Preventive Medicine 111 (2018) 466–472

Contents lists available at ScienceDirect

Preventive Medicine

journal homepage: www.elsevier.com/locate/ypmed

Review Article

Mapping the historical development of physical activity and health research: A structured literature review and citation network analysis☆

Andrea Ramirez Varela[a,*], Michael Pratt[b], Jenine Harris[c], Jesse Lecy[d], Deborah Salvo[e], Ross C. Brownson[c,f], Pedro C. Hallal[a]

[a] Post-Graduate Program in Epidemiology, Federal University of Pelotas, Brazil
[b] University of California San Diego, School of Medicine and Institute for Public Health, United States
[c] Prevention Research Center in St. Louis, Brown School, Washington University School of Medicine, Washington University in St. Louis, United States
[d] Syracuse University, United States
[e] The University of Texas Health Science Center at Houston (UTHealth), School of Public Health in Austin, United States
[f] Department of Surgery and Alvin J. Siteman Cancer Center, Washington University School of Medicine, Washington University in St. Louis, United States

ARTICLE INFO

Keywords:
Physical activity
Network analysis
History
Research
Review

ABSTRACT

Little has been published about the historical development of scientific evidence in the physical activity (PA) and public health research field. The study aimed to examine the evolution of knowledge in this field.

A structured literature review using formal citation network analysis methods was conducted in June-2016. Using a list of influential PA publications identified by domain experts, a snowball sampling technique was used to build a compact citation network of 141 publications that represents the backbone of the field. Articles were coded by study type and research team characteristics, then analyzed by visualizing the citation network and identifying research clusters to trace the evolution of the field.

The field started in the 1950s, with a health sciences focus and strong North American and European leadership. Health outcome studies appeared most frequently in the network and policy and interventions least. Critical articles on objective measurement and public policy have influenced the progress from an emphasis on health outcomes research at early stages in the field to the more recent emerging built environment and global monitoring foci. There is only modest cross-citation across types of study. To our knowledge, this paper is the first to systematically describe the development of research on PA and public health. The key publications include fundamental ideas that remain citable over time, but notable research and dissemination gaps exist and should be addressed. Increasing collaboration and communication between study areas, encouraging female researchers, and increasing studies on interventions, evaluation of interventions and policy are recommended.

1. Introduction

Physical inactivity is an important risk factor for chronic diseases such as diabetes, coronary heart disease, some cancers, depression and dementia (Bauman, 2004; Ding et al., 2016; Ekelund et al., 2016; Kohl et al., 2012; Lee et al., 2012; Sallis et al., 2016), and costs 67.5 billion dollars globally annually in health care expenditures and lost productivity (Ding et al., 2016). Since the first epidemiologic studies published in the 1950s there has been enormous growth in the number of papers, researchers, study types, and disciplines engaged in research on physical activity. However, little has been published about the historical development of scientific evidence in the field of physical activity and public health. Available publications are in the format of commentaries, review articles, and historic narratives (Blair and Powell, 2014; Paffenbarger et al., 2001; Park, 1995); but all lack a quantitative research approach. Citation analysis is a powerful tool that allows for a visual and objective representation of the past, present, and potential future directions of a research field (Lecy and Beatty, 2012). This information is important to identify knowledge gaps and communication barriers among research and practice communities, and may be helpful in moving the field forward. The aim of this study was to use citation analysis to provide insight into the evolution of knowledge in the field of physical activity and public health.

☆ No financial disclosures or conflicts of interest were declared by the authors of this paper.

* Corresponding author at: Post-Graduate Program in Epidemiology, Federal University of Pelotas, Rua Marechal Deodoro 1160 - Centro, Pelotas, RS 96020-220, Brazil.
E-mail address: aravamd@gmail.com (A.R. Varela).

https://doi.org/10.1016/j.ypmed.2017.10.020
Received 18 May 2017; Received in revised form 3 October 2017; Accepted 17 October 2017

2. Methods

A structured literature review was conducted from February 2015 to June 2016 using citation network analysis (Lecy and Beatty, 2012). A stepwise protocol (before, during, after) for citation data collection was conducted, through seven steps:

2.1. Prior to citation data collection

2.1.1. Identification of most cited publications

In June 2015, the most cited documents in the field since 1950 were searched in ISI Web of knowledge and Google Scholar (Lecy and Beatty, 2012), using the following search criteria: "physical activity AND public health", allowing keywords to be found anywhere in the text. All languages, countries, and study types were included. Documents included published articles, commentaries, books, and others (reports, dissertations). Resulting documents were ranked by number of citations. A final list of the forty most cited publications was derived from ISI Web of Knowledge and Google Scholar, by combining both lists, removing duplicates (n = 11), and leaving the 40 unique most cited articles. Citation counts data was not normalized by publication date.

2.1.2. Identification of most cited authors

To validate the preliminary list generated in Step 1, we undertook a systematic process for expert identification. A separate search for the most cited authors in the field was conducted in Scopus, Google Scholar and ISI Web of Knowledge using the same search criteria from step 1. Lists from each source were combined, duplicates were excluded, and authors were ranked based on their H index. Country of affiliation was included in the list. Authors were divided into five categories based on their expertise: 1) Physical activity levels, trends and measurement – the science of physical activity surveillance and measurement; 2) Determinants and correlates of physical activity – understanding why some people are active and others are not; 3) Health outcomes of physical activity – studies on the health outcomes of physical activity with physical activity as the main exposure variable; 4) Interventions in the field of physical activity that aim to increase physical activity as the primary objective; and 5) Policy and practice in the field of physical activity and public health. This classification system was originally developed for the 2012 Lancet Physical Activity Series (A. E. Bauman et al., 2012; Hallal et al., 2012; Kohl et al., 2012).

A list of the three most cited authors per category was created. To ensure adequate global research representation for each category, if all three authors were from the USA, the top two only were included and a third was identified by selecting the highest cited author from a non-US institution. The final list included academics from USA, Australia, Brazil, Japan, and Norway.

