çok merkezli çalışmaya ihtiyaç duyulmaktadır.

Anahtar kelimeler: Egzersiz, Mikrobiyota, Mikrobiyom, Bibliyometrik Analiz, Dayanıklılık Egzersizi

INTRODUCTION

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In recent years, microbiota—a microbial ecosystem whose critical role in human health is increasingly recognized (Sekirov et al., 2010; Yamashiro, 2017)—has laid the foundation for a novel and dynamic research domain intersecting with exercise science (Mach & Fuster-Botella, 2017). Microbial communities within the human body, particularly in the gastrointestinal tract, are known to influence a wide range of physiological functions, from digestive processes (Antonio et al., 2018; Passos & Moraes-Filho, 2017) and immune responses (Magrone & Jirillo, 2013; Yoo et al., 2020) to metabolic pathways (Sittipo et al., 2018; Woting & Blaut, 2016) and neurological mechanisms (Geng et al., 2022; Ullah et al., 2023). The composition and functionality of these microbial structures are shaped by various lifestyle factors, including nutrition, environmental conditions, genetic background, and notably, physical activity (Hentges, 2012; Schiffrin et al., 2014). Exercise has been scientifically shown to regulate not only the musculoskeletal system but also systemic physiological processes (Hinchcliff et al., 2008; Kraemer et al., 2011). Accordingly, the interaction between exercise and microbiota has recently become a compelling area of research across both basic and clinical sciences.

Modulation of the gut microbiota through exercise is considered a potential therapeutic target, particularly in the management of chronic conditions such as obesity, type 2 diabetes (Cani, 2013; Passos & Moraes-Filho, 2017), cardiovascular diseases (Nesci et al., 2023), and inflammatory bowel diseases (Kaur et al., 2021; Passos & Moraes-Filho, 2017). Animal and human studies investigating the effects of exercise on microbiota have shown that physical activity can increase microbial diversity (Zhang et al., 2024), promote the abundance of anti-inflammatory species, and improve intestinal barrier functions (Cook et al., 2016; Jurdana et al., 2023). For example, regular endurance exercise has been reported to enhance the production of short-chain fatty acids, thereby supporting metabolic health (Clauss et al., 2021; Huang et al., 2022; Okamoto et al., 2019). These findings suggest that exercise may exert systemic effects indirectly through the modulation of gut microbiota.

Conversely, there is growing evidence that microbiota itself may be a determinant of exercise capacity (Marttinen et al., 2020; Moitinho-Silva et al., 2021; Zhang et al., 2024). Considering the role of microbial metabolites in energy production (He & Slupsky, 2014; Yin et al., 2021), muscle function, and fatigue (Hawley et al., 2025; Yang et al., 2025; Yin et al., 2021), an individual's microbial profile may influence their exercise performance. This

bidirectional relationship underscores the necessity of investigating both the effects of exercise on microbiota and the influence of microbiota on exercise responses.

Despite the rapid growth of this research area, there remains a scarcity of comprehensive analyses in the literature that examine the thematic distribution, key concepts, leading researchers, and institutions within the field. Yet, revealing the current status and developmental trends is of strategic importance for future research planning. Therefore, the aim of this study is to examine the scientific landscape of the exercise–microbiota relationship using a bibliometric approach and to present a multidimensional perspective on research trends in this domain. Three main analyses were conducted: (1) identification of thematic foci via keyword co-occurrence network analysis; (2) evaluation of institutional visibility and collaborations through institutional cooperation network analysis; and (3) assessment of individual researchers' productivity and collaboration levels through author cooperation network analysis. Through these analyses, the study offers a detailed portrayal of the most frequently discussed topics, prominent researchers, productive institutions, and scientific collaboration dynamics in the field.

MATERIALS AND METHODS

Research Design

This study was conducted within the framework of the document analysis method, one of the qualitative research designs. A bibliometric analysis technique was employed to systematically evaluate the current scientific output in the literature. During the study, only the Web of Science (WoS) database was used, and relevant data were retrieved in accordance with predetermined search criteria. Web of Science was chosen for its reliability as an internationally recognized index of scientific publications. Following the data collection phase, the exported bibliographic data (n=12) were analyzed using VOSviewer software (version 1.6.17). Three main bibliometric analyses were performed during the process. First, a keyword co-occurrence network was constructed to identify thematic foci and research trends in the literature. Second, an institutional co-authorship network was examined to evaluate the visibility of leading universities and their collaborative relationships. Third, an author co-authorship network analysis was conducted to reveal the scientific productivity and collaborative patterns of individual researchers.

