

Bibliometric analysis of productivity and keyword trends in articles on physical therapy and ageing (1990–2014)

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Abstract

Introduction. The increase in population longevity has led the subject of ageing to take an important role in research and innovation policies. Considerable efforts have been made worldwide to promote research on physiotherapy and ageing. Therefore, applying bibliometric measures can be useful to identify emerging and innovative scientific indicators. This study identifies productivity and topic trends in physiotherapy in ageing and the main publishing authors, institutions, and countries.

Methods. A bibliometric analysis was applied in original articles published on the Science Citation Index Expanded of Web of Science Core Collection (1990–2014). Bibliometric indicators were obtained by using specific bibliometric software. Pearson's correlation coefficient (r) was applied for correlations; statistical significance was considered for $p < 0.01$.

Results. Overall, 2237 original articles were included. Topic trends show an initial focus on illness and evolve towards the study of prevention. Authors and institutions increased productivity and citation. The most productive country was the United States, and there was a significant correlation between productivity and gross domestic product ($p < 0.01$). No statistically significant relationship was observed between productivity and the countries' aged population.

Conclusions. Productivity increased, with a greater scientific interest in prevention. The published research was mainly related to wealthy and developed countries.

Key words: bibliometrics, physical therapy modalities, ageing, trends

Introduction

Worldwide, the number of older adults is expected to more than double by 2050 and more than triple by 2100, with most of the increase in developing countries [1]. Global statistics show that Japan leads the ranking of countries with the highest proportion of the population over 65 years of age (26.3%), followed by European countries: Italy (22.4%), Germany (21.2%), France (19.1%), Spain (18.8%), and the United Kingdom (17.8%). However, other countries, such as the United States (14.8%), reveal a much younger age structure than that of Europe. Developing countries show low percentages of population aged over 65 years, e.g. 7.8% in Brazil and 2.7% in Nigeria [2].

According to the World Health Organization, these data of populations' ageing can be considered a success of public health policies and socioeconomic development [3]. However, ageing has become a challenge to health professions such as physiotherapy (PT) specialists since it involves a gradual reduction in the capacity to adapt and an increase in vulnerability to health issues such as chronic non-communicable diseases and musculoskeletal disorders [4]. On the other hand, there are elder people who enjoy successful ageing, which implies not suffering from chronic diseases and having optimal social engagement and mental health, as well as no physical disability [5]. Moreover, healthy ageing [6] or successful ageing is a multi-domain concept that comprises and transcends good health, and it is made up of a wide spectrum of biopsychosocial factors [7]. Therefore, PT and other health professions play a fundamental part not only in illness, but also in maintaining or improving functionality

throughout the cycle of life [8] in order to prevent decreases in quality of life whenever the changes of old age start to appear [9].

Some previous bibliometric studies have already described PT research from different perspectives [10, 11]. One of the first PT bibliometric studies analysed citations of the *Physical Therapy* and *Physiotherapy Canada* journals between 1981 and 1982, concluding that the 5 authors who were considered as 'eminent' in the profession appeared regularly as highly cited in both journals [12]. In the same year, Bohannon and Gibson [13] published their citation analysis of journals cited in *Physical Therapy*, finding that *Physical Therapy* and *Archives of Physical Medicine and Rehabilitation* were the most cited.

Some authors have analysed the quality of PT research [10, 14–16]. In 1991, a citation analysis conducted by Bohannon and Roberts [17] helped to establish a 'core list' of rehabilitation journals. The authors concluded that information regarding rehabilitation was being published by a large number of different journals. Tesio et al. [18] found that rehabilitation scientific literature comprised a relatively small number of published articles, with a greater proportion of them published in journals with no impact factor (IF).

In 2001, another bibliometric study analysed IF in rehabilitation journals [19]. In the same year, Maher et al. [15] conducted a study on journals indexed in the Physiotherapy Evidence Database (PEDro) and compared their contents with previously published articles. Later, in 2004, they performed another bibliometric study in order to analyse the quality of scientific evidence in PT [20].

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In 2011, 2 bibliometric studies analysed content trends and themes of 2 journals: *Journal of Orthopaedic & Sports Physical Therapy* [21] and *Physical Therapy* [22]. In 2012, the latter journal was investigated with both traditional bibliometric indicators (such as citation) and more novel ones (as quantitative and collaborative indicators) to track trends in authors, productivity, and consumption of research from 1945 to 2010 [23].

PT bibliometric studies were also centred on specific areas. Svien et al. [24] reviewed 15 years of research in the field of paediatric PT. Hoffmann et al. [25] studied stroke-related interventions in the OTseeker database in terms of research evidence quantity, quality, and content.

PT publications, in spite of being a relatively new phenomenon in the scientific literature [26, 27], have undergone a considerable development worldwide and the theme of ageing has taken a prominent role owing to the increase in the population's longevity [28]. When dealing with a complex phenomenon such as ageing, it is very useful to apply bibliometric measures to identify emerging and innovative topics, anticipate advances, and determine which paradigms will dominate research in the future [29, 30]. Bibliometric research has already been implemented in most scientific fields [31, 32], and it can allow researchers and professionals of PT in ageing to analyse publications and identify future research opportunities [33].

The purpose of this study was to use bibliometric indicators to identify the productivity, evolution, and advances of topics within PT in ageing. Our study also reveals the main authors, institutions, and countries of the area, as well as their impact, in order to encourage communication among researchers and ultimately contribute to the building of the knowledge base in the field. Describing the publication patterns of PT in ageing over 25 years helps make inferences about the emerging and innovative themes, as well as the evolution of the profession in a worldwide perspective, and therefore offer clinicians and researchers a better understanding of the scientific literature.

Subjects and methods

Database selection

The Web of Science (WoS) database was searched to retrieve original articles related to PT in ageing published from 1900 to 2014 in order to conduct a bibliometric study. WoS is an international multidisciplinary tool which includes all scientific and technological areas and presents a detailed citation analysis [34]. More specifically, the Science Citation Index Expanded (SCI-E) of WoS Core Collection was selected, as in previous studies [35, 36].

