Chapter 10
Hospital Soundscapes

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Abstract Hospital soundscapes are challenging because there are many noise sources that contribute to the soundscape at all hours, which can potentially affect a vulnerable population. Traditional measures of sound in buildings tend not to capture the essential quality of the hospital soundscape, and interventions that have been perceived to produce improvements often show nearly no impact on such acoustic measures. Statistical approaches to hospital sound characterization offer a better means of correlating objective measures to subjective responses.

Hospital soundscapes affect staff and patients, potentially increasing stress in staff and anxiety in patients. Studies of hospital soundscapes using sophisticated statistical approaches suggest a key determinant of patient and staff satisfaction with the hospital soundscape is how calm or relaxing it seems to be. Interventions that might improve hospital soundscapes include the implementation of quiet times, architectural designs that reduce reverberation, addition of sound absorption, the use of earbuds or headphones, and the use of nature sounds to mask some less appreciated hospital sounds.

Keywords Noise control · Occurrence rate · Noise and sleep · Noise and psychological response · Noise and physiological response · Noise interventions

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10.1 Introduction

In many situations, the approach to noise control is to eliminate the offending sounds. As we have come to better understand human reaction to sound, we have also come to appreciate that people and sounds interact in complicated ways and that the eradication of noise is not always the best approach to produce environments that are viewed as positive experiences. Imagine, for instance, a silent playground—would we think this is desirable? It is the complex interaction between people and sound that we define as the soundscape, including the types of sounds that exist in an environment and the responses, physiological and emotional, they produce in people exposed to them (International Organization for Standardization 2014).

Hospitals are a very interesting and challenging environment in which to consider the soundscape. Hospitals are densely packed with people and noise sources, are places where auditory communication can be critical and urgent, and are places where staff are cognizant that their noisy operations might negatively affect their mission by interrupting sleep, interfering with speech communication, and producing irritation and anxiety in patients.

In this chapter, we discuss the compelling reasons to be concerned about hospital soundscapes and the challenges the environment presents in Sect. 10.2, then delve into what is known about the acoustic characterization of hospital environments and their psychoacoustic impacts in Sect. 10.3. In Sect. 10.4, we discuss the impact of the acoustic environment on patients, families, and staff. Finally, we present some work that has been done on interventions to improve hospital soundscapes in Sect. 10.5. Throughout, we will carefully describe both what is well researched and what areas are ripe for further study. This chapter is not intended to be an all-encompassing literature review that discusses and cites all papers published on hospital acoustics. More detailed literature reviews can be found in various articles (Cvach 2012; Hsu 2012; Ryherd et al. 2012).

10.2 Why Do We Care About Hospital Soundscapes?

There are a number of reasons to care about the soundscape in hospitals, ranging from economic to health mission-driven reasons, and an equally daunting set of challenges to improving hospital soundscapes given the constraints imposed by infection control and the seemingly endless production of new medical devices for the bedside.

10.2.1 Exposure to Hospital Noise—The Demographics

One reason to consider the hospital soundscape is simply the sheer volume of people who are in hospitals at any given moment. It is possible to get an estimate of how many people are being treated as in-patients in hospitals on any day by looking at the data collected by the Organisation for Economic Co-operation and Development (OECD) (2019). There are 31 countries for which OECD has information for the year 2016 on the total number of discharges of in-patients and on the average patient stay. Combining this with populations by country permits us to estimate the fraction of people in hospitals as a patient on a typical day. The numbers range from a low of 0.04% of the population (Mexico) to 1% (Japan) with a median of 0.3% among these countries. While patients are the most vulnerable population in hospitals at any moment, they certainly aren't the only people in hospitals. Hospital staff and visitors bump the density by a minimum of a factor of two to a median estimate of about 0.6%. The point is that a large number of people in the world are in a hospital on any given day, many on a recurring basis because they work in the hospital, and thus it behooves us to consider how the hospital environment affects them, including the sonic environment (i.e., the soundscape).

10.2.2 Economic Importance

In the United States, over 21 million people are currently employed in the labor sector identified as Healthcare and Social Assistance and it is the fastest-growing sector of the economy (Bureau of Labor Statistics 2018a). Hospitals are a large part of the healthcare cost and labor force, so it is clear that there are economic reasons to pursue making the experience of people in hospitals as pleasant, effective, and efficient as possible.

The appropriateness of a soundscape depends on the population occupying the space and its intended uses. While the hospital staff population is roughly the same age distribution as that seen in office buildings all over the world, the patient population in hospitals tends to be skewed toward the very young (under 5 years of age) and the old (over 65 and especially over 90 years of age) (Eurostat Data 2009). The very nature of the hospital mission mandates that we understand the soundscape in hospitals so as to create acoustic environments that promote healing rather than soundscapes that tend to delay healing and prolong hospital stays. While studies relating hospital stays and hospital noise are rare, a study by Fife and Rappaport (1976) showed that patients in hospital during a major construction phase (and its associated noise) had longer stays than were the norm when the hospital was modestly less noisy. There is an economic cost to prolonging hospital stays unnecessarily and although we are not yet at the point of being able to estimate this cost, we know enough to presume that it is non-zero and possibly quite significant.

10.2.3 Hospital Design and Noise Interact

Hospitals have some of the most stringent requirements found in buildings in order to deal with the large flow of people, the density of equipment, and the need for the control of pathogens. Hospitals have very high air flow rates, have hard surfaces that are frequently cleaned, have people and equipment constantly in motion, and operate through the transmission of a large amount of information orally. These characteristics pose challenges for crafting a soundscape that is pleasant. Hard, cleanable surfaces tend to be low in sound absorption while high airflow rates can result in increased systems noise, and the constant conversations of people in halls and rooms at all hours of the day disrupt the normal circadian rhythm of patients. A further complication is that hospitals have traditionally been designed to be efficient for staff with less regard for the impact of those designs on patients and on the soundscape, although this is changing in modern hospital designs.

10.2.4 Patient Views on the Hospital Soundscape

There is certainly evidence that patients are unhappy with the soundscape in hospitals. While noise in hospitals has been among the top few complaints of patients worldwide for decades, even surpassing complaints about the food by more than a factor of two (Fick and Vance 2006), the recent creation of patient satisfaction surveys has shown how pervasive and irritating this problem has become. From the moment the Hospital Consumer Assessment of Health Providers and Systems survey was created in the United States (known as the HCAHPS), the single question about noise universally received the lowest average score (Jha et al. 2008). This has recently changed due to modifications in the HCAHPS survey, but noise remains as the second lowest score in the survey. Given that government financial support is tied to performance in the HCAHPS survey, hospital administrators now care greatly about the soundscape in their hospitals. This is evident from the surveys by the Beryl Institute of hospital administrators about their top patient concerns, an example of which is demonstrated in the Fig. 10.1 word cloud (Wolf 2013).

What has been largely missing have been efforts to rigorously relate the sound in hospitals to impacts on patients, staff, and visitors as measured by more than complaints. We know, for instance, that the turnover rate of staff in hospitals is higher than seen in most other business sectors (Bureau of Labor Statistics 2018b), but we don't know the extent to which that relates to the soundscape. Nor do we know enough about the physiological and psychological impacts on patients of the soundscape in hospitals. We will delve further into what is known about the relationship between sound and human interactions in hospitals in later sections of this chapter.

Finally, work that has been done on hospital noise shows that new hospitals are not necessarily quieter than old hospitals (Madaras 2017). Madaras (2017) looked at HCAHPS scores for quiet at night in new hospitals (in operation under 3 years)

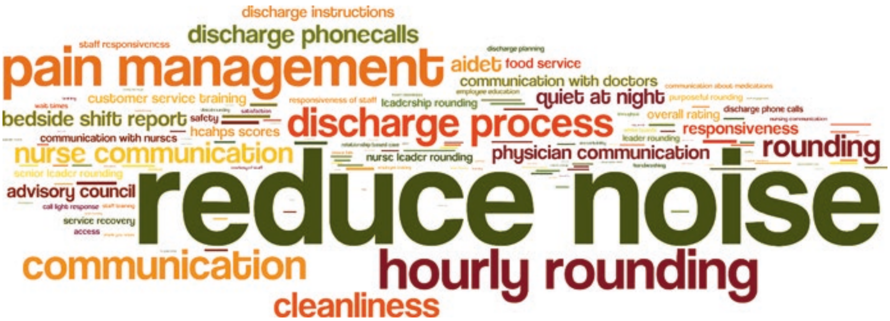

Fig. 10.1 Top patient management concerns from Beryl Institute, 2013

compared to the national average of all hospitals and found that results were either the same or different by the smallest amount possible. This suggests that the hospital soundscape has not been adequately considered in hospital design stages and that we need to have a better foundation of knowledge from which to create soundscapes conducive to healing, leading to healing architectures as described in Nickl and Nickl-Weller (2013).

10.3 The Characterization of Hospital Noise

Noise in hospitals has been recognized as a problem for patients for nearly as long as hospitals have existed. Indeed, in 1859 Florence Nightingale noted "unnecessary noise, then, is the most cruel absence of care which can be inflicted either on sick or well" (Nightingale 1969). Papers discussing noise in hospital date back as far as the 1860s and continue to appear in significant numbers annually.

10.3.1 Sound Pressure Levels

Hospital noise has tended to be characterized in much the way most noisy environments have been objectively described using the *A*-weighted equivalent sound pressure level, the $L_{eq}(A)$. The L_{eq} is defined as the steady-state sound pressure level containing the same sound energy as the original time-varying signal over a given time interval. The $L_{eq}(A)$ is viewed as an appropriate measure of noise in a space as it reflects the average sound energy present as filtered through a weighting network that roughly reflects the acuity of human hearing. This metric is thus a time and frequency average.

Busch-Vishniac et al. (2005) traced the trends in measured $L_{eq}(A)$ for hospitals from 1960 to 2005. The approach was to include all reports of hospital noise that used the $L_{eq}(A)$ and that could be trusted to have averaged correctly, regardless of the type of unit monitored or the country in which the hospital was located. Most of the papers on hospital noise follow the medical literature convention of presenting a mean and standard deviation and unfortunately most seem to calculate these by literally averaging the level values rather than converting back to energy, averaging, and then converting once again to decibel units. This is an error in approach that is prevalent still today.

The reported $L_{eq}(A)$ up to 2005 was expanded by Ryherd et al. (2011) to 2010. The results are shown in Fig. 10.1 for daytime and nighttime hours. There are a few items to note in these graphs. First, there is a monotonically rising trend to the levels as a function of year, indicating that hospitals have gotten progressively noisier. One can speculate on causes for this increase: hospitals first started to be air conditioned in the 1960s; required airflow rates have continued to increase to drive pathogens from the air; the use of hard surfaces has gained popularity as a means to reduce infection; the amount of equipment in use at bedsides has constantly risen with time and each new machine or instrument introduces some noise; the density of patients has increased greatly as time has marched on.

Second, virtually none of the recorded $L_{eq}(A)$ fall below the recommended maxima defined by the World Health Organization (WHO). The WHO guidelines recommend a maximum $L_{eq}(A)$ of 35 dBA in patient treatment and observation rooms and 30 dBA in ward rooms (Berglund and Lindvall 1999). However, the data in Fig. 10.2 are typically occupied background noise levels and the WHO guidelines are applicable for unoccupied (e.g., building system) noise levels. The WHO work in this area is intended to define the maximum level for which there is no evidence of an adverse impact on people. Clearly, the literature supports the assertion that current levels of sound in hospital are sufficient to have a negative impact on patients.

