Original Article

Environmental Noise Levels in Hospital Settings: A Rapid Review of Measurement Techniques and Implementation in Hospital Settings

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Abstract

Background: Hospitals provide treatment to improve patient health and well-being but the characteristics of the care environment receive little attention. Excessive noise at night has a negative impact on in-patient health through disturbed sleep. To address this hospital staff must measure night-time environmental noise levels. Therefore, an understanding of environmental noise measurement techniques is required. In this review, we aim to 1) provide a technical overview of factors to consider when measuring environmental noise in hospital settings; 2) conduct a rapid review on the equipment and approaches used to objectively measured noise in hospitals and identify methodological limitations. **Design**: A rapid review of original research articles, from three databases, published since 2008. Studies were included if noise levels were objectively measured in a hospital setting where patients were receiving treatment. **Results:** 1429 articles were identified with 76 included in the review. There was significant variability in the approaches used to measure environmental noise in hospitals. Only 14.5% of studies contained sufficient information to support replication of the measurement process. Most studies measured noise levels using a sound level meter positioned closed to a patient's bed area in an intensive care unit. **Conclusion**: Unwanted environmental noise in hospital setting impacts negatively on patient and staff health and well-being. However, this literature review found that the approaches used to objectively measure noise level in hospital settings have been inconsistent and poorly reported. Recommendations on best-practice methods to measure noise levels in hospital environments are provided.

Keywords: Hospital, indoor environment, measurement technique, noise, sound level

INTRODUCTION

"Noise" is defined as sound that is "unwanted",[2-4] with the environments we encounter every day containing numerous noise sources (i.e. "environmental" noise). Hospitals are noisy environments with sounds produced by equipment, the beeping of pagers, the voices of staff and other patients.[5] The effect that excessive levels of such noise can have on patient care has been the topic of much research. Environmental noise can impact patient safety[6]; an extensive review by Pope reported that environmental noise in hospitals affects the sleep of patients, can increase their blood pressure and diminish their immune responses, as well as a host of other negative side effects.[4]

The World Health Organization (WHO) issued guidelines on the maximum amount of noise that should be present in hospitals. The guidelines suggest that noise on wards should not exceed 30 dB L_{Aeq}, whilst noise in treatment rooms should be kept "as low as possible".[7] However, studies measuring environmental noise in hospitals have identified that such levels are not realistic. It has been noted that the guidelines did not account for the presence of patients, instead referring to buildings that are "empty".[4]

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Moreover, noise levels on nursing units "frequently" exceed 100 dB L_{Aeq}, this being the equivalent of a car horn and far removed from the WHO guidelines.[4] Numerous other studies have attempted to quantify the levels of noise in hospitals.[5,8-10]

There are a number of limitations when measuring noise in hospitals that make a comparison between studies difficult.[9] Noise levels usually vary rapidly with time and so some form of single-figure or average figure is usually reported. There are many factors to consider in noise measurement and not all are appropriate for hospital noise assessment. They include time period, sampling rate, frequency range, frequency weighting, peak, maximum, percentile levels or energy average. Different measuring devices (e.g. sound level meters and dosimeters) and the different ways in which a device can be calibrated yield different results.[4,9] The purpose of this rapid review was to describe the equipment and approaches used in studies that objectively measured noise levels in hospitals and identify any associated methodological limitations. Recommendations will be developed to guide the accurate measurement, documentation and reporting of environmental noise measurements in hospitals.

METHODS

A "rapid review" enables an evaluation of existing literature using systematic review methods, whilst allowing for a reduction in the breadth and depth of a full systematic review.[11] The WHO guidelines for rapid reviews states that the literature search can be limited to two or more databases with additional limits on date, language and study design.[12] Although potentially relevant research studies might not be identified using this approach, there is evidence to show that conclusions determined from rapid reviews are similar to conclusions reached in more comprehensive reviews.[13]

Search strategy

Original research articles were identified from three databases (Scopus, PubMed and Cochrane Library) to enable identification of research studies published in both medical and acoustics journals. Input from an Information Technologist enabled us to develop a robust search strategy (see Appendix A) which was piloted. Boolean operators were used to combine search terms relating to "noise" and "hospitals". Several search limits were applied to reduce the breadth and depth of the review, as permitted by rapid review guidelines.[11,12] Searches were limited to English Language only and due to technological advances in sound measurement, were restricted to articles published in the last ten years (≥2008).

Article selection process

Following removal of duplicates, all articles identified from the searches were screened firstly by title/abstract before full-text screening by one author (R.W.) who had expertise in acoustics. Research of any design was included into the review. A random sub-sample of 20 articles considered relevant for inclusion into the review were independently checked against the entry criteria by two authors (E.H. and F.A.). Included studies fulfilled the following criteria;

(1) Research studies focusing on environmental noise measurements in hospitals as a primary aim;
(2) Studies conducted in a hospital setting;
(3) Studies that report objectively measured noise levels using a device which gives an output in decibel (dB);
(4) Studies that report indoor levels of noise in areas where patients (adults and children) are being treated (i.e. wards, intensive care units, operating theatres, out-patient clinics);

Studies reported in English language.

Data extraction

Data were extracted from all included studies into a tabular format by one author (R.W.). To reduce reporting bias, data from a random sample of 20 studies was independently extracted by another author (WJD) and compared with the original data extraction table. Information extracted included authors, year of publication, setting, noise level measurement device details, location of device, time period of measurements, amplitude type, weight network, time constant, calibrations made and type of noise parameter recorded.

Quality appraisal

The way in which the technical aspects of the included studies were reported was appraised by one author (R.W.). To reduce reporting bias, a random sample of 20 articles were appraised independently by another author (H.L.). Classification of the reporting quality of the studies were based on inclusion of the following variables; the setting; the measuring device used; the location of the device; the time period for the measurement; the type of amplitude measured; the weighting network used; the time constant; the calibration process; and the type of sound level parameter measured (e.g. L_{eq}, L_{max}, etc.). Studies were appraised as "comprehensive" if all of these variables were provided in sufficient detail to enable an accurate reproduction of the measurement process; "average" for studies that included information on most of the aforementioned variables, but not all; and "limited" if either vital information was omitted or ambiguities demonstrated in their measurement process, or both. A variable was considered as being "vital" if significant changes in the measurement data could arise if the parameters were changed (this being judged based specifically on the present context of measurements within hospitals). For example, A-weighting in sound pressure level (SPL) measurement attenuates low frequencies heavily with respect to C-weighting and so it is reasonable to suggest that a 24-hour measurement on an ICU with the respective networks applied would yield different results. Given this, failure to indicate the weighting would mean that assumptions would need to be made about the measurement process and this can affect the validity of the data.

RESULTS

Fig. 1 provides an overview of study selection process; 1429 articles were screened (649 from Scopus, 74 from Cochrane and 706 from PubMed), of which, 111 full-texts were assessed for eligibility against inclusion criteria and 76 articles included in the review. The included studies were conducted across 22 countries; USA (26), UK (6), Turkey (5), Taiwan (4), Australia (4), Brazil (3), Canada (3), China (3), India (3), Iran (3), Portugal (2), Germany (2), Sweden (2), France (2), Spain (1), Greece (1), South Africa (1), Finland (1), Switzerland (1), Argentina (1), Belgium (1) and Italy (1).

Characteristics of the measurement approaches used in studies reporting noise levels in hospitals

Table 1 presents an overview of the study characteristics and measurement approaches used.

