Bibliometric Review

Medicine

OPEN

Global research on muscular fitness in children and adolescents, 2004–2025

A bibliometric analysis of themes, authors, countries, and journals

Qiyali Wang, PhD[a], Zehan Xu, PhD[b], Dong Li, PhD[c], Yingzhi Zhu, MEd[d], Yuanyuan Hao, PhD[e], Cheng Zhang, PhD[f,*]

Abstract

Background: This study aimed to analyze the literature on muscular fitness in children and adolescents from 2004 to 2025, providing an overview of the research landscape, foundational studies, key research hotspots, and emerging trends in the field.

Methods: A bibliometric analysis was conducted using 1435 unique publications retrieved from the Web of Science Core Collection and Scopus, covering the period from January 1, 2004, to December 31, 2025. Performance analysis and science mapping were used to examine publication patterns, citation indicators, collaborative networks, co-citation structures, and keyword trends.

Results: A total of 1435 publications were identified across 497 journals. The United States (328 publications) and Spain (267 publications) were the leading contributors. The University of Granada was the most productive institution (114 publications), while Ortega FB was the most prolific author (63 publications). The most-cited publication received 2326 citations. Keyword analysis highlighted physical fitness, physical activity, muscular strength, and cardiorespiratory fitness as major research topics, while keyword burst analysis identified strength training as the strongest historical burst and physical education and physical performance as prominent recent topics.

Conclusions: Research on muscular fitness among children and adolescents has expanded substantially over the past 2 decades. The findings highlight the contributions of leading countries, institutions, and researchers, while identifying established themes and emerging areas of research attention. This bibliometric overview may inform future research priorities and facilitate scientific collaboration in youth muscular fitness research.

Abbreviations: ACI = average citation impact, PA = physical activity, WHO = World Health Organization, WoSCC = Web of Science Core Collection.

Keywords: bibliometric analysis, children and adolescents, muscular fitness, physical activity, strength training

1. Introduction

Muscular fitness is crucial to overall health and well-being among children and adolescents. These components are fundamental to their daily physical activity (PA), potentially preventing several chronic diseases.[1–5] The optimal development of muscular fitness during childhood and adolescence facilitates PA and promotes better metabolic health, body composition, and mental well-being.[6–10] The World Health Organization (WHO) underscores that a lack of sufficient PA and poor muscular fitness play a critical role in increasing the likelihood of developing chronic diseases, including obesity, type 2 diabetes, and cardiovascular conditions.[3,11] These factors have been identified as key contributors to long-term health complications.[2,12–14] Previous studies have examined health-related

This study was supported by the Key Research Project of Humanities and Social Sciences of Universities in Anhui Province: Research on the Theoretical Logic, Level Measurement and Implementation Path of New Productivity Promoting the High-Quality Development of the Sports Industry in the Yangtze River Delta (2024AH052837); Anhui Provincial College Humanities and Social Sciences Key Project: Collection, Arrangement and Research of Oral History Materials on Anhui Province's Intangible Cultural Heritage of Sports (2022AH052408).

The authors have no conflicts of interest to declare.

All data generated or analyzed during this study are included in this published article [and its supplementary information files].

Supplemental Digital Content is available in the online version of this article (http://dx.doi.org/10.1097/MD.0000000000051644).

[a] Sports Coaching College, Beijing Sport University, Beijing, China, [b] Business School, The University of Sydney, Sydney, NSW, Australia, [c] School of Physical Education and Health, Zhaoqing University, Zhaoqing, China, [d] School of Education and Information Studies, University of California, Los Angeles, [e] Department of Physical Education, Bozhou University, Bozhou, China, [f] Department of Physical Education, Tongji University, Shanghai, China.

** Correspondence: Cheng Zhang, Department of Physical Education, Tongji University, No. 1239 Siping Road, Yangpu District, Shanghai 200092, China (e-mail: Jack@tongji.edu.cn).*

Copyright © 2026 the Author(s). Published by Wolters Kluwer Health, LLC. This is an open access article distributed under the Creative Commons Attribution License 4.0 (CCBY), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

How to cite this article: Wang Q, Xu Z, Li D, Zhu Y, Hao Y, Zhang C. Global research on muscular fitness in children and adolescents, 2004–2025: A bibliometric analysis of themes, authors, countries, and journals. Medicine 2026;105:47(e51644).

Received: 2 September 2025 / Received in final form: 5 November 2026 / Accepted: 6 November 2026

http://dx.doi.org/10.1097/MD.0000000000051644

physical fitness, PA, and muscle-strengthening behaviors among children and adolescents.[7,15–19] Additionally, WHO reports that more than 80% of adolescents worldwide cannot achieve the recommended level of PA, making them more susceptible to several chronic diseases.[20–22] A European study found that only 19.4% of adolescents engaged in sufficient muscle-strengthening activities, while 57.9% did not engage in any muscle-strengthening activities.[2,23] Similarly, research from Australia shows that only 22% of male and 8% of female adolescents met the muscle-strengthening activity guidelines.[19,24] In China, fewer than 40% of adolescents were reported to meet the recommended levels of muscle-strengthening exercises, with older adolescents and girls less likely to meet the guidelines.[25] Additionally, a study in the United States revealed a declining trend, where adherence to muscle-strengthening guidelines dropped from 55.6% in 2011 to 49.5% in 2019.[19] These findings have raised widespread concern among health professionals and policymakers, underscoring the urgent need to promote muscular fitness early to ensure a healthy and vibrant future population.[26]

Muscular fitness is crucial in children's and adolescents' overall health and development. It is essential for daily activities and sports participation and supports bone health, metabolic function, and injury prevention.[1,18,27] Optimal muscular fitness during childhood and adolescence could enhance cardiorespiratory fitness and bone density and help shape proper body composition.[27–29] Previous research has demonstrated that children who exhibit greater muscular fitness tend to have a lower risk of developing chronic health conditions like obesity, type 2 diabetes, and cardiovascular diseases as they grow older.[6,30–32] Moreover, muscular fitness is critical for maintaining independent living, reducing the risk of mobility impairments, and lowering the need for assistance in daily activities.[12,19] Beyond the various physical advantages, higher muscular fitness levels are closely linked to better mental health outcomes. These include lower rates of anxiety and depression, increased self-esteem, and an overall improvement in psychological well-being.[9,33] These diverse benefits highlight the importance of promoting muscular fitness from an early stage to foster a healthy and active lifestyle.[34,35]

Despite the well-established benefits of muscular fitness, current research on muscular fitness in children and adolescents reveals significant gaps and challenges. Much research has explored various aspects of muscular fitness, including participation guidelines, current participation levels, and barriers and facilitators to maintaining an active lifestyle.[36,37] However, a comprehensive understanding of specific trends, themes, and contributions within the field of muscular fitness among young populations remains lacking.[38] Existing research often focuses broadly on PA without delving deeply into muscle-strengthening exercises and their unique effects.[1] Current studies can be categorized into original research and reviews. Original research includes randomized controlled trials, cross-sectional studies, and longitudinal studies, which primarily provide empirical evidence.[6] Evidence synthesis takes 2 forms: in-depth synthesis and broad synthesis. In-depth synthesis, such as systematic reviews and meta-analyses, focuses on answering a specific question.[39] In contrast, broad synthesis, such as bibliometric analysis, depicts an entire research field's macro-structure and development trends.

As a broad synthesis approach, bibliometric analysis utilizes mathematical and statistical techniques to explore a large body of scientific literature. By carefully examining various patterns in academic publications, bibliometric analyses can reveal a research field's development trajectory and structural features and identify emerging research trends and hot topics.[40] Bibliometric analysis has been successfully applied in various fields, including medicine, environmental science, and education, offering valuable insights into research dynamics and supporting policy and funding decisions.[41] A recent study in aging and cognitive health reveals a shift from cognitive interventions to broader health outcomes, with emerging trends in sleep, sedentary behavior, and virtual reality shaping future research.[42] In the context of muscular fitness research, bibliometric analysis holds great potential. It can help identify the most influential studies, active authors, leading journals, and dominant research themes.[43] Moreover, it can highlight gaps and deficiencies in the literature, providing vital guidance for future research directions. For example, the study by Yang et al pointed out the distribution and research trends in sedentary behavior and cardiovascular disease literature.[40] By employing bibliometric methods, we can more accurately identify research hotspots, influential studies, and emerging trends, laying a solid foundation for future research and interventions to improve muscular fitness and well-being in younger populations.

A clearly defined topical scope is important when mapping a large scientific literature. Research on charge transport in organic semiconductor films,[44] multimodal video captioning,[45] cigarette-smoke-induced oxidative stress in rat lungs,[46] and zero-emission electric-vessel engineering[47] addresses scientific questions distinct from muscular fitness in children and adolescents. Accordingly, this bibliometric study focuses on research explicitly concerned with muscular fitness in young populations.

Thus, this study aimed to conduct a comprehensive bibliometric analysis of research on muscular fitness in children and adolescents published between January 1, 2004, and December 31, 2025. The study aimed to provide an overview of the research landscape, identify foundational studies, and characterize major research themes and emerging trends. Specifically, the study examined research themes, authors, countries, and journals to characterize the knowledge structure of muscular fitness research. Citation patterns, collaboration networks, and keyword co-occurrence were analyzed to identify major contributions and emerging research trends.

