Hospital Soundscapes: Characterization, Impacts, and Interventions

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Hospital soundscapes do not currently project the aura of calm and restfulness that patients and staff would prefer to experience.

Although hospitals are ubiquitous today, the contemporary hospital only emerged in the eighteenth century, in China and in parts of Europe. As hospitals grew more numerous and more accepted as central providers of healthcare, they became much more crowded. By the mid-nineteenth century, concerns about the noise in hospitals were already arising. For instance, Florence Nightingale noted in 1859 "unnecessary noise, then, is the most cruel absence of care which can be inflicted either on sick or well" (Nightingale, 1859).

Much has changed since the introduction of hospitals. Their operations have dramatically expanded, their customer base and their size have changed significantly, and the use of technology has transformed them. One of the constants, though, is that hospitals have always been considered to be noisy by patients and staff. Papers on hospital noise appear continuously in the research literature starting in the 1860s and continuing until today.

The first studies of hospital noise focused on objective measures, with modest attempts at interventions. Such studies continue to be published today. It has been difficult to draw detailed conclusions from these studies, however, because the hospital environment depends on a large number of factors, including the building design and materials, the number of patients, staff and visitors present, the intensity of the challenges of patients (which dictates the medical equipment present), and the communications technologies used.

Starting in the mid-twentieth century, studies emerged linking the sound in hospitals to the impacts on patients and staff. Again, this work has illuminated hospital issues slowly because it is very difficult to vary only the sound levels in a hospital environment. There are simply too many confounding factors in real hospital situations.

More recently, there is a growing focus on using the statistical approaches of soundscape analysis to study hospital environments. Soundscapes refer to the reactions of humans to sounds in context and have been used in many contexts (see, e.g., Brooks et al., 2014; Schulte-Fortkamp et al., 2007). Soundscape analysis uses statistical approaches from psychology to determine what factors are important rather than trying to modify one factor at a time and examine reactions.

Characterizing the Sound in Hospitals

A good bit of the history of noise control could be subtitled "The Search for the Perfect Noise Metric." In buildings, near airports, near highways, and in nature preserves, we have tried to find that single measure of the acoustic environment that

https://doi.org/10.1121/AT.2019.15.3.11

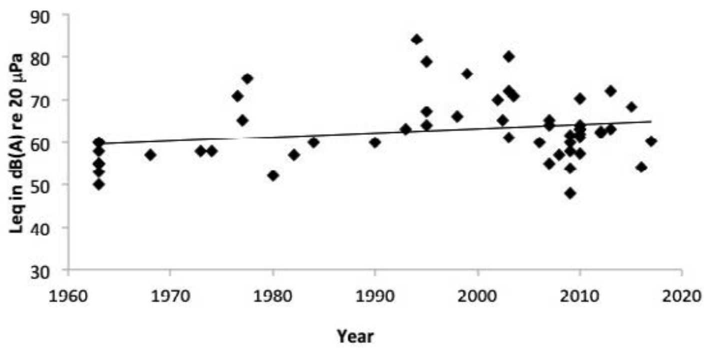

Figure 1. *Hospital noise levels from 1960s to 2017.* L_{eq}, *equivalent sound level averaged over time.*

best predicts reactions and allows for before/after and site A/site B comparisons. The most common noise metric used in buildings is the equivalent sound level (L_{eq}). The L_{eq} is that sound pressure level that would be present if the sound in the area were steady. In other words, it is a measure of the sound energy averaged over time and, usually, frequency as well.

Busch-Vishniac et al. (2005) showed the trends in the L_{eq} in hospitals from 1960 to 2005 and noted a monotonic increase in daytime levels of roughly 0.38 dB/yr over that period. Ryherd et al. (2011) later expanded that work to 2010 for a subset of data collected by the Healthcare Acoustics Research Team, and, more recently, Weber (2018) has expanded it to 2017. Note that the levels reported by Weber were all preintervention (baseline) and may include both day and night levels. The result is shown in **Figure 1**, which demonstrates that the L_{eq} reported in hospitals has continued to rise for nearly 70 years! There are many potential causes for this relentless increase in the sound levels: hospitals first started to be air-conditioned in the 1960s; the required air refresh rates keep rising to lower the number of pathogens in the air; the use of hard surfaces has gained popularity to reduce infections; the amount of equipment in use at bedsides has constantly increased and each new machine introduces noise; and the density of patients has greatly increased.