Of the 76 studies that measured environmental noise in hospitals since 2008, noise levels were most commonly measured in an intensive care unit (70% of studies), while the remaining studies reported noise levels in emergency departments, patient wards, operating theatres, a pharmacy department or multiple locations around a hospital. The majority of studies (66%) used some form of Sound Level Meter (SLM), whilst a further 20% used dosimeters to measure noise levels in a hospital setting. There was a large amount of variation in the location of the measuring device between studies, with 47% of studies using the area around the patient's bed as the location for recording noise measurements. Furthermore, the measurement durations varied widely, with numerous studies recording both day and night noise levels and at different periods of time throughout the day. The majority of studies (96%) explicitly stated that SPLs were measured and 66% of studies used an A-weighting network. The most popular measurement method was the time-average SPL (L_{eq}), being present in 58% of all studies. L_{max} (maximum SPL) and L_{min} (minimum SPL) were also popular (38% and 28% respectively). The arithmetic "average" of sound levels was calculated in 26% of all studies, but details on this calculation were ambiguous. Each study using this approach was rated as "limited" for reporting quality.

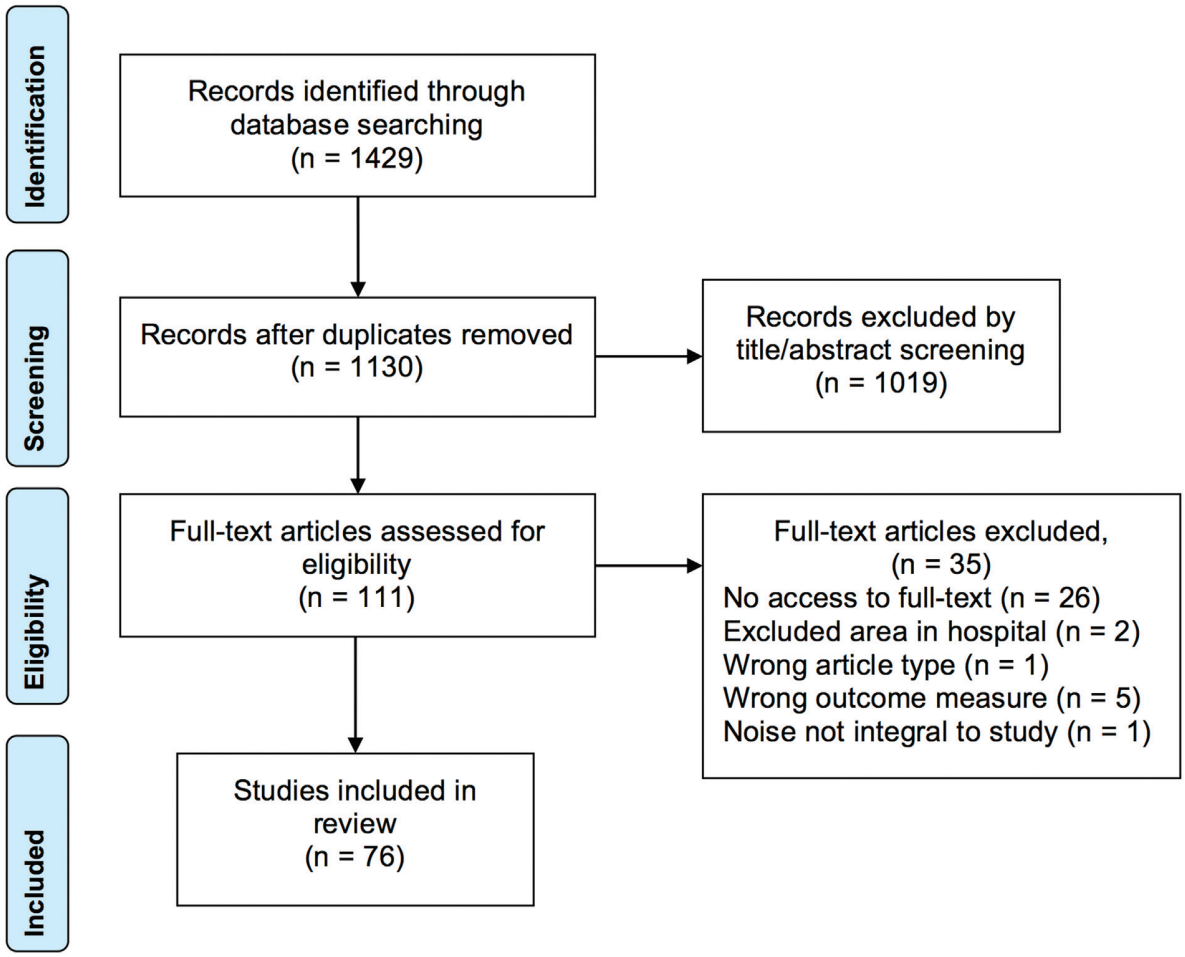

Figure 1: Flow diagram of search strategy and article selection for systematic search and review modified from Moher *et al.*[14]

Table 1: Study characteristics and approaches used to measure hospital noise levels from included studies

Author	Reporting rating	Setting	Device used	Device location	Time period	Type of amplitude measured	Weighting	Time constant	Calibration	Measurements Made
Elliott *et al.*[15]	Comprehensive	ICU (Australia)	Bruel and Kjaer 2250 SLM (class not stated)	Between 0.75 and 1 m above the patient's head, 1.75 m above the ground, 1 m below the ceiling, 1.5 m from the wall	24-hours	Pressure	A, C	Fast	Yes	LAeq, LCpeak, LAmax, LAmin, LCeq, LA90
Liu [16]	Comprehensive	NICU (USA)	Larson Davis Spark 706 dosimeter (Type-II)	Bedside (mic 12 inches above the infant's head), within an incubator (mic halfway between infant's head and top of incubator), staff work area (suspended from the ceiling, no more than 5 feet above the desk), central entry area (suspended from ceiling, no more than 5 feet above desk)	24-hours (Leq at 1-s, 1-min, 5-min and hourly intervals, LA10, LA50 and LA90 recorded for 1, 3, 4 and 6-hour intervals)	Pressure	A	Slow	Yes	LAeq, LA10, LA50, LA90
Matook *et al.*[17]	Comprehensive	NICU (USA)	Quest Sound Pro DL-2 SLM (class not stated)	In a b-ox placed on a shelf in the quadrant of an NICU bay	Two 12-hour recordings (0700-1900 and 1900-0700), 60-s intervals	Pressure	A	Slow	Yes	LAeq, LAmax, LApeak
Pope [4]	Comprehensive	Medical/ surgical nursing units (USA)	Quest Q300 noise dosimeters (class not stated)	Behind the beds of patients with additional measurements made both at nurse's station and with microphones attached to nurses	12-hours (0625-1830)	Pressure	A	Slow	Yes	LAeq, LAmin, LAmax, LApeak
Short *et al.*[18]	Comprehensive	Emergency department (Australia)	Digitech QM 1588 SLM (class not stated)	shelf, 1.4 m above the head of patients' beds in 6 areas – triage, acute, short stay, resuscitation, paediatrics and cubicles	24-hours at 15-min intervals	Pressure	A	Fast	Yes	LAeq, LAmax, LAmin
Memoli *et al.*[19]	Comprehensive	ICU (UK)	NPL-Minim with MEMS microphones (conforming to Class-I)	Detailed diagram provided of all microphone locations	30-min continuous recording, with all measurements taken at intervals of 15-min, 1-min and 1-s	Pressure	A	Fast	Yes	LAeq, LAmax, LAmin, LA0.1, LA5, LA10, LA25, LA50, LA75, LA90, LA95

(*Continued*)

Table 1 (*Continued*)

