Evaluating and Improving Hospital Soundscapes

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Many hospitals are noisy and stressful places. Evaluating the hospital soundscape requires insight into how the acoustics is impacted by architecture, building systems design, material selection, etc., and the corresponding response of staff, patients, and visitors to the sound environment. Healthy hospital soundscapes are vital to patient sleep and recovery, staff health, task performance, and communication, and visitor comfort. Although there is growing and strong evidence that the hospital soundscape is problematic, there are many remaining questions and obstacles. The Healthcare Acoustics Research Team (HART) is an international, interdisciplinary collaboration of specialists in architecture, engineering, medicine, nursing, and psychology. HART is actively engaged in research in the United States and Sweden, having worked in a dozen hospitals and a broad range of unit types including intensive care, emergency, operating, long-term patient care, mother-baby, and others. HART seeks to advance the understanding of how various aspects of the hospital soundscape impact occupants, how to best measure and quantify these aspects, and how to
translate results into evidence-based-design. Taken as a whole, these studies provide new insight into how to create healthier hospital acoustic climates.

1 INTRODUCTION

The acoustic environment, or “soundscape” in hospitals and other medical facilities is problematic. Beeping alarms, medical respirators, overhead paging systems, floor cleaners, and air-conditioning systems are just a few of the many noisy sources. Add patient distress sounds, speech, and activity noise from busy staff in a highly reverberant space, and the result is a dynamic soundscape that is far from restful. Indeed, there is growing evidence of the potential negative impacts of a poor soundscape on patient health and recovery, staff stress and communication, and visitor comfort. Evaluating the hospital soundscape requires insight into how the acoustics is impacted by architecture, building systems design, material selection, etc., and the corresponding response of staff, patients, and visitors to the sound environment. An international collaboration of acoustic and medical specialists has been formed to investigate several aspects of the hospital soundscape, including:

- Improving ways to measure and characterize the soundscape
- Determining the psychological and physiological responses of occupants to various aspects of the soundscape
- Identifying and evaluating ways to improve the soundscape, such as through architectural design, surface material selection, and equipment noise control.

2 HART OVERVIEW

The Healthcare Acoustics Research Team (HART) is an international, interdisciplinary collaboration of specialists in architecture, engineering, medicine, nursing, and psychology. HART is currently comprised of twelve founding members from academia and industry. Some related areas of specialty include architectural acoustics, noise control, acoustic instrumentation, human psychological / physiological responses to sound, evidence-based-design for hospitals, sustainable buildings, and statistics. Many graduate and undergraduate students have also participated in HART’s activities, as one of the team’s goals is to give students hands-on experience in measuring, analyzing, and improving healthcare soundscapes. The team is actively engaged in research in the United States and Sweden, having worked in a dozen hospitals and a broad range of unit types including intensive care, emergency, operating, long-term patient care, mother-baby, labor-delivery, burn units, ambulatory surgery, and others.

A key thrust of HART is to define relationships between acoustics, architecture, and occupant outcomes. Acoustic examples include noise types, loudness, sound quality, speech intelligibility, speech privacy, and energy decay measures. Architectural examples include surface materials and spatial layout metrics such as relative grid distance, visual fragmentation, number of turns, and branching corridors. Examples of occupant outcomes include staff communication, errors, job strain, and health, in addition to patient physiological arousals, sleep disturbance, anxiety, and intensive care unit delirium. The example findings below highlight some recent HART results related to hospital acoustics, architecture, and occupant outcomes.
3 RESULTS

3.1 Example Findings: Acoustics

Several studies have found drastic differences between noise levels in occupied and unoccupied spaces. The primary noise sources in unoccupied units are typically from building systems such as air-conditioning, noise from adjacencies, and exterior environmental noises such as traffic. Occupied units also have medical equipment, alarms, and occupant-generated sounds such as speech and patient noises. Ryherd et al. compiled A-weighted equivalent noise level (LAEQ) results for four intensive care units, two emergency departments, and a cancer unit. It was found that the differences between occupied and unoccupied units averaged 13 dB LAeq and ranged from 6 to 15 dB LAeq. Interestingly, many design guidelines are either written for unoccupied conditions or don’t specify occupancy.