Data Collection Process

The data collection process for this study was carried out on August 6, 2025, using the “advanced search” function in the Web of Science (WoS) database. The search was conducted using English keywords aligned with the research topic, and several filtering criteria were applied to narrow the scope to studies specific to the subject area. The criteria used in the filtering process are presented in Table 1.

Table 1. Filtering criteria used during data collection

Criterion	Description
Keywords	"acute exercise" AND "gut microbiota"
Subject Categories	All fields (no category restriction)
Document Type	Research articles
Time Span	All years (2016–2025)
Indexes	All indexes

As a result of applying the above filtering criteria, a total of 12 research articles were identified. The steps followed in exporting these articles are outlined below. Through the Web of Science interface, the “Export” option was used, and the "Tab Delimited File" format was selected. In the export window, the “All records on page” option was checked, and “Full Record and Cited References” was selected under the “Record Content” section. After finalizing all selections, the “Export” command was executed to download the relevant bibliographic records, which were then prepared for bibliometric analysis. These data were subsequently analyzed using VOSviewer to visualize the keyword co-occurrence, institutional collaboration, and author collaboration networks.

Data Analysis

The data analysis process of this study was conducted using VOSviewer (version 1.6.17), a software tool designed for visualizing bibliometric relationships. The bibliographic data of 12 research articles—retrieved from the Web of Science database using the keywords “acute exercise” and “gut microbiota”—were analyzed through this software. The following steps were followed within the VOSviewer interface: on the main screen, the "File" menu was accessed, followed by selecting "Create," and then the "Create a map based on bibliographic data" option was chosen. In the next step, "Web of Science" was selected as the data source,

and the Tab Delimited data files obtained from the identified studies were uploaded into the program.

In line with the research objectives, three main types of analyses were conducted. First, a keyword co-occurrence network was generated to identify thematic clusters within the research field. Second, a co-authorship analysis by organization was conducted to assess institutional visibility and collaboration. Third, a co-authorship analysis by author was carried out to examine individual researchers' publication productivity and collaboration levels. For each type of analysis, the "type of analysis" and "unit of analysis" settings within the VOSviewer interface were configured as presented in Table 2.

Table 2. VOSviewer analysis types and parameters

Analysis Type	Unit of Analysis	Counting Method	Threshold Value
Keyword Co-occurrence	All keywords	Full counting	1
Co-authorship (Organizations)	Organization	Full counting	1
Co-authorship (Authors)	Author	Full counting	1

In all analyses, a minimum threshold of one occurrence was applied. The number of elements (n) displayed on the visualization screen for each analysis unit was automatically determined by VOSviewer. As a result of this process, thematic clusters in the literature, as well as collaboration patterns among authors and institutions, were visualized, and the structural characteristics of the research field were revealed.

RESULTS

Based on the data obtained in this study, visualizations were generated for three distinct collaboration networks. Figure 1 presents the Keyword Co-occurrence Network Visualization, which reveals the interrelationships among key concepts in the research area. This network illustrates which keywords dominate the literature and the strength of the connections between them, thus highlighting the thematic concentrations in the field. Figure 2 displays the Institutional Collaboration Network Visualization, which analyzes the joint research conducted by different institutions and identifies which organizations hold central positions in terms of collaboration. Finally, Figure 3 shows the Author Collaboration Network Visualization, focusing on partnerships among individual researchers and identifying key focal points where academic collaborations are most concentrated. When these three visualizations are evaluated

together, they provide a comprehensive perspective on research trends, collaboration structures, and the directional flow of knowledge sharing within the field.

