Hamstring Rehabilitation Research: A Bibliometric Analysis of Themes, Authors, Countries and Journals

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ABSTRACT

Hamstring injuries are one of the most common lower limb injuries found in sport and this study illustrates the utility of bibliometric analysis in examining a topic from a strength and conditioning coach perspective.

This study identifies research relating to the rehabilitation of hamstring injury among athletes and compares this with the literature relating to the general population. A range of bibliometric measures are used that entail multi-dimensional scaling to identify clusters of related themes, authors, countries, and journals central to the evolution of the evidence-base.

A structured search of Scopus, the most appropriate and relevant database for this type of analysis, yielded a total of 2439 articles on hamstring rehabilitation and of these 815 papers related to hamstring rehabilitation in athletes. Indexed research on the topic commenced in the early 1980s and has expanded at an exponential rate since then. Two prominent authors (Dr J.I. Tol and Dr D.A. Opar) were repeatedly found in the literature, were frequently referenced, and played an important role in connecting other authors. Three countries dominated research in the field USA, Australia, and UK. Examination of journal sources reveals that research on this topic conforms to Bradford's law of scattering and a total of 7 journals form the core of published work in this space - British Journal of Sports Medicine; American Journal of Sports Medicine; Scandinavian Journal of Medicine and Science in Sport; Sports Medicine; Journal of Orthopaedic and Sports Physical Therapy; and Medicine and Science in Sports and Exercise.

This study demonstrates the utility of bibliometric analysis in identifying areas of significant importance, that is, common problems faced, treatment options being used and the evolution of intervention over time in the field of strength and conditioning. Practitioners can use these findings to identify relevant knowledge, seek out collaborative partners, identify and pursue under-researched areas of inquiry and target their work for publication at relevant journals adding to the evidence-base.

Keywords: Hamstring injury; bibliometrics; strength and conditioning; knowledge development; research agenda

INTRODUCTION

In recent times there has been a proliferation of evidence available in the peer-reviewed scientific

literature capable of informing best practices in the treatment of hamstring injury in athletes (1). Several studies (2-4) have highlighted, using systematic and meta-analytical reviews, where the current body of evidence on a specific topic can be assembled, minimizing bias through stringent analysis thereby allowing aggregation of findings that can then inform decisions on practice. Hence, by synthesizing findings across multiple studies and through applying structured analytical techniques, anomalous individual study results can be detected, and general findings determined. Through systematic and meta-analytical reviews, it has been possible to distil the most appropriate interventions to optimize treatment and performance improvement regimes associated with specific hamstring injuries and associated treatment modalities (5). However, to gain a wider understanding of research in the totality of hamstring injury treatments rather than the impact of a particular intervention an alternative analytical approach has been suggested. Bibliometric analysis can review the totality of the literature in an entire domain of interest highlighting key trends in research evolution and gaps in understanding in the science behind hamstring injury prevention and treatment. Benton and Ferguson (6) suggested that the method of bibliometric analysis, first described by Otlet (7), can be used to provide a "wide angle view of the literature under study" and is ideally suited to identifying and mapping research in any domain of interest as it can embrace a wider body of research material compared to the specificity demanded by both systematic and meta-analytical reviews.

Furthermore, Rastagar (8) has highlighted that there has been an exponential growth in the volume of research in the life sciences with medical literature doubling every three years. This is not a new phenomenon as it has been over three decades since Garfield (9) identified that it has become increasingly difficult to keep track of the state of the science in any area of inquiry. It is perhaps because of this growth in evidence alongside technological advancements in analytical tools that bibliometric analysis has gained in popularity and use (10).

Hamstring Rehabilitation and Strength and Conditioning Coaches

Hamstring injuries are one of the most common lower limb injuries to be found in sport (11). Australian Rules Football, Rugby and Soccer demonstrate high incidences (16 – 23%) due to the nature of these sports adopting high velocity repeated sprint efforts, kicking, acceleration and change of direction (12). These injuries often lead to a large loss of training and competition time, significantly impacting the athlete's quality of life, as well as physical and psychological wellbeing (13). These consequences alone emphasize the importance of the need to reduce the risk of initial hamstring injuries occurrence. Furthermore, re-injury rates remain high (12 – 31%) and thus can lead to further deterioration in athletic performance and or loss of position within the team, as well as fiscal and psychological costs to the individual and team. Indeed, in extreme cases, injury may result in premature exit from their chosen sport (14).

While bibliometrics, is a relatively new technique and is not routinely taught as part of research methods courses, it has been used as a means of exploring topics of interest to the strength and conditioning community. A search of the largest bibliographic database Scopus with more than 22 million entries, for papers indexed to "strength and conditioning" AND "bibliometrics", yields only five papers. These papers focused on comparing the academic output of different teaching roles, the research published during a specific time window on the sport of Taekwondo and the research relating to the use of fitness equipment (15-20). None of these papers pursued exploration of a specific condition commonly encountered in the work of strength and conditioning practitioners. While a slightly less specific search "sport" AND 'bibliometrics' has provided a more diverse range of content and the most common type of bibliometric analysis tends to focus on the coverage and content of specific journals over time. For example, Bosker and Verheyen (20) reviewed the international rank order of publications of major orthopedic journals from the year 2000 to 2004.

Although the use of bibliometrics to explore clinical topics has been rare in the field of sports science up to this point, clinical and sports science orientated articles are starting to appear in the literature (21). With the advent of more powerful computing technology and the proliferation of journal articles, bibliometric analysis is being used across a wide range of disciplines to gain new insights into evolving fields of practice (22). Specifically, bibliometrics can identify gaps in the research literature, areas where there is quantum of material that can be explored using systematic or meta-analytical reviews and is capable of identifying and tracking the evolution of practice over-time (22-23). However, there are a wide range of analytical techniques available to researchers conducting this type of study and in

this article only those techniques used to pursue the specific aims of this research will be highlighted. However, those wishing a more comprehensive understanding of the methodologies associated with bibliometric analysis and its specific use reference to one of the many specialist texts available on the subject should be pursued (23-25).

