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Innovation in sport medicine and science: a global social network analysis of stakeholder collaboration in rugby union

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ABSTRACT

Objectives To investigate the network of stakeholders involved in rugby union research across the globe.

Methods Using author affiliations listed on scientific publications, we identified the organisations that contributed to rugby union research from 1977 to 2022 and examine collaboration through coauthorship indicators. We determined the locations and sectors of identified organisations and constructed a collaboration network. Network metrics, including degree centrality and betweenness centrality, are computed to identify influential organisations and measure intersector collaboration.

Results There is an increase in scientific knowledge creation and collaboration between organisations for rugby union research over time. Among the sectors, the university, professional sports team and sports governing body sectors exhibit the highest intersectoral and intrasectoral density. Predominantly, influential actors are located in England, Australia, France, New Zealand, Ireland and South Africa. Australian Catholic University, Leeds Beckett University, Stellenbosch University, Swansea University, University College London and the University of Cape Town emerge as influential actors between 2016 and 2022.

Conclusions Our study underscores the ongoing growth of scientific knowledge generation in rugby union, primarily led by organisations in tier 1 rugby-playing nations within the university sector. Intersectoral collaboration with sports governing bodies plays a crucial role, acting as a broker between sectors. However, the overall collaboration landscape between and within sectors is low. These results highlight an opportunity for improved collaboration opportunities, as the organisations driving knowledge creation have been identified.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ It is known that innovating to improve athlete health and performance is a complex process involving diverse stakeholders, which can pose challenges for collaboration and innovation.

WHAT THIS STUDY ADDS

⇒ Using rugby union as an example, this study highlights the importance of network analysis for understanding collaboration dynamics in sport medicine and science research.

⇒ Based on our network analysis, we found that scientific output and collaboration increased overtime, the most number of publications are produced by tier 1 rugby-playing nations, governing bodies within rugby union are highly collaborative and universities are key players contributing to knowledge development.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The study's findings empower stakeholders by raising their awareness of current collaboration practices.

⇒ The study's methodology offers a framework that can be applied to various domains within the field of sport medicine and science.

INTRODUCTION

Innovation in sport is a broad concept that can be defined as the process of generating and adopting new and creative ideas, which aim to produce a positive qualitative change.[1] Examples of innovation in sport include the generation of new training models, technologies, medical treatments or recovery methods.[2] Although innovation is essential for optimising athlete health outcomes and performance, it is often met with resistance.[3] Innovating to improve athlete health and performance is complex,[4] involving multiple parts[5] which interact in unpredictable ways in an ever-changing context.[6 7] Context in innovation refers to the physical, social and cultural factors that influence the process.[8]

In sport specifically, the social context is made up of multiple stakeholders that span multiple disciplines, levels (individual, group and organisation) and sectors, forming a network of interactions which drive innovation.[7 9] Most implementation frameworks and models have recognised the social context as an important determinant to successfully innovating in sport[10]—notably, collaboration and engagement with stakeholders.[11] However, the number of different stakeholders—with

separate and unique needs, challenges, goals and beliefs[12]—make collaboration, engagement and ultimately innovation, challenging resulting in a gap between knowledge and practice.[13] With that said, for sports medicine and science to move forward, we need to understand and embrace the complex social context of innovation.

Using social network analysis (SNA) to study the network of interactions between stakeholders in sport can help us better understand the social context in which a sport functions.[9] SNA is a research paradigm concerned with the patterns of connections (ie, ties) between actors (ie, people or entities) within an interconnected group or network, and how this 'social structure' impacts outcomes of interest.[14 15] Through SNA, we are able to: (1) identify which actors and stakeholders are involved; (2) identify how these actors and stakeholders are connected and (3) measure the quality of these connections.[16] A visual representation is commonly used to gain a better understanding of a network and identify priority areas.

Rugby union is one of the most popular collision team sports in the world, with approximately 9.6 million players registered in 123 countries.[17] Rugby union is a physically and technically demanding sport, where players physically engaged the opposition to compete for territory and ball possession.[18] Frequent exposure to physical contact in events such as the tackle expose players to high-risk of injury.[18] Given the ever-increasing participation rates and known injury risks,[18] sport scientists and stakeholders in rugby union have been researching to develop innovative solutions to enhance performance and safeguard rugby union players. In this paper, stakeholders refer to those who are affected by research outcomes and may include patients, athletes, target populations, practitioners, clinicians, policy-makers or administrators. Research fuels innovation by providing the necessary information, evidence and understanding to identify opportunities for improvement and to develop innovative solutions.[19] It helps to identify gaps in current knowledge, explore alternative approaches, and validate the feasibility and effectiveness of new ideas.[20]

Understanding the social structure of research in rugby union—specifically, how stakeholders, at an organisational level, collaborate to generate scientific knowledge—will allow us to identify which organisations and sectors collaborate well (influential organisations) and those who do not (less influential). This would provide a stepping stone to improving collaboration between organisations for scientific publication, as it empowers them with a newfound awareness of their current collaborative practices as they endeavour to use an evidence-based approach. With this awareness, organisations are more likely to be motivated and inclined to take proactive steps towards improving their collaboration efforts, fostering a more effective and cooperative research community. Additionally, future studies can investigate these organisations and identify the factors and strategies that lead to successful collaboration, which less influential organisations can implement. Improving collaboration between organisations for scientific publication will arguably result in research objectives being more aligned to all the stakeholders' needs and context, thereby increasing the likelihood of successful implementation of scientific knowledge[11]—such as a new training model, technology or rehabilitation treatment—and reducing the knowledge to practice gap.[21]

Over the past 10 years, there has been a notable growth in the application of SNA to examine collaborations, especially within the field of biomedical engineering.[22–25] For example, Salie *et al*[22] conducted a study analysing the development and exchange of knowledge among actors patenting orthopaedic devices in South Africa from 2000 to 2015. They analysed collaboration networks in academia, healthcare, industry and science/support sectors using bibliometric data and identified dominant institutions through centrality measures. In another study by de Jager *et al*,[25] the evolution of medical device development in South Africa was investigated for the period 2001–2013. The researchers examined collaboration networks in academia, healthcare, industry and science and support (SAS) sectors using bibliometric data, with a focus on identifying dominant institutions through centrality measures. The results from these two studies provide valuable insights for guiding institutional strategies, promoting effective collaboration and supporting innovation management in the field of medical device development.

