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Next steps in hospital noise research

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ABSTRACT

Hospital noise is a topic of interest to medical staff, patients, and their families – i.e., to a large segment of the population. A great deal of work has been done on hospital noise in the last 15 years, but there is still much to learn. This paper summarizes the current state of knowledge of hospital noise and its impacts, more broadly stated as our understanding of hospital soundscapes, and focuses on research avenues that would most effectively advance our understanding and ability to intervene to produce improvements. While there are certainly opportunities to increase our knowledge of sound sources in hospitals and of the physiological and psychological impacts of hospital noises using traditional methods, soundscape analytical approaches are poised to provide much more clarity to the relationship between sound sources and human reactions, making it possible to focus interactions onto the most pressing problems.

Keywords: Noise, soundscapes, hospital noise

1. INTRODUCTION

There are a number of reasons to be interested in the noise in hospitals. Almost everyone spends time in a hospital at some point in their adult life, either as a patient, an employee, or a visitor and noise has long been among the top complaints about hospitals. Because healthcare is among the fastest growing labor sectors in the world, the number of people routinely exposed to hospital sound environments is rapidly growing. Additionally there are economic reasons to be concerned about hospital soundscapes. The healthcare sector typically accounts for about 10% of the labor force of a country and about 10% of a country's gross domestic product, with about half of that being for hospitals. Thus the combination of engaging large numbers of people, and involving huge amounts of funding mean that there is an incentive to make hospital soundscapes pleasant – certainly not a description that is typically applied to them now. Further, some countries have started monitoring hospital performance on a variety of measures, including acoustic, and making the results of patient surveys public as well as pinning government funding to results. In the US, the introduction in 2008 of the HCAHPS (Hospital Consumer Assessment of Health Providers and Systems survey) immediately sharpened the focus of healthcare systems on noise as the lowest score on that survey nationwide was the question of whether patients found their environment sufficiently quiet at night (1). Competitive pressure has thus added even greater incentive to improve hospital soundscapes.

Hospitals have several acoustic challenges. They tend to have walls, ceilings and floors that are highly reflective because of a desire to use materials that can be easily and frequently cleaned. Hospitals also have seen increasing rates of HVAC airflow in order to drive pathogens from circulation. And hospitals are not like office buildings in which people sit at desks to work. Staff, patients, visitors and equipment are constantly moving, creating non-stationary sources of noise. Hospitals also have a plethora of noise sources, including alarms, helicopter landings and takeoffs, overhead paging (although this is phasing out in many facilities), pneumatic tubes, motorized interior doors, and often noisy medical equipment such as respirators.

The mission of a hospital is to promote the healing and wellbeing of its patients, but there is surprisingly little known today about how the health of patients relates to hospital soundscapes. We don't know definitively, for instance, whether hospital noises cause patient anxiety and increase hospital stays or make patients more susceptible to hospital-acquired infections.

This paper will briefly present a summary of the current state of knowledge of hospital noise and its impacts on patients and staff, and then focus on potentially interesting avenues of research that follow

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on to the latest results. In particular, the use of statistical methods associated with soundscape analysis promises substantial progress in understanding what sound interventions are most likely to have a positive impact on occupants of hospitals.

2. CURRENT STATE OF KNOWLEDGE OF HOSPITAL NOISE

A good bit of the work on hospital noise has focused on objective measures of the sound levels in hospitals. As reported in Busch-Vishniac et al. (2), and later by Ryherd et al. (3), the sound levels measured by the L_{eq} in hospitals have been rising monotonically since the 1960s and well exceed the World Health Organization guidelines in virtually every hospital in the world. The sound levels, which typically range from L_{eq} values of 50-75 dB(A), are now sufficiently high that speech interference levels (SII) suggest speech recognition at normal vocal levels is typically fair to poor, a concerning result given the tradition of transfer of important medical information orally and the likelihood that patients in hospital are also compromised medically (4-6).

