EVALUATING THE HOSPITAL SOUNDSCAPE

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Environments where decisions are made affecting health and survival and where patients reside should promote thinking, communication, good patient care and restfulness for the patients. It may seem a strange principle to enunciate as the very first requirement in a hospital that it should do the sick no harm.[1] However, the complex hospital auditory environment or "soundscape" has long been a key source of complaints among hospital staff, patients, and visitors.[2,3] Hospitals are dense with ambulatory people who rely heavily on oral communication and therefore the hospital soundscape is densely populated by speech. There are also a variety of mechanical noise sources such as beeping alarms, medical respirators, overhead paging systems, floor cleaners, and air-conditioning systems. Couple speech and mechanical noises with patient distress sounds and activity noise from busy staff in a highly reverberant space, the result is a dynamic soundscape that is far from restful and can make understanding speech difficult. This article summarizes what is known about the hospital soundscape and its impacts and describes ongoing work for improvement.

Ultimately, we hope that our research facilitates change in the hospital soundscape—creating a safer, healthier environment for patients, staff, and visitors.

Effects of hospital soundscapes on occupants

Concerns about the hospital soundscape aren't new—researchers have been looking at ways to quantify this unique auditory environment and its effects for several years. Of particular interest are the negative health impacts of the hospital soundscape on patients, staff, and visitors. Ideally, hospitals should be conducive to patient recovery and safety, employee health and productivity, and visitor comfort. However, research suggests that a host of negative symptoms may be partially or primarily attributed to the hospital sound environment and warrant detailed investigation.

It is well-known that noise can have both psychological and physiological effects on humans.[4,5] Previous research on hospital patients have documented negative impacts such as a reduction in the recuperative properties of sleep, including depth, continuity, and duration.[6-9] Effects such as cardiovascular arousal,[10-11] extended hospital stay,[12] and increased dosages of pain medication[13] due to excessive noise levels have also been documented in patient studies. Decreased healing is another potential concern as a few studies on animals have revealed that noise exposure may slow wound healing.[14,15] Furthermore, increased sound absorption that tends to make speech more intelligible and lower background noise levels has been linked to improved sleep in an experimental study,[16] a reduction in cardiovascular arousals,[17] and decreased incidence of re-hospitalization.[17] Speech interference and increased medical errors are two additional potentially hazardous effects of hospital noise that could have obvious negative implications for patient safety.[2,18] Indeed, there is a growing body of research on pharmaceutical name recognition in noise similar to that found in hospitals.

The impact of the hospital soundscape on staff members is also a concern. Statistics indicate that 14 million people are employed in the U.S. healthcare industry, with 4.9 million of them working specifically in hospitals.[19] Therefore, the quality of this occupational environment affects a large segment of the population. There is some evidence that overall levels of hospital noise may contribute to stress[20-23] and burnout,[24] a serious concern given the current nursing shortage throughout the U.S. Other studies suggest that the acoustical environment contributes to decreased short-term memory,[25] decreased mental efficiency,[25] and decreased ability to aurally distinguish critical physiological functions such as heart and lung sounds.[26] Some studies indicate that orthopedic staff may be at risk for noise-induced hearing loss.[27,28] Increased sound absorption has been shown to correlate with improvement in the staff psychosocial environment[29] and improved perception of the soundscape (i.e., increased satisfaction with the overall noise level).[30]

Current knowledge

The consensus from previous work is that the hospital soundscape is problematic and that it is becoming worse, even in new construction. Recent research shows that hospital noise levels have been rising consistently over the last 45 years.[2] A compilation of published hospital noise levels indicated that average day-time equivalent sound pressure levels (L_{eq}) rose from 57 dB(A) in 1960 to 72 dB(A) in 2005, and night-time L_{eq} levels rose from 42 to 60 dB(A). The L_{eq} is defined to be the level of the continuous sound that would produce the same sound energy as the time-varying sound over a specified period. Many papers point out the lack of compliance with various standards and guidelines, such as those published by the World Health Organization (WHO),[18] the U.S. Environmental Protection Agency (EPA),[31] and the American National Standards Institute (ANSI).[32] The compilation showed that none of the previously published results complied with the WHO guidelines. It should be noted, however, that these guidelines were intended to specify sound levels known to have no negative health impact—they are very strict standards to meet.

