Influential literature in tennis medicine and science

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ABSTRACT

This study examined the most influential peer-reviewed journal articles and books in tennis medicine and science based on citations (C). Systematic searches were performed to extract authors, titles, year, journal, C, and research focus for the top cited publications indexed in Google Scholar (GS). The top 100 articles had high numbers of citations (85 to 1,164) and citation rates (3 to 41 C/year) that were similar between tennis medicine and science, with fewer citations to tennis books. The influence of tennis research has increased over the last decade, with citations and citation rates were higher than was previously reported (Knudson, 2012). The study confirmed important research topics and journal outlets and identified influential authors. Influential tennis research continues to focus on injuries, physiological and psychological factors, with recent increases in analytics and business aspects of the sport.

INTRODUCTION

There is worldwide interest in tennis as a recreational, competitive, and spectator sport. The health benefits and injuries of a lifetime sport like tennis result in considerable scientific interest. Several scientific and professional journals publish research on tennis, particularly tennis medicine and sport science. There are even several journals that specialize in tennis medicine and science like the International Journal of Racket Sport Science, the ITF Coaching & Sport Science Review, and the Journal of Medicine & Science in Tennis.

There has been initial bibliometric research on these specialized journals (Crespo & Over, 2010; Knudson, 2020; Knudson & Myers, 2021) and in Chinese publications (Yuhan, 2016). The development of knowledge in tennis medicine and science throughout the wider scientific literature, however, is less well known. One study documented the most cited original research, reviews, and books in tennis using Google Scholar (Knudson, 2012). This study found that the top 30 cited research articles emphasized sports medicine, exercise physiology, biomechanics, and psychology topics. Interestingly, original research articles were cited more frequently than review articles, with even fewer citations to tennis books. Bibliometric research often focusses on metrics derived from citations (C) to determine the usage, influence, or impact of published research (Knudson, 2019). A decade has passed since the Knudson (2012) study and research and journal outlets have dramatically expanded, so there was a need to update the most influential research in tennis medicine and science. The aim of this study was to document the most cited peer-reviewed journal articles and books in tennis medicine and science. The study identified the 100 most cited journal articles in both tennis medicine

and tennis science, as well as the twenty most cited tennis books. This may confirm trends reported in previous work and expand knowledge of influential research topics, journals, and authors in tennis.

METHOD

The study used the Google Scholar (GS) bibliometric service given its superior coverage of peer-reviewed literature compared to curated databases (e.g., CINAHL, PubMed, Scopus, SPORTDiscus, Web of Science) and other open (e.g., Dimensions) bibliometric services (Delgado-Lopez-Cozar & Cabezas-Clavjo, 2013; Halevi et al., 2017: Harzing & Alakangas, 2016; Martin-Martin et al., 2018, 2021; Meho & Yang, 2007; Walters, 2009). The advantage of more complete coverage of peer-reviewed publications comes at the cost of greater manual searching, extracting, and checking of

bibliometric records (Halevi et al., 2017; Schultz, 2007). This greater demand on the investigator in data extraction, review, and analysis was accepted to overcome the limited coverage and search engine errors common in most databases (Gusenbauer & Haddaway, 2020).

The GS database service was used to perform multiple searches using "tennis" and combinations of "tennis" with "science" and "medicine." The large numbers of GS indexed records ("tennis" returned "about 1.3 million records", "tennis and medicine" 486,000, and "tennis and science" 712,000), however, were not a problem for identifying the most cited publications. The GS algorithm returns only the top 1000 records, but they correspond roughly to descending order by citations. This combined with the strong positive skew of citations to scientific publications (Knudson, 2015; Opthof et al., 2004; Seglen, 1992) ensures that identification of the top 100 cited articles and top 20 cited books could be reliability achieved with careful, manual review. A positive skew means citations are not symmetrically distributed, with most citations in fewer highly cited publications, and fewer citations in a long "tail" of numerous publications with few or even no citations. The investigator manually accessed and reviewed all 3000 records for the three searches. For many searches, later records could be more easily scanned because they receive very few citations and sometimes include grey literature (Haddaway et al., 2015) that were not the focus of this study. Grey literature refers to non-profit publications by academics, businesses/organizations, or governments like technical reports, theses, conference abstracts, and white papers.