Third, the distribution of $L_{eq}(A)$ reported in the literature is tighter than one might expect given the wide variation of countries, ages of hospitals, and types of units measured (intensive care, medical/surgical, pediatric, and even psychiatric). Given that the buildings are very different and that they have widely varying utilities and equipment, one can surmise that the major source of noise in hospitals, at least as

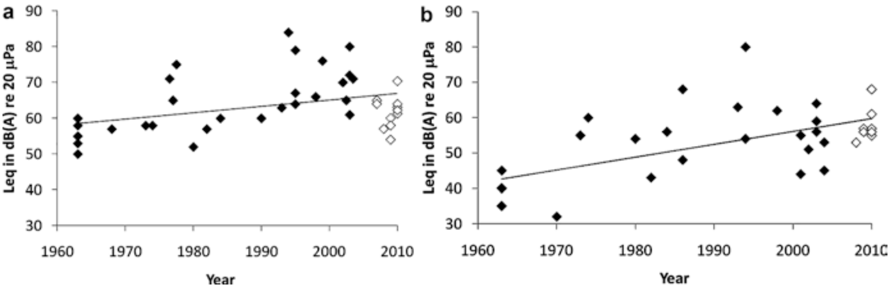

Fig. 10.2 A-weighted equivalent sound pressure levels as a function of year of publication during: (**a**) daytime hours, and (**b**) nighttime hours. (Reproduced with permission (Busch-Vishniac et al. 2005; Ryherd et al. 2011))

measured by the $L_{eq}(A)$, seems to be hospital occupants or standard and common medical equipment. There are two additional pieces of information that support this speculation—studies of occupied versus unoccupied hospital rooms, and studies of sound levels versus frequency in hospitals.

Ryherd et al. (2011) looked at sound levels with occupied and unoccupied rooms in seven different units of a hospital and found that occupied rooms showed higher $L_{eq}(A)$ by 6–15 dB. This identifies the dominant sound sources as those that exist only when patients are present—conversation and other human-origin sounds, and equipment noise for items only used when patients are present. Results were fairly uniform although the equipment used in the units was not, suggesting that it is human sound sources that dominate in a typical hospital.

10.3.2 Sound Spectra

Frequency spectra of hospital noise also support the hypothesis that humans are the major source of sound. Figure 10.3 shows a typical graph of sound versus frequency in octave bands in a variety of hospital units in a single hospital. The preponderance of low-frequency sound is typical of HVAC system noise. In the mid range, the level is flatter and it is this range where speech dominates and other human occupancy sounds also contribute. This is distinct from a typical unoccupied space, in which the level decreases monotonically with frequency.

Besides human-associated noises, there are many additional sources of noise that contribute to an overall hospital soundscape often described as pandemonium. Siebein and Skelton (2009) classed hospital sound sources into five distinct categories: occupational; medical equipment; conversational; building equipment; and

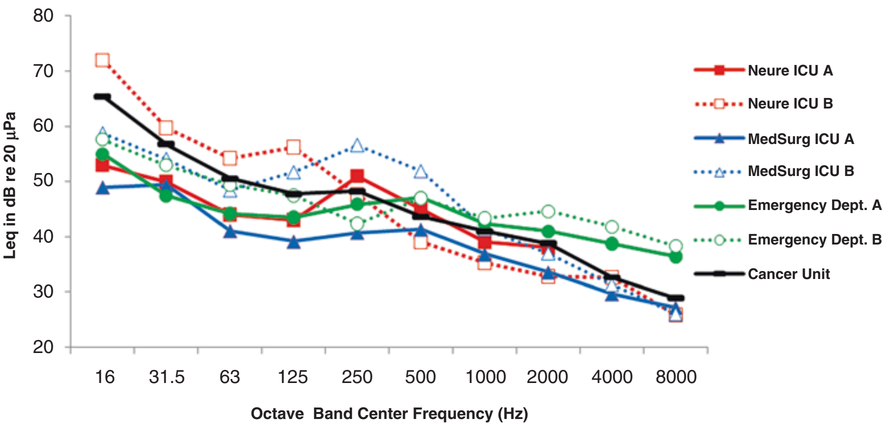

Fig. 10.3 Average unoccupied background noise levels in octave bands for various types of units (i.e., Neurological and Medical-Surgical Intensive Care Units, Emergency Departments, and Cancer Units). (Reproduced with permission (Ryherd et al. 2011))

exterior noise. Occupational sources include telephones, overhead paging systems, and food carts. Medical equipment includes EKG monitors, ventilators, and various pumps. Many of these devices have alarms which sound frequently but for such short durations that they would not be well captured by a measure which averages over time such as a L_{eq}. Building equipment sound sources include HVAC systems and floor cleaning equipment. Exterior noise sources are related to automobile traffic, helicopter landings and takeoffs, and sirens from ambulance arrivals. Compared to a typical household, the hospital sound sources differ in a few ways: there are more of them, they don't seem to quiet down at night, and some of them produce alarms.

10.3.3 Sound Levels Over Time

Hospitals are unusual environments in terms of sound versus time—typically displaying a great deal of variation of amplitude on short time scales but very little over longer time scales. Consider Fig. 10.4, which shows a typical sound recording versus time on a patient unit over the course of 6 h at night. Viewing the entire period, the average seems to be fairly constant and indeed little difference between night-time and daytime hours was found (Ryherd et al. 2008). By contrast, looking at the sound versus time on short time scales shows it is peaky.

10.3.3.1 Loudness Measures

Other standard measures shown in Fig. 10.4 include the minimum, maximum, and peak sound pressure levels (L_{min}, L_{max}, and L_{peak}). The L_{min} and the L_{max} are the minimum and maximum root-mean-squared sound pressure levels observed over a specified time-averaging period: 125 ms (fast), 1 s (slow), and 35 ms (impulse) time constants. The peak sound pressure level (L_{peak}) is the highest amplitude sound pressure level instantaneously sensed. It is traditional to use the L_{peak} to describe sounds of very short duration and to use the C-weighting scale, which is nearly linear and derived from human perception of loud sounds.

The $L_{eq}(A)$ is not terribly well suited to environments in which the sound is peaky or contains pure tone alarms. Further, the L_{min}, L_{max}, or L_{peak} values are highly influenced by single events. For this reason, many efforts to improve hospital soundscapes have found these measures alone do not predict response to interventions that produce noticeable changes in the soundscape. In the period from 2000 to 2020, researchers have made attempts to find measures of the sound in hospital settings that correlate better with subjective reactions as measured in surveys such as the HCAHPS.

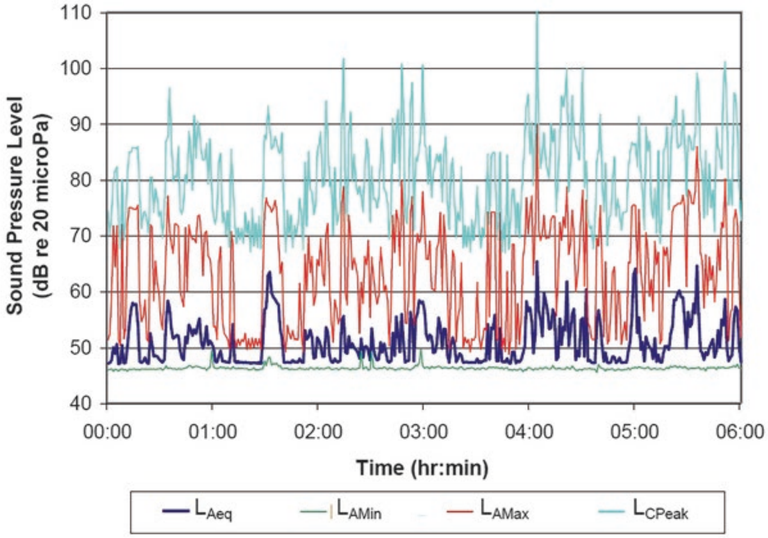

Fig. 10.4 A-weighted equivalent, minimum, and maximum (L_{Aeq}, L_{AMin}, L_{AMax}) and C-weighted peak (L_{CPeak}) sound pressure levels measured over 1 min intervals overnight. (Reproduced with permission (Ryherd et al. 2008)

10.3.3.2 OR(*N*) as a Measure

The occurrence rate is a newer measure that shows promise. It is derived from traditional statistical distribution analysis techniques such as standard noise percentile level analysis. Percentile or exceedance levels (L_n) are historically used to describe how often certain levels are exceeded, based on the running sound pressure level. For example, L_{90} reflects the sound level exceeded 90% of the time. The occurrence rate expands upon the traditional L_n by applying a statistical distribution analysis specifically to L_{min}, L_{max}, and L_{peak} metrics. The occurrence rate therefore gives a better sense of the distribution of L_{min}, L_{max}, and L_{peak} sound levels. The occurrence rate, which we will write as OR(*N*), thus shows the fraction the time that a measurement of sound pressure level has a value that exceeds *N* dB. For example, OR $(90)_{peak}$ indicates the fraction of the time that peak sound levels exceed 90 dBC. A typical example of an OR(*N*) graph is shown in Fig. 10.5. Note that, by definition, the graph starts at 100% at the lowest sound pressure level and decreases monotonically to 0% at the highest values of *N*.

The OR(*N*) was hinted at as an acoustic measure by Ryherd et al. (2008), Williams et al. (2007), and Kracht et al. (2007), who used similar techniques to describe the environments of adult and neonatal intensive care units, and to quantify noise from operating room surgeries, respectively. It was more formally defined in two papers by Okcu (2011) and Okcu et al. (2012) that examined the reaction of nursing staff in two different units of a hospital with similar staff activities and acuity levels. The units showed nearly the same noise levels using the standard L_{eq}, L_{max},

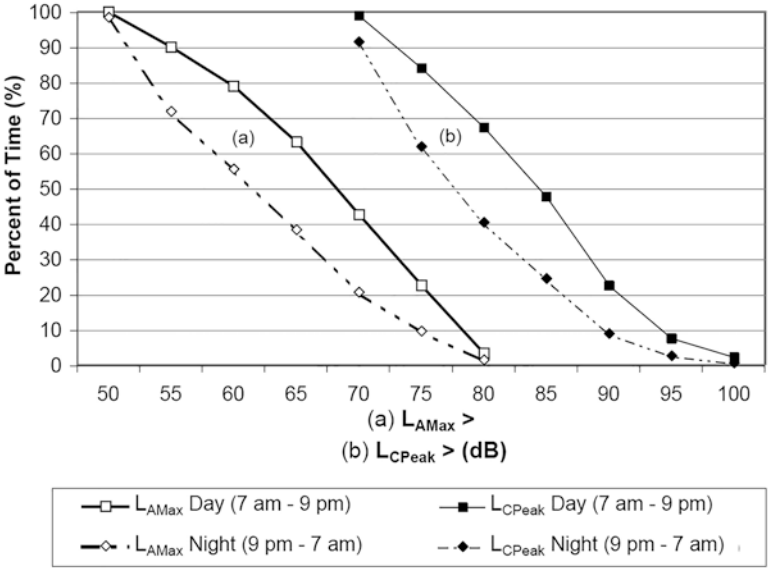

Fig. 10.5 Statistical distribution of peak and maximum levels. *Y* axis represents the percent of time, or occurrence rate (OR) that (a) L_{AMax} and (b) L_{CPeak} exceed *N* values shown on the *x* axis. (Reproduced with permission (Ryherd et al. 2008))

L_{min}, and L_{peak} measures, but staff views of how loud/annoying the environment was and of the impact of the noise on staff performance, health and anxiety were quite different. The unit in which staff had a harsher view of their soundscape had a much higher OR(90), with sound peaks in excess of 90 dBC more than 50% of the time as opposed to just over 20% of the time in the other unit (Okcu et al. 2012).