Despite evidence of increasing awareness of the issue and the potential for negative reactions of occupants, actual improvements have been sluggish at best in part because the pool of research remains limited in scope. The majority of articles that examine sound control strategies are mostly limited to administrative noise controls such as closing doors and asking staff to speak softly.[33,34] Such approaches have been shown to have limited success in combating noise in industry. Most of the previous work also has focused primarily on overall levels of noise (i.e., L_{eq}), but provide minimal examination of other detailed characteristics of sound such as the frequency distribution, tonality, and time-variance. Previous research has shown that these sound characteristics can potentially impact our reaction to the soundscape by causing annoyance, decreasing performance, eliciting physiological reactions, etc.[35-37]

The existing literature provides a good basis for understanding the problematic nature of the hospital soundscape. However, additional information on the psychological and physiological reactions of occupants to detailed properties of the acoustical environment is needed to improve conditions. To advance the state of knowledge, a research collaboration involving engineering, architecture, and medicine has been formed over the last several years.

Recent research on the hospital soundscape

One important aspect to consider in hospital or healthcare facility research is the uniqueness of the different spaces housed therein. Variations in the architecture, types of equipment, conditions of patients, presence of visitors, occupational culture, and occupant activities can be found when comparing different types of wards. In our work, we are endeavoring to take a comprehensive look at different types of wards. Together with our collaborators, we have thus far examined spaces including operating rooms, hematological cancer units, burn acute care units, adult emergency departments, and a variety of intensive care units (ICU). Hospitals that have been included are Johns Hopkins Hospital in Baltimore, MD, Emory University Hospital in Atlanta, GA, Parkland Hospital in Dallas, TX, and the Sahlgrenska University Hospital in Gothenburg, Sweden.

Overall hospital noise levels

An acoustical survey was conducted at a variety of wards in Johns Hopkins Hospital.[2] Average equivalent sound levels (L_{eq}), minimum sound pressure levels (L_{Min}) and maximum sound pressure levels (L_{Max}) as well as frequency distribution in octave bands were analyzed. A pediatric intensive care unit (PICU), children's ward, oncology ward, and adult medical/surgical unit were included.

Results showed average L_{eq} in the 50–60 dB(A) range. Corridors tended to be the noisiest areas, with nurses stations and occupied patient rooms the next noisiest. Empty patient rooms were significantly quieter. Of these types of spaces, only the empty patient rooms showed significant variations in noise levels as a function of time of day. On average, then, relatively constant sound levels were seen in areas that most impact patients, staff, and visitors.

The spectra were higher in the low frequencies (< 63 Hz), generally flat over the 63–2000 Hz octave bands, and followed by a gradual roll off above 2000 Hz. The low frequency energy was likely due to the heating, ventilating, and air-conditioning (HVAC) system. The flat sound spectrum region generally encompasses the speech band. This type of spectral distribution is not surprising given the high density of speech in hospitals. The high frequency energy was possibly due to alarms, mobile medical equipment, and high velocity airflow from the HVAC system.

During the course of this study, the opportunity arose to investigate overhead versus personal paging in the PICU. The PICU was originally dependent on overhead paging. Loudspeakers were active at least once every 5 minutes with each page typically lasting less than 30 seconds. An alternative was implemented in the form of a personal, hands-free call system that broadcast only to the individual desired to be reached. As a result of the personal paging system, overhead pages in the PICU have been reduced to roughly one or two per hour.

Operating room noise

In another study, sound measurements were conducted in 38 operating rooms (ORs) to quantify the acoustical events during surgical procedures.[38] Sound pressure levels were monitored before, during, and after a variety of operations on both adult and pediatric patients. The data were analyzed to determine the average L_{eq}, peak sound pressure levels (L_{Peak}), and frequency distribution in octave bands. Various classes of surgery were compared including cardiology, gastrointestinal, neurosurgery, orthopedic, pediatric plastic, plastic, thoracic, and urology.

Example results are shown in Table 1. The L_{eq} averaged between 55 and 70 dB(A) with significant sound peaks during surgical procedures. Orthopedic surgery had the highest L_{eq}. The fraction of time that unweighted L_{Peak} values exceeded 90, 95, 100, and 105 dB was also analyzed by category of surgery. This type of analysis provided insight into the "peakiness" of sound in an OR during surgery, giving a much more detailed impression of the sound environment. For example, peak levels exceeded 100 dB over 40% of the time for neurosurgery and orthopedic surgery. Peaks over 120 dB were not

Table 1. Average equivalent sound pressure levels (L_{eq}) for operating room surgeries by category (Reprinted with permission from reference 38. Copyright 2007, Acoustical Society of America).