Although somewhat less obvious from the literature, many studies of noise interventions at hospitals have found that traditional acoustic measures such as the L_{eq} are poor indicators of perceptions of change in the acoustic environment. The L_{eq} and similar measures average over time and frequency and are ill-suited to the hospital environment, with its rare moments of quiet and frequent peaks in the sound level. Attempts to find measures that better relate the sound level to perceptions have focused so far on the occurrence rate, defined as the fraction of time the level (usually peak or maximum level) is above a specified value. The occurrence rate, which we write as OR(N), was built upon traditional levels such as the L_1 and L_{10}, and is 100% at low levels (low values of N) and 0% at high levels. It was first introduced by Ryherd et al. (7) and later more fully discussed and used by Williams et al. (8) and Okcu (9). The OR(N) seems to correlate better with perceptions of hospital noise, with noise interventions that lower the occurrence rate faster as level increases perceived as acoustically improved. As an expansion of this metric for hospital environments, Bliefnick developed secondary occurrence rate metrics and found correlations between the occurrence rate range and patient satisfaction (10).

2.1 Soundscape Analytical Approaches

Starting in 2012 a number of researchers have studied hospital environments using the same techniques as were used earlier to study the complicated interactions between sound and human reactions in urban environments. These studies have significantly added to our knowledge of the hospital soundscape.

Mourshed and Zhao studied design factors in hospitals with the aim of determining which architectural features most related to satisfaction with the facility and delivery of safe care for patients (11). They analyzed the results of their questionnaire given to medical staff using principal component analysis and found three significant dimensions: spatial, environmental and maintenance. Overall they found cleanliness to be the top feature of concern for hospital staff, followed by air quality, then noise, and then thermal comfort.

Mackrill et al. used soundscape analytical approaches to study the noise in a cardiothoracic ward (12-14). These authors identified sound sources mentioned most often by hospital staff and patients and then conducted a listening test using the most important of these sources, asking participants to describe how the sounds made them feel. Remarks were used to generate bipolar scales and principal component analysis used to determine significant dimensions. They found two significant dimensions: relaxation and understanding, with understanding relating to the extent to which participants comprehended the need for the sound, and with relaxation accounting for more than four times the variance of the understanding dimension. Finally, based on the results, these researchers studied the impact of a noise intervention designed to produce greater calm and relaxation, namely the introduction of nature sounds for masking. They found that introduction of nature sounds was far more effective in improving the hospital soundscape than was traditional acoustic masking noise.

2.2 Alarm Noise

One of the key acoustic challenges in hospitals comes from the constantly sounding alarms. Alarms are specifically made to grab one's attention and are intended to indicate a situation that must be dealt with urgently. As analyzed by Busch-Vishniac, the literature suggests that alarms sound over 130 times per day per person in hospital in the US, with it not unusual for patients in intensive care to produce alarms at 2-5 times that rate (15).

Alarms have been established as one of the more irritating and disruptive sound sources in hospitals, affecting not only patients and their visitors, but staff as well. The strong bias in favor of false positive alarms rather than false negative alarms has created a situation in which it is estimated that over 90% of clinical alarms result in no action being taken. Further, clinical alarms are difficult to localize being largely pure tones, and very hard to distinguish from one another. Thus they provide caregivers with little information about location (patient) or the nature of the problem. Yet in spite of the constant sounding of alarms, their failure to sound or the failure of clinicians to respond to them has been shown to cause enough medical problems for patients (including death) that the Emergency Care Research Institute listed clinical alarms as among the top few medical hazards in years 2011-2014.

2.3 The Impact of Hospital Soundscapes on Staff and Patients

The most studied medical staff in hospitals are nurses, who are not only the majority of the medical staff but interact most closely with patients. Nursing in hospitals is a very stressful occupation, marked by burnout, large employee turnover, and a higher than normal rate of addiction, depression and suicide. Clearly the soundscape in hospitals contributes to the stress but our knowledge of the precise interactions is quite limited.

Topf reported one of the first studies linking noise to stress in nursing staff in hospitals (16). She showed that self-reported sensitivity to noise correlated with similar reports of stress-related symptoms. Morrison et al. later conducted a more nuanced study that showed elevated levels of cortisol, a known stress indicator, correlated with periods of increased sound levels (17). More recently, Ryherd et al. surveyed nurses in a neurological intensive care unit and found that the overwhelming majority (91%) reported that noise negatively affects them in their daily work (7). We conclude from these studies that noise is certainly a stressor to nurses.

