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THE CHALLENGES OF NOISE CONTROL IN HOSPITALS

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Abstract

Over the past few decades, the noise in hospitals has been monotonically rising and is now sufficiently high that speech communication clarity is a concern. The reason hospitals are noisy is clear: the density of people is very high, most of them are ambulatory, and all of them communicate primarily through speech. Add to this mix alarms, a paging system, electronic equipment, mandated high rates of air flow and you have a recipe for acoustic pandemonium. Further, the ability to control the noise through traditional approaches, such as sound absorbing material, are limited by hygiene considerations. In this talk we characterize interior hospital noise and discuss approaches to its reduction. Our focus is on noise control strategies that will work long term because they involve objective changes in the facilities and sound environment rather than behavioral changes in people.

1. INTRODUCTION

While there are many venues in which noise control is a significant issue, hospital interior noise control is one of the most interesting. The noise in hospitals has been understood to be the leading cause of irritation of patients for years [1,2]. It is also linked to nursing staff burnout [3]. However, what is more concerning is that hospital noise seems to represent a significant safety issue. Pharmaceutical errors occur on the order of 4 million times per year [4], and these errors often result from noise and cause significant harm (sometimes death).

Hospitals rely on auditory communication to an unusual extent compared to other businesses. Doctors typically communicate with medical staff via rounds and spoken orders. Patients and families are questioned and informed via conversations rather than written material. Urgent, life-threatening situations are often signalled through overhead paging and audio alarms. This heavy reliance on auditory information flow both causes noise problems in hospitals and is impeded by the ambient hospital noise. Thus, there is good reason to control the noise in hospitals.

This article describes current state of noise in hospitals, focusing on recent noise measurements made at Johns Hopkins Hospital [5 -8], the top ranked hospital in the US. The results will be put in the context of speech communication reliability and of the special challenges that face hospitals (such as mobility of noise sources, personnel turnover, and infection control). Interventions that have met with success will be discussed including the elimination of overhead paging in favor of personal communication units, and the introduction of sound absorbing material in public spaces.

2. THE CURRENT STATE OF NOISE IN HOSPITALS

While noise in hospitals has long been recognized as a major complaint of patients, staff, and visitors, there have been few studies that have looked at the issue in depth. Further, the vast majority of the studies that have monitored noise contain a systematic error stemming from the assumption that one can simply average decibel measures of sound. Figure 1 shows a compendium of the results of the hospital noise studies we found that present their data in A-weighted levels – either all of the data or a correct logarithmic average [9-11]. This figure is an update to the version found in Busch-Vishniac et al. [5]. The results shown here provide the average equivalent sound pressure level in dB(A) re 20μPa (data point), or the entire range of data (error bars) depending on how it is presented in the study. Also shown in Fig. 1 is the best straight line fit to this data and the World Health Organization (WHO) recommended upper limit for sound pressure levels in patient rooms [12].

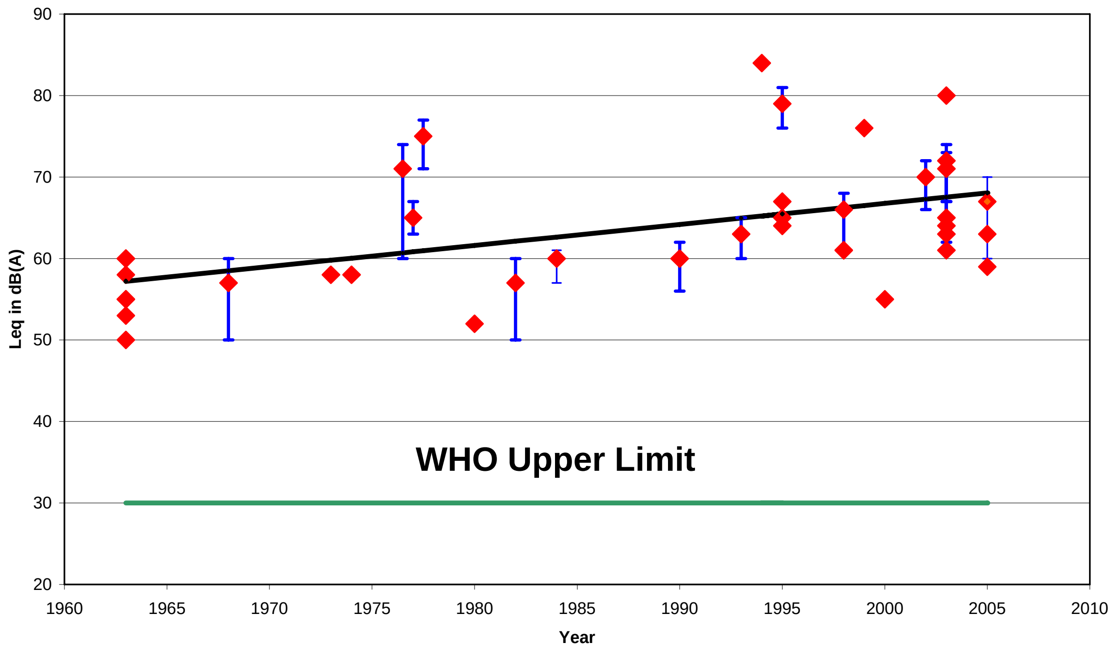

Figure 1: Equivalent Sound Pressure Level in dB(A) as a function of the year of publication of the study. Also shown are the WHO recommendation for maximum sound pressure level in patient rooms, and the best straight line fit to the data.

