

Physical activity and aging research: A bibliometric analysis

Andre Matthias Müller (M.A.)¹, Payam Ansari (M.A.)¹, Nader Ale Ebrahim (PhD)², and
Selina Khoo (PhD)¹

¹Sports Centre, University of Malaya, Kuala Lumpur, Malaysia

²Research Support Unit, Centre for Research Services, University of Malaya, Kuala Lumpur,
Malaysia

Email for correspondence:

André Matthias Müller, M.A.

Email: andrematthiasmueller@gmail.com

Abstract

Physical activity and aging research has burgeoned in the past few decades. Despite the increase in scholarly publications no attempts have been made to summarize the publication landscape and to identify works that had great impact to physical activity and aging research. We conducted a bibliometric analysis and collected publication data from 1980 to February 6, 2015 in the Web of Science Core Collection. Of the overall 9,935 publications most were published after 2007 and almost 60% were in the category of Geriatrics and Gerontology or Sport Sciences. Highly cited publications ($n = 45$) were mostly authored by researchers from US institutions and were quantitative in nature. Publications that reported on the associations or effects of physical activity on health in older adults made up 60% of the highly cited publications. We expect more scholars from various backgrounds and geographical regions to join the conversation on physical activity and aging.

Keywords: aging, bibliometrics, citation analysis, citation patterns, exercise, health, older adults, scientific publications

The world is aging at a rapid pace and it is predicted that by the year 2050, about 2 billion people, accounting for 20% of the global population, will be 60 years or older (United Nations, Department of Economic and Social Affairs, 2012). One of the most important non-pharmaceutical ways towards healthy aging is physical activity (PA) (Chodzko-Zajko, Proctor, Singh, Salem, & Skinner, 2009; Södergren, 2013; Vogel et al., 2009). One of the first journal articles describing the positive effects of PA on health was published in 1953, (Morris, Heady, Raffle, Roberts, & Parks, 1953), but it was only in the 1970s and 1980s that publications on PA and aging started to emerge (Spirduso, 1975; Morris, Vaccaro, & Harris, 1983). For example, a study conducted by Morris and colleagues reported on the changes in quality of life in older adults who do PA (Morris, Vaccaro, & Harris, 1983). Hence, PA and aging research has a relatively short history (Berryman, 2010). Initially, PA and aging research mainly focused on the effects of PA (especially exercise) (Paffenbarger, Hyde, Wing, & Hsieh, 1986; Wagner, 1992) and PA predictors as well as barriers (Duda & Tappe, 1988). During the 1990s, research evolved and concentrated mainly on measuring PA in older adults (Kuhn, Fried, & Allen, 1992; Nichols, Patterson, & Early, 1992). The Physical Activity Scale for the Elderly (PASE) by Washburn, Smith, Jette, and Janney (1993) was the first valid and reliable instrument to measure PA in older adults. With the publication of PA guidelines for older adults (Nelson et al., 2007; World Health Organization, 2010) and the emerging evidence of the benefits of PA, recent studies have focused primarily on interventional research (King, 2001; Chase, 2015).

Although the field of PA and aging has produced a great number of publications, there have been few attempts to gather bibliometric data in a systematic manner to identify research trends and highlight publications which have impacted the development of the field. There has only been one bibliometric study in a related field, namely, sport and exercise science. However, it merely focused on abstracts published in *Research Quarterly for*

Exercise and Sport between 1992 and 2011 with no information on PA (Cardinal & Lee, 2013).

Traditionally, the field of bibliometrics is concerned with the analysis of citation indices in order to identify highly cited authors, publications and the most productive countries as well as institutions. This information is crucial because it highlights those who drive the trend in a research field and provides information on what is topical (Eshraghi et al., 2013). Bibliometric studies have been widely applied in a variety of other research areas and provided valuable insights (Eshraghi et al., 2013; Ho, 2014; Tian, Wen, & Hong, 2008).

One of the most popular bibliometric measures is the citation index introduced by Garfield in 1955 (Garfield, 1955). The citation index traces references in a published article and shows how many times a publication has been cited by other publications (Garfield & Merton, 1979). Although the citation frequency of a publication is a measure of its impact, it is not necessarily an indicator of quality (Brandt, Downing, Howard, Kofinas, & Chasen, 2010). Evidently, citation count alone is not sufficient in judging the quality of a scientific publication, particularly when there are numerous mechanisms to increase the citation count of a publication (Bornmann, Leydesdorff, & Wang, 2014). On the other hand, the citation count remains a main indicator of the significance of research output rather than alternative metrics (Priem, 2013; Shotton, O'Steen, Dutton, Peroni, & Gray, 2013). However, by eliminating the effect of article lifetime that increases the opportunity of increasing citations, the citation per year metric reflects the quality of an article better than the total citation frequency (Chuang, Wang, & Ho, 2011). Recognizing that a pure analysis of citation quantity by author, institution and country is not sufficient to identify research trends, the current paper also attempts to analyze the content of PA and aging research by providing analysis of the topics covered in highly cited articles.

With this, the purpose of this paper is to bibliometrically analyze the publications registered in the Web of Science (WoS) Core Collection on PA and aging from 1980 until February 6, 2015 and to also provide an overview of the highly cited articles.

Methods

The bibliometric data for this paper were derived from WoS Core Collection citation indexes databases on February 6, 2015. Prior to data collection we circulated a survey to 20 researchers in the field of PA and/or aging. In this survey respondents were asked to indicate search terms they would use to retrieve publications on PA and aging. For the search category PA, we searched titles in published articles using the following search terms that were combined with the Boolean Operator “OR”: “physical activit*”, “exercise*”, “walk*”, “fitness”, “aerobic”, “active living”, “active commuting”, “physical fit*”, “physical training”, “sport*”, “master athlete”, “active transport*” and “leisure activit*”. This search yielded 240,610 citations. We further refined the search by excluding the following search terms using the Boolean Operator “NOT”: “adolescen*”, “young”, “youth”, “school”, “kid”, “child*”, “kindergarten” and “middle-aged”. With this, we reduced the citations to 215,222.

