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Increasing the Quality of Patient Care by Reducing Noise Levels in the Healing Environment

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Increasing the Quality of Patient Care by Reducing Noise Levels in the Healing Environment

A study of the noise levels at the West Roxbury, Massachusetts Veterans Affairs Hospital

An Interactive Qualifying Project (IQP)

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ABSTRACT

Increased efficiency in medical device technology has also led to an increase in overall noisiness of hospitals. The Boston VA Healthcare system has headed a project aimed at decreasing the overall noise throughout one of their hospital branches. The design team from WPI has decided to take their study a step further, and to analyze the noise associated with various alarms to better understand the phenomena known as alarm fatigue. Alarm fatigue is a desensitization of personnel to alarms that usually results in missed and ongoing alarms; it can effect both the caregivers as well as the patients themselves. Additionally, it was agreed that the noise levels in the CCU (Cardiac Care Unit), far exceeded *World Health Organization* and *FDA* recommended levels – suggesting the need to be further examined and potentially decreased by means of technological or commercial innovation. By the monitoring of patient room noisiness and the use of software data analysis techniques, the team could numerically describe how effective a change in technology, a change in the implementation of devices, or a change in the physical infrastructure of ceiling tiles, curtains, or monitors could be. The goal of the team is to provide the VA Hospital with convincing numerical evidence to justify a reduction of Sp02 threshold level, on a patient by patient basis. There have been numerous studies focused on reducing false alarms by a reduction of Sp02 threshold level, alarm time delay and alarm averaging techniques. We hope to provide the VA Hospital with the means to confidently apply modern technological techniques to their alarm policy to reduce alarm fatigue in the hospital environment.

INTRODUCTION TO PROJECT GOALS

The goals of this project are three-fold: to characterize sources of noise in the hospital environment, indicate noise sources that can be reduced or eliminated, and propose a set of solutions to increase acoustic comfort in intensive care units. The first of these goals requires the acquisition of noise data. By monitoring and recording sound levels, it will be possible to identify that a sound problem exists and to what extent it exists. This will also means the analysis of trends to discover when and where noise is most prevalent within the intensive care unit. After characterizing the noise within the intensive care unit, it will possible to identify large contributors to the overall noise level. This means not only the categorizing of noise producers but the exact functions that are producing noise. Once the precise sources of noise can be identified, solutions can be constructed that will remove o reduce the noise pollution from these sources.

The first step in the investigation of noise levels with the intensive care unit, in this case a cardiac care unit, is creating a noise profile for the unit. This means taking noise level recordings and analyzing them based on a variety of variables. The way this was done was with sound logging devices used to record decibel levels within the CCU over the course of many days. Three of these devices were placed within the unit at various locations in order to accurately understand the whole unit. These devices measured decibels at a rate of one measurement every second; these values were time and date stamped and saved to large spreadsheets on SD cards within the devices. At various times these SD cards were removed and the data on them retrieved. Since the sheer volume of this data makes it impossible to understand in any meaningful way, some analysis is required to see even basic trends. Thus the data is averaged in hour increments and plot with amplitude on the y axis and x axis representing time of day. This information can be divided based on different factors such as day of the week or based on the schedule of the CCU. Further data is acquired from Phillips software that is integrated with the alarms in the CCU and details each alarm that goes off within the CCU so it can be related to previously recorded noise levels to reveal how the alarms contribute to noise in the CCU. This data can then be related to human factors detailed by the nursing staff which will suggest how much the human actions performed in the CCU affect the overall noise level. Correlating these three sources of information suggest which factors create the largest contribution to the noise experienced in the CCU.

The three sources of data will give a great deal of detail to the broad picture of sound levels in the CCU. The goal is to narrow the search for noise pollutants from the general categories of alarms or human to the exact alarms or routines that produce noise. This means identifying the urgency of alarms between yellow and red so that excess nonessential alarms can be noted. The schedule of actions within the CCU will allow elevated noise averages by hour to be related to the activities that produce them. Not all noises are subject to change, however, and thus it is important to focus on sources of noise that it may actually be possible to change. Federal laws will prevent the change of some settings or thresholds while other may be at the will of the hospital's judgment. Therefore it is important to identify the sources of noise that may be changed and focus resources there.

Identifying these sources of noise and targeting them for change sets up the final stage of the project. Solutions must then be implemented that will reduce or remove the noise contributions of the factors. Solutions for alarms may include the changing of alarm thresholds in order to reduce the number of false alarms, however, such a conclusion could only be made is data were taken in relation to that particular alarm to relate how many of the signaled alarms were false alarms. Solutions in the human activities can be made more easily since they are less likely to endanger patients if made incorrectly. Solutions may be as simple as changing when an action is performed to minimize the impact on sleeping habits or the action can be performed in a different manner or with special care to avoid unnecessary disruptions.