There are a few items of interest that can be gleaned from Fig. 1. First, it is clear that the average sound pressure levels in hospitals are rather high and have been for decades. We find no hospital that comes close to meeting the WHO recommendation for noise in patient rooms. It is also clear that sound levels in hospitals have been rising monotonically since

1960. The straight line fit to the data in Fig. 1 yields an increase of about 0.26 dB(A)/yr from about 57 dB(A) in 1963 to 68 dB(A) in 2006. The current sound pressure levels exceed those quoted by WHO for speech at normal levels, an issue we consider further below.

The results in Fig. 1 are relatively tight when one considers that the data include hospitals of various types (small community to major research facilities), different sorts of units (e.g. psychological wards, intensive care units, operating rooms, etc.), locations dispersed throughout the world, and presumably different sound level meters with settings on *either* fast or slow. We conclude from the fairly tight sound level distribution that noise is ubiquitous in hospitals and similar in form. If a means is found to solve the problem permanently at one institution, it is likely to apply to most or all hospitals in the world.

3. NOISE IN JOHNS HOPKINS HOSPITAL

The Johns Hopkins Hospital (JHH) in Baltimore, Maryland is among the top hospitals in the world. It is a large research hospital serving an urban community. Like many of its sister institutions, it is currently expanding its physical plant dramatically.

Over the last few years we have characterized the sound in JHH [5-8]. We have focused on in-patient units and used a standard protocol in each: We measure short time (one minute) average equivalent sound pressure levels (Leq) in many locations on each unit including patient rooms, hallways, and nursing stations. We also monitor the level in at least three locations in a unit as a function of time over a 24-h period, averaging over half hour time periods.

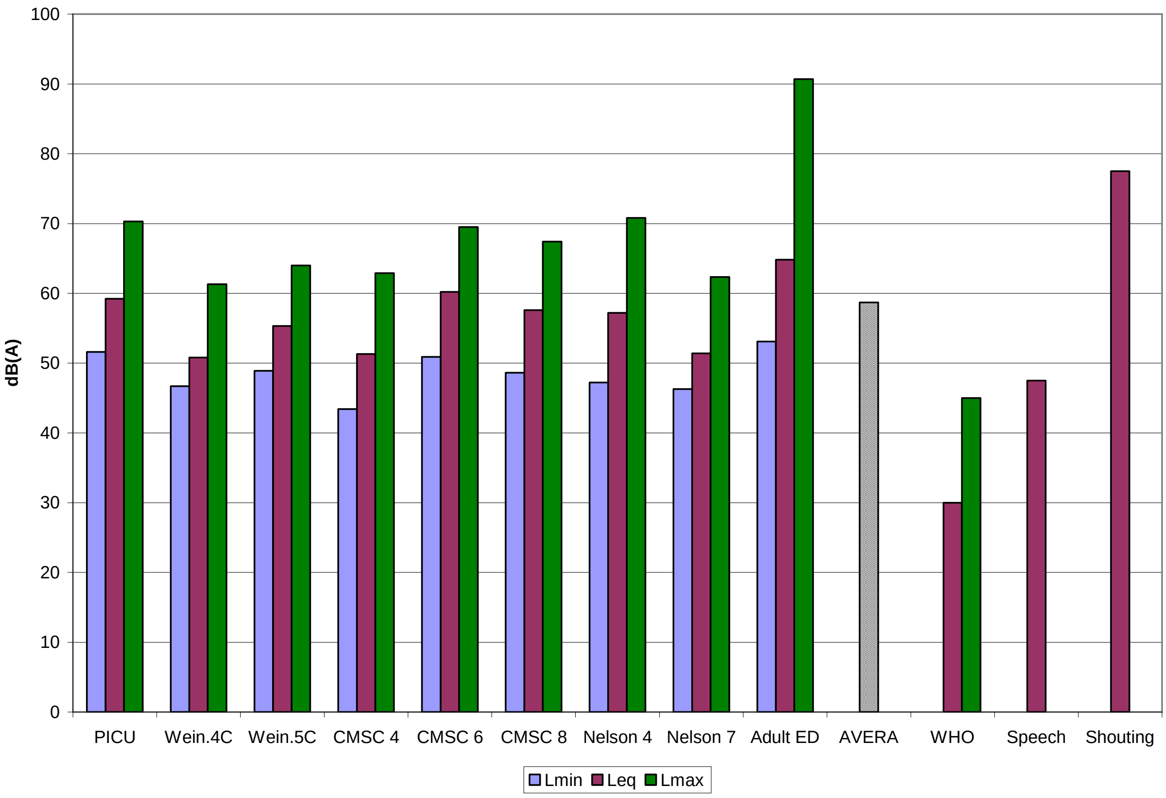

Figure 2: Sound pressure levels in various units of JHH, including old buildings and new. Also shown is the hospital average Leq, the WHO recommended maximum levels, and typical levels for speech and shouting.