Beyond stress, concerns for clinical staff include noise-induced hearing loss and impacts on task performance. Although noisy, hospitals generally don't present a level of noise sufficient to cause hearing loss. The exception to this rule is the operating room, where peak sound levels have been shown to be over 120 dB(C) on occasion. As Kracht et al. showed this is particularly a problem for neurosurgery and orthopedic surgeries (18). The impact of noise on performance is not clear based on research to date, with some results indicating performance is independent of noise and others suggesting that individual preferences for quiet play a role in determining whether noise impacts performance.

The impact of hospital soundscapes on patients has generally focused on sleep and other physiological measures, and psychological measures. One of the first studies linking sleep physiological measures to sound on the hospital unit was conducted by Gabor et al. and showed that only about 20% of patient arousals could be linked to noise events (19). More recently, the Sound Sleep Study by Buxton et al. found that as sounds got louder they were more likely to result in patient arousals (20). Further, they found that heart rate increases correlated with arousals, particularly during REM sleep. The sound sources most likely to arouse patients were alarms and ringing phones although self-reports of sources that awakened patients were not well correlated to these actual arousing sounds.

In addition to sleep, there are a few studies that have considered other physiological impacts of hospital soundscapes. For instance, Hsu et al. studied patient physiological measures as a function of sound levels and found increasing sound levels correlate with increases in patient heart rate respiration rate, and systolic and diastolic blood pressure, and a decrease in blood oxygen level. Patients exposed to sound levels over 50 dB(A) were found to have a 22% risk of having an increased heart rate (21).

There are fewer psychological studies of patients exposed to hospital soundscapes than physiological studies. Research in this area has tended to concentrate on the impact of music and patient perceptions of wellbeing. For instance, a study by McClurkin and Smith showed that listening to as little as 15 minutes of music by preoperative patients can significantly reduce patient anxiety (22). This result might well correlate with the soundscape studies that found the most important dimension for the hospital soundscape to be relaxation.

Patient wellbeing is measured using the Positive and Negative Affect Schedule (PANAS). Cunha and Silva studied the link between wellbeing and sound levels and found statistically significant correlations between them, with higher noise levels linking to a decreased sense of wellbeing (23). More recently, Bliefnick showed that listening to hospital sounds for 30 minutes was sufficient to reduce listening participant mood (10).

3. RESEARCH QUESTIONS TO PURSUE

While the research literature on hospital soundscapes is growing significantly, almost all studies rely on objective measures from a small number of units in, at most, a couple of hospitals. This makes it very difficult to generalize results except at a very high level, and rarely produces information that can be used directly to suggest useful noise interventions. Thus, a first step in increasing our knowledge of noise sources that help form hospital soundscapes would be to gather information that is as independent as possible of specific location – i.e. to gather sound power measurements and directivity in frequency bands for common sound sources such as medical equipment (e.g. cardiac monitors and ventilators), system equipment (e.g. floor cleaners and motorized doors), external sources (e.g. helicopter landings and takeoffs). By adding these to sound sources that are somewhat known (e.g. human speech and telephone ringing) we can build the important components of a hospital soundscape. Given advances in acoustical modeling of spaces, this would permit us to study the relative impacts of various noise sources and hospital geometries through simulation. Results would then apply more universally than current studies of a given geometry.

Additionally, it would be quite useful to pursue further studies of objective measures and how they correlate with subjective assessments. Again, through simulations using room acoustics programs, we might be able to determine the sensitivity of various measures such as the occurrence rate in predicting perceptions.

A clearly underappreciated problem in hospitals is speech intelligibility. This is an area well deserving of much greater attention. Starting with straightforward research, it would be useful to have a broader range of SII studies (more units in more hospitals) from which to draw conclusions. Additionally it would be useful to determine the extent to which patients and their caregivers are aware of the speech recognition challenges in the hospital. Progressing from that, it would be useful to identify the sound sources that most cause interference with speech intelligibility as this would identify prime targets for remediation.

