A BIBLIOMETRIC ANALYSIS OF RESEARCH ON CLIMATE CHANGE AND PHYSICAL ACTIVITY: KNOWLEDGE VISUALIZATION AND REVIEW

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Abstract. Climate change and physical activity have emerged as focal points of contemporary research. This study adopts a scientometric approach to review 1,268 bibliographic records and 70,522 citation records from the WoS Core Collection database, aiming to outline the research domains of climate change and physical activity through co-authorship, co-citation, and keyword co-occurrence analyses. Our findings highlight that: firstly, the research landscape is predominantly shaped by developed nations in Europe and North America, with the USA, Canada, and England being key contributors; secondly, the top ten authors in this field are spotlighted based on co-citation frequency, burst intensity, and centrality. Additionally, we identified four primary research themes and further unveiled the evolving research hotspots, delineating two promising research trajectories. In conclusion, potential future directions for research in climate change and physical activity are proposed. Furthermore, the study's principal contributions and limitations are elaborated upon, acknowledging the constraints imposed by utilized tools and data sources, and the influence of the researchers' expertise on result interpretation.
Keywords: *bibliographic coupling, climate studies, co-citation analysis, research trends, science mapping*

Introduction

Climate change, often termed global warming, encompasses various alterations in climatic parameters (Weber and Stern, 2011). For over four decades, climatologists have cautioned that the inability to swiftly reduce ecological impacts might result in permanent harm to ecosystems, economies, and societies (Ripple et al., 2020). Public discourses on climate change predominantly focus on global surface temperatures, overlooking the comprehensive effects of human actions and the genuine threats of global warming (Bandh et al., 2021). The consequences of climate change are multifaceted, positioning it as a prominent interdisciplinary research domain (Peng et al., 2023). Human-induced greenhouse gas emissions stand as the principal contributors to climate change (Fiske et al., 2018), emphasizing the significance of human behaviors in climate studies. As common everyday activities, sports and physical activities contribute considerably carbon emissions (Chard and Mallen, 2012; Wicker, 2019), as do associated activities like driving to facilities (Bunds et al., 2018). Conversely, climate change exerts multifaceted effects on physical activities. A moderate rise in temperature can enhance participation in physical activities (Saneinejad et al., 2012), whereas extreme heat, particularly in tropical and subtropical zones, deters sports engagement (Maloney and Forbes, 2011; Rung et al., 2011). Additionally, severe weather conditions attributed to climate change present unprecedented challenges for organizers of athletic events and the training schedules of athletes (Mallen et al., 2023). Given the recognition of the profound impacts of climate change on human health and its potential to alter physical activity (PA) patterns, interdisciplinary research bridging climate science and sports science is expanding, as evidenced by the growing body of literature. It is important to note that in this study, physical activity is defined broadly, encompassing both recreational and transportation-related human behaviors that contribute to climate change through greenhouse gas emissions, and are in turn affected by the effects of climate change, necessitating an interdisciplinary approach to understanding this intricate relationship.

In this context, several studies have examined research themes and methodologies related to climate change and physical activity. Owing to the interdisciplinary character of research concerning climate change and transportation, these reviews present varied viewpoints. These encompass the interrelation between climate change, physical activity, and health (Townsend et al., 2003), the repercussions of temperature elevation on physical activity (Wallace et al., 2019), the ramifications of climate change for sports organizations (Orr et al., 2022), and the impact on specific physical activities (Kerr et al., 2009). Nonetheless, the literature selection in these reviews predominantly hinges on individual expertise, often narrowing down to a singular theme within the research domain, without incorporating quantitative bibliometric assessments. Despite the burgeoning literature in this arena, the overarching structure of the knowledge domain remains largely uncharted.

Originating in the 1970s, bibliometrics is a discipline that employs quantitative techniques to analyze the progression of scientific research. It enables the illustration of the knowledge architecture of a particular research domain and forecasts future trajectories through the examination of academic citation patterns (Nalimov, 1972). Over the years, bibliometrics has evolved significantly, with visualization tools like CiteSpace (Chen et al., 2012), VOSviewer (Van Eck and Waltman, 2010), and HistCite (Garfield, 2009) becoming prevalent for knowledge mapping. Each tool possesses distinct advantages and limitations. Notably, CiteSpace stands out for its ability to perform bibliometric evaluations coupled with data mining and visualization features (Chen, 2006), making it the most widely adopted. While scholars actively create knowledge maps in various domains, a holistic analysis of the nexus between climate change and physical activity remains absent. This study was conceived to fill this gap. Leveraging bibliometric techniques, we scrutinized pertinent literature from the Web of Science core database, aiming to furnish researchers with a lucid knowledge framework, developmental trend predictions, and dependable references for decision-makers.

The subsequent sections of this paper are organized as follows: Section 2 delineates the data acquisition process and research methodology. Section 3 elucidates the analytical outcomes. Section 4 extrapolates future research directions based on the findings from Section 3. We conclude by highlighting the principal insights and underscoring the study's widespread relevance.

Materials and Methods

Bibliometrics focuses on the analysis of cited literature. To ensure comprehensive data representation and accessibility, we selected the Web of Science (WoS) Core Collection database, a standard choice for many studies employing CiteSpace as their analytical instrument (Chen et al., 2022; Che et al., 2022). The WoS Core Collection encompasses several indices, including the Science Citation Index Expanded (SCI-E), Social Sciences Citation Index (SSCI), Arts and Humanities Citation Index (A&HCI), and others. Recognized for its coverage of over 12,000 premier journals, WoS has traditionally served as the primary source for scientometric investigations (Mingers and Leydesdorff, 2015). As delineated in *Table 1*, our bibliographic search strategy was formulated as: (TS=(climate change) AND TS=(physical NEAR/0 activit*)) OR (TS=(climate change) AND TS=(physical NEAR/0 exercise*)) OR (TS=(climate change) AND TS=(sport*)). To ensure thoroughness, we incorporated synonymous terms like "physical exercise" and "sport" alongside "physical activity". In this formula, the asterisk ("*") denotes unlimited truncation, while "NEAR/0" indicates that terms A and B are adjacent. The search spanned from 1900 to the present, conducted on October 30, 2023. Initially, 1398 papers were identified. Post exclusion of conference papers, notes, and non-English articles, the dataset comprised 1268 research and review papers.

