ALAM CIPTA
International Journal on Sustainable Tropical Design Research and Practice

AMBIENT SOUND IN HEALTHCARE SETTINGS AND ITS EFFECTS ON PATIENTS AND STAFF: A SYSTEMATIC REVIEW

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ARTICLE INFO

Keywords:
healthcare setting,
interventions,
media arts,
sound,
soundscape

ABSTRACT

Sound can affect patients, staff, and visitors in healthcare settings in many ways. The purpose of this review was to synthesize and investigate sound in healthcare settings and the effects of these sounds. Relevant studies published between January 2017 and June 2022 were searched through a systematic literature review process using the Google Scholar, PubMed, Scopus, Web of Science, and Wiley Online Library databases. A total of 25 papers met the inclusion criteria. The study results cover three main areas: perceived sound sources and sound levels; associations between healthcare settings and sound; and sound's effects on patients and staff. This study shows that in terms of sound, the environment in hospitals, nursing homes, and outpatient centers is boisterous. Among other findings, associations were identified between sound and types of healthcare services; activities and behaviors; architectural features and materials; and mobile communication devices. Most studies report that sound has adverse effects on patients and staff, while nursing home-related studies report the positive attitudes of residents to musical activities. By evaluating the multiple sound-related solutions available, this review indicates that future research in this area should focus on the long-term effectiveness of interventions and the provision of standards of practice for optimal sound environments, based on different healthcare settings.

1. INTRODUCTION

Healthcare settings can provide treatment and care to patients or residents. One source of sound in healthcare settings is people, including conversations between patients and family members, patients' painful voices, and discussions among hospital staff (Juang, Lee, Yang, & Chang, 2010). Other sources of sound are ventilators, air conditioners, medical equipment, alarm systems, and others (Johansson, Bergbom, Waye, Ryherd, & Lindahl, 2012). The World Health Organization (WHO) has issued guidelines on the maximum noise levels in hospitals. The guidelines recommend that the noise in inpatient wards should not exceed 30 decibels (dB), while the noise in operating rooms and intensive care units should be kept as low as possible (Busch-Vishniac et al., 2005). In practice, it is almost impossible for hospitals to fully comply with these proposed noise volume guidelines (Iyendo, 2017). The specific acoustic environment in a healthcare facility includes not only the sounds it produces itself but also the characteristic auditory image of the facility (Theodore, 2018). Positive sounds in an acoustic environment create a sense of safety and familiarity, while harmful sounds inevitably bring helplessness and anxiety (Johansson et al., 2012). Sound in healthcare settings is one factor to consider when attempting to guarantee a greater sense of physical and psychological safety among patients, residents, staff, and visitors (Bogaert, 2022).

A growing body of sound-related evidence produced in recent decades suggests that sound may affect patient outcomes or the mood of healthcare workers (Greenfield, Karam, & Iqbal O'Meara, 2020; Sreetharan, Schlesinger, & Schutz, 2021). Hospital patients and nursing home residents have weaker physical capabilities than those visiting other places, so they are more susceptible to noise interference (Jamshidi, Parker, & Hashemi, 2020). Noise in the hospital may increase patients' complications and adversely affect their health, cognitive ability, and physical recovery (Cabrera & Lee, 2000). Meanwhile, noise also affects the functional status of medical staff. Medical staff who have been exposed to noise for a long time tend to have decreased attention and make more judgment errors. Besides that, noise may lead to a decline in empathy and an inability to maintain the patience needed to communicate with patients effectively (Juang et al., 2010). Healthcare facilities must promote

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a healthy work environment for staff and a healing environment for patients and residents (Choiniere, 2010).

One current solution is to measure various sound sources and sound levels in healthcare settings to implement noise-reduction efforts (Oleksy & Schlesinger, 2019). For example, researchers have compared the sound levels of wards with different configurations and facilities to identify the main factors causing the differences. Others have added acoustic panels to improve the architectural design and thus achieve sound absorption (Farrehi, Nallamothu, & Navvab, 2016; Tegnestedt et al., 2013). Another solution is to add a soundscape to the hospital setting to create a healthy environment (Devos et al., 2019). A comfortable healthcare setting can reduce a patient's discomfort (Seyedfatemi, Rafii, Rezaei, & Kolcaba, 2014). Some studies have proposed that designing musical sound environments in conjunction with geographic locations creates a positive experience for patients and staff (Thorgaard et al., 2005). Therefore, the role of sound in healthcare settings must be better understood to identify positive sounds that would improve these settings (Watts, Khan, & Pheasant, 2016).