Two kinds of indexed publications on tennis were the focus of this study: research reports published in peer-reviewed journals and books. This study included both original research and review articles in the research reports extracted. Studies were considered focused on tennis if the topic was primarily on the sport, related medical conditions (e.g., epicondylosis; tennis leg), or tennis players. Chapters, proceeding articles, and patents were excluded. Studies comparing tennis players with controls or one other sport were included, while studies and reviews focusing on more than two sports including tennis were excluded. Studies comparing numerous sports are more likely to attract citations related to other sports and not specifically tennis.

GS and publication data for over 330 articles and 21 books were entered into an Excel spreadsheet to ensure that the top cited publications were obtained. Searches occurred during the first week in August 2023 and ended before GS refresh on August 8, 2023. The investigator used a combination of GS data and accessed the hyperlink to the original source to confirm the authors, title, source, year of publication, and citations (C). Author surname and initials were extracted for up to the first four authors, with an annotation made if there were more coauthors. GS citation rate was also calculated (CR = C/(2023-year published). Data were reviewed for errors and incorrect inclusion before proceeding to analysis.

The investigator subjectively classified the topic of each highly cited journal article and book into one of seven categories: Analytics/Coaching, Biomechanics, Exercise Physiology/Fitness, Multdisiciplinary, Psychology/Sociology/Motor Behavior, Sports Business, and Sports Medicine. Articles with two topics were classified based on the primary study question and articles with more than two topics were classified as Multidiscplinary. The top 100 cited articles classified as Sports Medicine were identified and compared to the top 100 cited with all other classifications. This combination of articles from other categories was considered the tennis sports science group. The focus on two areas of tennis research (medicine and science) was selected given the dominance (56-63%) of sports medicine in a previous study of tennis citation classics (Knudson, 2012). The larger and more diverse sample in this study promises to provide a superior description of influential tennis research.

Descriptive data were calculated using JMP Pro 14 (SAS Institute, Cary, NC). Content analysis was performed on article topic data. Citations and content of the most cited tennis publications were compared to previous studies of influential tennis medicine and science research (Knudson, 2012, 2021; Knudson & Myers, 2021).

RESULTS

The top 100 journal articles in tennis medicine and tennis science had 24,241 and 23,750 GS indexed citations, respectively. Descriptive data of article influence were also similar between primarily tennis medicine and tennis science (Table 1). Top cited tennis medicine articles were more skewed (γ = 2.3) than tennis science (γ = 1.7). Ninety of the top tennis medicine articles were citation classics, while all top 100 tennis science articles were citation classics. Citation classics are highly cited publications in a specific research area or specialization, usually defined as 100 or more (Gehanno, 2007, Knudson, 2012). Almost half of the citations in both areas were dominated by four journals. Highly cited tennis sports medicine articles were published most often in British Journal of Sports Medicine (21%), American Journal of Sports Medicine (11%), Journal of Bone and Joint Surgery (7%), and Clinics in Sports Medicine (7%). Highly cited tennis sports science articles appeared more often in the British Journal of Sports Medicine (16%), Medicine and Science in Sports and Exercise (11%), American Journal of Sports Medicine (9%), and Journal of Sports Sciences (9%).

Most top cited tennis medicine articles focused on tennis elbow (39%), injury epidemiology (13%), shoulder injury (7%), bone development (5%), and heat illness (4%). The top 100 cited tennis science articles included all topical categories with relatively more papers in Exercise Physiology/Fitness (46%) and Biomechanics and Psychology/Sociology/Motor Behavior both with 22%. Table 2 lists the 20 most cited articles in tennis medicine and science, as well as the top 17 cited tennis books.

Table 1
Influence statistics for the top cited 100 journal articles indexed in Google Scholar.

	Mean	SD	Max	75th	Me	25th	Min
Tennis Medicine							
Citations	242	206	1,164	284	155	123	85
CR	11.6	8.5	41.3	14.3	9.1	5.5	2.2
Tennis Science							
Citations	238	136	765	279	186	140	116
CR	12.7	7.2	35.3	16.4	10.8	8.0	2.8

Note: Citation Rate (CR) = Citations/(2023-year published) and median (Me).