Figure 2 shows a summary of results for a variety of units. Here the Pediatric Intensive Care Unit is labelled PICU. All other names refer to buildings except for the Adult ED which is the Adult Emergency Department. Figure 2 shows that the average equivalent sound levels vary from 52 to 65 dB(A) at JHH with the Adult ED being the most noisy and Nelson 7, CMSC 4, and Weinberg 4C being the quietest. There is no pattern of new buildings being generally less noisy (Weinberg 5C and 4C are new units while Nelson, CMSC, the PICU, and the Adult ED are in older buildings). In all cases, the Leq measurements exceed the level for normal speech, and the maximum levels in the Adult ED exceed those for shouting. These results suggest that people in JHH must raise their voice to be heard clearly, and that even this might be ineffective on occasion in some locations.

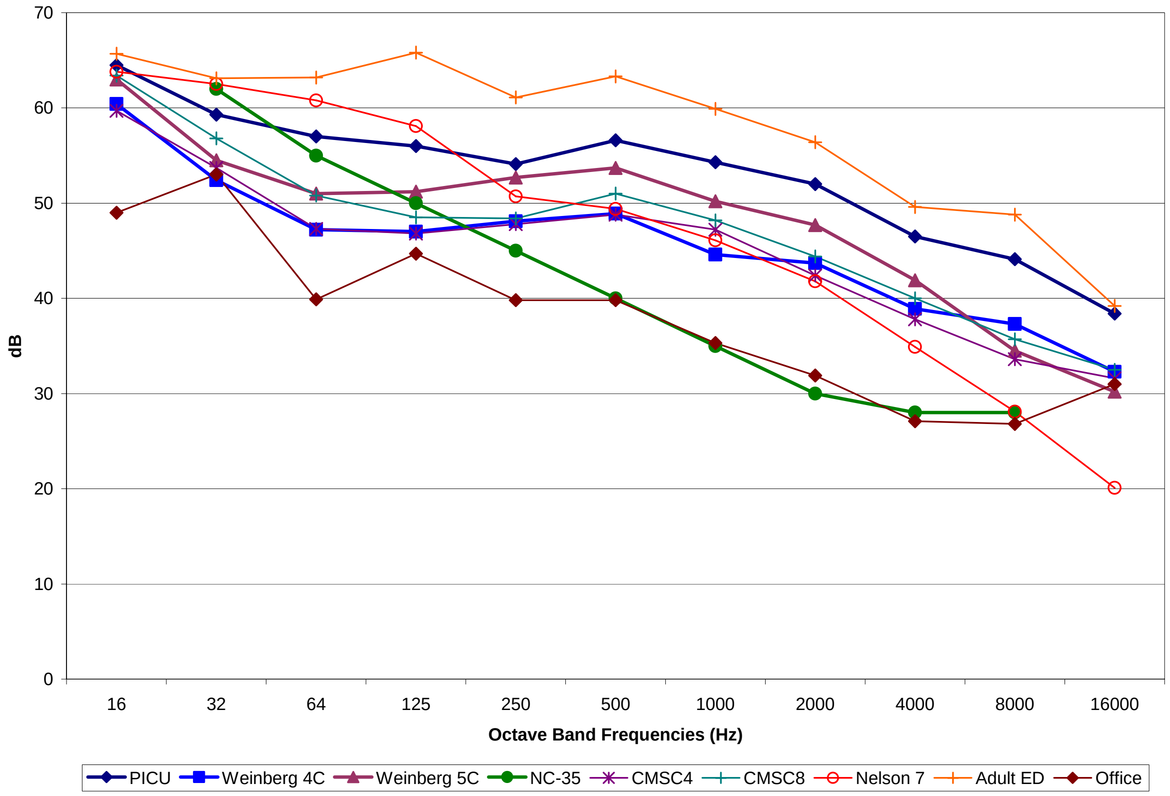

Figure 3: Octave band sound spectra on various units of JHH. Also included are the NC-35 curve and the spectrum in an office of JHH with the door closed.

Figure 3 shows the sound spectra in several units in octave bands. Also shown for comparison purposes are a hospital office and the NC-35 spectrum (often used for building construction design specifications). Note that the JHH units show a strong similarity, with a great deal of sound concentrated in the speech bands of 250 Hz – 2000 Hz. By comparison, the hospital office and the NC-35 curve drop off with increasing frequency much more quickly.

It is easy to understand the concentration of noise in the speech bands when one considers normal hospital operations. Hospitals have a very high density of people, most of whom are ambulatory, and nearly all of whom are talking most of the time. Although there are certainly other sources of noise – alarms, pneumatic tubes, carts, pumps and ventilators – the average background noise is dominated by air handling and speech.

Figure 4 shows the sound in several units of JHH as a function of time of day. Each of the data points in the figure are time averages over 30 minutes. There are two items of interest in this figure. First, it is hardly possible to tell whether it is day or night by looking at the sound levels on any of the units shown. Of the five units, only CMSC4 and Weinberg 5C, a children's medical/surgical unit and an oncology unit, show any sustained period of relative quiet and it is only 3.5 hours long in each case. The other units show no periods of sustained quiet. In the case of the Adult ED and the PICU, the levels show sustained noise over the entire 24-h period with little variation from period to period.