Search strategy

The search strategy was based on terms related to PT, physical therapist, ageing, and PT techniques in ageing. The terms were selected owing to their presence in the Medical Subject Headings (MeSH) thesaurus [37] or in previous bibliometric studies [21–23, 38–40], or they were professional terms of PT [8, 41]. The final search strategy had 115 combined terms (Appendix 1).

As for the limits, the time limit was initially from 1900 to 2014 but finally started with 1990, the year of the first result. The *articles* type of document was selected, since original articles of scientific journals with peer review are the most appropriate for bibliometric studies [31]. All categories of SCI-E

were selected in order to obtain the multidisciplinary view that the ageing process requires. No language limits were applied. The literature search was performed in July 2015 and a total of 2417 documents were retrieved.

Standardization of the bibliographic information

After manually removing 180 non-pertinent references, the bibliographic information from the 2237 finally selected documents was downloaded to a specific bibliometric relational database (Bibliométricos.mdb) in a Microsoft Access file. This information was then subjected to a standardization process to bring together the different names of a particular author, institution, or keyword.

The authors' signatures were standardized because sometimes an author appears as 2 or more signatures. This is due to authors' using only 1 surname or 2, or only 1 first name or more, as well as because graphic signs, such as hyphens, are applied to separate names, and there are variations in the indexing process (e.g. the standardized author Abbott, J Haxby had the variants of Abbott, J. H.; Abbott, J. Haxby; and Abbott, J.).

In relation to institutions, the different variants of university or hospital names were unified. Some institutional signatures collected 2 or more institutions, like university hospitals and universities. With the aim of not losing information, these signatures were differentiated in order to indicate, for each bibliographic record, as many macro-institution signatures as could be identified.

Keywords were standardized with the consideration of the World Confederation for Physical Therapy (WCPT) glossary [41], Medline Plus dictionary of the United States National Library of Medicine, and MeSH thesaurus [37].

Analysis of the scientific production

A series of global bibliometric indicators were obtained. The first ones were the number of articles and productivity distribution through quinquennia. Secondly, in relation to the topics, the occurrence of the keywords and their distribution over quinquennia were calculated. Regarding the graphic representation of the links between keywords, the existence of a link was considered when 2 or more keywords were used together in at least: 2 articles (1st quinquennium), 4 articles (2nd quinquennium), 10 articles (3rd quinquennium), 20 articles (4th quinquennium), and 35 articles (5th quinquennium). For the graphic representation of the links, the Pajek network analysis program was used.

Thirdly, regarding authors, the following bibliometric indicators were calculated: number of authors, citation of the authors, and Lotka's productivity index (PI) [42]. PI allows to identify highly productive authors, who are those with 10 or more published papers ($PI \geq 1$); medium producers, with 2–9 published papers ($0 < PI < 1$); and small producers, with only 1 article ($PI = 0$). The citation for each quinquennium and the *h*-index [43] of the highly productive authors were identified. The *h*-index is the result of the combination of productivity and citation given in an index: an author has an *h*-index if all of their *h* articles receive at least *h* citations each and the rest have at most *h* citations [44].

Finally, the same methodology was applied to analyse the institutional signatures and the countries productivity, identifying citations and PI for the institutions and countries.

Statistical analysis

Descriptive results for continuous data were expressed as mean and standard deviation, while nominal data were described as frequencies and percentages. In order to identify the level of statistically significant correlations between productivity and citation, Pearsons' correlation coefficient (*r*) and the coefficient of determination (*r*²) were applied for correlations between productivity and citation. Statistical significance was considered for *p* < 0.01. Coefficient determination (*r*²) was reported as a measure of exposure influence on outcome variability. The same methodology was applied to analyse the correlation between productivity and countries' aged population, and productivity and the gross domestic product (GDP) of the countries in order to offer a broader view of scientific activity associated with sociodemographic and economic indicators, respectively, and therefore be able to explain imbalances of resources allocated to research which may be caused by population or wealth differences.

Ethical approval

The conducted research is not related to either human or animal use.

Results

Articles productivity and topic trends

The number of analysed articles was 2237, with an average of 447.4 (*SD* = 406.98) articles per quinquennium (Figure 1). Between the 1st quinquennium and the last one, publications increased by 45.33% (1014 articles), with an average growth between quinquennia of 9.70% (217 articles).

In relation to the topics, the 2237 analysed articles used 3396 different keywords, with the following ones being the most frequent during the whole studied period: physical therapy (45.69%), older people (31.96%), rehabilitation (26.96%), clinical trial (24.05%), and exercise (23.60%).

In addition, the co-occurrence links between highly used keywords were analysed for each quinquennium: (a) In the 1st period (1990–1994), the keywords that were used together in a greater number of articles were: physical therapy and pain (8.5%), followed by physical therapy and rehabilitation (7%) (Figure 2). (b) In the 2nd quinquennium (1995–1999), the previous links were consolidated and there was an outstanding increase in the association of physical therapy and clinical trial (6.8%). On the whole, in the first 2 quinquennia, there were prominent associations of keywords related to pathologies such as hemiplegia, chronic bronchitis, cystic fibrosis, or heart disease, which did not appear in the following quinquennia. (c) In the 3rd quinquennium (2000–2004), there was a highlighted increase in the association of physical therapy and exercise (from 5.6% in the 1st quinquennium to 14.52% in the 3rd one). Moreover, the keywords physical therapy and quality of life appeared for the first time as a prominent association, which increased and consolidated in the following periods. In fact, the keyword quality of life presents an increased percentage from the 1st to the last quinquennium of 63.03%. (d) In the period 2005–2009, associations were consolidated between physical therapy and: clinical trial (18%), exercise (15%), and rehabilitation (14.6%). (e) In the last quinquennium (Figure 3), there was still an outstanding association between physical therapy and rehabilitation (16.22%), followed by physical therapy and clinical trial (15.29%) and physical therapy and exercise (15.20%). On the whole, in the last 3 quinquennia, some keywords such as exercise, physical activity, prevention, health care, exercise therapy, risk factor, or quality of life had a highlighted position; however, they were not so significant in the first 10 years.