Table 2
Highest cited tennis journal articles and books.

Author	Year	Title	Journal	C
Tennis Medicine				
Nirschl RP et al.	1979	Surgical treatment of lateral . . .	J Bone Joint Surg	1,164
Kannus P et al.	1995	Effect of starting age of physical . . .	Ann Inter Med	990
Kraushaar BS et al.	1999	Tendinosis of the elbow . . .	J Bone Joint Surg	932
Roles NC et al.	1972	Radial tunnel syndrome . . .	Bone Joint J	733
Bisset L et al.	2006	Mobilisation with movement . . .	Br Med J	702
Nirschl RP	1992	Elbow tendinosis/tennis elbow	Clinics Sports Med	683
Haapasalo H et al.	2000	Exercise-induced bone gain . . .	Bone	657
Bass SL et al.	2002	The effect of mechanical loading . . .	J Bone Min Res	632
Bisset L et al.	2005	A systematic review and meta . . .	Br J Sports Med	631
Coonrad RW et al.	1973	Tennis elbow: Its course . . .	J Bone Joint Surg	608
Sharma R et al.	2002	Physiologic limits of left . . .	J Am Col Cardio	473
Vergaar JAN	1994	Tennis elbow	Int Orthopaedics	428
Pluim BM et al.	2006	Tennis injuries: Occurrence . . .	Br J Sports Med	424
Huddleston AL et al.	1980	Bone mass in lifetime tennis . . .	J Am Med Assoc	419
Kibler WB	1995	Biomechanical analysis of the . . .	Clinics Sports Med	389
Bjordal JM et al.	2008	A systematic review with . . .	BMC Musculosk DIsord	379
Gruchow et al.	1979	An epidemiological study of tennis . . .	Am J Sports Med	353
Boyer MI et al.	1999	Lateral tennis elbow: Is there . . .	J Shoulder Elbow Surg	350
Nirschl RP et al.	2003	Elbow tendinopathy . . .	Clinics Sports Med	347
Kibler WB et al.	1996	Shoulder range of motion in elite . . .	Am J Sports Med	323
Tennis Science				
Gould D et al.	1996	Burnout in competitive junior tennis. . .	Sport Psych	765
Williams AM et al.	2002	Anticipation skills in a real. . .	J Exp Psych	676
Fernandez-Fernandez J et al.	2006	Intensity of tennis match play	Br J Sports Med	600
McPherson SL et al.	1989	Relation of knowledge and . . .	Res Quart Exerc Sport	557
Kovacs MS	2007	Tennis physiology: training . . .	Sports Med	542
O'Donoghue P et al	2001	A notational analysis of elite . . .	J Sports Sciences	542
Lees A	2003	Science and the major racket . . .	J Sports Sciences	516
Gould D et al.	1996	Burnout in competitive junior . . .	Sport Psych	506
Kovacs MS	2006	Applied physiology of tennis . . .	Br J Sports Med	502
Ward P et al.	2002	Visual search and biological . . .	Res Quart Exerc Sport	442
Ellenbecker TS et al.	2002	Glenohumeral joint rotation . . .	Med Sci Sports Exerc	432
Elliott B	2006	Biomechanics of tennis	Br J Sports Med	424
Smekal G et al.	2001	A physiological profile of tennis . . .	Med Sci Sports Exerc	422

Kraemer WJ et al.	2000	Influence of resistance training . . .	Am J Sports Med	401
Elliott B et al.	2003	Technique effects on upper . . .	J Sci Med Sport	372
Elliott B et al.	1995	Contributions of upper limb . . .	J Appl Biomech	350
Fernandez-Fernandez J et al.	2009	A review of the activity profile . . .	Strength Cond J	330
Kraemer WJ et al.	2003	Physiological changes with . . .	Med Sci Sports Exerc	330
Chandler TJ et al.	1990	Flexibility comparisons of junior . . .	Am J Sports Med	330
Bergeron MF et al.	1991	Tennis: A physiological profile . . .	Int J Sports Med	311