Author	Reporting rating	Setting	Device used	Device location	Time period	Type of amplitude measured	Weighting	Time constant	Calibration	Measurements Made
Carvalhais *et al.*[20]	Comprehensive	NICU (Portugal)	01 dB model Solo-Premium Class-I SLM (model not stated)	At least 1 m away from the wall at a height between 1 and 1.65 m	24-hours	Pressure	A, C	Slow	Yes	LAeq, LCpeak, LA90
Knauert *et al.*[21]	Comprehensive	ICU (USA)	Extech Instruments HD600 SLM (Type-II)	Central location in patient's room adjacent to the foot of the patient's bed	2000-0800, 2000-2359, 0000-0359 and 0400-0800, 10-s intervals	Pressure	A, C	Fast	Yes	LAeq, LCpeak
Luetz *et al.* [22]	Comprehensive	ICU (Germany)	XL2 SLM with M2233 microphone (class and manufacturer not stated)	40 cm from patient's head (additional SLMs placed at windows and doors)	24-hours, 1-min intervals	Pressure	A	Fast	Yes	LAeq, LAmax
Fasih-Ramandi and Nadri [23]	Comprehensive	ICU (Iran)	Cel 450 SLM (class not stated)	Above the beds	24-hours, 5-min intervals	Pressure	A	Fast	Yes	LAeq, LAmax, LAmin
Santos *et al.*[24]	Comprehensive	NICUs of 3 hospitals (Portugal)	Solo-Premium Class-I SLM (model not stated)	At least 1 m away from walls/equipment at a height of between 1 and 1.65 m and also inside incubators	24-hours	Pressure	A, C	Slow	Yes	LAeq, LCpeak
McLaren and Maxwell-Armstrong [25]	Average	Surgical Wards (UK)	Type 230 Integrating octave band SLM (manufacturer and class not stated)	Entrance to the second bay (consisting of 6 beds), approximately 4 m from the nursing station.	24-hours (15 minute intervals at 4-hourly time periods), Wednesday-Thursday	Pressure	A	Not stated	Not stated	LAmax, LAeq
Nathan *et al.* [26]	Average	NICU (South Africa)	Type-I SLM (manufacturer and model not stated)	Suspended from the ceiling in each room at a height of 2 m	Two 12-hour intervals in each room (0800 – 2000) on consecutive weekdays	Pressure	A	Not stated	Not stated	LAeq, LAmax, LAmin
Chen *et al.* [27]	Average	NICU (Taiwan)	NL-31 & Rion Co. SLMs (class not stated)	Bedside, away from walls & floor	24 hours, with hourly data reported	Pressure	A	Slow	Not stated	LAeq, LAmax, LA10, LA90
Lasky and Williams[28]	Average	NICU (USA)	Larson Davis Spark 703+ PND (class not stated)	Inside patients' beds, within 30 cm of their ears	1-s intervals	Pressure	A	Not stated	Not stated	LAeq
Richardson *et al.*[29]	Average	Wards (UK)	Norsonic NOR-116 SLM (class not stated)	Corner of a 6-bed bay, 1 m from the ground and 1 m from the wall, on a tripod	24-hours	Pressure	A	Not stated	Yes	LAeq, LApeak
Williams *et al.*[30]	Average	NICU (USA)				Pressure	A		Yes	dBA SPL

(*Continued*)

Table 1 (*Continued*)

Author	Reporting rating	Setting	Device used	Device location	Time period	Type of amplitude measured	Weighting	Time constant	Calibration	Measurements Made
			Larson Davis Spark 703+ PND (class not stated)	Inside the upper corner of the incubator, 12 inches from the child's ear	2-hours (1-s intervals) in the period between 0800 and 1700, ideally between 1000 and 1200 (Monday-Friday)			Not stated		
Hsu *et al.*[31]	Average	ICU (Taiwan)	RION NL-22 Type-II SLM	Bedside, 30 cm from the patients' heads	42-hours (1-s intervals), divided into seven 6-hour periods	Pressure	A	Not stated	Not stated	LAeq, LAmax, LAmin
Hu *et al.*[32]	Average	ICU (China)	AWAI AWA5610D SLM (class not stated)	Bedside	24-hours	Pressure	A	Not stated	Not stated	Mean, peak and minimum LpA
Lawson *et al.*[33]	Average	ICU (both in patient rooms and in rooms adjacent to them) (USA)	Bruel and Kjaer SLM (model and class not stated)	Microphone suspended from ceiling (6 inches above bed pillow)	Ten 24-hour periods with 15-min intervals for the LAeq measurement, 10-s intervals for peak measurements	Pressure	A, C	Not stated	Yes	LCpeak, LAeq
Gladd and Saunders[34]	Average	Treatment room of chemotherapy clinic (USA)	Bruel and Kjaer 2250 SLM (class not stated)	Suspended 1 foot from the ceiling in the centre of each room	11-hours (daytime), 1-s intervals	Pressure	A, C	Not stated	Yes	LCpeak, LAeq
Johansson *et al.*[35]	Average	ICU (Sweden)	Bruel and Kjaer 2260 SLM (class not stated)	Close to patients' beds	24-hours	Pressure	A	Fast	Not stated	LAeq24hours, LAFmax
Liu[36]	Average	NICU (USA)	Larsen Davis Spark 706 dosimeter (class not stated)	Bedside, 8-12 inches above the infant's head	24-hours	Pressure	A	Slow	Not stated	LAmin, LAmax, LA90, LA50, LA10, LAeq
Xie and Kang[37]	Average	ICU	Solo Type-I SLM (model and class not stated)	1.2 m height between the wall and patient's bed (close to the patient's head), away from reflecting surfaces	30-min measurements periods throughout the night, 1-s intervals	Pressure	A	Not stated	Not stated	LAeq, LAmax, LA5, LA10, LA50, LA90 & LA95
Zamberlan-Amorim[38]	Average				Fourteen 12-hour recordings	Pressure	A	Not stated	Not stated	LAeq, LAmax, LApeak

(*Continued*)

Table 1 (*Continued*)

Author	Reporting rating	Setting	Device used	Device location	Time period	Type of amplitude measured	Weighting	Time constant	Calibration	Measurements Made
		NICU & nursing ward (Brazil)	Quest-400 dosimeter (class not stated)	Central area of each room and suspended 70 cm from the ceiling	(0700-1900 and 1900-0700)					
Cordova *et al.*[39]	Average	Burn ICU (USA)	A-weighted SLM (manufacturer, model and class not stated)	Centre of the nurses' station, 6 m from the patients' rooms on average, additional measurements within random rooms (near patients' heads)	24-hour measurements with 5-s intervals over 1 month	Pressure	A	Not stated	Not stated	LAmax, LAmin, LAeq
Darbyshire and Young[40]	Average	ICU (UK)	CEL-630 SLM (class not stated)	One SLM central in the room and another near the patients' heads (patients central to the room were generally chosen)	24 hours, 1-min intervals	Pressure	A	Not stated	Yes	LApeak, LAeq
Ginsberg *et al.*[41]	Average	Operating theatre (USA)	Thomas Scientific 8331A20 SLM (class not stated)	Flat on the anesthesia machine in the operating room	2-minute intervals at different points throughout the surgery	Pressure	A	Not stated	Not stated	LAmax
Fortes-Garrido *et al.*[42]	Average	NICU (Spain)	Bruel and Kjaer 2270 & 2250 SLMs (Type-I)	Central in the NICU, 80 cm below the ceiling, 153 cm from the wall in one room & 80/215 in the other	15 days (1-s intervals)	Pressure	A	Fast	Not stated	LA10, LA50, LA90, LAeq1h
Kol *et al.* [43]	Average	Pediatric ICU (Turkey)	Extech 407780 SLM (class not stated)	At least 1 m away from surfaces and 1-1.5 m away from architectural elements (windows/air vents/ etc.)	12-hour measurements with 5-s intervals over 1 month	Pressure	A	Not stated	Yes	LAeq, LAmax, LAmin
Kol *et al.*[44]	Average	ICU (Turkey)	Extech 407780 SLM (class not stated)	Between 2 patient's beds and the nurses' station, at least 1 m away from surfaces and architectural elements	24-hours	Pressure	A	Not stated	Yes	LAeq, LAmax, LAmin
Hu *et al.*[45]	Average	ICU (China)	AWAI AWA5610 SLM (class not stated)	Horizontally, 10 cm away from the patient's auricle	24-hours, 20-min intervals	Pressure	A	Not stated	Not stated	LAeq
Calikusu and Balci[46]	Average	NICU (Turkey)	Geartech DT-8852 SLM (class not stated)	On a table in the noisiest area of the ICU (diagram provided in study)	24-hours, 1-s intervals	Pressure	A	Not stated	Yes	dBA SPL
Giv *et al.*[47]	Average	Operating theatre (Iran)	Noise level gauge	At the location of staff and surgeons	5-min periods at the start of,	Pressure	A	Not stated	Yes	LAeq, LAeq10, LAeq50, LAeq90, noise