2.1.3. Expert validation of the list of most cited publications

Between April and June 2015 a letter of request including the list of 40 most cited physical activity articles from step 1 was sent by email to the 15 experts identified in step 2. Experts chose the ten articles they considered most influential for the field's development, and ranked by importance (ranking: 1–10). They were encouraged to suggest articles that were not on the list. The final list of most influential articles consisted of 15 articles with 4 or more expert votes each. The response rate from the initial author list was 80% (12/15). Three authors did not reply and therefore the next author in the list was invited to participate until 15 responses were achieved.

2.2. Citation data collection

2.2.1. Data collection with Citation Network Analyzer tool

The Citation Network Analyzer-CNA tool developed by Lecy et al. (Lecy and Moreda, 2011) was chosen for data collection because of its functions of citation link identification, citation patterns tracking, and selection of highly influential publications based on the PageRank indicator, which fit the study objectives.

A citation network was collected in August 2015 using the most influential papers (n = 15, step 3) as "seeds" for a snowball sample. The sampling technique builds the network by identifying articles citing the seeds, articles citing those, etc. Since a snowball sample grows exponentially, we utilized a constrained snowball, which collects only a percentage of articles at each level, retaining the highly-cited articles and discarding the rest, resulting in a compact sample that represents the backbone of a literature since it contains the most-cited articles and linkages between them and is not biased by researcher preferences (Lecy and Beatty, 2012).

Two parameters were considered for the constrained snowball sampling: a) number of levels of data collection from the seeds; and b) percentage of articles to be sampled by level. Seed articles constitute the baseline level of data collection. Two levels of data were collected: articles that cite the seeds are in level 1 and articles that cite level 1 are in level 2. For this study, it was estimated that an initial five level selection strategy would produce over 10,000 publications, too many for practical analysis and effective interpretation. Thus, data were collected in two levels from the previously selected fifteen seeds, with a sampling of the top 2% most cited articles at each level (Lecy and Beatty, 2012). This produced a citation network with 5217 articles and 9132 citation links.

This sample was further refined by filtering by the group of those at the 75th percentile and above for total citations, i.e., only articles with at least 674 Google Scholar citations. This subsample contained 1131 articles, including 80% of the original seed articles identified by field experts (step 3). Since this is the most highly-cited set of articles in the network it represents the arterial flows of research through the field (Lecy and Beatty, 2012). Appendix graph A includes a representation of the complete citation network explaining the need for filtering in order to conduct the main path analysis.

2.3. After citation data collection

2.3.1. Main path identification

The sample was further refined through main path analysis, a method to identify the set of articles that mathematically represents the optimal path for information to flow through the network between the seed articles and the last level of collected data. Links with the highest transversal weights were retained. Transversal weight is the proportion of all paths between the first/source document (not citing any others in the network) and the last/sink document (not cited by any others in the network) that contain a particular link or article. It represents the extent to which an article or link is needed for keeping the network connected (De Nooy et al., 2011; Harris et al., 2009). Using the search path count strategy to extract the main path (De Nooy et al., 2011), and based on a transversal weight cut point of 0.03 to ensure the inclusion of at least 80% of the seed articles, we obtained a network of 141 articles. This set contains the nodes with strongest citation linkages as you move forward in time from the seeds, representing the strongest path by which knowledge in the field has been generated and disseminated, i.e., it is the backbone of the literature (Harris et al., 2009).

2.3.2. Network data extraction

Abstracts from the main path articles (n = 141) were coded according to the previously described five categories, plus first author gender and country of residence based on affiliation. Main path abstract coding was conducted independently by authors AR and DS, who agreed with a weighted kappa of 0.77 and percent agreement of 82.8%. Discrepancies were resolved until reaching 100% agreement.

2.3.3. Statistical and graphic analyses

Traditional and network descriptive statistics and exponential random graph modeling (ERGM) were conducted to examine network composition and patterns of ties in the main path (Harris et al., 2011; Harris et al., 2009). Descriptive characteristics included out-degree centrality, defined as the number of ties (citations) received by a node (citations). Nodes with higher out-degree are more prestigious/influential.

ERGMs offer an empirical means of describing citation patterns as a probabilistic function based upon characteristics of articles and their position within the network. They provide an odds ratio as an effect measure, similar to logistic regression, but take into account dependence between observations as a result of network structure (Harris et al., 2009). The model was built to formally test the hypothesis that nodes cluster in a network as a result of common characteristics (in this case, type of study). ERGMs in this context predict the likelihood of one article citing another as a function of either characteristics of the publication, or global network structures.

To better understand the development of the field an ERGM was estimated using the articles from the main path and including first author gender and article topic as covariates. Author's country of residence was not included in the model given the dominance of the US and the large proportion of non-US countries contributing just a single article to the network. Consistent with other citation network studies using ERGM (Harris et al., 2009, 2011), model building started with a null model, added main effects terms for author gender and article topic (model 1), added terms for same sex or same study topic citation (model 2), and added geometrically weighted terms to account for the underlying distribution of ties often observed in networks (model 3) (Harris, 2014). To further identify who the most influential authors of the field are, we ran an additional analysis including all authors and co-authors of the main path of the article citation network analysis, using node size to represent number of publications. This was filtered to only include authors with three or more publications in the main path of the network (n = 141 articles), to facilitate visual interpretation (Appendix graph B). Analyses were conducted in R 3.2, and visualization in the Pajek 4.10 and Gephi 0.9.2 programs.

3. Results

The first peer reviewed paper in the field of physical activity and public health was published in 1953: Morris et al., a study of physical activity and mortality at work (Morris et al., 1953). The field gradually evolved, reaching over one thousand publications per year by 2015, and developed with a predominance of US or UK male authors with a health sciences background. Over this period, most studies focused on health outcomes. Intervention studies appeared in the 1990s. Appendix Table A shows the list of most influential physical activity articles (resulting from step 3 and including 1 suggested article from the experts) since 1950 until June 2015, which were used as seeds for the citation network analysis.

