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REVIEW ARTICLE

Environmental noise in hospitals: a systematic review

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Abstract

Environmental noise has been growing in recent years, causing numerous health problems. Highly sensitive environments such as hospitals deserve special attention, since noise can aggravate patients' health issues and impair the performance of healthcare professionals. This work consists of a systematic review of scientific articles describing environmental noise measurements taken in hospitals between the years 2015 and 2020. The researchers started with a consultation of three databases, namely, Scopus, Web of Science, and ScienceDirect. The results indicate that for the most part, these studies are published in journals in the fields of medicine, engineering, environmental sciences, acoustics, and nursing and that most of their authors work in the fields of architecture, engineering, medicine, and nursing. These studies, which are concentrated in Europe, the Americas, and Asia, use as reference values sound levels recommended by the World Health Organization. L_{eq} measured in hospital environments showed daytime values ranging from 37 to 88.6 dB (A) and nighttime values of 38.7 to 68.8 dB (A). L_{eq} values for outdoor noise were 74.3 and 56.6 dB (A) for daytime and nighttime, respectively. The measurements were taken mainly inside hospitals, prioritizing more sensitive departments such as intensive care units. There is a potential for growth in work carried out in this area, but research should also include discussions about guidelines for improvement measures aimed at reducing noise in hospitals.

Keywords Noise pollution · Acoustics · Hospital environment · Public health · Environmental noise · Sound pressure level

Introduction

Over the last few decades, noise pollution has grown mainly due to urban expansion and the increasing size of vehicle fleets, which is considered an aggravating factor for public health (Hanninen et al. 2014). Several problems related to human health and cognitive activities are attributed to noise, such as sleep disturbance (Muzet 2007; Basner and McGuire 2018), annoyance (Miedema and Oudshoorn 2001; Licitra et al. 2016; Guski et al. 2017; Paiva et al. 2019), cardiovascular diseases (Babisch et al. 2005; Dratva et al. 2012; Sorensen et al. 2017; Héritier et al. 2018; van Kempen et al. 2018; Lin et al. 2020), perception, and learning (Erickson and Newman 2017; Minichilli et al. 2018).

There is even a greater concern in areas considered sensitive to noise, such as hospitals, where noise affects the well-being of patients, slowing their recovery, reducing the productivity of professionals, and increasing the occurrence of medical errors (Hsu et al. 2012; Loupa et al. 2019; Montes-González et al. 2019; Loupa 2020). Moreover, noise can also have a negative effect on visitors and the hospital as a whole (Zannin et al. 2019) and can increase the incidence of rehospitalization (Hagerman et al. 2005). The main factors involved in noise audible inside hospitals may originate outdoors, e.g., vehicle traffic, or indoors, e.g., conversations among employees and/or patients (Ravindra et al. 2016).

Several studies on environmental noise measurements in hospitals that have been carried out around the world (Busch-Vishniac et al. 2005; Fortes-Garrido et al. 2014; Zannin and Ferraz 2016; Montes-González et al. 2019) have revealed noise levels exceeding those recommended for a healthy environment. The World Health Organization (WHO) suggests that sound levels should not exceed L_{eq} 35

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dB (A) in the daytime and L_{eq} 30 dB (A) to L_{max} 40 dB (A) at night in hospital environments (Berglund et al. 1999). The United States Environmental Protection Agency (USEPA) recommends daytime and nighttime sound levels of less than L_{eq} 45 and 35 dB (A), respectively (USEPA 1974).

In practice, even with technological advances in hospital equipment and construction processes, noise levels inside hospitals have gradually increased from the 1960s to the present day (Busch-Vishniac et al. 2005; Busch-Vishniac and Ryherd 2019). Sound level assessments in hospitals are performed in various ways, given the complexity of hospital environments (Wallis et al. 2019).

The purpose of this systematic review was to survey research conducted between the years 2015 and 2020 pertaining noise measurement in hospitals around the world by examining top ranking scientific and academic journals.

Methods

The systematic review of the literature in electronic format involved three databases, Scopus, Web of Science, and ScienceDirect. The first filter employed in the search selected articles published in the last 6 years (from 2015 to 2020), only articles in English, research articles (excluding technical and review notes), and keywords "Noise" and "Hospital." The second filter excluded duplicate articles, while articles found in the Web of Science database were kept as reference (without excluding them). The third filter removed articles containing titles outside the context of the research, such as other types of interventions in hospitals or noise from hospital imaging equipment (e.g., X-ray machines). The fourth filter excluded articles whose abstract did not contain elements that met the objective of this review, such as those that did not measure sound pressure levels outside or inside hospitals. Lastly, in the fifth filter, after the articles were read in full, those stating that their authors had taken measurements using noise dosimeters (that evaluated only the noise dose) were excluded, since this is a special device for measuring individual exposure to sound pressure levels. Research that used class 2 equipment was excluded in order to equalize the work in terms of quality and quantity of resources of class 1 equipment. Also excluded were articles involving only simulations and modeling, but not measurements.

The articles selected after applying the five filters revealed the following information: (a) the databases containing the largest number of published articles; (b) the areas of knowledge of the journals in which the articles are published; (c) the countries whose hospitals have been studied and the laws/standards used as reference; (d) the authors' profession/area of expertise and the main focus of their studies (areas outside or inside hospitals); (e) measurement methods and parameters that were used; (f) works that adopted/proposed noise mitigation measures; and (g) future perspectives for the area. Figure 1 summarizes the literature review filtering scheme, while Appendix 1 Table 6 provides information about all the final articles selected.

Results and discussion

Databases and areas of knowledge of journals

After applying the filters, the database found to contain the largest number of articles was Web of Science, with 73%, followed by Scopus with 21% and ScienceDirect with 6%. Figure 2 shows the areas of knowledge of the journals (SCImago 2020) in which the articles were published.