The OR(*N*) measure of noise in hospitals is growing in popularity and several papers have used this measure and linked it to staff outcomes. For example, Sbihi et al. (2011) studied three long-term care facilities and found peak occurrence rates were correlated with staff perception of noise-related health effects including distraction, stress, fatigue, and tension headache. Okcu et al. (2011, 2012) linked nurse loudness and annoyance perception to mid-level occurrence rates.

Theoretically, occurrence rate analysis can be applied to any acoustic metric. For example, Ryherd et al. (2013) used occurrence rate to determine how often speech intelligibility fell within certain thresholds such as “poor,” “marginal,” and “good.” They found that a unit retrofitted with sound absorption had higher speech intelligibility ratings for a larger percentage of time compared to an identical untreated unit.

While the OR(*N*) is a significant improvement, modified versions might be even more useful in predicting startle responses of patients, visitors, and staff. For example, the OR(*N*) looks at the peak or max sound pressure level only and the result is independent of the average or minimum level present at the time of measurement. If one is concerned about sharp changes in sound energy of the sort that might awaken or startle a patient, then the interest might more appropriately be on the range of noise levels encountered. Work by Bliefnick (2018) developed secondary occurrence rate metrics to account for the range of sound levels experienced and found correlations between the occurrence rate range and patient satisfaction. Follow-up laboratory listening studies found correlations between the occurrence rate range and annoyance. However, some conflicting results indicate this area needs additional research.

10.3.4 Speech in Hospitals

Hospitals are unusual in that an extraordinary amount of information is communicated orally—when medical orders are issued, when staff and patients converse, and when patients and visitors interact. In spite of this reliance on oral communication, little work has focused on the quality of these speech interactions. Kwon et al. (2007), Godfrey and Feth (2011), and Ryherd et al. (2013) measured the Speech Intelligibility Index (SII) in seven different hospitals from 2007 to 2013. In not one of these hospitals did the SII predict good speech communication. Indeed, the environments typically were found to be marginal or poor for speech communication. Further, Ryherd et al. (2013) found SII to be correlated with nurse perception of communication problems. This has serious repercussions. Patients might not follow medical directions because they didn't hear or comprehend them, a problem exacerbated by patients being less able to focus due to their illness or medications they are taking. Speech communication problems also contributed to medication errors prompting rules to be changed to require written drug orders in hospitals. Characterizing hospital speech communication issues, their impact on patients, staff, and visitors, and a means of improving speech communication are areas ripe for further research work.

10.3.5 Alarms

Hospital soundscapes typically include a large number of alarms. Most of the studies reporting on alarm frequency in hospitals have focused on intensive care units, where alarms sounding 150–500 times per day per patient are the norm (Cvach et al. 2013; Whalen et al. 2014). Even on units with lower acuity, such as medical/surgical units in community hospitals, alarm rates of about 100 per patient per day are common.

Alarm noise poses quite a challenge for hospital soundscapes. Sounding alarms have traditionally been used to indicate an urgent situation that staff must address, and the sounds are specifically intended to grab attention. Further, for a variety of legal and medical reasons, there is a desire to err on the side of false positive alarms rather than false negative alarms. This has led to a situation in which over 90% of clinical alarms in hospitals result in no action being taken (Cvach 2012).

In spite of this enormous rate of excess alarms, there are consistent problems in hospitals with alarm failures resulting in deaths and loss of function of patients. The Emergency Care Research Institute (ECRI) listed clinical alarms as the top medical technology hazard in 2013 and 2014, and number 2 in 2015 (ECRI Institute 2013). During those years, alarm failures accounted for about 200 deaths in the United States annually. An analysis of the literature and databases on alarm errors by Busch-Vishniac (2015) estimated that about 3% of the time, alarms that sound are not responded to in a timely fashion, and another 9% of the time, alarms that should sound according to current standards do not.

The impact of alarms in the hospital soundscape is very different for staff and for patients and their visitors. Staff are expected to respond to alarms but they sound so frequently that they tend to produce a response referred to as "alarm fatigue" in which caregivers become desensitized to alarms, leading to sometimes missing critical clinical alarms. In one study more than half (56%) of nurses admitted they sometimes tune out alarms (Okcu et al. 2012) and in another study almost half (49%) revealed they sometimes adjust the alarm levels so that they would not hear them (Ryherd et al. 2008). For staff, then, alarms contribute to a very stressful environment.

For patients and their visitors, alarms sounding at or near the bedside can produce anxiety and disrupt conversation and sleep. Alarms are routinely listed by patients as one of the most disturbing noise sources.

The hospital soundscape could be improved by reducing the number of clinical alarms and changing the sound they produce. There are a number of issues with the use of alarms that merit further study. For instance, currently alarms sound not because of a medical diagnosis (as in cardiac arrest) but rather because a physiological measure, such as oxygen saturation level, exceeds or goes below a threshold. Further, we have not made clinical alarms particularly smart. For instance, a study of patients by Gorges et al. (2009) indicated that incorporating a 14 s delay before alarming would eliminate most of the alarms. We have virtually no information available at this point on whether the presence of alarms sounding at a patient bedside has an impact on the medical outcomes for that patient—yet hospital staff would agree that there is no medical reason for patients to hear the alarms going off.

There are a host of questions that should be studied related to the alarms themselves. Current alarms contain little information: they can be hard to localize because they tend to be pure tones and they aren't standardized so the alarm source can't be easily recognized. An early study of alarms by Lawless (1994) that was equivalent to a "name that tune" test found that hospital staff were largely unable to identify the equipment alarming based on the sound. Since that time, the number of alarms has exploded making the problem worse. Even more basic is the question of when alarms should sound rather than providing an electronic notice or visual alarm, and what sounds might be used to provide information beyond merely a location. Work on the latter question is considered by Edworthy and her collaborators (e.g., Edworthy and Hellier 2006).

10.4 The Impact of Hospital Soundscapes on Staff and Patients

Most of the work on noise in hospitals has sought to characterize the sound environment. Because of the difficulty in conducting studies with human subjects, especially a vulnerable group in hospital, there are a limited number of rigorous studies of the impacts of the soundscape on staff and patients. The studies that exist tend to examine how a specific physiological or psychological characteristic or behavior correlates with a measure of the overall loudness of the environment. It is only starting in the 2000s that the methods of analysis developed to study the complex sound/reaction interactions of humans have been applied to hospital soundscapes.

In what follows, we describe the early work to identify the impacts of hospital soundscapes on staff and patients, and then present the work using soundscape analytical approaches. We begin with staff studies and then move to patient studies, with special note on the impact of the soundscape on neonates.

10.4.1 The Impact of the Hospital Soundscapes on Staff

The literature examining the impacts of hospital noise on staff outcomes is relatively sparse compared to the number of studies done with hospital patients and there are some conflicting findings. Overall research generally points to the importance of the sound environment on staff stress, job performance, and occupational health (Ryherd et al. 2012). Examples of the potential impacts of hospital soundscapes on staff outcomes are depicted in Fig. 10.6.

10.4.2 Staff Stress and Auditory Monitoring

The most studied group of staff in hospitals is nurses, who are not only a large fraction of the staff but also the people who work in closest contact with patients. Nursing is a difficult occupation and stress and burnout have been identified as significant job issues, leading to higher rates of substance abuse, depression, suicide, and reduced satisfaction with care among patients/clients (Dyrbye et al. 2017). In addition to having a negative impact on health and wellbeing, stress leads to a high turnover rate for staff in hospitals, especially registered nurses, which negatively affects the quality of patient care and the operating costs of hospitals.

Because stress has been identified as a top concern for hospital staff, most studies of noise impacts in hospitals have focused on the noise/stress nexus. Two of the earliest studies relating noise to stress in nurses were reported by Topf (1988) and Topf and Dillon (1988) who studied 100 critical care nurses and showed that

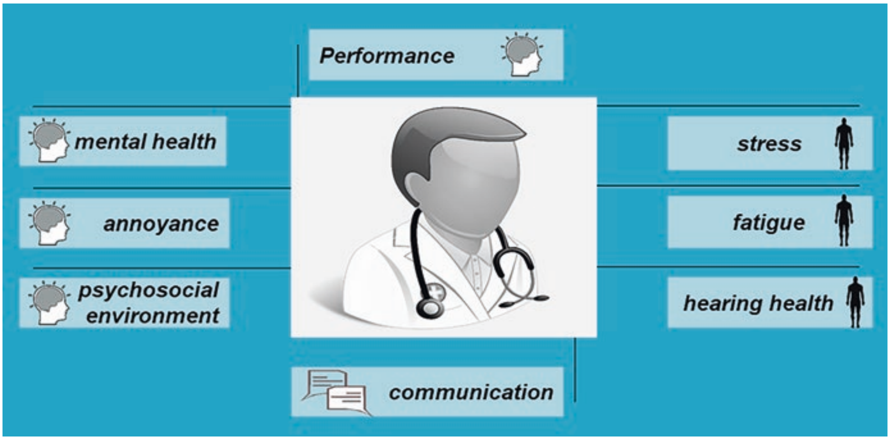

Fig. 10.6 Potential impacts of hospital soundscapes on staff outcomes. (Ryherd et al. 2012)

self-reported sensitivity to noise on the unit correlated with self-reports of stress-related health issues such as headaches on the job. Morrison et al. (2003) later conducted a more nuanced study in which nurses in a pediatric intensive care unit were individually followed for a period of 3 h, during which they were surveyed about their level of stress and annoyance while their heart rate, cortisol levels in saliva (a known stress indicator) and sound level exposure were monitored. They found a correlation between self-assessed annoyance and sound level, between self-reported stress and sound level, and between cortisol levels in saliva and sound level.

Ryherd et al. (2008) surveyed 47 nurses in a neurological intensive care unit and found that 91% reported that noise negatively affects them in their daily work environment. Many of those surveyed reported symptoms of noise-induced stress including irritation (66%), fatigue (66%), concentration problems (43%), and tension headaches (40%). Mahapatra (2011) surveyed 65 staff members in two Emergency Departments and found that 96% of physicians, 89% of nurses, and 91% of other staff (e.g., nurse practitioners, emergency medical technicians, and patient relations staff) felt that their workplaces were "somewhat" to "extremely" noisy. Another study by Applebaum and Fowler (2010) examined the impact of odor, noise, light, and color on nursing stress by surveying nurses in medical and surgical suites in a 500-bed level I trauma center. They found that among the characteristics considered, only noise was significantly related to perceived stress. Further, this study reported that perceived stress was significantly related to job satisfaction and turnover intention, thus indirectly linking noise to job satisfaction and nursing turnover.

From these studies, we conclude there is a correlation between noise and stress in nursing staff in hospitals. Less is known at this point about the contribution to stress from specific sources of sound and the extent to which a reduction in stress might be obtained through soundscape interventions. Without this information, it is difficult to determine soundscape interventions that might improve the working environment for hospital staff.

The Mahapatra (2011) Emergency Department study provides some insight, as subjects were asked to evaluate whether various noise sources disturbed their concentration. Items that most often were reported as “moderately” to “extremely” disturbing are shown in Fig. 10.7. The majority of disturbing sounds were mechanical or human generated. Subjects reported visitor conversation, patient sounds, emergency procedures, operational sounds of medical equipment, building and service sounds, and exterior sounds to be “not at all” to “somewhat” disturbing.