In order to retrieve publications that specifically focused on older adults, we refined our search with the following search terms (in title, abstract or keywords of articles) that were combined with the Boolean Operator “OR”: “older adult*”, “pensioner*”, “retiree*”, “senior*”, “elder*”, “older person*”, “older people”, “aging”, “aged”, “mature adult*”, “aging population*”, and “geriatric*”. This refinement led to 9,935 publications being included in the current research. Data of these articles were downloaded to Microsoft Excel. Highly cited publications were selected according to the Essential Science Indicators (ESI). This indicator highlights publications that are ranked within the top 1% of the citations list over the past 10 years (Bornmann, Mutz, Marx, Schier, & Daniel, 2011). To determine which papers are highly cited, an annual threshold per field is established in WoS.

For the overall publication sample, we explored the publication output over time and described some characteristics (e.g., publication category, institutions and authors with the highest publication output, and journals that published most articles). For highly cited publications, we calculated the citations per year by dividing the total citations of a paper (citation count) by the number of years since publication. We used this citation rate in our analysis. The citation rate is a more accurate and reliable measure of the impact of a research paper compared to the citations count because the latter depend on time of publication (Chuang et. al., 2011; Ho, 2014). From this analysis, we identified the top five papers in PA and aging research. We also described other characteristics of these highly cited papers such as journals publishing the highly cited papers and most prolific authors of highly cited papers. Additionally, the publications were categorized based on type, namely cross-sectional, experimental, review/meta-analysis, longitudinal, position paper/recommendation, and validation/reliability studies. Finally, we categorized the publications according to study focus, e.g., associations/effects of PA with health related outcomes, PA levels, and PA promotion.

Results

Overall Trend

The systematic search identified 9,935 citations published between 1980 and February 6, 2015. The majority of published items were published in the English language (96%) and appeared as journal articles (55.5%). However, 33% of the publications were published as a meeting abstract. Figure 1 displays the steady increase of publications over time with the most items published in 2012 ($n = 972$). About one-third of the publications were in the Geriatrics and Gerontology category (30.1%), with a substantial number of publications in Sport Sciences (27.5%) and Psychology (7.6%) as the second and third most represented publication categories, respectively.

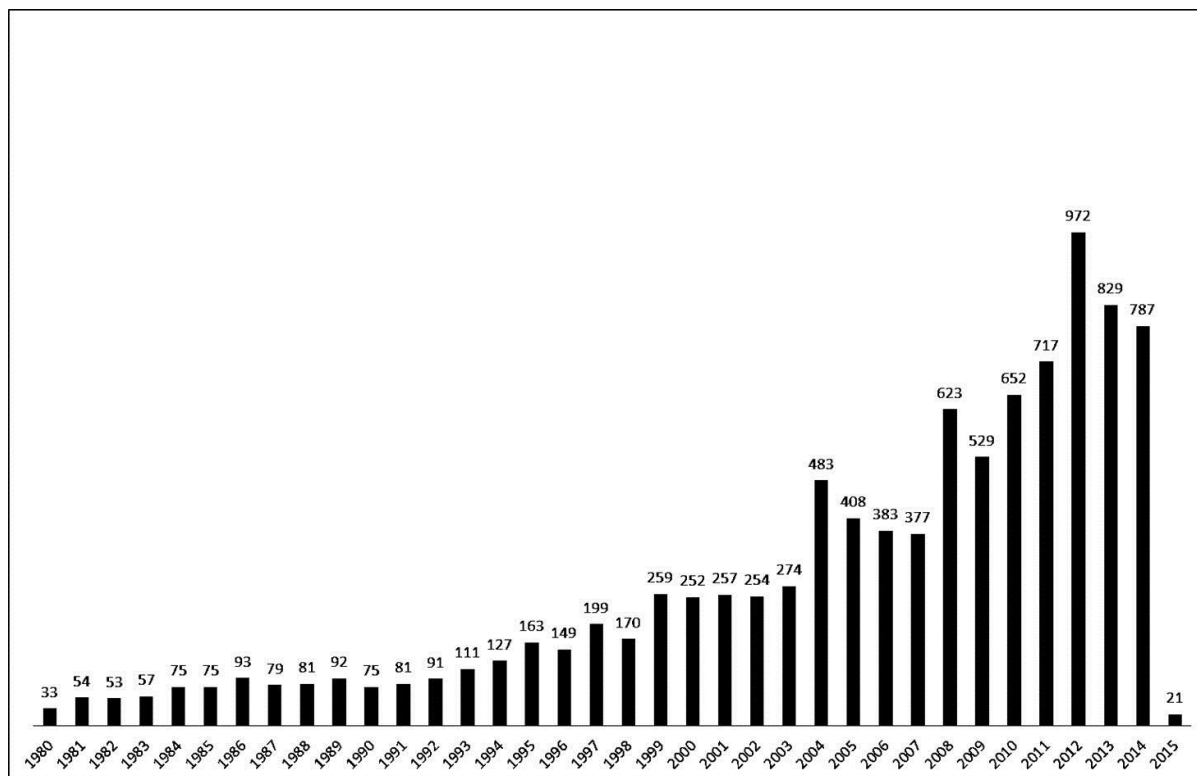


Figure 1. Publication output in PA and aging between 1980 and February 6, 2015.

Among the top 10 institutions in terms of publication output, 9 are based in the United States (US) with the University of Illinois (2.7%), the University of Pittsburgh (1.7%) and Wake Forest University (1.7%) publishing the most items. The University of Tsukuba from Japan (1.2%) was the only institution among the top 10 that is not based in the US.

A total of 25,544 authors contributed to the 9,935 publications, with a publication authored by an average of 2.47 authors. Several authors contributed to more than 50 publications of the overall body of literature with E McAuley, AC King and DR Seals contributing to 107 (1.1%), 81 (0.82%) and 66 (0.65%) publications, respectively. The most publications were published in the *Journal of Aging and Physical Activity* (7.62%, $n = 757$). The *Journal of Medicine and Science in Sport and Exercise* (7.35%, $n = 730$) and *The Gerontologist* (4.85%, $n = 482$) published the second and third most articles, respectively.