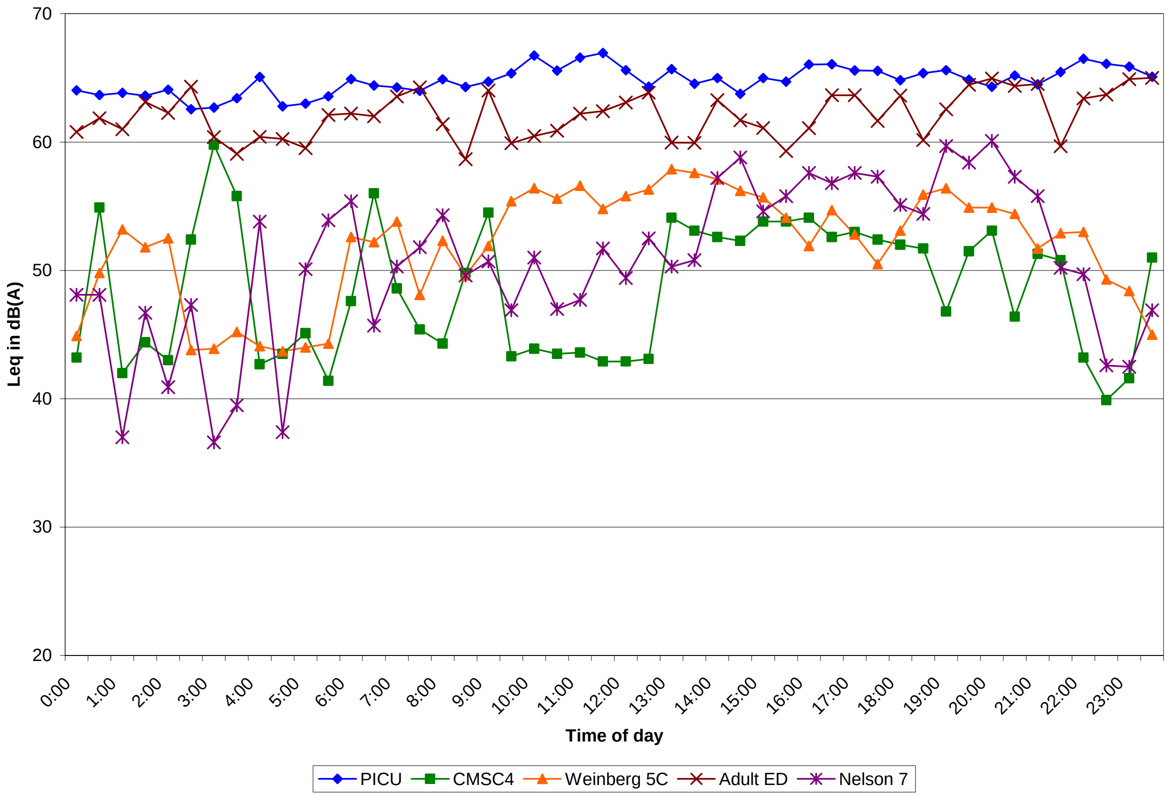

Figure 4: Leq versus time of day for five different units of JHH.

Taken together, Figs. 2-4 show JHH to be an environment in which there are typically sustained levels of noise over a broad spectrum. These results certainly explain patient complaints that it is "too noisy to sleep" and frequent staff complaints that it is "too noisy to think." Both of these comments reflect problems in all hospitals throughout the world and suggest that a real, lasting solution is required.

In addition to monitoring noise on in-patient units, we have studied the noise in operating rooms of JHH [8]. By monitoring the sound pressure levels in each operating room (OR) for a 24-h period we were able to determine ambient noise levels and average and peak levels associated with surgical procedures. Table 1 shows the average Leq measured for various surgical specialities. Also shown are the range of highest peak sound pressure levels found during surgeries.

There are a couple of interesting points raised by these results. First, we note that all surgery specialities seem to be noisy, but perhaps less noisy than prior literature might suggest [13 -15]. Further, the variation in Leq for different surgical specialities is not large, spanning a range from 58 – 67 dB(A). Second, the maximum peak levels observed during surgery are extremely high, with levels above 120 dB (flat) not unusual.

By considering the peak and average sound pressure levels, it is possible to develop a pattern which distinguishes various surgical types. Gastrointestinal and thoracic surgery are relatively quiet while neurosurgery and orthopaedic surgery have sustained high levels of sound. Cardiology surgery has brief periods of extremely high peak sound pressure levels but is generally quieter than orthopedic surgery.

Table 1. Equivalent and peak sound pressure levels for various surgical specialities.

Speciality	**Average Leq in dB(A)**	**Range of max. Lpeak in dB**
Cardiology	63.5	98-123
Gastrointestinal	63	89-112
Neurosurgery	64.5	103-115
Orthopedics	66.5	102-121
Otolaryngology	65	106-115
Pediatric Plastic	65	101-128
Thoracic	63	103-107
Urology	63.5	102-122

4. SPEECH INTELLIGIBILITY

Given the nature of hospitals, it is imperative that clear speech communication be the norm. There are a variety of ways to evaluate the probability of clear speech communication. We have opted for the Speech Intelligibility Index (SII). This index is easily computed given measurements of background sound pressure levels, and there is a long history of relating the SII (formerly known as the articulation index) to the fraction of words or sentences understood [16]. However, the SII does not take reverberation into account and hospitals are highly reverberant spaces. Thus, our results here should be viewed as *best case scenarios*. The Speech Transmission Index (STI) does include reverberation, but we were without the equipment needed to measure the STI. Further, we thought it might be needlessly disruptive of normal business in the hospital.