The current literature review focuses on reviews of noise issues in hospital settings (Brown, Rutherford, & Crawford, 2014; de Lima Andrade et al., 2021; Iyendo, 2017; Konkani & Oakley, 2012). Reviews have been undertaken on the sound environment in long-term care facilities and nursing homes (Graham, 2020; Janus et al., 2021). The above studies address the acoustic environment in a particular type of healthcare facility and its impact on patient health. This paper focuses on a wide range of services and healthcare settings, such as hospitals, rehabilitation centres, nursing homes, and long-term care facilities, to bridge the evidence gap on sound in a broader range of healthcare settings and provide insights for future research in this area. This systematic evaluation aims to identify and synthesize sound sources and sound levels, as perceived by patients and staff in healthcare settings, to systematically understand the associations between healthcare settings and sound, as well as the impacts these sounds have on patients and staff. The main research questions of this study are as follows:

RQ1: What sound levels are found in healthcare settings?
RQ2: What is the association between healthcare settings and sound?
RQ3: How does perceived sound affect patients and staff?

2. METHOD

2.1 Data Sources and Search Strategy

According to the guidelines provided by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement (Moher et al., 2009), the authors electronically searched the published literature using the Google Scholar, PubMed, Scopus, Web of Science, and Wiley Online Library databases. The timeline ran from January 1, 2018, to June 1, 2022, a sufficient period to understand the latest research progress. The search string for this review consisted of two sets of keywords related to healthcare settings and sound. The specific search strategy employed was as follows: ("healthcare settings" OR "healthcare facilities" OR "hospital " OR "nursing homes" OR "long-term care" OR "outpatient ") AND ("sound" OR "noise" OR "acoustic" OR "auditorium" OR "soundscape" OR "music").

2.2 Inclusion and Exclusion Criteria

For this review, inclusion and exclusion criteria were constructed based on the PICOS model (Table 1). The study population was patients, residents, and professionals in hospitals, nursing homes, and long-term care facilities. The review did not include those receiving healthcare services in private settings or at home. The studies reviewed were sound-related measurements and interventions, excluding records about sound in medical diagnoses. It is important to note that sound was also included in the review when discussed in combination with other factors. All the studies had to be measured or experimental to improve the validity and quality of the review's results. The study designs included observational studies, cross-sectional studies, and randomized/non-randomized trials but excluded review studies, case reports, medical studies, and conference abstracts. All the studies were written in English and peer-reviewed.

Table 1: *Inclusion and exclusion criteria based on the PICOS model*

Criteria	Inclusion	Exclusion
Population	Patient, resident, and professional populations in hospitals, outpatient clinics, nursing homes, and long-term care facilities	Target population not clearly defined; study population accessing healthcare in non-healthcare settings, private offices, or homes
Interventions	Sound-related measurements and interventions in healthcare settings	Sound in medical diagnoses and cochlear implant-related studies
Comparisons	Separate groups, or comparisons with a clear rationale	
Outcomes	Results related to sound measurements or to the study population	Studies describing sound only, without field measurements or experiments
Study designs	Observational studies, cross-sectional studies, comparative trials - both randomized and non-randomized trials	Review studies, case reports, medical studies, conference abstracts

2.3 Study Selection

The study selection was done jointly by two authors and began with the title and abstract of each article being read to determine if the study met the inclusion criteria. Duplicates were automatically removed using Endnote. The full text of each initially screened study was then read and critically evaluated to determine whether the article should be included in the discussion and analysis for this review. Disagreements were resolved by joint discussion among the three authors.

2.4 Data extraction and analysis

This systematic review developed a data-extraction table, which involved the first author independently extracting material and information related to the research questions from 25 studies. The study characteristics in the data-extraction table included basic data, descriptive data, and outcome data (Munn, Tufanaru, & Aromataris, 2014). More specifically, the extracted basic data included the author/s, year of publication, and country. The extracted descriptive data involved the healthcare setting, purpose, study design, sample size and population, as well as the key findings (Table 2).