To summarise, there has been a wealth of original research on the topic of hamstring injury over the years (26). Furthermore, various authors have conducted systematic and meta-analytical reviews into the prevention, etiology, and treatment of hamstring injury (27-29). Hence, the purpose of this study is three-fold. Firstly, the study has been designed to illustrate how the bibliometric method can be used as a technique to offer a broader understanding of research in an area of interest to the strength and conditioning community. Secondly, by conducting a comprehensive analysis of the current body of research on hamstring rehabilitation literature relating specifically to the treatment of athletes, practitioners will gain insights into the current body of research that can be explored and utilized to inform the further develop of their own interests. Finally, the study sought to identify the potential for systematic consolidation of evidence, including the identification of thematic trends and insights into the research landscape, including mapping out key contributors to research underpinning the science of the strength and conditioning community relative to hamstring injury.

METHODS

This study uses a mixed-methods approach, by applying bibliometric analysis to the indexed literature relating to hamstring injury in general and compares this with that relating to hamstring injury of athletes. Both quantitative, multi-variant analysis and qualitative, thematic analysis were used.

Literature Search and Retrieval

There are a range of bibliometric databases that can be used to investigate the topic of hamstring injury and its treatment and rehabilitation. However, not all databases offer information on the number of times and by whom papers are cited. Accordingly, to enable the aims of this study to be met three widely available databases were considered – Scopus (Elsevier), Web of Science [WOS] (Clarivate Analytics) and Google Scholar. Both Scopus and WOS are curated products, and as such the list of

sources (journals, conferences, etc.) are available. Whereas Google Scholar utilizes a web-crawler technique to identify content, so the coverage of sources is not routinely specified. This means that work retrieved through Google Scholar may not be subjected to full peer review and hence the quality of the studies cannot be assured. Accordingly, Google Scholar was rejected as a source for this study. Of the two remaining sources, Scopus had the greatest coverage of relevant material dating back to 1823 and has been identified repeatedly by researchers as the database of choice when conducting bibliometric studies relating to health sciences (30-32).

A structured search of Scopus was conducted on July 29, 2021, using the following search query – TITLE-ABS-KEY ("Hamstring Injury" OR "Hamstring Strain" OR "Hamstring Tear" OR "Hamstring Damage") to identify the body of research used for the study. No year or other delimiters were used to initially exclude any papers. Since the search was conducted using logical operators the relevant terms may be found but placed in a random order in the title or abstract or indeed in a combination of the fields and on closer examination of content this may result in content not specifically related to the topic of interest. Hence, the titles and abstracts of those papers identified were subsequently reviewed by the authors to ensure that only those papers that related explicitly to hamstring injury and its rehabilitation were retained. Any duplicate papers, where authors publish the same results using the same data set resulted in only the first published work being included for analysis. Subsequently, studies that related to athletes and sport were extracted from the main body of papers through the addition of the terms (AND ("athlete" OR "sport")) in the search string.

Data extraction and Visualization

Scopus provided a range of options in terms of extracting data. In this case two files were downloaded. One, a simple excel file, that stores the number of papers published per year and the second a file with full citation, bibliographic, abstract, funding, and other information that can be imported into the bibliometrics analysis software. In this case the software used to undertake the bibliometric analysis was the freeware package VOSviewer, developed by Van Eck and Waltman (33) [ver. 1.6.15, Center for Science and Technology Studies (CSTS), University of Leiden, Leiden, Netherlands]. VOSviewer (Visualization Of Similarities) was used to calculate, using multi-variant analysis, the various

clusters of related terms and then displays the variables of interest in a two dimensional map (33). Variables of interest are plotted as circles (nodes), the size of which is scaled to represent the frequency of occurrence of the variable. Links between variables are displayed as lines and the thickness of these are based on the strength of the relationship between the variables. Calculation of strength of relationship depends on the variable of interest and can, for example, include the number of times authors have published work together, commonality of references cited by papers or the proximity of terms as they occur in the title or abstract of the paper. Clusters of variables are colour coded to illustrate related groups or can be coloured to represent further variables of interest such as number of citations or average year of publication of the work contributing to the node. Unless otherwise stated the default values for analysis were used in generating the various visualizations using VOSviewer version 1.6.15.

Describing Measures

Basic information on the numbers of papers and their year of publication was extracted to identify trends in publication productivity. By examining this information an indication of the volume of research and its rate of change over time can be determined.

Additionally, as a means of identifying the journals focused most upon the research topic the frequency of number of papers published in the various journals were examined to ascertain if the profile of publication follows Bradford's law of scattering (34). Bradford's law of scattering, developed in 1934, demonstrates that the sources of literature can be divided into three or more zones of impact. In this case, due to the relatively small number of papers on the topic, (hundreds rather than tens of thousands), a three-zone analysis was used. Zone one, the first third of all papers, consists of those journals that routinely cover material in the topic of interest and are most likely to be cited by other authors working on the topic (34). Deasi, et al (34), contended that with the ever-increasing number of journals it is likely that zone one journals will contain material most relevant to the researcher's interests. Zones two and three contain content likely to be less impactful to the evolution of the topic as they tend to be cited less often than content published in zone one journals.