Tennis Books

Author	Year	Title	Publisher	C
Gallwey WT	1975	The inner game of tennis (Mult. Editions)	Macmillan	1,877
Brody H	1987	Tennis science for tennis players	Univ Penn Press	198
Kovacs MS et al.	2016	Complete conditioning . . . (2 editions)	Human Kinetics	177
Groppel JL	1992	High-tech tennis (2 editions)	Leisure Press	164
Brody H et al.	2002	The physics and technology of tennis	Rac Tech Pub	152
Elliott BC et al.	2003	Biomechanics of advanced tennis	Int Tennis Fed	105
Baltzell ED	2017	Sporting gentlemen: Men' tennis . . .	Taylor Francis	95
Roetert EP et al.	2001	World-class tennis technique	Human Kinetics	93
Loehr J	1990	The mental game: winning . . .	S Greene Press	86
Knudson D	2006	Biomechanical principles of tennis . . .	Rac Tech Pub	71
Chu DA	1995	Power tennis training	Human Kinetics	68
Braden V et al.	1998	Tennis 2000: Strokes . . . (2 editions)	Little Brown	65
Plagenhoef S	1970	Fundamentals of tennis	Prentice Hall	54
Roetert EP et al.	2019	Tennis anatomy	Human Kinetics	52
Kovacs M et al.	2007	Tennis training: enhancing . . .	Rac Tech Pub	49
Pluim BM et al.	2004	From breakpoint to advantage . . .	Rac Tech Pub	49
Elliott B et al.	1983	The art and science of tennis	Sanders	49

The most prolific authors of highly cited research were different between tennis medicine and tennis science (Table 3). The top cited authors in tennis medicine focused on tennis elbow, injuries, bone development, and heat illness. The top cited dozen authors in tennis science focused on all topic categories and primarily biomechanics, fitness, physiology, and psychology.

Table 3
Top authors and number of coauthored articles in top 100 cited tennis medicine and science publications.

Tennis Medicine	n	Tennis Science	n
Nirschl RP	8	Fernandez-Fernandez J	11
Haapasalo H	5	Ellenbecker TS	8
Kannus P	5	Elliott BC	7
Kibler WB	5	Gould D	7
Bergeron MF	4	McPherson SL	7
Pluim BM	4	Roetert RP	7
Sievanen H	4	Reid M	6
Bisset L	3	Girard O	4
Renstrom PA	3	Mendez-Villanueva A	4
Kontulainen S	3	Sanz-Rivas D	4
Sobel J	3	Kovacs MS	3
Ellenbecker TS	2	Kraemer WJ	3

DISCUSSION

This study confirmed that research interest in tennis medicine and science has continued to grow over the last decade. The top 25% cited articles in this study (Table 1) had between 279 and 1,163 citations which was higher than the 113 to 499 citations for tennis articles in July of 2012 (Knudson, 2012). The high citation totals and citation rates in the current study (Table 1) were similar between tennis medicine and tennis science research. This indicates that there is approximately equal influence and knowledge development in both medical and sport science areas. Inspection of Table 1 shows that influential tennis research with high citation totals result from both long-term relevance with lower citation rates (4 - 19 C/year) and more recent articles that represent hot topics with higher citation rates (> 20 C/year). A current GS search "tennis" returns "About 1.3 million" records compared to the 550,000 reported a decade ago (Knudson, 2012). The expansion of research and journal outlets may also contribute to the increasing citation of tennis medicine and science research.

Separating tennis medicine from tennis science topics shows more journals for the former (45) than the latter (27) publishing the top cited 100 articles indexed in GS. While a few sports medicine journals publish about half of the highly cited tennis research (British Journal of Sports Medicine, American Journal of Sports Medicine, Medicine and Science in Sports and Exercise), influential tennis medicine and science is published in a variety of multidisciplinary and specialized journals. One ITF Coaching & Sport Science Review article was in the top 100 most cited tennis science articles (Cross & Pollard, 2009), having 131 citations and a citation rate (9.4) higher than is common in highly specialized journals (Knudson, 2020; Knudson & Myers, 2021; Postma, 2007). Scholars interested in tennis research should search a variety of bibliometric databases to be sure to identify relevant research (Gusenbauer & Haddaway, 2020; Knudson, 2019).