Table 2: *Study characteristics and CCAT scores*

Authors	Country	Healthcare Settings	Objective	Study Design	Sample Size and Population	Key Findings	CCAT score/40 (%)
D'Souza et al. (2017)	India	NICU	To determine and describe the ambient noise levels in the acute NICU of tertiary referral hospitals.	Descriptive	N/A	There is a high level of ambient noise in an NICU. The noise generated by the equipment is beyond the scope of repair.	23 (57)
Disher et al. (2017)	Canada	NICU and PICU	To determine baseline sound levels, sound level patterns, as well as potential barriers and facilitators to sound-level reduction.	Mixed-methods	12 staff and parents of currently hospitalized children or infants	The greatest variation in the sound of the ICU environment may come from design and equipment purchase decisions.	25 (63)
Fasih-Ramandi and Nadri (2017)	Iran	ICU	To evaluate the background noise to which ICU patients are typically exposed by means of a noise standard curve.	Cross-sectional	N/A	The sound levels, noise criterion, and preferred noise criteria curves in the ICU exceed the national and international recommended standards for hospital environments.	21 (53)
Giv et al. (2017)	Iran	Operating rooms	To evaluate and measure noise pollution in operating rooms during different surgical procedures.	Cross-sectional	N/A	The highest level of operating room noise pollution is higher than the current standard. Falling object noise is the main source of noise pollution.	27 (68)
Jaiswal et al. (2017)	United States	Patient rooms	To compare ambient sound and light levels and sound level changes in ICU and non-ICU.	Observational	N/A	Quieter non-ICU wards have as much sound level variation as ICU.	32 (80)
Ramm et al. (2017)	Australia	NICU	To compare noise levels recorded in pods and open NICU environments.	Repeated measurements	N/A	Noise levels in both areas exceeded the recommended range. The pods are quieter. Busy periods such as check-in and handover can cause noise peaks.	28 (70)
Wang et al. (2017)	China	Operating rooms	To describe the noise level in the operating room of a tertiary care hospital in China.	Cross-sectional	N/A	High noise levels were found in all operating rooms and consistently exceeded the currently accepted standards.	25 (63)
Aletta et al. (2018)	Belgium	Nursing home	To outline the noise sensitivity and sound perceptions of staff in their work environment.	Cross-sectional	214 staff members	Investigating other personal factors of staff may be important in determining an individual's perception of an acoustic environment.	34 (85)
Baqar et al. (2018)	Pakistan	Public-sector hospital and private-sector hospital	To investigate the noise pollution levels in public and private hospitals in Lahore.	Repeated measurements	N/A	All public and private hospitals recorded noise levels exceeding the permissible limits. The noise levels in public hospitals were higher than those in private hospitals throughout the day.	25 (63)
Alzoubi and Attia (2019)	Jordanian	Patient room	To assess the acoustic privacy and acoustic comfort of a patient's room during the stay.	Repeated measurements	N/A	The doors tested in this study did not meet international standards and the door construction should be reconsidered.	24 (60)

Authors	Country	Healthcare Settings	Objective	Study Design	Sample Size and Population	Key Findings	CCAT score/40 (%)
Bevan et al. (2019)	United Kingdom	Pediatric medical ward	To measure the quality of sleep and noise levels in a hospital and compare these measurements to the home environment.	Observational within case-controlled	40 children (19 male (average age 9.3) and 16 mothers (average age 37.9)	Poor sleep quality for children and their mothers in children's wards may affect children's behavior, recovery and pain tolerance while increasing parental burden and stress.	38 (95)
Bliefnick et al. (2019)	United States	Patient rooms and nursing stations in the hospital.	To discover acoustic indicators that correlate with patients' perceptions of hospital soundscape conditions.	Repeated measurements	N/A	None of the five units achieved a good rating.	26 (65)
Loupa et al. (2019)	Greece	General hospital	To investigate indoor noise conditions in Greek general hospitals	Repeated measurements	N/A	Noise levels varied considerably over time. The noise exposure levels were all below the guideline values for the lowest exposure action values recommended for the workplace.	33 (83)
Wu et al. (2019)	China	General wards	To identify the effects of heat and sound on environmental comfort in heating zones in northern China.	Mixed-methods	220 participants (M = 49, SD = 15.01, 110 males and 110 females)	Acoustic comfort in the ward was satisfactory due to the acceptable range of measured sound levels. The thermal environment can improve the evaluation of acoustic comfort.	24 (60)
Yarar et al., 2019	Turkey	Operating room, clinics, outpatient in the hospital	To determine the noise levels in different parts of a hospital in maternity and pediatric education and research. hospital	Descriptive	N/A	The noise levels measured in this study were far higher than the international recommended noise levels.	30 (75)
Zijlstra et al. (2019)	Netherlands	Outpatient infusion center	To evaluate the effect of non-talking rules on actual sound levels and the perceptions of patients in outpatient infusion centers.	Quasi-randomized trial	263 participates (M = 53, SD = 14.33, 126 patients in non-talking conditions and 137 patients in talking conditions).	Behavioral rules are not sufficient to reduce sound levels and improve the perceptions of patients in outpatient infusion centers.	25 (63)
Chaudhary et al. (2020)	India	ICU	To evaluate and compare the effectiveness of ear plugs and eye masks with ocean sound on sleep quality in ICU patients.	Crossover randomized controlled trial	68 participants with at least 24 hours of ICU stay	Ear plugs and eye masks are more effective than ocean sound in improving sleep quality in ICU patients.	24 (60)