2. Methods

2.1. Design and data

An integrated bibliometric approach combining performance analysis and science mapping was applied in this study.[48] Bibliographic records were retrieved from the Web of Science Core Collection (WoSCC) and Scopus to improve the coverage of relevant literature and reduce the limitations associated with relying on a single database.[49] Both databases were searched for publications covering the period from January 1, 2004, to December 31, 2025. Database-specific search strategies were developed using terms related to children and adolescents and muscular fitness. The complete search strategies and applied restrictions are provided in Table S1, Supplemental Digital Content 1.

According to the guidelines for bibliometric analysis, the initial search terms for this study were identified by examining keywords from relevant systematic reviews, followed by brainstorming by the authors to add additional terms.[48] All data retrieval was performed on October 29, 2026 to minimize variation associated with database updates. Boolean operators were used to combine 2 groups of search terms: terms related to children and adolescents (e.g., child, children, adolescent, youth, and teen) and terms related to muscular fitness (e.g., muscular fitness, muscular strength, muscular endurance, and muscular power). Terms referring to university/college populations and adults were excluded where applicable. The complete search strategy for each database is provided in Table S1, Supplemental Digital Content 1. The publication time was limited from January 1, 2004 to December 31, 2025. Only Articles and Reviews published in English were included in the final analysis.

WoSCC records were exported in plain-text format and Scopus records in CSV format, including bibliographic information and cited references. The records were imported using

the bibliometrix package in R[43] and merged using R scripts. Duplicate records were identified primarily using standardized digital object identifiers. Records without conflicting digital object identifiers were additionally matched using normalized titles, publication years, and first-author names. Each unique publication was retained once, with its database provenance preserved.

A total of 2563 records were available for cross-database merging after within-database deduplication. After removing 1128 duplicate records identified across the 2 databases, 1435 unique publications remained. Of these, 1128 were indexed in both databases, 95 exclusively in WoSCC, and 212 exclusively in Scopus. Accordingly, the merged dataset comprised 1223 publications indexed in WoSCC and 1340 indexed in Scopus. The database merging and deduplication process is illustrated in Figure 1.

2.2. Data analysis

The 1435 unique publications were analyzed using R (version 4.4.1), bibliometrix (version 5.5.0), CiteSpace (version 7.0.R1), and VOSviewer (version 1.6.20). Microsoft Excel 2019 was used for other data management and analysis.

For publications indexed in both databases, the higher available database-specific citation count was used rather than summing the 2 counts. For publications indexed in only 1 database, the available citation count was used. This convention was applied consistently to citation totals, average citation impact (ACI), H-index, and G-index. It represents a mixed-source citation measure rather than a deduplicated count of unique citing publications across databases.

Collaborative network analysis in VOSviewer was used to identify collaborations among authors, institutions, and

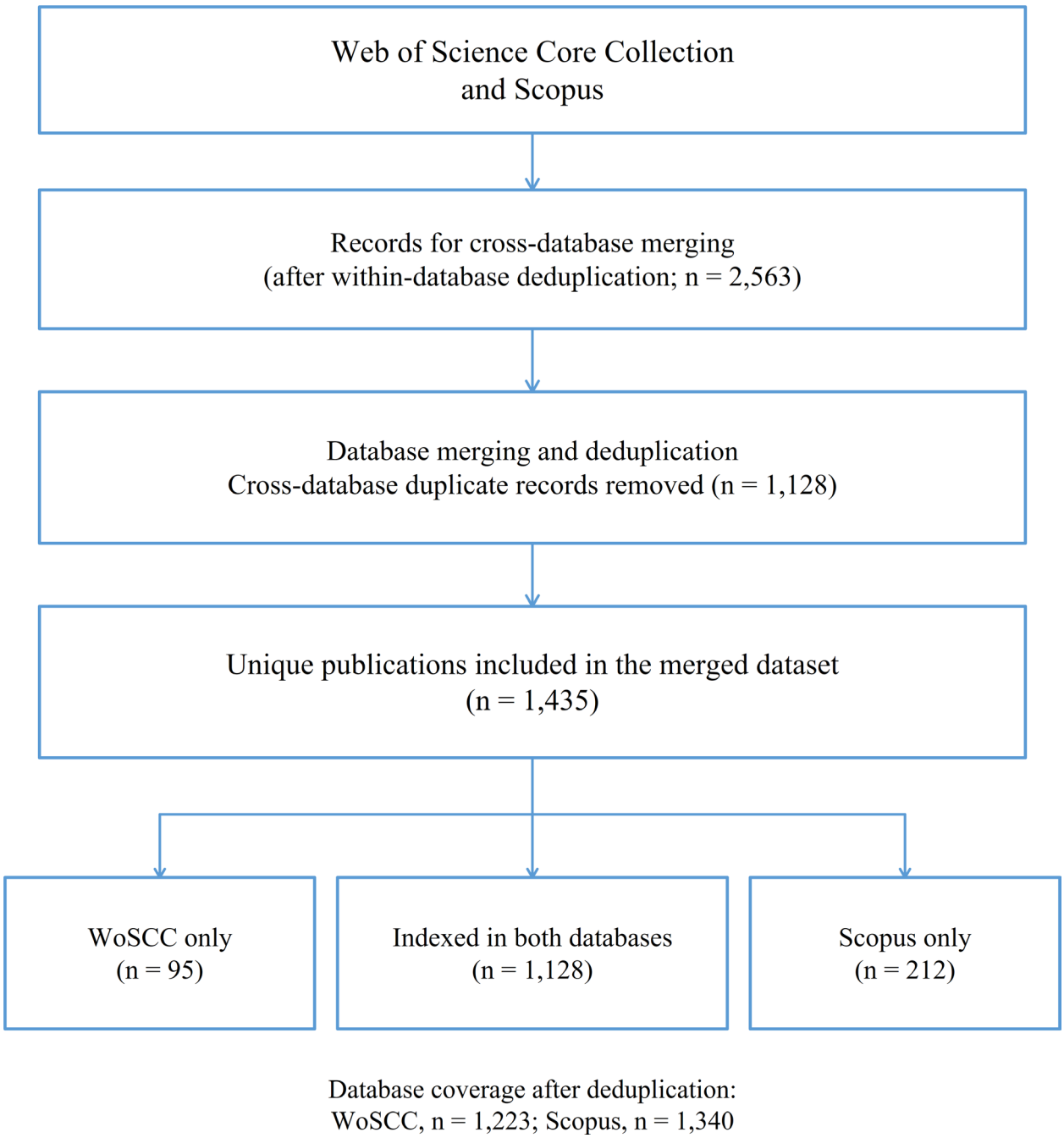


Figure 1. Flow diagram of bibliographic record identification, database merging, and deduplication. WoSCC = Web of Science Core Collection.

countries/regions. In the network visualizations, node size represents the publication output of an author, institution, or country/region, whereas link thickness represents the strength of collaboration between 2 nodes. Different colors represent clusters identified by VOSviewer, and total link strength represents the overall strength of the links between a given item and all other items in the network. For performance analyses, institution and author name variants were reconciled, and each publication was counted once for each attributed author, institution, or country/region. Reference co-citation analysis was performed using CiteSpace on the cited-reference records from the merged WoSCC–Scopus dataset to characterize the intellectual structure of the field. The analysis covered 2004 to 2025, with a time slice of 1 year. Nodes were selected using the g-index criterion (k = 100; LRF = 2.5; L/N = 10; LBY = 5; e = 1.0), and no network pruning was applied. Modularity Q and weighted mean silhouette S were used to assess the resulting cluster structure. Keyword co-occurrence analysis was conducted using VOSviewer to examine the relationships among frequently occurring research terms. Keyword occurrence frequencies and thematic clusters were used to characterize the main areas of research. Keyword burst detection was performed using CiteSpace to identify terms exhibiting marked changes in research attention over time. The twenty keywords with the strongest bursts were presented.

For annual publication analyses, the recorded early-access year was used when it preceded the indexed publication year; otherwise, the indexed publication year was used. Figure 2 displays annual publication output and cumulative citations to publications grouped by publication year, rather than citations received during each calendar year.

ACI was calculated as the total number of citations received by publications attributed to a given country, institution, author, or journal divided by the corresponding number of publications. Thus, ACI represents the average number of citations per publication. The ACI values were calculated using raw citation counts and were not normalized by year of publication.

The H-index and G-index were additionally calculated for the selected authors, institutions, countries/regions, and journals using the publications attributed to each entity in the merged dataset. The H-index combines publication output with citation performance: an entity has an H-index of h when h of its publications have each received at least h citations.[50] The G-index gives greater weight to highly cited publications. After publications are ranked by decreasing citation count, G is the largest number for which the top g publications have collectively received at least g^2 citations.[51] Both indices were calculated in R from publication-level citation counts. In this implementation, G was capped at the number of included publications. These are topic- and dataset-restricted indicators rather than authors' lifetime indices or journal-wide indices.