Co-Author Analysis and Countries of Research

A range of relationships can be explored using bibliometrics but for the purpose of this study, with regards to authorship, only actual relations between authors and their countries of origin have been analysed (Co-authorship analysis). Other virtual relationships - such as patterns relating to work that was regularly cited together (co-citation analysis); where papers share several cited works (bibliographic coupling); or in the case of citation analysis the number of times they cite each other can be conducted and these methods have been described elsewhere (35). However, for the purpose of this study, methods that unearth virtual or potential collaborations were not explored as the intent was to identify the actual research networks that are informing the evidential base relating to hamstring rehabilitation.

Co-occurrence Analysis of Keywords

To map the thematic content of research there are several techniques that could have been used. Co-occurrence analysis of keywords uses the keywords attributed to the paper by either the indexing service or by the authors of the specific paper. By using author keyword general terminology can be excluded since the indexing service will categorize papers based on whether the content relates to humans or animals, males, or females and hence the interpretation of clusters of keywords can be overly populated by generalities (36). Additionally, Benton and Benton (21) noted that identifying clusters within large datasets can be complex and hence they used, in addition to the visualization of the data maps, detailed examination of the keywords associated with each cluster. To do this Benton and Benton (21) recommended that the relative size of the nodes determined by frequency, the terms occurring within the dataset, and the strength of the connections between the various nodes within the cluster as indicated by the thickness of the lines connecting nodes, can be used to formulate thematic titles and associated descriptions. This was the approach followed to determine themes and associated descriptions.

To enhance reliability and validity of the analysis of data both authors of this study independently examined the visual mapping of themes and analyzed the individual cluster content to allocate a short thematic title for each cluster and an associated description. Where there were differences of

interpretation these were discussed until agreement was reached. As a result, patterns of terms that are repeatedly used together in describing the published work were identified and interpreted to reveal the underlying thematic focus of the research contained within the clusters generated by multi-variant analysis of the indexed papers (36).

Additionally, the authors also independently proposed further opportunities for research based on the cluster content. Including, highlighting that an author may be considered prominent within this field when an author or their work is repeatedly referenced or played a bridging role in connecting groups of authors through their collaboration. Again, this information was then compared until consensus between the authors was reached. The intent of this exercise was not to provide definitive recommendations but rather point towards areas for potential further inquiry.

RESULTS

A total of 2,439 articles on Hamstring rehabilitation were retrieved, of these 815 papers related to hamstring rehabilitation and athletes from the indexed literature stored in Scopus on the 29th of July 2021. In the case of the entire body of research, 8,155 authors contributed to the 2,439 papers. Of those relating to the rehabilitation of athletes or sports practitioners, 815 papers, with 2,736 authors contributed to this work. As can be seen from Figure 1, nearly 50% of all published work focused on sports and athletes. Trend data were calculated indicated by the dotted lines, and as can be seen by the high "R^2" values the equation estimating expected frequency of publications (Y value) is extremely accurate.

Close examination of the journal sources revealed that the research on this topic conforms with Bradford's law of scattering and a total of 7 journals formed the core for the publication of work in this space and are listed in rank order - British Journal of Sports Medicine; American Journal of Sports Medicine; Scandinavian Journal of Medicine and Science in Sport; Sports Medicine; Journal of Orthopaedic and Sports Physical Therapy; and Medicine and Science in Sports and Exercise.

The second zone composes 33 journals, again in rank order – Physical Therapy in Sport; Journal of Sport Rehabilitation; Orthopaedic Journal of Sports Medicine; International Journal of Sports Medicine; Clinical Journal of Sports Medicine; Journal of Athletic Training; Journal of Strength and Conditioning Research; Knee Surgery Sports Traumatology Arthroscopy; Muscles Ligaments and Tendons Journal; Sports Health; Journal de Traumatologie du Sport; Journal of Biomechanics; Athletic Therapy Today; BMC Musculoskeletal Disorders; Current Sports Medicine Reports; Journal of Bodywork and Movement Therapies; Journal of Sport and Health Science; Journal of Sports Sciences; Physician and Sportsmedicine; Journal of sports Medicine and Physical Fitness; Asian Journal of Sports Medicine; Clinics in Sports Medicine; European Journal of Sports Science; Frontiers in Physiology; Isokinetics and Exercise Science; Plos One; Strength and Conditioning journal; American Journal of Roentgenology; Disability and Rehabilitation; Journal of Sports Science and Medicine; Manual Therapy; Operative Techniques in Sports Medicine; and Skeletal Radiology. Zone three consisted of a further 120 journals.

Co-author analysis identified that 517 authors were prominent in relation to the topic, that is, 6.4% contributed three or more papers to the body of research. Of those papers relating to athletes and sport 146 prominent authors or 5.3% contributed three or more papers. Furthermore, of those authors that contributed three or more papers to the total body of research 231 of these or 44.7% of prominent authors, formed a loosely connected group (see left image Figure 2). In the case of those working with athletes or sport 30, or 20.5% of prominent authors, formed the largest less well-connected group (right-side image in Figure 2).

As can be seen in Figure 2 there were several authors that have contributed large numbers of papers as indicated by the size of their nodes. In the case of the literature relating to hamstring rehabilitation with athletes the most prominent of these is Dr. Johannes I. Tol. Dr Tol has worked with a wide range of authors (Figure 2 right) many of whom are part of established groups of researchers as indicated by the differing cluster colours. Simple examination of the size of the author nodes, (indicating the cumulative output) and the thickness of connections between nodes the frequency of collaboration between authors, is insufficient. Neither the size of the nodes nor the thickness of the connections between them offer information on the quality of the paper or the relevance to the strength and conditioning community. However, from closer examination of Dr. Johannes I. Tol's work identified in the co-authorship mapping, details of titles, content of abstracts and