Authors	Country	Healthcare Settings	Objective	Study Design	Sample Size and Population	Key Findings	CCAT score/40 (%)
Greenfield et al. (2020)	Canada	PICU	To describe the light and sound characteristics of the rooms of critically ill children.	Prospective observational cohort study	100 critically ill patients aged 0 to 18 requiring respiratory or cardiovascular support.	Sound levels barely changed during the day and night. Most patients experienced significant sound peaks overnight.	28 (70)
Hughes Driscoll et al. (2020)	United States	Labor and delivery unit	To assess the impact of mobile communication devices and clinical mobility on noise levels in the labor and delivery unit of a medical center.	Cross-sectional	N/A	The use of a clinical mobile platform for smartphones as an alternative to overhead paging communications is associated with a significant reduction in transient noise.	27 (68)
Xie et al. (2020)	China	Nursing units	To investigate the subjective perceptions of residents and caregivers, as well as the objective acoustic parameters of each care unit.	Mixed-methods	75 residents and 30 members of the nursing staff	Residents spent the majority of their waking hours in bedrooms and nursing stations. Both residents and staff ranked the sound environment as the second most important factor in the physical environment after air quality.	25 (63)
Cui et al. (2021)	China	Nursing home	To investigate the sound perceptions and preferences of the elderly in the main indoor public spaces of the nursing home,	Mixed-methods	348 elderly people	This study may help to improve the quality of life of elderly people in nursing homes and provide a reference for the construction and design of nursing facilities.	24 (60)
Darbyshire and Duncan Young (2021)	United Kingdom	ICU	To collect sound level data from a general adult intensive care unit.	Observational	N/A	In the ICU, environmentally sound protection may need to focus on reducing disturbances rather than reducing the overall decibel values.	29 (73)
Mu et al., 2021	China	Comprehensive activity hall of nursing home	To evaluate the perceptions and preferences for sound among elderly nursing home residents.	Mixed-methods	320 elderly people	The overall environment and facilities of the nursing home were good, featuring a large integrated activity hall, but the acoustic environment in the activity hall was not ideal.	31 (78)
Capriolo et al. (2022)	United States	NICU	To determine the effects of neonatal intensive care unit design and environmental factors on neonatal sound exposure.	Observational	N/A	Smartphone application may help to audit an NICU's voice exposure in quality-improvement efforts.	28 (70)
Foo et al. (2022)	Australia	Acute, non-ICU hospital setting	To examine environmental and operational factors that disrupt sleep in an acute non-ICU hospital setting.	Randomized controlled trial	60 patients (20 in shared ward, 20 in single ward, 20 in sleep laboratory)	Noise levels and frequent operational interruptions are significant barriers to sleep.	30 (75)

ICU, intensive care unit; M, mean age; N/A, not applicable; NICU, neonatal intensive care unit; PICU, pediatric intensive care unit; SD, standard deviation.

2.5 Quality Assessment

Following the study selection described above, the Crowe critical appraisal tool (CCAT) was used to assess the quality of the selected literature (Crowe, 2013). The CCAT emphasizes using a research design appropriate to the research question rather than how good the research design is. The compass scores each paper on eight categories: preliminaries, introduction, design, sampling, data collection, ethical matters, results, and discussion. Each category was scored in whole numbers from 0 to 5, with a total maximum score of 40 for a paper. Following the thorough review, the quality assessment scores and percentages for all the reviewed studies are listed in Table 2.