Figure 2 shows that 28% of the articles were published in medical journals, followed by 21% in engineering, 18% in environmental sciences, 15% in acoustics, 9% in nursing, 6% in pediatrics, and 3% in multidisciplinary journals, indicating the interdisciplinarity of the subject and its importance in several fields of science.

Countries where the studies were conducted

Among the 33 studies selected in this review, the countries with the highest participation rates were the USA (n = 3), Brazil (n = 3), China (n = 3), England (n = 3), Portugal (n = 3), and Turkey (n = 3) (9% each), followed by Colombia (n = 2) and Iran (n = 2) (6% each one), Germany, Australia, Bosnia and Herzegovina, Canada, South Korea, Spain, Greece, the Netherlands, India, Peru, and Taiwan (each with 1 study, corresponding to approximately 3% each) (see Fig. 3).

Approximately 42% of studies are located in Europe (although Turkey is geographically situated between two continents, for the purpose of this review it was considered in Europe), 18% in South America, 12% in North America, 24% in Asia, and 4% in Oceania. Research on the African continent does not exist for the period and the criteria adopted in this review. One of the hypotheses for the paucity of studies on noise in hospitals in the African continent is that there are other more urgent needs, such as access to drinking water and treatment of some diseases, such as HIV and Ebola. Several researchers cite the lack of noise-related research in Africa (Okokon et al. 2018; Sieber et al. 2018). In a review study on noise pollution, Khan et al. (2018) found that most research on the subject has been conducted in Europe, demonstrating a potential gap for studies in this area in Africa, Oceania and South America. In a review study on noise in hospitals, Wallis et al. (2020) found that 33% of research was performed in Europe (in twelve countries), 38% in North America (in two countries), 5% in South America (two countries), 17% in Asia (four countries), 5% in Oceania (one country), and 2% in Africa (one country). In addition to the global geographic

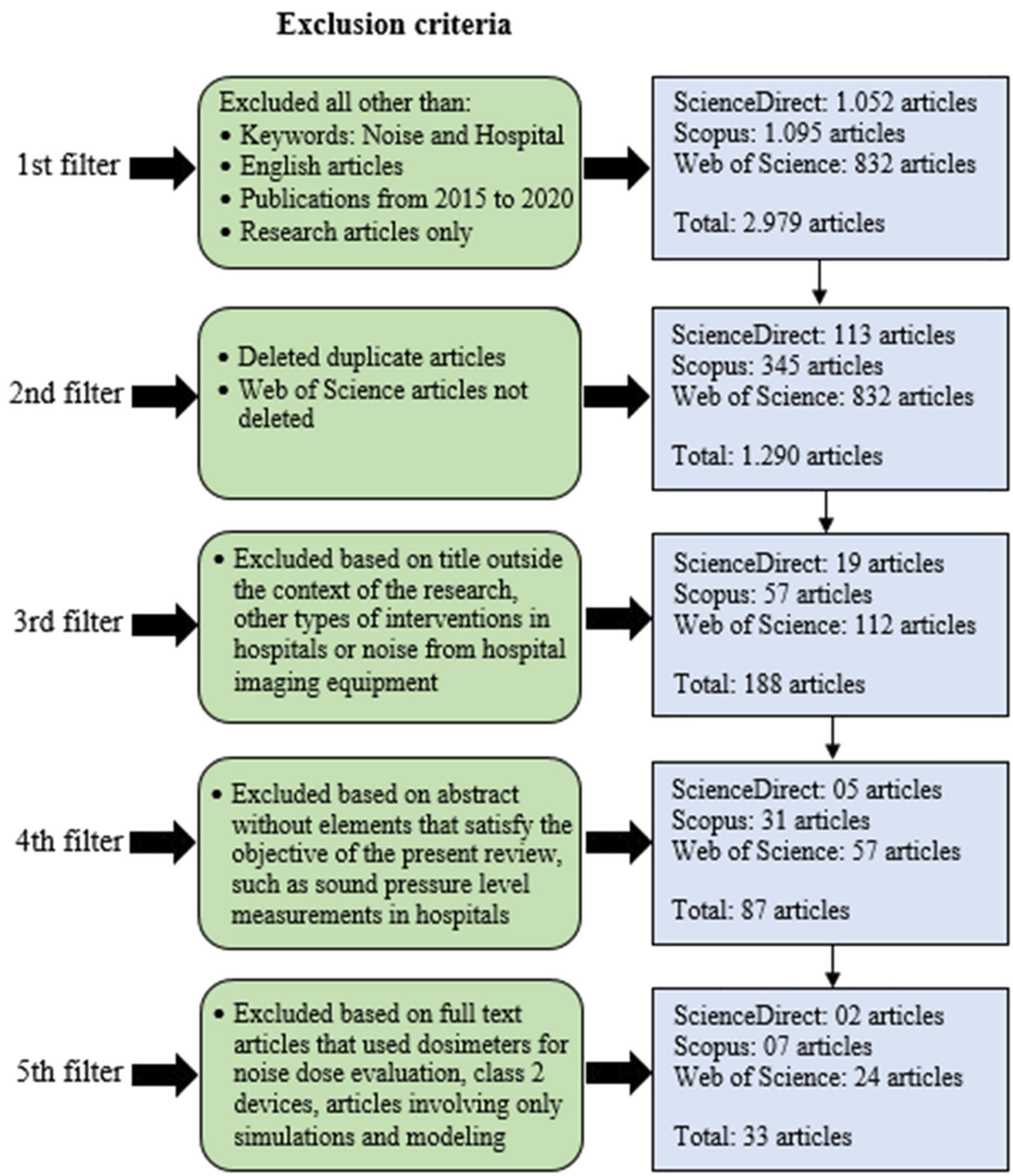

Fig. 1 Literature review filtering scheme

gap, if one considers, for example, that the USA has 6090 hospitals (AHA 2021), there is also a regional/local gap, since hospitals have different configurations, activities, layouts, etc.