Globally, the graphic representation of the keyword links in the 1st and last quinquennium (Figures 2 and 3) shows the increase in productivity, since the thickness of both vertices and edges, which represent the number of articles, increased in an outstanding way.

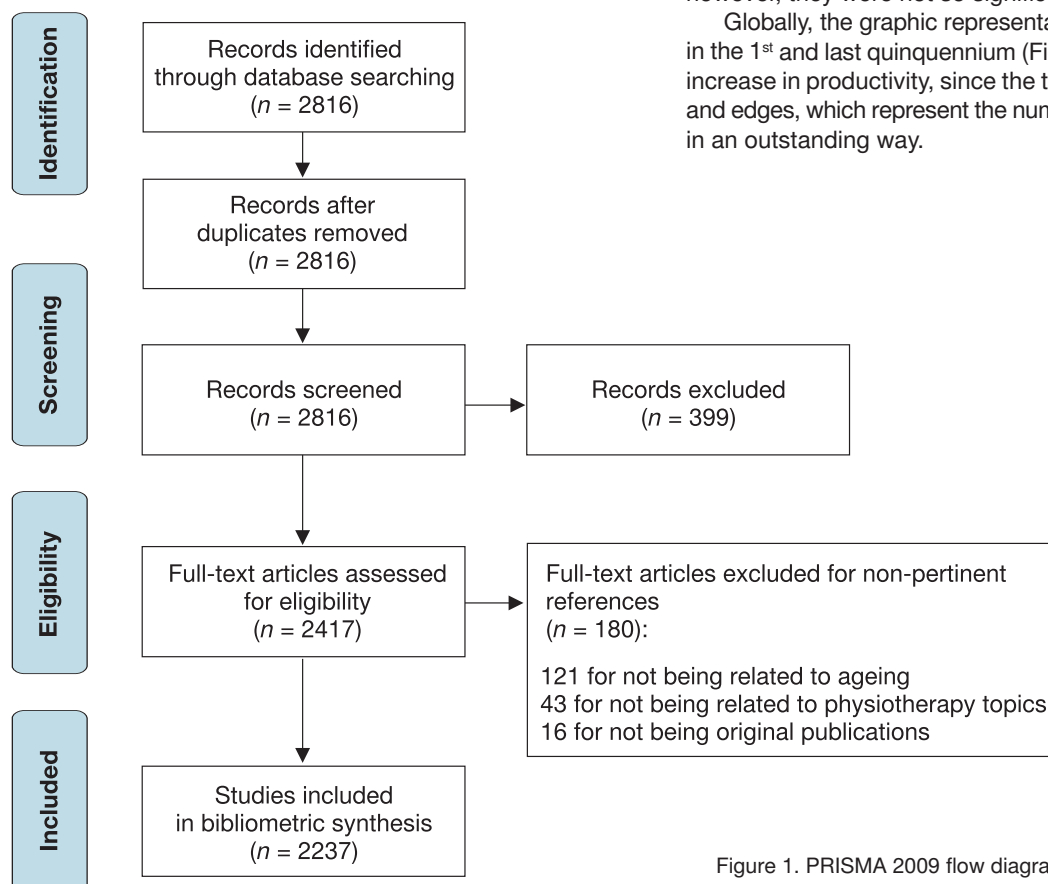
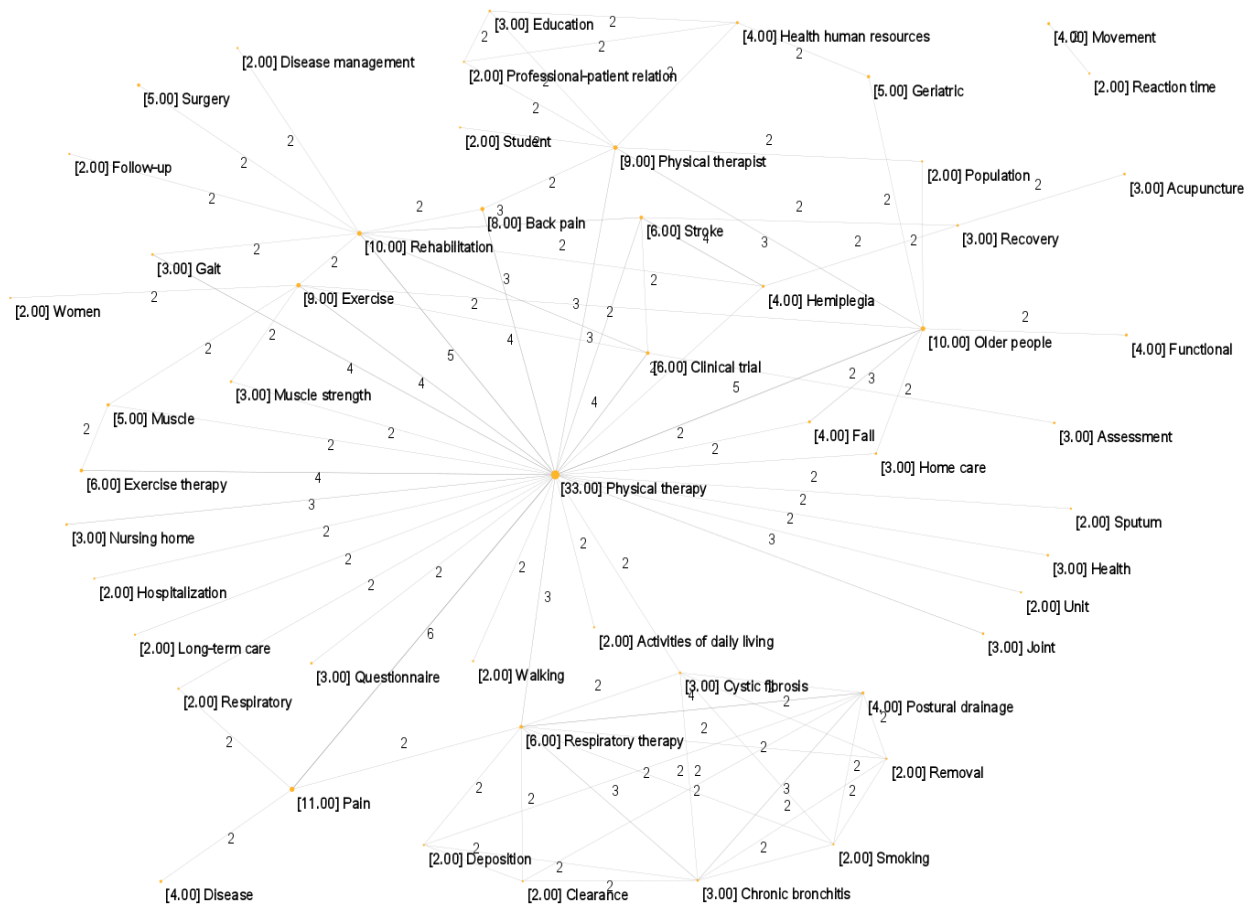
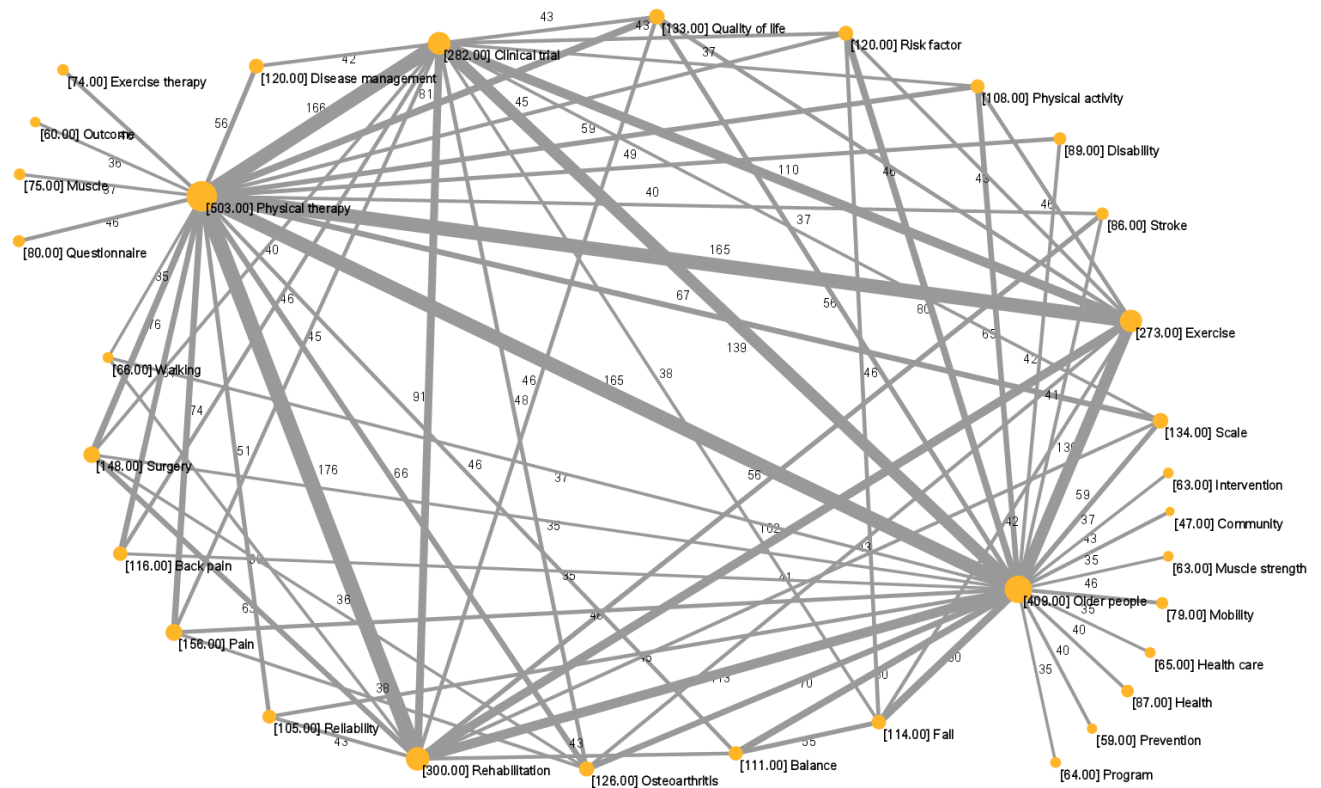