Table 1. *The search query used in this study*

Data Source	WoS
Search query	(TS=(climate change) AND TS=(physical NEAR/0 activit*)) OR (TS=(climate change) AND TS=(physical NEAR/0 exercise*)) OR (TS=(climate change) AND TS=(sport*))
Retrieval time	October 30, 2023
Time span	Unlimited
Quality measure	Peer-reviewed research papers in English
No of records	1398

Note: The analysis in this table is based on a subset of the dataset, consisting of 1268 papers. Some publications were excluded from the analysis for specific reasons

This study employed knowledge mapping to provide a visual representation of literature data, a methodology frequently adopted in scientometrics. Prominent tools in scientometrics, such as CiteSpace, VOSviewer, and HistCite, facilitate the visual portrayal of a research field's knowledge structure. Of these, CiteSpace is the most prevalent, uniquely offering burst detection, network, timeline, and geospatial analyses within a single platform (Bankar and Lihitkar, 2019). It enables a comprehensive visualization of a knowledge domain, which encompasses a broad delineation of a research area, typically characterized by a collection of bibliographic records from pertinent publications. Given its robust and multifaceted capabilities, this study utilized CiteSpace 6.2.R4 for visualizing and analyzing the knowledge landscape of research on climate change and physical activity.

The research framework is delineated in *Figure 1*. This study incorporated three primary bibliometric techniques: collaboration analysis, co-citation analysis, and co-word analysis. The analytical process entailed the following steps: initially, we established collaboration networks to unearth potential collaborative endeavors. Subsequently, co-citation analysis was executed to ascertain the field's knowledge

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structure. We then undertook co-word analysis to trace the progression of research focal points and pinpoint prevailing research trends. Concludingly, informed by the preceding analyses, we suggested prospective research avenues in the realm of climate change and physical activity.

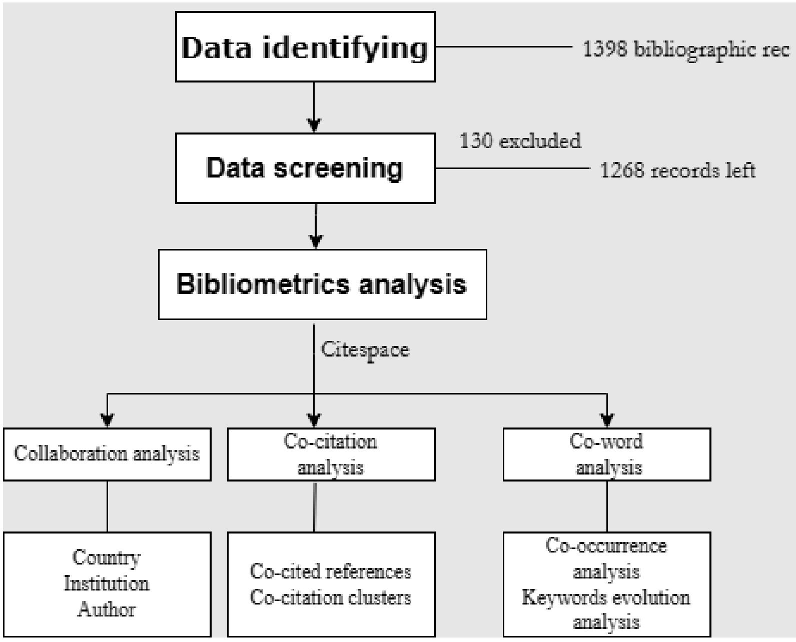

Figure 1. *Research framework*

Results

Collaboration Analysis

The "Collaboration Analysis" function is designed to examine collaborations among researchers. It facilitates the exploration of collaborative ties between authors, institutions, or nations, aiming to understand the structure and progression of scientific partnerships (Newman, 2001; Barabâsi et al., 2002). Utilizing this feature, users can produce collaboration network diagrams, pinpoint central collaborators, assess the intensity and geographic spread of collaborations, and discern collaboration dynamics. Such insights illuminate prominent researchers and institutions within a domain and their collaborative behaviors, offering scholars a valuable instrument to deeply comprehend patterns and trajectories of scientific collaboration (Chen, 2006).

Country/Region Collaboration Network

Through country/region collaboration analysis, we can discern when scholars from various countries entered this research field, the scale of their research, and their collaborative connections. *Figure 2* illustrates the country/region collaboration network in the field of climate change and physical activity research, comprising 104 nodes and 1020 links. Here, nodes symbolize countries/regions, and links denote academic collaborations between two countries. Node colors indicate the year of publication, with darker hues representing earlier works and lighter colors like yellow and orange signifying more recent publications. The field's inception dates back to 1991 with

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contributions from Norwegian scholars, followed by researchers from Switzerland, the Netherlands, and other European nations. American scholars joined in 1997, introducing new dynamics to the field, soon followed by Canadian participation. This initial phase of research exhibits distinct regional characteristics. Subsequently, several developing countries, including China, Mexico, and Brazil, also engaged in the research.

Figure 2. *Country/region collaboration network: a timezone view*

To further elucidate the country/region collaboration network, *Table 2* lists the top 10 countries/regions based on publication quantity and betweenness centrality. According to Chen et al. (2022), the creator of CiteSpace, betweenness centrality measures how frequently a node serves as the shortest path between two other nodes, indicating its role in connecting different nodes within the network. As *Table 2* reveals, the United States leads with the highest number of publications (432 articles) and the greatest centrality (0.13), surpassing England (187 publications) and Canada (centrality of 0.12). England, Canada, and Australia contributed 187, 160, and 158 records, respectively. The United States emerges as the foremost contributor in this research area. Furthermore, developed countries generally outperform developing nations in both publication quantity and betweenness centrality. China, the only developing country in the top 10 for publication quantity, exhibits a lower centrality value, suggesting its relatively smaller role in the collaboration network compared to its publication output.