Standards/laws used as references in studies

Although several countries have noise pollution laws and/or standards, many studies use other references as a parameter to assess whether or not measured noise levels pose risks to human health. Table 1 describes the main characteristics of laws and standards used as references in the studies.

It was found that 45% of the studies cited the WHO as a reference for noise values, followed by the United States Environmental Protection Agency (EPA) with 15% and the American Academy of Pediatrics (AAP) with 12%. The WHO has more restrictive noise values than the other laws/standards cited in other studies, since it considers overall well-being. Taken together, WHO and EPA are the pioneer institutions in creating standard values for hospital noise (Baqar et al. 2017). Other studies have shown that the values recommended by the WHO are widely used as a reference for noise

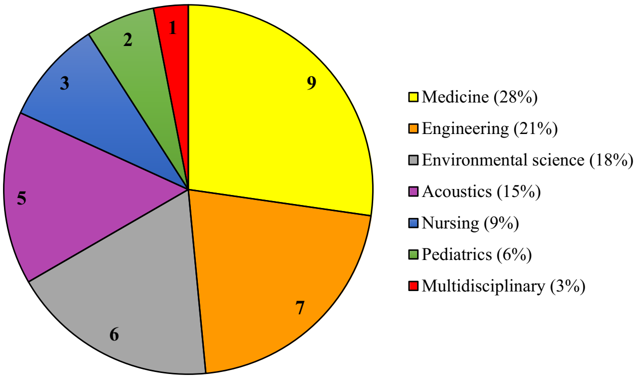

Fig. 2 Areas of knowledge of scientific journals. Areas of knowledge of scientific journals extracted from the site: https://www.scimagojr.com

levels in hospitals (Wallis et al. 2019), although these levels are often exceeded and unlikely to be achieved (Loupa 2020).

Other countries and/or cities had their own particularities when they created their reference laws and considered not only the general health and well-being of the population. Most of these laws/standards are quite old, dating back to the 1970s, 1980s, or 1990s, when cities were less crowded and vehicle fleets smaller. Jahan et al. (2016) state that noise pollution was not a major concern for the population of Bangladesh in the 1970s and early 1980s, but that the risk of noise pollution increased and exceeded the level of tolerance in response to the growing number of motor vehicles in the country. Urban and demographic growth is not always planned, and it is difficult to adjust external environmental noise emission standards to acceptable levels.

To assess the effect of noise exposure of people in different countries, other factors must be considered as well, such as psychological, economic, social, cultural, climatic, and others not yet identified (Sieber et al. 2018).

Table 2 shows the range of equivalent sound pressure levels (L_{eq}) for indoor and outdoor environments observed in the studies.

The indoor daytime L_{eq} values in hospitals ranged from 37 dB (A) (Cho et al. 2019) to 88.6 dB (A) (Pirsaheb et al. 2016), while the nighttime levels varied from 38.7 dB (A) (Bevan et al. 2018) to 68.8 dB (A) (Filus et al. 2015). The outdoor noise level (L_{eq}) was 74.3 in the daytime and 56.6 dB (A) at night. For measurements lasting 24 hours or longer, the values ranged from 39.7 (Zijlstra et al. 2019) to 71.7 dB (A) (Carvalhais et al. 2015; Santos et al. 2017). As for studies of outdoor noise levels, these varied from 83.3 to 88.6 dB (A) in the daytime (García-Rivero et al. 2020), from 58.3 to 65.4 dB (A) at night (Predrag et al. 2018), and from 62.7 to 84.7 dB (A) in a 24 h period (Tezel et al. 2019).

Even in countries that have technical guidelines for measuring indoor sound levels, such as Brazil through the NBR 10152 standard, it was found that the levels exceeded recommended ones (Filus et al. 2015; de Araújo Vieira et al. 2016).

Authors' field of expertise

Like the journals that publish articles on noise in hospitals, the main authors of the publications also have different areas of expertise. In Table 3, note that the total of 33 selected articles

