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Review

Scientific production on indoor air quality of environments used for physical exercise and sports practice: Bibliometric analysis

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ABSTRACT

Introduction: In order to minimize adverse health effects and increase the benefits of physical activity, it is important to systematize indoor air quality study in environments used for physical exercise and sports.
Objectives: To investigate and analyze the scientific production related to indoor air quality of environments used for physical exercise and sports practice through a bibliometric analysis.
Methods: The databases Scielo, Science Direct, Scopus, Lilacs, Medline via Pubmed, and SportDiscus were searched from their inception to March 2016.
Bibliometric analysis was performed for authors, institutions, countries, and collaborative networks, in relation to publication year, theme, citation network, funding agency, and analysis of titles and keywords of publications. Country, area, and impact factor of the journals were analyzed.
Results: Of 1281 studies screened, 34 satisfied the inclusion criteria. The first publication occurred in 1975. An increase in publications was observed in the last 15 years. Most of the studies were performed by researchers in the USA, followed by Portugal and Italy. Seventeen different scientific journals have published studies on the subject, and most are in the area of Environmental Sciences. It was noted that the categories of author keywords associated with "Pollutants," "Sport Environment," and "Physical Exercise" were the most commonly used in most studies. A total of 68% of the studies had at least one funding agency, and 81% of studies published in the last decade had funding.
Conclusions: Our results demonstrate that there is recent exponential growth, driven in the last decade by researchers in environmental science from European institutions.

Contents

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1. Introduction

Physical exercise is important for maintaining good health, and the choice of practice environment has proven relevant, since the consequences of environmental pollution can affect the health of practitioners (Branis et al., 2009). Sports facilities have unique features according to the nature of exercise, energy consumption, and pattern of use (Revel and Arnesano, 2014).

Indoor air quality is determined by a combination of various pollutants from various sources, and is influenced by construction materials, building maintenance and ventilation type, and the type of activity performed and occupation by humans (Ramos et al., 2014). Studies indicate a relationship between human occupation and higher concentration of pollutants such as carbon dioxide (CO_2) and particulate matter (PM) (Buonanno et al., 2013; Ferro et al., 2004).

Literature evidence suggests that people exercising in polluted environments may be putting their health at risk (Ramos et al., 2014). During exercise, air tends to be inhaled through the mouth, not the nasal filtering mechanism. The increase in air flow velocity results in the transport of pollutants into the deepest part of the respiratory system (Carlisle and Sharp, 2001).

A growing number of studies analyzing indoor air quality in environments such as hospitals and nursing homes (Almeida-Silva et al., 2014; El-Sharkawy and Noweir, 2014), schools (Buonanno et al., 2013; Diapouli et al., 2008; Fuoco et al., 2015), kitchens (Buonanno et al., 2009) and offices (Zuraimi et al., 2006) have been performed. Indoor environments used for physical exercise and sports practice are important places to study air quality, as they contribute to the increase in total daily time people spend indoors, which reaches 95% of the day (Castro et al., 2015; Godoi et al., 2009).

Recently, researchers have systematically studied the association between air pollution and diseases such as diabetes (Eze et al., 2015), tuberculosis (Jafta, 2015), stroke (Shah et al., 2015), heart disease (Teng et al., 2014; Hu et al., 2014) and decline in cognitive function (Peters et al., 2015). The aim is to minimize the adverse health effects on exercise practitioners, but also to potentiate the physical activity benefits. The importance of systematizing indoor air quality study in environments used for physical exercise and sports practice is apparent, since relevant studies were not identified in a systematic literature review analyzing air quality in these environments.

Bibliometric analyzes are important tools to evaluate and quantify the growth of literature for a particular subject. Recently, the bibliometric method has been used in different contexts to investigate data showing increases in the number of publications, and identification of the main authors, research institutions, and countries investigating a topic (Bramness et al., 2013).

However, Hu et al. (2014) concluded that the literature is limited to presenting specific bibliometric analyses of journals or only a specific topic, to establish research trends or future directions. More information about institutions, authors and collaborators, author keyword, citation network, length, funding and journals should be introduced into the research trend study (Xie et al., 2008; Li et al., 2009).

To the best of our knowledge, there has been no previous bibliometric analysis of the scientific production in Environmental Science related to physical exercise and sports practice.

Therefore, this study aims to investigate and analyze the scientific production related to indoor air quality of environments used for physical exercise and sports practice through a bibliometric analysis. To accomplish this, we performed an in-depth analysis of publications, authors, and journals.

2. Methods

2.1. Search strategy

Representing a significant part of the world scientific production, the search for studies was performed using the following electronic databases: Scientific Electronic Library Online, SciELO (≅1156 periodicals and 479,891 articles), Science Direct (≅2500 periodicals and 13,397,561 articles), SCOPUS (21,000 titles from 5000 international publishers), Literatura Latino-Americana e do Caribe em Ciências da Saúde, LILACS (≅877 periodicals and 551,904 articles), Medical Literature Analysis and Retrieval System Online, MEDLINE (≅5600 periodicals and 21,000,000 articles) via PubMed (≅4916 periodicals and 3,300,000 articles), and SPORTDiscus (≅670 periodicals). We searched these databases from their inception through March 2016. The search terms used in the databases were {air pollution" OR "air pollutants" OR "air quality"} AND {"physical exercise" OR "physical activity" OR "sport"}. This strategy was permuted in all bases, with an integrated search in the fields title, abstract, and subject of each database.

2.2. Eligibility criteria

The following inclusion criteria were adopted: (i) original articles; (ii) articles investigating indoor environments used for physical exercise and sports practice; and (iii) full texts published in English. There were no restrictions on the date of publication.

Criteria for exclusion were: (i) review articles, (ii) articles investigating outdoor air quality of environments used for physical exercise and sports practice, and (iii) published papers with only English abstracts but without full texts in English.

2.3. Data extraction

The authors independently extracted data from included studies (differences were resolved by consensus). We screened all resulting titles and abstracts and reviewed full texts of articles that met our predetermined inclusion and exclusion criteria.

For bibliometric analysis and discussion, we defined the following categories and extracted the following data: year of publication, study theme (based on the title), number of citations in Web of Science (WoS), networks cited by the studies selected for review, the total number of references cited in each article, and the

study length (number of pages), title length (number of words), and number of tables and figures. In order to enhance the analysis of the main issues, we also surveyed the keywords used by the authors. These were later categorized and used to describe the association between words, in order to identify those that were most influential and important. We analyzed the funding of studies by identifying funding agencies, as reported in articles and Web of Science. For the authors, we extracted the following data: number of authors and institutions, country, and area. We identified the authors who published on the subject, their respective collaborative networks, and period of influence. For the journals, we collected data on: impact factor (IF), country, and area. The IF and the area of the journals were obtained by consulting Web of Science and SCImago, respectively.

2.4. Statistical analysis

Data analysis was conducted using *"Statistic Packcage for the Social Sciences"* (SPSS) for Windows version 20.0. For inferential analysis comparing studies published before 2005 and studies published in the last decade, independent t-tests and the Mann-Whitney *U* test were performed for comparison of means regarding the IF, number of citations in Web of Science, the number of authors and institutions, study length and title, number of tables, figures, and keywords. A chi-square test was performed to investigate the association between the presence of funding and the publication period. The significance level was defined as $p < 0.05$ for all tests.

3. Results

Our search identified a total of 1.281 articles, of which the full texts for 39 were reviewed, and 34 met the inclusion criteria. A flowchart of the study selection process is reported in Fig. 1.

3.1. Regarding the publications

The first publication occurred in 1975 (Fig. 2). An increase in publications was noted in the last 15 years, and 67.6% of the studies were published in the period 2000–2015 (23 studies). The studies found were only published in English.