Figure 5 shows the fraction of time that speech communication is likely to be unacceptable, poor, good, and excellent in four areas of JHH using a normal voice level. This result was obtained as follows. Using octave band level measurements of noise, the SII was calculated as a function of time. Each data point represented a time average over a significant period of time (5s to 30 minutes) so peak levels of noise were not captured. A judgement was made that an SII below 0.4 is unacceptable, from 0.4 to 0.6 is poor, from 0.6 to 0.8 is good, and above 0.8 is excellent. This judgement is based on quite old studies of percent sentence intelligibility when presented to listeners for the first time [17]. It once again represents a *best case scenario* given that the population of patients in hospitals is more likely to be ill, sedated, or hard of hearing than the population at large. Further, medicine is rife with unusual terminology which likely lessens word recognition.

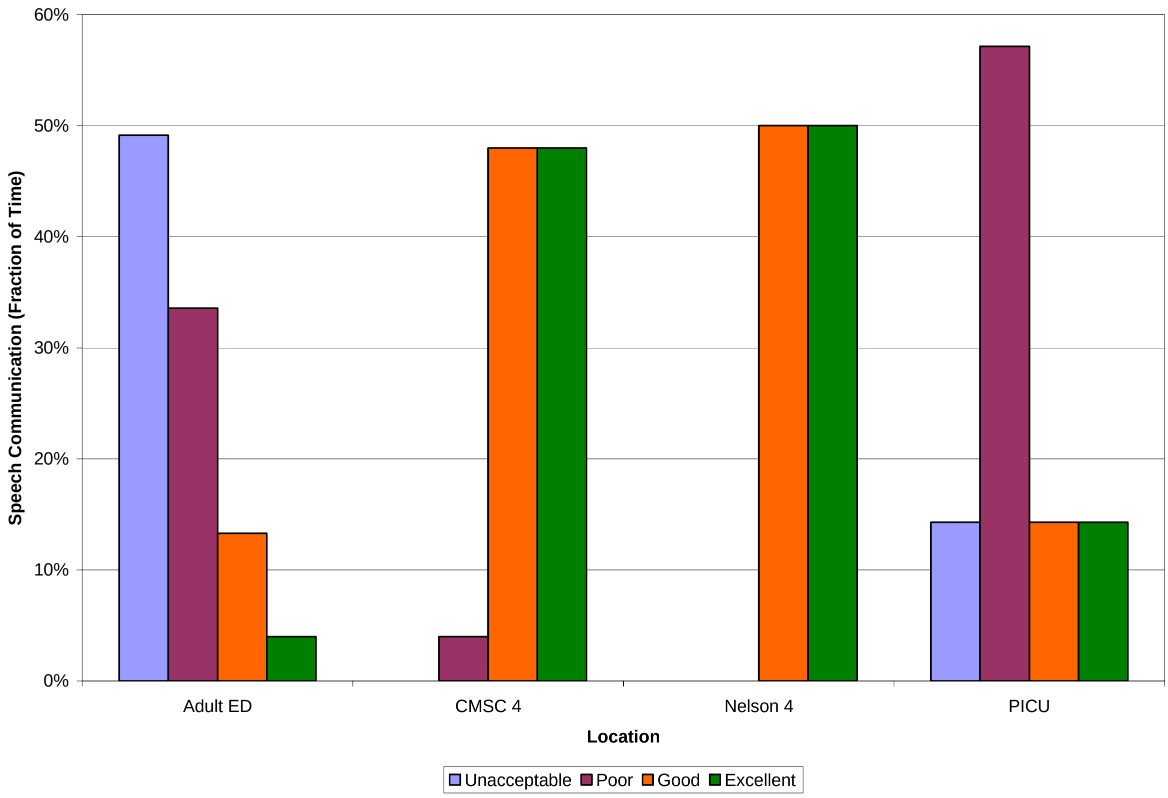

Figure 5: The fraction of the time speech communication is unacceptable, poor, good, or excellent as based on the SII in four locations of JHH. Results are for normal voice levels.

The results of Fig. 5 are quite troubling. In none of the four areas we considered was speech communication likely to be excellent more than 50% of the time when using normal vocal effort. Indeed, in the Adult ED and the PICU, the speech communication at a normal voice was overwhelmingly likely to be poor or unacceptable. This leaves only two possibilities – either speech communication in hospitals is not clear, or people must speak with a raised vocal effort. Since increased vocal effort is accompanied by fatigue, the latter option, while an improvement over the former, is worrisome.

Over the last several decades the fraction of our gross national product spent on medicine has risen monotonically. With a hope for greater efficiency and fewer errors, there is now a great push to create a digital hospital – i.e. a hospital in which as many functions as possible are computerized and automated. For instance, instead of a written chart for each patient, the newest trend is to use a PDA for each person with wireless connection to a central computer. In this manner doctors can submit orders directly to a pharmacy or laboratory without the intermediate step of transcribing.