Simply eliminating noise is not an option for hospital staff. For nurses, auditory monitoring of patients is a key part of their job. A conceptual overview of the components of auditory monitoring is shown in Fig. 10.8. We know that staff rely on auditory cues and they must be able to hear calls for help, listen to body sounds and discriminate normal from abnormal, hear sounds indicating threats to patient safety (as in slips and falls), and notice and respond to clinical alarms (Okcu et al. 2008). Further, nurses report that effective auditory monitoring requires recognition, localization, and immediate reaction to these auditory cues. Thus, hospital soundscapes are a good example of a situation where the required solutions are much more complex than simply elimination of noise.

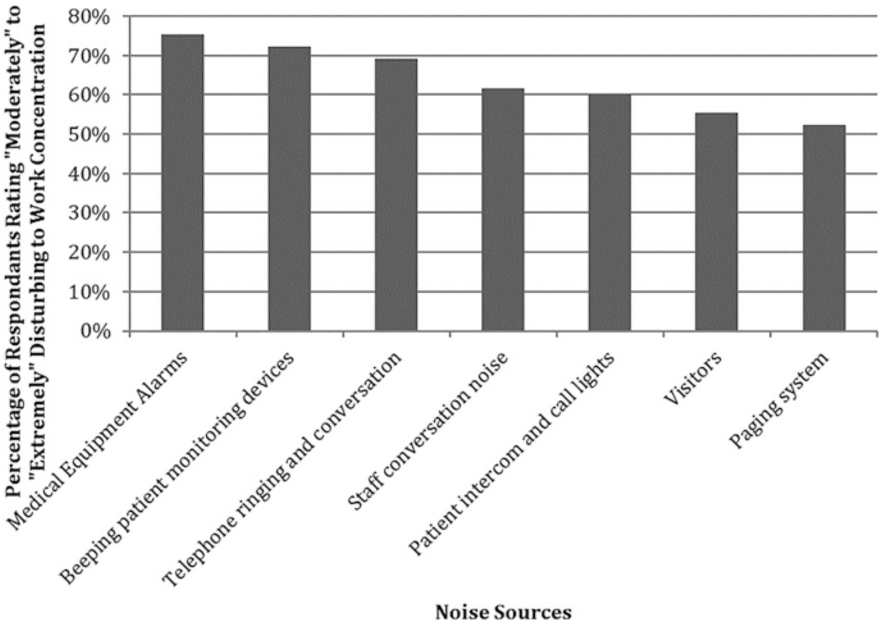

Fig. 10.7 Perceived work concentration disturbance due to various noise sources in the Emergency Department. (Mahapatra 2011)

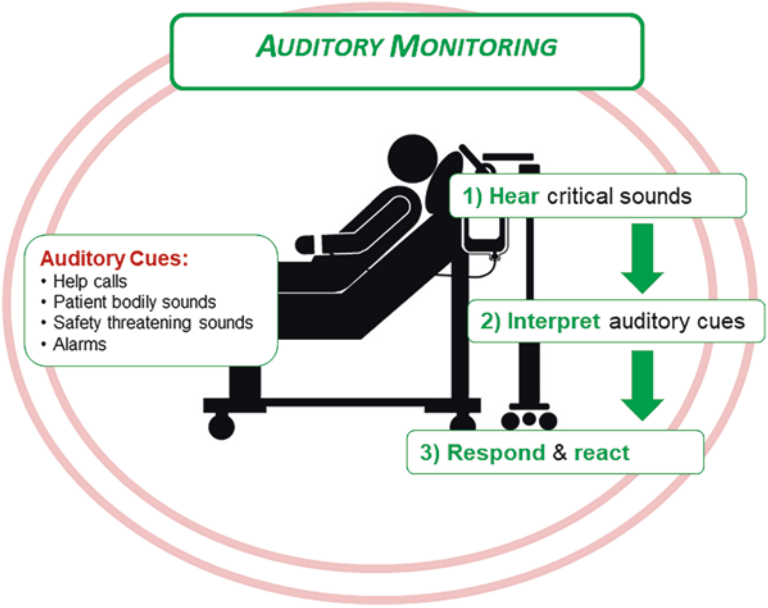

Fig. 10.8 Components of caregiver auditory monitoring (Okcu et al. 2008)

10.4.3 Hearing Loss and Staff Performance

There are two additional impacts of the soundscape worth mentioning: noise-induced hearing loss and impact on performance. Hospitals generally aren't sufficiently loud that there is concern about noise-induced hearing loss. However, operating rooms can be hearing hazards. Operating rooms have very high air flow rates because surgical site infections decrease with the number of room air changes per hour. They are also equipment dense, with each device capable of producing alarms or making other noises. Kracht et al. (2007) looked at the sound levels of typical surgeries at Johns Hopkins Hospital (Baltimore, MD) and categorized them by the type of surgery involved (e.g., cardiology, neurology, etc.). While none of the surgeries produced $L_{eq}(A)$ values which would cause hearing loss concern, many of them showed the presence of high peak sounds, as characterized by an occurrence rate-type measure shown in Fig. 10.9. Neurosurgery and orthopedic operations were found to have peak levels over 100 dBC more than 40% of the time with peaks occasionally exceeding 120 dBC. A handful of studies specifically examined hearing health among orthopedic surgeons and staff (Willett 1991; Holmes Jr. et al. 1996). Though results were mixed, findings point to potential risks for occupational noise-induced hearing loss among this population due to the high levels produced by orthopedic instruments.

Operating rooms often include music at the request of the surgical team. According to Spotify, 90% of doctors listen to music in the operating room

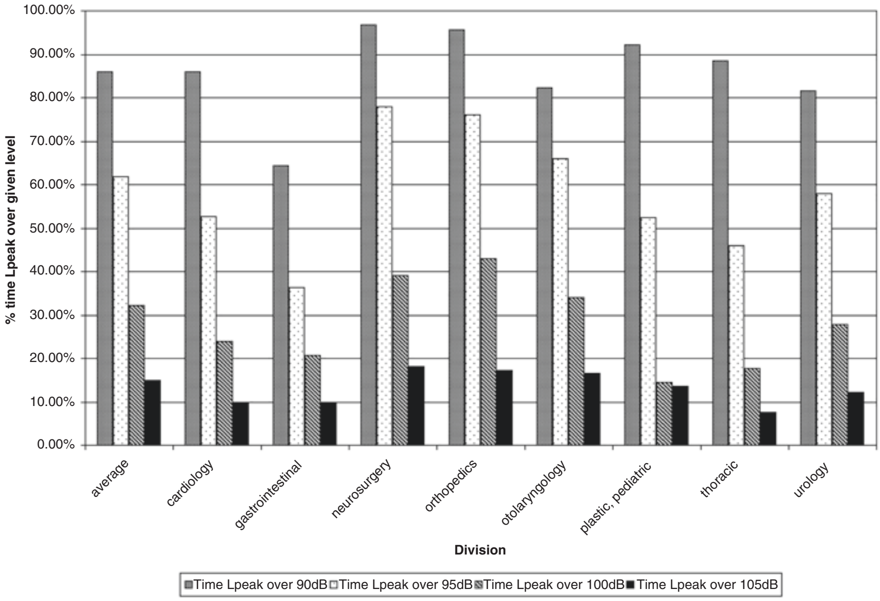

Fig. 10.9 Fraction of time L_{peak} exceeds 90, 95, 100, and 105 dB (unweighted) by category of surgery. (Reproduced with permission (Kracht et al. 2007))

(Ahmed 2019), although a review by Vahed and Kabiri (2016) cited a rate of 62–72%. There are articles that suggest that music can relax surgeons and improve their performance, though the research findings in this area are sparse and conflicting (Moorthy et al. 2004; Zun and Downey 2005).

There have been concerns that the hospital soundscape with its intensity, its many sound sources, its alarms, and its dynamic nature could have a negative impact on task performance. However, the research literature is not clear, with some studies finding no significant difference in performance between quiet and noisy conditions (Hawksworth et al. 1998; Moorthy et al. 2004), while others have found the impact of noise on performance depends on individual preference for quiet or noise and that the impact mostly seems to affect short term memory and mental efficiency (Park and Song 1994; Murthy et al. 1995). There is certainly room for further investigation of task performance in hospitals and how it relates to the soundscape.

10.4.4 The Impact of the Hospital Soundscapes on Patients

The impact of hospital soundscapes on patients is quite different from staff because patients in hospitals are present round-the-clock and rely on the hospital to provide all of their required services. Additionally, patients are a vulnerable population, often anxious about their condition and trying to recover. Further, while staff

Fig. 10.10 Potential impacts of hospital soundscapes on patient outcomes. (Hsu et al. 2012)

members have modest control over the noise produced in a unit, patients have almost none, with the exception of conversations with visitors and choosing whether to watch TV. This lack of control tends to negatively affect the patient's experience with the hospital environment.

A host of potential reactions have been investigated over the years, including sleep disturbance, physiological responses (e.g., cardiovascular response, hospital stay, pain management, wound healing, other physiological reactions), and psychological reactions (e.g., general perception, delirium, satisfaction) (Hsu et al. 2012). Example potential impacts of hospital soundscapes on patient outcomes are depicted in Fig. 10.10. Results generally show that hospital soundscapes impact patients.

10.4.4.1 Sleep

There is a significant body of literature on the impact of noise in hospitals on patients, much of which focuses on sleep. Disrupted sleep is known to relate to changes in blood pressure, weight gain, heart disease, pain, stress, and inflammation. Therefore, a key issue is whether hospital soundscapes promote or inhibit patient sleep.

A study by Gabor et al. (2003) set the stage for what we understand today about the relationship between noise and sleep for patients. Prior to this study, most of the research focused on indirect correlations of sleep and noise. In this study, healthy subjects and subjects on ventilators were monitored for noise arousals and awakenings. Results showed some commonality between healthy and ventilated patients and some differences. For healthy subjects, the majority of arousals were caused by sound peaks. For ventilated patients, the *minority* of arousals (about 20%) were caused by sound. For both healthy subjects and patients, alarm sounds were less disruptive to sleep than conversation or staff activities. Overall, the majority of awakenings were of unknown cause. When asked the next day about the noise sources causing arousals, subject perceptions did not generally match reality well.

Another study of the noise-sleep link for hospital sounds that is widely cited is the Sound Sleep Study (Buxton et al. 2012). The aim of this study was to determine the influence of typical hospital noises on various sleep stages as measured under controlled conditions in a sleep lab. Buxton et al. (2012) found that as sounds got louder they were more likely to cause arousal. They also found that heart rate increases correlated with arousals, particularly during REM sleep. Among the sounds, alarms and ringing phones were most likely to cause arousal, then conversations and overhead paging. Once again, self-reports of noise sources were not well correlated with actual noise sources to which they were exposed.

These two studies provide information about what hospital sounds disrupt sleep. A number of other studies confirm the potential impacts of the hospital soundscape on patient sleep, through direct and indirect measures of polysomnography, electroencephalography (EEG), structured questionnaires, and interviews (Hsu et al. 2012). For example, Persson Waye et al. (2013) found that sleep was more fragmented with less slow-wave sleep, more arousals, and more time awake among subjects exposed to typical ICU noise as compared to a quieter, reference night. Berg (2001) linked the addition of sound-absorbing ceiling tiles to a significant reduction in EEG arousals for laboratory subjects exposed to a variety of specific noise sources. What these and other sleep studies do not do is provide information about whether the type of sleep that patients achieve in the hospital is prolonging hospital stays, delaying medical improvements, or preventing recovery. While a study of medical outcomes linked to sleep quality in hospitals would be extremely difficult to conduct, this is certainly an area that would benefit from the knowledge that would be gained in such studies.