Self-citations were neither separately quantified nor excluded from the citation-based indicators. Therefore, ACI, the h-index, and the g-index were interpreted as descriptive measures of citation performance rather than direct indicators of research quality. Differences in citation windows and database coverage were also considered when interpreting these measures.

2.3. Ethical considerations

Ethical approval and informed consent were not required because this bibliometric study analyzed secondary bibliographic records retrieved from the WoSCC and Scopus and did not involve human participants, identifiable personal information, or animal subjects.

3. Results

3.1. Annual distribution of publications and citations

From 2004 to 2025, the merged WoSCC and Scopus dataset comprised 1435 unique publications on muscular fitness in children and adolescents. Using the higher available database-specific citation count for each publication, the corpus had a total of 47,192 recorded citations at retrieval (mean 32.89 per publication). This total should not be interpreted as a

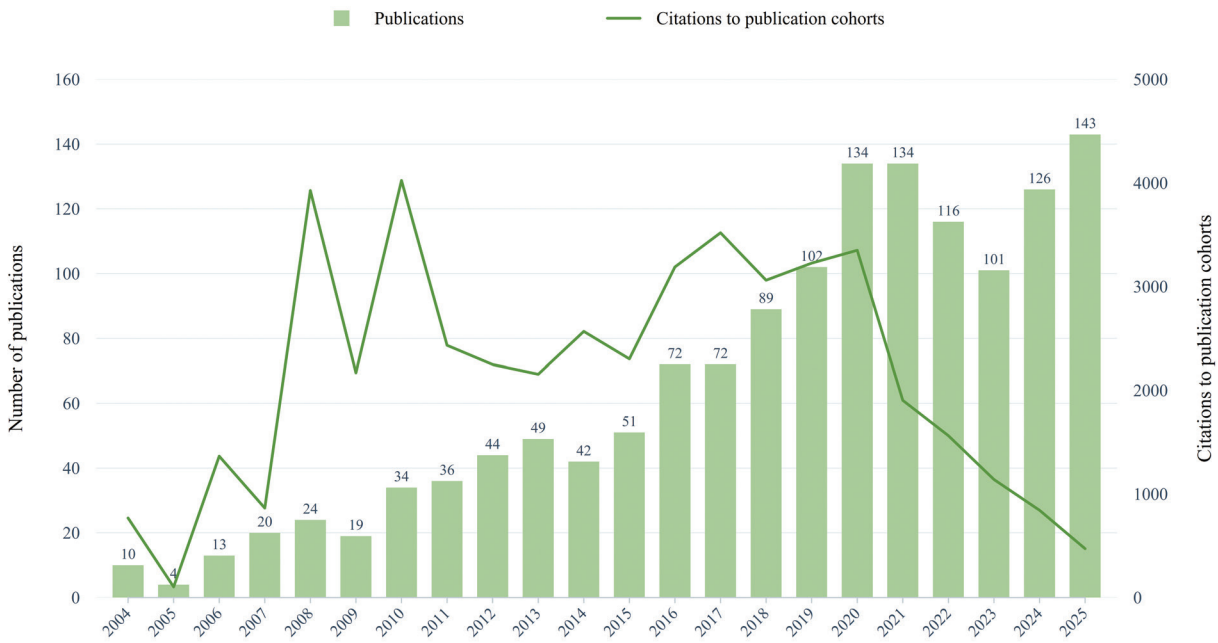


Figure 2. Annual distribution of publications and citations in the field of muscular fitness in children and adolescents from 2004 to 2025.

deduplicated count of distinct citing documents. Articles accounted for 92.40% of the dataset (1326 publications), while reviews represented 7.60% (109 publications). Annual publication output showed an overall upward trend with fluctuations, increasing from 10 publications in 2004 to a peak of 143 in 2025. Output reached 134 publications in both 2020 and 2021, declined to 116 in 2022 and 101 in 2023, and subsequently recovered to 126 in 2024 and 143 in 2025. Figure 2 presents annual publication output and the cumulative citations received by publications grouped by publication year.

3.2. Country publication performance

Table 1 presents the publication and citation performance of the 10 most productive countries/regions. The United States ranked first with 328 publications (22.86%), followed by Spain with 267 (18.61%) and Australia with 144 (10.03%). Brazil (n = 126), Chile (n = 104), and England (n = 103) were also among the leading contributors. Sweden had the highest ACI (124.32), while the United States had the highest corpus-restricted h-index (62) and Spain had the highest g-index (117). The international co-authorship network is illustrated in Figure 3, showing collaboration patterns among countries/regions.

3.3. Institution publication performance

Table 2 presents the publication and citation performance of the 11 most productive institutions. The University of Granada ranked first with 114 publications (7.94%), followed by the

Table 1

Publication and citation indicators for 10 selected productive countries/regions in muscular fitness research in children and adolescents.

Rank	Country/region	Quantity	%	ACI	TLS	H-index	G-index
1	USA	328	22.86	44.64	338	62	109
2	Spain	267	18.61	57.01	441	57	117
3	Australia	144	10.03	60.12	225	47	90
4	Brazil	126	8.78	17.57	148	26	41
5	Chile	104	7.25	25.29	173	27	48
6	England	103	7.18	48.92	193	39	69
7	Portugal	86	5.99	22.85	146	27	41
8	People's Republic of China	84	5.85	19.86	70	24	37
9	Sweden	77	5.37	124.32	220	44	77
10	Canada	69	4.81	51.51	92	28	59

Quantity and percentage refer to the 1435 unique publications in the merged corpus. Full counting was used: each country/region was counted once per publication, based on explicit affiliation-country information in either database. Internationally coauthored publications may contribute to multiple countries/regions. ACI, H-index, and G-index use the larger available WoS or Scopus citation count for each publication, rather than the sum. These corpus-restricted indicators include self-citations and are not normalized by publication year; G-index is capped at the number of included publications. Publication period: January 1, 2004 to December 31, 2025. Download date: October 29, 2026.

ACI = average citation impact (citations per publication), TLS = total link strength.

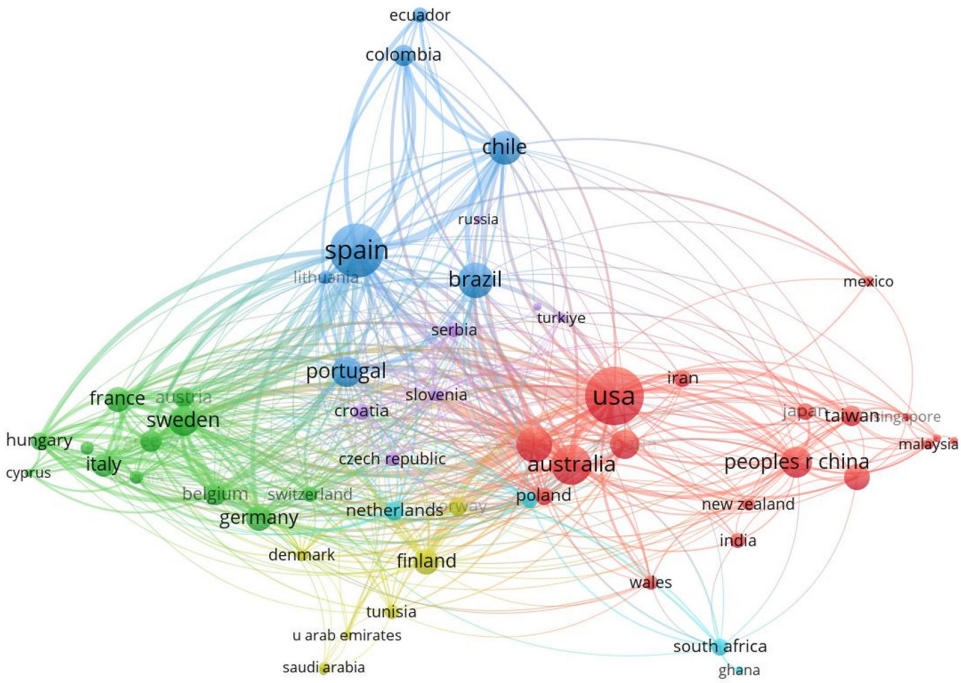


Figure 3. International collaborative network in the field of muscular fitness in children and adolescents. Node size represents the number of publications contributed by each country/region, link thickness represents the strength of collaboration between countries/regions, and different colors represent collaboration clusters identified by VOSviewer.

University of Newcastle with 62 (4.32%), and Karolinska Institutet with 61 (4.25%). Four of the 11 institutions were located in Spain, while 2 were located in Australia. Karolinska Institutet had the highest ACI (147.15), whereas the University of Granada had the highest h-index (47) and g-index (103) among the listed institutions. The institutional collaboration network is presented in Figure 4.

3.4. Author publication performance

Table 3 presents the 10 most productive authors in the study corpus. Ortega FB was the most prolific author, contributing 63 publications (4.39%), followed by Lubans DR (n = 49), García-Hermoso A (n = 46), and Ruiz JR (n = 45). Among the listed authors, Ruiz JR had the highest ACI (170.98), while Ortega FB had the highest h-index (41) and g-index (63). Eight of the 10 most productive authors were affiliated with institutions in Spain, reflecting the substantial contribution of Spanish research groups to this field. The co-authorship network is shown in Figure 5.