While there are many technological challenges in the concept of the digital hospital, one key issue that has not yet been appreciated is that hospitals are so noisy that the current generation of speech recognition equipment can not work reliably. This means that noise reductions will be necessary not only to improve person to person speech communication, but also to improve person to computer speech communication.

5. NOISE INTERVENTIONS

Because of the advances in medicine and the gradual aging of the population, there is currently an enormous construction boom for hospitals. In the US alone, it is estimated that over $20B will be spent in this decade constructing new hospitals [18]. Thus, there is an unusual opportunity (some might say imperative) to find effective noise interventions for hospitals. As in other aspects of noise control, it is generally far less expensive to design new facilities to be relatively quiet than to retrofit them after they are opened and found to be unacceptably noisy. This is particularly true for hospitals, because they generally can not be taken off line while renovations are made. Instead, it is typical to limit renovations to small areas of a hospital and to enclose them to reduce negative impacts on air quality while work is ongoing.

Hospitals are generally difficult venues for noise control interventions because of a number of considerations imposed by their primary function. For instance, the regulations for hospitals mandate a very high air flow rate in order to help remove pathogens from the building air. While new hospitals can be designed to accommodate this high air flow, most hospitals are renovated many times over their life and air handling systems are frequently over-burdened rather than replaced, causing increases in air handling noise. Further, infection control also makes it highly unlikely that air ducts can be lined with sound absorbing material.

Hospitals also have very strict standards for flammability, cleanability, and smoke generation of materials. These have become serious impediments to acoustical treatments, as many of the common sound absorbing materials have tiny holes. It is feared that these holes could trap bacteria, particularly since these absorbing materials are not easily cleaned. As a result, many new hospitals are either eliminating sound absorbing ceilings, or seeking new materials capable of meeting all of the hospital construction standards. We know of only one company currently making sound absorption panels suitable for hospitals.

As mentioned earlier, hospitals also have a much higher reliance on oral communication than is normally found in other businesses. Further, many of the noise sources are mobile, so conventional treatments may not be appropriate. Complicating this a bit further is the enormous turnover of people in a hospital. Thus, while medical professionals are in hospitals routinely, patients and their visitors are infrequently in hospitals. This makes it very difficult to accomplish significant noise reduction through administrative means – i.e. through requesting that people speak softly, wear soft soled shoes, etc.

Within this context, we have successfully demonstrated two interventions in hospitals: the elimination of overhead paging in favor of personal insonification devices, and the placement of new sound absorption materials in the public spaces of an oncology unit. These are each described below.

5.1 Elimination of Overhead Paging

One of the unique characteristics of hospitals is the prevalent use of overhead paging day and night. While overhead paging serves an important purpose in hospital settings, it also insonifies a large population rather than the one person or few people who are meant to receive the communication.

When we first visited the JHH PICU, we were struck by the pandemonium. Each patient was surrounded by a plethora of equipment most of which was emitting noise. Additionally, the overhead paging system was in use roughly every five minutes, with each message lasting typically under 30 seconds. The public address system in use was so loud that it was not possible to speak over it in most locations.

The alternative to an overhead paging system is the use of personal communication units. These may take a few forms: pagers, cell phones, and speciality devices. Medical pagers are ubiquitous and generally display a number to be called to get a message. While in heavy use in hospitals, these devices are not ideal because they require medical staff to move to a telephone in order to receive the message. Thus, they require a series of steps to finally link people who need to converse. Cell phones have also been tried as a replacement for overhead paging in hospitals, but these are less than optimal because they can be hard to access while in the midst of a procedure and because they are used frequently for other purposes so hospitals often must resort to either leaving a voice mail or using an overhead page. An alternative to these is a personal unit complete with microphone and speaker which can be worn. We know of only one such device available commercially, and that is produced by Vocera Communications [19].

The Vocera device is a badge which is either pinned to clothing or worn dangling around the neck. Communication via wireless networks to a central server completes the system. A single touch to the unit is required for instigating or responding to a call. This is important because it makes it more feasible to respond to an urgent message during a procedure and minimizes the likelihood of contamination of the device.

A decision was made to try the Vocera communication system for a limited period of time. Because the badges are closer to each person's ears than the typical overhead speaker, these devices produce noticeably lower sound levels in their immediate vicinity. However, the greater gain is that only a few people are insonified rather than a large group. A pilot study of personal communication units was conducted in the JHH PICU and a post implementation survey done of staff. Figure 6 summarizes the results obtained after starting the Vocera pilot study, which are overwhelmingly positive. However, more telling then these results were the actions taken by the staff. When the time came to end the pilot study, they refused to give up their personal communication units, opting instead to purchase them.