Table 2. *Top 10 countries/regions based on the number of publications*

Country	Publications	Centrality	Country	Publications	Centrality
US	432	0.13	Germany	93	0.06
England	187	0.10	Spain	75	0.01
Canada	160	0.12	Italy	57	0.02
Australia	158	0.09	France	46	001
China	97	0.03	Sweden	46	0.03

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Institution Collaboration Network

In the analysis of institutional collaborations, we discern the contributions and collaborative ties of various academic institutions within the realm of climate change and physical activity research. *Figure 3* and *Table 3* depict the results. The institutional collaboration network comprises 448 nodes and 1474 links, with nodes symbolizing the number of publications, links indicating institutional collaborations, and node colors reflecting the publication timeline. The University of California System leads in publication quantity with 43 articles, followed by institutions such as the University of London (31 articles) and the University of British Columbia (26 articles). Among the top ten contributors, renowned universities coexist with institutions specializing in climate and health research. Notably, nine out of the top ten institutions are from America and Europe, with only one Chinese institution making the list. The University of California System stands out both in terms of publication quantity and centrality, while Harvard University also exhibits a significant centrality contribution. This underscores the pivotal roles these premier American institutions play in fostering collaborations in the specified research domain.

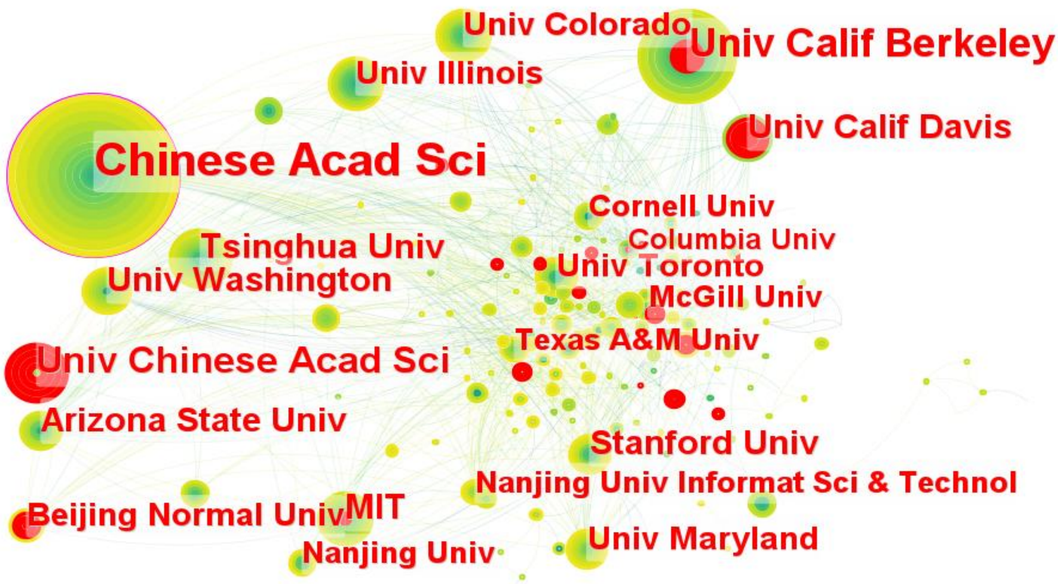

***Figure 3.** Institution collaboration network*

***Table 3.** Top 10 institutions based on the number of publications*

Institution	Publications	Centrality	Country/Region
University of California System	43	0.22	US
University of London	31	0.05	England
University of British Columbia	26	0.07	US
Harvard University	18	0.16	US
State University System of Florida	17	0.10	US
UDICE-French Research Universities	17	0.09	France
Chinese Academy of Sciences	17	0.04	China
Deakin University	16	0.05	Australia
London School of Hygiene & Tropical Medicine	15	0.04	England
Helmholtz association	15	0.05	Germany

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Author Collaboration Network

In the author collaboration analysis, we present an author collaboration network comprising 469 nodes and 1000 links. Consistent with the prior sections, nodes symbolize authors, links denote collaborations between authors, and node colors reflect publication years. *Figure 4* illustrates the network structure, suggesting a relatively nascent research community given its loose configuration. This implies limited and fragmented collaborations among scholars in the nexus of climate change and physical activity research. *Table 4* enumerates the top 10 authors based on publication count, with Madeleine Orr from Loughborough University London identified as the most prolific author in this domain. However, the publication counts of these authors are relatively low, which also suggests a lack of collaboration among researchers in this field. It's worth noting that all author centralities are registered as 0, due to their values being too minuscule for system representation. This further underscores the limited collaborative endeavors within this interdisciplinary field.