Limited research of this nature has been conducted in the field of sport science, specifically in rugby union. Martín *et al*[26] performed a bibliometric analysis of research journals on rugby from 1922 to 2009, examining variables such as publication year, thematic areas and authorship. However, their study did not employ an SNA to assess collaboration between organisations in rugby union research. Moreover, the Martín *et al*[26] study did not exclusively focus on rugby union and included papers only up until 2009. As such, more up-to-date analyses are required.

Therefore, the purpose of this study is to conduct an SNA of stakeholders involved in rugby union research. The research question guiding this investigation is: What is the social structure of research in rugby union and how do stakeholders at an organisational level collaborate to generate scientific knowledge? The specific objectives of this study are threefold: (1) to identify the organisations and sectors involved in rugby union research, (2) to examine the connections and relationships among these organisations and sectors and (3) to measure the extent of collaboration between them.

METHODS

Overview

A bibliometric study[27] approach was used to investigate the network of actors involved in rugby union research across the globe. Using author affiliation listed on scientific publications, we identified the organisations that contributed to rugby union research. Coauthorship on

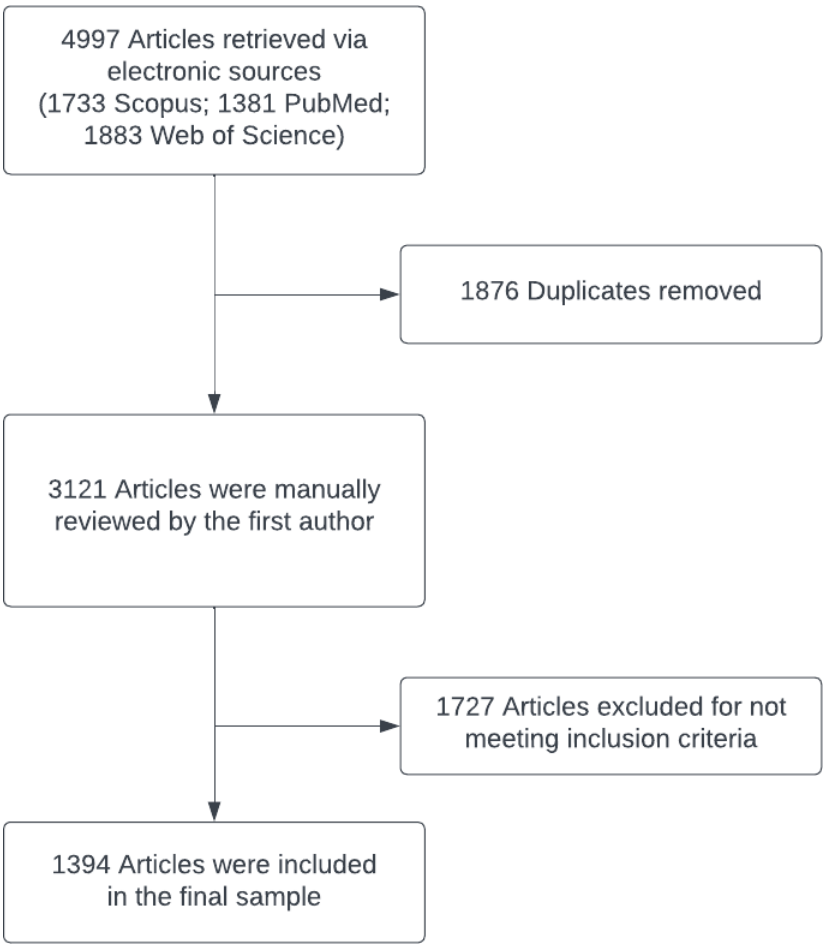

Figure 1 Literature search strategy.

scientific publications served as an indicator of collaboration between authors from different organisations. Once the organisations were identified, we determined their location (country) and sector. Subsequently, we generated a collaboration network from coauthorship (co-occurrence) matrices and computed network metrics—degree centrality and betweenness centrality—to identify influential organisations and measure the extent of the collaboration between sectors.

Publication search strategy

A systematic search of three electronic databases—PubMed, Web of Science Core Collection and Scopus—was conducted to retrieve all relevant publications. The

Table 1 Sector name, abbreviation and definition

University (U)	Higher education institutions involved in academic research; predominantly consisting of universities, polytechnics and colleges.
Healthcare (H)	Clinics, hospitals and medical facilities whose primary function is patient care; essential for identifying healthcare needs.
Industry (I)	Companies, firms, organisations and individuals involved in sport device development for purposes of commercialisation.
Science and support (SAS)	Any organisation, not belonging to one of the other sectors, that contributes to, or uses, the scientific body of knowledge through research, education and training, clinical services and/or community services. This includes science councils, other research facilities, non-government organisations (NGOs), non-profit organisations (NPOs) and designated special interest groups; sports institutes.
Sports governing body (SGB)	Includes international sports federations, trusts, national governing bodies, event organisers, professional leagues.
Professional sports team (PST)	Professional sports team means a sports team that is a member or an affiliate of a member of a sports governing body.

Table 2 Breakdown of organisations by sector and country

	U	SGB	PST	SAS	H	I	
USA	51	6	3	10	18	1	89
Argentina	5	1	4	0	2	0	12
Australia	42	18	17	15	35	4	131
Austria	1	0	0	0	0	0	1
Belgium	3	0	0	0	3	0	6
Bosnia And Herzegovina	1	0	0	0	0	0	1
Brazil	18	1	1	2	1	0	23
Canada	18	3	1	3	4	1	30
Cayman Islands	0	1	0	0	0	0	1
Chile	2	0	0	0	0	0	2
China	1	0	0	0	0	0	1
Colombia	2	1	0	0	0	0	3
Croatia	1	0	1	0	0	0	2
Cyprus	1	0	0	0	0	0	1
Denmark	1	0	0	0	0	0	1
England	89	9	32	13	52	13	208
Fiji	0	0	1	0	1	0	2
Finland	1	0	0	0	1	0	2
France	33	4	13	9	23	1	83
Georgia	0	1	0	0	0	0	1
Germany	7	0	0	1	0	0	8
Hong Kong	3	1	0	0	1	0	5
India	0	0	0	2	0	0	2
Ireland	18	3	4	4	16	2	47
Israel	1	0	0	0	0	0	1
Italy	14	1	1	2	5	0	23
Japan	23	2	2	3	12	0	42
Kenya	2	0	0	0	3	0	5
Lithuania	1	0	0	0	0	0	1
Luxembourg	1	0	0	0	0	0	1
Malaysia	1	0	0	2	0	0	2
Netherlands	6	1	0	2	4	0	13
New Zealand	15	8	4	5	16	1	49
Nigeria	0	0	0	0	1	0	1
Norway	2	0	0	1	0	0	3
Padua	1	0	0	0	0	0	1
Poland	5	0	0	1	1	0	7
Portugal	13	2	0	3	6	0	24
Qatar	2	1	0	0	1	0	4
Russia	1	1	0	0	0	0	2
Scotland	12	1	1	3	10	0	27
Singapore	1	0	0	0	0	0	1
Slovenia	1	0	0	0	0	0	1
South Africa	15	2	7	8	4	0	36
Spain	27	3	2	5	7	0	44
Sri Lanka	0	1	0	0	0	0	1
Sweden	2	0	0	1	3	0	6
Switzerland	3	1	0	1	1	1	7
Taiwan	0	0	0	1	0	0	1
Thailand	1	0	0	0	0	0	1
United Arab Emirates	0	0	0	0	1	0	1
Wales	12	1	5	0	8	1	27
Zimbabwe	1	0	0	0	0	0	1
	461	74	100	96	240	25	996