We analyzed the network citations for 34 studies selected for review and the number of citations for each study in Web of Science (WoS) (Table 1). A study by Spengler et al. (1978) was cited in 7 other studies of the review, and was the study with the highest number of citations in WoS (31). A study by Lee et al. (1999) was cited 49 times in WoS, and was the most cited article in WoS among those selected. The study with the highest average citations per year was by Branis et al. (2009), with an average of 5 citations per year. The number of references cited in the first study was only 3, while the study with the largest number of references had 72 citations. The average number of references cited per article was 30.7.

Analysis of the network of citations between the selected articles found that 2 publications stand out (Fig. 3): Spengler et al. (1978) and Branis et al. (2009). The first group consists of authors who investigated air quality in indoor ice rinks. The second group of citations consisted of more recent studies, and consisted of authors who investigated the air quality in several indoor environments, such as gyms and fitness centers.

Analysis of the titles identified 2 main themes associated with the studies (Table 2). Twenty-one studies associated with pollutants (monitoring, effect), 10 associated with air quality (comfort, evaluation), and 3 related to practice (sport, exercise, and physical activity) were found.

The quantitative analysis of the number of words in the title, keywords, tables, figures, and pages has gained relevance in bibliometric studies (Brimblecombe and Grossi, 2009; Habibzadeh and Yadollahie, 2010) due to the use of these data to infer the scope and depth. Analysis of the selected publications found that the number of words in the title ranged from 5 to 19 (Table 3). Keywords started appearing in studies only since 1994, and in recent years have used between 5 and 6. The number of tables, figures, and pages was variable, since studies showed no tables in results (Žitnik et al., 2015) up to 7 (Johnson et al., 1975). Whereas early studies showed no figures (Spengler et al., 1978; Johnson et al., 1975), a recent study by Rajagopalan and Luther (2013) presented 22 figures. The number of pages ranged from 3 to 15 (median 7).

The survey of studies revealed 99 different keywords. We identified 12 categories of keywords (Fig. 4). Categories associated with keywords mentioned by the authors regarding "pollutants" were the most commonly used (48 related terms) in most studies (25 studies) (keywords such as "Carbon Monoxide," "Particulate Matter," and "Nitrogen Dioxide"). The categories of Environment Sports" (20 terms in 16 studies) (keywords such as "Gymnasiums" and "Fitness Centers"), and "Air Quality" (13 terms in 11 studies) were notable.

It was observed that 23 (68%) of the studies reported at least 1 funding agency, while 11 (32%) had none. Among the studies that reported funding, 15 (65%) had a funding agency, 5 (22%) had 2, and 3 (13%) had 3 agencies (Fig. 5). Of the 16 studies published by authors from institutions in Europe, 14 (87.5%) had a funding agency.

Countries with the largest number of funding agencies were Canada and the USA, with 3 different agencies (Table 4). However, the funding agencies that were most cited in the studies were the Portuguese Science Foundation (present in 5 studies), CESAM of the University of Aveiro of Portugal (4 studies), and the Spanish Ministry of Science and Innovation (4 studies).

For the inferential analysis, we observed a significant association between study period and the presence of funding (Table 5). Of the 13 studies published before 2005, 6 (46.2%) were funded. While 17 (81%) of the 21 studies published in the last decade had funding.

3.2. Regarding authors

The number of authors of studies varies from 2 to 10 (Table 6). We identified 114 different authors, of whom 17 were present in 2 different studies. The average number of authors per article was 4.3. We identified 55 different institutions, ranging from 1 to 6 involved in work. The internationalization of research was verified in 10 studies that showed the collaboration of institutions in different countries. We identified 16 different areas related to the institutions to which the authors of the articles belonged, the majority being in the area of Environmental Sciences.

Indoor air quality of environments used for physical exercise and sports practice is a research theme in several countries (Fig. 6). Most of the studies were conducted by researchers from the United States (10), followed by Portugal (6), and Italy (3).

Of the 114 different authors of publications on indoor air quality of environments used for physical exercise and sports, the most published on the subject was "John D. Spengler," with 7 studies. Also standing out were Y. Yanagisawa and K. Lee, with 5 studies for each author. However, the majority (97) of the researchers were the authors of only 1 study (Fig. 7).

It was possible to identify 2 main researchers from 2 different institutions (Harvard University School of Public Health and Center for Environmental and Marine Studies), with their respective networks of employees and periods of influence well-defined (Fig. 8). The researcher John D. Spengler (USA) has a network with 8 collaborators and the publication period of the studies was 1978–1994. While the research group of Célia Alves (Portugal), has

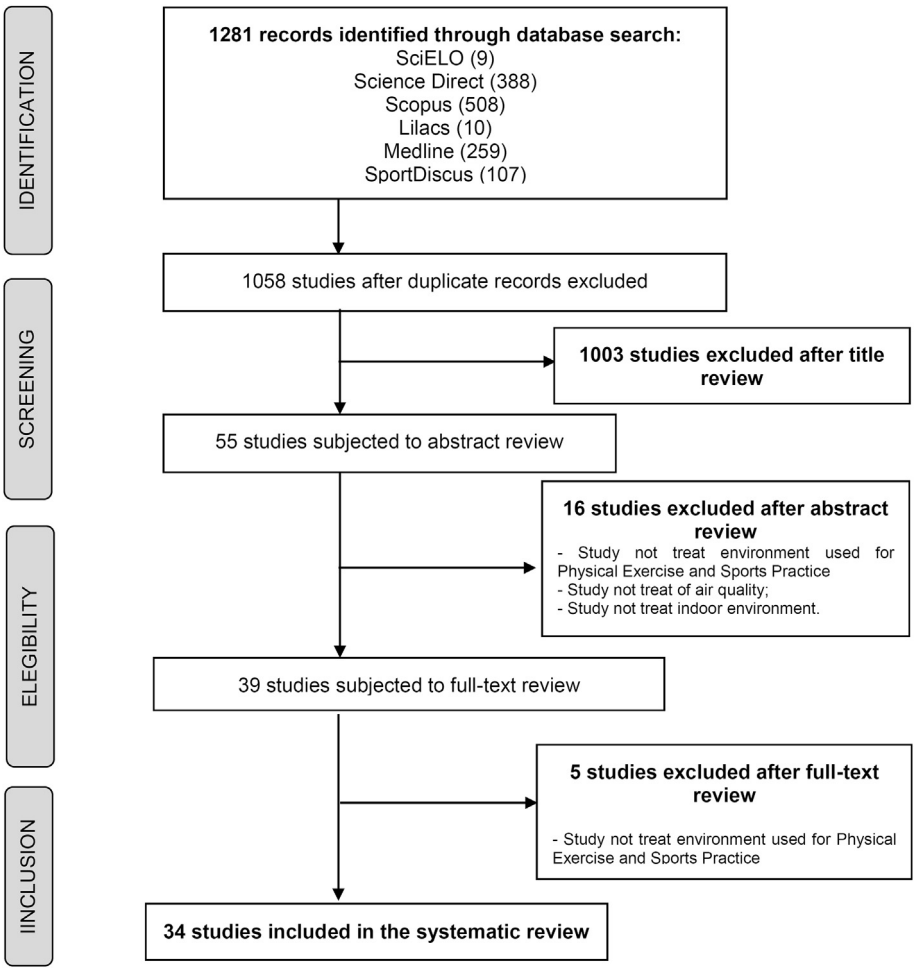

Fig. 1. Flow diagram illustrating literature research and selection process.