(*Continued*)

Table 1 (*Continued*)

Author	Reporting rating	Setting	Device used	Device location	Time period	Type of amplitude measured	Weighting	Time constant	Calibration	Measurements Made
					during and after surgery					pollution level (NPL)
Parra *et al.*[48]	Average	NICU (France)	ACOEM WED noise dosimeter (class not stated)	One microphone in the centre of the room (50 cm from any surface) and another inside the incubator within 30 cm of the ear of each patient	24-hours, 1-s intervals	Pressure	A	Not stated	Not stated	LAeq, LAmax, LA10
Voigt *et al.*[49]	Average	ICU (USA)	IC Sentinel (for simultaneous sound and light measurement)	Placed to the left of the patient's bed, near the head, directly under the main ceiling lights	1-hour periods, with different times of day simulated	Pressure	A	Not stated	Yes	dBA SPL
Akansel and Kaymakci[50]	Limited	ICU (Turkey)	Bruel Kjaer 2144 Model Deal Channel Frequency Analyser SLM (class not stated)	Patients' beds (1.5 m above the floor)	24 hours (15-min intervals), Monday-Friday	Pressure	A	Not stated	Not stated	Average from individual dBA SPL readings
Darcy *et al.*[51]	Limited	NICU (USA)	Sper Scientific Mini Sound Meter 840014C SLM (class not stated)	Central location for each room (within reason to avoid getting in the way)	12-hours (day & night periods), 5-min intervals	Pressure	A	Slow	Yes	Average from individual dBA SPL readings
Dube *et al.*[9]	Limited	PCU (USA)	Type-II noise dosimeter (Quest Technologies Q-300), Type-II SLM (Quest Technologies 2900)	Central desk	24-hours	Pressure	A	Not stated	Yes	Average from individual dBA SPL readings
Livera *et al.*[52]	Limited	NICU (India)	Digital SLM (class not stated)	Single measurements in adjoining rooms of NICUs and hourly measurements in the centre of NICU rooms	Single measurements at 3 AM, additional hourly measurements for 15 days	Pressure	Not stated	Not stated	Not stated	Average from individual dB SPL readings
Taylor-Ford *et al.*[53]	Limited	Surgical Wards (USA)	Quest 2900 SLM (class not stated)	Nursing station, suspended from ceiling	6 days, 10-min intervals	Pressure	Not stated	Not stated	Not stated	Leq, Lmin, Lmax, L10, L90
Tsara *et al.*[54]	Limited	ICU (Greece)	Cirrus CR: 245/R2 Environmental Noise Analyser (Type-I)	Noise-monitoring stations placed in each department	24-hours (divided into three 8-hour periods), 1-hour intervals	Pressure	A	Not stated	Not stated	dBA SPL & LAmax
	Limited					Pressure	A	Fast	Not stated	

(*Continued*)

Table 1 (*Continued*)

Author	Reporting rating	Setting	Device used	Device location	Time period	Type of amplitude measured	Weighting	Time constant	Calibration	Measurements Made
Vinodhkumaradithyaa *et al.*[55]		Tertiary Care Hospital (India)	Type-I Digital SLM (Manufacturer and model not stated)	At body level in 14 areas of the hospital	1-hour (morning & evening periods), 3-min intervals					LAeq, LA10, LA90, LAmax, LAmin
Altuncu *et al.*[56]	Limited	NICU (Turkey)	2235 Bruel & Kjaer SLM (class not stated)	Near the head of the infant in the NICU	5-minute period in the morning, 15-s intervals	Pressure	A	Slow	Not stated	Median from individual LpA readings
Macedo *et al.*[57]	Limited	ICU (Brazil)	Minipa MSL-1532C SLM (class not stated)	Not stated	2-hour periods for morning, afternoon & night	Pressure	A	Not stated	Not stated	Average from individual dBA SPL readings
Ramesh *et al.*[58]	Limited	NICU (India)	Portable digital SLM (manufacturer, model and class not stated)	Centre of each room in the NICU	Hourly noise measurements over 15 days	Pressure	Not stated	Not stated	used "standard sounds"	Geometric mean of individual LpA readings
Dennis *et al.*[59]	Limited	Emergency Department (USA)	Sper Scientific 8400029 SLM (class not stated)	Central nursing station, entrance of patient's doorway & next to patient's right ear	5-s measurements – 30 mins before & after quiet time and one 1h 30m before the end of quiet time	Pressure	Not stated	Not stated	Not stated	Average from individual LpA readings
Juang *et al.*[60]	Limited	Hospital ward (Taiwan)	Lutron 4030 SLM (class not stated)	1.5 m above the ground	1-hour recordings over 5 days between 0830-0930, 1130-1230 and 1600-1700	Pressure	Not stated	Not stated	Yes	Average from individual dB SPL readings
Merilainen *et al.*[61]	Limited	ICU (Finland)	Not stated	Next to patient's bed	Not stated	Not stated	Not stated	Not stated	Not stated	Average from individual dB SPL readings
Khademi *et al.*[62]	Limited	Wards of ICU, emergency & kidney transplant departments of hospital (Iran)	EXTECH 407727 SLM (class not stated)	Not Stated	2-min intervals every 30-mins for 5 days	Pressure	Not stated	Not stated	Yes	Leq, Lpeak

(*Continued*)

Table 1 (*Continued*)

Author	Reporting rating	Setting	Device used	Device location	Time period	Type of amplitude measured	Weighting	Time constant	Calibration	Measurements Made
Kurmann *et al.*[63]	Limited	Operating theatre (Switzerland)	PCE 353 SLM (Class not stated)	Directly above the operative field	Measurements taken once per second	Intensity?	Not stated	Not stated	Not stated	dB
Li *et al.* [64]	Limited	Surgical ICU (Taiwan)	TES-1352A-RS232 SLM (class not stated)	30 cm away from the head of the bed with another on the nurses' station	Nighttime	Pressure	Not stated	Not stated	Not stated	Average from individual dB SPL readings
Linder and Christian[65]	Limited	Pediatric oncology unit (USA)	Extech Instruments 407736 digital SLM Type-II (class not stated)	Bedside supply cart for each patient (48 inches from the bed)	12-hours, 30-s intervals (nighttime)	Pressure	Not stated	Not stated	Yes	dB SPL
Olivera *et al.*[66]	Limited	NICU (Argentina)	Type-II Center 322 Sonometer	In a corner between 2 incubators	24 hours, 5-s intervals	Pressure	A	Fast	Yes	Average from individual dBA SPL readings
Salandin *et al.*[10]	Limited	ICU (Germany)	Integrated acoustic-level-analyser (DIN EN 60651, Class-I)	"Representative locations of an ICU"	48-hours	Pressure	A	Fast	Not stated	LAeq, LAmax, LA5, LAmin
Van Enk and Steinberg[67]	Limited	NICU (USA)	Extech Instruments 407736 dosimeter (class not stated)	Near the patient's head	Two 30-s readings taken over a 90-s period	Pressure	A	Slow	Not stated	Median from individual dBA SPL readings
Elser *et al.*[68]	Limited	NICU (USA)	Quest Technologies NoiseProDL dosimeter (class not stated)	Within 6 inches of the child's head in an incubator	20-mins	Pressure	Not stated	Not stated	Not stated	Leq, Lpeak
Guerin *et al.*[69]	Limited	Pharmacy department (Canada)	Class-II TES 1353 & Class-II Bruel & Kjaer 2240 SLMs mounted on tripods (1.45 m from floor)	Measurements made in 13 zones in the department, 1-5 measurement points were used based on the surface area of each zone	A series of 3-hour periods for both day and night with LAeq recorded at 5-min intervals	Pressure	A	Slow	Yes	LAeq5min
Padmakumar *et al.*[70]	Limited	ICU (UK)	Tecpel DSL-330 SLM (Type-II)	Adjacent to patient's bedside, 1 m above and to the right of the patient	24-hours with 3-s intervals	Pressure	A	Fast	Yes	LAmax, LAmin, 'average'
Tegnestedt *et al.*[71]	Limited	3 different rooms within an ICU (Sweden)	Spark 706 Larson Davis dosimeter (class not stated)	Behind the headrest of the ICU bed, 1 m from the patient's head	Five 24-hour periods	Pressure	A,C	Slow for LAeq, fast for Lpeak	Not stated	LAeq, LAmax, Lpeak
Verhaert *et al.*[72]	Limited	Operating theatre (Belgium)	CR110A doseBadge dosimeter & NOR140 sound	Dosimeter attached to shoulders of surgeon & surgeon's assistant	Measurement periods between 1h 47m & 2h 49m depending	Pressure	A,C	Not stated	Yes	LAeq, LCpeak, LA95