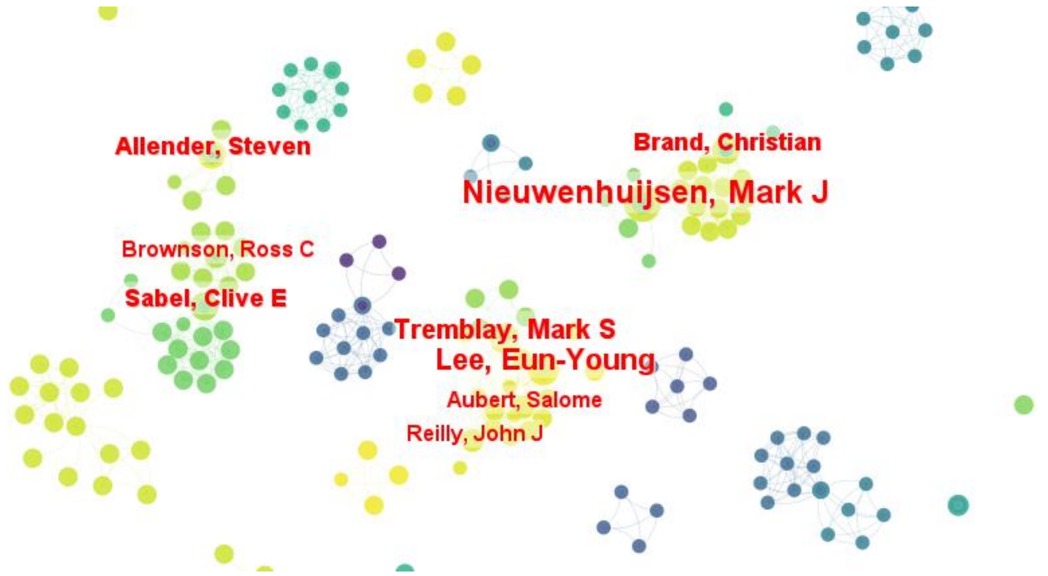

Figure 4. *Author collaboration network*

Table 4. *Top 10 authors based on the number of publications*

Author	Publications	Centrality	Author	Publications	Centrality
Madeleine Orr	8	0	Clive Sabel	4	0
Mark Nieuwenhuijsen	7	0	Christian Brand	4	0
Eun Young Lee	6	0	Steven Allender	4	0
Mark Tremblay	5	0	Leah E. Robinson	4	0
Brian P. McCullough	5	0	Greg Dingle	4	0

Co-Citation Analysis

The "Co-Citation Analysis" function is designed to assess co-citation relationships within the literature. A co-citation relationship arises when two journals, papers, or authors are jointly cited in the references of another paper. For instance, if paper A cites both papers C and D, then C and D share a co-citation relationship (Hou et al., 2018).

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The strength of this relationship is determined by the number of papers that co-cite them. A higher co-citation frequency suggests a stronger academic bond between the entities. It's important to note that these relationships evolve over time. By examining co-citation networks, one can trace the developmental trajectory and dynamic shifts within a discipline (Chen, 2006). This study delved into both co-cited authors and references, employing methods such as cluster analysis, high co-citation reference analysis, burst detection, and turning point analysis for comprehensive validation.

Author Co-Citation Analysis

Co-cited author analysis seeks to pinpoint frequently cited authors, shedding light on academic affiliations among authors or research groups and highlighting pivotal figures and seminal research in the domain. *Figure 5* depicts the author co-citation network, encompassing 1259 nodes and 5720 links. Here, node size signifies an author's citation frequency, links denote co-citation relationships, and node colors correspond to the publication years of the cited articles, with red indicating a surge in an author's citations over a specific duration. *Table 5* lists the ten least cited authors, including WHO (102), James F Sallis (77), Daniel Scott (69), Richard M Ryan (60), R CoreTeam (55), Christopher Ames (54), Valérie Masson-Delmotte (54), Nick Watts (49), IPCC (48), and Edward L. Deci (47). Notably, the World Health Organization (WHO) and the Intergovernmental Panel on Climate Change (IPCC) are featured, underscoring the influential role of their official documents in shaping climate change and physical activity research. The R CoreTeam, responsible for the development and upkeep of the R language, ranks fifth, indicating the prevalent use of R in this research area. The remaining scholars primarily hail from three disciplines: climate change (Daniel Scott and Valérie Masson-Delmotte), human behavior (James F Sallis, Richard M Ryan, Carole Ames, and Edward L. Deci), and the nexus of climate change and physical activity (Nick Watts). Their collective work constitutes the foundation of this research field (Chen, 2006).

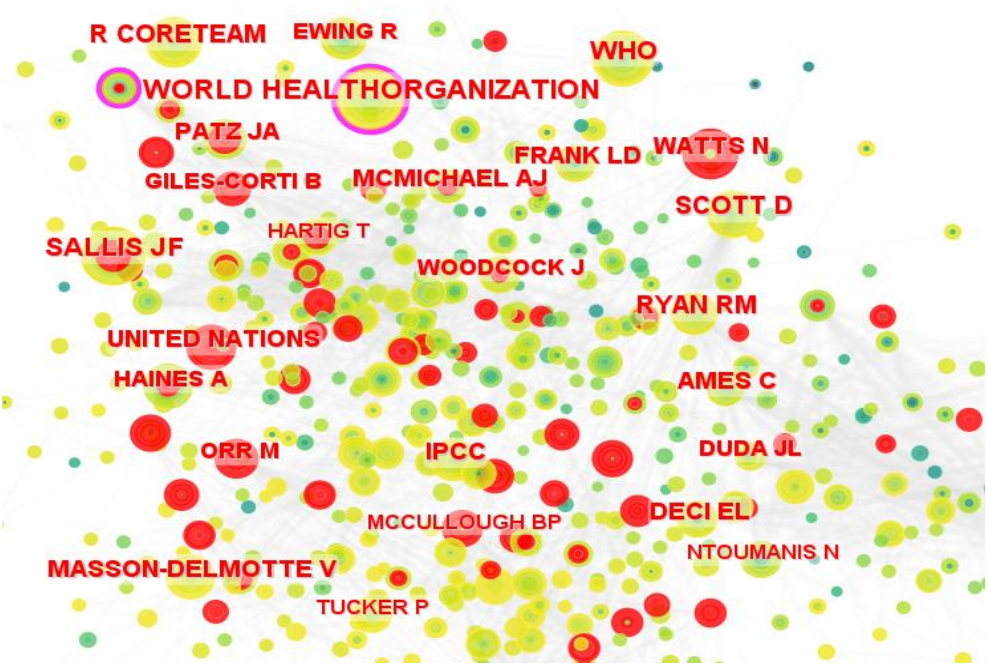

Figure 5. *Author/organisation co-citation network*

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Table 5. *Top 10 authors/organisations in co-citation frequency and burst strength*