The overall identified network included 5217 nodes and its citation links. The median, mean, and 75th percentile for citations were 381, 619 and 674 respectively. Among these 5217 nodes, the most cited article network (≥ 75th percentile) included 1131 nodes, which were used to identify the main path.

3.1. Most influential studies and authors

The main path had 98 lead authors, each contributing an average of 1.43 articles (s.d. = 1.26; range 1–10). Most lead authors (n = 79) contributed one article, and one third were women (29/98). Fig. 1 shows the timeline of the main path publications by study type, year of publication and number of citations.

Appendix Table B shows the 25 most cited articles in the main path network. Most articles had a lead author from the USA (n = 69), followed by the UK (n = 10); Canada (n = 5); Australia (n = 3); Netherlands (n = 3); and Brazil, Finland, Germany, Ireland, Israel, New Zealand, Spain, and Sweden (n = 1).

There were 45 journals contributing an average of 2.71 articles each (s.d. = 3.44). Top-ten journals were: JAMA (n = 16); Circulation (n = 12); American Journal of Preventive Medicine (n = 10); Medicine and Science in Sports and Exercise (n = 10); New England Journal of Medicine (n = 10); The Lancet (n = 7); Journal of the American College of Cardiology (n = 5); Archives of Internal Medicine (n = 3) and Preventive Medicine (n = 3). Fourteen of the 141 documents were books.

3.2. What characterized the composition and network structure as it developed over time?

Fig. 2 shows the publication and citation patterns by type of study from 1950 to 2015. Fig. 3 shows the main path publications forming the field of physical activity and health research, organized by type of study and author. Of the 141 articles in the main path, 15.6% were classified as levels, trends, and measurement (n = 22); 19.9% determinants or correlates (n = 28); 41.1% health outcomes (n = 58); 7.1% interventions (n = 10); and 16.3% policy and practice (n = 23).

Physical activity and health outcomes publications represent the beginning of the research field with first publication found in 1953 and 45.0% (26/58) of work published before 2000. In this study category, the median number of citations was 690 with a mean of 1037 (range 127–3530). First author countries included USA (49), UK (4), Finland (1), Australia (1), Germany (1) and Ireland (1) and Israel (1). Female first authors were found in 31% (18/58) of the papers. The Lancet, New England Journal of Medicine and Circulation were the most frequent journals for this category.

The first physical activity measurement and trends publication was in 1960, with 50.0% (11/22) were published between 2000 and 2010. Median and mean citations were 689 and 1041, respectively (range 245–5065). First author affiliations included USA (13), Canada (3), UK (2), Australia (2), Sweden (1), and Brazil (1). Thirty-two percent of authors were female (7).

The first correlates and determinants paper was published in 1985, and 68.0% (19/28) were published between 2000 and 2010. Median citations were 660 with a mean of 1011 (range 153–1118). First author affiliations included USA (20), UK (2), Canada (3), Australia (1), Netherlands (1) and New Zealand (1). A quarter of papers had female first authors (7).

The first policy publications appeared in 1992 and have been regularly distributed over the last 3 decades with 35% (8/23) published in the 1990s, 39.1% (9/23) during the 2000s, and 26% (6/23) after 2010. Median citation counts were 614 with a mean of 940 (range 123–7830). First authors were from USA (19), UK (2), Netherlands (1) and Spain (1). This category had the lowest proportion of female first authors: 13.4% (3).

Intervention publications were the most recent type of study to enter the network, starting in 1996. Half (50.0%, 5/10) of the studies were published during between 2002 and 2007. Median citation count was of 674, with a mean of 1019 (range 403–1753). First author affiliations included USA (8) and UK (2). Half of the first authors were female 50.0% (5), the highest proportion among all categories.

Determinants articles were 49% less likely than physical activity levels, trends, and measurement articles to be cited by other main path articles (0.51, 95% CI 0.32–0.83). No other article type was significantly more or less likely to be cited compared to physical activity levels, trends, and measurement articles.

As shown in Table 1, with the exception of policy and practice articles, articles of all topics were more likely to cite other articles of the same topic. Specifically, two articles about physical activity levels, trends, and measurement had 2.94 times higher odds of being linked by a citation (95% CI: 1.67–5.18) compared to two articles of other types. Odds Ratios of linkage among two articles of the same type, using articles of other types as reference, were as follows: 6.74 for determinants and correlates, 2.44 for health outcomes, and 8.52 for interventions.

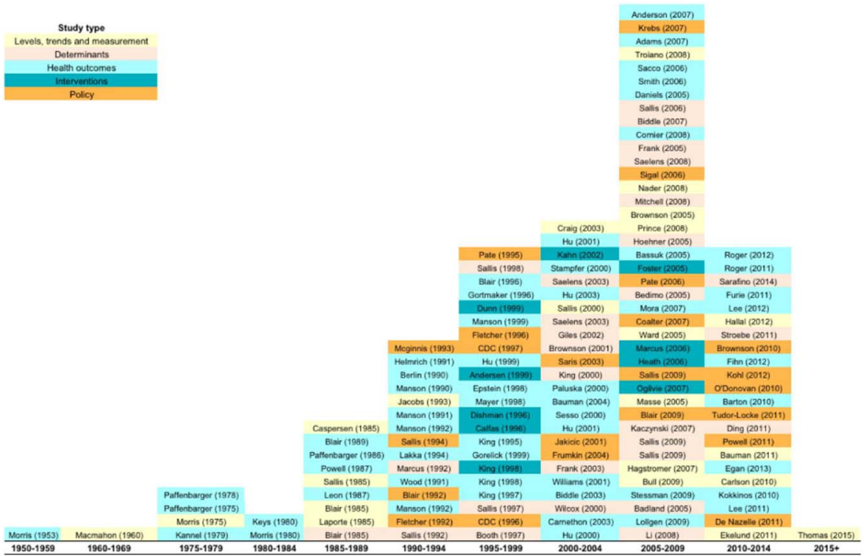

Fig. 1. Timeline with the main path publications according to type of study, year of publication and number of citations.
On each 5-year period, publications are organized from top to bottom by number of citations in a decreasing order.