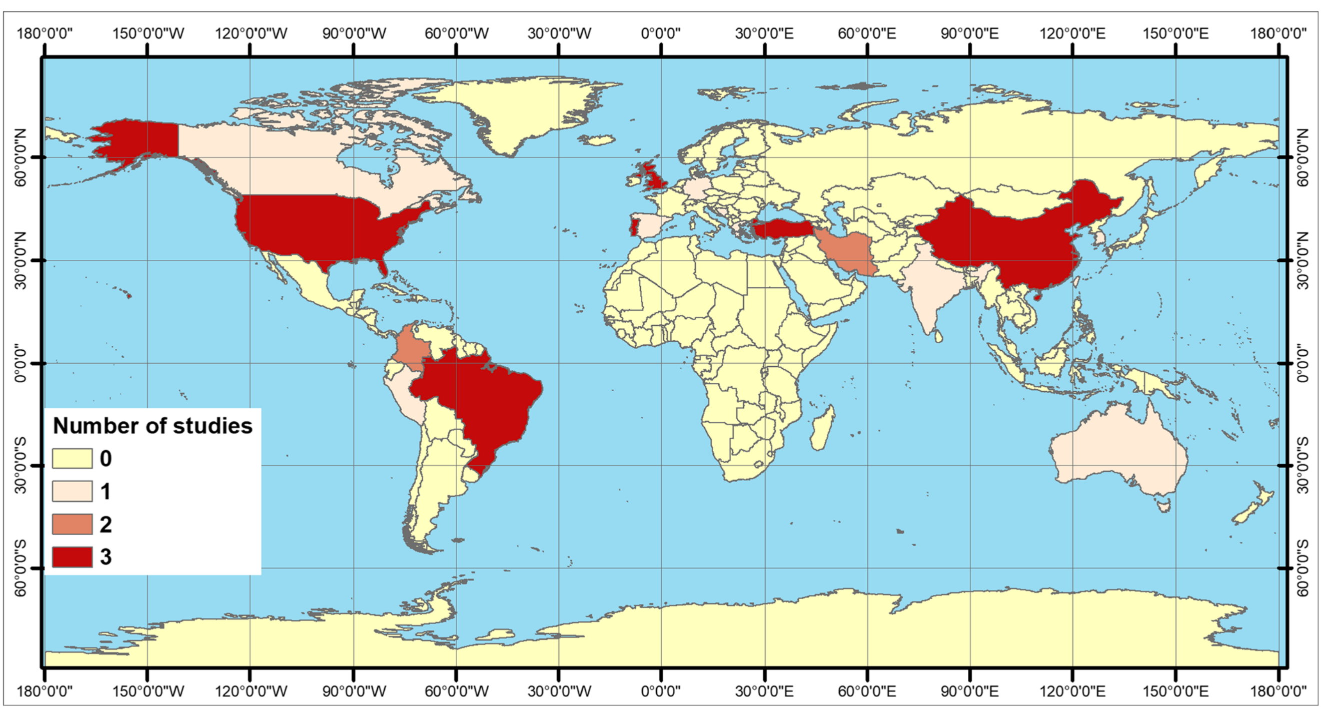

Fig. 3 Global map showing the distribution of countries where studies were performed

Table 1 Laws and standards used as references

Evaluated parameters	W	E	AA	IR	BR	N	CL	A	CC	RD	GB	PR	NC
No. of citations	15	5	4	2	2	1	1	1	1	1	1	1	7
Outdoors, daytime (dB)	-	55	-	55	-	50	55	-	-	60	-	50	-
Indoors, daytime (dB)	35	45	45	45	35-45	40	-	45	65	40-45	55	-	-
Outdoors, nighttime (dB)	-	55	-	45	-	55	45	-	-	50	-	-	-
Indoors, nighttime (dB)	30	35	45	35	-	35	-	45	65	30-35	-	-	-

W World Health Organization, *E* United States Environmental Protection Agency 1974, *AA* American Academy of Pediatrics, *IR* Iranian Standards, *BR* Brazilian Standards (NBR 10152/1987), *N* National Institute for Occupational Safety and Health – Occupational Noise Exposure 199 8, *CL* Curitiba Municipal Law no. 10625/2002, *A* Australian Standards, *CC* Consensus Committee for Neonatal Intensive Care Unit Design, *RD* Real Decreto 1367/2007, *GB* Chinese GB/T 51153-2015 standard, *PR* Peruvian National Environmental Standards for Noise, *NC* not cited

were divided into 21 distinct areas. Areas such as architecture and engineering, which represent 27% of the authors' specialties, contribute to the quality and interpretation of noise assessments in hospitals. Among the authors' areas of expertise, 36% are in medicine, nursing and other related areas such as pediatrics, communication disorders, public health, health sciences, health and environment, and experimental clinical sciences. One of the explanations for these numbers is that most of the authors have some connection with hospitals (medical, nursing, pediatrics, and other departments, as well as medical laboratories). This facilitates not only the development of the study, in terms of bureaucracy, but also the methodology (choice of noise measurement points, authorization from specific departments, and analysis in different layouts, among others). The areas of expertise of the remaining 37% of authors are in environment, physics, and acoustics. This indicates that the subject has attracted increasing attention from different areas (Loupa 2020), since noise is often underestimated.

Focus of the studies (areas outside and/or inside hospitals)

Table 4 describes the focus of the studies in terms of location, which may be outside or inside the hospital building, as well as the number of studies.

Eighty-two percent of studies measured noise levels inside hospitals, while 15% measured noise outside hospital buildings and 3% took measurements both outdoors and indoors. Indoor measurements are important to evaluate the level of acoustic comfort of patients and medical staff, since a quiet environment is beneficial for both, lowers the physical and mental stress of hospital staff, and contributes to hasten patient recovery (Mousavi and Sohrabi 2018). Outdoor measurements are normally taken to draw up acoustic maps, which are useful tools for diagnosing and evaluating urban noise and indicating the noise levels that reach the hospital facade (Fiedler and Zannin 2015; Zannin and Ferraz 2016). Studies combining outdoor and indoor noise measurements are more laborious, but they can better describe the stressors that may originate outside buildings, such as vehicle traffic, or inside, such as medical equipment and loud conversations (Zannin and Ferraz 2016). Hospitals are environments where patients need to rest and recover and should therefore be quiet indoors and outdoors (Ramadhan and Talal 2015).

Measurements taken outside hospitals usually evaluate traffic noise generated by light vehicles, e.g., motorcycles and cars, and by heavy vehicles, e.g., buses, trucks, and trains. The studies conducted inside hospital environments in specific locations or in various departments are listed in Fig. 4.

Most of the studies available in the literature that involved measuring noise inside hospitals prioritized departments where patients are most vulnerable. Of the total of studies carried out indoors, 26% were conducted in neonatal ICUs, 22% in various different ICUs, and 19% in multiple locations inside hospitals. In addition, 22% were carried out in private and waiting rooms and 11% in emergency rooms, infusion center, and dental clinic. In another review of the literature on noise in hospitals, the authors found that 70% of the studies involved measurements taken in ICUs, and the remainder in different hospital departments (Wallis et al. 2019).