(*Continued*)

Table 1 (*Continued*)

Author	Reporting rating	Setting	Device used	Device location	Time period	Type of amplitude measured	Weighting	Time constant	Calibration	Measurements Made
			analyzer (class not stated)		on surgical procedure being measured					
Wang *et al.*[73]	Limited	ICU (USA)	Bruel and Kjaer 2260 SLM (Class not stated)	Nine locations around the ICU, with an additional six in corridors	Six 90-min periods, 8-min intervals	Pressure	A	Not stated	Not stated	LApeak, mean
Bano *et al.*[74]	Limited	Internal medicine ward (Italy)	PCE-222 phonometer	Placed on a 1.4 m high trolley in the middle of each room	5-min periods, 1-s intervals, during 0730-0830, 1330-1430, 1830-1930 and 2330-0030	Pressure	A	Not stated	Not stated	Average
Filus *et al.*[75]	Limited	Emergency ward (Brazil)	Bruel and Kjaer 2230 SLM (class not stated)	Carried by evaluator, measurements made at 10 sites in the ER	2m 30s periods with three repeats for each site throughout the day	Pressure	A	Not stated	Yes	LAmin, LAmax, LAeq
Wang *et al.*[76]	Limited	NICU (Canada)	SoundEar noise meters (class and model not stated)	Single noisemeters placed in each patient area (pod), with another in a central desk area	2 months, 5-min intervals	Pressure	Not stated	Not stated	Not stated	Leq
Wang *et al.*[77]	Limited	NICU (Canada)	SoundEar noise meters (class and model not stated)	Noisemeters placed in 4 locations in the ward	2 months, 5-min intervals	Pressure	Not stated	Not stated	Not stated	Leq
Hill and LaVela[78]	Limited	Patient rooms & nursing stations (USA)	Amprobe SM-20A SLM (class not stated)	3 patient rooms & 3 nursing substations	24-hours, 8-min intervals	Pressure	A	Slow	Yes	Average, LAmax, LAmin
Watson *et al.*[79]	Limited	NICU, PICU, CICU (USA)	QuestTechnologies dosimeter (class and model not stated)	Attached to the lapels of patients	Six 4-periods over 24-hours	Pressure	A	Not stated	Not stated	Mean dBA
Yelden *et al.*[80]	Limited	Inpatient neurological rehabilitation unit (UK)	Tecpel 331 SLM (Class-I)	Within 1 m of patient's bedside at head level and at least 2 m from the door	Six 2-hour periods over 12-hours, 30-s intervals	Pressure	Not stated	Not stated	Not stated	Mean from collected SPL readings
Chow and Shellhaas[81]	Limited	NICU (USA)	Digital language processor – noise levels extracted using software	On the arm of each infant's isolette	16-hour recordings, split into day & night, with 5-min intervals	Not stated	Not stated	Not stated	Not stated	Mean, peak

(*Continued*)

Table 1 (*Continued*)

Author	Reporting rating	Setting	Device used	Device location	Time period	Type of amplitude measured	Weighting	Time constant	Calibration	Measurements Made
Daraiseh *et al.*[82]	Limited	Pediatric inpatient units (USA)	QuestTechnologies Noise Pro DL(class not stated)	Dosimeter attached to the shirt collar of nurses (as close to the ear as possible), additional dosimeters attached to the head of patients' beds	Six 4-hour recordings over a 24-hour period (5-min intervals)	Pressure	A	Not stated	Not stated	Mean from individual readings
Kramer *et al.*[83]	Limited	Pediatric ICU (USA)	QuestTechnologies NoisePRO DLX dosimeter(class not stated)	Microphone 1 m from the patient's head	24-hours, 1-min intervals	Pressure	A	Not stated	Yes	Average, LApeak
Delaney *et al.*[84]	Limited	ICU (Australia)	Extech SDL 600 (class not stated)	Nurses' station & patient's clinical environment (mounted adjacent to patient's head, 155 cm away)	9-hours, 5-s intervals	Pressure	A	Not stated	Not stated	dBA SPL (mean and peak taken from these)
Elbaz *et al.*[85]	Limited	ICU (France)	NoxMedical T3 Microphone (class not stated)	40 cm from patient's head	24-hours, 30-s intervals	Pressure	C	Not stated	Not stated	Took medians from collected SPL data
Ramm *et al.*[86]	Limited	NICU (Australia)	Extech Sound Level Datalogger Dosimeter (class not stated)	Above a sink in a "high traffic area" in each room (0.5 m from the ceiling and 2.16 m from the floor) between 2 bed spaces	4-weeks, 60-s intervals (day broken down into different periods for analysis)	Pressure	Not stated	Not stated	Not stated	Max, min
White and Zomorodi[87]	Limited	Nurses' stations in critical care units (USA)	Decibel 10th iPhone App (version 3.8.1–iPhone model not stated)	Central nurses' station and individual nurses' station	Six 30-s periods both for morning and evening	Pressure	Not stated	Not stated	Not stated	Average from individual LpA readings

Quality appraisal of measurement approaches

The way in which the technical aspects of the included studies was reported was appraised as "comprehensive" for 11 studies, "average" for 25 studies and "limited" for 40 studies. This means that only 14.5% of the 76 hospital studies included in the review, provided sufficient details to enable the authors to repeat the measurement.

A high proportion of studies were able to provide sufficient information about the measurement process in some areas. With respect to the time periods in which the measurements were conducted, 97% of all studies provided information on both the duration of the measurement process and also the sampling period for measurements. Similarly, most studies (87%) also provided details about the specific location of the measuring instruments.

However, it is important to note that there were a number of key absences across the studies. The time constant, for example, was only discussed in 33% of all studies, whilst only 43% provided information about the calibration process. Moreover, although the details on the frequency weighting function used in the respective studies was generally present, with 78% of studies including this information (65.8% for A-weighting, 10.5% for C-weighting and 1.3% for both), 22% were not explicit as to which network was used.

Recommendations

Based on this review, the following recommendations are provided to guide the accurate measurement and documentation of environmental noise measurements in hospitals.

Purpose. A noise survey may have a variety of different approaches and the specific purpose should be identified. The noise survey may be designed to assess the noise exposure at specific patient bed spaces, noise exposure of staff or measuring the noise climate of specific rooms or types of setting. The measurements may be made to assess compliance with a benchmark (such as WHO) or to compare with environmental noise levels across similar settings or as part of a noise reduction programme.