$$y = 0.0829e^{0.0955x}$$
$$R^2 = 0.9634$$

$$y = 0.021e^{0.1002x}$$
$$R^2 = 0.9593$$
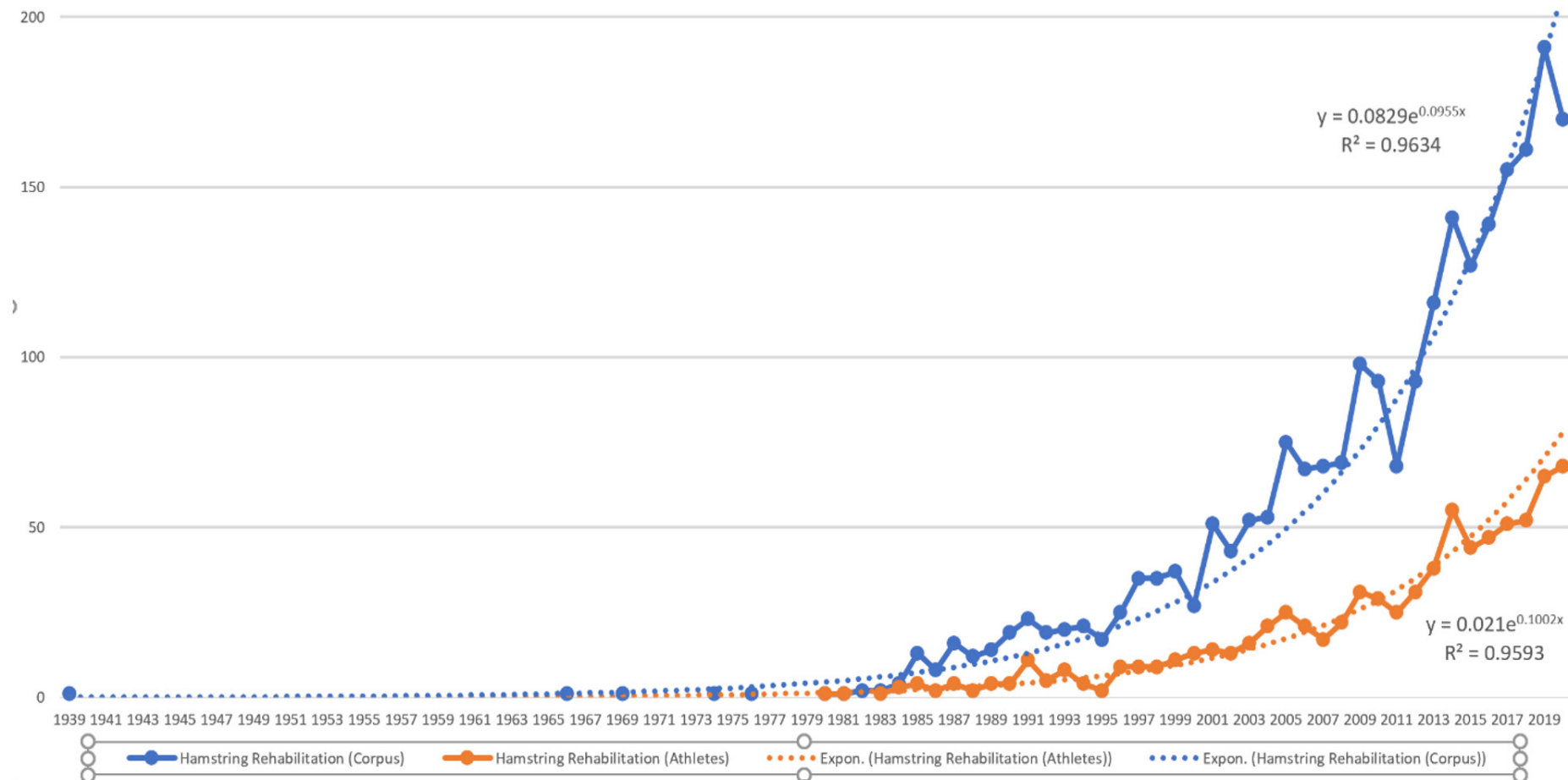
Figure 1. Frequency of Research on Hamstring Rehabilitation as Indexed in Scopus

citation received, it would suggest that Dr. Tol has established himself as a prominent figure within the field of Sports Medicine.

One of the clusters in the sports mapping, the yellow group, have as a team produced multiple papers as indicated by the fact that many of the authors have similar large nodes and thick lines connecting between the nodes. The most prominent member of this group being Dr. David A. Opar. Again, from detailed examination of the results it can be determined that Dr. Opar's work has made significant contributions to the current field of hamstring rehabilitation, specifically identifying athletes at risk from and how to better manage and rehabilitate such injuries.