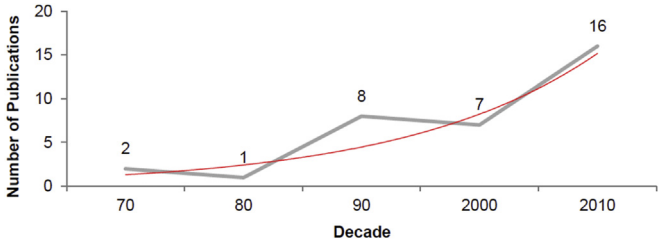

Fig. 2. Distribution of the number of publications related to indoor air quality of environments used for physical exercise and sport practice, by decade. *The red line represents the exponential fit of the number of publications. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

a network of 14 collaborators, with recent publications from 2010 to 2015.

3.3. Regarding the journals

It was observed that 17 different scientific journals had published studies on the subject. Journals with more publications were *Building and Environment* and *Environment International*, with 5 and 4 articles, respectively. The impact factor of journals varied from 0.47 to 5.92. The Netherlands and the United Kingdom were the countries with the highest number of journals. Most were in the area of Environmental Sciences (Table 7).

Studies published before 2005 had a higher number of citations in Web of Science ($p < 0.01$) compared to those published in the last decade (2005–2015). In the last decade, studies have been longer ($p < 0.01$), with more pictures ($p < 0.05$) and keywords ($p < 0.01$), compared to older studies (Fig. 9).

4. Discussion

Considering the importance of air quality related to physical exercise and sports, the aim of this study was to investigate and analyze the scientific production related to indoor air quality of environments used for physical exercise and sports practice, to develop a bibliometric analysis. Bibliometric data analyzed were related to publications, authors, and journals.

4.1. Publications: history, network citations, keywords, themes, and funding of research

The number of identified studies ($n = 34$) shows that although there are few publications on the subject, there is growth in scientific production. Most of the studies were published in the last decade, especially in 2014 and 2015. The pioneering study of indoor air quality of environments used for physical exercise and sports practice by Johnson et al. (1975) investigated the CO in ice skating rinks in the United States and how to reduce toxic levels of the

Table 1
Indoor air quality of environments used for physical exercise and sports practice: Citations between publications and in Web of Science.

Ref	Reference	Cited by	N. of citations	Studies that reference quotes	N. of ref. that the study cites	N. cit WoS	N. cit WoS/ year	Total number of cited references
34	Zhai et al. (2015)	–	–	27	1	0	0	32
33	Žitnik et al. (2015)	–	–	18,20,28	3	–	–	28
32	Lühe et al. (2015)	–	–	–	–			25
31	Goung et al. (2015)	–	–	–	–	1	0.50	18
30	Castro et al. (2015)	–	–	18,20,22,25	4	0	0	35
29	Ramos et al. (2015)	–	–	21,28	2	0	0	48
28	Ramos et al. (2014)	29,33	2	18,20,21,27	4	3	1.50	72
27	Revel and Arnesano (2014)	28,34	2	24	1	7	3.50	27
26	Martins et al. (2014)	–	–	–	–	–	–	9
25	Alves et al. (2014)	30	1	13,16,18,20,21,22	5	1	0.33	48
24	Rajagopalan and Luther (2013)	27	1	–	–	7	3.50	18
23	Bisht et al. (2013)	–	–	–	–	2	0.67	38
22	Alves et al. (2013)	25,30	2	18,21	2	5	1.67	41
21	Buonanno et al. (2012)	22,25,26,29	4	18	1	6	1.50	39
20	Braniš and Šafránek (2011)	28,30,33	1	18		22	3.67	49
19	Viegas et al. (2010)	–	–	–	–	2	0.33	38
18	Branis et al. (2009)	20,21,22,28,30,31,33	7	–	–	35	5.00	32
17	Hug et al. (2008)	–	–	–	–	–	–	52
16	Salonen et al. (2008)	25	1	7,8,10,13	3	8	1.00	33
15	Stathopoulou et al. (2008)	–	–	–	–	7	0.88	36
14	Game and Bell (2006)	–	–	–	–	5	0.50	34
13	Guo et al. (2004)	16,25	2	2,4,5,7,9	5	14	1.08	31
12	Dacarro et al. (2003)	–	–	–	–	25	1.92	42
11	Lee et al. (1999)	–	–	–	–	49	2.88	12
10	Levy et al. (1998)	16	1	5,7,8,9	4	18	1	27
9	Yoon et al. (1996)	10	1	1,2,4,5,6,7,8	7	9	0.45	16
8	Lee et al. (1994a,b)	9,16	2	1,2,4	3	4	0.18	16
7	Brauer and Spengler (1994)	6,9,16	3	2,4,5	3	29	1.32	36
6	Lee et al. (1994a,b)	9	1	2,4,5,7	4	28	1.27	27
5	Lee et al. (1993)	3,6,7,9,10	5	1,2,4	3	12	0.52	10
4	Lévesque et al. (1990)	5,6,7,8,9	5	1,2	2	26	0.96	36
3	Georghiou et al. (1989)	–	–	2	1	3	0.11	18
2	Spengler et al. (1978)	3,4,5,6,7,8,9,13	8	1	1	31	0.82	20
1	Johnson et al. (1975)	2,5,8,9	4	–	–	20	0.48	3

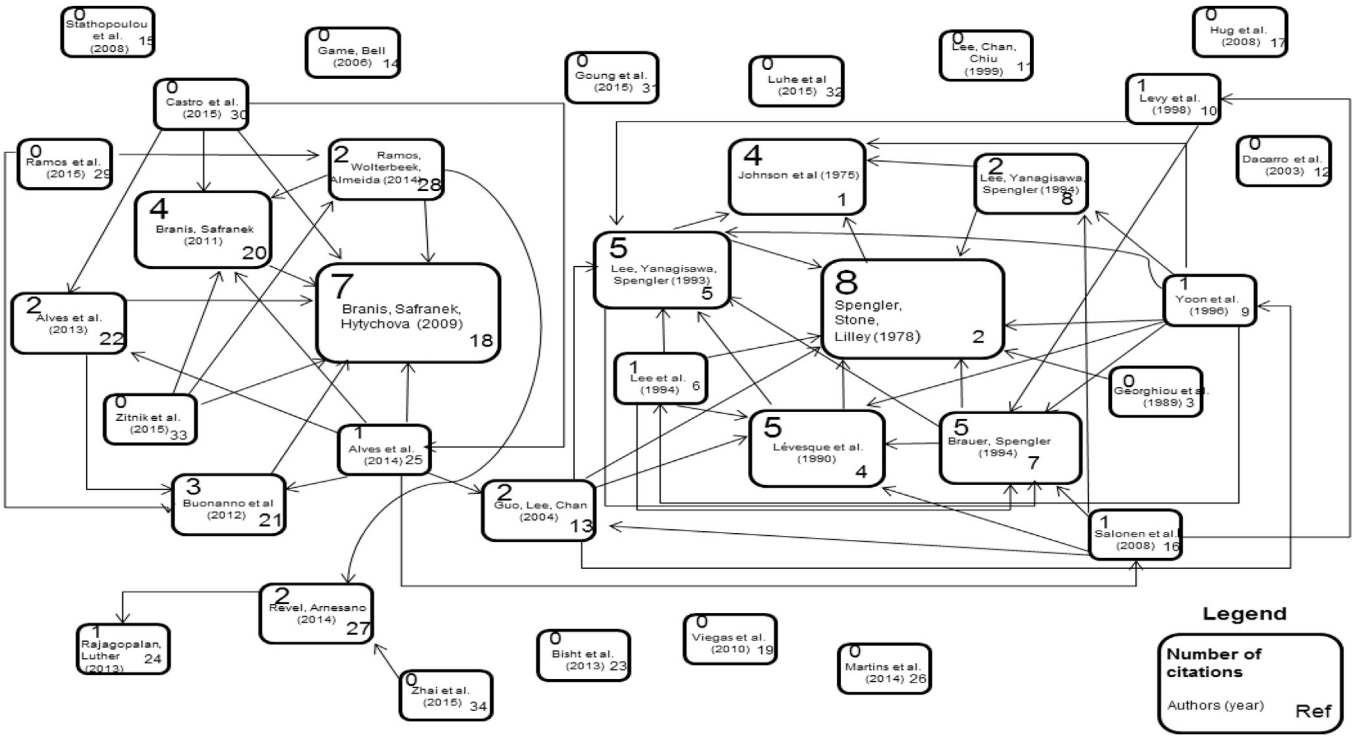

Fig. 3. Citation network between publications of indoor air quality of environments used for physical exercise and sports practice.