SLM setting. The purpose of the noise survey will determine the choice of instrumentation. Currently there is no standardised method for measuring hospital noise. Modern sound level meters are often capable of measuring many different acoustic metrics. The accuracy and comparability of all of these metrics is not guaranteed, not least because permitted tolerances of sound level meters are defined for a limited range of metrics.[1] This makes it difficult for the non-specialist to know what to measure and why. Many of the studies included in this review compared their results to the WHO guidelines, which are expressed in L_{Aeq} (A-weighted time-average SPL) and L_{AFmax} (A-weighted maximum SPL measured over a given period of time with 'fast' time constant (i.e. 125ms)).

For most long-term measurement applications in a hospital environment, A-weighting would be most appropriate since it considers the frequency-dependent loudness perception of the human hearing system (i.e. L_{Aeq}). There are large meta-analyses of outdoor environmental noise which indicate that variants of L_{Aeq} are an adequate predictor of noise annoyance.[88]

Care should be exercised when attempting to measure the maximum SPL, for three main reasons. Firstly, even if a researcher considers a maximum value to be representative of a distribution of noise levels measured in a location, it is unlikely to be generalisable. For example, if a hospital ward measurement is repeated on the next night, a different maximum value will likely occur. Secondly, there are several different ways of measuring a maximum value. For example, L_{peak} means decibel value corresponding to the maximum pressure (positive or negative) arriving at the microphone,[1] while L_{AFmax} means the maximum A-weighted SPL measured with a Fast time constant. L_{peak} will typically be many decibels higher than L_{AFmax}. Finally, the evidence relating measured maxima to human responses is not as strong as for average values like L_{Aeq}, at least for noise exposures below the range where noise-induced hearing loss is likely. This is reflected in the widespread use of L_{Cpeak} in workplace noise exposure legislation, but not in standardised methods intended to predict annoyance or disturbance from noise.

If it is desired to measure the maximum SPL, it is recommended that the device be set to 'fast' and A-weighted (i.e. L_{AFmax}). This would allow comparison with WHO guidelines. L_{A10} (SPL exceeded for 10% of the measurement time period) and L_{A90} (SPL exceeded for 90% of the measurement time period) would be useful alternative metrics. They are widely used in environmental noise surveys as markers of the near-highest and background sound levels, respectively. Measured over day, night or 24-hour periods, they might also be useful measures of the noise climate on a hospital ward.

Locations. The positioning of the measuring device should be made sufficient for the "point-of-interest" for your study. For example, if a patient's noise exposure is of interest, then a location close to the patient's ear will be more appropriate than a central location in the room. The measuring device should be positioned in a location that is not disruptive to the day-to-day clinical activity of the hospital staff. Any contact with the measuring device during measurements should be avoided as this can affect the maximum SPL to be recorded. Compromises may be required to balance preferences for the ideal location for the point-of-interest with practical considerations. It is important to ensure that any measuring devices are at least 1 m (more if possible) away from any large reflecting surfaces (doors, walls, windows, floors, ceilings, etc.) and that they are on a stable surface, such as being mounted on a tripod. Close reflecting surfaces will increase the measured sound level,

dependent on several factors which make the result less generalisable, like the size and acoustic absorption coefficient of the surface.

Documentation and reporting. It is essential to be explicit about the procedure that was followed and equipment used. Failure to document this information can cause the measurement data to be uninterpretable and meaningless. The provision of detailed information will avoid any unnecessary confusion and support the perceived accuracy of your results. The essential information to be reported is as follows:

(1) The precise location of the measuring device, using a picture or diagram if necessary.
(2) The time period and sampling intervals for the measurement.
(3) Equipment manufacturer and model.
(4) Equipment calibration process.
(5) Time constant and frequency weighting (e.g. L_{Aeq}, L_{AFmax}, L_{A90}, etc.).

Data analysis. Researchers should exercise caution when attempting to manipulate the measurement data and avoid this where possible. Instead, all desired measurements and results should ideally come directly from the measuring instrument, and any supporting software, in order to minimise data errors. To calculate the "average" environmental noise level when this is not achievable with the instrumentation at your disposal, then the calculation of the arithmetic mean is not recommended because this does not produce an L_{eq}. Instead, the L_{eq} should be estimated from the measured data and the process used to do described in detail. To avoid confusion the use of the term "average" in this context should be avoided.

CONCLUSION

This rapid review of 76 studies provides a detailed overview of the equipment and approaches used in studies that have measured noise levels in hospitals. There was significant variability in the approaches used to measure environmental noise in hospitals. Few studies (14.5%) contained sufficient technical information to support the replication of the environmental noise measurement process; descriptions on important parameters such as weighting, time constant and measurement time period were missing. In hospital environments, it is recommended to use L_{Aeq} or L_{AFmax}. The measurement equipment setting and process should be fully documented with details on device location and the time period of the recording noted. Attempts to average any measured data should be avoided where possible. In addition, most studies measured noise levels using a SLM positioned closed to a patient's bed area in an intensive care unit. It is recommended future studies also measure noise levels in other areas of a hospital such as in-patient wards, where the impact of noise can have a negative impact on patients' health.

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Conflicts of interest

There are no conflicts of interest.

Appendix A—Search terms

Scopus database

#1 "noise" [NDEXTERMS]

#2 "noise, occupational" [NDEXTERMS]

#3 "sound" [NDEXTERMS]

#4 "acoustics" [NDEXTERMS]

#5 "loudness perception" [NDEXTERMS]

#6 "sound intensity" [NDEXTERMS]

#7 "acoustic noise measurement" [NDEXTERMS]

#8 "acoustic measuring instruments" [NDEXTERMS]

#9 "noise measuring" [NDEXTERMS]

#10 "psychoacoustics" [NDEXTERMS]

#11 "noise spectrum" [TITLE-ABS]

#12 reverb* [TITLE-ABS]

#13 "noise level" [TITLE-ABS]

#14 "sound level" [TITLE-ABS]

#15 #1 or #2 or #3 or #4 or #5 or #6 or #7 or #8 or #9 or #10 or #11 or #12 or #13 or #14

#16 "intensive care units" [NDEXTERMS]

#17 "neonatal intensive care unit" [INDEXTERMS]

#18 "patients' rooms" [INDEXTERMS]

#19 "hospitals" [INDEXTERMS]

#20 "critical care" [INDEXTERMS]

#21 "health facilities" [INDEXTERMS]

#22 hospital* [TITLE-ABS]

#23 "patients' ward" [TITLE-ABS]

#24 "patients' room" [TITLE-ABS]

#25 "emergency room" [TITLE-ABS]

#26 "emergency ward" [TITLE-ABS]

#27 "intensive care" [TITLE-ABS]

#28 "critical care" [TITLE-ABS]

#29 #16 or #17 or #18 or #19 or #20 or #21 or #22 or #23 or #24 or #25 or #26 or #27 or #28

#30 #15 and #29

Cochrane library

#1 MeSH descriptor: [Noise] explode all trees

#2 MeSH descriptor: [Noise, Occupational] explode all trees

#3 MeSH descriptor: [Sound] explode all trees

#4 MeSH descriptor: [Acoustics] explode all trees

#5 MeSH descriptor: [Loudness Perception] explode all trees

#6 MeSH descriptor: [Psychoacoustics] explode all trees

#7 "noise spectrum" or reverb* or "noise level" or "sound level":ti,ab,kw (Word variations have been searched)

#8 MeSH descriptor: [Intensive Care Units, Neonatal] explode all trees

#9 MeSH descriptor: [Intensive Care Units] explode all trees

#10 MeSH descriptor: [Patients' Rooms] explode all trees

#11 MeSH descriptor: [Hospitals] explode all trees

#12 MeSH descriptor: [Critical Care] explode all trees

#13 MeSH descriptor: [Health Facilities] explode all trees

#14 hospital* or "patients' ward" or "patients' room" or "emergency room" or "emergency ward" or "intensive care" or "critical care":ti,ab,kw (Word variations have been searched)