Category	L_{eq} (dB(A))
Pediatric orthopedic	58
Thoracic	63
Gastrointestinal	63
Cardiology	64
Urology	64
Pediatric Urology	64
Neurosurgery	65
Otolaryngology	65
Pediatric Plastic	65
Orthopedic	67
Plastic	67

uncommon. In future work, we intend to conduct studies linking specific acoustical events, such as the use of a bone saw, to measured sound pressure levels.

Noise in an adult emergency department

The constant flow of patients, doctors, nurses, and moving equipment in emergency departments all contribute to one of the most dynamic sound environments in the hospital.[39] Twenty-four hour noise measurements were conducted in an adult emergency department to gain a better understanding of the soundscape in this busy space. The data were analyzed to determine the L_{eq}, L_{Min}, and L_{Max} levels as well as frequency distribution in octave bands.

The L_{eq} measured throughout the department were on average 61–69 dB(A). These levels are roughly 5–10 dB(A) higher than those measured previously at a variety of inpatient units of the same hospital.[2] The triage area at the entrance to the department had the highest L_{eq} at 65–73 dB(A). The measured sound pressure levels were particularly high in the speech frequency band. The high levels due to speech are not surprising given the large amount of verbal communication in the emergency department.

Neuro-ICU acoustics and staff response

In this study, sound measurements and staff perception evaluations were conducted in a neurological intensive care unit (Neuro-ICU) over five days.[22,23] The data were analyzed to determine the L_{eq}, L_{Min}, L_{Max}, and L_{Peak} levels as well as frequency distribution in octave bands. The patients in the Neuro-ICU were sedated most of the time and required constant monitoring by the nurses.

Average L_{eq} values of 53–58 dB(A) were measured near the patients. Dosimeters (body mounted microphones) worn by the staff revealed values 13 dB(A) higher than stationary microphones on average. Other acoustical metrics investigated in this study were found to give a more detailed impression of the sound environment than was achieved from the overall level descriptors. Examples included statistical level distributions, restorative periods, and indoor noise criteria evaluations of spectral content. Figure 1 shows an example result from this study that presents statistical distributions of peak and maximum levels measured over five days. As shown on the figure, L_{Max} exceeded 50 dB(A) and L_{Peak} exceeded 70 dB(C) over 90% of the time. The behavior of noise over time was further investigated by analyzing the occurrence and length of quieter or "restorative" periods. For example, it was found that the mean length of L_{eq} restorative periods (where L_{eq} was below 50 dB(A) for a minimum of 5 minutes) was 9 and 13 minutes for the day and night, respectively.

Nursing staff members completed questionnaires regarding general reactions to the ICU environment as well as perceived psychological and physiological reactions. Questionnaire results indicated that 91% of those surveyed perceived noise as negatively affecting them in their daily work environment. They perceived the noise as contributing to stress symptoms such as irritation, fatigue, tension headaches, and difficulties concentrating. Some of the nurses in the study believed the alarm environment in particular was related to negative reactions such as influencing their ability to perform job tasks or affecting their sleep after an intensive work day. Many of the nurses were willing to consider alternative systems such as vibrating or visual alarms. Other studies have raised concern over the alarm environment, noting the difficulties in detecting alarms due to factors such as the sheer density of signals, masking effects of background noise, and the hearing acuity of staff.[40,41] Results from previous work also indicate that even experienced staff members incorrectly identify many alarms.[42]

Aural connectivity for ICU staff

This on-going study examines how architectural design and material properties influence the concept of "aural connectivity" where staff members rely on localization of audito-

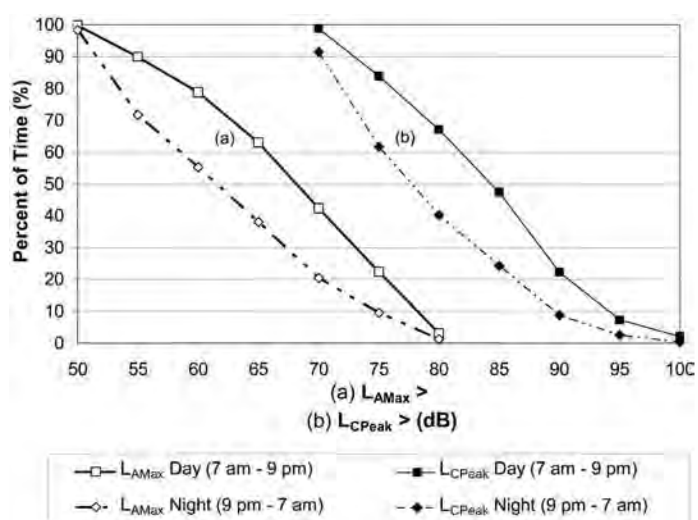

Fig. 1. Statistical level distributions of peak and maximum levels measured in a neurological intensive care unit. Y-axis represents the percent of time that (a) L_{AFMax} and (b) L_{CPeak} exceed values shown on the x-axis (Reprinted with permission from ref. 22, Copyright 2008, Acoustical Society of America).

ry cues to attend to patients.[43,44] Two ICU hospital settings with similar patient acuity levels but differing layout and construction are being studied. Preliminary noise measurements and staff qualitative interviews have been conducted.