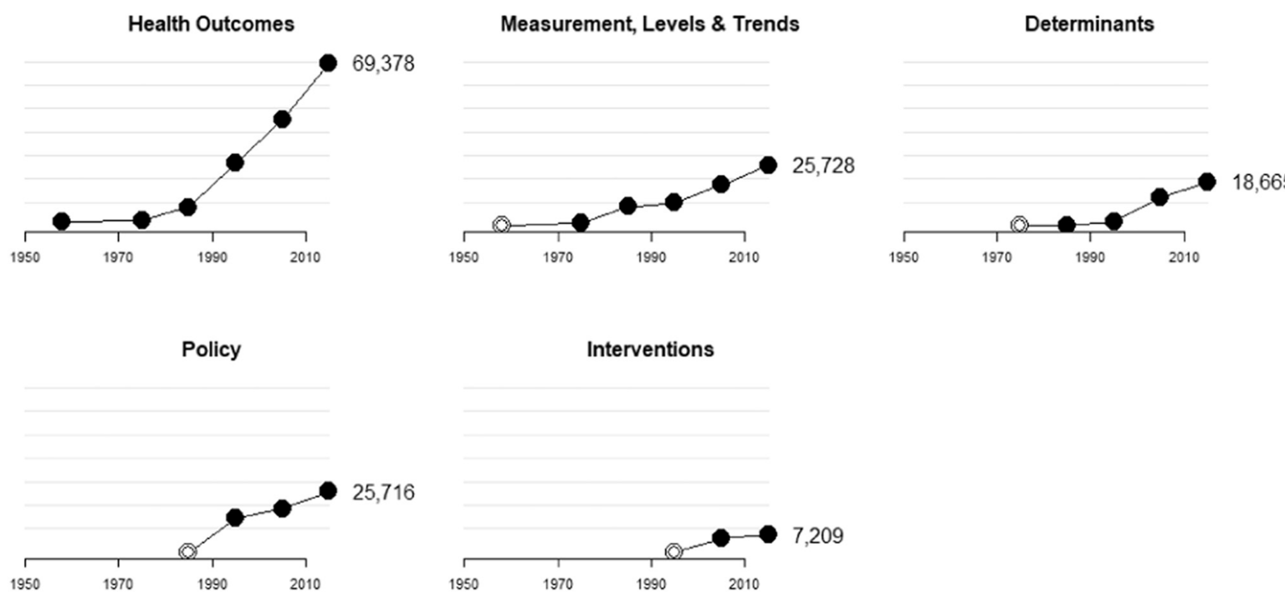

Fig. 2. Cumulative number of citations of publications in each type of study over time. (White dot is when the first publications appeared and black dots when the citations start; Y axis is number of citations).

First author gender was not significantly associated with citations (0.91, 95% CI 0.72–1.15).

3.3. *Brief historical reconstruction according to the citation network analysis*

Fig. 3 shows the main path publications forming the field of physical activity and health research, organized chronologically and by study topic and author. The five largest nodes in the network (most cited articles) are publications by Pate et al. (1995), Troiano et al. (2008), Powell et al. (1987), Morris et al. (1953) and Kahn et al. (2002). Appendix graph B shows the main path author network analysis, showing the most influential authors in the field and the connections among them.

The field developed in the 1950s around the association between physical activity and health with the classic study of coronary heart disease and physical activity of workers in London (Morris et al., 1953; Morris et al., 1958), followed by studies on the same topic in the US (Paffenbarger and Hale, 1975; Paffenbarger et al., 1978).

In the 1980s, important methodological contributions (LaPorte et al., 1985) and standardization of the field's terminology emerged (Caspersen et al., 1985). One of the first reviews in the field (Powell et al., 1987) concluded that there was consistent epidemiological evidence of an inverse and causal relation between physical activity and incidence of coronary heart disease and, that physical activity promotion was fundamental to public health (Powell et al., 1987). This evidence was central to the population based physical activity recommendation launched in 1995 from the Centers for Disease Control and Prevention and the American College of Sports Medicine (Pate et al., 1995).

In the following years, randomized trials with physical activity as the intervention were conducted and the role of physicians in prescribing physical activity began to be discussed in the literature (Calfas et al., 1996; Dunn et al., 1999). By the end of the 1990s, studies evaluating sociodemographic inequalities and physical activity (Sallis and Owen, 1998) and correlates of activity among children, adolescents and the elderly started to be published.

From 2000 onward, research was conducted across all study types.