3.5. Journal publication performance

The 1435 publications were distributed across 497 journals. As shown in Table 4, the *International Journal of Environmental Research and Public Health* was the most productive journal, with 58 publications (4.04%), followed by the *Journal of Strength and Conditioning Research* with 41 (2.86%). The 11 journals listed in Table 4, including ties at the top-10 cut-off, collectively accounted for 317 publications (22.09%) of the study corpus. The *Journal of Strength and Conditioning Research* had the highest corpus-restricted h-index (28) and g-index (41), whereas *Sports Medicine* had the highest ACI (189.95).

Table 2

Publication and citation indicators for 11 selected productive institutions in muscular fitness research in children and adolescents.

Rank	Institution	Country	Quantity	%	ACI	TLS	H-index	G-index
1	University of Granada	Spain	114	7.94	94.06	427	47	103
2	University of Newcastle	Australia	62	4.32	84.98	122	32	62
3	Karolinska Institutet	Sweden	61	4.25	147.15	250	39	61
4	University of Zaragoza	Spain	54	3.76	65.69	255	30	54
5	University of Porto	Portugal	44	3.07	25.82	81	21	33
=6	University of Cádiz	Spain	40	2.79	67.58	136	22	40
=6	University of Jyväskylä	Finland	40	2.79	22.93	138	15	29
8	The College of New Jersey	USA	34	2.37	79.32	51	24	34
9	University of Castilla-La Mancha	Spain	31	2.16	32.55	97	16	31
10	Universidad Autónoma de Chile	Chile	29	2.02	24.21	79	16	26
11	University of Wollongong	Australia	27	1.88	105.89	72	20	27

Quantity and percentage refer to the 1435 unique publications in the merged corpus. Institution-name variants were reconciled using affiliation information from both databases. Full counting was used, with each institution counted once per publication. The University of Newcastle, Australia, was distinguished from Newcastle University, UK. ACI, H-index, and G-index use the larger available WoS or Scopus citation count per publication, rather than the sum. These corpus-restricted indicators include self-citations and are not normalized by publication year; G-index is capped at the number of included publications. Publication period: January 1, 2004 to December 31, 2025. Download date: October 29, 2026.

ACI = average citation impact (citations per publication), TLS = total link strength.

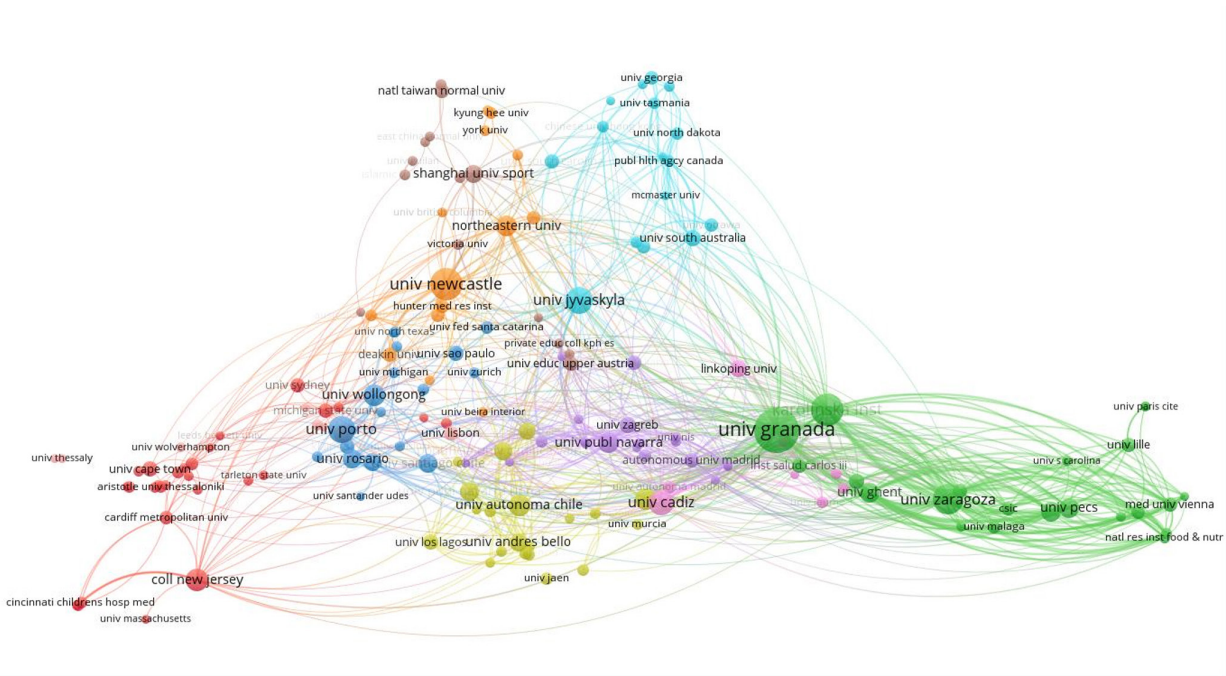


Figure 4. Inter-institutional collaborative network in the field of muscular fitness in children and adolescents. Node size represents institutional publication output, link thickness represents collaboration strength between institutions, and different colors represent institutional collaboration clusters identified by VOSviewer.

Table 3

Publication and citation indicators for 10 selected productive authors in muscular fitness research in children and adolescents.

Rank	Author	Institution	Country	Quantity	%	ACI	TLS	H-index	G-index
1	Ortega FB	University of Granada	Spain	63	4.39	143.97	419	41	63
2	Lubans DR	University of Newcastle	Australia	49	3.41	100.86	178	30	49
3	García-Hermoso A	Universidad Pública de Navarra	Spain	46	3.21	40.04	179	22	42
4	Ruiz JR	University of Granada	Spain	45	3.14	170.98	300	37	45
5	Cadenas-Sánchez C	University of Granada	Spain	35	2.44	47.94	222	25	35
6	Ramírez-Vélez R	Universidad Pública de Navarra	Spain	31	2.16	36.81	148	20	31
7	Faigenbaum AD	The College of New Jersey	USA	29	2.02	89.31	38	22	29
8	Moreno LA	University of Zaragoza	Spain	28	1.95	83.71	200	21	28
9	Esteban-Cornejo I	University of Granada	Spain	25	1.74	45.20	183	20	25
10	Castro-Piñero J	University of Cádiz	Spain	24	1.67	94.08	142	17	24

Quantity and percentage refer to the 1435 unique publications in the merged corpus. Author-name variants were reconciled across both databases. Affiliations shown are representative; authors may have multiple affiliations. ACI, H-index, and G-index use the larger available WoS or Scopus citation count for each publication, rather than the sum. These corpus-restricted indicators include self-citations and are not normalized by publication year; G-index is capped at the number of included publications.

ACI = average citation impact (citations per publication), TLS = total link strength.

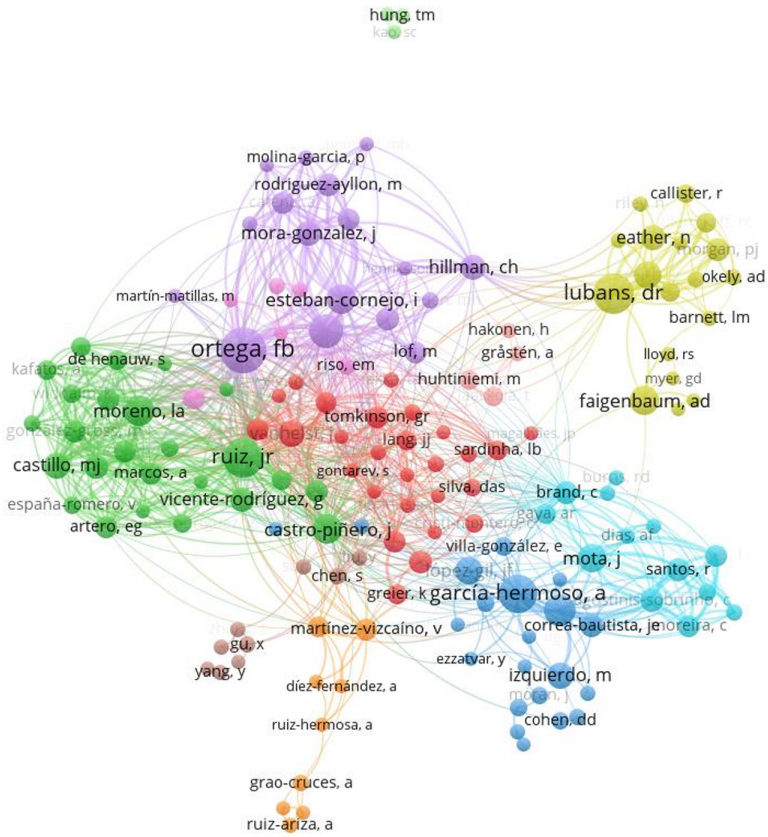


Figure 5. Author collaborative network in the field of muscular fitness in children and adolescents. Node size represents author publication output, link thickness represents co-authorship strength, and different colors represent author collaboration clusters identified by VOSviewer.