The HCAHPS question about sound, asking patients to rate whether the area around their room is always, usually, sometimes, or never quiet at night, is aimed at determining whether patients believe their sleep is disturbed by noise. The results of HCAHPS surveys are available online and Locke and Pope (2017) compared the responses to the noise question in 2010 and 2014. They found in 2010 that 70% of patients said their room was always quiet at night, 25% said it was usually quiet at night, and 5% said it was sometimes or never quiet at night. The 2014 data shows a drop in the fraction of patients saying their room is always quiet at night (down to 62%), with an increase to 29% finding their room is usually quiet and an increased 9% saying their room is sometimes or never quiet at night. This result shows patient perceptions moving in an undesirable direction.

10.4.4.2 Physiology

In addition to sleep, there have been a few studies of patient physiological measures as a function of the level of noise in hospitals to which they are exposed. For instance, Hagerman et al. (2005) reported on a study of patients and staff in a unit in which they could change the soundscape by changing the material used for the ceiling in the central area and patient rooms. They compared a reflective ceiling to an absorptive ceiling, a change that dropped the reverberation time from 0.8 s to 0.4 s and dropped the background L_{eq} by 5–6 dB. The study found that speech intelligibility improved and staff felt fewer demands and less irritation (Blomkvist et al. 2005). However, there were initially no significant differences observed in patient heart rate, heart rate variability (a stress measure), or blood pressures. In subsequent analysis, acute myocardial infarction and unstable angina pectoris patient groups were found to have significantly lower values of pulse amplitude at night with the absorptive ceiling. There was also a higher rate of rehospitalizations at 3 months for the group of patients exposed to a reflective ceiling and the patients exposed to a sound-absorbing ceiling considered staff attitudes to be better.

Hsu et al. (2011, 2012) found that sound levels at various thresholds are correlated with increases in patient heart rate, respiration rate, and systolic and diastolic blood pressure, and a decrease in blood oxygen saturation level. While the patient cohort was relatively small, it was possible to evaluate the risk likelihood of these physiologic changes. For instance, this study found that exposures to levels over 50 dBA meant patients had a 22% risk of having a higher heart rate.

Again, what is generally missing from these and other studies of physiological measures of patients is a determination of whether the physiological changes result in a significant change to medical outcomes. Also, since many studies have relied on the L_{eq} to describe the sound environment, it isn't clear whether there are particular sorts of sounds that are more likely than others to affect patient physiological measures. Some insight was provided by Hsu et al. (2012), which linked a variety of psychoacoustic metrics (i.e., loudness, sharpness, fluctuation strength, and roughness) to patient physiology in addition to the more traditional metrics. However, more research on the relationships between detailed characteristics of soundscapes and patient physiology across a broad variety of patient populations is needed.

There is also a significant body of literature on the impact of sound on neonates in hospitals. Wachman and Lahav (2011) presented a review of the literature in this area, addressing how neonatal intensive care unit soundscapes impact the cardiovascular, respiratory, auditory, and nervous systems of preterm neonates. These authors note that while the survival rate of very low birth-weight neonates has dramatically improved, as these children have reached school age, they seem to be displaying a high incidence of neurodevelopmental problems. There is a concern that the NICU environment might be responsible, in part, for these problems—an issue still unresolved. Wachman and Lahav (2011) show that noise in the NICU can increase neonatal blood pressure and heart rate, depress respiration rate, reduce sleep time, and make babies fussier.

10.4.4.3 Psychology

Finally, we note that there have been some studies of patient psychological responses to the hospital soundscape. These studies have considered the impact of music on patients, and the perception of wellbeing as it relates to noise.

There are a number of studies on the impact of music on patients, their visitors, and staff. For instance, Perez-Cruz and Nguyen (2012) exposed patients, caregivers, and healthcare providers to background music and surveyed their reaction. Overwhelmingly, all groups preferred having the music present with no significant difference between the groups. McClurkin and Smith (2016) studied the impact of music on preoperative patients to understand whether music can reduce the need for anti-anxiety medications prior to surgery. They determined that listening to as little as 15 min of music prior to surgery was sufficient to reduce anxiety. Iyendo (2016) presented a very complete review of the work on music and its healing properties particularly related to hospital environments. In addition to research in this area, there are companies that have produced soothing sound products for hospitals and clinics to use.

A study by Johansson et al. (2012) examined the link between patient perception of sounds, ICU delirium, and noise. While patients generally prefer a quieter environment, if rooms were too quiet it could create feelings of being abandoned. Positive sounds such as quietly working staff created feelings of safety, security, and familiarity. Conversely, negative sounds such as sick patients or medical equipment created feelings of fear, helplessness, and anxiety. This work points to the importance of considering holistic soundscapes that reduce negative noises while promoting positive sounds.

Finally, Cunha and Silva (2015) studied the relationship between the hospital soundscape and a patient's perception of wellbeing. They had subjects from three units in a hospital (post-anesthesia care, coronary intensive care, and intermediate surgical care) take two surveys: the Environmental Comfort Questionnaire (EMQ) to assess noise perception and the Positive and Negative Affect Schedule (PANAS) to measure emotion. They compared the results of these surveys with sound levels measured and found statistically significant correlations between wellbeing and noise levels, with higher noise levels leading to lowered sense of wellbeing. This is important because a patient's sense of wellbeing tends to be a good indicator of health-related benefits they are enjoying. Another study by Bliefnick (2018) utilized PANAS in hospital occurrence rate listening tests. Positive mood was found to significantly decrease after 30 subjects listened to simulated hospital soundscapes for 30 min. Though follow-up studies are needed, these results might indicate that simply being immersed in hospital soundscapes may negatively impact mood.

Overall, we know a fair amount about the correlation between noise and patient physiological and psychological reaction, but we have merely scratched the surface of what we could know. In the next section, we will discuss studies that specifically use soundscape analytical approaches. These studies are producing results that have already started to guide hospital interventions to produce soundscapes more conducive to healing.

10.4.5 Studies of the Hospital Soundscape Using Soundscape/ Analytical Approaches

One of the earlier efforts to use analytical techniques developed for psychology and now applied to soundscape analysis was reported by Mourshed and Zhao (2012). They developed a list of 16 design factors in hospitals that had been previously shown to be important for workers in healthcare facilities, both from a perspective of satisfaction with the facility and delivery of safe, high-quality care for patients. They visited hospitals in China to determine what options were open to them for architectural changes and administered a questionnaire to doctors, nurses, technicians, and administrative staff that focused on topics they could change. They analyzed their results using principal component analysis and followed up with selective interviews to confirm results.

The results obtained in this study showed three significant dimensions in hospital designs, which they labeled as spatial, environmental, and maintenance. Overall, they found that cleanliness was the top concern of hospital staff, followed by air quality, then noise, then thermal comfort. While the goal of this work was not aimed at understanding the hospital soundscape in detail, but rather to understand architectural design options in hospitals, this work makes it clear that noise (and thus the soundscape) in hospitals is one of the top concerns of staff as well as patients. As we will discuss below, changing hospital layouts and designs is one significant means of altering the hospital soundscapes.

An impressive body of work on hospital soundscapes using sophisticated analytical approaches was conducted by Mackrill et al. (2013a, b, 2014). This study of a cardiothoracic ward had multiple parts and was aimed to identify the positive and negative aspects of the hospital soundscape as described by nurses and patients. The idea was that interventions would then be based upon the results of the study, preserving positive aspects of the soundscape while mitigating or eliminating negative aspects. In the first part of the work, Mackrill et al. (2013a) used semi-structured interviews on topics covering the hospital general environment, sound as part of that environment, and future designs. Results of this study identified sound sources most often mentioned and whether the sounds were viewed positively or negatively.

The next part of this study used recordings of the sounds most likely to be mentioned by the staff and patients in a laboratory listening study (Mackrill et al. 2013b). Subjects were asked to listen to each sound sample and to describe how it made them feel. Then a principle component analysis was used to determine significant dimensions for assessment of sound sources in their ward. They found two perceptual dimensions, the first of which they labeled as relaxation and the second as interest and understanding. The relaxation dimension described 56.8% of the variance seen in their results and the interest and understanding dimension 13.2%. These results are not surprising. Overall, staff and patients seek a soundscape that is relaxing. Further, they are more willing to forgive sound intrusions if they understand why they exist and view them as necessary.

The last part of the work reported to date by Mackrill et al. (2014) involves the potential to improve the soundscape by introducing masking sounds or sounds of nature. That work will be discussed in the following section of this chapter.

Subsequent to the publication of the work by Mackrill, there have been other studies using similar approaches. The study by Azzahra et al. (2017), for instance, asked nurses in an intensive care unit to rate the soundscape on a variety of pre-established scales such as pleasant to unpleasant, and anxious to calm. Results were analyzed using principal component analysis and three significant dimensions identified. The first dimension was labeled information, accounted for 31% of the variance, and related to the scales uninformative/informative, unclear/clear, and complex/simple. The second dimension was labeled calmness, accounted for 31% of the variance, and related to the scales pleasant/unpleasant, anxious/calm, and uncomfortable/comfortable. The final significant dimension found was labeled dynamics, accounted for 23% of the variance, and related to the scales of loud/quiet, soft/hard, and flat/sharp.

The results obtained by Azzahra et al. (2017) agree well with those found by Mackrill et al. (2013b) in that they both identify information and calmness (or relaxation) as important dimensions. The information dimension isn't typically found in urban soundscape analysis. Azzahra et al. (2017) hypothesize that this demonstrates that information content is critical in hospital environments for patients and staff.

Work by Hasegawa and Ryherd (2019) utilized sophisticated statistical approaches applied to both occupant response surveys and acoustic measurements in hospital settings. Principle component analysis utilized in staff perception of specific noise sources revealed three inherent categories for noise source annoyance (facility noise, human/speech activity noise, and alarm noise) that were also grouped by frequency content (broadband, speech band, and narrow band, respectively). Statistical clustering analyses allowed for measured background noise to be post-processed and classed into active (louder) and quieter periods. This approach may provide better insight into the distributions of typical "occupied" and "unoccupied" noise levels experienced in units.

Sophisticated statistical approaches to the hospital soundscape are providing a nuanced insight into the soundscape in hospitals. These approaches are informing us about the links between sounds in hospitals and perceptions of staff and patients, identifying which sounds are most concerning, and suggesting means of mitigating negative aspects of the soundscape. There remains much research to be done using these techniques, for instance introducing interventions and testing the impact to see whether the results support the original soundscape analysis.

10.5 Interventions

One measure of how successfully we have come to understand hospital soundscapes is how well we have produced interventions that improve them. By this measure, we have had only modest success. In this section, we discuss hospital soundscape interventions from a research perspective. Our aim is to connect interventions to soundscape research (i.e., we focus on evidence-based interventions). Further, we aim to establish a framework for consideration of interventions and identification of potentially fruitful avenues for further work.

Hospital soundscape interventions are much like noise control work in nearly any venue in that they can be categorized in terms of the classical source-path-receiver model. In this model, noise control can be accomplished by changing sound sources in some way to mitigate their impact, by impeding the path the sound follows from sound sources to an observer, or by protecting the person observing the sound (the receiver). Among these approaches, noise control at the source is normally viewed as most effective and efficient, although it is often impossible to take this approach to intervention. Noise control along-the-path from the source to the receiver is a very common approach, often involving the use of sound barriers or acoustical absorption. Noise control at the receiver is normally reserved for situations that don't yield to other approaches as it requires equipment for each individual.