Top 10 Authors/Organisations in Co-Citation Frequency	Top 10 Authors/Organisations in Burst Strength
WHO (102)	Daniel Scott (8.24)
James F Sallis (77)	Terry Hartig (7.67)
Daniel Scott (69)	Lilah Besser (7.65)
Richard M Ryan (60)	Lawrence Frank (6.96)
R CoreTeam (55)	Albert Bandura (6.84)
Carole Ames (54)	Reid Ewing (6.70)
Valérie Masson-Delmotte (54)	Richard M Ryan (6.43)
Nick Watts (49)	Catharine Ward Thompson (6.14)
IPCC (48)	**Mireia Gascon (6.08)**
Edward L. Deci (47)	Nikos Ntoumanis (6.00)

The co-citation analysis also spotlighted ten authors with pronounced citation bursts: Daniel Scott (8.24), Terry Hartig (7.67), Lilah Besser (7.65), Lawrence Frank (6.96), Albert Bandura (6.84), Reid Ewing (6.70), Richard M Ryan (6.43), Catharine Ward Thompson (6.14), Mireia Gascon (6.08), and Nikos Ntoumanis (6.00). These authors experienced heightened citations in varying years, indicating their research addressed emerging topics of interest at distinct junctures. Notably, Daniel Scott is the sole author featured in both the top 10 co-cited and bursting citations lists, marking him as a pivotal figure in the discipline.

Reference Co-Citation Analysis

The co-cited reference network was constructed utilizing the co-citation analysis function. This analysis employed the log-likelihood ratio (LLR) weighted algorithm to examine articles and their associated references. The LLR algorithm assigns clusters with pertinent professional vocabularies, facilitating the comparison of the suitability of two statistical models based on their likelihood ratio (Huang et al., 2023). *Figure 6* illustrates the co-cited reference network, comprising 1112 nodes and 3510 links. Here, the node size denotes the co-cited frequency, links represent associations between references, and node colors correspond to the timeline of the literature's publication. The co-cited reference analysis encompassed a cluster analysis, segmenting the entire co-citation network into 45 distinct clusters. *Table 6* provides a detailed overview of the top 10 clusters. Notably, all clusters in *Table 6* achieved commendable silhouette scores, signifying the co-cited network's robust homogeneity. To further elucidate the foundational research in the realm of climate change and physical activity, *Table 6* enumerates the top 10 seminal references, often heralded as benchmarks due to their pioneering contributions (Chen et al., 2022).

Table 7 enumerates the ten most prominent subject clusters in the domain of climate change and physical activity research, offering a lucid representation of the field's knowledge structure. CiteSpace determines the ranking and cluster labels through the LLR algorithm, which is grounded in text analysis. This algorithm is renowned for delivering optimal results in terms of distinctiveness and comprehensiveness (Hu et al., 2020). For the purpose of this study, we focused on the ten leading clusters to delve into the knowledge structure, while omitting the less significant clusters. Subsequent

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sections provide an in-depth discussion of these clusters. Upon consolidating the ten clusters and amalgamating analogous themes, this study delineated five predominant research themes within the realm of climate change and physical activity.

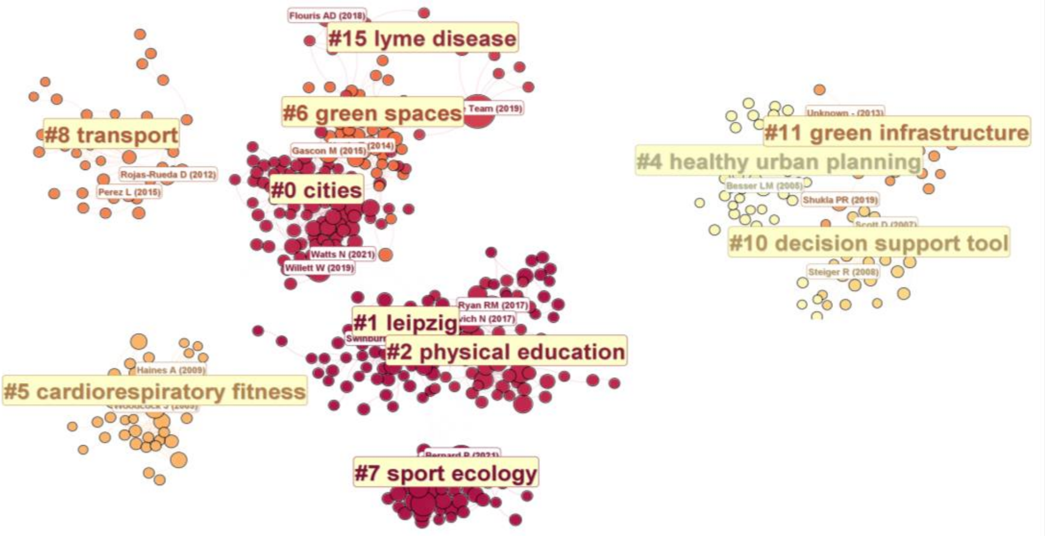

***Figure 6.** Reference co-citation network*

***Table 6.** Top 10 cited references*

No.	Citation Counts	References	Source journal/Publisher
1	39	R: A language and environment for statistical computing (R Core Team, 2013)	
2	27	Climate change 2021: The physical science basis. contribution of working group i to the sixth assessment report of the intergovernmental panel on climate change (Masson-Delmotte et al., 2021)	IPCC
3	27	Sport versus climate: Introducing the climate vulnerability of sport organizations framework (Orr and Inoue, 2019)	Sport Management Review
4	24	Climate change, physical activity and sport: a systematic review (Bernard et al., 2021)	Sports Medicine
5	20	Playing the climate game: Climate change impacts, resilience and adaptation in the climate-dependent sport sector (Dingle and Stewart, 2020)	Creating and Managing a Sustainable Sporting Future
6	19	Sport ecology: Conceptualizing an emerging subdiscipline within sport management (McCullough et al., 2020)	Journal of Sport Management
7	19	Self-determination theory: Basic psychological needs in motivation, development, and wellness (Ryan and Deci, 2017)	Guilford Publications
8	17	The 2020 report of the Lancet Countdown on health and climate change: responding to converging crises (Watts et al,. 2021)	The Lancet
9	17	Climate change and physical activity: estimated impacts of ambient temperatures on bikeshare usage in New York City (Heaney et al., 2019)	Environmental Health Perspectives
10	16	Nature and health (Hartig et al., 2014)	Annual Review of Public Health