The most highly cited tennis journal articles focused on tennis injuries/tennis elbow, physiology/fitness, biomechanics, and psychological/motor behavior topics. This was in general agreement with the five disciplinary areas reported in the Knudson (2012) study of tennis citation classics. New observations of the current study (larger with more topic areas) were the appearance of top cited tennis research in analytics/coaching (8%) and business/management (3%) aspects of the sport. The top cited books in the current study did confirm several observations of the previous study of tennis citation classics (Knudson, 2012): lower citations (60-70%) to books than journal articles, a majority on biomechanics (41 – 60%), and the fewest on sports medicine (5-7%).

Another novel observation of the current larger study of tennis research is the identification of influential researchers. Many of the authors of citation classics in tennis original research, reviews, and books reported in the previous study by Knudson (2012) were confirmed in the present study. Inspection of table 3 confirms highly influential authors of tennis sports medicine research on tennis elbow (RP Nirschl, L Bisset), heat illness (MF Bergeron), bone (H Haapasalo, P Kannus), and injuries and their treatment (WB Kibler, BM Pluim; PA Renstrom). The current study was able to identify that influential researchers in tennis science were different from tennis medicine and new influential researchers in topics with accelerating rates of citation. The most frequent authors in tennis science tended to publish in the Exercise Physiology/Fitness topic, both over a long time (TS Ellenbecker, EP Roetert) and in the last 15 years (J Fernandez-Fernandez). Influential long-term authors in tennis biomechanics (BC Elliott), psychology (D Gould), and motor learning (SL McPherson) were identified. A higher percentage of greater than four authors per article was observed in tennis medicine articles (37%) than in tennis science (22%). Future tennis bibliometric research should strive to replicate and extend these results on current authorship and research topics. Greater detail on knowledge development in tennis using interdisciplinary teams of scholars and on sport-specific topics would assist both coaches, researchers, and tennis organizations.

The results of this study should be interpreted in the context of its limitations. There is potential for error in the manual searching, extraction, entry, and cleaning of GS data. The lack of curation of GS and the unknown accuracy and reliability of the classification of primary topics by the investigator are also limitations. Focus on the top cited work is standard in bibliometrics, however limits the identification of potentially influential recent publications that do not have enough time to accrue citations, particularly in small fields like tennis medicine and science. The extensive coverage of GS, the high correlations between citations from GS and other curated databases (Knudson, 2019, 2022), the consistency of the study results with previous studies, and large sample however, all indicate the limitations do not likely bias the results of this study.

CONCLUSION

It was concluded that the influence of tennis research has increased based on increases in current citations in GS compared to a previous study (Knudson, 2012). The high citations and citation rates are approximately equal between top cited tennis medicine and tennis science journal articles, with fewer citations seen to top cited tennis books. Influential tennis research continues to focus on injuries, physiological and psychological factors, with recent increases in the analytics and business aspects of the sport.

CONFLICT OF INTEREST AND FUDING

REFERENCES

Cross, R., Pollard, G. (2009). Grand slam men's singles tennis 1991-2009 serve speeds and other related data. ITF Coaching & Sport Science Review, 15(49), 8-10.

Crespo, M., & Over, S. (2010). ITF Coaching and Sport Science Review: A analysis of 17 years—50 issues. ITF Coaching & Sport Science Review, 50(18) 32-33.

Delgado-Lopez-Cozar, E. & Cabezas-Clavjo, A. (2013). Ranking journals: Could google scholar metrics be an alternative to journal citation reports and scimago journal rank? Learned Publishing, 26, 101–114. https://doi.org/10.1087/20130206

Gehanno, J-F., Takahashi, K., Darmoni, S., & Weber, J. (2007). Citation classics in occupational medicine journals. Scandinavian Journal of Work and Environmental Health, 33(4), 245-251. https://www.jstor.org/stable/40967650

Gusenbauer, M., & Haddaway, N.R. (2020). What academic search systems are suitable for systematic reviews or meta-analyses? Evaluating retrieval qualities of Google Scholar, PubMed, and 26 other resources. Research Synthesis Methods, 11, 181-217. https://doi.org/10.1002/jrsm.1378