Figure 1. PRISMA 2009 flow diagram



The size and the numeric label of a node represent the number of articles that studied each keyword. The thickness and the numeric label of a line represent the number of articles that studied the 2 linked keywords.

Figure 2. Graphic representation of the co-occurrence of keywords in the 1st quinquennium, 1990–1994 (> 2 articles)



The size and the numeric label of a node represent the number of articles that studied each keyword. The thickness and the numeric label of a line represent the number of articles that studied the 2 linked keywords.

Figure 3. Graphic representation of the co-occurrence of keywords in the last quinquennium, 2010–2014 (> 35 articles)

Table 1. Quinquennium distribution of publications and citations, and the *h*-index of highly productive authors

Authors*	1990–1994		1995–1999		2000–2004		2005–2009		2010–2014		Total		<i>h</i> -index
	P	C	P	C	P	C	P	C	P	C	P	C	
Fritz JM	0	–	0	–	3	480	15	795	5	30	23	1305	25
Cleland JA	0	–	0	–	0	–	11	294	8	76	19	370	29
Hay EM	0	–	0	–	1	9	11	431	6	49	18	489	20
Lord SR	0	–	2	108	4	692	2	104	8	49	16	953	35
Bennell KL	0	–	0	–	1	49	2	41	11	95	14	185	27
Sherrington C	0	–	2	108	2	94	3	118	6	42	13	362	24
Brennan GP	0	–	0	–	0	–	8	404	4	18	12	422	13
De Bie RA	0	–	0	–	1	29	4	48	7	78	12	155	21
Foster NE	0	–	0	–	1	9	6	211	5	26	12	246	23
Morris ME	0	–	1	95	4	175	3	24	4	61	12	355	22
Haines TP	0	–	0	–	0	–	5	87	5	37	10	124	2
Hill KD	0	–	0	–	1	38	1	7	8	84	10	129	19
Vicenzino B	0	–	1	123	1	73	4	207	4	74	10	477	35
Whitman JM	0	–	0	–	2	54	6	210	2	12	10	276	17

P – number of publications, C – number of citations
 * Authors are shown by productivity order.

Main authors and their impact

A total of 8486 authors were identified and accumulated 10,582 signatures. The number of publishing authors increased from 263 in 1990–1994 to 4716 in 2010–2014. The average number of signatures per article also increased: from 4.07 (*SD* = 1.14) in the first 5 years to 5.14 (*SD* = 0.34) in the last period.

PI allowed us to identify the number of authors for each productivity level: 14 (0.16%) were high producers, 1157 (13.63%) were medium producers, and 7315 (86.20%) were low producers. High producers (Table 1) published 191 articles (8.54% of the total number), with the most productive author being Fritz JM from University of Utah (United States), followed by Cleland JA of Franklin Pierce University (United States) and Hay EM from Keele University (United Kingdom).

For high producers, the most productive period was 2010–2014 (43.46% of publications), followed by 2005–2009 (42.40%). Only 4 authors published in 4 consecutive quinquennia: Lord SR, Sherrington C, Morris ME, and Vicenzino B, all affiliated to Australian universities.

Regarding citation, they accumulated a total of 5848 citations in 191 articles, with an average of 28.77 citations per article. Fritz JM, the most productive author, was also the most cited; she began to publish in this area in the period 2000–2004, and with only 3 articles she received 480 citations. This phenomenon was also observed with other authors, such as Lord SR, Sherrington C, Morris ME, and Vicenzino B, who, with their first publications in the 2nd or 3rd quinquennium, despite a reduction (1 to 4 articles), received more than 100 citations. As for the *h*-index, all the highly productive authors exhibited a value above 10, except Haines TP.

Pearson’s coefficient showed a positive and low correlation, although significant ($r = 0.38, p < 0.01, r^2 = 0.14$), between authors’ productivity and citation.

Institutions productivity and impact

A total of 2164 institutions were identified from 63 different countries and they accumulated a total of 5156 institutional signatures. The number of publishing institutions increased from 97 (1990–1994) to 2046 (2010–2014). In 38.31% of the articles, only a single institution signed, while in 53.24%, 2, 3, or 4 institutions collaborated in the same article. Only in 8.45% of the cases, 5–17 institutions collaborated.

The PI of the institutions revealed 79 (3.65%) high producers, 651 (30.08%) medium producers, and 1434 (66.27%) small producers. The 5 most productive institutions were: the University of Sydney, University of Queensland, University of Melbourne, University of Washington, and University of Toronto; all of them increased the publications in the 25 studied years (Figure 4).

With regard to citation, a total of 116,183 cites distributed in 1826 institutions (84.38%) were accumulated. The most cited institution was the University of Pittsburgh (United States), with 2140 citations, followed by Lund University (Sweden), with 1994 citations, and University of Washington (United States), with 1336 citations. The 5 most productive institutions were among the 20 most cited ones.

Pearson’s coefficient showed a high and significant positive correlation between institutions’ productivity and their citation ($r = 0.73, p < 0.01, r^2 = 0.53$).

Country productivity and impact

A total of 63 different countries were identified and accumulated 2584 signatures. The number of countries increased by an average of 17.86% (*SD* = 18.66), from 18 in 1990–1994 to 63 in 2010–2014.

There were 30 (47.62%) highly productive countries ($PI \geq 1$), 20 (31.75%) medium producers ($0 < PI < 1$), and 13 (20.63%) small producers ($PI = 0$). The 5 most productive countries were the United States (621 publications), the

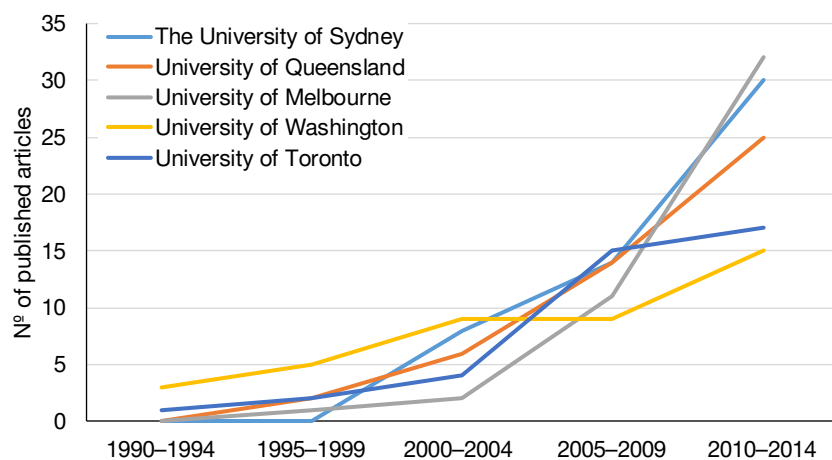


Figure 4. Evolution of publications of the 5 most productive institutions in the 25 studied years