H, healthcare; I, industry; PST, professional sports team; SAS, cience and support sector; SGB, sports governing body; U, university.

search contained the following search term: "RUGBY UNION". Data were retrieved in June 2023. The exact search query for each database was as follows:

PubMed search:

("Rugby Union"[Title/Abstract]) AND ((english[Filter]) AND (1977:2022[pdat]))

Scopus search:

TITLE-ABS-KEY (*"rugby union"*) AND (EXCLUDE (PUBYEAR, 2023)) AND (LIMIT-TO (DOCTYPE, *"ar"*) OR LIMIT-TO (DOCTYPE, *"re"*)) AND (LIMIT-TO (LANGUAGE, *"English"*))

Web of Science search

Results for TS=("Rugby Union") and PY=(1977–2022) and Article or Review Article (Document Types) and English (Languages)

Filtering the search results and data extraction

The search results were filtered and data extraction was performed based on the following inclusion and exclusion criteria: In terms of article type, the inclusion criteria varied depending on the database used. In Web of Knowledge, articles, review articles and early access articles were included. In Scopus, articles and review articles were considered. In PubMed, books and documents, clinical trials, meta-analyses, randomised controlled trials, reviews and systematic reviews were also included. Second, only research relating to rugby union or involving rugby union participants was included. Studies using mixed samples of rugby codes (for rugby union and rugby league) were excluded. The third criterion limited the scope to the fields of health science, sports science or exercise medicine. A subjective classification based on reading the article title and abstract was used to determine if publications were 'within the field of health science, sports science or exercise medicine' and 'related to rugby union or involving rugby union athletes'. Fourth, only English publications published within or before the year 2022 were included.

Once the publications were identified from the databases, duplicates were removed based on the title, authors and journal name. Thereafter, the individual journal websites for each article were accessed and the following data extracted: authors, year of publication,

Table 3 Publication characteristics for each window period

Period	No. of publications	No. of collaborations	No. of organisations	No. of countries
Pre-2000	79	92	71	12
2001–2010	216	576	191	19
2011–2015	287	1296	275	24
2016–2022	829	7324	727	46

article name; author affiliations; journal; keywords; publication type; affiliation country. The data extracted from the journal website were considered more reliable, minimising the impact of inconsistencies and errors across databases. The database searches identified 4997 titles. After removing duplicates and manually reviewing the search results, a total of 1394 were retained for bibliometric analysis. The search strategy workflow is presented in figure 1. Online supplemental appendix 1 provides a summary of the included studies.

Collaboration and sectoral information

Six sectors were identified based on the author affiliations—universities (U), healthcare (H), industry (I), science and support (SAS), sport's governing bodies (SGB) and professional sports teams (PSTs). The definition of each sector is provided in table 1.

Authors and their affiliations were presented in various ways in the dataset. To ensure uniformity across the dataset for inclusion in the actor–collaboration networks, the following steps were taken:

- Only parent organisations were retained; departmental affiliations were not considered.
- When a publication was authored by a single individual associated with one affiliation or by multiple authors