Results from the interviews show that effective auditory monitoring requires recognition, localization, and immediate reaction to critical sounds to improve patient safety, increase nurse work efficiency, and reduce nurse burnout. Critically important sounds that nurses use in accomplishing their tasks have been identified as key auditory cues including patient bodily sounds, threatening/unusual sounds, help calls from patients and other caregivers, and sounds from medical monitoring equipment.

In on-going phases, systematic mapping and documentation of auditory tasks is being used to define metrics for architectural enclosures that are pertinent to auditory connectivity. This approach to investigating the soundscape is crucial in order to retain the integrity of auditory cues while simultaneously reducing unwanted sounds.

Acoustical remodel of a burn acute care unit

This project, led by Howard Pelton, examined the various challenges faced in the acoustical remodeling of a burn acute care unit.[45,46] It focused on a debridement treatment facility where burn patients undergo daily procedures. Debridement involves the use of water and/or surgical instruments to remove dead tissue. Debridement, along with the care team's ability to keep the wounds clean and infection free, is a matter of life and death. Thus, maintaining an absolutely sterile and cleanable environment is vital and presents challenges in selecting acoustical absorption. Additionally, the debridement procedure is extremely painful for patients and loud distress sounds, including screams, are common. The existing facility consisted of hard surfaces with privacy curtains providing the only separation between the individual debridement stations. Sound isolation was also inadequate between the debridement facility and the rest of the ward. Patient distress sounds could clearly be heard throughout the ward creating a great deal of anxiety for patients—particularly for those awaiting their turn for treatment.

The remodeled facility was designed to have the amenities of spa-like finishes to provide a more calming space for patients and staff. The unit was designed for enhanced sound isolation and included high sound transmission loss (STC) walls and doors. Cleanable absorptive treatments were selected for ceilings and walls to meet high sanitary standards. Figure 2 provides a view of the acoustical ceiling tiles and a wall mounted absorptive panel in the interior of a debridement treatment room.

Sound data was collected in the original facility during debridement treatment sessions to design appropriate sound isolation and overall acoustical design goals for the remodel. L_{eq} and centile (L_n) sound pressure levels were measured to gauge the background sound levels and patient distress vocalization levels. L_1 values (or sound pressure level exceeded 1% of the measurement time) were measured for typical

Fig. 2. View of the acoustically absorptive treatment in the remodel of a burn acute care unit. An absorptive panel is wall mounted behind the sink in the interior of a debridement treatment room (Reprinted with permission from ref. 46. Copyright 2008, Institute of Noise Control Engineering).

patient distress sounds in adjacent spaces. The L1 values were reduced from 88 dB(A) before remodeling to 55–58 dB(A) after the remodel. As a result, privacy and acoustical comfort was markedly enhanced within the remodeled debridement treatment facility and between the debridement facility and the rest of the ward.

Acoustical remodeling of a hematological cancer unit

This project investigated the benefits of adding acoustical absorption in a hematological cancer unit.[30] The unit was perceived as relatively noisy by staff prior to the addition of absorption with an average L_{eq} of 55 dB(A). As in the burn acute care unit study, sound absorbing treatment options were limited as the cancer unit housed immuno-suppressed patients.

Sound absorbing panels were created and installed in a noise intervention effort. The panels consisted of 2-in.-thick fiberglass wrapped in anti-bacterial fabric. The fabric was affixed to the back of the panels with wallpaper paste. The panels were installed on the ceiling and high on the walls of corridors, as shown in Fig. 3. A concentration of absorbers was placed in circular architectural features at the nurses' stations and on corners where cabinets tended to reflect sound from one corridor to another. The selection and the placement of the absorbing panels were coordinated with the hospital architect to provide an aesthetically pleasing design.