#15 #1 or #2 or #3 or #4 or #5 or #6 or #7

#16 #8 or #9 or #10 or #11 or #12 or #13 or #14

#17 #15 and #16

Pubmed database

#1 "noise" [MeSH Terms]

#2 "noise, occupational" [MeSH Terms]

#3 "sound" [MeSH Terms]

#4 "acoustics" [MeSH Terms]

#5 "loudness perception" [MeSH Terms]

#6 "psychoacoustics" [MeSH Terms]

#7 "noise spectrum" [Title/Abstract]

#8 reverb* [Title/Abstract]

#9 "noise level" [Title/Abstract]

#10 "sound level" [Title/Abstract]

#11 #1 or #2 or #3 or #4 or #5 or #6 or #7 or #8 or #9 or #10

#12 "intensive care units" [MeSH Terms]

#13 "intensive care units, neonatal" [MeSH Terms]

#14 "patients' rooms" [MeSH Terms]

#15 "hospitals" [MeSH Terms]

#16 "critical care" [MeSH Terms]

#17 "health facilities" [MeSH Terms]

#18 hospital* [Title/Abstract]

#19 "patients' ward" [Title/Abstract]

#20 "patients' room" [Title/Abstract]

#21 "emergency room" [Title/Abstract]

#22 "emergency ward" [Title/Abstract]

#23 "intensive care" [Title/Abstract]

#24 "critical care" [Title/Abstract]

#25 #12 or #13 or #14 or #15 or #16 or #17 or #18 or #19 or #20 or #21 or #22 or #23 or #24

#26 #11 and #25

References

1. ISO IEC 61672-1:2013, in Electroacoustics—Sound Level Meters Part 1: Specifications. 2013, IEC.
2. Muzet A. Environmental noise, sleep and health. Sleep Medicine Reviews 2007;11:135-42.
3. Goines LHL. Noise pollution: a modern plague. Southern Medical Journal 2007;100:287-94.
4. Pope D. Decibel levels and noise generators on four medical/surgical nursing units. Journal of Clinical Nursing 2010;19:2463-70.
5. Wilson CW, Stephens K, Swanson-Biearman B, LaBarba J. Improving the patient's experience with a multimodal quiet-at-night initiative. Journal of Nursing Care Quality 2017;32:134-40.
6. Katz JD. Noise in the operating room. Anesthesiology 2014;121:898.
7. Berglund B, *et al.* Guidelines for Community Noise. 1999, World Health Organisation.
8. Christensen M. Noise levels in a general surgical ward: a descriptive study. Journal of Clinical Nursing 2005;14:156-64.
9. Dube JA, *et al.* Environmental noise sources and interventions to minimize them: a tale of 2 hospitals. J Nurs Care Qual 2008;23:216-24; quiz 225-6.
10. Salandin A, Arnold J, Kornadt O. Noise in an intensive care unit. Journal of the Acoustical Society of America 2011;130:3754-60.
11. Grant MJ, Booth A. A typology of reviews: an analysis of 14 review types and associated methodologies. Health Information & Libraries Journal 2009;26:91-108.
12. Tricco A, *et al.* Rapid reviews to strengthen health policy and systems: a practical guide. 2017, World Health Organisation: Geneva.
13. Watt A, *et al.* Rapid reviews versus full systematic reviews: an inventory of current methods and practice in health technology assessment. Int J Technol Assess Health Care 2008;24:133-9.
14. Moher DL, Tetzlaff AJ, Altman DG. Preferred Reporting Items for Systematic Reviews and Meta Analyses: The PRISMA Statement. Annals of Internal Medicine 2009;151:264-9.
15. Elliott RM, McKinley SM, Eager D. A pilot study of sound levels in an Australian adult general intensive care unit. Noise and Health 2010;12:26-36.
16. Liu WF. The impact of a noise reduction quality improvement project upon sound levels in the open-unit-design neonatal intensive care unit. Journal of Perinatology 2010;30:489-96.