Further data will have to be taken in the form of another project that builds on the research of this project. Such research could be done on specific alarms since background data has already been gathered. Alternatively the project could follow a similar methodology and structure to this project in order to analyze the impact of solutions proposed at the conclusion of this project.

CHAPTER 1: INTRODUCTION TO THE PROBLEM OF NOISE

We are working with Elena Simoncini and Margaret Byrne of the VA Hospital in West Roxbury to address the issue of noise within Cardiac Care Units (CCUs). The VA Hospital is a federally run hospital established by the Veterans Health Administration. The VA Hospital has discovered that noise levels within their units are too high and must be lowered in the interest of patient care. Noise levels can interfere with patient sleep which in turn can inhibit the healing process or can cause mental trauma over time. These noise levels may be a result of factors including alarms, staff, and machinery within the unit. As a hospital that works largely with veterans, they dedicate special attention to the elderly and those suffering from mental illness. These groups are two that are particularly susceptible to the effects of stress related to high noise levels. As of yet, the VA Hospital does not have conclusive evidence that would allow them to enact a serious change to their current procedures. Thus, we are working with the VA Hospital to investigate the sources of noise within their care units and attempt to provide solutions in whatever way possible. We intend to do this through the collection and analysis of data from the VA Hospital in conjunction with previously obtained data on the subject.

Through this project we are ultimately aiming to decrease the amount of alarm fatigue present in the Boston VA Hospital environment. By using experimental procedures to track and analyze alarm patterns present in the hospital we can pinpoint the main causes of false alarms in the hospital. We will draw conclusions between our findings and the findings of others in the field of hospital alarm fatigue research. We will do a feasibility study of alarm filtering techniques and other technological factors that can be employed by the VA Hospital to reduce the number of false alarms. Alarm fatigue is a highly studied topic by clinicians and there are numerous techniques available that lead to a decrease. Our group hopes to successfully apply some of these methodologies to the problems that are being encountered at the VA Hospital. We will report our findings to the VA Healthcare system with the hope that they will utilize our recommendations to decrease the overall noise levels in the hospital.

The overall process of our project begins and focuses extensively on the research and data collection of sound levels in the VA Hospital in West Roxbury, Massachusetts, and other similar hospitals in the surrounding area. As the project progresses it becomes increasingly important to accumulate educational research papers as a resource for our decision making and planning ahead. Chapter 2 of this report will predominantly focus on a review of our literature sources (some of which you will find at the end of Chapter 1 because we have already begun this process) and how they relate to our specific experimental findings. The third chapter in this research portfolio will take a look into our findings, the results of said findings, and an explanation &

analysis of our discoveries. We will describe our data and explain the process and instruments we used throughout our investigation, making sure to reflect upon the relationship between our findings and the findings of other sources. The fourth and final chapter of our portfolio will summarize our findings, suggest future improvements, and explain our limitations and shortcomings.

Chapter 2: Previous Studies on Hospital Noise

2.1 Introduction

The literature review is critical in determining what research has been done in the field of our project, in this case the research of noise in critical care units and the effect it has on the overall quality of patient care. We started with the knowledge that there would be many contributing factors to noise in an emergency care environment. Factors were expected to include hospital equipment, staff, visitors and environmental noises (doors, nearby roads, etc.). Our goal was to use the literature to narrow down the scope of our project in regards to the factors and gain some insight as to how to quantify each of these factors. The literature review is also imperative in the learning of standards that apply to our particular research. For instance we need to find standards that pertain to FDA approved noise levels in a hospital setting and noise levels are typically regarded to be acceptable to attain restful sleep. It would also be critical to find research beyond our ability to test; information like the affect noise has on patients in regard to mental well-being along with physical healing time. Going into our literature review these were some of the main points we intended to look at and information we deemed necessary to the successful creation of an experimental procedure and proper interpretation of the results of the aforementioned testing.

2.2 *Literature Review*

The occurrence of false and nuisance alarms in the hospital environment has continually been ranked one of the "Top 10" technology hazards by the ECRI Institute (Emergency Care Research Institute. Recent studies have pointed to the fact that over active alarms, and overall clinical noisiness, can lead to a decline in the recovery rates of patients and a decline in clinical attentiveness by nurses and doctors. Decreasing the amount of alarm fatigue in the hospital environment is a responsibility taken on by not only clinicians, but also biomedical engineers and industry leaders. In a study conducted by one emergency department, less than 1% of alarm occurrences were clinically actionable; suggesting that a large majority of alarms are unnecessary and may therefore be reduced to lower noise levels for patients and caregivers alike.