The impact of the noise intervention was evaluated using both objective and subjective measures. After installation of the panels, the noise (as measured by L_{eq}) was reduced by 5 dB(A) and the reverberation time dropped by a factor of 2. Anecdotal evidence revealed that the immediate impact of the panels was to permit occupants to lower the level of their speech while still being well understood. Additionally, subjective data collected through surveys of staff and patients before and after the treatment showed that perception of noise improved after the installation of the panels. For example, nearly 30% of the patients surveyed felt that noise interfered with daytime rest before the treatment compared to 0% afterward. The majority (92%) of the nurses surveyed reported problems hearing during rounds prior to treatment and only 8% reported problems hearing after treatment.

Staff dosimeter study

During these studies, a great deal about measurement methodologies and metrics was learned. For example, we are investigating the differences between staff and patient noise exposure levels.[22,23,47] In the Neuro-ICU study discussed

Fig. 3. View of the acoustically absorptive treatment in the remodel of a hematological cancer unit. Sound absorbing panels are mounted high on the walls and on the ceiling of the corridor, as well as in the large circular architectural feature at the nurses' station. Note a person shown at the bottom center for scale (Reprinted with permission from ref. 30. Copyright 2007, Acoustical Society of America).

above, stationary sound level meters were used at the patient location while staff members wore body-mounted dosimeters. The average staff exposure levels were found to be between 12 and 13 dB(A) L_{eq} higher than the levels at the patient, depending on time of day.[22] It was hypothesized that these differences were primarily due to staff speech noise and activities close to the wearer. A separate study was then conducted to further investigate the effects of wearer's voice on body-mounted dosimeter measurements in sixteen noise conditions with overall levels resembling hospitals.[47] Future work should also consider the differences in exposure levels between patients and staff.

Conclusions and further work

Research to date has focused primarily on characterization of the sound environment. What remains to be done is to better link physiological and psychological reactions such as alterations in cardiovascular responses, breathing, and anxiety to specific sound environments. Ultimately, medical outcomes, such as the need for pain or sleep medication or the time for recovery, and their relation to particular noise measures must also be examined. Only then will it be possible to determine the appropriate noise interventions and mitigation for health and wellness promotion in the hospital soundscape.

Our findings indicate that many staff members perceived noise as a problem that may contribute to stress symptoms. More research is needed to correlate self-reported stress with physiological reactions and to understand the role of the acoustical and other environmental conditions on occupant response. The sustained sound pressure levels measured were generally not sufficiently high to cause hearing loss. However, high intensity sound peaks were common and warrant concern, particularly since the effect of noise peaks on hearing loss is less well understood. We found that modifications to the acoustical environment such as added absorption, improved sound isolation, and decreased levels of background noise were positively perceived by staff and patients. We are currently pursuing additional research on how these and other improvements to the environment might impact both psychological and physiological response. The sound environment is complex and a detailed description of its time and frequency characteristics is also necessary to fully understand and prevent its negative impact.

Our findings raise concerns about oral communication in hospitals since the overall loudness and spectral shape of the background noise may make understanding speech difficult. The typical speech level for communication between two people is around 50–55 dB(A) and a signal-to-noise ratio of 15 dB is generally necessary for clear communication. The measured background noise levels in our studies range from 50–70 dB(A) suggesting that the staff may need to routinely raise their voices in order to be heard and understood. The importance of good speech intelligibility cannot be understated. It is paramount throughout the hospital that speech must be clearly understood to reduce the possibility for medical errors. The issue of speech intelligibility, however, must be balanced with the concept of providing privacy for patients.[48] For example, while it is critical to understand speech within individual treatment spaces, adequate sound isolation must ensure that one cannot hear the diagnosis of the patient in the next room. Therefore, a holistic approach must be taken in the acoustical design of any ward.

Our primary goal is to understand better and to improve the hospital soundscape. Although much progress is being made, there is much more to learn. We will continue to investigate a variety of facets of this unique acoustic environment. This includes research on improvement of acoustic measurement and characterization techniques, response of occupants to the soundscape including psychological and physiological reactions as well as medical outcomes and errors, and identification and evaluation of acoustic treatments and noise mitigation strategies. Ultimately, we hope that our research facilitates change in the hospital soundscape—creating a safer, healthier environment for patients, staff, and visitors.

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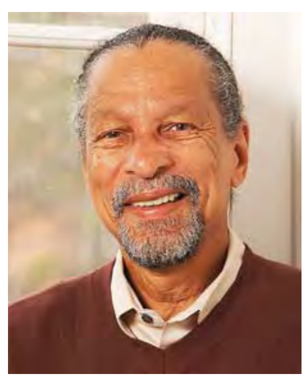

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