By plotting the countries of origin of the authors an indication of the diversity of country contributions and their collaborative behavior as indicated by the thickness of connections between nodes was assessed. In the case of hamstring rehabilitation of athletes 62 countries of which 45 form a connected network (left image - Figure 3) can be examined. In addition to the 45 connected countries Algeria, Bosnia and Herzegovina, Croatia, Georgia, India, Israel, Kuwait, Mexico, Romania, Russian Federation, Slovakia, South, Africa, South Korea, Thailand, Uzbekistan and Vietnam have all contributed unconnected papers. By highlighting the Australian node those countries where Australian authors have collaborated with colleagues from other nations were identified through the illuminated links to Austria, Brazil, Canada, France, Germany, Ireland, Italy, Netherlands, New Zealand, Qatar, Spain, Switzerland, United Kingdom, United States, (right image of Figure 3). Consideration of the thickness of links between countries and based on the current analysis Australian authors were more likely to collaborate with colleagues from the United Kingdom, United States, New Zealand and Canada than other nations. Furthermore, by reviewing the frequency by which the work of authors from various countries are being cited it was possible to identify that Australia, Belgium, Finland, and Sweden are currently having the most recent and frequent impact through repeated citation in the research domain. However, caution in interpretation of this finding is needed to ascertain the focus and relevance of the work to the role of the strength and conditioning coach. So, as is the case with authors, these maps may only be viewed as starting points for further exploration.
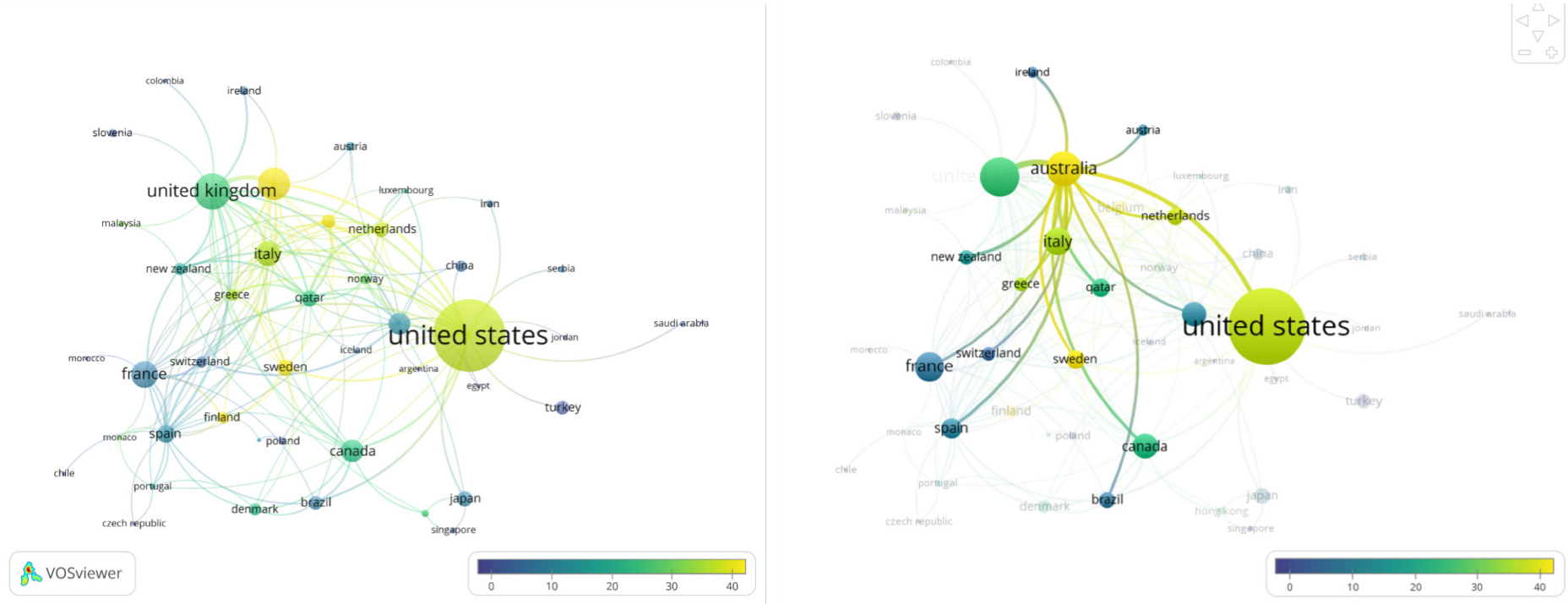
Co-occurrence analysis of author key words identified a total of 17 clusters of research relating to hamstring rehabilitation and 13 clusters specific to sport or athlete hamstring rehabilitation. The clusters are determined through multi-variant analysis and the proximity of nodes to one another is determined based on the co-occurrence of keywords within the originating papers. Resulting themes are documented in Table 1 and Table 2 respectively along with a brief description of the focus of each of the clusters alongside potential opportunities that the theme may provide for further strength and conditioning practice and research.

The second data set is a subset of the data contained in the total body of research, there were overlaps between the two data sets contained in Tables 1 and 2. However, the first data set, containing older material and focusing on the wider population, has a greater emphasis on surgical interventions.
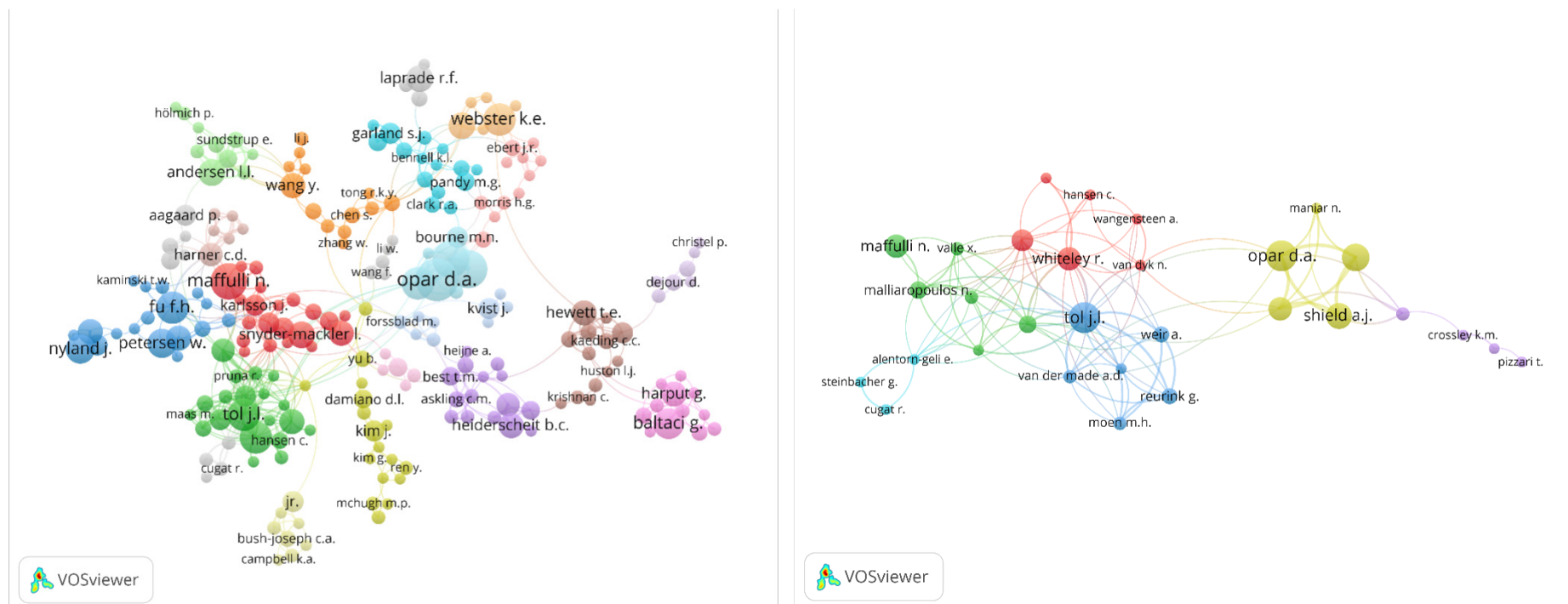
Figure 2. Co-author Connected Networks of 3 or more papers for hamstring rehabilitation (left) and hamstring rehabilitation in sport (right)