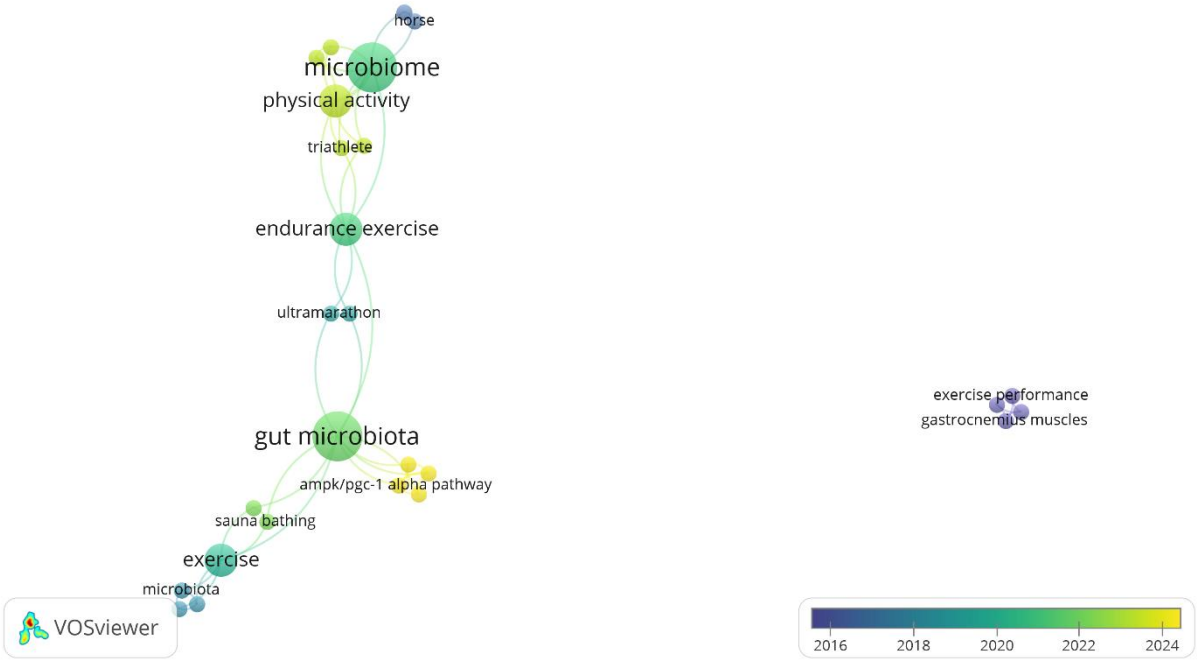

Figure 1. Keyword co-occurrence network visualization

Figure 1 presents the keyword co-occurrence network in the literature addressing the relationship between exercise and microbiota. This visualization, generated using VOSviewer software, represents each node (dot) as a keyword. The size of each node reflects the frequency of that keyword in the literature, while the lines between nodes indicate the co-occurrence of keywords within the same publications. The color scale illustrates the temporal distribution of keywords across the years, with blue tones representing studies closer to 2016 and yellow tones indicating more recent publications, closer to 2024. Upon examining the network structure, it is evident that the terms “microbiome,” “gut microbiota,” “endurance exercise,” and “exercise” are the most frequently used and centrally positioned concepts in the literature. This finding suggests that research in this domain has largely been shaped around the interaction between microbiota and exercise. The lighter-colored nodes representing terms such as “physical activity” and “triathlete” indicate a growing interest in these topics in more recent years. Similarly, terms referring to metabolic pathways—such as “AMPK/PGC-1 alpha pathway”—have also gained prominence in newer studies. On the other hand, keywords like “exercise performance” and “gastrocnemius muscles” appear isolated on the right side of the

visualization, relatively disconnected from the central network. This may suggest that these studies either do not directly address microbiota or belong to a distinct subcluster of the literature. In this context, the visualization reveals a growing emphasis on the interaction between various types of exercise—especially endurance training—and physiological mechanisms with the gut microbiota. Additionally, emerging topics such as sauna bathing and metabolic pathways appear to offer promising avenues for future research in this field.