3. RESULTS

Figure 1 shows the PRISMA flowchart of the study selection process. Using the initial search strategy, the authors identified 4,796 papers in the databases in the first stage. In the second stage, 3,031 duplicate records were automatically removed using Endnote software, and the titles and abstracts of 1,527 records were further screened manually, based on the inclusion and exclusion criteria. The third stage involved the full-text reading of 238 articles. Studies were excluded for the following reasons: they were non-general healthcare institutions, the study populations were patients with specific diseases, they featured treatment-related sound-level assessments, and they were review articles. In total, 25 articles were identified after this phase.

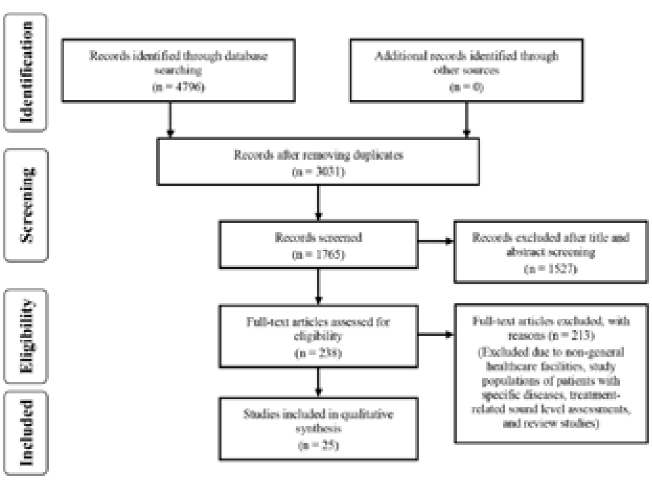

Figure 1: *PRISMA flow diagram*

In this review, there were five cross-sectional studies, seven descriptive studies, four observational studies, one prospective observational cohort study, three randomized controlled trials, and five mixed-methods studies. Twelve studies were conducted in Asian countries, four in the United States, three in Europe, two in the United Kingdom, two in Canada, and two in Australia. Eleven studies contained population samples with a minimum sample size of 12 participants (Disher et al., 2017), five studies had sample sizes between 40 and 100, and the remaining five had sample sizes greater than 200. Most studies were of moderate quality. According to the CCAT scores, four studies were above 80%, nineteen were between 60% and 80%, and two were below 60%.

3.1 Perceived sound in healthcare settings (RQ1)

Eighteen studies reported on sound levels in hospital settings. One study measured the equivalent continuous A-weighted sound pressure level (LAeq) over 24 hours in five units in the same hospital. All the units were deemed to have achieved a good rating for the sound environment. The minimum values ranged from 33 to 45 dB(A) and the maximum values ranged from 89 to 99 dB(A) (Bliefnick, Ryherd, & Jackson, 2019). Another study measured a minimum noise level of 52.51 ± 2.37 dB and a maximum noise level of 81.25 ± 3.21 dB in hospitals, well above the internationally recommended standards (Yarar, Temizsoy, & Günay, 2019). The study obtained sound measurements of 45-65 dB in hospitals in the heating zones of northern China (Wu, Meng, Li, & Mu, 2019). The average sound level in the pediatric ward of a UK children's hospital was 48.6 dB(A), compared to 34.7 dB(A) in a bedroom at home (Bevan et al., 2019). One study measured sound pressure levels indoors and outdoors in a general hospital in Greece. The highest noise levels, 73 and 79 dB(A), occurred in the blood donation unit and laundry room, respectively (Loupa, Katikaridis, Karali, & Rapsomanikis, 2019). One research investigation found that noise pollution was significantly higher in public hospitals than in private hospitals (Baqar et al., 2018). In acute hospital wards, overhead speaker announcements were the most common noise disturbance (Foo, O'Driscoll, Ogeil, Lubman, & Young, 2022). In delivery units, 77% of all sound levels measuring 60 dB or more were generated through overhead paging systems (Hughes Driscoll, Cleveland, Gurmu, Crimmins, & El-Metwally, 2020). A study by Wang et al. (2017) measured the noise levels in operating rooms at 64.2 (±2.1) dB(A), with a range of 59.2 - 72.3 dB(A). The maximum noise pollution associated with orthopedic surgery was 79 dB, and the lowest noise pollution related to cardiac and laparoscopic surgery ranged from 63 to 65 dB (Giv, Sani, Alizadeh, Valinejadi, & Majdabadi, 2017).