Of the total 9,935 publications, over 35% ($n = 3,489$) did not receive any citations, whereas 7.8% ($n = 771$) publications received less than 10 citations and more than half of the publications (57.1%, $n = 5,675$) received more than 10 citations.

Highly Cited Publication

We obtained 45 highly cited papers from the search. Highly cited publications for the year 2014 were published between 2004 and 2014, with a citation rate between 5.50 and 78.13 (21.18 ± 17.01 citations per annum). Combined, these publications received 6,758 citations (2.92% of the overall citations received by all 9,935 publications).

A 2007 paper providing PA recommendations for older adults received the highest number of citations (625) and the highest number of citations per year/citation rate (78.13) (Nelson et al., 2007). Table 1 displays the top 5 publications in the field of PA and aging research based on the conducted search (the remaining 40 publications are listed in the supplementary material).

Table 1

The Top five Publications in PA and Aging Research

Times Cited	Citation Rate	Title
625	78.13	Nelson, M. E., Rejeski, W. J., Blair, S. N., Duncan, P. W., Judge, J. O., King, A. C., ... & Castaneda-Sceppa, C. (2007). Physical activity and public health in older adults: Recommendation from the American College of Sports Medicine and the American Heart Association. <i>Medicine and Science in Sports and Exercise</i> , 116(9), 1094-1105.
456	76.0	Chodzko-Zajko W. J., Proctor, D. N., Singh, M. A. F., Salem, G. J., & Skinner, J. S. (2009). Position Stand. Exercise and physical activity for

-
- older adults. *Medicine and Science in Sports and Exercise*, 41(7), 1510–1530.
- 396 56.57 Lautenschlager, N. T., Cox, K. L., Flicker, L., Foster, J. K., van Bockxmeer, F. M., Xiao, J.;... & Almeida, O. P. (2008). Effect of physical activity on cognitive function in older adults at risk for Alzheimer disease: a randomized trial. *Journal of the American Medical Association*, 300(9), 1027-1037.
- 411 45.67 Larson, E. B., Wang, L., Bowen, J. D., McCormick, W.C., Teri, L., Crane, P., & Kukull, W. (2006). Exercise is associated with reduced risk for incident dementia among persons 65 years of age and older. *Annals of Internal Medicine*, 144(2), 73-81.
- 408 45.33 Colcombe, S. J., Erickson, K. I., Scalf, P. E., Kim, J. S., Prakash, R.; McAuley, E., ... & Kramer, A. F. (2006). Aerobic exercise training increases brain volume in aging humans. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 61(11), 1166-1170.
-

Three journals published 31% of the top cited articles, with the Journal of American Geriatrics Society publishing 8 articles that received a total of 667 citations ($M = 83.38$ citations per article) and 11.42 citations per annum. This journal received 9.9% of the total citations within the highly cited papers. Preventive Medicine and the Journal of the American Medical Associations published 3 articles each with 12.25 and 36.01 citations per year, respectively.

Authors and countries of origin (corresponding authors). AC King contributed most to the highly cited publications in the area of PA and aging research (6 publications)

followed by 3 authors with 4 publications each. Table 2 displays the total citations received and the citation rate of the top 4 authors.

Table 2

The Top four Authors of the Highly Cited Publications

Author's Name	Number of Publications	Citations	Mean Citation rate ¹
King, A. C.	6	1,041	24.65
Pahor, M.	4	859	21.76
Kritchevsky, S. B.	4	619	16.30
Frank, L. D.	4	190	11.10

¹ Mean citation rate per publication

The corresponding authors of the 45 highly cited publications were from 11 countries, with authors based in the US responsible for most of the papers ($n = 27$) followed by authors based in Canada with 6 publications.

Research type and focus of research. Publications reporting on cross-sectional ($n = 16$), experimental ($n = 14$) and systematic review/meta-analysis studies ($n = 9$) made up 87% of the highly cited publications. None of the publications used a qualitative approach. In terms of research focus, most research explored associations and/or effects of PA, exercise and/or fitness on health-related outcomes ($n = 27$). The highly cited publications were also frequently concerned with factors associated with participation in PA and exercise ($n = 10$). Table 3 displays the research fields covered by the highly cited papers.

Table 3

Research Fields of the Highly Cited Publications

Field	Papers	Mean Citation Rate ¹
Effects/Associations of PA/exercise/fitness with health related outcomes	27	24.30
Factors associated with PA participation	10	12.85
PA measurement	3	9.86
PA levels	2	6.25
PA promotion (interventions)	1	25.44
Recommendations for PA	1	78.13
Effect of X on PA and fitness	1	22.50

¹ Mean citation rate per publication

Discussion

PA and aging research is a field that has recently attracted increased attention. The bibliometric analysis presented in this paper adds value to the existing body of literature because it provides an overview of the overall publication landscape and informs the scientific community about the publications that had the most impact on PA and aging research (Chuang et al., 2011).

The publication output increased steadily over time, with a steep increase from 2008 and peak in 2012 where almost 1,000 scholarly works were published. This development coincides with the increased scientific recognition of the various health benefits of a variety of PAs in older adulthood (Keogh, Kilding, Pidgeon, Ashley, & Gillis, 2009; Paterson, Jones, & Rice, 2007; Taylor et al., 2004) and the publication of two influential works providing detailed PA recommendations for older adults (Nelson et al., 2007; World Health Organization, 2010). Further, not only has the amount of publications greatly increased over

time but researchers from various fields have entered the conversation allowing the field to mature. While the benefits of PA as well as the type, intensity, and frequency of PA are a primary concern of medical professionals (especially geriatricians and gerontologists) and sport scientists, health psychologists provide valuable insights on how to promote PA participation among older adults (Hobbs et al., 2013; McAuley et al., 2011; McAuley, Jerome, Elavsky, Marquez, & Ramsey, 2003).