Figure 3. Co-author analysis of countries of origin (left) coded based on most cited work and Australian connections highlighted on right.

Table 1. Synopsis of clusters identified through co-occurrence analysis of author keywords relating to hamstring rehabilitation.

Hamstring Rehabilitation

Cluster	Title	Descriptive Focus of Research	Strength and Conditioning Opportunity
One	Risk factors following hamstring injury	Factors that may contribute to injury or re-injury rates such as weight bearing status, inflammatory response, muscle atrophy, and muscle strength.	Highlights the diversity of risks that can contribute to the athlete injury. Points towards the need for strength and conditioning coaches to be aware of these risks and the contribution that they and other disciplines can make to their prevention, treatment, and remediation.
Two	Musculoskeletal injury diagnosis	Key diagnostic techniques and tools utilized within the assessment and diagnosis of hamstring injury.	Understanding of anatomy and physiology of injury diagnosis to gain reliable and valid measures of status so appropriate effective and efficient programming can be prescribed.
Three	Biomechanics and movement analysis	The influence of biomechanical and movement motion analysis to gain greater insights into human performance.	Improve and implement athlete technique with and without load to influence performance and improve efficiency of techniques.
Four	Return to sport considerations	Criteria that should be met to ensure a successful return to play with minimizing recurrence of injury.	Often lead by strength and conditioning coaches with further research there is a potential to develop optimal evidence-based guidance for creation and implementation of core-protocols.
Five	Sport and associated injury	Influence of multiple sports such as Gaelic Football, Football, Soccer, Volleyball contributing to hamstring injury research.	Multiple high-performance teams utilizing the specialization and expertise of strength and conditioning coaches to minimize the risk of injuries in individuals and team sports. Provides insights into the career opportunities for novice coaches.
Six	Neuromuscular considerations	The influence of the neuromuscular system on risk of injury and rates.	To implement and evaluate key motor control techniques, into training and learning as part of a comprehensive approach to injury reduction.
Seven	Surgical graft Interventions	Surgical grafting and other techniques utilized within the current medical field to assist in diagnosis and treatment of acute and chronic injuries.	Identifies an area where pre-surgery and post-surgery opportunities exist for strength and conditioning professionals to have a role in securing effective treatment and optimal recovery.
Eight	Imaging	The application of imaging techniques in the diagnosis of hamstring injuries.	Opportunity for research into how imaging technology could play a role in monitoring response to various strength and conditioning regimes.
Nine	Tendon grafting and fixation	Surgical interventions during the repair of tendons and Anterior Cruciate Ligaments.	Area that has limited research in terms of the contribution of strength and conditioning coaches to pre- and post-surgical preparation and recovery

Ten	Knee outcomes	Following surgical interventions and or musculo-skeletal injury, objective outcomes can be applied to provide both base line measures and or post rehabilitation progress	Highlights simple and effective tools for strength and conditioning coaches to implement as part of the multidisciplinary team, client assessment and recovery progression.
Eleven	Anatomy and associated injuries	Essential in the understanding of Hamstring injuries, not only the basic anatomy of the muscle and tendon but both structure and function.	Foundational content for inclusion in educational curricula for strength and conditioning programmes.
Twelve	Mobility and exercise prescription analysis	Exploration of the use of a range of treatments used in the management of acute and chronic injuries.	A key focus for the contribution of strength and conditioning coaches. Provides a focus for further quantitative research to generate sufficient evidence to assess optimal coaching strategies.
Thirteen	Knee bracing	Conservative management techniques to assist in the healing of injuries.	Opportunity for strength and conditioning coaches to explore their role as part of conservative management approaches.
Fourteen	Osteoarthritis	Natural degenerative condition that can impact individuals of any age and level of fitness	Exercise prescription is emerging as a key treatment technique to combat osteoarthritis and is an area for optimizing treatment regimens through quasi-experimental designed studies.
Fifteen	Therapy types	Multiple therapy types that can contribute to the management of hamstring injuries.	Strength and Conditioning is one of many therapy types that can contribute to hamstring rehabilitation and provides insights into the formation of multi-disciplinary research teams that could form collaborative research programs.
Sixteen	Neurophysiological control	The influence of neurophysiological components and their influence in injuries	Strength and conditioning coaches could explore the contribution they can make to neurophysiological control.
Seventeen	Knee reconstruction	Hamstring is a key surgical site for grafting to create the Anterior Cruciate Ligament	Strength and Conditioning coaches could explore the contribution that they could make in pre-graft harvesting and post-graft recovery.