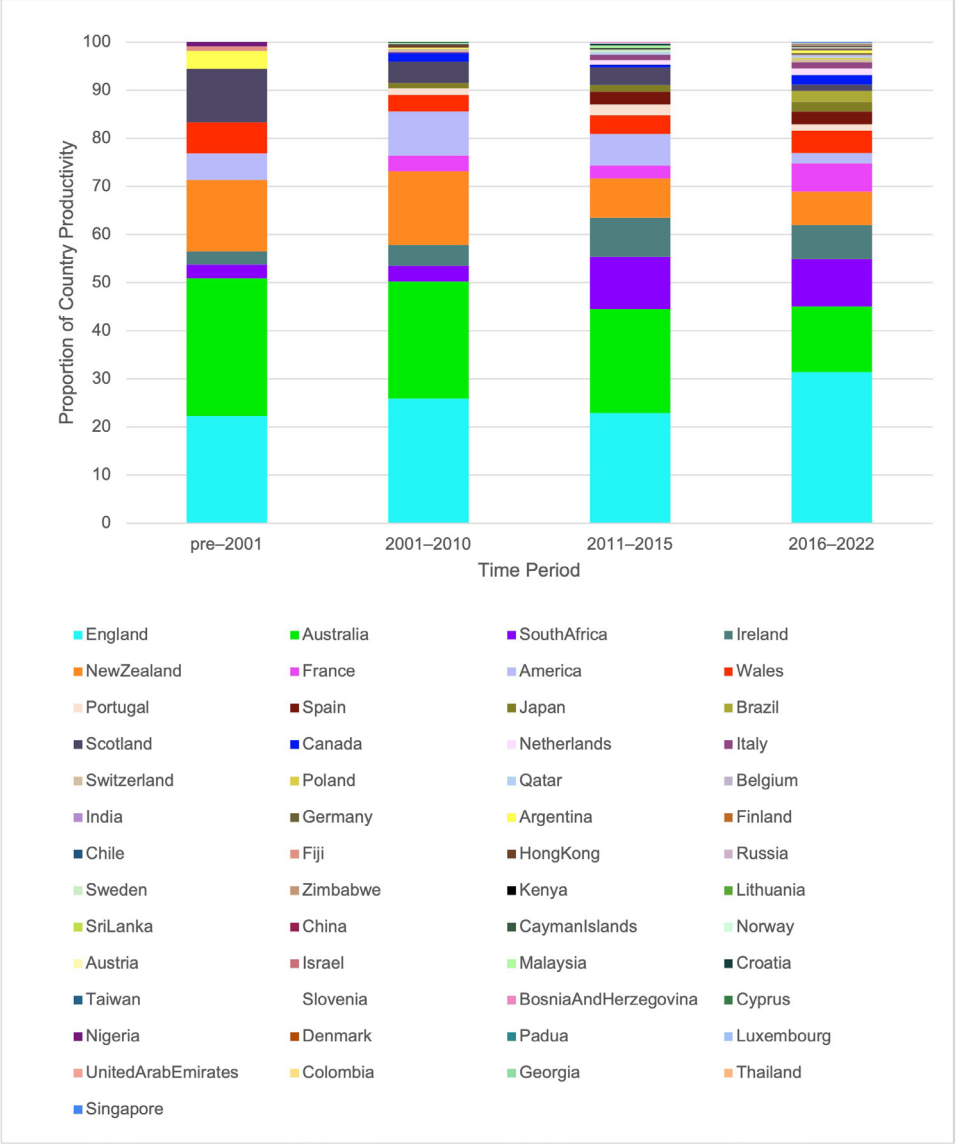

Figure 2 Distribution of productivity proportions for each country across different time frames. Productivity is determined based on the number of publications produced by each country during the respective time frames.

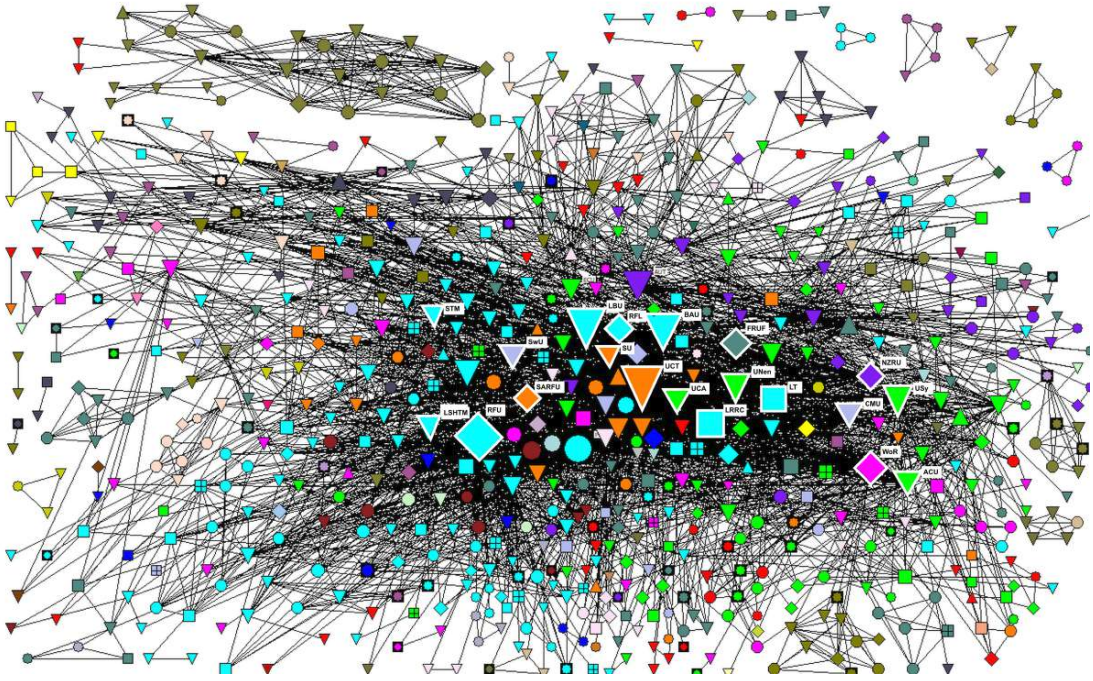

Figure 3 The rugby union research collaboration network for final time period (2016–2022). Node size is scaled to degree centrality. Only the labels of the organisations with the top degree centrality values are shown for clarity. Full names of the actors along with their abbreviations are presented in online supplemental appendix 2. The rugby union research collaboration network for final time period (2016–2022) with all labels shown can be found in online supplemental appendix 3. Nodes are coloured according to country and shaped according to sector (circle=healthcare, down triangle=university, diamond=sports governing body, square=professional sports team, circle-in-box=science and support, box=industry).

with the same affiliation, it signified that knowledge was generated within a singular organisation.

- In the case of a single author having multiple affiliations, each organisational affiliation was retained, coauthorship between those organisations was considered to have taken place.

Collaboration network generation

The collaboration networks were generated using UCINET 6 (V.6.573)[28] and NetDraw (V.2.152).[28] In the network, each organisation (also referred to as an 'actor') is represented by a network node, while edges (the connections/ties between nodes) represent publications on which the organisations collaborated. Edge thickness was weighted according to the number of collaborative publications; edges were undirected, as collaboration is a reciprocal relationship.[16] We also used Microsoft Excel to create the other graphical representations and perform basic statistical analyses.

The rugby union research landscape was investigated over four different time periods: pre-2000, 2001–2010, 2011–2015 and 2016–2022 as well as for each year of the final time period 2016, 2017, 2018, 2019, 2020, 2021 and 2022 to produce a set of 11 networks. We chose to present these individual years to illustrate the dynamism of the rugby union network over the last 7 years, as well as to focus on a more current picture of what rugby union networks represent. NetDraw's spring-embedding graph layout algorithm was used to draw the network, followed by manual manipulation of node positions as necessary to ensure labels were legible. The size, shape and colour of the nodes were used to highlight features of interest, namely connectedness to other institutions, sector classification and institutional location (country), respectively.[23]

Structural analysis

The following metrics[22 29] were used to analyse the network:

Centrality measures

Centrality measures are used to identify the most influential nodes within a network.[30 31] Several types of centrality measures exist, for which their suitability for identifying 'influential nodes' depends on the nature and complexity of the network to be analysed.[31] Two centrality measures with the ability to identify such nodes are the degree and betweenness centralities; both of which were calculated in UCINET for further analysis.[22]

Degree centrality

Degree centrality is a measure of the number of collaborations in which the node is involved, thereby serving as an indicator of how active the node is. In the rugby union innovation network, the size of each node is scaled according to the number of nodes to which it is connected (degree)—this enables the visual identification of the more active nodes. The higher the degree,