The distribution of sound levels in **Figure 1** is tighter than one might expect given that the hospitals represented are widely disbursed worldwide and vary greatly in architecture, acuity, speciality, and size. This suggests that the noise sources that dominate in hospitals are not simply related to building operations but are also strongly linked to the building occupants, in other words, conversations, activity noise, and commonly used medical equipment. Compared with office buildings, factories, or homes, hospitals tend to have more types of noise sources and they don't seem to quiet down at night because hospitals operate around the clock.

Hospitals also differ from typical workspaces or homes in that the sound tends to vary a great deal in amplitude on short timescales. In other words, the sound is peaky. This is shown in **Figure 2**, which is a typical hospital sound pressure level as a function of time (Ryherd et al., 2008). Overhead pages, alarms, pneumatic tube mechanisms, motorized doors, moving carts and equipment, and people all contribute to the transient sounds in hospitals. The L_{eq} does not fully capture the relative peakiness of noise, and this might explain why it is not the "perfect" stand-alone sound metric to characterize hospital noise. There are a fair number of hospitals that have benefited from noise interventions that are perceived as improving the soundscape, although the L_{eq} has remained nearly the same.

A new measure has been introduced to try to correlate better with the perceptions of hospital noise, namely, the occurrence rate. The occurrence rate [OR(N)] is defined as the fraction of time that a level (usually the peak or maximum sound level) exceeds N decibels. The measure is derived from the traditional percentile level metric (L_n) but is specifically applied to peak or other levels. For example, the maximum OR at 90 dB

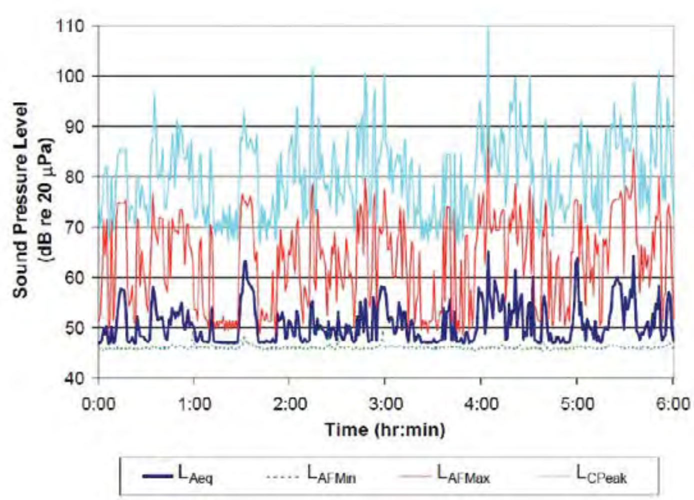

Figure 2. *Sound pressure level versus time for a typical hospital room.* L_{Aeq}, *equivalent A-weighted sound pressure level (**dark blue line**);* L_{AFmin}, *A-weighted minimum sound pressure level (fast averaging; **dotted line**);* L_{AFmax}, *maximum A-weighted sound pressure level (fast averaging; **red line**),* L_{CFpeak}, *peak sound pressure level with a C-weighting scale (**light blue line**). Reproduced from Ryherd et al., 2008.*

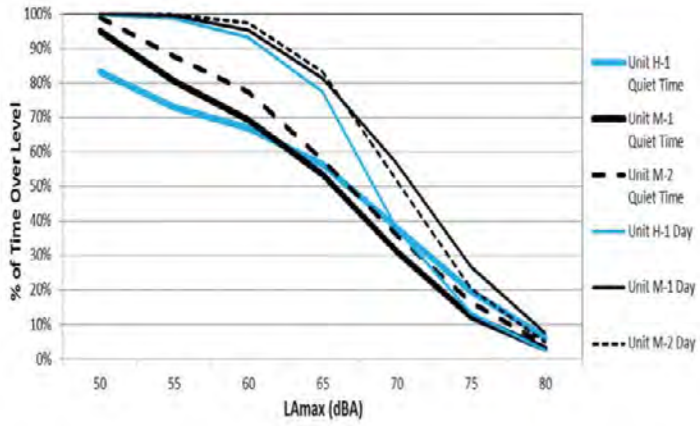

Figure 3. *Relationship between quiet time and* L_{Amax} *occurrence rate. Reproduced from Bliefnick et al., 2019.*

[$OR(90)_{max}$] is the fraction of the time the maximum sound pressure level in a space exceeds 90 dB(A) By definition, the OR starts at 100% at low levels and decreases monotonically to 0% as the sound level increases. An example is shown in **Figure 3**, which reveals reductions in occurrences of the maximum A-weighted sound levels (L_{Amax}) in three US adult hospital units during set quiet time hours (Bliefnick et al., 2019).