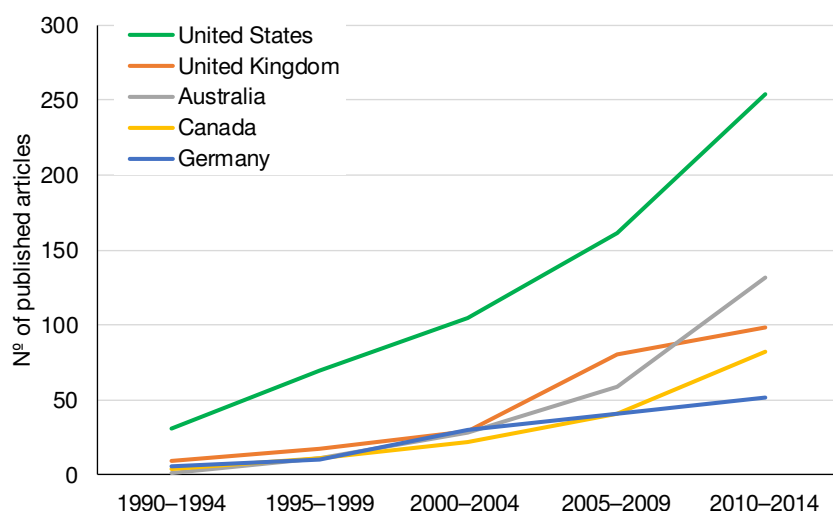


Figure 5. Evolution of publications of the 5 most productive countries in the 25 studied years

United Kingdom (233), Australia (231), Canada (160), and Germany (139). The productivity evolution of these 5 countries showed that in the 1st quinquennium, they published less than 35 articles, while in the last one, they all exceed 50 publications, with the United States even reaching 250 (Figure 5). Among these 5 countries, Australia experienced the highest percentage growth through the 25 studied years (56.70%).

In the highly productive countries, productivity related to the ageing of their population (Table 2) shows Sweden in first position, followed by Australia, Denmark, Norway, and Israel. The correlation between productivity and aged population was positive but very low and not significant ($r = 0.01$, $p > 0.01$, $r^2 = 0.00$).

Productivity as related to GDP was also led by Sweden, followed by Australia, New Zealand, Finland, and the Netherlands. The correlation between productivity and GDP was positive, high, and significant ($r = 0.70$, $p < 0.01$, $r^2 = 0.48$).

The 30 most productive countries accumulated a total of 58,958 citations, with the 3 most productive countries also being the most cited, in the same order. In fact, the correlation between productivity and country citation was positive and very high, almost perfect, and significant ($r = 0.97$, $p < 0.01$, $r^2 = 0.94$).

Discussion

The present bibliometric study allowed us to obtain a scientific description of PT research in ageing worldwide during the period 1990–2014. Interesting data have been obtained related to the change of the topic paradigm, from initial ar-

ticles focused on pathology to more recent studies concentrated on prevention. Quantitative and qualitative data of the activity of researchers and institutions have also been obtained, revealing an increase in production and citation in both cases, with positive and significant correlations between these aspects. Finally, it has been found that the United States had the lead in terms of absolute productivity and citation, followed by other developed countries, such as the United Kingdom and Australia.

To our best knowledge, this is the first study to analyse bibliometric data of PT in ageing. Although there is currently a growing interest in this subject, there are still few bibliometric studies that focused on PT [10, 11], and none of them analysed the specialty of ageing. In addition, not many PT bibliometric studies have investigated trends during periods of at least 25 years [10, 14–16] or have analysed more than 2000 PT articles [14, 45–47]. Moreover, few studies have used keywords analysis in order to determine associations of the topics [23, 48].

Bibliometric analysis allows to examine scientific literature and describe publication trends [49–51]. Previous studies show an increase of publications on ageing in WoS, from 2300 articles in 1989 to 16,000 in 2009 and to more than 56,000 in 2015 [52, 53]. Our study provides data on the increase in publications related to PT in ageing, as well as the productivity increase per quinquennia. For authors, institutions, and countries, this increase was more evident from the 2000–2004 quinquennium onwards, which concurs with the beginning in 2002 of the ‘Research agenda on aging for the 21st century’ of the International Association of Gerontology

Table 2. Highly productive countries' productivity in relation to number of inhabitants older than 60 years and GDP

Country*	No. of articles	Millions of people aged 60 or more**	Articles per million people aged 60 or more	Position: articles/aged population	GDP 2018***
United States	621	66	9.41	16	20412
United Kingdom	233	15	15.53	12	2936
Australia	231	5	46.20	2	1500
Canada	160	8	20	10	1798
Germany	139	22	6.32	17	4211
Brazil	137	24	5.71	18	2138
Netherlands	115	4	28.75	7	945
Sweden	105	2	52.50	1	600
Turkey	87	9	9.67	15	909
Italy	63	17	3.71	21	2181
France	59	16	3.69	22	2925
Switzerland	52	2	26	8	741
Spain	47	11	4.27	20	1506
Denmark	43	1	43	3	369
Belgium	42	3	14	13	562
Japan	39	42	0.93	29	5167
Norway	36	1	36	4	443
Finland	36	2	18	11	289
Israel	31	1	31	5	373
New Zealand	29	1	29	6	220
Poland	28	9	3.11	23	614
Ireland	24	1	24	9	385
China	24	209	0.11	28	14092
Taiwan	23	209	0.11	28	613
South Korea	21	9	2.33	24	1693
Austria	21	2	10.50	14	477
Iran	12	7	1.71	25	418
Thailand	12	11	1.09	26	483
India	11	117	0.09	27	2848
Saudi Arabia	10	2	5	19	748

GDP – gross domestic product

* Countries are shown by productivity order.

** Source: Global Age Watch Index 2015. Available from: <http://www.helpage.org/global-agewatch/> [20.11.2016]

*** Source: International Monetary Fund. World Economic Outlook database. Available from: <http://www.imf.org/external/pubs/ft/weo/2015/01/weodata/index.aspx> [20.11.2016]

and Geriatrics and the United Nations Programme on Aging of 2007 [54]. Therefore, the productivity trends show that the agenda was a unique initiative worldwide, which contributed to the direction and priorities of scientific gerontology [53].