Other studies have highlighted the usefulness of newer sound measures. The “occurrence rate” or related metrics have been used successfully in several studies. Occurrence rate is derived from traditional percentile level analysis and used to analyze the temporal distribution of sound. In Okcu et al., occurrence rates were statistically linked with self-reported nurse outcomes in two intensive care units (ICUs). Nurses perceived one of the ICUs as significantly louder, more annoying, and worse for nurse work performance, health, and anxiety. However, there was very little difference between the two ICU soundscapes based on traditional noise measures such as LAeq and the A-weighted maximum (LAmx) or C-weighted peak (LCpeak) sound levels. The occurrence rate was calculated as the percentage of time that peak and maximum sound levels exceeded certain thresholds. For example, although both ICUs had overall levels of 57-58 dB LAeq, one unit was found to be more “peaky” based on the occurrence rate – LCpeak exceeded 90 dB more of the time. The occurrence rate was therefore found to better reflect the fluctuating nature of the noise and was also significantly correlated with staff annoyance and loudness perception. A follow-up study further indicated the usefulness of this metric by showing that nurse perception and occurrence rate tracked across different times of the day and days of the week.

3.2 Example Findings: Architecture

One study aimed to discern whether architectural layout, as measured by floor-plate shape metrics, could be related to acoustics in hospital corridor settings. The corridors were of particular focus because hospital staff perform many important tasks in corridors including listening for auditory cues such as alarms, safety/threatening sounds, patient bodily sounds, and help calls. Although the relationships between floor-plate shape and acoustics has been explored in other settings such as concert halls, relationships between specific floor-plate metrics and acoustics in long enclosures or hospitals has not been established. In the first part of the study, 43 typical hospital corridor types were identified through heuristic analysis of 17 existing US hospitals. Basic layout trends such as dimensions and clustering schemes were identified and extracted to build 133 corridors in an acoustic computer simulation program. For each of the 133 corridors, floor-plate design metrics were calculated such as number of turns, number of branching corridors, total length, visual fragmentation, and relative grid distance. Note that the visual fragmentation metric reflects the convexity of a floor-plate shape as related to the number of directional changes in the floor plan and the relative grid distance is related to degree of elongation. Results showed that the reverberation time in the simulated corridors was significantly related to the architectural metrics. One unit change in the floor plate metrics (e.g.,
one more turn) was associated with changes in reverberation time ranging from 0.01 – 0.57 seconds.

A few studies have examined the impact of architectural acoustic retrofits on the soundscape. Pelton et al. described the acoustic renovation of a hospital burn acute care unit.\textsuperscript{11} Patients in these facilities undergo daily debridement treatments to remove dead tissue, and patient-generated distress sounds, including screams, are common. As part of the project, noise from patients undergoing debridement was measured. The patient noise was then used as a sound isolation criterion in the acoustic remodel so that patients and staff throughout the ward would no longer hear the distress sounds of the patients. Acoustical treatments included creating a sound lock area for the debridement treatment area, installing partitions and doors with high sound transmission class ratings, adding sound absorbing wall and ceiling panels in the debridement area, and paying close attention to door seals and fit. The result of the acoustic remodel was a markedly enhanced soundscape throughout the ward. For example, L1 values (sound level exceeded 1% of measurement time) was reduced from 88 to 55-58 dBA in spaces adjacent to the debridement area after the renovation.

Other studies focused more specifically on the benefits of adding sound absorption in hematological cancer units. In a first phase, MacLeod et al. engineered a new sound absorbing panel consisting of 2-inch thick fiberglass batts wrapped in a porous woven polyethylene fabric, Xorel\textsuperscript{®}.\textsuperscript{12} The panels were installed on the upper walls and ceilings of a hematological cancer unit. Results showed significant reductions in noise levels (5 dB LAeq) and reverberation time (decreased by a factor of 2). A survey of nurses also revealed perceived improvements in abilities to perform tasks and communicate. A follow-up study was conducted in an industry partnership to engineer more aesthetically pleasing panels and test their impact through a more in-depth staff survey and more detailed acoustic measurements.\textsuperscript{13,14} Findings revealed reductions in noise levels, reverberation time, less sound propagation down corridors, and better speech intelligibility after installation of the newly engineered panels. Survey results showed interesting improvements in perception of noise sources in areas where panels were installed, but no change in areas where panels were not installed.