The OR(*N*) was first used as an acoustic measure by Ryherd et al. (2008) and Williams et al. (2007) to describe the environments of adult and neonatal intensive care units, respectively. It was more formally defined by Okcu et al. (2011, 2012) who examined the nursing staff in two different hospital units with similar staff activities and acuity levels. These authors showed that the unit with a higher peak OR(90) [$OR(90)_{peak}$] was judged more harshly than the unit with nearly identical L_{eq} values but a lower $OR(90)_{peak}$. More recently, papers have linked staff perceptions to the OR(*N*). For instance, Sbihi et al. (2011) found that occurrence rates were correlated with the staff perception of noise-related health effects including distraction, stress, fatigue, and tension headaches. Bliefnick (2018) found correlations between the occurrence rate range in hospitals and patient satisfaction.

Alarm Noise

Ask people who have been hospital patients what sound they most associate with hospital stays. The likely answer is clinical alarms. As shown in an analysis by Busch-Vishniac (2015), alarms sound on average over 135 times per day per patient in the hospital, with soundings over 500 times per patient per day not unusual in intensive care units. Alarms sound so often that the staff becomes desensitized to them, a process referred to as alarm fatigue. Alarms result in no action being taken over 90% of the time (Cvach, 2012). Nonetheless, alarm failures (failure to sound or failure by staff to respond in a timely fashion) have led to deaths or loss of function, leading the Emergency Care Research Institute (ECRI; 2013) to list clinical alarms as the top medical technology hazard in 2013.

The impact of alarms is different for the staff and patients and their visitors. For the staff, alarms add to the stress level because each alarm demands a response. For patients and their visitors, alarms disrupt conversation and sleep and are routinely listed as one of the most disturbing noises.

Hospital soundscapes could be improved by changing the way we manage alarms, and there are many aspects of alarms that merit further study. For instance, alarms currently sound to indicate that a physiological measure has gone out of bounds. Instead, we could integrate sensors from various medical devices and alarms when they collectively indicate a medical problem such as a trend toward a cardiac arrest. Additionally, alarms provide very little information. They tend to be difficult to localize and hard to recognize. An early study by Lawless (1994) showed that no group of staff were able to identify more than half of the alarms. Work on alarm sounds that would be more effective in transmitting information is currently underway, with a paper by Edworthy and Hellier (2006) leading the way. More fundamentally, because there is never a reason for patients or visitors to hear alarms, there is a question as to when an alarm should sound as opposed to providing a visual or vibratory alert.

Speech Communication

The problem of speech communication in hospitals has been understudied and underappreciated. Speech communication in hospitals is a dual-edged sword: we want communication to be uninhibited by noise, but we also want to preserve patient privacy. These dual needs are challenging to meet simultaneously.

Studies of speech communication in hospitals indicate that they are very challenging venues for clear conversations. Kwon et al. (2007), Godfrey et al. (2011), and Ryherd et al. (2013) measured the speech intelligibility index (SII) in rooms and hallways of seven hospitals between 2007 and 2013. In not one of these hospitals did the SII indicate good speech communication was possible at normal voice levels. Instead, they were found to be fair or poor for speech communication.

The Impact of Hospital Soundscapes on Staff and Patients

Studies of the impact of hospital soundscapes on the staff and patients have been numerous. In what follows, we summarize the key findings.

Impact of Hospital Soundscapes on Staff

The traditional hospital is designed to be staffcentric. Architectural layouts are set to promote the efficient care of patients, and procedures are established with the staff workflow in mind. Thus, a patient in a hospital might be awakened to have their vital signs checked, reawakened to have the room cleaned, and awakened again to be examined by a doctor rather than being awakened once to have all of these operations done simultaneously. It seems reasonable then to begin our discussion of hospital soundscape impacts by considering the staff.