Although scholars from a number of different fields are contributing to the PA and aging research, there appears to be a regional dominance in terms of publication output with most publications coming from North American institutions, especially the US. The strong influence of US institutions in other fields of research has been previously reported (Eshraghi et al., 2013; Shadgan, Roig, HajGhanbari, & Reid, 2010). This is mainly due to funding opportunities and a great number of well-trained scientists in the US. Furthermore, approximately one-third (33.5%, $n = 2,894$) of journals indexed in Thomson Reuters' WoS under the science edition are based in the US (as of July 2015). This gives scholars and institutions in the US more opportunities to publish as many of these journals published predominantly articles by US-based authors (Campbell, 1990). This is mirrored in our findings where US-based journals published the most articles and the authors with the highest publication output are attached to US institutions. However, research and publications from other regions of the world are needed. This is especially true for Asia where the rapidly growing elderly populations in many countries lack adequate PA (Hallal et al., 2012; Ibrahim, Karim, Oon, & Ngah, 2013). Hence, it is vital to increase research that primarily focusses on promoting PA in various regions of the world. This is because current knowledge on ways to increase PA in older adults is based on research from developed countries which might not be applicable to developing countries.

Within the total of 9,935 publications in PA and aging research, the 45 highly-cited publications have greatly influenced the scientific community. All the highly cited publications were quantitative in nature and most were cross-sectional, experimental, and review or meta-analytic studies. This is not surprising because these study designs are frequently applied in health science and provide reliable information (Higgins & Green, 2008). However, qualitative research in the PA and aging field should not be neglected by scholars.

The majority of highly cited publications are concerned with the association or effect of PA on health-related outcomes in older adults. These studies provided the historical basis and justification for further PA and aging research and are therefore of invaluable importance to current scholars. For example, the early studies by Morris and colleagues (1953, 1983) triggered the initial debate on the health benefits of PA, whereas current reports on PA and e.g., brain plasticity as well as mental health (Colcombe et al., 2006; Larson et al., 2006; Lautenschlager et al., 2008) identified PA as a valuable non-pharmaceutical way of dementia prevention. These publications on the effects of PA in older adults have traditionally paved the way for further research and are, therefore cited frequently. However, other studies are equally important and are gaining popularity. This is especially so for interventional studies that aim to increase PA in older adults (Macera, Cavanaugh, & Bellettiere, 2015; Chase, 2015; Taylor et al., 2004). Since research on the effects of PA has undoubtedly confirmed that PA is beneficial for older adults the current and future challenge lies in the design of effective and economically viable PA interventions. Using modern technology to deliver PA interventions might prove particularly promising considering the increased use of mobile phones and the Internet by older adults (Müller & Khoo, 2014; Gell, Rosenberg, Demiris, LaCroix, & Patel, 2015).

The publication by Nelson et al. (2007) introducing PA recommendations for older adults was most highly cited. This article can be seen as one of the pillars of PA and aging research because it serves as a point of reference for many researchers in the field.

Although we conducted a methodologically sound bibliometric study, a number of limitations need to be acknowledged. First, our search for relevant publications was only conducted in WoS and hence, only publications registered in Thomson Reuters' WoS were included. Consequently, other potentially influential works such as reports and books were not captured. Second, we were not able to examine if every one of the 9,935 publications that we included were related to PA and aging research. However, considering our systematic search we assume that the vast majority of the publications matched our inclusion criteria. Finally, we used highly cited publications as suggested by WoS and based on the citation rate to determine the most influential works in PA and aging research. This is problematic because the citation rate is only one measure of impact and may not always be an indicator of research excellence (Brandt et al., 2010).

Conclusions

This paper presents the first attempt to conduct a bibliometric study in the field of PA and aging research. From the 9,935 publications included in this research, publication output across a variety of disciplines has steadily increased over time indicating the growing importance of the field. Most publications were authored by scholars from the US where most of the influential journals are located. Thus, the US appears to lead the scientific community in PA and aging research. However, it is expected that scholars from other fast aging regions will influence the research landscape in the future (Cramm & Lee, 2014). Highly cited publications reported on quantitative studies and focused predominantly on the association or effects of PA on health-related outcomes. Interventional PA research focusing on the increase of activity levels is strongly encouraged.

Competing Interests

The authors declare that they have no competing interests.

References

- Berryman, J. W. (2010). Exercise is medicine: A historical perspective. *Current Sports Medicine Reports*, 9(4), 195-210. doi: 10.1249/JSR.0b013e3181e7d86d
- Bornmann, L., Leydesdorff, L., & Wang, J. (2014). How to improve the prediction based on citation impact percentiles for years shortly after the publication date? *Journal of Informetrics*, 8(1), 175–180. doi: 10.1016/j.joi.2013.11.005
- Bornmann, L., Mutz, R., Marx, W., Schier, H., & Daniel, H. D. (2011). A multilevel modelling approach to investigating the predictive validity of editorial decisions: Do the editors of a high profile journal select manuscripts that are highly cited after publication? *Journal of the Royal Statistical Society: Series A (Statistics in Society)*, 174(4), 857–879. doi: 10.1111/j.1467-985X.2011.00689.x
- Brandt, J. S., Downing, A. C., Howard, D. L., Kofinas, J. D., & Chasen, S. T. (2010). Citation classics in obstetrics and gynecology: the 100 most frequently cited journal articles in the last 50 years. *American Journal of Obstetrics and Gynecology*, 203(4), 355-360. doi: 10.1016/j.ajog.2010.07.025
- Campbell, F. M. (1990). National bias: a comparison of citation practices by health professionals. *Bulletin of the Medical Library Association*, 78(4), 376–382.
- Cardinal, B. J., & Lee, H. (2013). Leading contributors to the Research Consortium's Annual Program, 1992–2011: High-visibility institutions, researchers, and topics. *Measurement in Physical Education and Exercise Science*, 17(1), 74–87. doi: 10.1080/1091367X.2013.741371
- Chase, J. D. (2015). Interventions to increase physical activity among older adults: A meta-analysis. *The Gerontologist*, 55(4), 706-718. doi: 10.1093/geront/gnu090
- Chuang, K. Y., Wang, M.-H., & Ho, Y. S. (2011). High-impact papers presented in the subject category of water resources in the essential science indicators database of the