Hospital soundscape interventions at the source include decreasing alarm numbers, lowering voices, and the implementation of quiet times. Along-the-path approaches include addition of sound absorption, closing doors, and adjusting architectural layouts. Noise control approaches at the receiver include adding masking or natural sounds locally and using earplugs, earphones, or headphones. Each of these is discussed below.

10.5.1 Source Interventions

It is no surprise interventions to change hospital soundscapes at sound sources have focused on alarms and conversations as these are routinely cited as some of the most disrupting sounds in hospitals. One approach that has succeeded to a modest extent is to reduce the number of alarms sounding or, at a minimum, to reduce their impact at the patient bedside. For instance, Cvach et al. (2013) have discussed how to reduce the number of nuisance alarms without compromising safety standards and have successfully done so on a number of units of Johns Hopkins Hospital. However, even with reductions, alarms in intensive care units sound often enough to remain terribly bothersome. Additional reductions in alarm numbers in the near future are difficult to imagine because of the potential medical and legal repercussions of an alarm not sounding in an urgent situation.

There are actions that could be taken that preserve patient safety but change the soundscape by mitigating alarms as a sound source. For example, many hospitals now collect alarms at monitors at the nursing station in a unit. Alarms show on the monitor (visual alarms) as well as sounding there. Alarms at bedside, then, are largely redundant and continue to exist to ensure that a nurse not at the nursing station is aware of an alarm. A solution to that problem might be to refer alarms to a device carried by the nurse assigned to a patient—a tablet computer, a phone, or equivalent. Even if these devices are to still produce sounding alarms, they can be set to insonify a much smaller number of people than currently exposed to alarms, likely improving the hospital soundscape for everyone. Another option is to use vibrating alarms. One pilot study found better identification rates using vibro-tactile alarms compared to auditory or combination auditory/vibro-tactile system (Ng et al. 2005). A final option is to change the way alarms sound. One study by Stanford et al. (1985) engineered alarms to mimic human vowel sounds. They found that the new alarms could be detected with at least 93% accuracy, even in the presence of masking noise. Although some improved alarm technologies exist and have been incorporated in newer facilities, progress is slow to implement these on a wide scale even though nurses seem open to the idea. For example, Ryherd et al. (2008) found that 62% of ICU nurses surveyed felt audible alarms could be replaced with visual alarms, though only 26% thought vibrating alarms were a feasible option. Interestingly, although many of the nurses were willing to change alarm systems, more than half (55%) did not think their managers were open to changing the alarm environment.

In addition to alarms, conversations are clearly seen as a major negative aspect of the hospital soundscape. There have been two approaches to mitigating conversational noise: campaigns to produce lowered voices, and the creation of designated quiet times. Campaigns to produce lowered voices are common and largely not terribly useful. Much of the conversational noise during the day is from visitors and patients themselves and requests for quiet don't tend to work on this cohort. Further, the turnover in hospital staff on wards is sufficiently high that quieting by changing behavior requires constant reinforcement. Some interventions have gone so far as to install devices that provide a visual indication of sound getting loud, but unfortunately staff tend to habituate to these visual alarms just as they do to the audio alarms. The bottom line is that asking people to change their behavior by talking more softly rarely works long term.

Contrary to lowered voice campaigns, the implementation of quiet times in hospitals has been shown to be effective. Quiet times are designated blocks of time (often two consecutive hours each day) during which operations are intentionally set up to produce a quieter environment. Typically, lights are dimmed, doors are closed, and fewer procedures are scheduled. Detailed protocols can be developed that incorporate behavioral, environmental, and scheduling components as shown in Fig. 10.11.

Both staff and patients appreciate these times of rest. Weber showed, for instance, that over 90% of nurses felt quiet time was useful to them, their patients, and the families of their patients, with some additional positive benefits to infant physiology (Weber et al. 2016; Weber 2018). Similarly, Adatia et al. (2014) showed that quiet times were useful to new mothers.

The approach of implementing quiet times suggests another way in which hospital soundscapes could be positively changed. The current method of operation in hospitals is staff centric. Procedures and various checks on patients are made on a schedule that works best for each staff member. Thus, a patient might be awakened to have his blood pressure and temperature taken and fall back asleep only to have someone come in shortly afterward to change the fluids being delivered

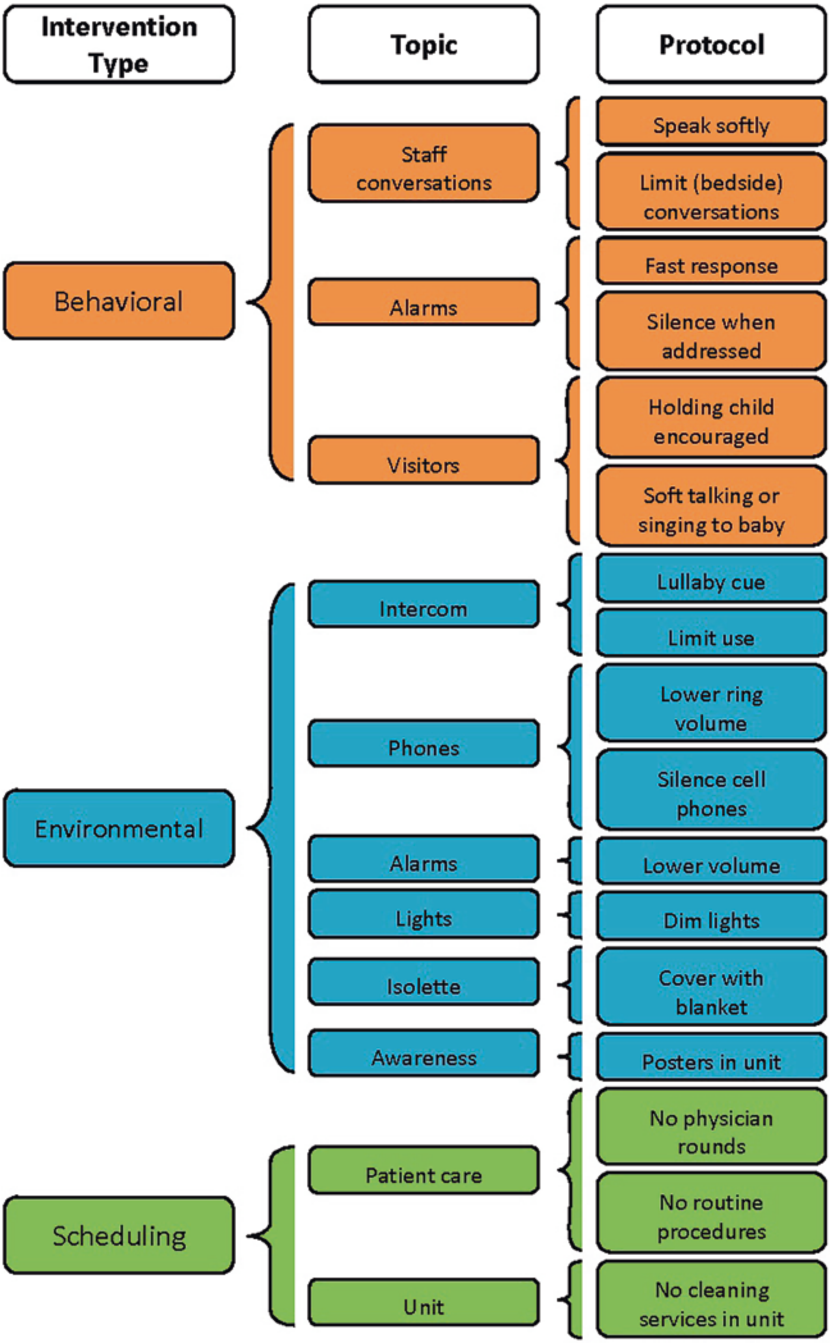

Fig. 10.11 Example quiet time protocol components for a NICU. (Weber 2018)

intravenously, and fall back to sleep again to have someone come into the room to remove trash. A patient-centric operating schedule would cluster procedures that require entering a room in order to minimize the number of disruptions to a patient and the period of noise exposure to those in his vicinity. However, this would require a level of coordination of staff duties that is not the norm in hospitals and there is fear that as some staff members might need to wait to run procedures on a patient, this mode of operation might require more staff in hospitals.

10.5.2 Path Interventions

One of the most common means of accomplishing along-the-path noise control in buildings is to add acoustical absorption to surfaces. Hospitals typically have hard surfaces due to the need for their easy and regular cleaning, and such surfaces do not tend to exhibit much sound absorption. In typical office spaces, acoustical ceiling tiles are used to introduce significant sound absorption, but most of these materials aren't easily cleaned and thus they were historically used sparingly if at all in hospitals. A few of lines of acoustical materials have now been created by major manufacturers with hospitals and clinics in mind. There are also research examples of what can be done by introducing absorption into hospital spaces. MacLeod et al. (2007) quieted a unit in Johns Hopkins Hospital by introducing acoustical absorption covered with hydrophobic (and thus anti-bacterial) materials. Follow-up studies by Barnhill et al. (2010) and Hsu et al. (2010) treated cancer units at Johns Hopkins Hospital by adding absorbing materials on walls and ceilings of corridors. This improved speech intelligibility, lowered overall sound levels, and improved the staff ability to communicate and concentrate.

Private patient rooms are the norm for new hospitals, but large rooms with patient pods separated by curtains remain in many existing hospitals. The curtains are usually there for purely visual reasons—to separate one patient from another. However, thanks to new products on the market it is possible to replace thin curtains with curtains that include sound-absorbing materials in pockets sewn into the curtains. This has the impact of introducing sound absorption to the room and can dramatically reduce sound transmission from one cubical to another, even with significant gaps in the curtain at the floor and ceiling. Diminishing sound transmission has the added impact of offering greater speech privacy. Pope and Miller-Klein (2016) and Locke and Pope (2017) reported on a study in which thin curtains were replaced with a sound absorbing yet cleanable curtain and found improvements in overall sound level and speech privacy. However, Locke and Pope (2017) noted that the new curtain took as much as twice as much time to hang and longer to dry after being cleaned compared to the thin traditional curtains, so it was not immediately adopted. It is this sort of tradeoff that is a constant issue in the development of materials for hospitals. If speech privacy and improved soundscapes are to be sought, there will necessarily be compromises such as increased time to hang curtains and added costs.

Another along-the-path intervention in hospital soundscapes is the simple action of routinely closing doors. Almost all hospital rooms have doors on them—the notable exceptions being intensive care unit rooms and NICUs, which sometimes use pods or gang rooms. Just as in homes and offices, closing doors affords significant transmission loss from the room to the corridor and vice versa. In practice, busy hospitals often leave doors ajar to facilitate quicker entry and exit from the room, and to make it easier to hear patients and assure their safety. Additionally, a study by Sobieraj et al. (2006) on the impact of closed doors showed that nurses on the unit had a more difficult time hearing and localizing alarms—a potential safety issue. Closing doors, while effective, is another mitigation measure that requires a change in behavior, and thus it is unlikely to happen quickly if at all. However, in a study by Kaur et al. (2016) of intervention strategies on a pediatric intensive care unit, closing patient doors ranked at the top in effectiveness as rated by staff and patient families, with 93% of respondents saying it worked to improve the environment. Asking staff to lower voices ranked second at 88%, followed by quiet times at 82% and then reducing the number of alarms at 80%.