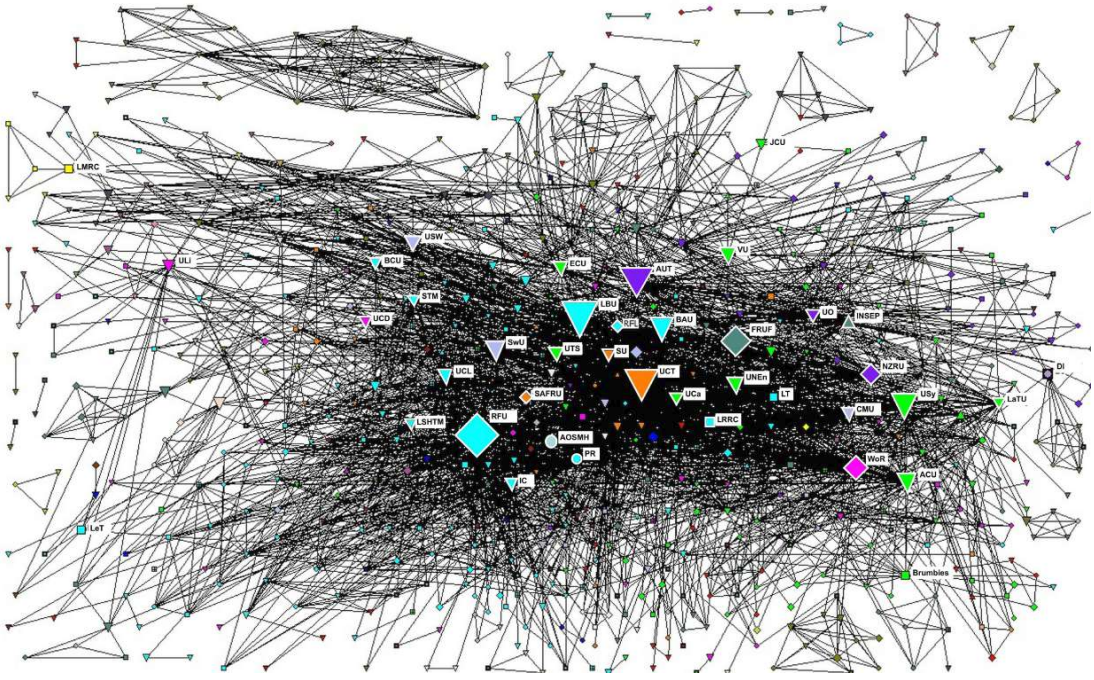

Figure 4 The rugby union research collaboration network for final time period (2016–2022). Node size is scaled to betweenness centrality. Only the labels of the organisations with the top 10 betweenness centrality values are shown for clarity. Full names of the actors along with their abbreviations are presented in online supplemental appendix 2. The rugby union research collaboration network for final time period (2016–2022) with all labels shown can be found in online supplemental appendix 4. Nodes are coloured according to country and shaped according to sector (circle=healthcare, down triangle=university, diamond=sports governing body, square=professional sports team, circle-in-box=science and support, box=industry).

the more likely the node is to catch the information that is propagating within the network and the more likely it is to affect the overall structure of the network.[24] It is calculated as the number of ties between a given node and other nodes in the network. As we are comparing networks, we report normalised degree centrality. The normalised degree centrality, as reported in Eq 1, is the node's degree, u(y), divided by the maximum possible degree in the network, u_{max} .

$$\left|D\left(y\right)\right| = \frac{u(y)}{u_{max}}$$

Betweenness centrality

Betweenness centrality is a measure of how often a node lies on the shortest path between two other nodes. It is calculated using the following equation[32]:

$$B\left(y\right) = \sum_{x \neq y \neq x} \frac{\delta_{xz}\left(y\right)}{\delta_{xy}}$$

Nodes with high betweenness centrality act as 'bridges' between other nodes with lower collaboration and are considered to influence the flow of information across the network. As we are comparing networks, we report normalised betweenness centrality. The normalised betweenness centrality is the node's betweenness centrality divided by the maximum possible betweenness of the network, and is reported as a percentage, as seen in Eq.3[22]

$$\left|B\left(y\right)\right| = \frac{B(y)}{B_{max}}$$

Intrasector and intersector collaboration

Intersectoral collaboration in this study was defined as the presence of a collaborative relationship between any two sectors at any point between 2016 and 2022. This was calculated in UCINET using the between-group density metric. Intrasectoral collaboration, which shows the extent of collaboration between nodes belonging to the same sector, was measured using the UCINET within group density metric. The collaboration of multiple authors affiliated with the same organisation was not considered as intrasector collaboration, but treated as a single node in the network.

Data reporting

Degree centrality

For each year for the last time period (2016–2022), the top five actors with the highest degree centrality are reported. Once the top actors were identified, the degree centrality values for each year of the fourth time period were extracted to assess actor evolution over the period between 2016–2022. The results are presented using a line graph. The line graph was deemed appropriate for

Table 4 The actors having highest degree centrality over the last time frame

	2016	2017	2018	2019	2020	2021	2022
ACU	0.001	0.022	0.002	0.014	0.014	0	0.006
AUT	0.018	0.022	0	0.011	0.011	0.009	0.016
BAU	0.015	0.016	0.007	0.037	0.025	0.017	0.022
BU	0.017	0.024	0.003	0	0.001	0	0.001
IOC	0	0	0.002	0.042	0.003	0.002	0.005
LBU	0.011	0.013	0.024	0.027	0.045	0.015	0.033
LRRC	0	0	0.008	0.013	0.039	0.01	0.02
LSHTM	0	0.006	0	0	0.010	0.011	0.01
LT	0.007	0.008	0.02	0.016	0.034	0.004	0.003
RFL	0	0.003	0.015	0.013	0.034	0.01	0.019
RFU	0.031	0.038	0.01	0.033	0.033	0.022	0.028
SU	0.003	0.002	0.002	0.044	0.006	0.004	0.011
SwU	0.019	0.016	0.014	0.016	0.010	0.004	0.009
UCL	0.011	0.023	0.003	0.012	0.004	0.008	0.012
UCT	0.034	0.055	0.025	0.047	0.043	0.015	0.026
UNen	0	0	0	0.018	0.034	0.009	0.024
VUUMC	0.007	0.019	0.01	0.035	0.007	0	0

ACU, Australlian Catholic University; AOSMH, Aspetar Orthopaedic And Sports Medicine Hospital; ARU, Australian Rugby Union; AUT, Auckland University of Technology; BAU, Bath University; BCU, Birmingham City University; BCU, Birmingham City University; BoU, Bond University; FUA, Federation University Australia; LBU, Leeds Beckett University; NZRU, New Zealand Rugby Union; RFU, Rugby Football Union; SU, Stellenbosch University; SwU, Swansea University; UAuc, University of Auckland; UCa, University of Canberra; UCL, University College London; UCT, University of Cape Town; UNe, University of Newcastle ; UNEn, University of New England; UTour, University of Tours; WoR, World Rugby.