3.1 Soundscape Analytical Approaches

While recent work using sophisticated statistical and semantic approaches to characterize soundscapes is transformative, the work is still in its infancy. We not only require more studies of units using such approaches, but also work to determine how well conclusions drawn from one study or unit apply to others. For instance, the work by Mackrill and colleagues considered a single cardiovascular ward in a single hospital. Would the same approach of introducing nature sounds to mask noise work as well in other units? Further, are there other interventions that would increase the sense of relaxation/calm and thus produce improvements in soundscape perceptions? A particularly interesting aspect of this work would be to investigate the interactions between acoustics and other sensory triggers (lighting or wall art for instance) to determine whether calming interventions need to be acoustic in order to produce improved acoustic perceptions.

Work to date on hospital soundscapes has effectively lumped staff and patients together, but another interesting question is whether these two groups truly respond the same to the soundscape or differently. If there are significant differences, why do these exist and what interventions make the most sense for each group? Similarly, are there interventions that are more appropriate for young patients and interventions that are best for older patients based on soundscape analysis?

As a broader view, it would be very interesting to determine how hospital soundscape preferences relate to those found in homes and other work environments. Is there a universal acoustic goal, for instance, for what people prefer in the space where they live or work? To the extent that we see distinctions in places used in various ways, how do we understand those differences?

3.2 Alarm Noise

The hospital soundscape certainly could be improved by reducing the number of clinical alarms and changing the sound they produce. There are many issues with use of alarms that suggest further avenues for research. Currently alarms sound not because of a medical diagnosis (as in stroke or heart attack) but rather because a physiological measure, such as blood oxygen saturation level, violates an established threshold. Additionally, we have not made clinical alarms smart even though we have the technology to do so. As a result we encourage multiple independent alarms to sound, sometimes producing conflicting information and sometimes producing an alarm cascade with many alarms sounding simultaneously but all indicating a single medical problem. 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 also are a host of questions relating to acoustic alarms themselves. A basic question is 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 being pursued by Edworthy and her collaborators (Edworthy and Hellier 2006 for example (24)). Further, it is worth considering whether there is a means to standardize alarms so that there is a single sound either for a given situation (as in a cardiac lead has failed), or a given level of urgency, or a given sort of medical device (as in an infusion pump). To date, medical equipment manufacturers have resisted standardizing alarms in any fashion and this has resulted in confusion and pandemonium.

3.3 Impacts on Staff and Patients

In spite of significant work, we have merely scratched the surface in terms of what we could know about the impacts of hospital soundscapes on staff and patients. To date, most studies have focused on a single impact such as sleep in the hospital or, occasionally, the impact of noise on physiologic measures of patients. What has been missing, largely because it is so difficult to determine, is a means of determining whether hospital soundscapes directly impact the medical outcomes of patients as measured, perhaps, by length of hospital stay, rate of readmission, or rate of negative outcome. The problem with such a study is in trying to conduct it opportunistically, i.e. trying to compare patient outcomes in existing hospitals that have different soundscapes. Naturally, there are many confounding factors in different hospitals that make it nearly impossible to single out the soundscape as the only changing variable. One possible means around this problem would be to conduct a small study using relatively quiet rooms for patients (such as sleep study rooms) and adding hospital soundscape noises with various levels through speakers. This would, of course, limit the sorts of patients that could be studied since quiet rooms are not typically outfitted with the sorts of equipment required for intensive care.

A similar problem exists for determining the impact of soundscapes on staff. Issues of the extent to which the soundscape affects stress or task performance are terribly difficult to determine using opportunistic studies. One might even argue that sound levels generally increase when there is more activity on the unit, and increased activity generally also means increased likelihood of stress, leading to the question of whether the soundscape is a consequence of the stress or the cause of increased stress in nurses. One could imagine a study using a hospital with very different units (perhaps one old and one new) and using the same staff to work a week in each while being monitored for stress and performance level, but even in new versus old hospitals the soundscapes don't vary much so it is unclear that this would uncouple the soundscape sufficiently from other variables, such as patient load and patient acuity at any specific time, to allow conclusions to be drawn.

4.0 CONCLUSIONS

While there is clearly great progress being made on understanding hospital soundscapes, there remain many unanswered questions. By addressing these questions we make it possible to set priorities for interventions to improve hospital soundscapes, with improvement being defined as making the environment more appropriate for healing and more pleasant for those who work in it.

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