- institute for scientific information. *Scientometrics*, 87(3), 551–562. doi: 10.1007/s11192-011-0365-2
- Chodzko-Zajko, W. J., Proctor, D. N., Singh, M. A. F., Salem, G. J., & Skinner, J. S. (2009). Position Stand. Exercise and physical activity for older adults. *Medicine and Science in Sports and Exercise*, 41(7), 1510–1530. doi: 10.1249/MSS.0b013e3181a0c95c
- Colcombe, S. J., Erickson, K. I., Scalf, P. E., Kim, J. S., Prakash, R., McAuley, E., . . . Kramer, A. F. (2006). Aerobic exercise training increases brain volume in aging humans. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 61(11), 1166–1170. doi: 10.1093/gerona/61.11.1166
- Cramm, J. M., & Lee, J. (2014). Smoking, physical activity and healthy aging in India. *BMC Public Health*, 14, 526. doi: 10.1186/1471-2458-14-526
- Duda, J. L., & Tappe, M. K. (1988). Predictors of personal investment in physical-activity among middle-ages and older adults. *Perceptual and Motor Skills*, 66(2), 543–549. doi: 10.2466/pms.1988.66.2.543
- Eshraghi, A., Abu Osman, N. A., Gholizadeh, H., Ali, S., & Shadgan, B. (2013). 100 top-cited scientific papers in limb prosthetics. *Biomedical Engineering Online*, 12, 19. doi: 10.1186/1475-925X-12-119
- Garfield, E. (1955). Citation indexes for science: A new dimension in documentation through association of ideas. *Science*, 122(3159), 108–111.
- Garfield, E., & Merton, R. K. (1979). *Citation indexing: Its theory and application in science, technology, and humanities* (Vol. 8). New York: Wiley.
- Gell, N. M., Rosenberg, D. E., Demiris, G., LaCroix, A. Z., & Patel, K. V. (2015). Patterns of technology use among older adults with and without disabilities. *The Gerontologist*, 55(3), 412-421. doi: 10.1093/geront/gnt166

- Hallal, P. C., Andersen, L. B., Bull, F. C., Guthold, R., Haskell, W., Ekelund, U., & Lancet Physical Activity Series Working Group. (2012). Global physical activity levels: surveillance progress, pitfalls, and prospects. *The Lancet*, *380*(9838), 247–257. doi: 10.1016/S0140-6736(12)60646-1
- Higgins, J. P. T., & Green, S. (2008). *Cochrane handbook for systematic reviews of interventions*. Chichester, England: Wiley-Blackwell.
- Ho, Y. S. (2014). Classic articles on social work field in Social Science Citation Index: a bibliometric analysis. *Scientometrics*, *98*(1), 137–155. doi: 10.1007/s11192-013-1014-8
- Hobbs, N., Godfrey, A., Lara, J., Errington, L., Meyer, T. D., Rochester, L., . . . Sniehotta, F. (2013). Are behavioral interventions effective in increasing physical activity at 12 to 36 months in adults aged 55 to 70 years? A systematic review and meta-analysis. *BMC Medicine*, *11*, 75. doi: 10.1186/1741-7015-11-75
- Ibrahim, S., Karim, N. A., Oon, N. L., & Ngah, W. Z. (2013). Perceived physical activity barriers related to body weight status and sociodemographic factors among Malaysian men in Klang Valley. *BMC Public Health*, *13*, 275. doi: 10.1186/1471-2458-13-275
- Keogh, J. W. L., Kilding, A., Pidgeon, P., Ashley, L., & Gillis, D. (2009). Physical benefits of dancing for healthy older adults: a review. *Journal of Aging & Physical Activity*, *17*(4), 479–500.
- King, A. C. (2001). Interventions to promote physical activity by older adults. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *56*(Suppl. 2), 36–46. doi: 10.1093/gerona/56.suppl_2.36
- Kuhn, K. E., Fried, L. P., & Allen, R. P. (1992). Measurement of low-level physical-activity in older adults. *Clinical Research*, *40*(2), A235-A235.

- Larson, E. B., Wang, L., Bowen, J. D., McCormick, W. C., Teri, L., Crane, P., & Kukull, W. (2006). Exercise is associated with reduced risk for incident dementia among persons 65 years of age and older. *Annals of Internal Medicine, 144*(2), 73–81. doi: 10.7326/0003-4819-144-2-200601170-00004
- Lautenschlager, N. T., Cox, K. L., Flicker, L., Foster, J. K., van Bockxmeer, F. M., Xiao, J.;... & Almeida, O. P (2008). Effect of physical activity on cognitive function in older adults at risk for Alzheimer disease: a randomized trial. *Journal of the American Medical Association, 300*(9), 1027–1037. doi: 10.1001/jama.300.9.1027
- Macera, C. A., Cavanaugh, A., & Bellettiere, J. (2015). State of the art review: Physical activity and older adults. *American Journal of Lifestyle Medicine*. doi:10.1177/1559827615571897
- McAuley, E., Jerome, G. J., Elavsky, S., Marquez, D. X., & Ramsey, S. N. (2003). Predicting long-term maintenance of physical activity in older adults. *Preventive Medicine, 37*(2), 110–118. doi: 10.1016/S0091-7435(03)00089-6
- McAuley, E., Mailey, E. L., Mullen, S. P., Szabo, A. N., Wójcicki, T. R., White, S. M., . . . Kramer, A. F. (2011). Growth trajectories of exercise self-efficacy in older adults: influence of measures and initial status. *Health Psychology, 30*(1), 75–83. doi: 10.1037/a0021567
- Morris, J. N., Heady, J. A., Raffle, P. A., Roberts, C. G., & Parks, J. W. (1953). Coronary heart-disease and physical activity of work. *The Lancet, 262*(6796), 1111–1120. doi: 10.1016/S0140-6736(53)91495-0
- Morris, A. F., Vaccaro, P., & Harris, R. (1983). Life quality changes of older adults during various physical-activity programs. *Medicine and Science in Sports and Exercise, 15*(2), 117. doi: 10.1249/00005768-198315020-00134