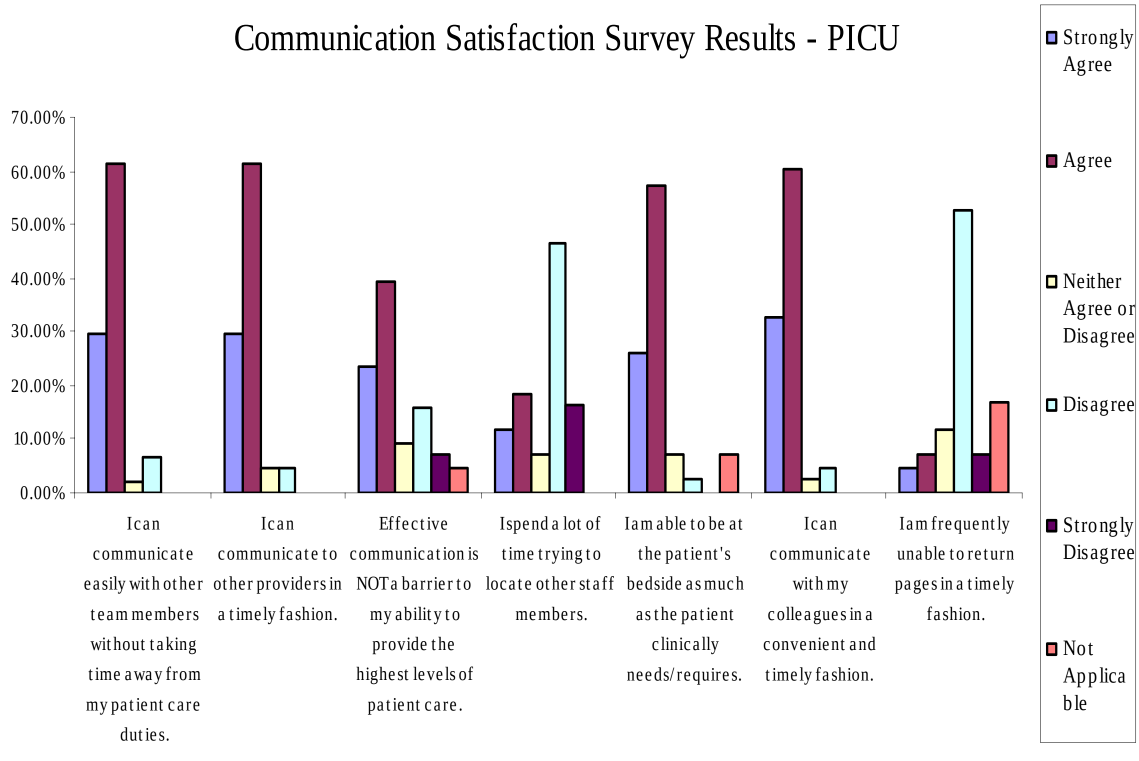

Figure 6: Results obtained using personal communication units to replace overhead paging in JHH PICU.

5.2 Addition of Sound Absorption

A second noise intervention was undertaken for the hematological oncology unit in the Weinberg Building (5C) of JHH [7]. This unit has patients with severely compromised immune systems. Hence there was no acoustical ceiling and every surface is required to be washable.

Our initial involvement with Weinberg 5C was prompted by staff complaints about noise. We were asked to look at the situation and visited the unit several times to make measurements. It became clear that the lack of sound absorption in any of the public spaces (hallways and nurses station) made the unit highly reverberant. Additionally, the space was poorly designed from the perspective of noise. It has four equal length hallways which form a square. At three of the hall intersections, there are cabinets oriented at 45 degrees which very efficiently reflect sound from one hall to another, forming a wonderful waveguide. The nursing area cuts a diagonal through the interior of the square formed by the halls and patient rooms are on the outside of the halls. At each end of the nursing station are large "circular architectural features". These exist purely for visual aesthetics, and tend to focus and amplify sound at the nurses station.