3.6. Reference analysis

Table 5 presents the 10 most-cited publications in the merged dataset. These publications received a combined total of 8300 citations, ranging from 400 to 2326 citations per publication. The most-cited publication was Ortega et al's review,[12] "Physical fitness in childhood and adolescence: a powerful marker of health," with 2326 citations. This was followed by Lubans et al's review, "Fundamental movement skills in children and adolescents: review of associated health benefits," with 1325 citations. Six of the 10 publications were reviews, while 4 were original research articles.

Reference co-citation analysis was performed to characterize the intellectual structure of the field (Fig. 6). The resulting network had a modularity Q value of 0.8935 and a weighted mean silhouette S value of 0.8998, indicating a clearly differentiated cluster structure. The largest cluster (#0) was labeled "LabMed physical activity study," while Cluster #2 was labeled "body fatness." Other clusters addressed topics such as physical fitness trainability, school-based interventions, and muscular fitness activities. These clusters suggest that research on muscular fitness has developed around several interrelated themes involving physical performance, fitness assessment, and health-related outcomes.

Table 4

Most productive journals in muscular fitness research in children and adolescents, including ties at the top-10 cutoff.

Rank	Journal	Quantity	%	ACI	H-index	G-index
1	*International Journal of Environmental Research and Public Health*	58	4.04	19.67	23	31
2	*Journal of Strength and Conditioning Research*	41	2.86	71.76	28	41
3	*Journal of Sports Sciences*	35	2.44	53.09	20	35
4	*Scandinavian Journal of Medicine & Science in Sports*	33	2.30	40.79	18	33
5	*Children*	26	1.81	10.23	11	15
6	*PLOS ONE*	22	1.53	32.64	13	22
=7	*BMC Public Health*	21	1.46	23.81	12	21
=7	*Sports Medicine*	21	1.46	189.95	21	21
=9	*Journal of Science and Medicine in Sport*	20	1.39	56.95	15	20
=9	*Journal of Sports Medicine and Physical Fitness*	20	1.39	30.95	13	20
=9	*Pediatric Exercise Science*	20	1.39	24.20	9	20

Quantity and percentage refer to the 1435 unique publications in the merged WoSCC–Scopus corpus. Journal-name variants were standardized; Children and Children-Basel were treated as the same journal. Tied ranks use competition ranking. Eleven journals are shown because 3 journals each published 20 papers at the cutoff. Average citation impact (ACI) is calculated as citations divided by publications. ACI, H-index, and G-index use the larger available WoS or Scopus citation count per publication, rather than the sum. The indices are restricted to this study corpus, include self-citations, and are not normalized by publication year. The G-index is capped at the number of included publications. Publication period: January 1, 2004 to December 31, 2025. Download date: October 29, 2026.
WoSCC = Web of Science Core Collection.

Table 5

Ten most-cited publications on muscular fitness in children and adolescents in the merged WoSCC–Scopus dataset.

Rank	Title	Journal	First author	Total citations	Year	A/R
1	Physical fitness in childhood and adolescence: a powerful marker of health	*International Journal of Obesity*	Ortega FB	2326	2008	R
2	Fundamental movement skills in children and adolescents: review of associated health benefits	*Sports Medicine*	Lubans DR	1325	2010	R
3	Predictive validity of health-related fitness in youth: a systematic review	*British Journal of Sports Medicine*	Ruiz JR	810	2009	R
4	International Society of Sports Nutrition position stand: safety and efficacy of creatine supplementation in exercise, sport, and medicine	*Journal of the International Society of Sports Nutrition*	Kreider RB	687	2017	R
5	The health benefits of muscular fitness for children and adolescents: a systematic review and meta-analysis	*Sports Medicine*	Smith JJ	685	2014	R
6	The relationship between peak height velocity and physical performance in youth soccer players	*Journal of Sports Sciences*	Philippaerts RM	670	2006	A
7	Muscular strength in male adolescents and premature death: cohort study of one million participants	*BMJ*	Ortega FB	513	2012	A
8	European normative values for physical fitness in children and adolescents aged 9–17 years: results from 2,779,165 Eurofit performances representing 30 countries	*British Journal of Sports Medicine*	Tomkinson GR	444	2018	A
9	Is muscular fitness associated with future health benefits in children and adolescents? A systematic review and meta-analysis of longitudinal studies	*Sports Medicine*	García-Hermoso A	440	2019	R
10	Physical fitness levels among European adolescents: the HELENA study	*British Journal of Sports Medicine*	Ortega FB	400	2011	A

Publications were ranked within the 1435-record merged dataset. For each publication, the higher available WoSCC or Scopus citation count was retained rather than summing citation counts across databases. Citation counts were retrieved on October 29, 2026, and include self-citations.
A = article, A/R = article/review, R = review, WoSCC = Web of Science Core Collection. Year denotes the indexed publication year.

3.7. Keyword analysis

Table 6 presents the 20 most frequently occurring keywords. Physical fitness was the most frequent keyword (n = 245), followed by children (n = 180), PA (n = 174), adolescents (n = 128), and muscular strength (n = 122). Other frequently occurring terms included cardiorespiratory fitness (n = 115), youth (n = 110), muscular fitness (n = 96), and obesity (n = 90). Figure 7 illustrates the keyword co-occurrence network and the relationships among the major research themes.

Keyword burst analysis identified strength training as the term with the strongest burst (strength = 4.06; 2004–2011), followed by aerobic fitness (strength = 3.69; 2018–2020). More recent bursts were observed for physical education (strength = 3.46; 2022–2025) and physical performance (strength = 3.09; 2023–2025). Public health also exhibited a recent burst during 2022 to 2023 (strength = 2.20). These findings indicate changing research attention over time, with a recent emphasis on physical education and physical performance (Fig. 8).

4. Discussion

4.1. Key findings

4.1.1. Trends in publications and citations. The present study identified 1435 publications on muscular fitness in children and adolescents between 2004 and 2025, reflecting a substantial expansion of research activity over the study period. Annual publication output increased from 10 publications in 2004 to 143 in 2025, although several fluctuations were observed. In particular, publication output declined during 2022 to 2023before recovering in 2024 and 2025. This overall growth is consistent with increasing scientific attention to muscular fitness as a component of health-related fitness in young populations. Previous research has documented associations between muscular fitness and multiple health-related outcomes in children and adolescents.[1,12]

The accumulated citation counts also varied across publication cohorts. However, comparisons of citation performance across publication years should account for differences in

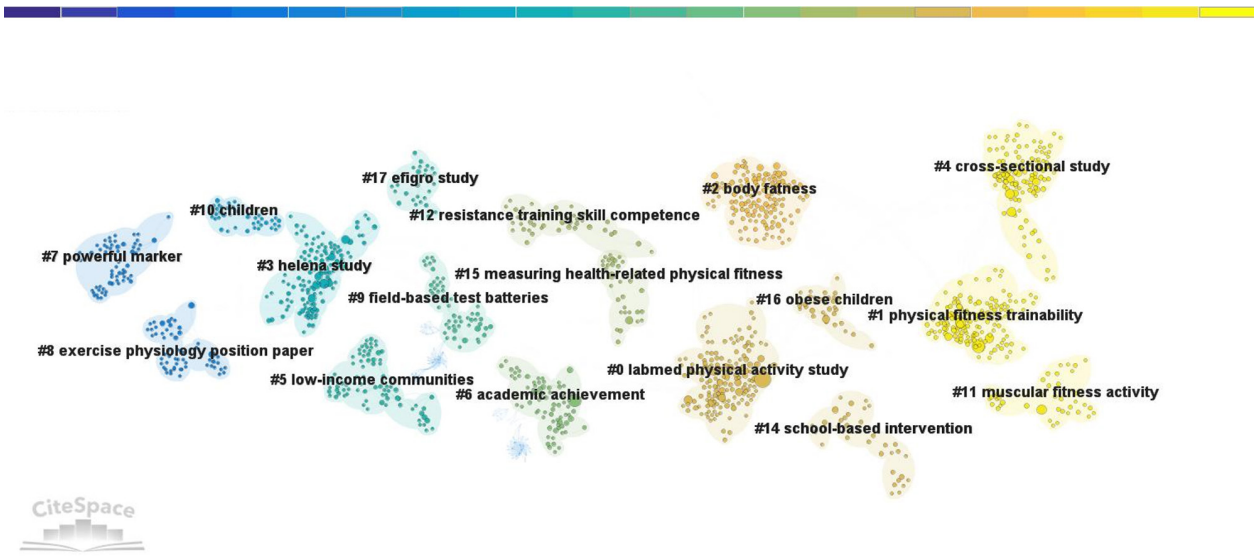


Figure 6. Reference co-citation cluster network based on the merged WoSCC and Scopus dataset for muscular fitness research among children and adolescents from 2004 to 2025. Nodes represent cited references, and links indicate co-citation relationships. Cluster labels were generated using CiteSpace. The network was constructed with 1-year time slices using the g-index node-selection criterion (k = 100), without network pruning. The modularity Q value was 0.8935, and the weighted mean silhouette S value was 0.8998.

citation windows, as older publications have had more time to accumulate citations, and the counts were obtained at a single retrieval date.