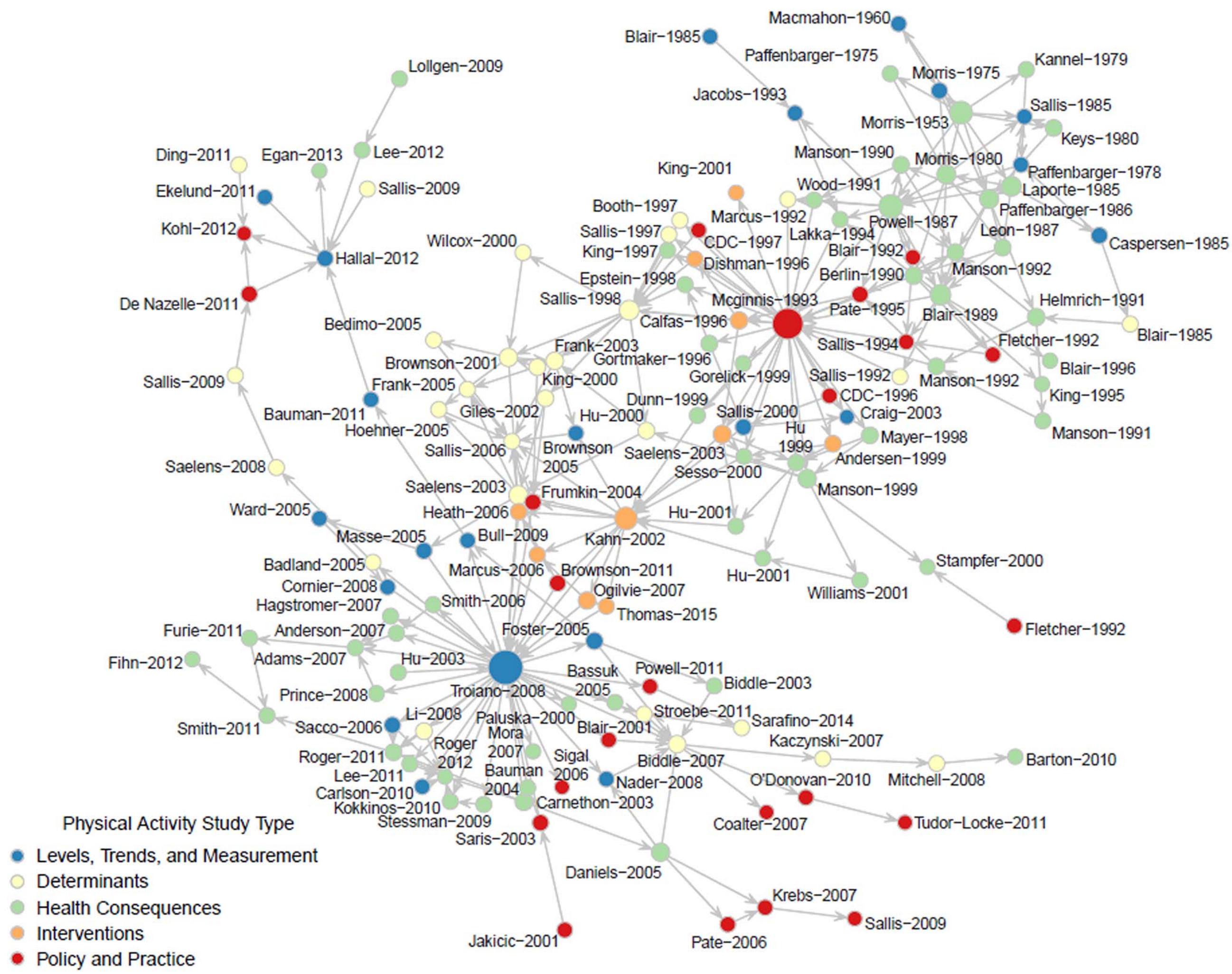

Fig. 3. Main path publications forming the field of physical activity and health research, organized by type of study and author (Node size display publication out-degree centrality*). *Out-degree is highest in nodes receiving more citations and therefore are more prestigious/influential. Receiving more citations means that these nodes were able to make the nodes who cite them aware of their results and therefore are better known among peers.

Table 1
Predictors of citation patterns estimated with Exponential Random Graph Models - ERGM's.

	Null	Main effects	Same sex or study type citation	Full
	Odds ratio (confidence interval)			
Characteristics				
Edges (relationship among authors)	0.01 (0.01–0.02)	0.01 (0.01–0.03)	0.01 (0.01–0.02)	**0.03 (0.02–0.04)***
Male	–	0.69 (0.52–0.92)	1.24 (0.95–1.62)	0.91 (0.72–1.15)
Asymmetric ties by study type (probability of being cited)				
Physical activity levels, trends and measurement	–	1.00	1.00	1.00
Determinants of physical activity	–	0.68 (0.46–1.00)	0.42 (0.24–0.74)	**0.51 (0.32–0.83)***
Health outcomes of physical activity	–	0.75 (0.54–1.05)	0.61 (0.39–0.96)	0.71 (0.48–1.05)
Interventions in the field of physical activity	–	1.18 (0.74–1.88)	1.07 (0.60–1.89)	0.98 (0.62–1.55)
Policy and practice in the field of physical activity	–	0.71 (0.47–1.07)	0.81 (0.50–1.31)	0.97 (0.66–1.41)
Mutual ties by study type (probability of clustering)				
Physical activity levels, trends and measurement	–	–	2.93 (1.65–5.21)	**2.94 (1.67–5.18)***
Determinants of physical activity	–	–	6.58 (3.67–11.81)	**6.74 (3.75–12.14)***
Health outcomes of physical activity	–	–	2.42 (1.64–3.58)	**2.44 (1.64–3.64)***
Interventions in the field of physical activity	–	–	8.14 (3.54–18.72)	**8.52 (3.61–20.15)***
Policy and practice in the field of physical activity	–	–	1.83 (0.92–3.65)	1.85 (0.94–3.66)
Global terms				
Geometrically weighted out-degree[a]	–	–	–	**0.17 (0.11–0.26)***
Models goodness of fit measures				
Model AIC	2941	2938	2855	2808
Model BIC	2949	2985	2950	2910

* $p < 0.05$.
[a] Out-degree is defined as the outgoing relations a node has. It is highest in nodes receiving more citations.

Important work on measurement, correlates and interventions shows the importance of collaboration between disciplines for exploring new topics and understanding physical activity monitoring and practice. Examples worth mentioning include: 1) a milestone study on validity and reliability of the International Physical Activity Questionnaire (Craig et al., 2003); 2) the ecological model for physical activity and active communities (Sallis et al., 2006); 3) studies exploring the associations between physical activity, psychological wellbeing, environment and policy (Brownson et al., 2001; Saelens et al., 2003; Sallis et al., 2006); 4) a systematic review reporting the most effective interventions to increase physical activity (Kahn et al., 2002); and, 5) the first population based study with objective measurement of physical activity levels in U.S. adults (Troiano et al., 2008).