In addition, eight studies related to hospital settings discussed sound levels and noise-producing sources in intensive care units (ICU). A study by Fasih-Ramandi and Nadri (2017) found that the noise exposure levels of ICU patients were consistently higher than the recommended range. One study found that ICU wards were louder than non-ICU wards (Jaiswal, Garcia, & Owens, 2017). The average sound level in one ICU was 47.4 dB(A) over the full time range (Darbyshire & Duncan Young, 2021). Furthermore, there was a slight diurnal variation in the sound levels in a pediatric intensive care unit (PICU) (Greenfield et al., 2020). An NICU could reach a maximum average noise level of 72.1 dB(A) during the week, while ventilators with alarms produced a maximum noise level higher than 82.14 dB(A) (D'Souza et al., 2017). Disher et al. (2017) measured upgrades in three types of NICU wards with high, medium, and low acuity. They found that both the maximum and minimum sound levels occurred in the low-acuity NICU wards, with a range of 43 - 61 dB(A). Two studies evaluated the ambient noise levels in a pod and an open-plan NICU in the same hospital. The sound levels in the open plan area in the first study were approximately 3 dB higher than in the pod (Ramm, Mannix, Parry, & Gaffney, 2017). The second study also obtained the highest sound levels from the open pod; they ranged from 53.8 - 78.9 dB (Capriolo et al., 2022).

An outpatient infusion center had sound levels of 39.7 dB(A) at night and above 39.7 dB(A) during treatment (Zijlstra, Hagedoorn, Krijnen, Van Der Schans, & Mobach, 2019). Four studies focused on noise levels in the nursing home environment. Three categories of sound levels were generated by the combined-activity spaces in nursing homes: resting and reading activities at less than 35 dB(A); low-decibel activities at less than 50 dB(A); and high-decibel activities at greater than 60 dB(A) (Mu, Kang, & Wu, 2021). The study by Cui, Zhang, and Li (2021) investigated the range of sound in the main areas inside a nursing home. The living space reached a maximum sound level of 60 dB(A) or more; the sunroom 45 dB(A), and the bedrooms 30 - 40 dB(A); the health center corridor sound levels did not exceed 60 dB(A) during working hours (Xie, Zhong, & Liu, 2020). A soundscape survey of nursing home staff found that those in the nursing unit had the lowest perception of sound (Aletta et al., 2018).

3.2 Associations between healthcare settings and sound (RQ2)

This paper supports the existence of an association between healthcare settings and sound through the assessment of the characteristics of healthcare settings and sound-related outcomes. Four studies illustrated the association between different healthcare services and sound. An ICU is unlikely to meet the recommended sound level standards in the absence of human factors. The ICU is a site with high sound levels, where equipment was found to cause the most significant variations in ambient sound (Disher et al., 2017). A descriptive study found that devices in a neonatal intensive care unit (NICU) produced noise beyond the repair range. Of these devices, ventilators with alarms caused the most noise (D'Souza et al., 2017). A cross-sectional study evaluated the sound levels in an ICU. As each bed in the ward was connected to medical equipment, the sound level was higher at lower frequencies (Fasih-Ramandi & Nadri, 2017). In addition, a cross-sectional study reported the association between the operating room and sound. The study measurements were taken during nearly five consecutive procedures of the same category performed in the operating room each day, reflecting the noisy environment of the operating room. Staff-related activities and conversations were found to be a major component of operating room noise (Wang et al., 2017).

Two studies identified associations between activities and behaviours and sound in healthcare settings. One study found that musical activities can improve the comfort of the sound environment in nursing homes. The study used questionnaires and field measurements to assess the sound-related perceptions and preferences of elderly nursing home residents. During music-related activities in the activity hall, older participants found the sounds of singing and dancing more comfortable than chess and card playing (Mu et al., 2021). A quasi-randomized controlled trial asked one group of patients not to talk to other patients and visitors, while another group was asked to talk. The results suggested that the behavioural rule of non-speaking reduced the sound levels in outpatient infusion centres, but the observed differences were minimal and insufficient to improve patient perceptions (Zijlstra et al., 2019).