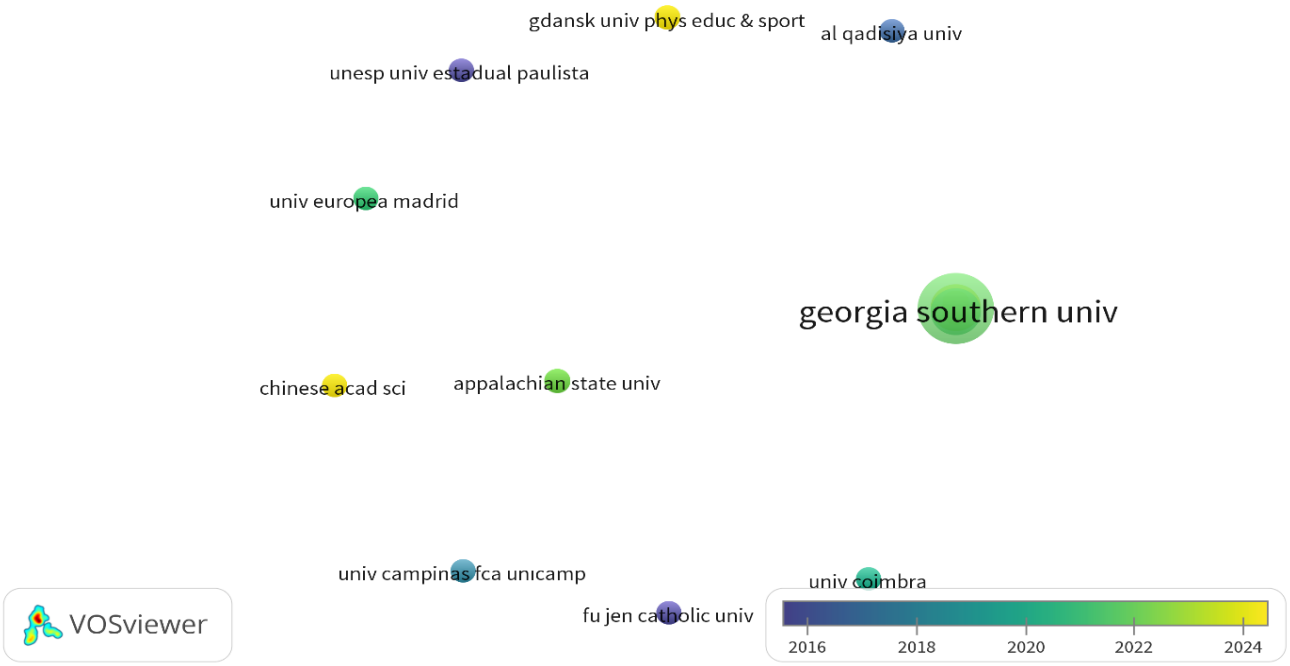

Figure 2. Institutional Collaboration Network Visualization

Figure 2 illustrates the structure of collaboration among universities contributing to academic publications on the topics of exercise and microbiota. In this network map, created using VOSviewer, each node represents a university. The size of a node corresponds to the number of publications affiliated with that institution, while the node colors indicate the average publication year, based on a chronological color scale. The absence of connections between nodes suggests a lack of co-authorship or formal collaboration between institutions. Upon examining the visualization, Georgia Southern University emerges as the most prominent node, indicating it is the most prolific institution in this research domain. The green color of the node suggests that its contributions have been particularly concentrated in the post-2020 period. In addition, institutions such as Appalachian State University, Universidad Europea de Madrid, and University of Coimbra also appear as moderate contributors. However, the overall network

lacks strong inter-institutional collaboration. Moreover, institutions represented in yellow—such as the Chinese Academy of Sciences and Gdansk University of Physical Education and Sport—appear to be more recent entrants into this field. In contrast, universities like UNESP (Universidade Estadual Paulista), Al Qadisiyah University, and Fu Jen Catholic University, depicted in dark blue, seem to have contributed during earlier years. A notable aspect of the network structure is its high degree of fragmentation and the absence of substantial collaboration links between institutions. This suggests that the majority of academic studies addressing the relationship between exercise and microbiota have been conducted within single institutions rather than through multi-institutional partnerships.