Table 2
Indoor air quality of environments used for physical exercise and sports practice: title and theme of the selected studies.

Reference	Title	Theme
Zhai et al. (2015)	Using **air movement** for comfort during moderate exercise	Air Quality
Žitnik et al. (2015)	**Exercise-induced effects** on a gym atmosphere	Physical Exercise
Lühe et al. (2015)	Factors associated with **dust dispersed** in the air of indoor riding arenas	Pollutants
Goung et al. (2015)	A pilot study of indoor **air quality** in screen golf courses	Air Quality
Castro et al. (2015)	Indoor **aerosol size** distributions in a gymnasium	Pollutants
Ramos et al. (2015)	Estimating the inhaled dose of **pollutants** during indoor physical activity	Pollutants
Ramos et al. (2014)	Exposure to indoor **air pollutants** during physical activity in fitness centers	Pollutants
Revel and Arnesano (2014)	Perception of the **thermal environment** in sports facilities through subjective approach	Air Quality
Martins et al. (2014)	**BTEX** inside a spinning classroom	Pollutants
Alves et al. (2014)	**Particulate matter** in the indoor and outdoor air of a gymnasium and a fronton	Pollutants
Rajagopalan and Luther (2013)	**Thermal** and ventilation performance of a naturally ventilated sports hall within an aquatic centre	Air Quality
Bisht et al. (2013)	Assessment of **air quality** during 19th Common Wealth Games at Delhi, India	Air Quality
Alves et al. (2013)	Indoor **air quality** in two university sports facilities	Air Quality
Buonanno et al. (2012)	**Particle resuspension** in school gyms during physical activities	Pollutants
Braniš and Šafránek (2011)	Characterization of coarse **particulate matter** in school gyms	Pollutants
Viegas et al. (2010)	Prevalence of **fungi in indoor** air with reference to gymnasiums with swimming pools	Pollutants
Branis et al. (2009)	Exposure of children to airborne **particulate matter** of different size fractions during indoor physical education at school	Pollutants
Hug et al. (2008)	Restorative **effects of physical activity** in forests and indoor settings	Physical Activity
Salonen et al. (2008)	Health risk assessment of indoor **air pollution** in Finnish ice arenas	Pollutants
Stathopoulou et al. (2008)	An experimental study of **air quality** inside large athletic halls	Air Quality
Game and Bell (2006)	The effect of a **competitive season** and environmental factors on pulmonary function and aerobic power in varsity hockey players	Sport
Guo et al. (2004)	Indoor **air quality** in ice skating rinks in Hong Kong	Air Quality
Dacarro et al. (2003)	Determination of **aerial microbiological** contamination in scholastic sports environments	Pollutants
Lee et al. (1999)	Indoor and outdoor **air quality** investigation at 14 public places in Hong Kong	Air Quality
Levy et al. (1998)	Determinants of **nitrogen dioxide** concentrations in indoor ice skating rinks	Pollutants
Yoon et al. (1996)	Surveillance of **indoor air quality** in ice skating rinks	Air Quality
Lee et al. (1994a,b)	Reduction of **air pollutant** concentrations in an indoor ice-skating rink	Pollutants
Brauer and Spengler (1994)	**Nitrogen dioxide** exposures inside ice skating rinks	Pollutants
Lee et al. (1994a,b)	**Carbon monoxide** and nitrogen dioxide exposures in indoor ice skating rinks	Pollutants
Lee et al. (1993)	**Carbon monoxide** and nitrogen dioxide levels in an indoor ice skating rink with mitigation methods	Pollutants
Lévesque et al. (1990)	**Carbon Monoxide** in Indoor Ice Skating Rinks - Evaluation of Absorption by Adult Hockey Players	Pollutants
Georghiou et al. (1989)	Air Levels and Mutagenicity of **PM-10** in an Indoor Ice Arena	Pollutants
Spengler et al. (1978)	High **carbon monoxide** levels measured in enclosed skating rinks	Pollutants
Johnson et al. (1975)	Abatement of toxic levels of **carbon monoxide** in Seattle ice-skating rinks	Pollutants

Table 3
Length of title, keywords, number of tables and figures, and length of publications (pages) on indoor air quality of environments used for physical exercise and sports practice.

Reference	Lenght of title	N. of keywords	N. of Tables	N. of Figures	Lenght (pages)
Zhai et al. (2015)	8	5	4	11	9
Žitnik et al. (2015)	7	6	0	8	10
Lühe et al. (2015)	12	6	2	3	6
Goung et al. (2015)	11	6	3	0	7
Castro et al. (2015)	7	6	5	3	9
Ramos et al. (2015)	10	6	4	4	8
Ramos et al. (2014)	11	5	5	10	12
Revel and Arnesano (2014)	11	6	6	8	8
Martins et al. (2014)	5	4	2	1	3
Alves et al. (2014)	14	6	4	7	13
Rajagopalan and Luther (2013)	14	5	4	22	12
Bisht et al. (2013)	12	4	2	5	14
Alves et al. (2013)	8	5	2	2	8
Buonanno et al. (2012)	8	5	5	2	12
Braniš and Šafránek (2011)	8	5	3	3	7
Viegas et al. (2010)	13	6	2	2	7
Branis et al. (2009)	17	5	3	3	7
Hug et al. (2008)	10	5	7	0	14
Salonen et al. (2008)	11	5	5	1	7
Stathopoulou et al. (2008)	10	5	6	3	15
Game and Bell (2006)	19	5	3	0	7
Guo et al. (2004)	10	4	3	5	9
Dacarro et al. (2003)	9	3	4	0	9
Lee et al. (1999)	13	1	3	2	8
Levy et al. (1998)	10	5	3	3	6
Yoon et al. (1996)	9	2	2	1	6
Lee et al. (1994a,b)	11	0	4	3	9
Brauer and Spengler (1994)	7	7	2	1	5
Lee et al. (1994a,b)	11	6	2	2	5
Lee et al. (1993)	15	0	1	1	3
Lévesque et al. (1990)	14	0	3	2	5
Georghiou et al. (1989)	11	0	1	1	3
Spengler et al. (1978)	9	0	4	0	4
Johnson et al. (1975)	12	0	7	0	4