Three studies demonstrated the association between architectural features/materials and sound. One study compared two NICU environments in the same hospital. The sound levels in the pod environment were statistically significantly lower than in the open NICU (Ramm et al., 2017). Building materials were associated with acoustic privacy and acoustic comfort in patient rooms. The study results showed that the sound transmission class (STC) of hospital ward walls was 45 dB and the external walls were thick enough to prevent sound transmission. In contrast, the sound transmission level of doors was 11 dB lower than the standard, which negatively affected indoor sound pressure levels (Alzoubi & Attia, 2019). Greenfield et al. (2020) found that the sound levels of new and existing paediatric wards were almost the same, even though both new rooms differed significantly from the existing ones in size and construction materials.

Two studies evaluated the association between mobile communication devices and sound levels. One study found that using a clinical mobile platform for smartphones as an alternative to overhead paging communication significantly reduced transient noise (Hughes Driscoll et al., 2020). Another observational study found that using a smartphone app could identify environmental factors in the NICU that could be improved and help to reduce sound exposure (Capriolo et al., 2022).

3.3 Effects of sound in healthcare settings on patients and staff (RQ3)

Sleep. The average night time sound levels in one hospital's general wards and telemetry floors reached the range of outdoor. They impacted the sleep environment of non-ICU patients (Jaiswal et al., 2017). A randomized controlled trial randomly assigned participants with poor sleep quality in an ICU setting to two groups. One consisted of participants wearing earplugs and eye masks, while the other group was provided with 30 minutes of ocean sound through headphones. The earplugs, eye masks, and ocean sound significantly improved the sleep quality of the ICU patients. Comparing the effects, earplugs and eye masks were more effective than ocean sound (Chaudhary, Kumari, & Neetu, 2020). Another randomized controlled trial documented disturbances to healthy sleep in a large tertiary care hospital. One group of patients was admitted to a shared room (n=20), one group was admitted to a single room (n=20), and the other group (a control) (n=20) was admitted to a sleep laboratory. The noise levels recorded for all three groups were consistently above the World Health Organization recommendations. Seventy percent of ward patients identified noise as a source of sleep disruption (Foo et al., 2022).

An observational study investigated differences in sleep measures at home and in a hospital through two main observations: total sleep time and sleep efficiency. The results indicated that children and mothers slept less in the hospital than at home and had relatively poorer sleep quality. The mean bedside sound level (48.2 dBA) exceeded the WHO guideline of 30 dBA (Bevan et al., 2019). The background noise levels of nursing home residents even increased by 3 to 12 dBA during sleeping hours. Noise levels in occupied bedrooms exceeded the standards for both waking and sleeping hours (Xie et al., 2020).

Health. One study measured sound for two areas of an NICU and found that the dB levels in the pod environment were statistically significantly lower than in the open-plan design NICU. The overall noise levels in both areas exceeded the recommended levels. Peak levels reached 74.5 dB in the NICU and 75.9 dB in the pod, which has profound implications for vulnerable newborns in such a room (Ramm et al., 2017). One study monitored noise in 10 different locations in a general hospital, finding that percussive sounds and noise from metal surfaces and medical equipment were prevalent in areas where patients were present or receiving treatment, such as the emergency room and outpatient department. In the pulmonary and children's wards, noise from equipment and other activities was higher than the recommended environmental guidelines for rehabilitation; patient recovery was adversely affected (Loupa et al., 2019).

Mood. Patients with a non-speaking preference exhibited higher levels of anxiety than those with a speaking preference and those without a preference. Furthermore, patients with a non-speaking preference perceived more crowding and noise (Zijlstra et al., 2019). However, nursing home residents rated background and foreground music in their activity hall as positive. The sounds of music-related activities brought comfort to the residents (Mu et al., 2021).

Attention. A cross-sectional study found that anaesthesia monitors produced numerous distracting alarms and alerts when operating room noise was being monitored. Surgical instruments were also found to produce sudden and noticeable noise (Wang et al., 2017).

4. DISCUSSIONS

This systematic review identified 25 articles exploring sound in healthcare settings and its impacts on patients and staff. Twenty studies were related to hospitals, four were nursing home studies, and one was an outpatient study. Outpatient centres are typically used by patients requiring short-term care and medical services, so most studies in the review focused on populations exposed to sound for extended periods. Twenty-three studies measured and analysed sound levels and sources, with the sound environment being discussed most frequently in the ICU (n = 8). In our review, sound levels were generally higher in ICU units than in non-ICU units, with slight diurnal variations. One study comparing ICUs of different configurations found that the sound-level reduction was unsatisfactory, despite the shortcomings involved in improving the otherwise open-space structure (Capriolo et al., 2022; Ramm et al., 2017). This reflects the complexity of the ICU sound environment, where the unavoidable variety of devices and specific disturbance events are the main factors contributing to persistently high noise levels. The amount of procedural work in the operating room contributes to the noisy sound, so the solutions proposed in the existing studies involve adapting and optimizing the medical procedures in ICU and operating room environments. However, medical procedures are only part of the noise problem and create some difficulties as a solution (Theodore, 2018; Yarar et al., 2019).