17. Matook SA, *et al.* Variations of NICU sound by location and time of day. Neonatal network: NN 2010;29:87-95. DOI: 10.1891/0730-0832.29.2.87.
18. Short AE, *et al.* Noise levels in an Australian emergency department. Australasian Emergency Nursing Journal 2011;14:26-31.
19. Memoli G, *et al.* Towards the acoustical characterisation of an Intensive Care Unit. Applied Acoustics 2014;79:124-30.
20. Carvalhais C, *et al.* Is there sufficient training of health care staff on noise reduction in neonatal intensive care units? A pilot study from neonoise project. Journal of Toxicology and Environmental Health—Part A: Current Issues 2015;78:897-903.
21. Knauert M, *et al.* Comparing average levels and peak occurrence of overnight sound in the medical intensive care unit on A-weighted and C-weighted decibel scales. Journal of Critical Care 2016;36:1-7.
22. Luetz A, *et al.* Feasibility of noise reduction by a modification in ICU environment. Physiological Measurement 2016;37:1041-55.
23. Fasih-Ramandi F, Nadri H. Background noise in Iranian hospital intensive care units. Noise Control Engineering Journal 2017;65:14-21.
24. Santos J, *et al.* Assessment and characterization of sound pressure levels in Portuguese neonatal intensive care units. Archives of Environmental and Occupational Health 2017:1-7.
25. McLaren E, Maxwell-Armstrong C. Noise pollution on an acute surgical ward. Annals of the Royal College of Surgeons of England 2008;90:136-9.
26. Nathan LM, *et al.* Noise levels in a neonatal intensive care unit in the Cape metropole. SAJCH South African Journal of Child Health 2008;2:50-4.
27. Chen HL, *et al.* The Influence of Neonatal Intensive Care Unit Design on Sound Level. Pediatrics and Neonatology 2009;50:270-4.
28. Lasky RE, Williams AL. Noise and light exposures for extremely low birth weight newborns during their stay in the neonatal intensive care unit. Pediatrics 2009;12:540-6.
29. Richardson A, *et al.* Development and implementation of a noise reduction intervention programme: a pre- and postaudit of three hospital wards. Journal of Clinical Nursing 2009;18:3316-24.
30. Williams AL, *et al.* Intensive care noise and mean arterial blood pressure in extremely low-birth-weight neonates. American Journal of Perinatology 2009;26:323-9.
31. Hsu SM, *et al.* Associations of exposure to noise with physiological and psychological outcomes among post-cardiac surgery patients in ICUs. Clinics 2010;65:985-9.
32. Hu RF, *et al.* Effects of earplugs and eye masks on nocturnal sleep, melatonin and cortisol in a simulated intensive care unit environment. Crit Care 2010;14:R66.
33. Lawson N, *et al.* Sound intensity and noise evaluation in a critical care unit. American Journal of Critical Care 2010;19:e88-e98.
34. Gladd DK, Saunders GH. Ambient noise levels in the chemotherapy clinic. Noise and Health 2011;13:444-51.
35. Johansson L, *et al.* The sound environment in an ICU patient room–a content analysis of sound levels and patient experiences. Intensive Crit Care Nurs 2012;28:269-79.
36. Liu WF. Comparing sound measurements in the single-family room with open-unit design neonatal intensive care unit: The impact of equipment noise. Journal of Perinatology 2012;32:368-73.
37. Xie H, Kang J. The acoustic environment of intensive care wards based on long period nocturnal measurements. Noise and Health 2012;14:230-6.
38. Zamberlan-Amorim NE, *et al.* Impact of a participatory program to reduce noise in a neonatal unit. Revista Latino-Americana de Enfermagem 2012;20:109-16.
39. Cordova AC, *et al.* Noise levels in a burn intensive care unit. Burns 2013;39:44-8.
40. Darbyshire JL, Young JD. An investigation of sound levels on intensive care units with reference to the WHO guidelines. Critical Care 2013;17.
41. Ginsberg SH, *et al.* Noise levels in modern operating rooms during surgery. Journal of Cardiothoracic and Vascular Anesthesia 2013;27:528-30.
42. Fortes-Garrido JC, *et al.* The characterization of noise levels in a neonatal intensive care unit and the implications for noise management. Journal of Environmental Health Science and Engineering 2014;12.
43. Kol E, Aydin P, Dursun O. The effectiveness of environmental strategies on noise reduction in a pediatric intensive care unit: Creation of single-patient bedrooms and reducing noise sources. Journal for Specialists in Pediatric Nursing 2015;20:210-7.
44. Kol E, *et al.* The effectiveness of measures aimed at noise reduction in an intensive care unit. Workplace Health Saf 2015;63:539-45.
45. Hu RF, *et al.* An investigation of light and sound levels on intensive care units in China. Australian Critical Care 2016;29:62-7.
46. Calikusu Incekar M, Balci S. The effect of training on noise reduction in neonatal intensive care units. Journal for Specialists in Pediatric Nursing 2017;22.
47. Giv MD, *et al.* Evaluation of noise pollution level in the operating rooms of hospitals: A study in Iran. Interventional Medicine and Applied Science 2017;9:61-6.
48. Parra J, *et al.* Sound levels in a neonatal intensive care unit significantly exceeded recommendations, especially inside incubators. Acta Paediatrica, International Journal of Paediatrics 2017;106:1909-14.
49. Voigt LP, *et al.* Monitoring sound and light continuously in an intensive care unit patient room: A pilot study. Journal of Critical Care 2017;39:36-9.
50. Akansel N, Kaymakçi S. Effects of intensive care unit noise on patients: A study on coronary artery bypass graft surgery patients. Journal of Clinical Nursing 2008;17:1581-90.
51. Darcy AE, Hancock LE, Ware EJ. A descriptive study of noise in the neonatal intensive care unit: Ambient levels and perceptions of contributing factors. Advances in Neonatal Care 2008;8:165-75.
52. Livera MD, *et al.* Spectral analysis of noise in the neonatal intensive care unit. Indian Journal of Pediatrics 2008;75:217-22.
53. Taylor-Ford R, *et al.* Effect of a noise reduction program on a medical-surgical unit. Clinical Nursing Research 2008;17:74-88.
54. Tsara V, *et al.* Noise levels in Greek hospitals. Noise and Health 2008;10:110-2.
55. Vinodhkumaradithyaa A, *et al.* Noise levels in a tertiary care hospital. Noise Health 2008;10:11-3.
56. Altuncu E, *et al.* Noise levels in neonatal intensive care unit and use of sound absorbing panel in the isolette. International Journal of Pediatric Otorhinolaryngology 2009;73:951-3.
57. Macedo ISC, *et al.* Noise assessment in intensive care units. Brazilian Journal of Otorhinolaryngology 2009;75.
58. Ramesh A, *et al.* Efficacy of a low cost protocol in reducing noise levels in the neonatal intensive care unit. Indian J Pediatr 2009;76:475-8.
59. Dennis CM, *et al.* Benefits of quiet time for neuro-intensive care patients. J Neurosci Nurs 2010;42:217-24.
60. Juang DF, *et al.* Noise pollution and its effects on medical care workers and patients in hospitals. International Journal of Environmental Science and Technology 2010;7:705-16.
61. Merilainen M, Kyngas H, Ala-Kokko T. 24-hour intensive care: an observational study of an environment and events. Intensive Crit Care Nurs 2010;26:246-53.
62. Khademi G, *et al.* Noise pollution in intensive care units and emergency wards. Iranian Journal of Otorhinolaryngology 2011;23:141-8.
63. Kurmann A, *et al.* Adverse effect of noise in the operating theatre on surgical-site infection. Br J Surg 2011;98:1021-5.
64. Li SY, *et al.* Efficacy of controlling night-time noise and activities to improve patients' sleep quality in a surgical intensive care unit. Journal of Clinical Nursing 2011;20:396-407.
65. Linder LA, Christian BJ. Characteristics of the nighttime hospital bedside care environment (sound, light, and temperature) for children with cancer. Cancer Nursing 2011;34:176-84.
66. Olivera M, *et al.* Acoustic pollution in hospital environments. Journal of Physics: Conference Series 2011;332.
67. Van Enk RA, Steinberg F. Comparison of private room with multiple-bed ward neonatal intensive care unit. HERD 2011;5:52-63.

68. Elser HE, *et al.* The effects of environmental noise and infant position on cerebral oxygenation. Advances in Neonatal Care 2012;12:S18-S27.
69. Guérin A, Leroux T, Bussières JF. Pre-post pilot study of noise levels at a university hospital center pharmacy department. Journal of Pharmacy Practice 2013;26:448-53.
70. Padmakumar AD, *et al.* Evaluation of noise levels in intensive care units in two large teaching hospitals – A prospective observational study. Journal of the Intensive Care Society 2013;14:205-10.
71. Tegnestedt C, *et al.* Levels and sources of sound in the intensive care unit – An observational study of three room types. Acta Anaesthesiologica Scandinavica 2013;57:1041-50.
72. Verhaert N, *et al.* Noise exposure of care providers during otosurgical procedures. B-ent 2013;9:3-8.
73. Wang Z, *et al.* Role of a service corridor in ICU noise control, staff stress, and staff satisfaction: Environmental research of an academic medical center. Health Environments Research and Design Journal 2013;6:80-94.
74. Bano M, *et al.* The influence of environmental factors on sleep quality in hospitalized medical patients. Frontiers in Neurology 2014;5.
75. Filus W, De Lacerda ABM, Albizu E. Ambient noise in emergency rooms and its health hazards. International Archives of Otorhinolaryngology 2014;19:205-9.
76. Wang D, *et al.* Examining the effects of a targeted noise reduction program in a neonatal intensive care unit. Archives of Disease in Childhood: Fetal and Neonatal Edition 2014;99: F203-F208.
77. Wang D, *et al.* Reduction of noise in the neonatal intensive care unit using sound-activated noise meters. Archives of Disease in Childhood: Fetal and Neonatal Edition 2014;99:F515-F516.
78. Hill JN, LaVela SL. Noise levels in patient rooms and at nursing stations at three VA medical centers. Health Environments Research and Design Journal 2015;9:54-63.
79. Watson J, *et al.* Impact of noise on nurses in pediatric intensive care units. American Journal of Critical Care 2015;24:377-84.
80. Yelden K, *et al.* A rehabilitation unit at night: Environmental characteristics of patient rooms. Disability and Rehabilitation 2015;37:91-6.
81. Chow VY, Shellhaas RA. Acoustic environment profile of the neonatal intensive care unit: High ambient noise and limited language exposure. Journal of Neonatal Nursing 2016;22:159-62.
82. Daraiseh NM, *et al.* Noise exposure on pediatric inpatient units. Journal of Nursing Administration 2016;46:468-76.
83. Kramer B, Joshi P, Heard C. Noise pollution levels in the pediatric intensive care unit. Journal of Critical Care 2016;36:111-5.
84. Delaney LJ, *et al.* The nocturnal acoustical intensity of the intensive care environment: An observational study. Journal of Intensive Care 2017. 5(1).
85. Elbaz M, *et al.* Sound level intensity severely disrupts sleep in ventilated ICU patients throughout a 24-h period: a preliminary 24-h study of sleep stages and associated sound levels. Annals of Intensive Care 2017;7.
86. Ramm K, *et al.* A comparison of sound levels in open plan versus pods in a neonatal intensive care unit. Health Environments Research and Design Journal 2017;10:30-9.
87. White BL, Zomorodi M. Perceived and actual noise levels in critical care units. Intensive and Critical Care Nursing, 2017;38:p. 18-23.
88. Miedema H, Oudshoorn C. Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals. Environmental health perspectives 2001;109:409-16.