Measurement methods and parameters used

Table 5 describes the criteria adopted in the studies for installing the microphone of the sound level meter, such as height and distance from reflective surfaces, measurement time, and evaluated parameters. Most of the studies examined in this review used L_{eq} dB (A) as a parameter. Other parameters such as L_{max} are present in 39% of the studies, followed by L_{min} with 27%. Some studies consider the statistical indices most commonly employed, such as L_5, L_{10}, L_{50}, L_{90}, and L_{95} (employed in approximately 73% of the studies), and others less common ones, such as L_1, L_{70}, L_{30}, and L_{33} (used in 12% of the studies). It is noteworthy that 27% of the studies also performed frequency analysis (Carvalhais et al. 2015; Chen 2015; Lahav 2015; Ai et al. 2017; Galindo et al. 2017; Santos et al. 2017; Bliefnick et al. 2019; Loupa et al. 2019; Hasegawa

Table 2 Equivalent internal and external noise levels from studies

Author	Indoor noise dB (A) L_{eq}		Outdoor noise dB (A) L_{eq}	
	Daytime	Nighttime	Daytime	Nighttime
Carvalhais et al. 2015	48.7–71.7 (24 h)			
Chen 2015	51–73			
Fiedler and Zannin 2015			> 65	
Filus et al. 2015	56.6–64.7	59.0–68.8		
Lahav 2015	58.7–60.0			
Monazzam et al. 2015			59.9–70.1	
Oliveira et al. 2015	54.8–65.2	43.4–54.9		
Garrido Galindo et al. 2016	58.9–65.7	57.0–64.2		
Luetz et al. 2016	50.9–56.2 (24 h)			
Pirsaheb et al. 2016	52.0–88.6			
Shield et al. 2016	50.0–60.6	41.4–52.9		
Shoemark et al. 2016	55–65 (24 h)			
de Araújo Vieira et al. 2016	58.2–65.6			
Ai et al. 2017	62.6–67.7			
Disher et al. 2017	43–70 (24 h)			
D'Souza et al. 2017	59.4–62.1			
Galindo et al. 2017	59.5–65.3 (24 h)			
Santos et al. 2017	46.6–71.7 (24 h)			
Bevan et al. 2018		38.7–62.0		
Predrag et al. 2018			64.6–69.9	58.3–65.4
Bliefnick et al. 2019	52–61 (24 h)			
Cho et al. 2019	37–67			
Loupa et al. 2019	57–76			
Montes-González et al. 2019	55.7–60.2	51.4–55.5		
Terzi et al. 2019	61–71 (24 h)			
Tezel et al. 2019			62.7–84.7 (24 h)	
Wu et al. 2019	57.3–63.8			
Yildirim and Mayda 2019	48.5–70.8			
Zijlstra et al. 2019	39.7–54.6 (24 h)			
Astin et al. 2020		49.2–51.6		
García-Rivero et al. 2020			83.3–88.6	
Hasegawa and Ryherd 2020	51.8–59.8 (24 h)			
Tang et al. 2020	45–70.5			

and Ryherd 2020). In addition, 30% performed subjective analysis with questionnaires (Chen 2015; Oliveira et al. 2015; de Araújo Vieira et al. 2016; Ai et al. 2017; Santos et al. 2017; Cho et al. 2019; Wu et al. 2019; Zijlstra et al. 2019; Astin et al. 2020; Tang et al. 2020), or used reverberation time measures such as RT_{30}, RT_{20} (Chen 2015; Cho et al. 2019), or the Speech Intelligibility Index (SII) (Bliefnick et al. 2019).

Distance of measurements from ground height ranged from 0.75 to 4 m, with some studies installing microphones on the ceiling or objects in order to protect the equipment, not disturb the hospital routine, or avoid the Hawthorne effect, enabling them to take long-term noise measurements (D'Souza et al. 2017; Cho et al. 2019; Zijlstra et al. 2019; Astin et al. 2020). As for the distance from reflective surfaces, 18% of the studies adopted 1 m.

Measurement times varied widely, ranging from 2.5 min to 52 days of uninterrupted measurement (Filus et al. 2015; Astin et al. 2020), although 21% of the studies took 24-h sound level measurements.

Studies that adopted/proposed noise mitigation measures

Some studies proposed or adopted measures to mitigate noise in hospitals, as indicated in Fig. 5. Studies that proposed

Table 3 Areas of expertise of the main authors of scientific papers

Area of expertise	Number
Architecture	5
Engineering	4
Health and environment	2
Medicine	2
Modeling of environmental systems	2
Nursing	2
Pediatrics	2
Air pollution	1
Applied physics	1
Applied sciences	1
Communication disorders	1
Environmental acoustics	1
Environmental health	1
Environmental science and technology	1
Environmental sustainability	1
Experimental clinical sciences	1
Health sciences	1
Occupational and environmental health	1
Physical metrology	1
Public health	1
Protection and ecology	1

The authors' areas of expertise were extracted from the information contained in their articles, sometimes in the headings, sometimes at the end

measures for possible noise mitigation in hospitals represent 36% of the total number of studies analyzed in this review, while 52% of studies did not adopt or propose measures and only took measurements. Studies that adopted measures in order to make "before and after" comparisons represent 3% of the total, while 9% proposed and adopted noise mitigation measures.

Luetz et al. (2016) adopted ICU room modification measures, achieving noise reductions in the order of 2.8 dB (A). The main measures proposed by the studies for noise reduction in hospitals involve preventive and educational actions (Filus et al. 2015; Disher et al. 2017; Santos et al. 2017; Astin et al. 2020); use of sound absorbing materials (Chen 2015); adoption of barriers and architectural designs (Monazzam

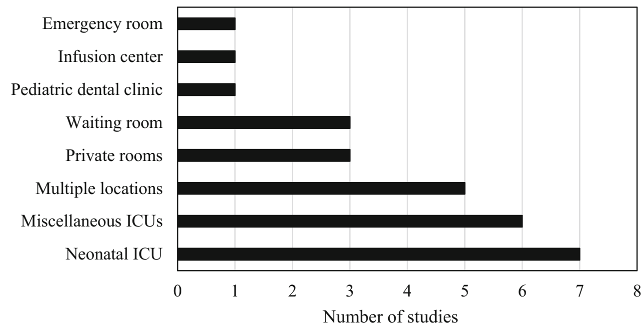

Fig. 4 Hospital environments and number of studies conducted

et al. 2015); simulations (Fiedler and Zannin 2015; Montes-González et al. 2019); changes in equipment; physical installations, and procedures (Pirsaheb et al. 2016; Shield et al. 2016); and more studies in different locations and hospitals (Hasegawa and Ryherd 2020; García-Rivero et al. 2020).