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Table 7. *Top 10 co-citation clusters*

Cluster ID	Size	Silhouette	Top Terms (Log-Likelihood Ratio)
0	93	0.946	Cities
1	69	0.849	Leipzig
2	51	0.994	Boys
3	51	0.883	Physical Education
4	49	0.984	Healthy Urban Plan
5	43	0.871	Green Spaces
6	43	0.990	Cardiorespiratory
7	42	0.983	Sport Ecology
8	41	0.946	Transport
9	32	1	PM2.5

a) Urban form, transportation and physical activity

This theme encompasses several clusters, notably cluster 0, cluster 4, cluster 5, and cluster 8, delving into the impact of urban planning and transportation policies on physical activity and emissions. The primary research areas focus on active travel, walkability, compact development patterns, and their subsequent health and environmental implications. The nexus between urban form, transportation, and physical activity has garnered attention across various disciplines. Research has identified significant correlations between walking, cycling, and environmental factors in urban design, transportation, and planning (Saelens et al., 2003), such as road design, accessibility to public spaces, and urban green spaces. The notion that built environments indirectly influence carbon emissions by shaping physical activity patterns has also been widely recognized (Handy et al., 2002). The interplay of urban design, land-use patterns, and transportation systems is deemed crucial in influencing daily activities and travel behaviors (Frank et al., 2004). Moreover, urban form attributes correlate with the duration spent in cars, levels of physical activity, and obesity rates (Frank et al., 2005). For example, factors like street connectivity, the presence of sidewalks, and bike lanes are associated with physical activity levels. Another study underscored the significance of employing objective methodologies to discern the relationship between physical activity and urban form, offering fresh insights into the link between built environments and physical activity (Frank et al., 2005). Ultimately, the efficacy of urban design, land use, and transportation policies in fostering physical activity has come to the forefront (Heath et al., 2006), with the goal of crafting environments that encourage walking, cycling, and other physical activities. This multifaceted interdisciplinary domain necessitates cross-disciplinary collaborations for comprehensive analysis and understanding.

b) Air pollution and physical activity

This theme encompasses documents from cluster1 and cluster9. Numerous studies have established negative correlations between air pollution and physical activity behaviors across varied populations and geographical settings. Both objective metrics of ambient air pollution levels, such as PM2.5, PM10, and NO_2 (An et al., 2018), and subjective perceptions of air quality, including pollution alerts (Noonan, 2014; Kim et al., 2020), have been linked to reductions in leisure-time physical activity and active transportation, as well as increased sedentary behavior. These correlations are more pronounced among vulnerable demographics, such as the elderly (Ward and Beatty, 2016). Efforts to mitigate air pollution by promoting active transportation, either

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independently (de Sá et al., 2017) or in conjunction with public transit (Xia et al., 2015), have resulted in modest declines in particulate matter emissions in urban areas. Nonetheless, the emission reductions achieved through active travel initiatives appear to be minimal, as evidenced by empirical studies (Brand et al., 2014; Chapman et al., 2014; Goodman et al., 2014). Collectively, these findings suggest that deteriorating air quality, exacerbated by climate change (Van Vuuren et al., 2011), could significantly hinder global physical activity participation. Ensuring public health necessitates a dual approach: enhancing air quality and creating environments conducive to promoting physically active lifestyles.

c) Physical activity, health and climate change

The interplay between physical activity, health, and climate change forms a complex relationship. This subject is prominently featured in the research domain of climate change and physical activity, with cluster1 and cluster6 being the pertinent cluster. Physical activity is instrumental in enhancing health and warding off various ailments (Trost et al., 2002). Nonetheless, the surrounding environment can either facilitate or impede physical activity. The design of urban spaces and community infrastructures profoundly affects individuals' propensity for physical engagement (Humpel et al., 2002). For example, thoughtfully planned urban areas can promote walking, cycling, and other active pursuits (Frank et al., 2004). Conversely, climate change, driven by human activities, can alter environmental conditions, rendering some areas less suitable for outdoor activities due to severe climatic patterns. Climate change presents considerable health challenges, including heightened risks of heat-induced ailments, respiratory issues, and diseases transmitted by vectors (Luber, 2014). The evolving climate can also create environmental conditions that deter outdoor physical endeavors, such as extreme meteorological phenomena or compromised air quality. However, endorsing active modes of transportation, like walking and cycling, can enhance personal health and simultaneously curtail greenhouse gas emissions, thereby alleviating climate change (Sallis et al., 2016). In summary, while climate change can detrimentally impact health and physical activity, embracing eco-friendly and active lifestyles can yield dual benefits: improved individual health and diminished environmental degradation. Hence, cultivating environments conducive to physical activity not only augments personal well-being but also aids in countering the detrimental repercussions of climate change (Sallis et al., 2016).

d) Sport ecology

The final theme under discussion is Sport Ecology, encompassing cluster2, cluster3, and cluster7. Sport Ecology is a nascent research domain that examines the interplay between sports and the ecological environment. This field integrates various interdisciplinary subjects, including management, sports education, behavior, and climatology. Given the escalating concerns about global climate change and environmental challenges, the significance of this domain is gaining traction. Recent studies have highlighted that major sporting events, such as the Olympic Games and the World Cup, not only consume vast amounts of energy but also produce substantial waste, exerting considerable environmental strain (Hoffmann et al., 2015). Furthermore, many sports venues operate even during off-seasons, leading to inefficient energy consumption and resource wastage (Trendafilova et al., 2013). Such events also contribute significantly to waste generation and greenhouse gas emissions (McGillivray et al., 2019). However, the nexus between sports and ecology isn't solely detrimental. Sporting events are evolving into facets of eco-tourism, offering tourists immersive

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experiences with nature. While this fosters economic growth, it also augments public environmental consciousness. Yet, this evolution is not devoid of challenges, as excessive sports tourism can negatively impact the environment, causing habitat disruption and vegetation degradation (Orr and Inoue, 2019).