Table 5 The actors having highest bettweenness centrality over the last time frame

	2016	2017	2018	2019	2020	2021	2022
ACU	0	6.11	4.35	1.32	2.22	0	0.66
AOSMH	0	3.90	0	0	0	0	0
ARU	13.10	0	0.16	0.10	0	0.07	0
AUT	11.45	12.68	0	0.10	3.53	11.41	9.99
BAU	0	0	4.38	2.06	2.90	8.99	4.54
BCU	0	0	0	0	0	13.55	2.55
BoU	12.59	0	0	1.04	0	0	0
FUA	13.60	0.85	0.71	0.26	0	0	0
LBU	0.86	0.51	6.47	0.88	8.51	7.07	13.49
NZRU	0.16	3.39	0	0.76	6.12	4.30	1.91
RFU	14.75	5.40	4.69	1.94	7.15	15.39	6.50
SU	0	0.01	0	5.96	0.80	2.83	4.86
SwU	9.73	1.42	6.65	1.23	4.85	1.41	3.85
UAuc	0	0	0	4.09	0	0	0
UCa	0	0	8.90	0.01	1.57	1.60	0
UCL	0	1.90	0	6.29	0.81	8.90	2.67
UCT	17.18	11.12	10.63	2.33	3.64	9.13	5.55
UNe	0	0.12	5.35	0	0	0.74	0
UNEn	0	0	0	3.53	7.99	3.20	8.07
UTour	0	0	0	4.17	0		
WoR	1.71	0.14	0.29	4.16	3.26	3.53	7.19

ACU, Australian Catholic University; AUT, Auckland University of Technology; BAU, Bath University; BU, Beckett University; IOC, International Olympic Committee; LBU, Leeds Beckett University; LRRC, Leeds Rhinos Rugby Club; LSHTM, London School of Hygiene and Tropical Medicine; LT, Leeds Tykes; RFL, Rugby Football League; RFU, Rugby Football Union; SU, Stellenbosch University; SwU, Swansea University; UCL, University College London; UCT, University of Cape Town; UNen, University of New England; VUUMC, VU University Medical Center.

two reasons—the first is to show who the high-degree actors are for a specific time frame (vertical axis), and the second is to show the evolution of these high-degree actors over time (horizontal axis).

Betweenness centrality

Betweenness centrality is presented similarly to degree centrality, where for each year of the last time period (2016–2022), the top five actors with the highest betweenness centrality are reported. The results are presented graphically, using a line graph, where the highest ranked actors by betweenness centrality are presented along the vertical axis, and the evolution of these actors over time is presented across the horizontal axis.

RESULTS

Overall, 995 unique organisations were identified from the included publications. Table 2 presents a breakdown of the organisations by country and sector. Full names of the organisations along with their abbreviations are presented in online supplemental appendix 2. Over the four time periods (from time period 1–4, respectively), the total of number of organisations (71, 191, 275, 727), publications (79, 216, 287, 829) and countries (12, 19, 24, 46) increased (table 3). Fifty per cent of the organisations came from the university sector (U); 26% from healthcare sector (H); 11% from PST sector; 8% from SAS; 8% from the sports governing body sector (SGB) and 3% from industry (I). Together, the organisations covered 53 different countries. Most of the organisations are located in England (208 (21%)) and Australia (131 (13%)), followed by USA (89 (9%)), France (83 (9%)), New Zealand (49 (6%)), Ireland (47 (5%)), Spain (30 (4%)), Japan (42 (4%)) and South Africa (33 (4%)).

Figure 2 shows the proportion of each country's productivity for each time frame. Productivity is determined by the number of publications the country has produced during the time frame. England (pre-2001 22%, 2001–2010 26%, 2011–2015 23%, 2016–2022 31%) and Australia (pre-2001 29%, 2001–2010 24%, 2011–2015 22%, 2016–2022 14%) are the most productive countries across all the time frames. South Africa (pre-2001 3%, 2001–2010 3%, 2011–2015 11%, 2016–2022 10%), Ireland (pre-2001 3%, 2001–2010 4%, 2011–2015 8%, 2016–2022 7%) and France (pre-2001 0%, 2001–2010 3%, 2011–2015 3%, 2016–2022 6%) increase in productivity over the four time frames. New Zealand (pre-2001 15%, 2001–2010 15%, 2011–2015 8%, 2016–2022 7%), USA (pre-2001 6%, 2001–2010 9%, 2011–2015 7%,

Table 6 Within (bold text) and between (normal text) group densities and sum of edge weights for the 2016–2022 time period

	SGB		U		PST		SAS		H		I	
	ρ	$\sum ew$	ρ	$\sum ew$	ρ	$\sum ew$	ρ	$\sum ew$	ρ	$\sum ew$	ρ	$\sum ew$
SGB	0.082	**272**	0.051	1103	0.53	217	0.038	153	0.019	555	0.032	33
U	0.051	1103	0.03	**4216**	0.024	629	0.025	650	0.011	154	0.011	73
PST	0.053	217	0.024	629	0.028	**138**	0.015	76	0.005	44	0.011	14
SAS	0.038	153	0.025	650	0.015	76	0.019	**92**	0.011	110	0.007	9
H	0.019	154	0.011	555	0.005	44	0.011	110	0.012	**226**	0.006	16
I	0.032	33	0.011	73	0.011	14	0.007	9	0.006	16	0.007	**2**

H, healthcare; I, industry; PST, professional sports team; SAS, science and support; SGB, sports governing body; U, university.

2016–2022 2%) and Scotland (pre-2001 11%, 2001–2010 4%, 2011–2015 4%, 2016–2022 1%) decrease in productivity across the four times frames (pre-2001, 2001–2010, 2011–2015, 2016–2022, respectively).

The rugby union research collaboration networks for each time period (pre-2000; 2001–2010; 2011–2015; 2016–2022) are presented in online supplemental appendix 3 and online supplemental appendix 4. Node size is scaled to degree centrality in online supplemental appendix 3 and to betweenness centrality in online supplemental appendix 4. Full names of the actors along with their abbreviations are presented in online supplemental appendix 2.