### 3.3 Example Findings: Occupant Outcomes

Several studies (including some described above) have aimed to link acoustics and architecture to the response of patients, staff, and visitors. One study used qualitative content analysis to describe patients’ recall of the soundscape during their stay in the ICU.\textsuperscript{15} Patients were interviewed following discharge from the ICU. Results showed that positive sounds such as staff working quietly could create feelings of safety, security, and familiarity, whereas negative sounds such as sick patients or medical equipment could create feelings of fear, helplessness, and anxiety. Another study linked acoustic measures to physiological arousals in a general medical-surgical intensive care unit patient population.\textsuperscript{16} Patient heart rate, blood pressure, oxygen saturation, and breathing rate were monitored alongside noise. Results showed that both traditional (e.g., LAeq, LAmx, LCpeak) and psychoacoustic (e.g., speech interference level, loudness, roughness, sharpness, fluctuation strength) were significantly related to patient physiology. Risk ratios were also calculated to estimate the likelihood of physiological arousals. For example, above 50 dBA, there was increased risk that heart rate (22%), respiratory rate (47%), systolic blood pressure (63%), and diastolic blood pressure (44%) would rise.

Other studies show that staff are also negatively impacted by the hospital soundscape. For example, in two ICU studies stress symptoms such as irritation, anger, tiredness, concentration problems, hearing fatigue, and tension headaches were reported.\textsuperscript{2,17} Noise measurements in the two ICUs revealed overall sound levels of 53-58 dB LAeq. In one of the ICUs, 91% of nurses...
surveyed felt that noise negatively affected them in their daily work environment. In this unit, very few “restorative periods” were measured (LAEq below 50 dB for more than 5 min). The mean length of restorative periods was 9 min during the day and 13 min during the night. The occurrence rate was also measured in this study and showed that LAmax exceeded 50 dB and LCpeak exceeded 70 dB almost all the time (>90% of the time). In the other ICU study, 44% of nurses surveyed were rather, very, or extremely annoyed by the noise. Three factors were found to explain 73% of the variance in annoyance responses: auditory fatigue (sound sensitivity, hearing fatigue, tinnitus), mental fatigue (tiredness, headaches, concentration difficulties, irritation), and tension (pain in the neck, stress, difficult to motivate myself). The results from this study population were compared to three other occupational groups in primary healthcare, office, and preschool facilities. The noise annoyance was significantly higher for the ICU nurses compared to the primary healthcare and office workers, but somewhat lower than the preschool teachers.

4 SUMMARY

This paper highlighted example findings from recent HART research. Several studies have been conducted to examine relationships between hospital acoustics, architecture, and occupant outcomes. Results show large differences between occupied and unoccupied noise levels. Newer metrics such as the occurrence rate reveal interesting differences in temporal distribution of sound and are also related to nurse perception. Architectural floor-plate shape metrics have been shown to be related to reverberation time in hospital corridors. The impact of architectural acoustic retrofits, such as adding absorption or installing door and partitions with high sound transmission ratings have been shown to improve acoustics and occupant perception. Humans were shown to respond to the hospital soundscape in a variety of ways—patients felt secure or fearful depending on the sound source, patients were potentially at risk for cardiovascular and respiratory arousals when exposed to increasingly loud or fluctuating noise, and staff commonly reported experiencing stress symptoms and annoyance due to noise in their units. Taken as a whole, these studies shed light on ways to measure and characterize the soundscape, understand occupant physiological and psychological responses to the soundscape, and improve the soundscape through architectural design.

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6 REFERENCES