Since 2005, two paths related to the built environment and global physical activity surveillance and policy have emerged. The built environment arm included pivotal studies about transport, urban design and walking (Badland and Schofield, 2005), a multicountry study (Sallis et al., 2009), and a review of evidence on active travel policies for health (de Nazelle et al., 2011). The global surveillance and policy arm included studies about the Global Physical Activity-GPAQ and International Physical Activity-IPAQ Questionnaires (Bauman et al., 2011; Bull et al., 2009), and articles of the first Lancet Physical Activity Series (Hallal et al., 2012; Kohl et al., 2012; Lee et al., 2012) that presented a global perspective on the prevalence, burden, and steps needed to address the pandemic of physical inactivity.

4. Discussion

To our knowledge, this is the first systematic historical reconstruction of the development of the physical activity and public health research field. This study is unique in that it is the first to use a quantitative methodology to map the most influential research articles of this field over a 60-year period starting with the first known peer reviewed publication in 1953.

Our findings indicate that the physical activity and health research field started in the 1950s, with a health sciences focus and North American and European leadership. Health outcome studies are most common and policy and intervention studies the least common. Critical articles on policy and objective measurement influenced progression from health outcomes research to more recent foci in built environment and global monitoring.

This body of work of the most influential papers includes important concepts that have remained citable for decades and constitutes the backbone of the physical activity research field (see Appendix graph C, showing citation volumes of seed articles over time). Key concepts identified from these publications include: 1) beneficial health effects of physical activity; 2) international health organizations focus on physical inactivity for chronic disease prevention; 3) physical activity recommendations for all population groups; 4) enhanced understanding of correlates and determinants, especially in low and middle income countries, can reduce inactivity and contribute to global prevention of chronic diseases; 5) effective interventions for increasing physical activity; and 6) most countries have physical activity prevalence estimates for informing surveillance and policy, but physical inactivity is at pandemic levels globally.

Some of the most cited papers connect different study categories around fundamental innovative concepts. For example, the two most central articles in the network (the largest nodes in Fig. 3) are a policy article (Pate et al., 1995) and an objective measurement article (Troiano et al., 2008), each of which introduced a new concept. Fig. 3 shows that these papers are among the first to be published in their category and are cited by papers of all study types, perhaps reflecting multidisciplinary and transdisciplinary communication through publications. Pate et al. (1995) links the predominantly health outcomes body of evidence to an emerging literature on determinants and interventions. This is also the case for Troiano et al. (2008) that links this previous literature to new studies using objective measurement and trends. Surprisingly, the best known authors and papers compromise only a small proportion of the 141 main path papers which are spread across 98 lead authors.

It is interesting to note that through 2012 researchers continued to primarily conduct health outcome studies, and that interventions and policy studies remained the least conducted. This raises the question of how much research provides new insights or fills research gaps in areas that could impact health (i.e., policy change) versus covering familiar ground (Control and Prevention, 1999). The low density of intervention and policy publications in the network also suggests the need to continue to fill the evidence gaps on the effects of large scale interventions and policy on physical activity and the extent to which evidence is being translated into action. This may be in part due to the greater complexity of design, funding requirement and specific training required to conduct intervention, intervention evaluation, policy and translation research. Translational research in physical activity is an important study area with relatively few examples of successful cases of collaboration between scientists and with policy makers (Brownson et al., 2006; Pratt et al., 2016; Reis et al., 2016). Studies on smoking cessation strategies and secondhand smoke have found similar disconnects in how effectively research is being translated into policy (Harris et al., 2009; Harris, 2010).

The citation patterns identified in this study show that studies about the determinants of physical activity are significantly less likely to be cited in the network compared to other types of articles. In addition, with the exception of policy and practice articles, most articles are more likely to cite other articles on the same topic, limiting the flow of information across the subfields of physical activity and public health (Rutter et al., 2017) Limited co-authorship and citations across subthemes within the network may compromise the evolution of the field and limit research translation and advocacy to address the global pandemic of inactivity and the WHO 2030 global health agenda (WHO, 2015).

The study had some limitations. Sampling for citation network analysis captures a representative but not exhaustive sample, and uses very specific search terms, therefore, some relevant publications may not have been identified. This limitation was addressed by inviting experts to add to the final selection of articles. Also, citation rates might not always accurately reflect the importance of the key papers due to differential dissemination, scientific promotion, and popularity of papers. Finally, literature published in non-English languages was not included.

5. Conclusion

This study identifies papers forming the backbone of the physical activity and public health research field. These publications include fundamental ideas that remain citable over time, however research and dissemination gaps exist in this network and should be addressed. Understanding the past and present of physical activity and public health research is critical for strategically determining the next steps for growing the field and its reach. The findings highlight the need to achieve more integrated and multidisciplinary collaboration, and to support emerging researchers in becoming a part of the backbone of the network (similar research groups as those that had great influence in the past remain the most influential currently). More emphasis should be placed on achieving gender equity in the field, by supporting female researchers. The results of this work could help in developing streamlined pathways to expedite growth of emerging sub-areas. One of the most pressing needs is capacity building in low and middle income countries. Finally, more studies on interventions, evaluation of interventions, policy, translation and scale-up are needed, as evidence in these areas is scarce, and impacts on population health are likely to be substantial. For this to happen, funding opportunities and research positions favoring this type of work are critical.

Transparency document

The Transparency document associated with this article can be found, in online version.

Acknowledgments

The authors would like to thank Adrian Bauman for feedback on the paper and Jenny Machetá from Academia Nacional de Medicina, Bogotá, Colombia.

The contributions of each author to the manuscript are as follows: AR, PH, MP proposed the initial hypothesis and idea for study. AR, JH and JL wrote the first draft of the report. JL and AR collected data. AR and DS coded the articles. JH, JL and AR did the analyses. AR, JH, JL, DS, PH, MP and RB reviewed this report, provided feedback on drafts, and approved the final version.

The information presented in this manuscript has not been presented elsewhere.

The authors declare no conflicts of interest and no financial disclosures.

Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ypmed.2017.10.020.

References

Badland, H., Schofield, G., 2005. Transport, urban design, and physical activity: an evidence-based update. Transp. Res. 10 (2005), 177–196. http://dx.doi.org/10.1016/j.trd.2004.12.001.