Table 2. Synopsis of clusters identified through co-occurrence analysis of author keywords relating to hamstring rehabilitation and sport or athlete.

Sport or Athlete Hamstring Rehabilitation

Cluster	Title	Descriptive Focus of Research	Strength and Conditioning Opportunity
One	Lower limb muscle injury	Commonly reported injuries in both individual and team sports resulting in acute and chronic injuries of the lower limb.	Provides a focus for curriculum content and research activity as well as potential topics where systematic reviews can be conducted to identify optimal evidence-based interventions specifically supporting the multi-disciplinary team [MDT] in the later stages of return to play.
Two	Surgical graft interventions	Surgical grafting and other techniques utilized within the current medical field to assist in diagnosis and treatment of acute and chronic injuries.	Identifies an area where pre-surgery and post-surgery opportunities exist for strength and conditioning professionals to have a role in securing effective treatment and optimal recovery.
Three	Strength testing	A variety of strength testing measures both subjective measurement and objective measurement commonly used in sports injury assessment, e.g. Isokinetic dynamometry, isometric muscle testing and eccentric strength measurement.	Strength and conditioning coaches are ideally suited to implement key strength testing measurements and gain experience in motion analysis tools to further develop strength and conditioning programmes.
Four	Injury classification	Injury classification is key to informing the MDT, the contributions that can be made by various disciplines and how to proceed within the injury management continuum.	Provides a framework for strength and conditioning coaches to assess their actual and potential contribution to treatment regimens.
Five	Injury in sport	Injures in sport are rarely limited to one sport and cover a variety of sports including Gaelic Football, Soccer, and Australian Rules Football to a name a few.	Strength and conditioning coaches should have a broad spectrum understanding of the athletes, sport and risk of injuries frequently associated with the various sports to ensure a greater specificity of treatment can be prescribed.
Six	Prevention and Rehabilitation	Identifies the contribution of strength and conditioning to the prevention, re-occurrence and rehabilitation of injury.	Highlights the continuum of practice that strength and conditioning practitioners can be involved in.
Seven	Testing measures	An overview of testing measures that can assist in analysing the athlete's abilities from limb symmetry, stability, and preparedness to play.	Illustrates the ability of the strength and conditioning coach to provide a multifactorial approach to testing encompassing not only strength measures but wider dimensions impacting performance.
Eight	Ligament and tendon surgical treatments	Key surgical techniques that are commonly used in the diagnosis and management of Anterior Cruciate Ligament tears and atrophy.	Educational aspect of injuries, to understand the full patient journey pathway and how this can affect other components of the athlete's recovery and return to fitness.

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and Conditioning Association

Nine	Return to sport criteria	Following an injury, and as a means of reducing re-occurrence of injury, athletes need to meet return to sport criteria that demonstrates if the athlete is prepared and ready for re-entry to sport.	Strength and conditioning coaches are in an ideal position to provide this final assessment along with the physiotherapist to ensure athletes readiness for play and reduced likelihood of injury recurrence.
Ten	Hamstring use and function	The utilization of the hamstring within the surgical intervention and the function that it plays in multiple sporting movements.	Understanding of the function and use of the hamstring and how implementing targeted programming can improve performance in various sports and limb usage.
Eleven	Knee injuries	Common site of injury during multiple sports, including tendinous, ligamentous, and meniscal etc.	Core content for curricula and provides a focus for strength and conditioning coaches to be involved in prevention and from the acute stages of injury through to return to play.
Twelve	Conservative treatment approaches	Originally, viewed as a second thought. Although new evidence suggested conservative management of acute and chronic injuries may be as effective as surgical interventions.	Offers a focus for coaches to apply strength and conditioning principles to provide a comprehensive progressive plan to ensure successful outcomes are met with conservative management.
Thirteen	Injury prevention	Identifies a range of techniques that can be used to prevent injury occurrence.	This is an area where only few studies have taken place and hence strength and conditioning coaches could focus on producing more evidence to demonstrate their impact.

DISCUSSION

This paper mapped and interpreted the development of indexed literature relating to hamstring injury and its treatment. The results identified the evolution of research, key contributors, dominant areas of inquiry, opportunities for systematic reviews as well as topics for further research within the field of strength and conditioning.

Notably, research relating to the contribution of strength and conditioning to hamstring rehabilitation treatments has evolved at an exponential rate. This was an expected finding and is congruent with the findings of Rastagar (8) in the general health sciences literature. Although, a relatively recent development there has been consistent and increasing volumes of contributions starting in the early 1980's where strength and conditioning practitioners have contributed to the generation of evidence-based practice both as solo practitioners and increasingly as part of multi-disciplinary teams.

The analysis of prominent authors clearly demonstrated the utility of bibliometrics as a tool capable of identifying research leaders and their established research groups. Such information may be useful for novice researchers or for those with an interest in the specific topic and who may be looking for mentors to support them in their research career. Additionally, for more established researchers, the identification of leaders and teams may offer a means of expanding their existing research networks with the potential to conduct multi-center studies or expand their work to different populations.

As was noted by the analysis of country-based contributions there was a set of core countries. However, increasingly research has been generated from a wider range of nations both as isolated contributions and as part of multi-national collaborative teams. The multi-national nature of this evolution may not only help facilitate multi-centered research but may also assist in diversification of cultural and resource-based perspectives. Specifically, Figure 3 provides a clear visual representation of countries that are prominent in the landscape of hamstring injury rehabilitation and through isolating the links between a particular country and connected nations the reach of existing collaborations was identified. Simultaneously, identification of those countries active in the topic but not yet part of the directly connected network offers potential targets for future collaboration hence accelerating the growth of increasingly diverse multi-

centered studies. Hence, the example provided where the current links between Australian authors and those from other nations illustrates the possibility for active researchers to seek out less prominent yet interested nations. Consequently, Australian researchers could play a significant role in global capacity building while opening opportunities to test the generalizability of their work to athletes from other nations.