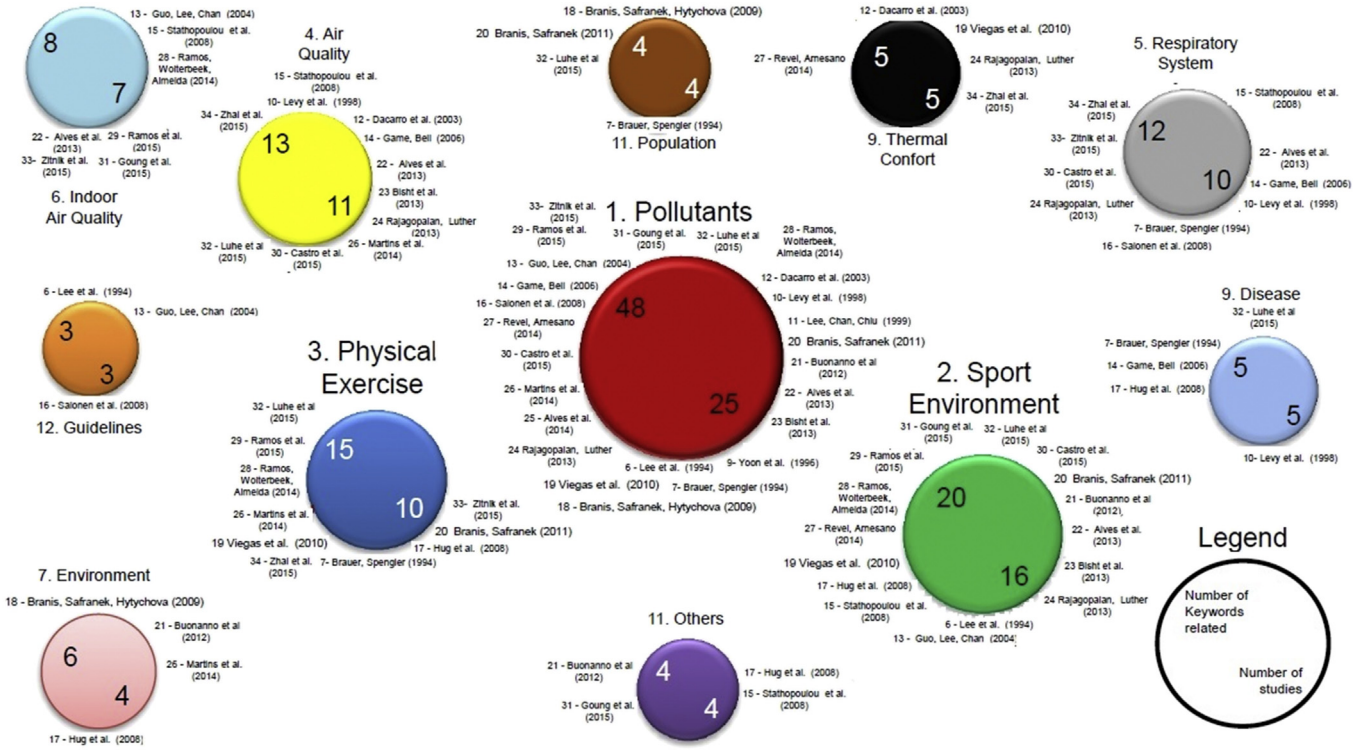

Fig. 4. Categories of keywords.

pollutant. The second published study, by Spengler et al. (1978), was notable for the number of citations in WoS, and among the selected articles was one of the most cited studies in the literature on the subject; it is characterized as a classic study in this field, and is still being cited in recent studies. This study verified the effect of the ice-resurfacing process on the CO concentration in the environment. These initial studies support the analysis of the subject and title related to pollutants (effect and monitoring). Older studies showed a higher number of citations in relation to studies published in the last decade; this was an expected result due to the length of time that the first studies have been available for citation in databases.

The predominance of research through the 1990s focused on ice rinks due to high levels of CO, nitrogen dioxide (NO_2), and particulate matter (PM). According to a review by Pelham et al. (2002), CO is the gas most cited in academic reports and in the media as responsible for polluting ice rinks. CO is also cited in a number of other publications selected in this review. This pollutant reduces the blood's ability to carry oxygen (Who, 2013) and can cause nausea and dizziness, while NO2 at high levels in the indoor environment is associated with asthma symptoms (Cibella et al., 2015; Kattan et al., 2007). These pollutants are harmful to human health, especially when high concentrations occur indoors (Gillespie-Bennett et al., 2011).

The concentration of these pollutants in rinks depends on the type of fuel used in equipment for ice resurfacing, frequency of use, and degree of ventilation of the sports facility (Lee et al., 1993). Equipment powered by propane emits more NO_2 compared to that powered by gasoline, which emits more CO, hydrocarbons (HC) and PM (Brauer and Spengler, 1994). Only the first publications in the review were conducted in ice rinks, with no recent publications; thus, it appears that the problem of pollutant emissions by equipment may have been solved through the use of electrically-powered ice-resurfacing, as suggested in the first study (Johnson et al., 1975).

The study by Branis et al. (2009) had the highest number of citations in WoS/year. This work aimed to evaluate the exposure of children to PM with a diameter less than 2.5 μm in a school gym during exercise in physical education classes.

An important aspect of this study is the relationship of citations between authors, and these types of relationships are defined as scientific collaboration networks (Newman, 2001). The scientific collaboration networks responsible for the largest number of publications have been established by authors belonging to only one institution and that predominate in relation to citations for a certain period of time.

With the analysis of the author keywords, it is possible to identify and quantify the trend of certain scientific field research (Wang et al., 2014). Keyword investigation helps researchers choose keywords related to new publications, and contributes to database access with the correct term for the research theme (Blank et al., 2016). Moreover, some databases do not show the full text of articles; therefore, keywords refine the search strategy and

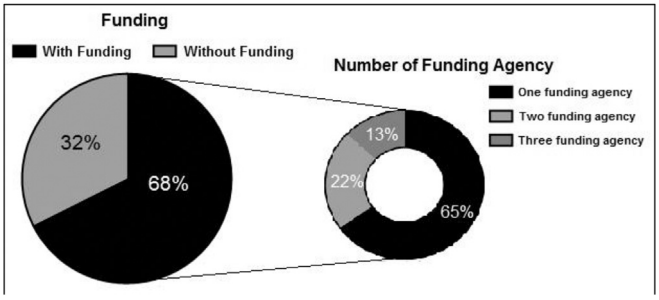

Fig. 5. Funding of publications of indoor air quality of environments used for physical exercise and sports practice.

Table 4
Funding of publications of indoor air quality of environments used for physical exercise and sports practice: Number of agencies by country, agencies, and funded studies.

N. of Agencies	Country	Agencies	Funded Studies
3	Canada	Sports Science Association of Alberta	Game and Bell (2006)
		Fonds pour la Formation de Chercheurs et l'Aide a la Recherche	Lévesque et al. (1990)
		Supply and Services Canada	Georghiou et al. (1989)
3	USA	Big Ass Solutions	Zhai et al. (2015)
		Center for the Built Environment	
		Metropolitan District Commission	Levy et al. (1998)
3	Finland	Finnish Ice Hockey Foundation	Salonen et al. (2008)
		Ministry of Education	
		Ministry of Social Affairs and Health	
2	Brazil	CNPq	Martins et al. (2014)
		FAPERJ	
2	Spain	Fundacion Ramon Areces	Castro et al. (2015)
			Goung et al. (2015)
		Spanish Ministry of Science and Innovation	Castro et al. (2015)
			Goung et al. (2015)
			Alves et al. (2014)
			Alves et al. (2013)
2	Europe	EU SportE2	Revel and Arnesano (2014)
		European Social Fund	Stathopoulou et al. (2008)
2	Portugal	Centre for Environmental and Marine Studies (CESAM) of the University of Aveiro	Castro et al. (2015)
			Goung et al. (2015)
			Alves et al. (2014)
			Alves et al. (2013)
		Portuguese Science Foundation	Ramos et al. (2015)
			Ramos et al. (2014)
			Alves et al. (2014)
			Alves et al. (2013)
			Buonanno et al. (2012)
1	Germany	H. Wilhelm Schaumann Stiftung	Lühe et al. (2015)
1	China	Hong Kong Polytechnic University	Guo et al. (2004)
			Lee et al. (1999)
1	Slovenia	P1-0112 research programme of the Slovenian Research Agency	Žitnik et al. (2015)
1	Greece	IRAKLEITOS	Stathopoulou et al. (2008)
1	Italy	University of Pavia	Dacarro et al. (2003)
1	Czech Republic	Ministry of Education, Youth and Sport of the Czech Republic	Braniš and Šafránek (2011)
			Branis et al. (2009)

Table 5
Association between study period and the presence of funding.