- Müller, A. M., & Khoo, S. (2014). Non-face-to-face physical activity interventions in older adults: a systematic review. *International Journal of Behavioral Nutrition and Physical Activity, 11*, 35. doi: 10.1186/1479-5868-11-35
- Nelson, M. E., Rejeski, W. J., Blair, S. N., Duncan, P. W., Judge, J. O., King, A. C., . . . Castaneda-Sceppa, C. (2007). Physical activity and public health in older adults: recommendation from the American College of Sports Medicine and the American Heart Association. *Medicine and Science in Sports and Exercise, 116*(9), 1094–1105. doi: 10.1161/CIRCULATIONAHA.107.185650
- Nichols, J. F., Patterson, P., & Early, T. (1992). A validation of a physical activity monitor for young and older adults. *Canadian Journal of Sport Sciences-Revue, 17*(4), 299–303.
- Paffenbarger, R. S., Jr., Hyde, R., Wing, A. L., & Hsieh, C. C. (1986). Physical activity, all-cause mortality, and longevity of college alumni. *New England Journal of Medicine, 314*(10), 605–613. doi: 10.1056/NEJM198603063141003
- Paterson, D. H., Jones, G. R., & Rice, C. L. (2007). Ageing and physical activity: evidence to develop exercise recommendations for older adults. *Applied Physiology, Nutrition, and Metabolism, 32*(Suppl. 2E), 69–108. doi: 10.1139/H07-111
- Priem, J. (2013). Scholarship: Beyond the paper. *Nature, 495*(7442), 437–440. doi: 10.1038/495437a
- Shadgan, B., Roig, M., HajGhanbari, B., & Reid, W. D. (2010). Top-cited articles in rehabilitation. *Archives of Physical Medicine and Rehabilitation, 91*(5), 806–815. doi: 10.1016/j.apmr.2010.01.011
- Shotton, D., O'Steen, B., Dutton, A., Peroni, S., & Gray, T. (2013). Open citations. *Nature, 502*(7471), 295–297. doi: 10.1234/12345678

- Spiriduso, W. W. (1975). Reaction and movement time as a function of age and physical activity level. *The Journal of Gerontology*, 30(4), 435-440. doi: 10.1093/geronj/30.4.435
- Södergren, M. (2013). Lifestyle predictors of healthy ageing in men. *Maturitas*, 75(2), 113–117. doi: 10.1016/j.maturitas.2013.02.011
- Tian, Y., Wen, C., & Hong, S. (2008). Global scientific production on GIS research by bibliometric analysis from 1997 to 2006. *Journal of Informetrics*, 2(1), 65–74. doi: 10.1016/j.joi.2007.10.001
- Taylor, A. H., Cable, N. T., Faulkner, G., Hillsdon, M., Narici, M., & van der Bij, A. K. (2004). Physical activity and older adults: a review of health benefits and the effectiveness of interventions. *Journal of Sports Sciences*, 22(8), 703–725. doi: 10.1080/02640410410001712421
- United Nations, Department of Economic and Social Affairs. (2012). *Population ageing and development 2012 (wall chart)*. New York: United Nations Publications.
- Vogel, T., Brechat, P. H., Leprêtre, P. M., Kaltenbach, G., Berthel, M., & Lonsdorfer, J. (2009). Health benefits of physical activity in older patients: a review. *International Journal of Clinical Practice*, 63(2), 303–320. doi: 10.1111/j.1742-1241.2008.01957.x
- Wagner, E. (1992). Effects of physical activity on health status in older adults I: Observational studies. *Annual Review of Public Health*, 13(1), 451–468. doi: 10.1146/annurev.publhealth.13.1.451
- Washburn, R. A., Smith, K. W., Jette, A. M., & Janney, C. A. (1993). The Physical-Activity Scale for the Elderly (PASE) - Development and evaluation. *Journal of Clinical Epidemiology*, 46(2), 153–162. doi: 10.1016/0895-4356(93)90053-4
- World Health Organization. (2010). *Global recommendations on physical activity for health*. Geneva, Switzerland: World Health Organization.

Table of the top 45 publications in Physical Activity and Aging Research

Rank	Citation Rate	Title
1	78.13	Nelson, M. E., Rejeski, W. J., Blair, S. N., Duncan, P. W., Judge, J. O., King, A. C., ... & Castaneda-Sceppa, C. (2007). Physical activity and public health in older adults: Recommendation from the American College of Sports Medicine and the American Heart Association. <i>Medicine and Science in Sports and Exercise</i> , 116(9), 1094-1105.
2	76.0	Chodzko-Zajko W. J., Proctor, D. N., Singh, M. A. F., Salem, G. J., & Skinner, J. S. (2009). Position Stand. Exercise and physical activity for older adults. <i>Medicine and Science in Sports and Exercise</i> , 41(7), 1510–1530.
3	56.57	Lautenschlager, N. T., Cox, K. L., Flicker, L., Foster, J. K., van Bockxmeer, F. M., Xiao, J.; Greenop, ... & Almeida, O. P. (2008). Effect of physical activity on cognitive function in older adults at risk for Alzheimer disease: a randomized trial. <i>Journal of the American Medical Association</i> , 300(9), 1027-1037.
4	45.67	Larson, E. B., Wang, L., Bowen, J. D., McCormick, W.C., Teri, L., Crane, P., & Kukull, W. (2006). Exercise is associated with reduced risk for incident dementia among persons 65 years of age and older. <i>Annals of Internal Medicine</i> , 144(2), 73-81.
5	45.33	Colcombe, S. J., Erickson, K. I., Scalf, P. E., Kim, J. S., Prakash, R.; McAuley, E., ... & Kramer, A. F. (2006). Aerobic exercise training increases brain volume in aging humans. <i>The Journals of Gerontology Series A: Biological Sciences and Medical Sciences</i> , 61(11), 1166-1170.
6	42.27	Colcombe, S. J., Kramer, A. F., Erickson, K. I., Scalf, P., McAuley, E., Cohen, N. J., ... & Elavsky, S. (2004). Cardiovascular fitness, cortical plasticity, and aging. <i>Proceedings of the National Academy of Sciences of the United States of America</i> , 101(9), 3316-3321
7	40.50	Villareal, D. T., Chode, S., Parimi, N., Sinacore, D. R., Hilton, T., Armamento-Villareal, R., ... & Shah, K. (2011). Weight loss, exercise, or both and physical function in obese older adults. <i>New England Journal of Medicine</i> , 364(13), 1218-1229.
8	33.91	Messier, S. P., Loeser, R. F., Miller, G. D., Morgan, T. M., Rejeski, W. J., Sevick, M. A., ... & Williamson, J. D. (2004). Exercise and dietary weight loss in overweight and obese older adults with knee osteoarthritis: the Arthritis, Diet, and Activity Promotion Trial. <i>Arthritis and Rheumatism</i> , 50(5), 1501-1510.
9	30.73	Heyn, P., Abreu, B. C., & Ottenbacher, K. J. (2004). The effects of exercise training on elderly persons with cognitive impairment and dementia: a meta-analysis. <i>Archives of Physical Medicine and</i>