Haddaway, N.R., Collins, A.M., Coughlin, D., & Kirk, S. (2015). The role of Google Scholar in evidence reviews and its applicability to grey literature searching. PLoS ONE, 10(9), e0138237. https://doi.org/10.1371/journal.pone.0138237

Halevi, G., Moed, H., & Bar-Ilan, J. (2017). Suitability of Google Scholar as a source of scientific information and as a source of data for scientific evaluation— Review of the literature. Journal of Informetrics 11(3), 823–834. https://doi.org/10.1016/j.joi.2017.06.005

Harzing, A-W., & Alakanagas. S. (2016). Google Scholar, Scopus and the Web of Science: A longitudinal and cross-disciplinary comparison. Scientometrics, 106, 787-804. https://doi.org/10.1007/s11192-015-1798-9

Knudson, D. (2015). Evidence of citation bias in kinesiology-related journals. Chronicle of Kinesiology in Higher Education, 26(1), 5-12.

Knudson, D. (2012). Citation classics in tennis medicine and science. Journal of Medicine & Science in Tennis, 17, 118-122.

Knudson, D. (2019). Judicious use of bibliometrics to supplement peer evaluations of research in kinesiology. Kinesiology Review, 8, 100-109. https://doi.org/10.1123/kr.2017-0046

Knudson, D. (2020). Bibliometrics of ITF Coaching and Sport Science Review. ITF Coaching & Sport Science Review, 82(28), 21-23.

Knudson, D. (2022). Citations to biomechanics articles from four databases. ISBS Proceedings Archive, 40(1), Ar. 82. https://commons.nmu.edu/isbs/vol40/iss1/82/

Knudson, D., & Myers, N. L. (2021). A bibliometric analysis of the Journal of Medicine & Science in Tennis. Journal of Medicine & Science in Tennis, 26(1), 15-21.

Martin-Martin, A., Orduna-Malea, E., Thelwall, M., & Lopez-Cozar, E. D. (2018). Google Scholar, Web of Science, and Scopus: A systematic comparison of citations in 252 subject categories. Journal of Informetrics, 12, 1160-1177. https://doi.org/10.1016/j.joi.2018.09.002

Martin-Martin, A., Thelwall, M., Orduna-Malea, E., & Lopez-Cozar, E. D. (2021). Google Scholar, Microsoft Academic, Scopus, Dimensions, Web of Science, and OpenCitations' COCI: A multidisciplinary comparison of coverage via citations. Scientometrics, 126, 871-906. https://doi.org/10.1007/s11192-020-03690-4

Meho, L. I., & Yang, K. (2007). Impact of data sources on citation counts and rankings of LIS faculty: Web of Science versus Scopus versus Google Scholar. Journal of the American Society for Information Science, 58, 2105-2125. https://doi.org/10.1002/asi.20677

Opthof, T., Coronel, R., & Piper, H. M. (2004). Impact factors: No totum pro parte by skewness of citation. Cardiovascular Research, 61, 201-203. https://doi.org/10.1016/j.cardiores.2003.11.023

Postma, E. (2007). Inflated impact factors? The true impact of evolutionary papers in non-evolutionary journals. PLoS ONE, 2(10), e999. https://doi.org/10.1371/journal.pone.0000999

Seglen, P. O. (1992). The skewness of science. Journal of the American Society for Information Science, 43(9), 628-638. https://doi.org/10.1002/(SICI)1097-4571(199210)43:9<628::AID-ASI5>3.0.CO;2-0

Schultz, M. (2007). Comparing test searchers in PubMed and Google Scholar. Journal of the Medical Library Association, 95, 442-445. https://doi.org/10.3163/1536-5050.95.4.442

Walters, W. H. (2009). Google scholar search performance: Comparative recall and precision. Libraries and the Academy, 9, 5-24. https://doi.org/10.1353/pla.0.0034

Yuhuan, L. (2016). Bibliometric analysis of the sport core periodicals scientific literature of tennis research in recent ten years. Contemporary Sports Technology, 14, 159-160.

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