	Before 2005	Last Decade	p
Without Funding	7 (53.8%)	4 (19%)	0.04*
With Funding	6 (46.2%)	17 (81%)	

*Significant difference at $p < 0.05$.

retrieve studies that are related to the topic. Identifying publication themes from keywords is an important means of enhancing visibility and scientific communication, thereby promoting higher quality research and discussion.

Our study revealed that most of the keywords and themes extracted by the title are related to pollutants. Based on this analysis, research in the field of indoor air quality of environments used for physical exercise and sports practice shows a focus on the study of pollutants (monitoring and effect), and little has been produced on the relationship with human health and the respiratory system in this type of environment, as demonstrated by few keywords and studies associated with the respiratory system and diseases.

Studies have highlighted Europe in relation to the funding of research and scientific development (Luukkonen, 2014). Scientific progress is one of the most important indicators of community and economic development in different countries (Lin and Rosenblatt, 2012). It is important to emphasize the need to continue the production of scientific knowledge on air quality, since pollution can have a major impact on public health and is showing alarming levels in some countries (Lü et al., 2015).

The last decade of publications on indoor air quality of environments used for physical exercise and sports practice showed funding in most studies, indicating an increase by funding agencies over time, but the articles do not report the amounts of funding. There is no doubt that with more publications and knowledge about how air quality affects health and sports performance, there may be greater investment for the financing of future studies.

4.2. Authors: network of institutions and collaborators, countries and areas

There has been a growth in production in the last decade, especially in publications by authors from Europe, with 21 countries and authors from 27 research institutions. These results are related to the ranking of countries with environmental concerns, with a predominance of European countries. This ranking considers the Environmental Performance Index and the number of articles published per one million inhabitants of the country (Dragos and Dragos, 2013).

A study of 357 cities in 33 European countries in 2009 showed that almost 83% of the population was exposed to PM_{10} levels exceeding WHO guidelines (Who, 2013). This may explain the growth of research on air quality in Europe in the last decade, also stimulated by the presence of funding agencies in the most developed research environments. Some European countries, such as the UK, have dual support systems for the funding of research at universities, which include institutional funding, grants, and contracts (Geuna and Martin, 2003).

The USA has pioneered in research on the subject, as all the

Table 6
Indoor air quality of environments used for physical exercise and sports practice: number of authors and institutions, country, and area.

Reference	N. authors	N. of Institutions	Country of Institutions	Authors Area
Zhai et al. (2015)	6	2	USA/China	Arch
Žitnik et al. (2015)	10	6	Slovenia	Med, Elec Eng,Mat
Lühe et al. (2015)	5	3	Germany	Vet
Goung et al. (2015)	4	3	South Korea	Envi Sci, Pub Healt
Castro et al. (2015)	9	3	Spain/Portugal	Phys, Env Eng
Ramos et al. (2015)	6	3	Portugal/Netherlands	Phys Ed, Chem
Ramos et al. (2014)	3	2	Portugal/Netherlands	Chem
Revel and Arnesano (2014)	2	1	Italy	Eng
Martins et al. (2014)	6	2	Brasil	Env Eng, Tech
Alves et al. (2014)	7	3	Portugal/Spain	Env Eng
Rajagopalan and Luther (2013)	2	1	Australia	Arch
Bisht et al. (2013)	4	2	India	Geo, Met
Alves et al. (2013)	6	2	Portugal/Spain	Phys, Env Eng
Buonanno et al. (2012)	4	2	Italy/Australia	Mec Eng, Tech
Braniš and Šafránek (2011)	2	1	Czech Republic	Envi Sci, Phys Ed
Viegas et al. (2010)	5	3	Portugal	Pub Healt
Branis et al. (2009)	3	1	Czech Republic	Envi Sci, Phys Ed
Hug et al. (2008)	5	3	Swiss	Envi Sci
Salonen et al. (2008)	6	3	Finland	Pub Healt, Med
Stathopoulou et al. (2008)	4	2	Greece	Phys, Env Eng
Game and Bell (2006)	2	1	Canada	Phys Ed
Guo et al. (2004)	3	1	Hong Kong	Eng
Dacarro et al. (2003)	4	1	Italy	Bio
Lee et al. (1999)	3	1	Hong Kong	Eng
Levy et al. (1998)	5	4	USA/Australia	Envi Sci, Pub Healt
Yoon et al. (1996)	5	2	USA	Envi Sci
Lee et al. (1994a,b)	3	1	USA	Envi Sci
Brauer and Spengler (1994)	2	2	USA/Canada	Med, Envi Sci
Lee et al. (1994a,b)	4	1	USA	Envi Sci
Lee et al. (1993)	3	1	USA	Envi Sci
Lévesque et al. (1990)	5	1	Canada	Envi Sci
Georghiou et al. (1989)	5	3	USA	Chem; Envi Sci
Spengler et al. (1978)	3	3	USA	Envi Sci
Johnson et al. (1975)	5	1	USA	Pub Healt

Abbreviations: Production of the authors. USA = United States of America; Envi Sci: Environmental Science; Chem: Chemistry; Med: Medicina; Eng = Engineering; Phys Ed = Physical Education; Env Eng: Environmental Engineering; Pub Healt = Public Health; Mec Eng: Mechanical Engineering; Elec Eng: Electrical engineering; Geo: Geophysics; Bio = Biology; Phys: Physical; Met: Meteorology; Tech: Technology; Arch: Architecture; Mat: Math; Vet: Veterinary.