The rugby union research collaboration network for final time period (2016–2022) is presented in figures 3 and 4. Node size is scaled to degree centrality in figure 3 and betweenness centrality in figure 4. Additionally, only the labels of the organisations with the top betweenness and degree centrality, respectively, are shown for clarity. The rugby union research collaboration networks for each year of the final time period (2016–2022) are presented in online supplemental appendix 5 where node size is scaled to degree centrality. Full names of the actors along with their abbreviations are presented in online supplemental appendix 2.

Degree and betweenness centrality

The actors having highest degree centrality over the last time frame are presented in table 4. In 2016 and 2017, the University of Cape Town (UCT) (0,034 and 0,055) and Rugby Football Union (RFU) (0,031 and 0,038) are the highest degree actors; In 2018, UCT (0,025) and Leeds Beckett University (LBU) (0,024) are the highest degree actors; in 2019, UCT (0,047), Stellenbosch University (SU) (0,044) and the International Olympic Committee (0,042) are the highest degree actors; in 2020, LBU (0,045), UCT (0,043) and LRRC (Leeds Rhinos Rugby Club) (0,039) are the highest degree actors; in 2021, RFU (0,022) and University of Bath (UBA) (0,017) are the highest degree actors; and in 2022, LBU (0,033) and RFU (0,028) are the highest degree actors. The degree centrality values for all organisations between 2016 and 2022 are shown in online supplemental appendix 6. A graphical representation of the actors having highest degree centrality is shown in online supplemental appendix 7. The actors having the highest betweenness centrality over the last time frame are presented in table 5. While all actors present in a network have degree centrality, not all actors lie between other actors, and hence, not all have betweenness centrality. In 2016, the UCT (17,18) is the node with the highest betweenness centrality; in 2017, the Auckland University of Technology (AUT) (12,68) and UCT (11,1) have high betweenness centrality; in 2018, the UCT (10,63) and the University of Canberra (8,9) have high betweenness centrality; in 2019, the University College London (UCL) (6,290) and SU (5,96) have high betweenness centrality; in 2020, LBU (8,509), University of New England (UNen) (7,99) and RFU (7,15) have high betweenness centrality; in 2021, RFU (15,39), Birmingham City University (13,55) and AUT (11,4) have high betweenness centrality; and in 2022, LBU (13,5) and AUT (10) have high betweenness centrality. The betweenness centrality values for all organisations between 2016 and 2022 are shown in online supplemental appendix 6. A graphical representation of the actors having the highest betweenness centrality is shown in online supplemental appendix 8. Australian Catholic University, AUT, RFU, UNen, UBA, LBU, SU, Swansea University, UCL and the UCT have high degree centrality and high betweenness centrality, that is, they appear in tables 4 and 5.

Intrasector and intersector collaboration

Table 6 summarises the state of intrasector and intersector collaboration for rugby union innovation in the 2016–2022 time period using the within and between-group densities, respectively, which give an indication of interconnectedness within and between sectors. Within-group densities lie on the diagonal of the table, shown in bold and represent intrasectoral collaboration. The remaining entries in the table are the between-group densities, which represent cross-sectoral collaboration. The sum of edge weights ($\sum_{ew}$) used to calculate the densities is also shown in the table; these values indicate the number of edges present in the network, taking into account the weight of the edges, which connect all the

nodes belonging to the various sectors. For instance, the summed weight of all edges in the network that connect institutions from the SGB sector to those of the U sector is 1103.

Intrasectoral collaboration was highest for the SGB followed by the university (U), PST, SAS, healthcare (H) and industry (I) sector. With regard to intersectoral collaboration, the five highest ranking collaboration types according to the between group density metric are PST-SGB, SGB-U, SGB-I, SGB-SAS and U-SAS, while the five lowest-ranking collaboration types are PST-H, I-H, I-SAS, I-PST and I-U.

DISCUSSION

In this study, we present a global SNA of stakeholder collaboration in rugby union research. Based on our network analysis, we found that scientific output and collaboration increased over time, the most number of publications is produced by tier 1 rugby-playing nations, governing bodies within rugby union are highly collaborative, and universities are key players contributing to knowledge development. We discuss each of these key findings below, along with points on how to improve collaboration and future directions.

Scientific output and collaboration increased over time

Scientific knowledge production for rugby union increased over time illustrated by the increasing rate of publications between 1977 and 2022 (table 2). This increase in publications over time has also been found in other sports such as badminton,[33] football[34] and basketball.[35] Additionally, there is an increase in collaboration based on the increase in links between nodes. Our findings are in line with the areas of medicine and sport science, where a positive relationship between international collaboration and productivity has been shown.[36 37] Moreover, collaboration increased faster than the total academic outputs, therefore, collaboration is likely the driving force for the growth in rugby union research. Our findings support Wang *et al* who also found collaboration to be a driver for the growth in sports science publication.[37] The increase in scientific output in rugby union could also be explained by the high injury risk nature of the sport, along with the performance demands.[18] That is, rugby union stakeholders have a major interest in preventing and managing injury, while also improving player performance.[38–40] As this paper is part of a larger project, it will be complemented by a subsequent study that will include comprehensive content analysis, identifying the primary research domains of interest within rugby union.

The greatest number of publications are produced by tier 1 rugby-playing nations

At a country level, the greatest number of publications came from England, Australia, New Zealand, Ireland and South Africa—in all time periods. Similar results were found by Martín *et al*[26] who conducted a bibliometric study on rugby articles from 1922 to 2009. However, our findings differ from Martín *et al* in that France becomes one of the main contributors to rugby union publications in the fourth time period (2016–2022). Coincidentally, the countries identified in this study with the greatest number of publications are considered tier 1 rugby-playing nations with the national side consistently ranked in the top five performing countries.[41] As such, one possible reason that these countries are large contributors to rugby union research because they are traditionally rugby-playing nations. These data are also consistent with other studies in countries where sports practice and sports performance are associated with the high scientific contribution to the sport.[33–35] The USA also had many publications in rugby union despite the sport not enjoying popularity compared with other American team-based sports.[42] However, USA and China are commonly leaders in scientific publications, regardless of the topic as seen in other bibliometric studies.[43 44]