Moreover, this continuous increase of research in PT in ageing has important implications at both clinical and academic levels, since it facilitates decision making concerning the treatment of patients [10]. Precisely, our results indicate a change in the paradigm of the scientific study of the treatment of ageing. The keyword bibliometric analysis in the 1st

quinquennia showed words related with chronic diseases and disability among the elderly. Therefore, much of the initial focus was on the determinants of mortality, illness, and disability, as observed with other health professions [55]. However, the fact that elder people may have a successful ageing has transformed the study of ageing from a discipline concentrated on disease and decline to one emphasizing health and growth [56]. This is in line with recent studies analysing the need for medical and nonmedical services among the elderly through FIMA, a questionnaire for health-related

resource use [57, 58]. Standardized instruments like the FIMA questionnaire plus the results of the present study, which show prevention as a key instrument, may help clinicians understand the trends of health demands of the ageing population and therefore improve patient satisfaction with their care.

Our study reports some important associations of PT with exercise, prevention, and movement, especially from the 2000–2004 quinquennium onwards. The change of the scientific perspective concurs with the active ageing definition publication by the World Health Organization in 2002. The definition refers to active ageing as the generation of healthy lifestyles, which are multidimensional and promote health but also prevent frailty and provide longevity and a good functional status [59]. Therefore, in the last quinquennium, there was a superabundance of terms and co-occurrences among keywords implying the prevention of diseases and disorders of the elderly and the improvement of their quality of life. In fact, there are recent studies that focus on how to prevent age-related physical fitness decline even in the aged working population. Representatives of certain professions, such as police officers, need minimum physical standards to perform their jobs and, therefore, a regular training programme is required as they get older [60]. The productivity trends shown in our study highlight the fact that clinicians have more evidence on which to base their decisions when preventing age-related physical changes.

On the other hand, links with keywords such as fall, stroke, osteoarthritis, or surgery ascertain that, as in other geriatric studies [61], research on PT in ageing is also related to aspects of the most common pathologies among the elderly, such as cerebrovascular disease, arthritis, or coronary artery disease [62].

From the 2nd quinquennium (1995–1999) onwards, keywords related to scientific research, such as clinical trial, scale, reliability, follow-up, or outcome, were consolidating and increasing. This reveals a greater interest of PT in ageing towards research [39] and concurs with the rise of the concept of evidence-based practice in the early 1990s, marked by the founding of the Cochrane Collaboration in 1993. Moreover, our results show that research methods evolved toward higher designs. As Wiles et al. [23] highlight in their study, this research evolution is necessary to underpin treatment decision making, which subsequently informs the provision of effective and resource-efficient health services.

Regarding authors and institutions, our results facilitate, on the one hand, choosing, on the basis of science, where to focus both human and financial resources [31, 63]; on the other hand, they may improve contact and promotion of research groups so that innovative projects can be developed based on interdisciplinary collaboration agreements [64, 65]. In fact, authors' collaboration has improved since there was an increase in the number of signatures per article, which indicates an increase of researchers' participation. This reflects the complexity of and effort involved in integrating the different approaches to the study of ageing. Consequently, there are authors who point out the need for broadening the collaboration of professionals who investigate ageing, thus creating the conditions for multidisciplinary research as a guarantee of future progress [66].

Identifying the main authors of the area is important if one considers that scientific publications become the best presentation of a scientist and allow to obtain a series of advantages, such as promotions, improvement in the academic positions, or prestige [67]. By using Lotka's PI, the 14 highly productive authors of the area have been identified. All of them exhibited increasing productivity percentages throughout the studied

period, which indicates that they are consolidated authors in the area. However, a high transience has also been shown since 86.20% are 'occasional authors,' who only produced an article within the 25 studied years. This aspect has also been observed in other biomedicine studies, which have presented transience indexes above 70% [68].

In terms of impact, the most productive author is also the most cited one, accumulating the highest number of citations in the period of 2005–2009, as in previous bibliometric studies on PT [21, 22]. Therefore, she is a consolidated author in the area of PT in general and in ageing in particular.

The fact that authors present a low correlation between productivity and citation indicates that they did not adjust to the consideration that for a certain number of published articles they received n citations [69]. However, it does explain that some authors received a high number of citations with few publications. Moreover, since research is a multidimensional process, the h -index was also analysed to evaluate the researchers' impact. The h -index tends to penalize authors who prioritize quality over quantity [44]. Nevertheless, this has not been observed, since the highly productive authors published a large number of documents and also their contributions exhibited much relevance.

In relation to institutions, there is a high percentage of articles with only one signing institution, while in smaller percentages, 2, 3, or 4 institutions collaborated. This could indicate that the research in PT in ageing is not usually of a multicentre type, although a more exhaustive analysis through collaborative networks will be addressed in future lines of investigation.

The 5 most productive institutions were all universities and were included in the Academic Ranking of World Universities (ARWU) 2018. As Wiles et al. [23] point out, productivity in PT has changed since 1945, when only 22.2% of the author affiliations were to educational or research institutions: in 2010, the percentage of this type of institution equalled 69.6%. Taking into account this general evolution of PT, our results, and the arousing interest of universities and governments throughout the world on ARWU, the increase in the quality of PT publications on ageing is evident.

With reference to countries, in absolute terms, scientific production was led by the United States and followed the pattern of other ageing studies [53] and other bibliometric studies of different scientific areas [36, 37]. In terms of productivity, the United States were followed by other developed countries, such as the United Kingdom, Australia, Canada, or Germany, as in other biomedicine or health sciences bibliometric studies [70, 71]. All of these countries are well represented and consolidated in WCPT [23], which promotes and supports PT research.