Studies that proposed and adopted noise control measures involved a training program (Carvalhais et al. 2015) in which the noise levels showed no variation after implementation of the program, a non-talking rule (Zijlstra et al. 2019) whose implementation led to a noise reduction of 1.1 dB (A), and a quiet hospital environment (Bliefnick et al. 2019).

Vehicle traffic noise is what most affects the modern human lifestyle (Ruiz-Padillo et al. 2016). Changes in driver behavior can contribute to reduce noise levels that reach hospital facades. However, some studies have indicated that despite the significant reduction in the number of vehicles circulating during the COVID-19 pandemic, reductions in noise levels were lower than expected, a fact that is attributed the high driving speed of the remaining vehicles (Asensio et al. 2020). Other factors that contribute to traffic noise levels and that deserve attention are the types of tires (Licitra et al. 2017) and of paving (Praticò and Anfosso-Lédée 2012; Praticò 2014; Licitra et al. 2015; Licitra et al. 2019; Del Pizzo et al. 2020).

Future perspectives in this field

Noise measurements are extremely important for assessing the level of exposure to which people are subjected, given the risks associated with this type of pollution. In hospitals, these measurements are even more important, given the physical

Table 4 Focus of studies and number of studies conducted outdoors and indoors

Focus of study			Hospitals studied indoors				Hospitals studied outdoors				Hospitals studied outdoors and indoors		
Out. and In.	Out.	In.	One	Two	≥ Three	N.c.	One	Two	≥ Three	N.c.	One	Two	≥ Three
1	5	27	21	2	3	1	-	2	3	-	1	-	-

Out. outdoors, *In.* indoors, *N.c.* not cited

Table 5 Microphone installation height, distance from reflective surfaces, measurement time, and evaluated parameters

Source	Microphone		Time	Parameters
	Height (m)	Distance (m)		
Carvalhais et al. 2015	1–1.65	1	24 h	L_{Aeq}, L_{AFmax}
Chen 2015	1.2	1	15 min	L_{Aeq}, L_{min}, L_{max}, L_5, L_{95}, L_{10}, L_{90}, L_{70}, L_{30}
Fiedler and Zannin 2015	1.3	2	10 min	L_{Aeq}
Filus et al. 2015	-	-	2.5 min	L_{Aeq}, L_{min}, L_{max}
Lahav 2015	-	-	5 days	L_{Aeq}
Monazzam et al. 2015	1.3	3	10, 15, 30 min	L_{Aeq}
Oliveira et al. 2015	Corner of the ceiling	Beside the bed	3 days	L_{Aeq}
Garrido Galindo et al. 2016	0.55 of the ceiling	1.23–5.4	24 h	L_{Aeq}, L_{max}, L_{90}
Luetz et al. 2016	-	0.40 next to the patient's head, door and window	24 h	L_{Aeq}, L_{AFmax}
Pirsaheb et al. 2016	1.5	-	-	L_{Aeq}
Shield et al. 2016	3 of the ceiling	-	5–14 days	L_{Aeq}, L_{max}
Shoemark et al. 2016	Near the head of the beds	-	24 h	L_{Aeq}, L_{min}, L_{max}
de Araújo Vieira et al. 2016	Ear height of professionals	1	8 h	L_{Aeq}
Ai et al. 2017	1.1–1.2	-	10 min	L_{Aeq}
Disher et al. 2017	-	-	24 h	L_{Aeq}, L_{max}, L_{10}
D'Souza et al. 2017	-	0.15 of hospital equipment	1 week	L_{Aeq}, L_{min}, L_{max}, L_{10}
Galindo et al. 2017	0.60 of the ceiling	2.15	20 days	L_{Aeq}, L_{min}, L_{max}, L_{10}, L_{50}, L_{90}
Santos et al. 2017	1–1.65	1	7 days	L_{Aeq}, L_{Cpeak}
Bevan et al. 2018	-	-	2 nights	L_{Aeq}
Predrag et al. 2018	1.7	3	15 min	L_{Aeq}, L_1, L_{10}
Bliefnick et al. 2019	1 m behind the patient	-	1 week	L_{Aeq}, L_{min}, L_{max}, L_{Cpeak}, L_5, L_{95}, L_{10}, L_{90}, L_{50}
Cho et al. 2019	Near the ceiling, shelves, bed	-	10 min–22 h	L_{Aeq}
Loupa et al. 2019	0.9–1.8	2	8 h	L_{Aeq}, L_{min}, L_{max}, L_{10}, L_{95}
Montes-González et al. 2019	1.5	-	15 min, 14 days	L_{Aeq}
Terzi et al. 2019	-	-	24 h	L_{Aeq}
Tezel et al. 2019	4	-	24 h	L_{Aeq}
Wu et al. 2019	1.2–1.5	1	5 min	L_{Aeq}
Yildirim and Mayda 2019	1.5	1	8 h	L_{Aeq}
Zijlstra et al. 2019	On the ceiling	-	4 days	L_{Aeq}, L_{min}, L_{max}
Astin et al. 2020	On the ceiling	-	52 days	L_{Aeq}, L_{max}
García-Rivero et al. 2020	1.5	3	5 min	L_{Aeq}, L_{min}, L_{max}, L_{Apeak}
Hasegawa and Ryherd 2020	0.76 above the patient's head	-	48 h	L_{Aeq}, L_{min}, L_{max}, L_{Cpeak}, L_5, L_{95}, L_{10}, L_{90}, L_{50}, L_{33}
Tang et al. 2020	0.75	-	3 min	L_{Aeq}

and emotional vulnerability of patients and the stress to which hospital staff are subjected daily. Hence, working in extreme situations while subjected to noise levels exceeding those established by laws, standards, or agencies such as the WHO can delay the recovery of patients and impair the performance