This study found associations between types of services; activities and behaviours; building features and materials; and mobile communication devices and sound in healthcare settings. Healthcare services represented by ICUs and operating rooms were strongly associated with high noise levels. A positive correlation has been identified between musical activities and the comfort level of sound environments in nursing homes. Non-speaking behavioural rules are associated with reduced sound levels in outpatient centres. Moreover, there is evidence that improvements to a building's physical structure and materials can effectively control noise, but varying results have been obtained. One study showed significantly lower sound levels in a pod environment than in an open NICU (Ramm et al., 2017), while another prospective study found little difference between the sound levels of the wards of the two structures (Greenfield et al., 2020). Finally, the existing studies reveal that it is challenging to reduce background noise by changing the devices needed for patient care. In comparison, mobile communication devices can not only replace noise-generating paging communication in clinical settings (Hughes Driscoll et al., 2020) but also recognize sounds in the environment through apps to identify parts that need improvement (Capriolo et al., 2022). Mobile technology-related interventions could provide feasible solutions for acoustic environments and deserve further attention.

Additionally, sound in healthcare settings can affect patients' sleep, physical health, and mood, as well as staff attention. Most studies in this review (n = 5) focused on sleep issues, with two randomized controlled trials, two observational studies, and one mixed-methods study. Although intervention studies have demonstrated sleep disturbance due to high noise levels and specific events in healthcare settings, limitations remain. Specifically, frequent night time sound peaks are a significant factor in sleep disruption. Nevertheless, the available studies do not propose targeted interventions for this. In addition, none of the studies report the long-term effectiveness of such an intervention, which presents a challenge when addressing patients' sleep problems. Only one study mentioned the impact of sound on staff in terms of their attention, which mainly involved distractions caused by operating room equipment and frequent alarms (Wang et al., 2017).

Sound in healthcare settings is usually discussed in combination with other factors. Examples include sound and light (Greenfield et al., 2020; Jaiswal et al., 2017), sound and room configuration (Ramm et al., 2017), as well as sound and thermal environment (Wu et al., 2019). None of these studies provide practical standards for optimal sound environments, although observations and measurements were made for each of these considerations.

Based on these studies, sound effects in healthcare settings have primarily been regarded as negative. However, a recent nursing home-related study showed that residents could perceive positive effects of sound from various activities in the activity halls (Mu et al., 2021). In our review, the number of studies on nursing homes was only one-fifth of the number of studies in hospital settings. Institutional nursing homes are more enduring care settings than hospitals, and they play a decisive role in people's understanding of and engagement with voice (Greubel, 2020). More attention to the acoustic environment in nursing homes and long-term care facilities is still needed in the future. This article has a limitation. Most of the studies included in the review did not have a study population. The included studies may not be sufficiently comprehensive when examining the impacts of sound in healthcare settings on patients and staff.

5. CONCLUSION

This study reports a systematic review of the literature on sound in healthcare settings. Twenty-five of the papers reviewed explored perceived sound sources or sound levels in healthcare settings, or the effects of sound on patients and staff in terms of sleep, physical health, mood, and attention. The review attempted to discuss relevant studies from a broad perspective to obtain evidence of variations between different healthcare settings. The results indicate that sound in all healthcare settings is boisterous. Most studies in hospital settings discussed the noise inevitably generated by medical equipment in ICUs and operating rooms. Although considering building-related factors was effective in improving the acoustic environment of hospitals, the results of solutions regarding sound were not significant. The review found positive resident evaluations of sound only in the context of musical events in nursing homes. Current evidence is limited, and the evaluation of long-term solutions is lacking. Future standards of practice should provide optimal acoustic environments for patients and staff, based on different healthcare settings.

ACKNOWLEDGMENTS

The authors wish to thank the Universiti Sains Malaysia for supporting this research.

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