The most studied group of medical staff in hospitals are the registered nurses (RNs), who are a large portion of the staff and also work in closest contact with patients. Nursing is a difficult occupation, and stress and burnout are serious job issues. Compdata Surveys studied the problem of turnover in healthcare jobs and found that the average turnover in nurses in 2017 was 20.6%, up from 15.6% in 2010. This turnover rate is second only to that in the hospitality sector and is more than double that found in occupations with similar education requirements (Rosenbaum, 2018). The cost per nurse turnover in a hospital was estimated by Jones (2008) to be $82,000 to $88,000.

Most of the noise studies on nurses consider the noise/stress nexus. One of the earliest studies was conducted by Morrison et al. (2003), who followed nurses in a pediatric intensive care unit for three hours and measured the cortisol levels in their saliva (a known stress indicator) while simultaneously monitoring the sound pressure level. These authors found correlations between sound level and three items: self-assessed annoyance, self-reported stress, and cortisol levels. More recently, Ryherd et al. (2008) surveyed 47 nurses in a neurological intensive care unit, finding that 91% reported noise negatively affects them in their daily work environment. Many reported known symptoms of stress: irritation (66%), fatigue (66%), concentration problems (43%), and tension headaches (40%). Applebaum and Fowler (2010) reported that perceived stress was significantly related to job satisfaction and turnover intention, thus indirectly linking noise to job satisfaction.

Although these studies show noise and stress are correlated for nurses, they don't demonstrate a causal relationship. Sound levels on hospital units tend to rise when there is increased activity, usually indicating a medically unstable patient. This makes it impossible to know whether the rise in stress is noise induced or activity induced.

In addition to stress studies, there are some studies of hearing loss and task performance impacts from noise in hospitals. Generally, hospital environments are not sufficiently intense to make hearing loss a concern, but operating rooms are an occasional exception to this rule. Kracht et al. (2007) looked at sound levels in typical surgeries at Johns Hopkins Hospital (Baltimore, MD) and classified the peak levels by type of surgery, as shown in **Figure 4**. They found that neurosurgery and orthopedic operations have peak levels over 100 dB more than 40% of the time, with peaks occasionally exceeding 120 dB. Sound levels in other forms of surgery were significantly less intense, possibly because they don't rely on use of bone saws and drills.

Operating rooms are often made louder by the music that surgeons play. A review by Vahed and Kabiri (2016) suggests that 62-72% of surgeons play music while they operate. The wisdom of playing music during surgery has been debated for decades, with no clear research conclusions. The impact of noise on task performance in hospitals is not clear, with some studies finding no significant difference between quiet and noisy conditions (Hawksworth et al., 1998; Moorthy et al.,

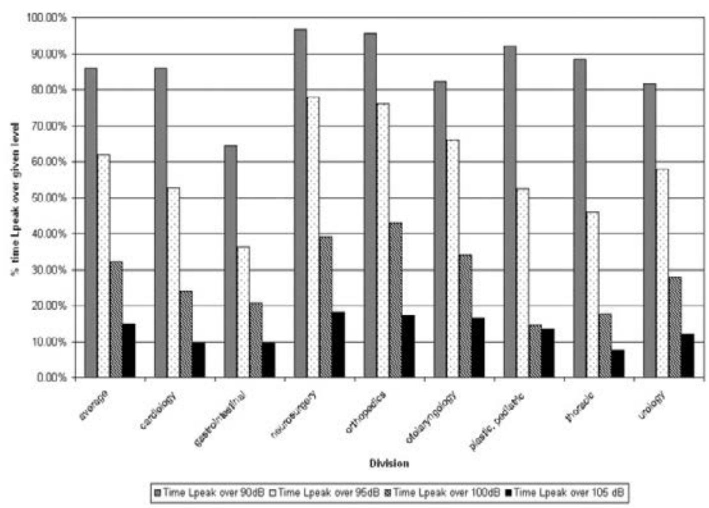

Figure 4. *Fraction of time that the peak noise level (L_{peak}) exceeds 90, 95, 100, and 105 dB (unweighted) by category of surgery. Reproduced from Kracht et al., 2007.*

2004) and others finding that the effect depends on individual preference and seems to impact short-term memory and mental efficiency (Park and Song, 1994; Murthy et al., 1995).

The Impact of Hospital Soundscapes on Patients

Hospital soundscapes affect patients quite differently from staff because patients in hospital are present around the clock. Patients are a vulnerable population, often anxious about their medical situation and recovering from illnesses or surgical procedures. Furthermore, although staff members have some modest amount of control over the noise produced in a unit, patients have almost no such control. This negatively affects the patient 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). Results generally show that hospital soundscapes impact patients.