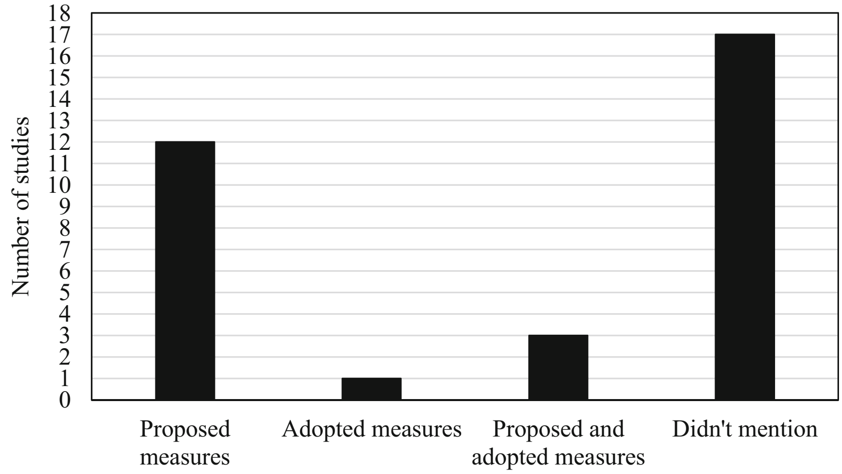

Fig. 5 Studies that proposed or adopted noise mitigation measures

of healthcare professionals (Zannin and Ferraz 2016; Zannin et al. 2019; Busch-Vishniac and Ryherd 2019; Loupa 2020).

An average of 5.5 articles per year were published in the period studied in this review, as illustrated in Fig. 6.

In order to improve noise assessments in hospitals, research must contain as much information as possible, e.g., locations where equipment was installed, measurement height from ground level, distance from reflective surfaces, measurement time, noise sources, and measurement period (Wallis et al. 2019). As can be seen in Table 5, the information provided by some studies is insufficient for a careful reproduction or analysis, even those that took measurements for 24 h or more. Studies published in journals in the area of acoustics (e.g., Bliefnick et al. 2019; Hasegawa and Ryherd 2020) offer more complete information, extracting the maximum quality and diversity of resources provided by the equipment used, thus enabling the analysis of a series of interventions and improvements in the quality of the environment. Given the diversity of ways in which the studies are conducted, perhaps a more comprehensive standardization strategy is needed in order to balance noise measurement procedures in indoor hospital environments, considering that the forms of noise measurements in outdoor environments with validation on maps ensure more reliable results.

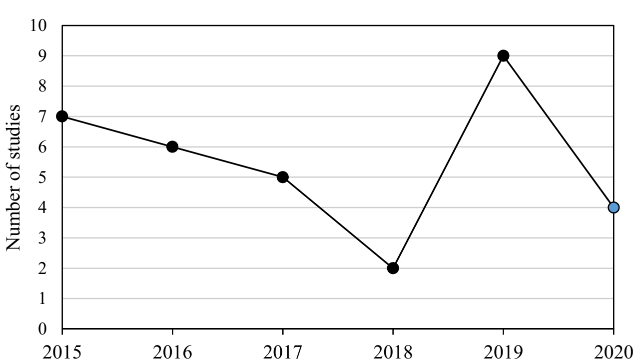

Fig. 6 Number of studies conducted in the last 6 years

Conclusions

Several scientific journals have published studies on environmental noise assessment in hospitals, mainly in the areas of medicine, engineering, environmental sciences, acoustics, and nursing. The areas of expertise of the authors of these studies correspond to those of the journals, since most of them are doctors, nurses, and engineers. The studies are concentrated mainly in Europe, the Americas, and Asia.

Most of the studies use the noise levels recommended by WHO as a reference to determine whether the measured noise levels may be harmful to human health in the hospital environment. However, it should be noted that the levels recommended by WHO are the most restrictive possible and that the noise levels measured in practically all the studies selected for this review were much higher. The L_{eq} levels measured in indoor hospital environments varied from 37 to 88.6 dB (A) in the daytime and from 38.7 to 68.8 dB (A) at night, while the outdoor noise levels were 74.3 in the daytime and 56.6 dB (A) at night.

The main focus of the studies was the internal part of the hospitals, and most of them took measurements in only one hospital. Departments treating more sensitive and vulnerable patients that require greater attention from health care professionals, such as ICUs, were preferred environments for environmental noise measurements.

A considerable number of the studies only indicate if the measured noise levels are in conformity with some reference standard or law, but do not adopt or propose measures to reduce the levels.

This is a field of research with a potential for growth. However, there is a need for a more critical assessment of the quality of studies, aiming at scientific advances and reliable dissemination of information to the community in general.