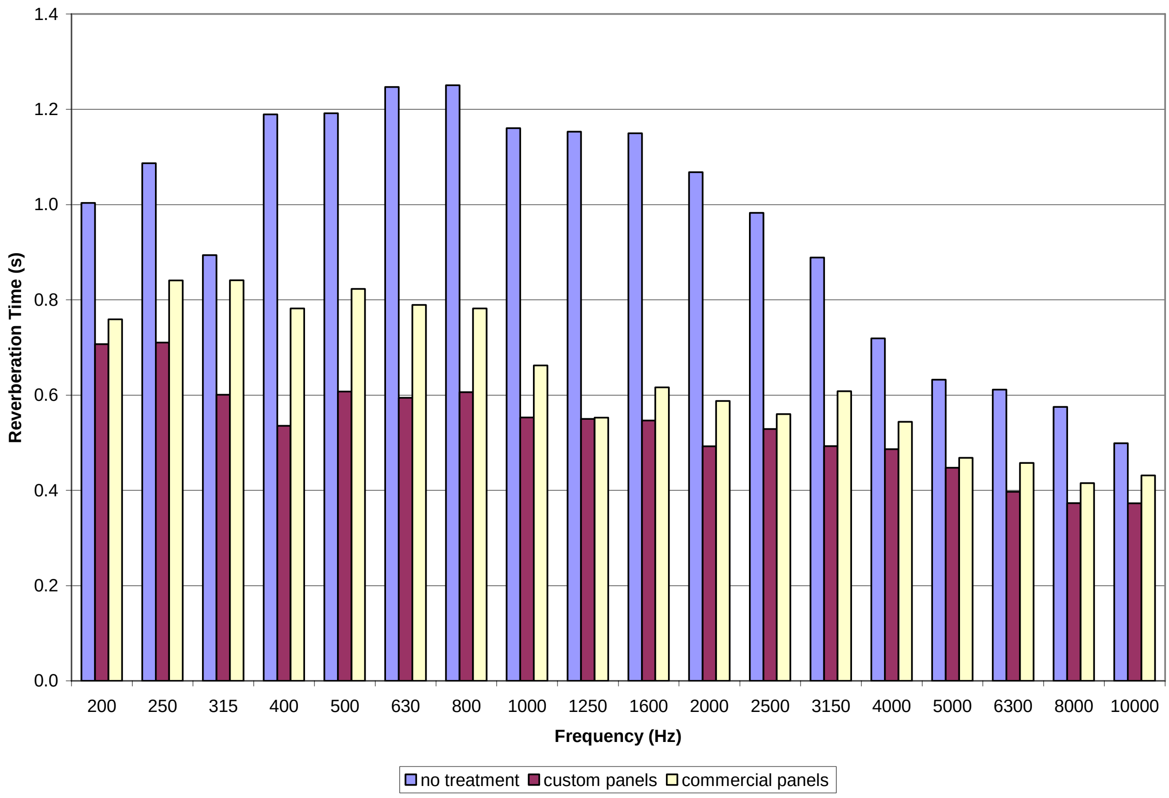

Figure 7: Reverberation time in third octave bands measured in halls of three units on Weinberg 5: one with no sound absorption added, one with custom sound panels, and one with commercial sound panels.

We opted to treat the noise problems in Weinberg 5C by making sound absorption panels to put on the ceiling and high on hallway walls. The panels were made from two inch thick, uncompressed fibreglass. They were covered with an antibacterial fabric and then installed with Velcro to avoid any need for drilling holes in an active unit. Overall, less than 50% of the ceiling area and a very small amount of the vertical walls in the halls were covered. As a result, we measured a reverberation time drop of more than a factor of two, and an ambient sound pressure level drop of more than 5 dB(A). Figure 7 shows the reverberation time in three units of Weinberg 5: the unit in which we installed our custom panels, an identical unit in which we installed a commercial product which is ¾ in thick in precisely the same pattern as in 5C, and another identical unit with no sound treatment.

The results of Fig. 7 show that both the custom panels and commercial panels make a large difference in reverberation time on the units. The custom panels work better in every band, and are particularly better than the commercial panels at low frequencies. This is important in a hospital, where air flow is mandated to be quite high and there is usually significant low frequency noise.

A survey was conducted before and after the custom sound panel installation. Prior to installation, 83.3% of staff were dissatisfied with the effect noise had on their ability to communicate with health care providers and 91.7% were *dissatisfied* with their ability to hear clinical conversation during morning rounds. After panel installation, 91.7% of the staff were *satisfied* with their communication ability in every situation on the unit.

6. OTHER ISSUES

While the focus of our work has been on noise reduction, there are certainly other acoustical issues of interest in the hospital setting. For instance, new regulations regarding patient privacy have been enacted in many countries. In the US, HIPAA now mandates medical privacy for all individuals and this has been assumed to include speech privacy. Speech privacy in a hospital setting poses a very interesting challenge for the acoustics community. There is a significant literature on speech privacy in buildings, and the treatment of choice is to introduce masking noise. However, with levels already so high that speech communication is compromised, it is clear that masking noise is not an acceptable solution. It will simply force the sound level even higher and compromise speech comprehension further. Given this situation, it is not clear how to ensure privacy short of making all rooms single-patient rooms. Recent work by *** has cited single-patient rooms as the most important change that can be made to improve the acoustic environment for hospital patients [20]. It is clear that such an approach will also address the privacy issue and improve medical care because patients will be less likely to keep important medical information hidden.

A second issue that still needs to be addressed is the use of stereo sound in medical telecollaboration. As hospitals make greater use of technology and the need for remote collaboration increases, systems have been created that permit remote visual connection and monaural audio connection between spaces. This permits hospitals to eliminate the use of operating room theatres, with students moved to remote locations connected visually and acoustically. It also permits doctors in geographically dispersed areas to be consulted on challenging medical issues in real time. The additional bandwidth required for stereo audio rather than monaural is small and the improvements in virtual presence and sound source discrimination are substantial. Thus, there is a strong impetus to consider the challenges of stereo sound systems for hooking remote locations together. This includes the use of noise-cancelling microphone arrays, signal processing, and loudspeaker arrays.

7. CONCLUSIONS

Noise in hospitals remains a challenging problem with many, mobile sound sources and restrictions on interventions imposed by health concerns. Today's hospitals are very noisy and the trend is for increasing noise. This is a cause for concern given that the levels of today already suggest highly compromised speech comprehension if using a normal vocal effort.

There are interventions which promise to improve the soundscape in hospitals without requiring patients, visitors, or staff to change their habits. These include the replacement of overhead paging with personal communication units, and the addition of sound absorption in hospitals which meets stringent flammability, smoke generation and cleanliness standards.

Beyond relatively straightforward noise intervention strategies, what is currently needed is a research program to determine the most effective and efficient means of improving the acoustical environment in hospitals. It is important to establish the links between interventions, acoustical measures, and patient and staff outcomes. Until this action is taken, it isn't clear what acoustical measures are best at predicting patient and staff impacts. Once we know which acoustical measures best correlate with outcomes we can be more effective at crafting noise interventions which target those measures instead of simply seeking to reduce the average sound pressure levels.

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