The most-studied impact of hospital noise on patients considers the interaction of noise and sleep. Disrupted sleep is known to relate to blood pressure increases, weight gain, heart disease, pain, stress, and inflammation. A study by Gabor et al. (2003) was among the first to directly measure sleep stage and correlate it with noise. Subjects were both patients on mechanical ventilators in an intensive care unit and healthy subjects sleeping in the unit. For healthy subjects, the majority of arousals from sleep were correlated with the sound peaks. For ventilated patients, only about 20% of the arousals were related to sound. Overall, most of the causes of sleep arousals were unknown and surveys the following day were unlikely to accurately identify noise sources causing arousals. The Sound Sleep Study reported by Buxton et al. (2012) was conducted in sleep labs using recorded sounds typical in hospitals and found that as sounds got louder, they were more likely to cause sleep arousals, with alarms and ringing phones the most likely culprits. Again, subjects were unable to identify the noise sources that caused them to awaken. Persson Waye et al. (2013) found that for subjects exposed to intensive care unit noise, sleep was more fragmented, with less slow-wave sleep, more arousals and more time awake compared with a reference night.

Although these studies suggest that hospital soundscapes impact sleep, the repercussions remain unclear. We don't know, for instance, whether poor sleep in hospitals causes extended stays. We do know that patients do not view the hospital as a place where it is easy to fall asleep. The Hospital Consumer Assessment of Healthcare Providers and Systems survey (HCAHPS), mandated in the United States since 2008, has a single question about acoustics, asking patients to rate the area around their room as always, usually, sometimes, or never quiet at night. This was routinely the question receiving the lowest patient score on the survey until recently when the survey was changed. Locke and Pope (2017) compared the responses of patients to the noise question in 2010 and 2014. They found a drop in the fraction of patients regarding their room as always quiet at night from 2010 to 2014 and an increase in the fraction saying their room was never quiet at night, results trending in the wrong direction.

In addition to sleep studies, there has been some research on other physiological impacts of sound on patients. For instance, Hsu et al. (2012) studied patient heart rate, respiration rate, systolic and diastolic blood pressure, and blood oxygen saturation levels as a function of sound pressure level. This study found correlations between increasing levels and increases in physiological measures except for blood oxygen saturation, which trended downward with increasing level.

Studies of the psychological impacts of hospital sounds on patients have focused on the sense of well-being and on the impact of music. For example, Cunha and Silva (2015) had patients take two surveys: the Environmental Comfort Questionnaire (EMQ) to measure noise perception and the Positive and Negative Affect Schedule (PANAS) to measure emotion. They found significant correlations between noise levels and perceptions of well-being, with higher noise levels leading to a reduced sense of well-being. A more recent study by Bliefnick (2018) also utilized the PANAS and found that subjects listening to hospital soundscapes for 30 minutes displayed decreased moods.

There are interesting studies on the impact of music on patients. For instance, McClurkin and Smith (2016) studied the impact of music on preoperative patients. They determined that listening to as little as 15 minutes of music before surgery reduced anxiety. There are companies that are producing soothing sound products for hospitals and clinics to use.

Studies Using Soundscape Analytical Approaches

One of the earliest efforts to use analytical techniques developed for psychology on hospitals was reported by Mourshed and Zhao (2012). Their aim was to determine which healthcare facility design factors are most significant for clinical workers. They formed a list of 16 design factors that had been shown previously to be important to healthcare workers and administered a questionnaire to the medical staff. Analyzing their results using principal component analysis, they found three significant dimensions of importance in hospital designs: spatial, environmental, and maintenance. They found that cleanliness was the top concern of the staff, followed by air quality, then noise, and then thermal comfort.

More recently, an impressive body of work on hospital soundscapes has been reported by Mackrill et al. (2013a,b, 2014), who studied a cardiothoracic ward. The aim of this study was to identify the positive and negative aspects of the hospital soundscape and to craft interventions based on the results. The first part of the study used semistructured interviews with patients and staff to associate positive and negative words to sound sources. The next part of the study used recordings of the important noise sources in a laboratory listening study. Subjects were asked to listen to each sound and describe how it made them feel. Semantic analysis was used to group results into positive, negative, or neutral emotions. Bipolar semantic scales were created from the expressions of subjects and then principal component analysis was used to determine significant dimensions. For instance, one scale went from calm to agitated and another from relaxed to stressed. This study found two significant perceptual dimensions: relaxation, which described 57% of the variance, and interest and understanding, which accounted for 13% of the variance. From this, the investigators concluded that patients and staff seek a relaxing soundscape and are more forgiving of noise if its purpose is understood.