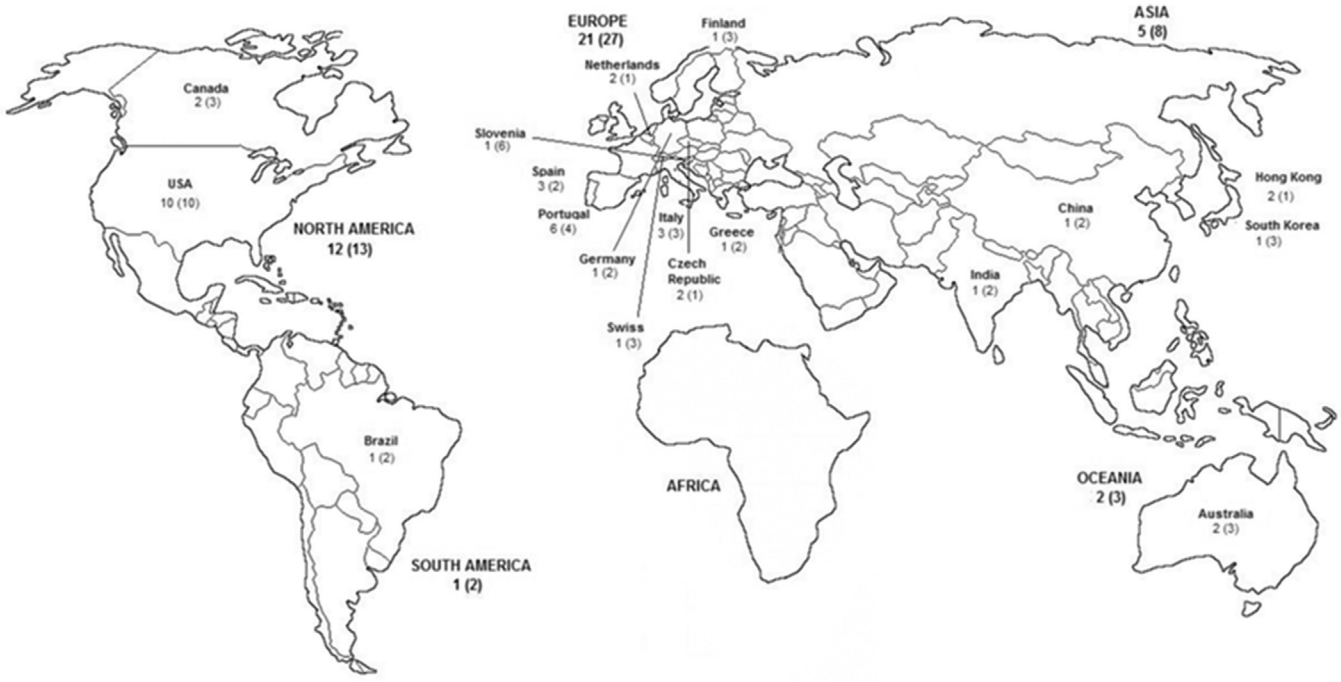

Fig. 6. Global geographical distribution of studies of indoor air quality of environments used for physical exercise and sports practice. Number of publications (number of institutions) by country and continent.

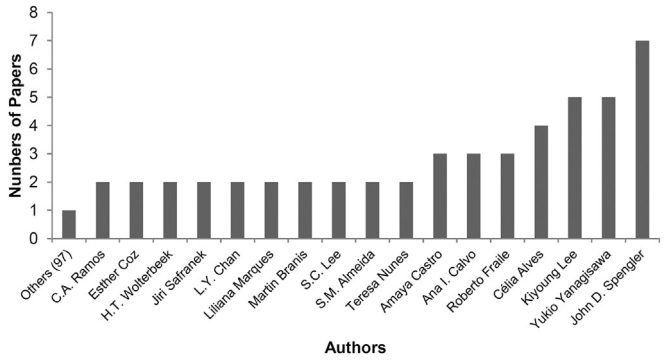

Fig. 7. Number of publications by author.

research on air quality in Brazil. Among these are the lack of specific legislation for the adoption of standards and methodology for sampling of organic compounds, and the lack of funding for research in this area.

Several institutions and research groups from different areas and countries have published studies on air quality. The air quality was investigated in research institutions in 18 countries, and the papers were published in journals with a high impact factor, demonstrating international research activity on the subject. Of the 114 different authors, 97 (85%) published only 1 article, and only 17 (14.9%) published at least 2 different studies. Thus, a small percentage of the authors was responsible for most of the publications.

4.3. Journals: relevance, impact factor, countries, and areas

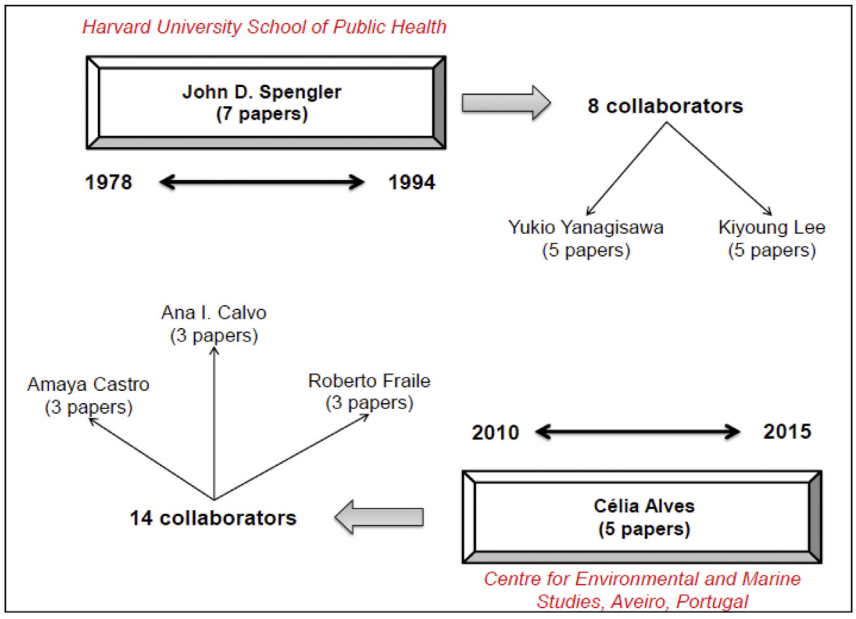

Fig. 8. Main authors, network collaboration, and period of publications.

initial studies from this country were investigations of indoor ice rinks (Lee et al., 1993; Levy et al., 1998). Among the first 10 studies in the review, John D. Spengler was the author or co-author of 7 studies; he is a professor at Harvard University School of Public Health, based in the Department of Environmental Health. This author was the most cited from the review of studies, with 20 citations.

Studies on the subject have been developed jointly by researchers from different institutions. In this regard, we emphasize the study of Žitnik et al. (2015), which was carried out with the collaboration of 10 authors from 6 different institutions in Slovenia. It was also observed that 9 of the 34 studies was conducted in partnership with institutions from different countries, especially Portugal, which was involved in 5 of these studies.

Analysis of the scientific literature on air quality in South America identified only one study that investigated the indoor quality of environments used for physical exercise and sports practice. Considering the growing number of environments such as fitness centers and gyms, Brazil has the second highest number of fitness centers, behind only the USA (IHRSA, 2013).It is necessary and relevant to perform and publish more research on air quality related to physical exercise in Brazil. Schirmer et al. (2011) concluded that there are limiting factors for the development of

Building and Environment was the journal that published most studies on the subject, and had a study with a larger number of citations, reflecting activity in other fields of research (Peset et al., 2013); an article of higher quality published in a periodical with a high impact factor becomes a reference for other studies.

The studies related to the subject are published in the most relevant journals in the environmental area. We showed that of 34 studies identified, 33 had an Impact Factor (IF). The journal *Environment International* has the highest IF (5.92), with 4 studies published, and is one of the most important journals in the field of Environmental Science. These results demonstrate the importance of this issue for this area of research. The IF, published by Web of Science, is one of the most cited data used in bibliometric studies (Tan et al., 2014). It is a tool for classification, evaluation, and comparison of scientific journals, and is a measure of the frequency with which the article has been cited in a year or other specific period in a journal (Bramness et al., 2013).

Most studies (18 in total) had been published in journals of European countries. In fact, in the area of Environmental Sciences, the most relevant journals, according to SCImago, are from the UK and the Netherlands, in addition to the USA. Although there is a prevalence of journals about environmental sciences and engineering, the fact that studies are published in journals indexed as

Table 7
Indoor air quality of environments used for physical exercise and sports practice: Impact Factor (IF), country, and area of journals.