A third along-the-path intervention is to design hospitals while recognizing the inherent link between architectural layouts and acoustical performance. An extensive series of studies by Okcu et al. (2011) and Okcu et al. (2013) statistically investigated the links between hospital corridor layout, acoustics, and occupant response. Floor plate design features such as corridor length, number of turns and branching hallways, relative grid distance, and visual fragmentation were significantly related to reverberation time in real and simulated settings. To provide a less reverberant environment—which may in turn improve the ability of nurses to localize auditory cues—designers might consider more compact and fragmented floor plate shapes.

Finally, sound isolation properties of building partitions, floor-to-ceiling assemblies, and exterior envelope must all be considered in noise control along-the-path, though there is very little research published in this area for hospitals. One study by Pelton and Ryherd (2009) examined the acoustical remodel of a burn acute care unit (BACU), with a focus on debridement treatment areas where patients undergo the removal of dead tissue. Curtains separated the debridement stations and isolation to the rest of the unit was inadequate, resulting in patient distress sounds being heard throughout the unit. The acoustic remodel included creating sound locks, incorporating high-isolation doors and partitions, and addition of acoustic absorption. As a result, L_1 values (i.e., those exceeded 1% of the time) for patient distress sounds were reduced by 30 dBA and the overall soundscape was markedly improved.

10.5.3 Receiver Interventions

Work on hospital soundscape improvements has focused a great deal of attention on solutions at the receiver. These include adding sound locally (masking or natural sounds) and use of earplugs, earphones, or headphones.

A significant amount of work has been done on the impact of views of nature on hospital patients (see, for instance, the seminal paper by Ulrich 1984). Generally, these studies show that nature views have a strong positive influence on patients, enhancing recovery, reducing the need for pain medications, and improving moods. Based on these studies, work has also been done to examine the impact of sounds of nature on patients. A study by Annerstedt et al. (2013) found that sounds of nature reduce cardio stress markers and cortisol levels after a stressing event. A later study by Largo-Wight et al. (2016) considered the impact of nature sounds (ocean waves), classical music (Mozart), and silence on stress by monitoring muscle tension (EMG), pulse rate, and self-reported stress of subjects who listened to sounds using headphones for 15 min. Baseline measurements were taken and compared to results after the listening period. Results found that only sounds of nature had a significant impact, and these reduced stress measures.

Mackrill et al. (2013b) in their soundscape studies also looked at sounds of nature (song of a blackbird and babbling brook sound) as well as masking noise. They presented sounds with and without nature or masking sounds as part of their extended listening lab study. They found, for added nature sounds, that the ratings of hospital sounds by subjects significantly changed (improved) along the relaxation perceptual dimension. There was no change seen in the interest and understanding dimension. Further, masking noise had a much smaller impact than nature sounds. This work was expanded upon at a workshop in 2017 that compared the impact of three states (masking noise, no additional sound, and natural sounds) on the framework Mackrill et al. (2013b) developed. In this small study, the nature sounds used were falling rain and bird songs. Participants generally preferred the sound of falling rain to the bird songs, with significant individual variation.

While more work is needed on added nature sounds as a means of mitigating irritating sound sources in the hospital soundscape, it is clear that this is a potential means of improving the hospital soundscape that is relatively easy to implement. Prior to work on nature sounds added to hospital sounds, it was widely held that the soundscape in hospitals is sufficiently intense that adding sound to the mix would simply make the sound more irritating rather than less. Research to date has shown this belief to be incorrect, even if there is an irony in improving the soundscape in a loud area by adding more sound. That said, before sound is added to any hospital setting, care must be taken to ensure the existing ambient environment, delivery methods, and patient/staff interfaces are all appropriate. Additional research is warranted on optimum ways to present good sounds while also reducing unwanted sounds.

A second approach to sound control at the receiver is the use of earmuffs, earplugs, earphones, and headphones. Abou Turk et al. (2009) were early to study the impact of protecting the ears of neonates from loud noises. They used earplugs on very low weight newborns and found that this facilitated weight gain. Duran et al. (2012) looked at very low weight neonates, equipping them with earmuffs for 2 days and without for 2 days. They found that neonates with earmuffs slept more. The results on neonates with earmuffs or earplugs suggest another potential means of improving the soundscape for vulnerable individuals. However, there are issues with outfitting neonates with earplugs or earmuffs that must be considered, as their skin can be very fragile and there are concerns that posture and head shape might be affected. Further, one would anticipate that a similar approach for adult patients could improve the hospital soundscape for them as well.

In addition to simply earplugs or earmuffs, there is a growing body of work on the use of noise-canceling devices on patients. For instance, participants in the Hospital Project on Noise Sound and Sleep workshop experimented with sleep-friendly headphones and noise-canceling earphones. They concluded that both offered advantages that could be useful in the hospital environment, although a more systematic study is needed. Schlesinger et al. (2017) also looked at noise-cancellation earphones in the hospital environment. The aim of this work was to create a means of eliminating alarm noise from the soundscape for patients while passing on all other sounds with little to no distortion. Results showed significant improvement in the fraction of word scores correctly identified with the alarm canceling engaged.

These early studies using noise-canceling devices suggest a new avenue of potential improvement of the hospital soundscape for patients but there is much work yet to be done before they will be adopted by hospitals. For instance, what are the relative advantages and disadvantages of the various options: passive earplugs versus active noise-cancellation? Are there side effects to long-term wearing of such devices for patients? What conditions prevent earplugs or noise-canceling earphones or headphones from being worn and are there alternatives that accomplish essentially the same results in other means?

Taken as a whole, interventions to change the hospital soundscape have not yet taken hold on a large scale, although there is reason to be hopeful that current avenues of research might provide solutions in the future. Of particular interest are interventions that will work long term and without requiring behavioral changes. Examples of potential changes to consider are expanded implementation of quiet times, reducing audible alarms by changing the current alarm system fundamentally, developing architectural designs for hospitals that include acoustical considerations, adding sound absorption materials, piping in background sounds of nature, and using earplugs, earmuffs, earphones, or headphones on patients. All of these techniques could benefit from additional investigations.

10.6 Summary

The soundscape in hospitals is interesting for many reasons but paramount among them is the likelihood that soundscapes impact patient recovery and staff resilience. Current hospital soundscapes are not viewed positively by patients, their visitors, or staff.

Hospitals have been getting noticeably louder for decades, in spite of a fleet of new hospitals coming online. Key sound sources that influence perceptions in hospitals include alarms and conversations. Although alarm noise is well studied, there has been far less work to understand the extent to which the current hospital soundscape produces an environment in which speech intelligibility is marginal or poor and how to balance caregiver intelligibility with patient privacy.

Traditional acoustic measures of hospital soundscapes don't seem able to predict the impact of interventions—loudness alone does not predict human response in hospitals. Work to define newer measures, such as the occurrence rate, promises some improvement but further research is needed.

There is a significant body of literature that suggests that the hospital soundscape increases the stress felt by staff and impacts the ability of patients to sleep. Work using sophisticated techniques common in soundscape studies has found that key perceptual dimensions of hospital soundscapes are relaxation (calmness) and information.

Intervention strategies for hospital soundscapes can be divided into the typical at the source, along-the-path, and at the receiver categories. Quiet times in hospitals have been found to be effective and there are also case studies indicating the addition of sound-absorbing materials to hospital ceilings and walls can be useful. Work with earplugs, earmuffs, earphones, and headphones to control noise at the receiver is encouraging as is work using positive sounds added to the soundscape. More work is needed to introduce and promote positive sounds while reducing negative sounds.

There are many avenues of research still to be pursued to understand hospital soundscapes. These include investigations of how we might better use audible and nonaudible alarms, studies to determine whether there is a direct link between patient medical outcomes and elements of the hospital soundscape, and demonstration of interventions that can be scaled across a broad range of hospitals.

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Erica Ryherd declares that she has no conflict of interest.

References

Abou Turk CA, Williams A, Lasky RE (2009) A randomized clinical trial evaluating silicone earplugs for very low birth weight newborns in intensive care. J Perinatol 29(5):358–363

Adatia S, Law S, Haggerty J (2014) Room for improvement: noise on a maternity ward. BMC Health Serv Res 14:604–606

Ahmed T (2019) Spotify reveals the music surgeons love listening to in the operating room. Newsweek, 10 January 2019

Annerstedt M, Jönsson P, Wallergård M, Johansson G et al (2013) Inducing physiological stress recovery with sounds of nature in a virtual reality forest – results from a pilot study. Physiol Behav 118:240–250

Applebaum D, Fowler S (2010) The impact of environmental factors on nursing stress, job satisfaction, and turnover intention. J Nurs Adm 40:323–328

Azzahra IRN, Fela R, Sarwono J, Utami SS (2017) Hospital soundscapes: perception analysis of acoustics environment in intensive care unit. Inter-Noise, Hong Kong, 27–30 August 2017

Barnhill C, West J, Hsu T, Ryherd EE (2010) Further studies of hospital noise control at the Johns Hopkins Hospital: Part I. 159th meeting of the Acoustical Society of America, Baltimore, MD, 19–23 April 2010

Berg S (2001) Impact of reduced reverberation time on sound-induced arousals during sleep. Sleep 24(3):289–292

Berglund B., Lindvall T (eds) (1999) Guidelines for community noise. Technical Report, World Health Organization, Geneva

Bliefnick JM (2018) Evaluation of hospital soundscapes to improve patient and staff experience. PhD Dissertation, Architectural Engineering Program, University of Nebraska – Lincoln

Blomkvist V, Eriksen C, Theorell T, Ulrich R et al (2005) Acoustics and psychosocial environment in intensive coronary care. Occup Environ Med 62:1–8

Bureau of Labor Statistics (2018a) U.S. Department of Labor, https://www.bls.gov/emp/tables/employment-by-major-industry-sector.htm. Accessed 14 June 2018

Bureau of Labor Statistics (2018b), U. S. Department of Labor, Occupational Outlook Handbook. Registered Nurses. https://www.bls.gov.ooh/healthcare/registered-nurses.htm. Accessed 30 May 2018

Busch-Vishniac IJ, West JE, Barnhill C, Hunter T et al (2005) Noise levels in Johns Hopkins Hospital. J. Acoust Soc Am 118(6):3629–3645

Busch-Vishniac I (2015) A model of clinical alarm errors in hospital. Biomed Instrum Techn 49(4):280–291

Buxton OM, Ellenbogen JM, Wang W, Carballeira A et al (2012) Sleep disruption due to hospital noises: a prospective evaluation. Ann Intern Med 153:170–179

Cunha M, Silva N (2015) Hospital noise and patients' wellbeing. Procedia Soc Behav Sci 171:146–151

Cvach M (2012) Monitor alarm fatigue: an integrative review. Biomed Instrum Technol 46(4):268–277

Cvach MM, Currie A, Saperstein A, Doyle P et al (2013) Managing clinical alarms: using data to drive change. Nurs Manag 44(11):8–12

Duran R, Ciftdemir NA, Ozbek UV, Berberoğlu U et al (2012) The effects of noise reduction by earmuffs on the physiologic and behavioral responses in very low birth weight preterm infants. Int J Pediatr Otorhinol 76:1490–1493

Dyrbye LN, Shanafelt TD, Sinsky CA, Cipriano CF, et al (2017) Burnout among health care professionals: a call to explore and address this unrecognized threat to safe, high-quality care. NAME Perspectives Discussion Paper, National Academy of Medicine, Washington, DC, 5 July 2017

ECRI Institute (2013) Top ten health hazards. Health Devices 42(11):1–16

Edworthy J, Hellier E (2006) Alarms and human behavior: implications for medical alarms. Brit J Anaesth 97(1):12–17