The realm of sports management is progressively integrating the sports ecology perspective. Scholars have introduced innovative management strategies to address the ramifications of climate change and environmental dilemmas (McCullough et al., 2020). Research has delved into sports decision-making through the lens of ecological psychology, emphasizing swift and precise decisions in intricate competitive settings (Araújo et al., 2006). Skill acquisition, pivotal in sports training, is now extensively explored from an ecological standpoint. Emulating real competition settings can enhance athlete training and boost performance (Handford et al., 1997). This ecological perspective also offers profound insights into athletes' decision-making and skill execution (Araujo and Davids, 2009). For orchestrating large-scale events, global sports entities like the International Olympic Committee have initiated environmental protection standards to champion sustainable sports practices (Hugaerts et al., 2021). Numerous sports venues have also implemented sustainable measures, such as renewable energy sources and rainwater harvesting, to minimize environmental impacts (Dingle and Mallen, 2020). As a multidisciplinary field bridging sports, ecology, psychology, and management, sports ecology's relevance is on the rise.

Co-Word Analysis

Co-word analysis in CiteSpace facilitates the identification and visualization of patterns in co-occurring terms across a collection of documents. This aids researchers in discerning potential themes and trends within the literature (Chen, 2013). To trace the progression of research topics related to climate change and physical activity, this study undertook a keyword co-occurrence analysis, with findings presented in *Figure 7* and *Table 8*. The analysis emphasized the top 10 keywords based on burst strength, co-occurrence frequency, burst intensity, and centrality ranking. These keywords epitomize distinct research topics that have significantly influenced the domain of climate change and physical activity at various junctures.

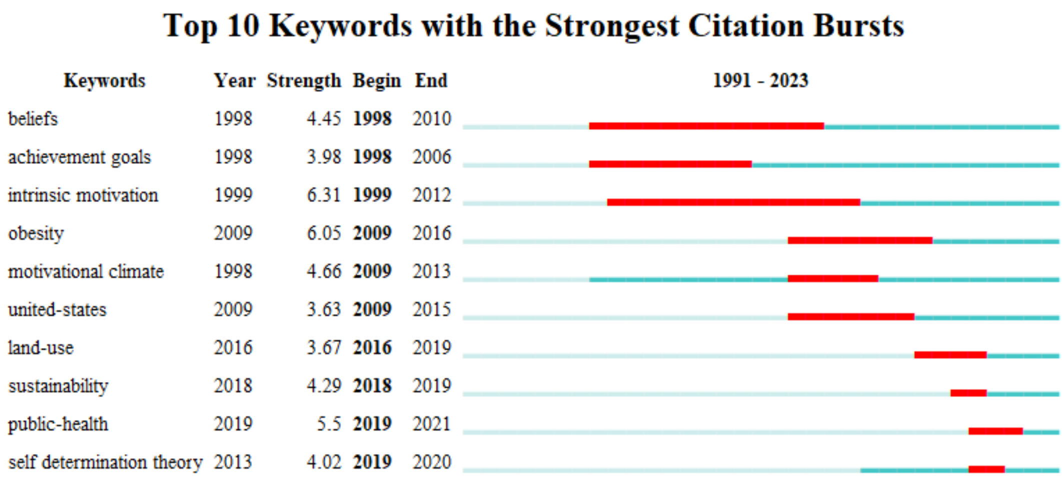

Figure 7. *Top 10 keywords with the strongest citation bursts*

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Table 8. *Top 10 keywords in co-occurrence frequency, burst strength, and centrality*

Top 10 Keywords in Co-Occurrence Frequency	Top 10 Keywords in Burst Strength	Top 10 Keywords in Centrality
Climate change (392)	Intrinsic motivation (6.31)	Climate change (0.22)
Physical activity (311)	Obesity (6.05)	Physical activity (0.14)
Health (135)	Public-health (5.50)	Weather (0.10)
Impact (106)	Motivational climate (4.66)	Walking (0.09)
Temperature (81)	Beliefs (4.45)	Model (0.08)
Mortality (66)	Sustainability (4.29)	Impact (0.07)
Air pollution (65)	Self determination theory (4.02)	Performance (0.07)
Motivational climate (62)	Achieved goals (3.98)	Health (0.06)
Sport (61)	Land-use (3.67)	Motivational climate (0.06)
Exercise (59)	(3.63)	Exercise (0.06)

Figure 7 enumerates the top 10 keywords based on burst strength. For instance, "intrinsic motivation" exhibited sustained bursting co-occurrences from 1999-2012, while "obesity" demonstrated a similar pattern from 2009-2016. Sequentially, "achieved goals" and "motivational climate" emerged as research focal points, culminating in the introduction of "self-determination theory" as a prominent keyword in 2019. The emphasis on individuals' living environments remains a steadfast theme, with terms like "land-use" and "sustainability" showcasing consecutive bursting co-occurrences. Recent keywords with notable burst values include "sustainability" (4.29), "public-health" (5.50), and "self-determination theory" (4.02). When examining co-occurrence frequency and centrality, beyond prevalent terms such as climate change, physical activity, and health, keywords like "temperature" (81) and "mortality" (66) stand out due to their frequency. In contrast, "weather" (0.10) and "walking" (0.09), owing to their high centrality, suggest potential avenues for collaboration within the field.