A wealth of information was derived from both Table 1 and 2. Based on the current analysis both datasets highlight, areas for further research that could be used to identify the contribution of the strength and conditioning coach to holistic multi-disciplinary prevention, treatment, and recovery from injury or dealing with atrophy or degenerative conditions. Although these suggestions are somewhat speculative, it is possible to identify key opportunities for growth and development within the strength and conditioning research arena such as contributing to the evidence based on injury prevention (Table 2, cluster 13) or in the development of return to sport criteria (Table 2, cluster 9). These tables demonstrated the potential capacity for strength and conditioning to pursue original research in all stages of the hamstring injury rehabilitation process from acute, chronic, return to play, surgical and conservative management. It is therefore reasonable to contend that bibliometrics is a useful tool in supporting the identification of further research topics that aspiring strength and conditioning coaches could pursue either as single researchers or as part of a multi-disciplinary rehabilitation team.

The identification of prominent authors in this space offers novice practitioners insights into those that have expertise in the field. With modern author tracking systems such as Google Scholar or ResearchGate notifications of further publications by these individuals could be requested hence keeping the novice coach up to date with developments in their area of interest. In addition, by identifying the academic affiliation of these prominent individuals, institutions that have a track-record of strength and conditioning research production could be identified. For those coaches considering advanced academic study institutions offering relevant research programs as well as potential mentors or research collaborators may be pursued.

As identified through the application of Bradford's law of scattering the most relevant journals, at this point in time, have been identified. For those that

wish to publish further research these journals may be a good starting point for submissions as they may be receptive to further studies on the topic. Alternatively, looking at the zone two journals may provide opportunities where the journal is seeking to develop its presence in the space. Hence revisiting these rankings over time may offer further insights into the evolution of the field and the foci of journals.

LIMITATIONS

Bibliometrics has been used to help explore the content, actors, geography and sources of knowledge in a particular domain of inquiry. This exploration can look at actual links between data elements such as in the case of co-authorship but also inferred links by examining the co-occurrence of key words (35). Hence, it is important to recognize that the thematic results, their definition, and their potential impact in terms of trends or potential for further work is grounded in an interpretation of the data rather than a definitive solution. While the authors worked independently to generate these solutions and then collaborate to reach consensus other interpretations are possible. Accordingly, these results should be viewed as a starting point for further inquiry.

CONCLUSIONS AND PRACTICAL APPLICATIONS

This was, to the best of our knowledge, the first study to use bibliometrics focused on the indexed hamstring injury literature and hence offers an exemplar that could be used to explore other common conditions and areas of interest to the strength and conditioning community. As noted, there are a wide range of bibliometric measures that can be used in such a study and researchers may wish to explore areas such as citation analysis or bibliographic coupling to gain a deeper understanding of the origins and evolution of research themes (37).

The utilization of bibliometrics provided educators and educational institutions the basis for curriculum review as the role of strength and conditioning coaches develop and indeed other members of the mulit-disciplinary team engaged in improving athlete performance. Additionally, for those strength and conditioning coaches who wish to develop their research skills and contribution to the growth and advancement of the profession a range of topics of interest or areas of further research that are currently underdeveloped have been identified.

Specifically, the strength and conditioning community could utilize this publication to explore the opportunities that have been identified in Tables 1 and 2 to further expand their knowledge and skill base as well as address further research gaps in the understanding of how strength and conditioning coaches could optimally contribute to athlete outcomes and their participation as part of multidisciplinary teams. Furthermore, some of the topics identified can be explored in greater depth to gain a better understanding of the role of the strength and conditioning coaches, not only in the return to performance phase, but also in prevention and in the acute stages of injury.

Finally, examination of coauthorship links not only identified prominent authors such as Dr Tol and Dr Opar but also by examining their closely connected collaborators a wider group of researchers with a common interest in specific areas such as plasma rich protein therapy in the case of Dr Tol or work on the use of the Nordbord in the case of Dr Opar. By examining the clusters of collaborators and their links, insights can be gained into how ideas spread and develop within the research community and how original research evolves over time. For example, Dr Opar who co-invented the Nordbord has provided the sporting industry with a key analytical tool measuring eccentric hamstring strength that provides practitioners with real time data for performance outcome measures.

KEY PRACTICAL APPLICATION POINTS:

- This research provides an example of the application of bibliometrics analysis that can be replicated or expanded to explore other issues of importance to the strength and conditioning community.
- A range of topics that are underdeveloped have been identified that can form a focus for the strength and conditioning community to conduct further research in the form of synthesis of available material to guide the development and application of evidence-based practices.
- Insights into existing national and international collaborations have been mapped providing a baseline for tracking the expansion of strength and conditioning contributions over time as well as identifying countries that may be interested in collaborating on common topics trans-nationally.
- Key prominent authors and their impact on knowledge evolution have been identified

that has relevance to the work of strength and conditioning coaches. Through following their work using tracking tools such as ResearchGate or Google Scholar the next generation of practitioners can be updated as new work in their field of interest is generated and published.

- A core list of journals that routinely publish articles on the topic hamstring injury and rehabilitation and its relevance to sport and athletes have been identified and can be used to prioritise future journal scanning or to make subscription recommendations to librarians.

DECLARATION OF CONFLICT OF INTEREST

We confirm that we have no conflicts of interest and did not receive any financial support in relation to this study

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