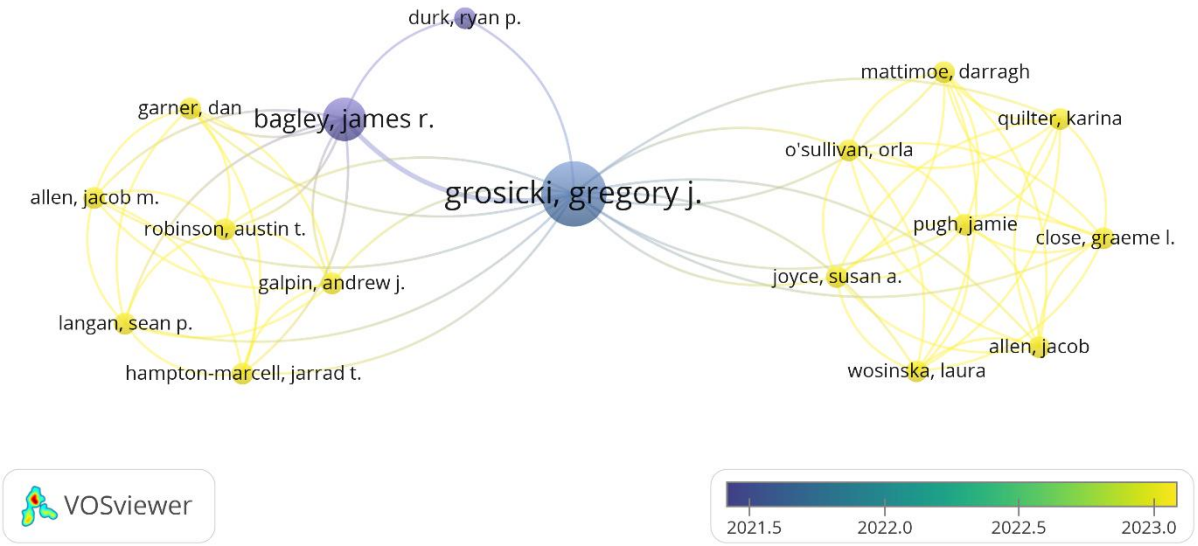

Figure 3. Author Collaboration Network Visualization

Figure 3 illustrates the collaboration network among authors who have published in the field of exercise and microbiota. In this network, generated using VOSviewer, each node represents an author, with the size of the node corresponding to the author's publication count or impact within the field. Connections between authors indicate co-authored publications, while the color and thickness of the links reflect the intensity and timing of these collaborations. The color scale represents the temporal distribution of collaborations: dark blue corresponds to 2021, and yellow indicates collaborations closer to 2023. Analysis of the network structure reveals that Gregory J. Grosicki holds the most central position, standing out as the author with

the most intensive collaborations. His strong and consistent partnership with James R. Bagley is particularly notable. Together, these two authors appear to serve as a bridge linking different research groups within the network. On the right side of the visualization, a newer group consisting of Susan A. Joyce, Jamie Pugh, Jacob Allen, Graeme L. Close, and Darragh Mattimoe is evident. The color scale indicates that this cluster has been particularly active in the 2022–2023 period, suggesting a recent intensification of collaborations. On the left side of the network, another group includes Andrew J. Galpin, Dan Garner, Austin T. Robinson, and Jarrad T. Hampton-Marcell. While this group also demonstrates strong internal collaboration, they appear to be connected to the broader network primarily through Gregory J. Grosicki. Overall, the structure of this author network indicates a multi-centered but interconnected collaboration landscape, with Gregory J. Grosicki playing a central, unifying role. Furthermore, the visualization highlights a notable increase in collaborative activity after 2022 and the emergence of new author groups contributing to the literature in this field.

CONCLUSION AND RECOMMENDATIONS

The bibliometric analyses conducted in this study comprehensively reveal how the relationship between exercise and microbiota has been structured within the scientific literature. The separate examination of keyword co-occurrence, institutional collaboration, and author collaboration networks has contributed to a deeper understanding of the thematic orientations, key actors, and collaboration dynamics in this research field.

According to the keyword analysis, the focal points of the research have coalesced around the terms “microbiome,” “gut microbiota,” and “exercise.” This highlights the significant emphasis placed on the relationship between microbiota and exercise in the literature. Notably, the growing prominence of terms such as “endurance exercise” and “physical activity” in recent years indicates an increasing interest in how endurance-based physical activities influence the gut microbiota. Furthermore, the emergence of terms like “AMPK/PGC-1 alpha pathway” in newer studies suggests a shift toward exploring biochemical and molecular mechanisms, moving beyond observational studies.

Certain keywords—such as “exercise performance” and “gastrocnemius muscles”—appear isolated from the core network, implying that some studies may have addressed exercise physiology without directly connecting it to microbiota, or that these studies belong to distinct

subfields. This suggests that the field is inherently interdisciplinary, shaped by various focal points and methodological approaches.

The institutional collaboration network indicates that scientific output in this field has predominantly been generated through intra-institutional efforts. While Georgia Southern University stands out as the most productive institution, there is little evidence of strong collaborative ties with other universities. The recent inclusion of institutions such as the Chinese Academy of Sciences and Gdansk University of Physical Education and Sport suggests that the field is geographically expanding. However, the overall fragmented structure and lack of interconnectivity within the network highlight the need for more extensive international collaboration in future research.

From the author collaboration network, a clear leadership structure can be identified. Gregory J. Grosicki plays a central role in terms of both publication output and collaborative diversity. His strong and sustained collaboration with James R. Bagley serves as a bridge linking otherwise separate author clusters. Meanwhile, a newer group comprising authors such as Susan A. Joyce, Jamie Pugh, and Jacob Allen has emerged more recently, reflecting a generational shift in research contributors and the formation of new, potentially influential research groups.

These findings indicate that both thematic and structural transformations are occurring in the field. Research is increasingly focusing on biological mechanisms, delving deeper into specific areas such as endurance exercise, and expanding through emerging collaborative efforts. Nonetheless, the limited scope of international collaboration underscores the necessity of creating a more integrated global research framework in the future.

Therefore, it is recommended that future studies promote more integrated and multi-center research structures. Such approaches would not only enrich the depth of the literature but also enhance the overall quality of scientific output. Additionally, translational research aimed at clinical applications may facilitate the transfer of scientific knowledge into public health strategies and exercise recommendations.

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