Future Research Prospects

In the past twenty years, significant research has been undertaken in the domains of climate change and physical activity. As this field of study evolves, novel research perspectives and methodologies are anticipated. Consequently, drawing from the findings presented in Section 3, we delineate the subsequent potential research trajectories.

a) Prioritize Adaptation Research in Low- and Middle-Income Countries: An examination of national cooperation networks and existing literature suggests that scholars from developed countries predominantly contribute to the research in the fields of climate change and physical activity. However, many developing nations, particularly those undergoing rapid growth, face severe environmental challenges (Li et al., 2020). There is a noticeable dearth of research focusing on climate change and physical activity in low- and middle-income countries, underscoring the need for further studies across diverse regions. Initiatives spearheaded by researchers from these countries should explore the potential adaptive and mitigative roles of physical activity concerning varied climate change outcomes. Investigating physical activity in diverse global contexts can yield insights into region-specific climate adaptation strategies. Community-based participatory research methods might be especially effective in understanding the interplay between physical activity and climate in lesser-studied

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regions. Enhancing research capacity in these countries is essential for achieving global equity in climate change adaptation.

b) Emphasize Physical Activity in Vulnerable and High-Risk Populations: The co-word analysis highlights that high temperatures and weather patterns have consistently been central to scholarly pursuits in this domain. As a consequence of climate change, the rise of vector-borne diseases may lead to alterations in physical behaviors, potentially impacting event transportation, professional sports, and outdoor recreational activities. Activities like hiking might correlate with heightened exposure risks to certain diseases, e.g., Lyme disease (Richter and Matuschka, 2011; Whitmee et al., 2015). The repercussions of climate-induced extreme weather on specific professions and groups warrant further exploration. This includes studying the risks posed by heatwaves to outdoor workers like farmers or delivery personnel and devising protective measures for athletes susceptible to diseases in high temperatures. Collaborative interdisciplinary research, bridging physical activity experts, occupational health specialists, and policymakers, is essential.

c) Focus on Sustainable Community Sports Facilities: In the context of climate change, residents' daily physical activities are predominantly localized within their communities. Adapting to drastic temperature fluctuations and extreme weather necessitates that community sports facilities are constructed with materials ensuring participant safety and comfort (Hassani and Golizadeh, 2016). Moreover, leveraging renewable energy sources, such as solar and wind (Trendafilova and McCullough, 2018), coupled with efficient irrigation systems (Trendafilova et al., 2013), can significantly benefit this research domain.

d) Consider Comprehensive Models of Environmental Impacts on Sports Activities: The relationship between climate change and physical activity is multifaceted, encompassing environmental, social, and economic dimensions. This study's co-citation analysis revealed the predominant use of the R language in this research area. Anticipated research models will likely holistically examine these interactions, offering nuanced predictions about potential future scenarios. For instance, rising global temperatures might necessitate modifications in sports schedules and venues. Climate change could also influence athlete health and performance metrics, such as heat stress or air quality variations. Economically, climate change might alter the sports industry's revenue streams and expenditure patterns, impacting facility upkeep, sponsorships, and sustainability-centric marketing strategies (Trendafilova et al., 2013). Socially, physical activity can serve as a conduit for enhancing climate change awareness and fostering sustainable practices (Kellison and Hong, 2015).

Conclusions

This study examines the prevailing state and trajectories of research in the domains of climate change and physical activity. Utilizing a scientometric approach, we reviewed 1,268 bibliographic records and 70,522 citation records sourced from the WoS Core Collection database. This review aimed to delineate the research areas of climate change and physical activity through co-authorship, co-citation, and keyword co-occurrence analyses. From our analysis, several conclusions emerged. Firstly, the research landscape is predominantly shaped by developed nations in Europe and North America, with the United States, Canada, and England being pivotal contributors. Secondly, our author co-citation analysis spotlighted the top ten authors based on co-

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citation frequency, burst intensity, and centrality, underscoring their leadership in this domain. Thirdly, we identified four primary research themes: Urban Form and Transportation's Influence on Physical Activity, The Interplay between Air Pollution and Physical Activity, The Nexus of Physical Activity, Health, and Climate Change, and Sport Ecology. These themes collectively define the knowledge structure of this field. Our keyword co-occurrence analysis further revealed evolving research hotspots and highlighted two promising research trajectories. Conclusively, our findings suggest potential future directions for climate change and physical activity research, including prioritizing adaptation studies in low- and middle-income countries, emphasizing physical activity among vulnerable populations, focusing on sustainable community sports infrastructure, and developing holistic models to assess environmental impacts on sports.

The primary contributions and limitations of this study are delineated in this subsection.

Contributions

This study offers both theoretical and practical contributions to the field of climate change and physical activity. Theoretically, it extends previous bibliometric studies by employing visualization tools to delineate the structure of this research domain. The developed knowledge map captures the evolution, domains, and emerging frontiers The developed knowledge map captures the evolution, domains, and emerging frontiers literature in this area. in this area. Our analysis traces pivotal milestones and the developmental trajectory of the field. Through co-citation analysis, we discern key research areas, elucidating the prevailing knowledge structure. The highlighted knowledge frontiers suggest prospective research directions. Practically, this study equips researchers with a comprehensive understanding of the field's progression. The findings can guide scholars in identifying pertinent publications for reference and suitable journals for submissions. Moreover, policymakers can benefit from the structured references provided.

Limitations

This study acknowledges two primary limitations. Firstly, the tools and data sources used imposed constraints. The bibliographic references were limited to English peer-reviewed articles from the WoS Core Collection database. While WoS offers high-quality research, broadening the data sources in subsequent studies might yield a more nuanced understanding of the domain. To maintain quality, only articles and reviews were selected, but future studies could consider a wider range of publication types. The exploration of alternative visualization tools is also recommended to enhance knowledge domain mapping.

Secondly, the inherent limitation pertains to the researchers. While scientometric mapping offers an objective method to analyze knowledge domains, the interpretation of results is inevitably influenced by the researchers' expertise. Future endeavors might benefit from independent domain experts validating the results and interpretation

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