Australia was among the 3 most productive countries, both in absolute terms and in relation to GDP and the ageing population, and it was the country of the 3 most productive institutions. In 2001, the Ministry for Ageing of Australia established a series of lines of action for ageing. These included more research in order to guide policies development, establish priorities for future action, and evaluate the impact of policies, programmes, and services, guiding individual and social action, with special emphasis on research related to healthy ageing [72]. This fact makes it clear that research support from governmental policies is very important for high quality scientific productivity.

Some authors point out that the demographic change that ageing implies is a planetary process that has not yet finished because ageing is not homogeneous in all countries [73, 74]. Moreover, in many developed and developing countries,

PT is underfunded, underestimated, and understaffed [75]. Therefore, global, advanced, diversified and specialized research on ageing in all developing countries is encouraged [54]. Despite these worldwide guidelines to increase research on ageing both in developed and developing countries, our results show a significant and positive correlation between GDP and scientific productivity ($p < 0.01$). This implies higher productivity of countries with a wealthier position [70, 71], and thus developed countries are consolidated as ones with influence and repercussion of PT in ageing research.

On the other hand, productivity in relation to population ageing shows that Sweden was the country in the first position. Sweden was among the first nations to experience a rapid ageing of the population [76] and therefore it has a longer history in gerontological research when compared with other countries [77]. The United States, United Kingdom, Canada, or Germany, with an outstanding situation in absolute productivity terms, had a lower position in productivity related to their populations' ageing. In fact, the correlation between productivity and population ageing is very low ($p > 0.01$) and thus Japan, the country with the highest proportion of the population over 65 years and with higher life expectancy [78], does not appear among the 10 most productive or most cited, although this may also be due to a linguistic bias [71].

Regarding institutions and countries citations, they were both led by the United States. Considering that in the United States, the granting of subsidies to institutions is based on the evaluation of results and number of citations of their publications [79–81], this may be explained. Moreover, the correlation between productivity and citation for both institutions and countries was positive, significant, and high or very high, respectively. That is, as institutions and countries become more productive, the number of citations increases, aspect that can encourage PT researchers in ageing to collaborate with certain institutions.

Limitations

The current study is not exempt from limitations: (a) Only choosing the SCI-E of WoS Core Collection database restricted the inclusion of journals indexed elsewhere. (b) Furthermore, there were often problems of quality in the bibliographic data. These issues are important when analysing authorship, either because the authors themselves do not always sign the papers in the same way or because of errors at the time of processing the information. To minimize this problem, a careful manual check was carried out to unify different variations in the names of particular authors or institutions.

Given that ageing is related to social aspects, one of the future lines of research is to expand the search in the Social Sciences Citation Index. It would also be interesting to analyse other databases, such as Scopus or PEDro.

Conclusions

The findings of this bibliometric study show an exponential increase in productivity of PT in ageing research over the period 1990–2014, which indicates the consolidation of the discipline. Initially, topics were related to the treatment of pathologies, while at the end of the 25-year period, trends reveal a change of paradigm, with articles focused on prevention and quality of life improvement in the aged population. Publishing authors and institutions of the area increased, as well as their citation and impact. As for the countries, the United States were the leader in terms of absolute produc-

tivity, Australia had 3 of the main publishing institutions, and Sweden was the most productive in relation to ageing of the population and also to GDP. Moreover, the correlation analysis of the bibliometric and socioeconomic indicators has demonstrated a significant relationship between productivity and the wealth of the countries, but not between productivity and the ageing of their populations.

All this information makes it possible to clearly observe the evolution of scientific research and to consider where to aim in future studies, on the basis of the concerns and deficiencies of the profession. Describing the publication patterns of PT in ageing over the presented 25-year period allows inferences about the evolution of this speciality.

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Conflict of interest

The authors state no conflict of interest.

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Appendix 1

The final search strategy was as follows:

((“Physical Therap*”) OR (Physiotherap*) OR ((“Physical Therap*” OR Physiotherap*) AND (Modalities OR Specialty OR Assistants))) AND ((Aging OR ageing OR elder* OR Aged OR “grey-headed” OR senior OR senil* OR “old age” OR “old adult” OR “older adults” OR frailty OR “frail elderly” OR geriatric OR pensioner OR “retired person” OR senescence OR gerontology) NOT (pediatric OR child* OR infancy OR adolescen* OR “young adult” OR teen* OR juvenile OR youth*)) AND (((Musculoskeletal OR chiropractic OR vertebral OR spinal OR osteopathic) AND Manipulations) OR (postural AND (control OR balance)) OR ((exercise OR music OR respiratory OR acupuncture OR (“Electric Stimulation”) OR (“Animal Assisted”) OR myofascial OR (“soft tissue”) OR (“articulatory manual”) OR manual OR aquatic) AND therapy) OR (exercise AND (test OR (“movement techniques”) OR breathing OR aerobic OR program OR (“muscle stretching”)) OR (“Integumentary System”) OR (((“Public Health Profes-

sional”) OR Graduate OR Continuing OR Health) AND Education) OR (Research) OR (“Clinical Protocols”) OR (Practice AND (Professional OR Guideline OR Evidence-Based OR (“Public Health”))) OR (Health AND (Policy OR Promotion OR (“National Programs”))) OR (Acupuncture) OR (“Hot Temperature”) OR (Cryotherapy) OR (“Physical Fitness”) OR ((Gait OR Functional OR strength OR balance OR resistance OR endurance) AND training) OR (Hydrotherapy) OR ((Ortho*) AND (procedures OR devices)) OR (“Motor Skills”) OR (Sports) OR (“Range Motion, Articular”) OR (“Wound Healing”) OR (Balneology) OR (“Hyperthermia, Induced”) OR (“alternative and complementary medicine”) OR (bio-feedback) OR (Massage) OR ((cardiac OR pulmonary OR neurological) AND rehabilitation) OR (home AND (program OR exercises)) OR (mobilization) OR (electrotherapy) OR (hydrotherapy) OR (osteopathy) OR (Stretching) OR (“Trunk muscle strength”)))