4.1.2. Geographical and institutional contributions. The United States and Spain were the leading contributors to muscular fitness research, with 328 and 267 publications, respectively. Australia, Brazil, Chile, and England also made substantial contributions. Sweden demonstrated the highest ACI among the 10 most productive countries/regions, whereas the United States and Spain ranked highest in the corpus-restricted h-index and g-index, respectively. These findings indicate geographical differences in research productivity and citation performance. Such differences may reflect variation in research capacity, institutional specialization, and international collaboration, although these potential explanations were not directly examined in the present study.

4.1.3. Institutional and author contributions. The University of Granada was the most productive institution, contributing 114 publications, followed by the University of Newcastle and Karolinska Institutet. The prominent representation of Spanish institutions was also reflected in author-level publication patterns. Ortega FB ranked first in publication output, followed by Lubans DR, García-Hermoso A, and Ruiz JR. Notably, Karolinska Institutet exhibited the highest ACI among the leading institutions, while Ruiz JR had the highest ACI among the 10 most productive authors. These findings suggest that research activity in this field is concentrated within several established research groups. However, citation-based indicators should be interpreted as measures of citation performance within the study corpus rather than direct measures of research quality.

4.2. Comparison with existing research

4.2.1. Growth of muscular fitness research. The increase in publication output observed in this study is consistent with the broader expansion of research on physical fitness and health among children and adolescents. Although annual output fluctuated, the overall growth suggests sustained scientific interest in muscular fitness as a component of health-related fitness. Bibliometric studies in related pediatric research areas, including aerobic fitness and obesity, have also examined publication patterns and evolving research interests.[2,52] A systematic review and meta-analysis of longitudinal studies additionally reported associations between higher muscular fitness during childhood and adolescence and more favorable subsequent adiposity, cardiometabolic, and bone-health outcomes.[53] However, direct comparisons of growth rates across research fields should be interpreted cautiously because differences in search strategies, database coverage, and publication periods may influence the observed patterns.

4.2.2. Impact of collaborative networks. The co-authorship networks revealed connections among researchers and institutions across different countries, particularly among established research groups in Spain, the United States, and Australia. These collaboration patterns illustrate the international structure of muscular fitness research and may provide opportunities for knowledge exchange and methodological collaboration. Bibliometric guidance emphasizes that co-authorship networks characterize research collaboration but should not be interpreted as direct evidence that international collaboration improves research quality or citation impact.[53] Further research would be needed to examine the relationship between collaboration patterns and scientific outcomes.

4.2.3. Research hotspots and emerging trends. Keyword co-occurrence and reference co-citation analyses identified several interconnected research themes, including physical fitness, muscular strength, PA, cardiorespiratory fitness, and obesity. The co-citation clusters further highlighted research on physical fitness assessment, fitness trainability, and school-based interventions. Together, these findings suggest that muscular fitness research in children and adolescents encompasses a range of topics extending beyond isolated strength-related outcomes toward broader investigations of physical performance and health-related fitness. This thematic profile is consistent with previous evidence on the health benefits and behavioral correlates of muscular fitness, including its associations with cardiometabolic risk among adolescents.[1,26,28]

Keyword burst analysis revealed changes in research attention over time. Strength training was particularly prominent during the earlier period, whereas aerobic fitness attracted increased

Table 6

Top 20 most frequently occurring keywords in the field of muscular fitness in children and adolescents.

Rank	Keyword	Quantity	Rank	Keyword	Quantity
1	Physical fitness	245	11	Exercise	74
2	Children	180	12	Fitness	64
3	Physical activity	174	13	Adolescent	57
4	Adolescents	128	14	Strength	51
5	Muscular strength	122	=15	Physical education	50
6	Cardiorespiratory fitness	115	=15	Body composition	50
7	Youth	110	17	Health	45
8	Muscular fitness	96	18	Resistance training	39
9	Obesity	90	19	Flexibility	37
10	Muscle strength	75	20	Body mass index	36

Quantity denotes keyword occurrences reported by VOSviewer. Keyword variants were retained as separate entries, consistent with the supplied output. Equal occurrence counts share the same rank.

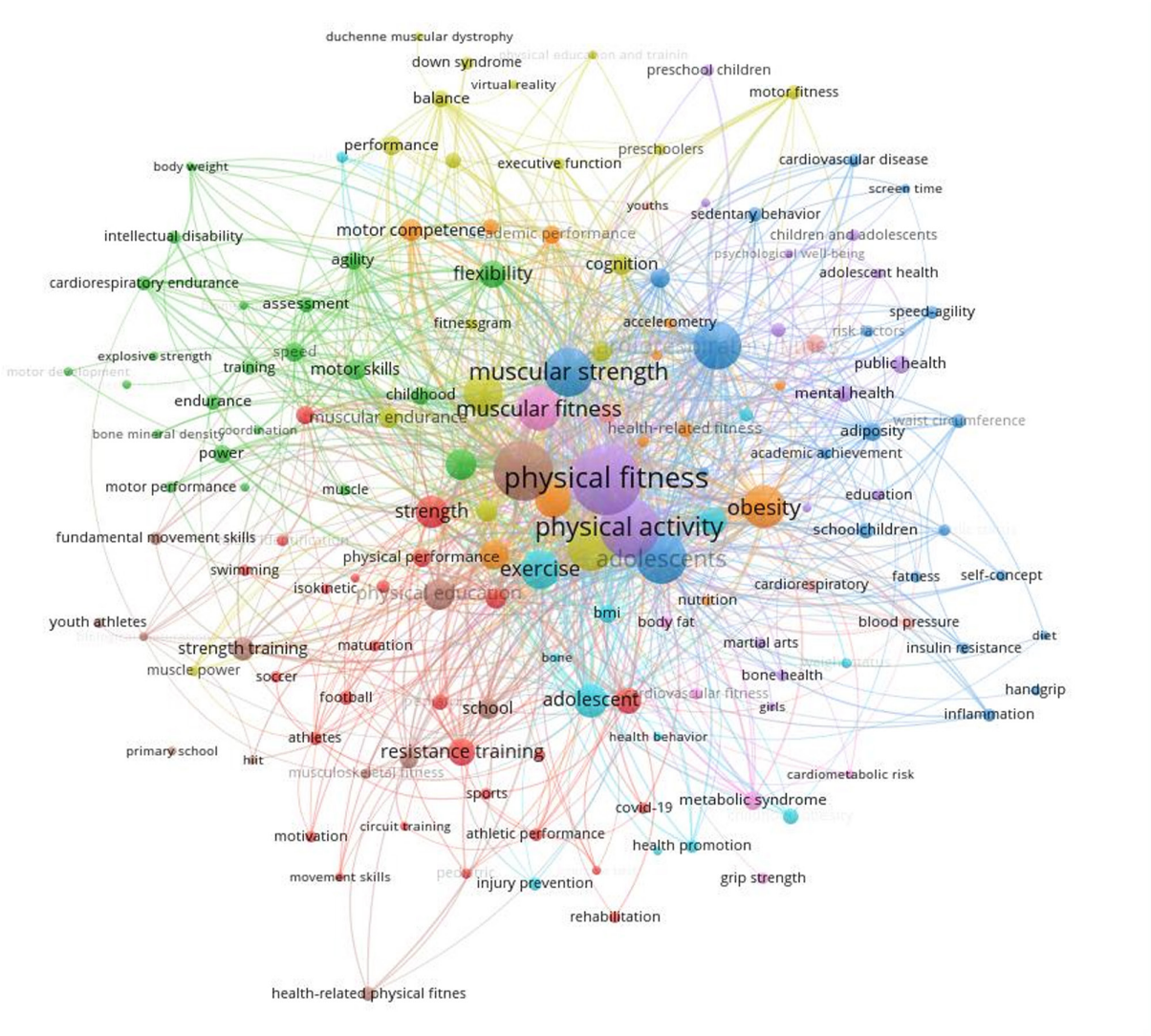


Figure 7. Keyword co-occurrence network in muscular fitness research among children and adolescents. Node size represents keyword occurrence frequency, link thickness represents co-occurrence strength, and different colors indicate thematic clusters identified by VOSviewer. Keyword variants were retained as separate entries in the analysis.

attention during 2018 to 2020. More recent bursts in physical education and physical performance indicate recent attention to educational and performance-related topics of muscular fitness. These trends may help inform future research on school-based fitness promotion, age-appropriate strength development, and the integration of muscular fitness assessment into youth health research. Previous studies have investigated school-based interventions targeting muscular fitness and the measurement properties of field-based muscular-strength assessments in adolescents.[11,39] Muscular fitness (a physical capacity) should also be distinguished from muscle-strengthening activity (a behavior). The international consensus on youth resistance training emphasizes developmentally appropriate, supervised training,[54] while the 2020 WHO guidelines recommend incorporating