Bauman, A.E., 2004. Updating the evidence that physical activity is good for health: an epidemiological review 2000-2003. J. Sci. Med. Sport 7 (1 Suppl), 6–19.

Bauman, A., Ainsworth, B.E., Sallis, J.F., Hagstromer, M., Craig, C.L., Bull, F.C., ... Sjostrom, M., 2011. The descriptive epidemiology of sitting. A 20-country comparison using the International Physical Activity Questionnaire (IPAQ). Am. J. Prev. Med. 41 (2), 228–235. http://dx.doi.org/10.1016/j.amepre.2011.05.003.

Bauman, A.E., Reis, R.S., Sallis, J.F., Wells, J.C., Loos, R.J., Martin, B.W., Lancet Physical Activity Series Working, G, 2012. Correlates of physical activity: why are some people physically active and others not? Lancet 380 (9838), 258–271. http://dx.doi.org/10.1016/S0140-6736(12)60735-1.

Blair, S.N., Powell, K.E., 2014. The evolution of the physical activity field. J. Phys. Educ. Recreat. Dance 85 (7), 9–12. http://dx.doi.org/10.1080/07303084.2014.937174.

Brownson, R.C., Baker, E.A., Housemann, R.A., Brennan, L.K., Bacak, S.J., 2001. Environmental and policy determinants of physical activity in the United States. Am. J. Public Health 91 (12), 1995–2003.

Brownson, R.C., Royer, C., Ewing, R., McBride, T.D., 2006. Researchers and policymakers: travelers in parallel universes. Am. J. Prev. Med. 30 (2), 164–172. http://dx.doi.org/10.1016/j.amepre.2005.10.004.

Bull, F.C., Maslin, T.S., Armstrong, T., 2009. Global physical activity questionnaire (GPAQ): nine country reliability and validity study. J. Phys. Act. Health 6 (6), 790–804.

Calfas, K.J., Long, B.J., Sallis, J.F., Wooten, W.J., Pratt, M., Patrick, K., 1996. A controlled trial of physician counseling to promote the adoption of physical activity. Prev. Med. 25 (3), 225–233. http://dx.doi.org/10.1006/pmed.1996.0050.

Caspersen, C.J., Powell, K.E., Christenson, G.M., 1985. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. Public Health Rep. 100 (2), 126–131.

Control, C. f. D., & Prevention, 1999. Ten great public health achievements–United States, 1900–1999. Morb. Mortal. Wkly Rep. 48 (12), 241.

Craig, C.L., Marshall, A.L., Sjostrom, M., Bauman, A.E., Booth, M.L., Ainsworth, B.E., ... Oja, P., 2003. International physical activity questionnaire: 12-country reliability and validity. Med. Sci. Sports Exerc. 35 (8), 1381–1395. http://dx.doi.org/10.1249/01.mss.0000078924.61453.fb.

De Nooy, W., Mrvar, A., Batagelj, V., 2011. Exploratory Social Network Analysis With Pajek. vol. 27 Cambridge University Press.

Ding, D., Lawson, K.D., Kolbe-Alexander, T.L., Finkelstein, E.A., Katzmarzyk, P.T., van Mechelen, W., ... Committee, L.P.A.S.E., 2016. The economic burden of physical inactivity: a global analysis of major non-communicable diseases. Lancet 388 (10051), 1311–1324. http://dx.doi.org/10.1016/S0140-6736(16)30383-X.

Dunn, A.L., Marcus, B.H., Kampert, J.B., Garcia, M.E., Kohl 3rd, H.W., Blair, S.N., 1999. Comparison of lifestyle and structured interventions to increase physical activity and cardiorespiratory fitness: a randomized trial. JAMA 281 (4), 327–334.

Ekelund, U., Steene-Johannessen, J., Brown, W.J., Fagerland, M.W., Owen, N., Powell, K.E., ... Committe, E., 2016. Does physical activity attenuate, or even eliminate, the detrimental association of sitting time with mortality? A harmonised meta-analysis of data from more than 1 million men and women. Lancet 388 (10051), 1302–1310. http://dx.doi.org/10.1016/S0140-6736(16)30370-1.

Hallal, P.C., Andersen, L.B., Bull, F.C., Guthold, R., Haskell, W., Ekelund, U., Lancet Physical Activity Series Working, G, 2012. Global physical activity levels: surveillance progress, pitfalls, and prospects. Lancet 380 (9838), 247–257. http://dx.doi.org/10.1016/S0140-6736(12)60646-1.

Harris, J.K., 2010. Connecting discovery and delivery: the need for more evidence on effective smoking cessation strategies for people living with HIV/AIDS. Am. J. Public Health 100 (7), 1245–1249. http://dx.doi.org/10.2105/ajph.2009.172460.

Harris, J.K., 2014. An Introduction to Exponential Random Graph Modeling. SAGE Publications, Inc., Thousand Oaks, CA.

Harris, J.K., Luke, D.A., Zuckerman, R.B., Shelton, S.C., 2009. Forty years of secondhand smoke research: the gap between discovery and delivery. Am. J. Prev. Med. 36 (6), 538–548. http://dx.doi.org/10.1016/j.amepre.2009.01.039.

Harris, J.K., Beatty, K.E., Lecy, J.D., Cyr, J.M., Shapiro, R.M., 2011. Mapping the multidisciplinary field of public health services and systems research. Am. J. Prev. Med. 41 (1), 105–111. http://dx.doi.org/10.1016/j.amepre.2011.03.015.

Kahn, E.B., Ramsey, L.T., Brownson, R.C., Heath, G.W., Howze, E.H., Powell, K.E., ... Corso, P., 2002. The effectiveness of interventions to increase physical activity. A systematic review. Am. J. Prev. Med. 22 (4 Suppl), 73–107. http://dx.doi.org/10.1016/S0749-3797(02)00434-8.