Reference	Journals	IF	Country	Área
Zhai et al. (2015)	Building and Environment	3,39	Netherlands	Eng; Envi Sci
Žitnik et al. (2015)	Indoor Air	4,33	Dinamarca	Eng
Lühe et al. (2015)	Equine Veterinary Journal	2,47	UK	Vet
Goung et al. (2015)	Environmental Science and Pollution Research	2,76	USA	Envi Sci
Castro et al. (2015)	Science of the Total Environment	3,90	Netherlands	Envi Sci
Ramos et al. (2015)	Science of the Total Environment	3,90	Netherlands	Envi Sci
Ramos et al. (2014)	Building and Environment	3,39	Netherlands	Eng; Envi Sci
Revel and Arnesano (2014)	Building and Environment	3,39	Netherlands	Eng; Envi Sci
Martins et al. (2014)	Cadernos Saúde Coletiva	0,47	Brazil	Pub Healt
Alves et al. (2014)	Environmental Science and Pollution Research	2,76	USA	Envi Sci
Rajagopalan and Luther (2013)	Energy and Buildings	2,97	Netherlands	Eng
Bisht et al. (2013)	Natural Hazards	1,74	Netherlands	Planet Sci; Envi Sci
Alves et al. (2013)	Aerosol and Air Quality Research	2,39	Taiwan	Envi Sci
Buonanno et al. (2012)	Aerosol and Air Quality Research	2,39	Taiwan	Envi Sci
Braniš and Šafránek (2011)	Environmental Research	3,08	EUA	Envi Sci
Viegas et al. (2010)	Indoor and Built Environment	0,94	UK	Med
Branis et al. (2009)	Building and Environment	3,39	Netherlands	Eng; Envi Sci
Hug et al. (2008)	International Journal of Fitness	–	India	Phys Ed
Salonen et al. (2008)	Environment International	5,92	UK	Envi Sci
Stathopoulou et al. (2008)	Building and Environment	3,39	Netherlands	Eng; Envi Sci
Game and Bell (2006)	Applied Physiology, Nutrition, and Metabolism	2,22	Canada	Phys Ed, Nut
Guo et al. (2004)	Environmental Research	3,08	USA	Envi Sci
Dacarro et al. (2003)	Journal of Applied Microbiology	2,15	UK	Bio
Lee et al. (1999)	Environment International	5,92	UK	Envi Sci
Levy et al. (1998)	American Journal of Public Health	4,13	USA	Pub Healt
Yoon et al. (1996)	Environment International	5,92	UK	Envi Sci
Lee et al. (1994a,b)	Environment International	5,92	UK	Envi Sci
Brauer and Spengler (1994)	American Journal of Public Health	4,13	USA	Med
Lee et al. (1994a,b)	Journal of Sport Sciences	2,14	UK	Phys Ed
Lee et al. (1993)	Journal of the Air and Waste Management Association	1,61	USA	Envi Sci
Lévesque et al. (1990)	American Journal of Public Health	4,13	USA	Med
Georghiou et al. (1989)	Journal of the Air and Waste Management Association	1,61	USA	Envi Sci
Spengler et al. (1978)	Journal of the Air and Waste Management Association	1,61	USA	Envi Sci
Johnson et al. (1975)	American Journal of Public Health	4,13	USA	Med

Abbreviations: Production of the authors. Legend: IF = Impact Factor; USA = United States of America; UK = United Kingdom; Envi Sci: Environmental Science; Phys Ed = Physical Education; Pub Healt = Public Health; Bio = Biology; Nut = Nutrition; Eng = Engineering; Med: Medicine; Planet Sci: Planetary Sciences; Vet = Veterinary.

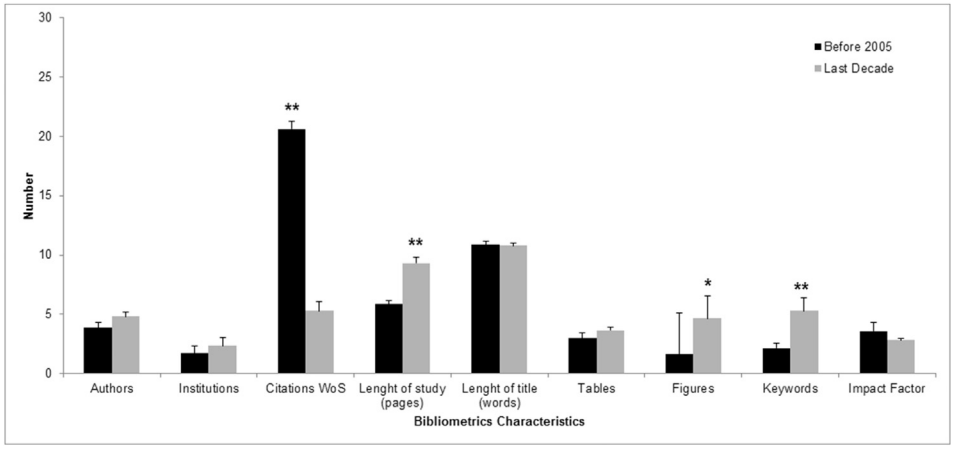

Fig. 9. Comparison of means of studies published before 2005 and studies published in the last decade, regarding the impact factor, number of citations in Web of Science, number of authors and institutions, study length and title, number of tables, figures, and keywords. * Significant difference at $p < 0.05$. ** Significant difference at $p < 0.01$.

physical education and medicine demonstrates the relevance of the subject to these two areas.

Although most journals, institutions, and authors belong to the area of environmental sciences, this is an area where the use of bibliometry is relatively recent, and has been applied rarely to environment science (Sheehan et al., 2016). Our study seeks to innovate because it develops bibliometric analysis, with unrevealing searches in this form in the literature to date.

4.4. Limitations

This systematic review was limited to analysis of the bibliometric data on scientific production about air quality in indoor environments used for physical exercise and sports. Data from instruments, pollutants, and outcomes need to be analyzed in future investigations.

5. Conclusion

Our results for 16 analyses of publications, authors, and journals provide an overview of the international literature on indoor air quality of environments used for physical exercise and sports practice demonstrate that this is a recent exponential growth theme, driven in the last decade mainly by researchers from European institutions. For 40 years, researchers mainly in the environmental sciences have published in important journals, showing that air quality study is a globally relevant research topic. The publications demonstrate a focus on pollutants, with sports environments and air quality as themes, highlighting authors of the United States, Portugal, and Italy.

Additionally, these bibliometric approaches allowed us to recognize two well-defined groups of collaborators that investigated indoor air quality of physical exercise and sports practice environments. These groups worked in different countries, and had different periods of influence and focus. In analyzing the data extracted from the studies, we hypothesized that the initial research by Dr. Spengler's group helped environmental managers to solve the problem of pollutant emissions caused by equipments in ice rinks.

The scientific production on air quality in indoor physical exercise and sports environments remains a prominent theme of interest in publications and research on environmental science. Future studies investigating the physiological, psychological, biochemical, and performance-influencing effects of pollution may integrate sports science with studies on air quality in indoor physical and sports environments.

The comparison of studies published in the last decade with those published more than 10 years ago allow us to conclude that there is increased support by funding agencies in recent years, especially in Canada, USA, and Finland. Our results indicated that recently published studies presented more complete analyses.

One of the topics in environmental management studies examines methods for prevention of indoor air pollution. Identification of research groups and their main focus of research enabled us to identify environmental concerns in each country.

Thus, there is no doubt about the relevance of this theme, as the investigation of the effects of air pollution on practitioners of physical exercise and sports in indoor environments is innovative.

We have the goal of integrating research, innovation, and environmental policy with sports science. Our study is an effort in this direction, as it unites researchers from the sports sciences, exercise psychology, and mechanical and environmental engineering.

The strength of our study lies in the extensive analysis of global publications on physical exercise and sports practice environments as they relate to air quality. Moreover, the study analyzed published and funded reports that reflected the interests of researchers and institutions.

In addition, this analysis and results examined themes that have not yet been adequately studied, such as physiological and inflammatory processes in practitioners of physical exercise in polluted environments. Only two such studies were published, measuring the effects of pollution on physiological performance.

There has been no publication on psychological effects induced by the practice of physical exercise in polluted environments.

Faced with the lack of studies that investigate the state of the art in this area, our study contributes significantly to environmental and sports science, enabling researchers and managers to make better decisions.

Conflict of interest

The authors declare that no conflicts of interests exist.

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