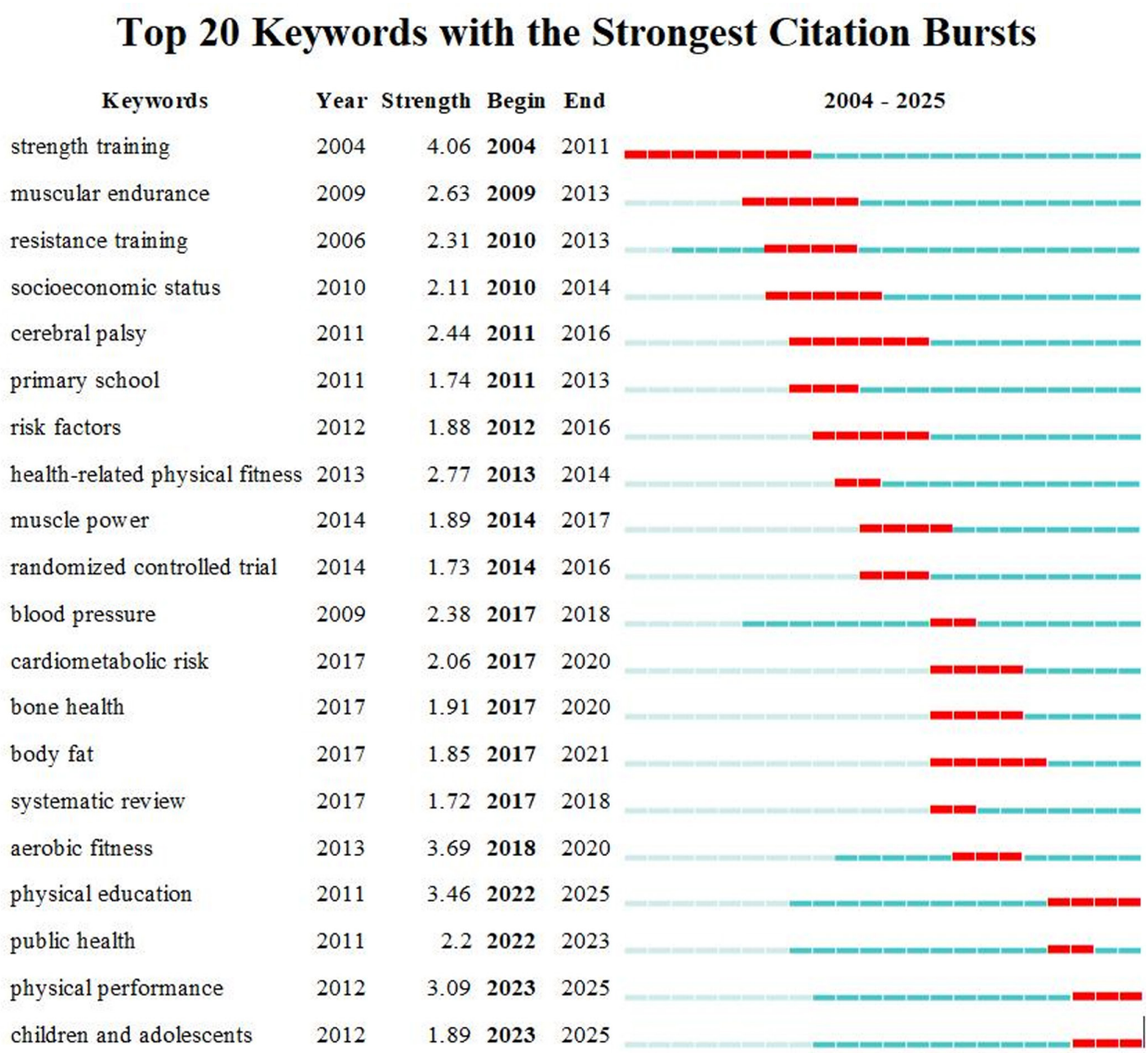


Figure 8. Top 20 keywords with the strongest bursts in muscular fitness research among children and adolescents from 2004 to 2025. Red segments indicate the periods during which keywords exhibited bursts, while the remaining segments represent the observation period.

activities that strengthen muscle and bone at least 3 days per week for children and adolescents aged 5 to 17 years.[55] These recommendations provide a practice-oriented context for the emerging educational and performance-related themes, without establishing that particular interventions were effective in the present bibliometric dataset. Nevertheless, bibliometric trends indicate patterns of research activity rather than the effectiveness of specific interventions or policies.

4.3. Limitations and future research

Several limitations should be acknowledged. First, although bibliographic records from WoSCC and Scopus were integrated to improve literature coverage, other relevant databases, such as PubMed, SPORTDiscus, and PsycINFO, were not included. Consequently, some relevant publications may have been missed. In addition, the analysis was restricted to English-language articles and reviews, which may have excluded relevant publications in other languages or document formats.

Second, citation indicators were calculated using the higher available citation count from WoSCC or Scopus for each publication rather than a deduplicated count of unique citing documents. Although this approach avoided directly summing potentially overlapping citation counts, differences in database coverage may have influenced the results. Citation indicators were also not normalized by publication year, and self-citations were neither separately quantified nor excluded. Therefore, ACI, the h-index, and the g-index should be interpreted cautiously and should not be regarded as direct measures of research quality.

Third, the h-index and g-index were calculated within the study corpus and therefore do not represent the complete publication performance of the included authors, institutions, or journals. Furthermore, bibliometric mapping depends on database indexing, metadata completeness, and network analysis settings. Keyword variants were retained as separate entries, which may have split closely related terms across network nodes and influenced the apparent thematic structure. Future studies could expand database coverage, assess the influence of self-citations, incorporate normalized citation indicators, and examine the stability of bibliometric networks across alternative analytical settings.

5. Conclusions

This bibliometric analysis examined 1435 publications on muscular fitness in children and adolescents published between 2004 and 2025. Research output increased substantially over the study period, with the United States and Spain making the largest contributions. Several institutions and research groups, particularly the University of Granada and leading researchers such as Ortega FB, made notable contributions to the development of this field. Keyword and co-citation analyses identified major research themes related to physical fitness, muscular strength, PA, and health-related outcomes. More recent keyword bursts highlighted physical education and physical performance as emerging areas of research attention. These findings provide an overview of the field's scientific development and may help inform future research priorities in youth muscular fitness and health promotion.

Author contributions

Conceptualization: Qiyali Wang.
Data curation: Qiyali Wang.
Funding acquisition: Qiyali Wang, Yingzhi Zhu.
Investigation: Yingzhi Zhu.
Methodology: Dong Li, Yingzhi Zhu, Yuanyuan Hao.
Project administration: Dong Li, Yuanyuan Hao.
Resources: Dong Li, Yuanyuan Hao, Cheng Zhang.
Software: Yuanyuan Hao, Cheng Zhang.
Supervision: Cheng Zhang.
Validation: Zehan Xu, Cheng Zhang.
Visualization: Zehan Xu, Cheng Zhang.
Writing – original draft: Qiyali Wang, Zehan Xu, Cheng Zhang.
Writing – review & editing: Qiyali Wang, Zehan Xu, Cheng Zhang.