Kohl 3rd, H.W., Craig, C.L., Lambert, E.V., Inoue, S., Alkandari, J.R., Leetongin, G., Kahlmeier, S., 2012. The pandemic of physical inactivity: global action for public health. Lancet 380 (9838), 294–305. http://dx.doi.org/10.1016/S0140-6736(12)60898-8.

LaPorte, R.E., Montoye, H.J., Caspersen, C.J., 1985. Assessment of physical activity in epidemiologic research: problems and prospects. Public Health Rep. 100 (2), 131–146.

Lecy, J.D., Beatty, K.E., 2012. Representative Literature Reviews Using Constrained Snowball Sampling and Citation Network Analysis. (Available at SSRN 1992601).

Lecy, J.D., Moreda, D., 2011. cna: Citation Network Analyzer R package version 0.2.0.

Lee, I.M., Shiroma, E.J., Lobelo, F., Puska, P., Blair, S.N., Katzmarzyk, P.T., 2012. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. Lancet 380 (9838), 219–229. http://dx.doi.org/10.1016/s0140-6736(12)61031-9.

Morris, J.N., Heady, J.A., Raffle, P.A.B., Roberts, C.G., Parks, J.W., 1953. Coronary heart disease and physical activity of work. Lancet 262 (6796), 1111–1120. http://dx.doi.org/10.1016/S0140-6736(53)91495-0.

Morris, J.N., Heady, J.A., Raffle, P.A., Roberts, C.G., Parks, J.W., 1958. Coronary heart-disease and physical activity of work. Lancet 265 (6795), 1053–1057 (contd).

de Nazelle, A., Nieuwenhuijsen, M.J., Anto, J.M., Brauer, M., Briggs, D., Braun-Fahrlander, C., ... Lebret, E., 2011. Improving health through policies that promote active travel: a review of evidence to support integrated health impact assessment. Environ. Int. 37 (4), 766–777. http://dx.doi.org/10.1016/j.envint.2011.02.003.

Paffenbarger, R.S., Hale, W.E., 1975. Work activity and coronary heart mortality. N. Engl. J. Med. 292 (11), 545–550. http://dx.doi.org/10.1056/nejm197503132921101.

Paffenbarger Jr., R.S., Wing, A.L., Hyde, R.T., 1978. Physical activity as an index of heart attack risk in college alumni. Am. J. Epidemiol. 108 (3), 161–175.

Paffenbarger Jr., R.S., Blair, S.N., Lee, I.M., 2001. A history of physical activity, cardiovascular health and longevity: the scientific contributions of Jeremy N Morris, DSc, DPH, FRCP. Int. J. Epidemiol. 30 (5), 1184–1192.

Park, R.J., 1995. History of research on physical activity and health: selected topics, 1867 to the 1950s. Quest 47 (3), 274–287.

Pate, R.R., Pratt, M., Blair, S.N., Haskell, W.L., Macera, C.A., Bouchard, C., et al., 1995. Physical activity and public health. A recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine. JAMA 273 (5), 402–407.

Powell, K.E., Thompson, P.D., Caspersen, C.J., Kendrick, J.S., 1987. Physical activity and the incidence of coronary heart disease. Annu. Rev. Public Health 8, 253–287. http://dx.doi.org/10.1146/annurev.pu.08.050187.001345.

Pratt, M., Salvo, D., Cavill, N., Giles-Corti, B., McCue, P., Reis, R.S., ... Foster, C., 2016. An international perspective on the nexus of physical activity research and policy. Environ. Behav. 48 (1), 37–54.

Reis, R.S., Salvo, D., Ogilvie, D., Lambert, E.V., Goenka, S., Brownson, R.C., Committee, L.P.A.S.E., 2016. Scaling up physical activity interventions worldwide: stepping up to larger and smarter approaches to get people moving. Lancet 388 (10051), 1337–1348. http://dx.doi.org/10.1016/S0140-6736(16)30728-0.

Rutter, H., Savona, N., Glonti, K., Bibby, J., Cummins, S., Finegood, D.T., ... White, M., 2017. The need for a complex systems model of evidence for public health. Lancet. http://dx.doi.org/10.1016/s0140-6736(17)31267-9.

Saelens, B.E., Sallis, J.F., Frank, L.D., 2003. Environmental correlates of walking and cycling: findings from the transportation, urban design, and planning literatures. Ann. Behav. Med. 25 (2), 80–91.

Sallis, J.F., Owen, N., 1998. Physical Activity and Behavioral Medicine. vol. 3 SAGE publications.

Sallis, J.F., Cervero, R.B., Ascher, W., Henderson, K.A., Kraft, M.K., Kerr, J., 2006. An ecological approach to creating active living communities. Annu. Rev. Public Health 27, 297–322. http://dx.doi.org/10.1146/annurev.publhealth.27.021405.102100.

Sallis, J.F., Bowles, H.R., Bauman, A., Ainsworth, B.E., Bull, F.C., Craig, C.L., ... Bergman, P., 2009. Neighborhood environments and physical activity among adults in 11 countries. Am. J. Prev. Med. 36 (6), 484–490. http://dx.doi.org/10.1016/j.amepre.2009.01.031.

Sallis, J.F., Bull, F., Guthold, R., Heath, G.W., Inoue, S., Kelly, P., ... Hallal, P.C., 2016. Progress in physical activity over the Olympic quadrennium. Lancet 388 (10051), 1325–1326. http://dx.doi.org/10.1016/S0140-6736(16)30581-5.

Troiano, R.P., Berrigan, D., Dodd, K.W., Masse, L.C., Tilert, T., McDowell, M., 2008. Physical activity in the United States measured by accelerometer. Med. Sci. Sports Exerc. 40 (1), 181–188. http://dx.doi.org/10.1249/mss.0b013e31815a51b3.

WHO, 2015. Health in 2015: from MDGs, Millennium Development Goals to SDGs. In: Sustainable Development Goals. World Health Organization Retrieved from. http://apps.who.int/iris/bitstream/10665/200009/1/9789241565110_eng.pdf?ua=1.