Sports governing bodies are highly collaborative

The top five intersector collaborations show that each sector collaborates strongly with the SGB sector and the weakest with the industry sector. This shows that sports governing bodies are highly collaborative and act as a broker between actors across sectors. Removal of the SGB sector from the network not only leaves isolated nodes but potentially decreases collaboration across sectors as well. Sports governing bodies are an essential element of sport and play an important role in administrating and regulating participation, development and fostering a positive sporting environment.[41] To ensure they optimally deliver on these functions, sports governing bodies seem highly invested and engage in research. For example, to enhance player welfare standards, Word Rugby operates an internal research programme. Some research they have undertaken recently includes trialling the use of tackle-law changes to reduce concussion risk,[45] understanding the collision demands at different levels of play[46] and examining World Rugby's Head Injury Assessment protocol to strengthen diagnostic accuracy.[41 47] Partnerships with sports governing bodies are desirable because they have the resources to implement innovation nationally and globally, for example, New Zealand Rugby and the Accident Compensation Corporation partnered together to develop and deliver RugbySmart: a Nationwide Sports Injury Prevention Programme in New Zealand.[48] Another example is the *BokSmart* National Rugby Safety Programme—a joint initiative between the South African Rugby Union and the Chris Burger/Petro Jackson Players Fund aimed at implementing evidence-based sports medicine and science to prevent injury and enhance performance at all levels of rugby union in South Africa.[49]

Professional Sports Teams had the second highest intrasectoral collaboration after sports governing bodies. A likely explanation for this high collaboration is that professional teams are recognising the value of sharing

and merging data with other teams to produce high-quality research to answer the 'big' questions related to the sport.[50] Universities also seem to have a preference for collaborating with PSTs after sports governing bodies. This is unsurprising, as university-sport team collaborations allow researchers to gain access to elite sporting populations to conduct their studies.[51] Additionally, universities act as a neutral third party mediating the coopetition relationships (simultaneously cooperating and competing) between rival sports teams when merging their performance data for research.[50] Intrasectoral and intersectoral collaboration was lowest for the industry sector, which could be related to our choice of outcome measure. For this network analysis, publications were deemed a form of innovation, as opposed to patents, which may be a more industry sector outcome. Sports teams and the industry sector were also found to be collaborative. Possible reasons for sports teams industry sector collaborations include access to cutting-edge technology,[52] exchange of expertise, research and product development (to improve performance)[53] and/or product validation and improvement.[44]

Universities are key players contributing to knowledge development

Normalised degree centrality is an indicator of knowledge development and showed that productive actors in terms of high-quality outputs, are also more likely to have more connections in the network. The key actors contributing to knowledge development are research-intensive universities (Australian Catholic University, LBU, SU, Swansea University, UCL, UNen, UBA and the UCT). Looking at the innovation networks, these universities also have strong ties to sports teams, sports governing bodies and other research-intensive universities. For example, in 2016, LBU had strong ties to Leeds Tykes (PST), the UCT, Leeds Rhino's (PST), the Rugby Football League (SGB) and the RFU. These strong ties may also be the result of authors on the publication representing more than one actor—for instance, when an author is affiliated with both the university and a PST.

There is room for improved collaboration

Throughout the study period, many organisations were found to be unreachable from each other in the network due to disconnected components. While knowledge is certainly being developed, and being developed at an increasing rate, knowledge is not being diffused with increasing efficiency. This is also shown by the within and between sector densities as they are all much closer to 0 than to 1, which shows that all sectors have room for increased collaboration.

While there are tight clusters of activity driven by research-intensive universities with strong ties to sports teams and sports governing bodies, our findings also illustrate that there are many organisations sitting on the outside of the network with very few publications and collaborations. Speculatively, the reasons for low collaboration and publication could be related to a language barrier experienced by non-English-speaking countries, lack of interest in rugby union related research in non-rugby union playing countries and/or lack of resources to conduct rugby union research. Further investigation into these organisations is required to determine the exact reasons for lower levels of collaboration and publication.

Future research

While it is understandably recognised that research outcomes may differ between researchers and stakeholders[54]—for example, researchers may be primarily concerned with injury surveillance, determining injury mechanisms and developing preventative interventions, while sporting federations are more concerned with better understanding intervention implementation[46 55]—researchers and stakeholders can have the same research priorities.[11] However, more work is required in describing the process of collaboration between successful partnerships. For instance, recently, Hendricks *et al* highlighted that research findings of a partnership are primarily shared and published in the literature, and rarely describe the collaborative process between researchers and stakeholders in the development of tools that address the specific needs of the stakeholders.[56] In this regard, case studies can be conducted to explore the enablers and barriers of successful collaboration between organisations, countries and sectors. The findings presented in this paper would form the foundation for such work.

Implications

This study highlights the use of network analysis for understanding research collaboration dynamics in a sport medicine and science setting, using rugby union as an example. The findings offer valuable insights for organisations to evaluate their collaborative practices using an evidence-based approach. Moreover, these insights can guide institutional strategies aimed at enhancing research collaboration, which may lead to research objectives that are better aligned with stakeholders' needs and context. Consequently, this alignment increases the probability of successful implementation of scientific knowledge. Additionally, the study's methodology offers a framework that can be applied to various domains within the field of sport medicine and science.

Limitations

As the network was investigated using a bibliometric approach, institutions and sectors that publish scientific output are favoured, that is, universities. This may explain why these institutions are more prominent in the network. Alternative outputs which also show collaboration, such as patents, have not been captured and presented here but may be more representative of collaboration trends in the industry sector. Another limitation of this study is the exclusion of publications not included in the three databases searched (PubMed, Web of Science and

Scopus). Third, no specific data treatment procedures were performed. While we collected data from various sources, including PubMed, Web of Science and Scopus, no standardised data cleaning or normalisation procedures were implemented. Instead, a manual approach was employed to ensure consistency and accurate data extraction, as implemented in previous studies.[23 25] Relying on external software and programmes may not have been sensitive to potential variations or inconsistencies in the collected data, such as names of organisations. Finally, our findings may have limited transferability to other sports. The influence and location of organisations largely depend on the popularity and geographical distribution of each sport worldwide. However, our study does offer a methodological approach that researchers can adapt to investigate the organisational dynamics within their specific sport.

CONCLUSION

In this study, we present a global SNA of stakeholder collaboration in rugby union research. We identified organisations that contribute to the scientific base of rugby union innovation across the globe, the sectors to which they belong and characterised the interaction between organisations by performing a spatial and sectoral analysis. We found scientific knowledge for rugby union has grown over time and that the organisations that produce this knowledge are primarily located in countries that are considered tier 1 rugby-playing nations. Universities are largely responsible for this knowledge production, however, it should be noted that the network analysis was based on publications. There is a preference for intersectoral collaboration with sports governing bodies for knowledge creation, however, overall collaboration between and within sectors is low. These results highlight an opportunity for collaboration as the organisations creating knowledge in rugby union have been identified. This study will, in the future, be complemented by a content analysis of the research focus areas of the organisations and, together, form the basis for case studies for further examination of enablers and barriers of successful collaboration for rugby union innovation.

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