Eurostat Data (2009). https://bit.ly/3Z8LFTC. Accessed 23 March 2023

Fick DD, Vance GL (2006) Quiet zone: reducing HVAC system noise. Hosp Fac Manag Mag 19(8):21–24

Fife D, Rappaport E (1976) Noise and hospital stay. Am J Public Health 66:680–681

Gabor JY, Cooper AB, Crombach SA, Lee B et al (2003) Contribution of the intensive care unit environment to sleep disruption in mechanically ventillated patients and healthy subjects. Am J Respir Crit Care Med 167:708–715

Godfrey RD, Feth L (2011) Benchmark measurements of noise, reverberation time, and an estimate of speech intelligibility in a representative operating room at Nationwide Children's Hospital in Columbus, OH. J Acoust Soc Am 130(4):2318

Gorges M, Markewitz BA, Westenskow DR (2009) Improving alarm performance in the medical intensive care unit using delays and clinical context. Int Anesthesia Res Soc 108(5):1546–1552

Hagerman I, Rasmanis G, Blomkvist V, Ulrich R et al (2005) Influence of intensive coronary care acoustics on the quality of care and physiological state of patients. Int J Cardiol 98:267–270

Hasegawa Y, Ryherd E (2019) Subjective and objective assessments of pediatric and neonatal hospital soundscapes. 177th meeting of the Acoustical Society of America, Louisville, KY, 13–17 May 2019
Hawksworth C, Sivalingam P, Asbury AJ (1998) The effect of music on anesthetists' psychomotor performance. Anaesthesia 53:195–197
Holmes GB Jr, Goodman KJ, Hang DW, McCorvey VM (1996) Noise levels of orthopedic instruments and their potential health risks. Orthopedics 19(1):35–37
Hsu TY, Ryherd EE, West JE, Barnhill CL (2010) Further studies of hospital noise control at the Johns Hopkins Hospital: Part II. 159th meeting of the Acoustical Society of America, Baltimore, MD, 19–23 April 2010
Hsu TY, Ryherd EE, Ackerman J (2011) Psychoacoustic measures and their relationship to patient physiology in an intensive care unit. 161st meeting of the Acoustical Society of America, Seattle, WA, 23–27 May 2011
Hsu TY (2012) Relating acoustics and human outcome measures in hospitals. PhD Dissertation, George W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology 2012
Hsu T, Ryherd E, Waye KP, Ackerman J (2012) Noise pollution in hospitals: impacts on patients. J Clin Outcomes Manag 19(7):301–309
International Organization for Standardization (2014) ISO 12913-1:2014 acoustics-soundscape-part 1: definition and conceptual framework. Geneva
Iyendo TO (2016) Exploring the effect of sound and music on health in hospital settings: a narrative review. Int J Nurs Studies 63:82–100
Jha AK, Orav EJ, Zheng J, Epstein AM (2008) Patients’ perception of hospital care in the United States. N Engl J Med 359(18):1921–1931
Johansson L, Bergbom I, Waye KP, Ryherd E et al (2012) The sound environment in an ICU patient room – a content analysis of sound levels and patient experiences. Int Crit Care Nurs 28(5):269–279
Kaur H, Rohlik GM, Nemergut ME, Tripathi S (2016) Comparison of staff and family perceptions of causes of noise pollution in the Pediatric Intensive Care Unit and suggested intervention strategies. Noise Health 18(81):78–84
Kracht JM, Busch-Vishniac IJ, West JE (2007) Noise in the operating rooms of Johns Hopkins Hospital. J Acoust Soc Am 121(5):2673–2680
Kwon P, Busch-Vishniac I, West J (2007) Assessing the speech intelligibility index in Johns Hopkins Hospital. 153rd Meeting of the Acoustical Society of America, Salt Lake City, UT, 4–8 June 2007
Largo-Wight E, O’Hara BK, Chen WW (2016) The efficacy of a brief nature sound intervention on muscle tension, pulse rate, and self-reported stress: nature contact micro-break in a office or waiting room. HERD J 10(1):45–51
Lawless ST (1994) Crying wolf: false alarms in a pediatric intensive care unit. Crit Care Med 22(6):981–985
Locke C, Pope DS (2017) Assessment of medical-surgical patients’ perception of hospital noises and reported ability to rest. Clin Nurs Spec 31(5):261–267
Mackrill JB, Jennings PA, Cain R (2013a) Improving the hospital ‘soundscape’: a framework to measure individual perceptual response to hospital sounds. Ergonomics 56(11):1687–1697
Mackrill J, Cain R, Jennings P (2013b) Experiencing the hospital ward soundscape: toward a model. J Environ Psych 36:1–8
Mackrill J, Jennings P, Cain R (2014) Exploring positive hospital ward soundscape interventions. Appl Ergon 45:1454–1460
MacLeod M, Dunn J, Busch-Vishniac IJ, West JE et al (2007) Quieting Weinberg 5C: a case study in hospital noise control. J Acoust Soc Am 121:3501–3508
Madaras GS (2017) An overview of the key misperceptions that are preventing any significant improvements when addressing operational noise in acute care hospitals. Paper presented at 174th Meeting of the Acoustical Society of America, New Orleans, LA, 4–8 December 2017

Mahapatra AK (2011) Investigation of noise in hospital emergency departments. MS Thesis, George W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology
McClurkin SL, Smith CD (2016) The duration of self-selected music needed to reduce preoperative anxiety. J Perianesth Nurs 31(3):196–206
Moorthy K, Munz Y, Undre S, Darzi A (2004) Objective evaluation of the effect of noise on the performance of a complex laparoscopic task. Surgery 136:25–30
Morrison W, Haas E, Shaffner DH, Garrett ES et al (2003) Noise stress and annoyance in a pediatric intensive care unit. Crit Care Med 31:113–119
Mourshed M, Zhao Y (2012) Healthcare providers' perception of design factors related to physical environments in hospitals. J Environ Psych 32:362–370
Murthy V, Malhotra S, Bala I, Raghunathan M (1995) Detrimental effects of noise on anesthetists. Can J Anaesth 42:608–611
Ng J, Man J, Fels S, Dumont G et al (2005) An evaluation of vibro-tactile display prototype for physiological monitoring. Anesth Analg 101:1719–1724
Nickl H, Nickl-Weller C (2013) Healing architecture. Braun Publishing, Salenstein
Nightingale F (1969) Notes on nursing. Dover Publishing, New York
OECD Data website. http://www.oecd.org/els/health-systems/health-data.htm. Accessed 10 Jan 2019
Okcu S, Zimring C, Ryherd EE (2008) Developments in 'aural connectivity': enhancing sound environments in critical care settings for effective nurse auditory monitoring. 155th Meeting of the Acoustical Society of America, Paris, 29 June – 4 July 2008
Okcu S (2011) Developing evidence-based design metrics and methods for improving healthcare soundscapes. PhD Dissertation, College of Architecture, Georgia Institute of Technology
Okcu S, Ryherd E, Zimring C, Samuels O (2011) Soundscape evaluations in two critical healthcare settings with different designs. J Acoust Soc Am 130(3):1348–1358
Okcu S, Ryherd E, Pelton H, Zimring C (2012) Characterizing impulsiveness of hospital sound environments. Noise Control Eng J 60(3):246–257
Okcu S, Shpuza E, Ryher E, Zimring C (2013) Linking acoustics and floor-plate shape qualities of healthcare settings. Archit Sci Rev 56(4):315–332
Park S, Song H (1994) Effect of noise on the detection of rib fractures by residents. Investig Radiol 29:54–58
Pelton H, Ryherd MM (2009) Acoustical design of a burn acute care unit for enhanced patient comfort. Noise Control Eng J 57(1):32–41
Perez-Cruz P, Nguyen L (2012) Attitudes and perceptions of patients, caregivers, and health care providers toward background music in patient care areas: an exploratory study. J Palliat Med 15(10):1130–1136
Persson Waye K, Elmenhorst EM, Croy I, Pedersen E (2013) Improvement of intensive care unit sound environment and analyses of consequences on sleep: an experimental study. Sleep Med 14(12):1334–1340
Pope DS, Miller-Klein ET (2016) Acoustic assessment of speech privacy curtains in two nursing units. Noise Health 18(80):26–35
Ryherd E, Persson Waye K et al (2008) Characterizing noise and perceived work environment in a neurological intensive care unit. J Acoust Soc Am 123(2):747–756
Ryherd E, Okcu S, Hsu T (2011) Hospital noise and occupant response, ASHRAE Winter Meeting Conference, Las Vegas, NV, 20 January – 2 February 2011
Ryherd E, Okcu J, Ackerman J, Zimring C (2012) Noise pollution in hospitals: impacts on staff. J Clin Outcomes Manag 19(11):491–500
Ryherd E, Moeller M Jr, Hsu T (2013) Speech intelligibility in hospitals. J Acoust Soc Am 134(1):586–595
Sbihi H, Hodgson M, Astrakianakis G, Ratner P (2011) Measuring how acoustical environments affect staff in health-care facilities? 161st Meeting of the Acoustical Society of America, Seattle, WA, 23–27 May 2011

Schlesinger JJ, Reynolds E, Sweyer B, Pradhan A (2017) Frequency-selection silencing device for digital filtering of audible medical alarm sounds to enhance ICU patient recovery. 23rd Int'l Conf. on Auditory Display, Penn State U, State College, PA, 20–23 June 2017
Siebein GS, Skelton R (2009) Soundscape analysis of a neonatal intensive care unit. Inter-Noise 2009, Ottawa, 23–26 August 2009
Sobieraj J, Ortega C, West I, Voepel L et al (2006) Audibility of patient clinical alarms to hospital nursing personnel. Mil Med 171(4):306–310
Stanford L, McIntyre J, Hogan JT (1985) Audible alarm signals for anaesthesia monitoring equipment. Int J Clin Monit Comput 1:251–256
Topf M (1988) Noise-induced occupational stress and health in critical care nurses. Hosp Top 66(1):30–34
Topf M, Dillon E (1988) Noise-induced stress as a predictor of burnout in critical care nurses. Heart Lung 17(5):567–574
Ulrich RS (1984) View through a window may influence recovery from surgery. Science 224(4647):420–421
Vahed N, Kabiri N (2016) The effect of music in the operating room: a systematic review. 5th International Society for Evidence-Based Healthcare Congress, Kish Island, December 2016
Wachman EM, Lahav A (2011) The effects of noise on preterm infants in the NICU. Arch Dis Childhood Fetal Neonatal Ed 96:F205–F209
Weber JR, Ryherd EE, Mahoney AD, Rolfes M, et al (2016) Evaluating hospital quiet time from engineering, medical, and nursing perspectives. 171st meeting of the Acoustical Society of America, Salt Lake City, UT, 23–27 May 2016
Weber JR (2018) The impact of quiet time on the neonatal intensive care unit soundscape and patient outcomes. PhD Dissertation, Architectural Engineering Program, University of Nebraska – Lincoln 2018
Whalen DA, Covelle PM, Piepenbrink JC, Villanova KL et al (2014) Novel approach to cardiac alarm management on telemetry units. Cardiovasc Nurs 29(5):E13–E22
Williams AL, van Drongelen W, Lasky RE (2007) Noise in a contemporary neonatal intensive care. J Acoust Soc Am 121(5):2681–2690
Willett KM (1991) Noise-induced hearing loss in orthopaedic staff. J Bone Joint Surg 73(1):113–115
Wolf JA (2013) The state of patient experience in American hospitals 2013: positive trends and opportunities for the future. The Beryl Institute
Zun LS, Downey L (2005) The effect of noise in the emergency department. Acad Emerg Med 12:663–666