References

[1] Smith JJ, Eather N, Morgan PJ, Plotnikoff RC, Faigenbaum AD, Lubans DR. The health benefits of muscular fitness for children and adolescents: a systematic review and meta-analysis. Sports Med. 2014;44:1209–23.
[2] Xia R, Yang L, Liang C, et al. Research on aerobic fitness in children and adolescents: a bibliometric analysis based on the 100 most-cited articles. Front Med (Lausanne). 2024;11:1409532.
[3] Li H, Zhang W, Yan J. Physical activity and sedentary behavior among school-going adolescents in low- and middle-income countries: insights from the global school-based health survey. PeerJ. 2024;12:e17097.
[4] Su H, Lyu D, Huang K, Yan J. Association of physical activity, screen time and sleep with substance use in children and adolescents: a large sample cross-sectional study. Front Public Health. 2024;12:1432710.
[5] Yan J, Jones B, Smith JJ, Morgan P, Eather N. A systematic review investigating the effects of implementing game-based approaches in school-based physical education among primary school children. J Teach Phys Educ. 2023;42:573–86.
[6] García-Hermoso A, Ramírez-Vélez R, Saavedra JM. Exercise, health outcomes, and pædiatric obesity: a systematic review of meta-analyses. J Sci Med Sport. 2019;22:76–84.
[7] Zheng W, Shen H, Belhaidas MB, Zhao Y, Wang L, Yan J. The relationship between physical fitness and perceived well-being, motivation, and enjoyment in Chinese adolescents during physical education: a preliminary cross-sectional study. Children (Basel). 2023;10:111.
[8] Li D, Wang D, Zou J, et al. Effect of physical activity interventions on children's academic performance: a systematic review and meta-analysis. Eur J Pediatr. 2023;182:3587–601.
[9] Liu T, Li D, Yang H, Chi X, Yan J. Associations of sport participation with subjective well-being: a study consisting of a sample of Chinese school-attending students. Front Public Health. 2023;11:1199782.
[10] Hao Y, Lyu D, Zhang S, Guo B, Yan J. Sports participation and depressive symptoms in youth: demographic differences. Int J Ment Health Promot. 2024;26:865–73.
[11] Belhaidas MB, Tahar T, Yan J, Atallah A, O'Keeffe BT, Eather N. Psychometric properties of the basketball throw test as a health-related field-based measure of muscular strength for use with adolescents in school settings. J Teach Phys Educ. 2026;45:129–38.
[12] Ortega FB, Ruiz JR, Castillo MJ, Sjöström M. Physical fitness in childhood and adolescence: a powerful marker of health. Int J Obes (Lond). 2008;32:1–11.
[13] World Health Organization. The global health observatory: explore a world of health data. 2024. https://www.who.int/data/gho/data/themes/topics/indicator-groups/insufficient-physical-activity-indicator-group#:~:text=Insufficient%20physical%20activity%20increases%20the%20risk%20of%20noncommunicable,diabetes%20-%20all%20leading%20causes%20of%20premature%20death. Accessed November 17, 2024.
[14] Shi F, Huang K, Wang H, Zhang Z, Yan J. No or low self-reported moderate to vigorous physical activity among Chinese children and adolescents: a large-scale cross-sectional study. BMC Public Health. 2025;26:113.
[15] Ganley KJ, Paterno MV, Miles C, et al. Health-related fitness in children and adolescents. Pediatr Phys Ther. 2011;23:208–20.
[16] Chen Z, Chi G, Wang L, Chen S, Yan J, Li S. The combinations of physical activity, screen time, and sleep, and their associations with self-reported physical fitness in children and adolescents. Int J Environ Res Public Health. 2022;19:5783.
[17] Shi J, Gao M, Xu X, Zhang X, Yan J. Associations of muscle-strengthening exercise with overweight, obesity, and depressive symptoms in adolescents: findings from 2019 youth risk behavior surveillance system. Front Psychol. 2022;13:980076.
[18] Liu S, Yu Q, Hossain MM, et al. Meeting 24-h movement guidelines is related to better academic achievement: findings from the YRBS 2019 cycle. Int J Ment Health Promot. 2022;24:13–24.
[19] Chen S, Yan J, Zhao Y. A trend analysis of adherence to the muscle strengthening exercise guidelines in US adolescents. Int J Public Health. 2022;67:1605022.
[20] Agostinis-Sobrinho C, García-Hermoso A, Ramírez-Vélez R, et al. Longitudinal association between ideal cardiovascular health status and muscular fitness in adolescents: the LabMed physical activity study. Nutr Metab Cardiovasc Dis. 2018;28:892–9.
[21] World Health Organization. New WHO-led study says majority of adolescents worldwide are not sufficiently physically active, putting their current and future health at risk. 2019. https://www.who.int/news/item/22-11-2019-new-who-led-study-says-majority-of-adolescents-worldwide-are-not-sufficiently-physically-active-putting-their-current-and-future-health-at-risk. Accessed January 22, 2024.
[22] Yang L, Zhang Q, Yan J. Dose-response associations between physical activity and poor mental health among high-school students: sleep duration as a potential mediator. Int J Ment Health Promot. 2026;28:1–10.
[23] Bennie JA, Faulkner G, Smith JJ. The epidemiology of muscle-strengthening activity among adolescents from 28 European countries. Scand J Public Health. 2021;50:295–302.
[24] Kelly HT, Smith JJ, Verdonschot A, et al. Supporting adolescents' participation in muscle-strengthening physical activity: protocol for the "Resistance Training for Teens" (RT4T) hybrid type III implementation–effectiveness trial. BMJ Open. 2023;13:e075488.
[25] Xin F, Zhu Z, Chen S, et al. Prevalence and correlates of meeting the muscle-strengthening exercise recommendations among Chinese children and adolescents: results from 2019 physical activity and fitness in China—the youth study. J Sport Health Sci. 2022;11:358–66.
[26] Smith JJ, Eather N, Weaver RG, Riley N, Beets MW, Lubans DR. Behavioral correlates of muscular fitness in children and adolescents: a systematic review. Sports Med. 2019;49:887–904.
[27] Su H, Chi X, Li H, Du S, Yan J. Are more muscle-strengthening exercise participations associated with weight status in children and adolescents? Results from 67,281 participants. BMC Public Health. 2025;25:2408.
[28] Artero EG, Ruiz JR, Ortega FB, et al.; HELENA Study Group. Muscular and cardiorespiratory fitness are independently associated with metabolic risk in adolescents: the HELENA study. Pediatr Diabetes. 2011;12:704–12.
[29] Sheng H, Ge B, Li Y, et al. Determinants of engagement in muscle-strengthening activities among children and adolescents: insights from a large-scale school-based study. Front Public Health. 2025;13:1526907.
[30] Sun Q, Xu Z, Lyu D, et al. Physical activity and cognitively difficulties in adolescents: a cross-sectional study of 13,677 participants. Complement Ther Clin Pract. 2025;59:101965.
[31] Xia M, Wang P, Feng B, Zhang Q, Yan J. Relationships between vigorous physical activity and psychological complaints in adolescents: findings from 240,951 participants. BMC Public Health. 2026;26:1962.

[32] Dykstra BJ, Griffith GJ, Renfrow MS, Mahon AD, Harber MP. Cardiorespiratory and muscular fitness in children and adolescents with obesity. Curr Cardiol Rep. 2024;26:349–57.
[33] Padilla-Moledo C, Ruiz JR, Ortega FB, Mora J, Castro-Piñero J. Associations of muscular fitness with psychological positive health, health complaints, and health risk behaviors in spanish children and adolescents. J Strength Cond Res. 2012;26:167–73.
[34] Archer T. Health benefits of physical exercise for children and adolescents. J Nov Physiother. 2014;04:203.
[35] Rozanski A. New principles, the benefits, and practices for fostering a physically active lifestyle. Prog Cardiovasc Dis. 2023;77:37–49.
[36] Martins J, Marques A, Sarmento H, Carreiro da Costa F. Adolescents' perspectives on the barriers and facilitators of physical activity: a systematic review of qualitative studies. Health Educ Res. 2015;30:742–55.
[37] Fan H, Yan J, Yang Z, Liang K, Chen S. Cross-sectional associations between screen time and the selected lifestyle behaviors in adolescents. Front Public Health. 2022;10:932017.
[38] Masanovic B, Gardasevic J, Marques A, et al. Trends in physical fitness among school-aged children and adolescents: a systematic review. Front Pediatr. 2020;8:627529.
[39] Cox A, Fairclough SJ, Kosteli M-C, Noonan RJ. Efficacy of school-based interventions for improving muscular fitness outcomes in adolescent boys: a systematic review and meta-analysis. Sports Med. 2020;50:543–60.
[40] Yang Z, Chen S, Bao R, et al. Public health concern on sedentary behavior and cardiovascular disease: a bibliometric analysis of literature from 1990 to 2022. Medicina (Kaunas). 2022;58:1764.
[41] Zhang Z, Zhu Y, Wang Q, et al. Global trends and research hotspots of exercise for intervening diabetes: a bibliometric analysis. Front Public Health. 2022;10:902825.
[42] Yang Z, Hotterbeex P, Marent P-J, Cerin E, Thomis M, van Uffelen J. Physical activity, sedentary behaviour, and cognitive function among older adults: a bibliometric analysis from 2004 to 2024. Ageing Res Rev. 2024;97:102283.
[43] Wu C-C, Huang C-W, Wang Y-C, et al. mHealth research for weight loss, physical activity, and sedentary behavior: bibliometric analysis. J Med Internet Res. 2022;24:e35747.
[44] Chan KH, So SK. Using admittance spectroscopy to quantify transport properties of P3HT thin films. J Photon Energy. 2011;1:1–10.
[45] Huang X, Chan K-H, Wu W, Sheng H, Ke W. Fusion of multi-modal features to enhance dense video caption. Sensors (Basel). 2023;23:5565.
[46] Lau WK, Li X, Yeung DS, Chan KH, Ip MS, Mak JC. The involvement of serotonin metabolism in cigarette smoke-induced oxidative stress in rat lung in vivo. Free Radic Res. 2012;46:1413–9.
[47] Cheng K, Xue X, Chan K. Zero emission electric vessel development. In: 2015 6th International Conference on Power Electronics Systems and Applications (PESA). IEEE; 2015.
[48] Donthu N, Kumar S, Mukherjee D, Pandey N, Lim WM. How to conduct a bibliometric analysis: an overview and guidelines. J Bus Res. 2021;133:285–96.
[49] Echchakoui S. Why and how to merge Scopus and Web of Science during bibliometric analysis: the case of sales force literature from 1912 to 2019. J Market Anal. 2020;8:165–84.
[50] Hirsch JE. An index to quantify an individual's scientific research output. Proc Natl Acad Sci U S A. 2005;102:16569–72.
[51] Egghe L. Theory and practise of the g-index. Scientometrics. 2006;69:131–52.
[52] Coronado-Ferrer S, Ferrer-Sapena A, Aleixandre-Benavent R, Valderrama Zurián JC, Cogollos LC. Global trends in scientific research on pediatric obesity. Int J Environ Res Public Health. 2022;19:1251.
[53] García-Hermoso A, Ramírez-Campillo R, Izquierdo M. Is muscular fitness associated with future health benefits in children and adolescents? A systematic review and meta-analysis of longitudinal studies. Sports Med. 2019;49:1079–94.
[54] Lloyd RS, Faigenbaum AD, Stone MH, et al. Position statement on youth resistance training: the 2014 International Consensus. Br J Sports Med. 2014;48:498–505.
[55] Bull FC, Al-Ansari SS, Biddle S, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. Br J Sports Med. 2020;54:1451–62.