Rehabilitation, 85(10), 1694-1704.

- 10 30.00 Erickson, K. I., Prakash, R. S., Voss, M. W., Chaddock, L., Hu, L., Morris, K. S., ... & Kramer, A. F. (2009). Aerobic fitness is associated with hippocampal volume in elderly humans. *Hippocampus*, 19(10), 1030-1039.
- 11 27.63 Sui, X., LaMonte, M. J., Laditka, J. N., Hardin, J. W., Chase, N., Hooker, S. P., & Blair, S. N. (2007). Cardiorespiratory fitness and adiposity as mortality predictors in older adults. *Journal of the American Medical Association*, 298(21), 2507-2516.
- 12 25.44 Pahor, M., Blair, S. N., Espenland, M., Fielding, R., Gill, T. M., Guralnik, J. M., Hardley, E. C., ... & Studenski, S. (2006). Effects of a physical activity intervention on measures of physical performance: results of the Lifestyle Interventions and Independence for Elders Pilot (LIFE-P) study. *The Journals of Gerontology: Series A: Biological Sciences and Medical Sciences*. 61(11), 1157-1165.
- 13 23.82 Abbott, R. D., White, L. R., Ross, G. W., Masaki, K. H., Curb, J. D., & Petrovitch, H. (2004). Walking and dementia in physically capable elderly men. *Journal of the American Medical Association*, 292(12), 1447-1453.
- 14 23.67 Buchman, A. S., Boyle, P. A., Yu, L., Shah, R. C., Wilson, R. S., & Bennett, D. A. (2012). Total daily physical activity and the risk of AD and cognitive decline in older adults. *Neurology*, 78(17), 1323-1329.
- 15 22.50 Caminiti, G., Volterrani, M., Iellamo, F., Marazzi, G., Massaro, R., Miceli, M., ... & Rosano, G. M. (2009). Effect of long-acting testosterone treatment on functional exercise capacity, skeletal muscle performance, insulin resistance, and baroreflex sensitivity in elderly patients with chronic heart failure: a double-blind, placebo-controlled, randomized study. *Journal of the American College of Cardiology*, 54(10), 919-927.
- 16 22.33 Tieland, M., Dirks, M. L., van der Zwaluw, N., Verdijk, L. B., van de Rest, O., de Groot, L. C., & van Loon, L. J. (2012). Protein supplementation increases muscle mass gain during prolonged resistance-type exercise training in frail elderly people: a randomized, double-blind, placebo-controlled trial. *Journal of the American Medical Directors Association*, 13(8), 713-719.
- 17 19.00 Berke, E. M., Koepsell, T. D., Moudon, A. V., Hoskins, R. E., & Larson, E. B. (2007). Association of the built environment with physical activity and obesity in older persons. *American Journal of Public Health*, 97(3), 486-492.
- 18 17.60 Li, F., Fisher, K. J., Brownson, R. C., & Bosworth, M. (2005). Multilevel modelling of built environment characteristics related to neighbourhood walking activity in older adults. *Journal of Epidemiology and*

Community Health, 59(7), 558-564.

- 19 15.82 Colbert, L. H., Visser, M., Simonsick, E. M., Tracy, R. P., Newman, A. B., Kritchevsky, S. B., ... & Harris, T. B. (2004). Physical activity, exercise, and inflammatory markers in older adults: findings from the Health, Aging and Body Composition Study. *Journal of the American Geriatrics Society*, 52(7), 1098-1104.
- 20 15.09 Schutzer, K. A., & Graves, B. S. (2004). Barriers and motivations to exercise in older adults. *Preventive Medicine*, 39(5), 1056-1061.
- 21 14.40 Buman, M. P., Hekler, E. B., Haskell, W. L., Pruitt, L., Conway, T. L., Cain, K. L., ... & King, A. C. (2010). Objective light-intensity physical activity associations with rated health in older adults. *American Journal of Epidemiology*, 172(10), 1155-1165.
- 22 14.14 Nagel, C. L., Carlson, N. E., Bosworth, M., & Michael, Y. L. (2008). The relation between neighborhood built environment and walking activity among older adults. *American Journal of Epidemiology*, 168(4), 461-468.
- 23 13.75 Van Cauwenberg, J., De Bourdeaudhuij, I., De Meester, F., Van Dyck, D., Salmon, J., Clarys, P., & Deforche, B. (2011). Relationship between the physical environment and physical activity in older adults: a systematic review. *Health & Place*, 17(2), 458-469.
- 24 13.29 Li, F., Harmer, P. A., Cardinal, B. J., Bosworth, M., Acock, A., Johnson-Shelton, D., & Moore, J. M. (2008). Built environment, adiposity, and physical activity in adults aged 50–75. *American Journal of Preventive Medicine*, 35(1), 38-46.
- 25 13.20 Paterson, D. H., & Warburton, D. E. (2010). Review Physical activity and functional limitations in older adults: a systematic review related to Canada's Physical Activity Guidelines. *International Journal of Behavioral Nutrition and Physical Activity*, 7: 38.
- 26 13.20 Pang, M. Y., Eng, J. J., Dawson, A. S., McKay, H. A., & Harris, J. E. (2005). A Community-Based Fitness and Mobility Exercise Program for Older Adults with Chronic Stroke: A Randomized, Controlled Trial. *Journal of the American Geriatrics Society*, 53(10), 1667-1674.
- 27 12.09 Brach, J. S., Simonsick, E. M., Kritchevsky, S., Yaffe, K., & Newman, A. B. (2004). The association between physical function and lifestyle activity and exercise in the health, aging and body composition study. *Journal of the American Geriatrics Society*, 52(4), 502-509.
- 28 11.86 Nicklas, B. J., Hsu, F. C., Brinkley, T. J., Church, T., Goodpaster, B. H., Kritchevsky, S. B., & Pahor, M. (2008). Exercise Training and Plasma C-Reactive Protein and Interleukin-6 in Elderly People. *Journal of the American Geriatrics Society*, 56(11), 2045-2052.