The last part of the study by Mackrill and colleagues (2014) considered the potential to improve the soundscape by introducing masking sounds. They found that added nature sounds improved the ratings of the soundscape by subjects along the relaxation dimension and that the improvement was greater than for traditional masking sounds. This result parallels Ulrich's (1984) seminal work on the impact of views of nature on hospital patients and is aligned with a study by Annerstedt et al. (2013) that found that sounds of nature reduced cardio stress markers and cortisol levels after a stressing event.

Azzahra et al. (2017) asked nurses to rate the soundscape in an intensive care unit on a variety of preestablished bipolar scales such as pleasant to unpleasant. This work found three significant dimensions: information, which accounted for 31% of the variance; calmness, which described 31% of the variance; and dynamics (e.g., loudness), which accounted for 23% of the variance.

There is much work still to be done using soundscape analytical tools. For instance, noise interventions based on results have not yet been fully tested to confirm the techniques.

Interventions

Hospital soundscape interventions parallel typical noise control approaches, which are normally classified as at the source, along the path, or at the receiver. Noise interventions are also conventionally described as physical, meaning there is a change in structure causing sound to be reduced, or administrative, meaning that behaviors or processes change. In what follows, we highlight a few of the more unusual and interesting noise interventions in hospitals.

At the source, noise interventions are hard to find in hospitals. Medical equipment manufacturers are not focused on producing quieter machines, oral communication reigns supreme in medical facilities, and alarms continue to sound constantly. One administrative approach has, however, managed to improve the soundscape at least periodically, namely, the implementation of quiet times.

Quiet times are designated blocks of time (often two consecutive hours each day) during which hospital unit operations are intentionally minimized. Typically, lights are dimmed, doors are closed, and fewer procedures are scheduled. Both staff and patients appreciate these times of rest. Weber and Ryherd (2016) showed, for instance, that over 90% of nurses surveyed felt quiet times were useful to them, their patients, and the families of their patients. Similarly, Adatia et al. (2014) showed that quiet times were useful to new mothers.

Along the path, noise interventions usually consider the addition of sound absorption or insertion of some sort of sound barrier. These are both problematic approaches in hospitals, where the ability to clean all materials regularly is important and where unit staff want to be able to see patients clearly to ensure safety and promote an efficient workflow. There are now a few lines of acoustical materials appropriate for use in hospitals, but the problem of direct sound paths remains.

An interesting approach to along the path noise interventions in hospitals was presented by Okcu et al. (2013), who studied floor layout designs such as corridor turns and branching hallways, relative grid distance, and visual fragmentation. These architectural features were found to relate to the reverberation time in units and allow for hospital designs to consider the soundscape at the design stage.

Finally, at the receiver, interventions that have been studied include earplugs and headphones. Schlesinger et al. (2017) studied noise-canceling headphones designed to specifically eliminate clinical alarms while passing the rest of the sound with as little distortion as possible. Laboratory results showed significant improvement in speech intelligibility while alarms were sounding.

Taken as a whole, interventions to improve the hospital soundscape show some benefits but have not been consistently successful. They have tended to focus on modest improvements rather than the significant reuse, redesign, and transformation that is probably required for hospital soundscapes to become more pleasant for staff, patients, and visitors.

Conclusions

Hospital soundscapes do not currently project an aura of calm and restfulness that patients and staff would prefer. Instead, they are loud and chaotic, with lots of sound peaks from normal hospital operations and medical equipment. Furthermore, hospital sound levels have been increasing for decades. There is research that supports the notion that the soundscape impacts medical staff primarily by increasing stress and patients through impacting the ability to sleep and the sense of well-being.

Recent work on hospitals indicate that staff and patients crave a soundscape that could be described as calm, and patients are willing to experience noises when they understand their origin and meaning. Interventions parallel work more generally on building noise. The addition of quiet times on units has been found to be useful for staff and patients and their families and masking the sounds of nature show promise in creating a more restful space as well.

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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BioSketches

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