Appendix 1

Table 6 Information about all the final articles selected

Authors of the studies	Area of knowledge of the scientific journal	City and country of study	Laws/ standards of reference	Authors' field of expertise	Focus of study	Equipment used	Proposed and/or adopted measures
Carvalhais et al. 2015	Environmental science	Porto, Portugal	WHO	Health and environment	Inside 1 hospital (neonatal ICU)	01-DB Solo-Premium	Proposed and adopted measures
Chen 2015	Acoustics + ultrasound	Several cities in Taiwan	WHO	Architecture	Inside 16 hospitals (several waiting rooms)	Brüel & Kjær Pulse	Proposed one measure
Fiedler and Zannin 2015	Environmental science	Curitiba, Brazil	Curitiba Municipal Law No. 10625/2002	Environmental acoustics	Outside 2 hospitals	Brüel & Kjær 2250 and 2238	Proposed measures in simulations
Filus et al. 2015	Medicine	Curitiba, Brazil	NBR 10152/87	Communication disorders	Inside 1 hospital (emergency room)	Brüel & Kjær 2230	Proposed measures
Lahav 2015	Medicine	Boston, USA	American Academy of Pediatrics (AAP)	Medicine	Inside 1 hospital (neonatal ICU)	Brüel & Kjær 2250-L	No
Monazzam et al. 2015	Medicine	Teheran, Iran	National Iranian Department of Environment	Occupational, public and environmental health	Outside 3 hospitals	Brüel & Kjær 2230	Proposed measures
Oliveira et al. 2015	Medicine	Portugal	WHO	Pediatrics	Inside 1 hospital (5 pediatric wards and corridors)	01 dB Symphonie	No
Garrido Galindo et al. 2016	Medicine	Santa Marta, Colombia	Cited only a national law and several international laws	Environmental systems modeling	Inside 1 hospital (3 ICUs)	Casella CEL-633-C1-K1	No
Luetz et al. 2016	Genetic engineering	Germany	WHO	Medicine	Inside 1 hospital (2 ICU rooms)	XL2	Adopted measures
Pirsaheb et al. 2016	Engineering	Kermanshah, Iran	NIOSH (98)/EPA (74)/Iranian standards	Engineering (environmental health)	Inside 1 hospital (several points)	TES 1358	Proposed measures and external studies
Shield et al. 2016	Acoustics + ultrasound	London, England	WHO	Architecture and built environment	Inside 2 hospitals (5 wards)	Norsonic 140	Proposed measures
Shoemark et al. 2016	Pediatrics	Melbourne, Australia	National		standard/American Academy of Pediatrics Committee on Environmental Health/Consensus Committee on Newborn ICU Design	Pediatrics	Inside 2 hospitals (neonatal/-pediatric ICU and nursery)
Quest Sound Pro DL	No						
de Araújo Vieira et al. 2016	Engineering	João Pessoa, Brazil	NBR 10152/87	Engineering	Inside, but do not mention number of hospitals (9 adult ICUs)	Brüel & Kjær 2250-L	No
Ai et al. 2017	Civil engineering	Hong Kong, China	Not cited	Engineering	Inside 1 hospital (pediatric dental clinic and lab for dental implants and prosthetics)	Brüel & Kjær 2270	No
Disher et al. 2017	Ward nursing	Nova Scotia, Canada	Not cited	Nursing	Inside 1 hospital (3 neonatal ICUs and 1 pediatric ICU)	3 M SoundPro	Proposed measures
D'Souza et al. 2017	Medicine	Udupi, India	EPA/WHO/-American Academy of	Nursing	Inside 1 hospital (neonatal ICU)	Brüel & Kjær 2250	No

Table 6 (continued)

Authors of the studies	Area of knowledge of the scientific journal	City and country of study	Laws/ standards of reference	Authors' field of expertise	Focus of study	Equipment used	Proposed and/or adopted measures
			Pediatrics Committees				
Galindo et al. 2017	General medicine	Santa Marta, Colombia	Did not use any, but quoted other authors	Environmental systems modeling	Inside 1 hospital (neonatal ICU)	Casella CEL-633-C1-K1	No
Santos et al. 2017	Environmental science	Northern Portugal	WHO/EPA/-American Academy of Pediatrics -AAP	Environmental health	Inside 3 hospitals (neonatal ICU)	01 dB Solo-Premium	Proposed measures
Bevan et al. 2018	Medicine: pediatrics	Southampton, England	WHO	Clinical and experimental medical sciences	Inside 1 hospital (private rooms)	Brüel & Kjær 2236	No
Predrag et al. 2018	Engineering	Banja Luka, Bosnia and Herzegovina	National standard	Protection and ecology	Outside 2 hospitals	Brüel & Kjær 2260	No
Bliefnick et al. 2019	Acoustics + ultrasound	Central USA	WHO	Architectural engineering and construction	Inside 1 hospital (15 patient rooms and 5 nursing stations)	Larson Davis 831	Proposed and adopted measures
Cho et al. 2019	Medicine	Seoul, South Korea	WHO	Physical metrology	Inside 1 hospital (several points)	Brüel & Kjær 2270	No
Loupa et al. 2019	Environmental science	Kavala, Greece	Not cited	Air pollution	Inside and outside 1 hospital (several locations)	Casella CEL-490	No
Montes-González et al. 2019	Environmental science	Badajoz, Spain	WHO/EPA/-Spanish legislation	Applied physics	Inside 1 hospital (16 points)	01 dB OPER@/Brü-el & Kjær 2250 L and 2238	Proposed measures
Terzi et al. 2019	Nursing	Istanbul, Turkey	WHO	Health sciences	Inside 1 hospital (10 ICUs)	Brüel & Kjær 2250-L	No
Tezel et al. 2019	Environmental science	Trabzon, Turkey	Turkish legislation	Environmental engineering	Outside 48 hospitals	SVAN 958	No
Wu et al. 2019	Engineering	Harbin, Wuchang, Qitaihe, Chifeng, Changchun, Meihekou, China	Not cited	Environmental science and technology	Inside 18 hospitals (wards)	BSWA-801	No
Yildirim and Mayda 2019	Medicine	Düzce, Turkey	WHO/EPA/-Turkish legislation	Public health	Inside 1 hospital (11 waiting areas of the outpatient clinics)	SVAN 957	No
Zijlstra et al. 2019	Multidiscipl-inary	Groningen, Netherlands	WHO	Applied sciences	Inside 1 hospital (infusion center)	Brüel & Kjær 2250	Proposed and adopted measures
Astin et al. 2020	Nursing	Northern England	WHO	Health sciences	Inside 1 hospital (2 rooms)	Casella, CEL-632C	Proposed measures
García-Rivero et al. 2020	Acoustics + ultrasound	Lima, Peru	WHO/Peruvian regulations	Environmental sustainability	Outside 4 hospitals	BSWA-308	Proposed measures
Hasegawa and Ryherd 2020	Acoustics + ultrasound	Midwestern USA	Not cited	Architecture	Inside 1 hospital (PICU and pediatric medical-surgical)	Larson Davis 831	Proposed measures
Tang et al. 2020	Engineering	Shenzhen, China	Chinese GB/T 51153-2015 standard	Architecture	Inside 1 hospital (hospital street, outpatient waiting areas)	Casella CEL-6X0	No

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Data Availability All data generated or analyzed in this study are included in this published article [and its supplementary information files].

Declarations

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Consent for publication Not applicable.

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