- 29 11.33 Bridle, C., Spanjers, K., Patel, S., Atherton, N. M., & Lamb, S. E. (2012). Effect of exercise on depression severity in older people: systematic review and meta-analysis of randomised controlled trials. *The British Journal of Psychiatry*, 201(3), 180-185.
- 30 11.33 Carlson, J. A., Sallis, J. F., Conway, T. L., Saelens, B. E., Frank, L. D., Kerr, J., ... & King, A. C. (2012). Interactions between psychosocial and built environment factors in explaining older adults' physical activity. *Preventive Medicine*, 54(1), 68-73.
- 31 11.00 Cheng, S. T., Chow, P. K., Song, Y. Q., Edwin, C. S., Chan, A. C., Lee, T. M., & Lam, J. H. (2014). Mental and physical activities delay cognitive decline in older persons with dementia. *The American Journal of Geriatric Psychiatry*, 22(1), 63-74.
- 32 10.50 Copeland, J. L. & Eslinger, D. W. (2009). Accelerometer assessment of physical activity in active, healthy older adults. *Journal of Aging and Physical Activity*, 17(1), 17-30.
- 33 10.40 Middleton, L. E., Barnes, D. E., Lui, L. Y., & Yaffe, K. (2010). Physical activity over the life course and its association with cognitive performance and impairment in old age. *Journal of the American Geriatrics Society*, 58(7), 1322-1326.
- 34 10.33 Kim, H. K., Suzuki, T., Saito, K., Yoshida, H., Kobayashi, H., Kato, H., & Katayama, M. (2012). Effects of exercise and amino acid supplementation on body composition and physical function in community-dwelling elderly Japanese sarcopenic women: A randomized controlled trial. *Journal of the American Geriatrics Society*, 60(1), 16-23.
- 35 10.33 Murphy, S. L. (2009). Review of physical activity measurement using accelerometers in older adults: considerations for research design and conduct. *Preventive Medicine*, 48(2), 108-114.
- 36 9.40 Frank, L., Kerr, J., Rosenberg, D., & King, A. (2010). Healthy aging and where you live: community design relationships with physical activity and body weight in older Americans. *Journal of Physical Activity and Health*, 7(Suppl 1), S82-S90.
- 37 9.25 King, A. C., Sallis, J. F., Frank, L. D., Saelens, B. E., Cain, K., Conway, T. L., ... & Kerr, J. (2011). Aging in neighborhoods differing in walkability and income: associations with physical activity and obesity in older adults. *Social Science and Medicine*, 73(10), 1525-1533.
- 38 9.00 Snowden, M., Steinman, L., Mochan, K., Grodstein, F., Prohaska, T. R., Thurman, D. J., ... & Anderson, L. A. (2011). Effect of exercise on cognitive performance in community-dwelling older adults: review of intervention trials and recommendations for public health practice and

- research. *Journal of the American Geriatrics Society*, 59(4), 704-716.
- 39 9.00 Langlois, F., Vu, T. T. M., Chassé, K., Dupuis, G., Kergoat, M. J., & Bherer, L. (2013). Benefits of physical exercise training on cognition and quality of life in frail older adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, 68(3), 400-404.
- 40 8.75 Hart, T. L., Swartz, A. M., Cashin, S. E., & Strath, S. J. (2011). How many days of monitoring predict physical activity and sedentary behaviour in older adults. *International Journal of Behavioral Nutrition and Physical Activity*, 8: 62.
- 41 8.67 Freiburger, E., Häberle, L., Spirduso, W. W., & Rixt Zijlstra, G. A. (2012). Long-Term Effects of Three Multicomponent Exercise Interventions on Physical Performance and Fall-Related Psychological Outcomes in Community-Dwelling Older Adults: A Randomized Controlled Trial. *Journal of the American Geriatrics Society*, 60(3), 437-446.
- 42 7.33 Sitjà-Rabert, M., Rigau, D., Fort Vanmeerghaeghe, A., Romero-Rodríguez, D., Bonastre Subirana, M., & Bonfill, X. (2012). Efficacy of whole body vibration exercise in older people: a systematic review. *Disability and Rehabilitation*, 34(11), 883-893.
- 43 7.00 Hilgenkamp, T. I., Reis, D., van Wijck, R., & Evenhuis, H. M. (2012). Physical activity levels in older adults with intellectual disabilities are extremely low. *Research in Developmental Disabilities*, 33(2), 477-483.
- 44 6.00 Inoue, S., Sugiyama, T., Takamiya, T., Oka, K., Owen, N., & Shimomitsu, T. (2012). Television viewing time is associated with overweight/obesity among older adults, independent of meeting physical activity and health guidelines. *Journal of Epidemiology*, 22(1), 50-56.
- 45 5.50 Sun, F., Norman, I. J., & While, A. E. (2013). Physical activity in older people: a systematic review. *BMC Public Health*, 13: 449.
-