Over the past 45 years there has been a significant increase in sound levels apparent in hospitals around the nation. To add to this problem, it has been discovered that "many units exhibit little if any reduction of sound levels in the nighttime." The levels of noise apparent in the hospital environment may be detrimental to patients and care givers in more ways than simply the most obvious way (noise leads to lack of "peace and quiet" → disrupting). "There is evidence that the high sound levels in hospitals contribute to stress in hospital staff and a suggestion from one study that noise contributes to staff burn-out. Further, there is some evidence that noise negatively affects the speed of wound healing." (Busch-Vishniac, West, Barnhill, Hunter, Orellana,

& Chivukula, 2005). These arguments are very valid, and furthermore some may argue that the elevated sound levels may contribute to *medical errors* – instrument noise may interfere with communication attempts by caregivers, causing safety hazards from the inability to accurately comprehend what was being said. Overall, the sound levels in hospitals have several detrimental causations, which lead many professionals to argue for a more efficient system for the future.

In 1995 the *World Health Organization* published an article entitled, *Guidelines for Community Noise*, which attempted to regulate the "allowable" sound levels for hospitals. The article "recommended an L_{max} of no more than 40 dB at night. They also suggest a patient room $L_{average}$ of no more than 55 dB during the day and 35 dB at night…"[3] Current data samples from hospitals around the United States show that average decibel levels in patient rooms exceed these "recommendations", therefore, action must be taken in any way possible to provide the best possible patient care.

Hospital Noise Pollution: An Environmental Stress Model to Guide Research and Clinical Interventions, a 2000 publication by Margaret Topf of the University of Colorado, is an article which addresses the strains put on hospital patients by the ambient noise of their surroundings. The first topic addressed in the article is the idea of ambient stressors. An ambient stressor is defined as any environmental factor that can contribute to stress in an individual. For the purpose of this article Topf focuses on the concept of noise pollution within the hospital as a stressor. The article presents data that indicates that noise is in fact a major stressor that is found in most, if not all, hospital CCUs (similar to the Roxbury, Mass VA Hospital).

Stressors are objective observations of the environment that have strong links to subjective feelings of stress within the patients' mind. This subsequently means that noise is characterized as a stressor objectively by observing that it is loud; this does not necessarily indicate that people are stressed by it, just that the high noise levels exist. Once noise has been identified as an ambient stressor, the correlation between the stressor and the subjective feeling of stress can be made. The aforementioned article suggests that there is a parallel between people who indicate that the noise level is too high, and those who also report a high level stress. Another interesting anomaly discovered by Topf is that demographics a rather influential effect on a patients' susceptibility to stress and uneasiness. It was shown, for instance, that women are more likely to suffer stress from high noise levels than men. In a very similar manner, elderly patients were far more likely to suffer from high stress levels induced by the ambient noise. Finally, patients in more pain, or under heavier medication, showed a higher level of affectedness to ambient room noise.

Stress created by excessive noise has been experimentally linked to significant physical and mental ailments experienced by patients. The easiest way noise can have an impact on patients is through the disturbance of sleep. The FDA recommends that noise levels during the night in a hospital setting should not exceed 45 dB. Despite this recommendation, data taken from numerous hospitals have shown that noise levels rarely ever dropped below 50 dB throughout the night and even spiked as high as 80 dB. Studies have shown that under simulated CCU noise, subjects have a significantly harder time falling asleep than subjects who slept under normal residential noise levels. Sleep is essential in a CCU where patients may be recovering from serious procedures; healing of tissues and cell regeneration is imperative to healing correctly. Without proper rest, patients can experience significantly impaired levels of healing as well as sleep deprivation, low attentiveness, and lethargy. In addition to impaired attentive senses, mental issues such as irritability, social withdrawal, disorientation, delusions, or hallucinations can result.

Average decibel readings in hospital settings over the past few decades have suggested that the problem of elevated noise levels is becoming worse, rather than improving. Members of the Biomedical Engineering board at John's Hopkins Hospital in Baltimore, Maryland have performed numerous tests which analysis the average noise level in the ICU (intensive care unit) for a typical day. The resulting graph, shown on the next page in Figure 1, depicts that there is no real decline in decibel readings within the patient's rooms, nurse's station, and hallway during the night. The graph shows that for the most part, with a small exception for the hours of 1AM to 5AM, the sound level is constant at around 50-60 dB max and 40-52 dB average throughout the day. In addition, the hospital has been able to compound multiple year worth of data together in order to determine that: "A straight line fit to the data shows an increase, on average, of .38 dB per year for daytime levels, and .42 dB per year for the nighttime levels [since 1960]…" (Vishniac-Busch, 2005)

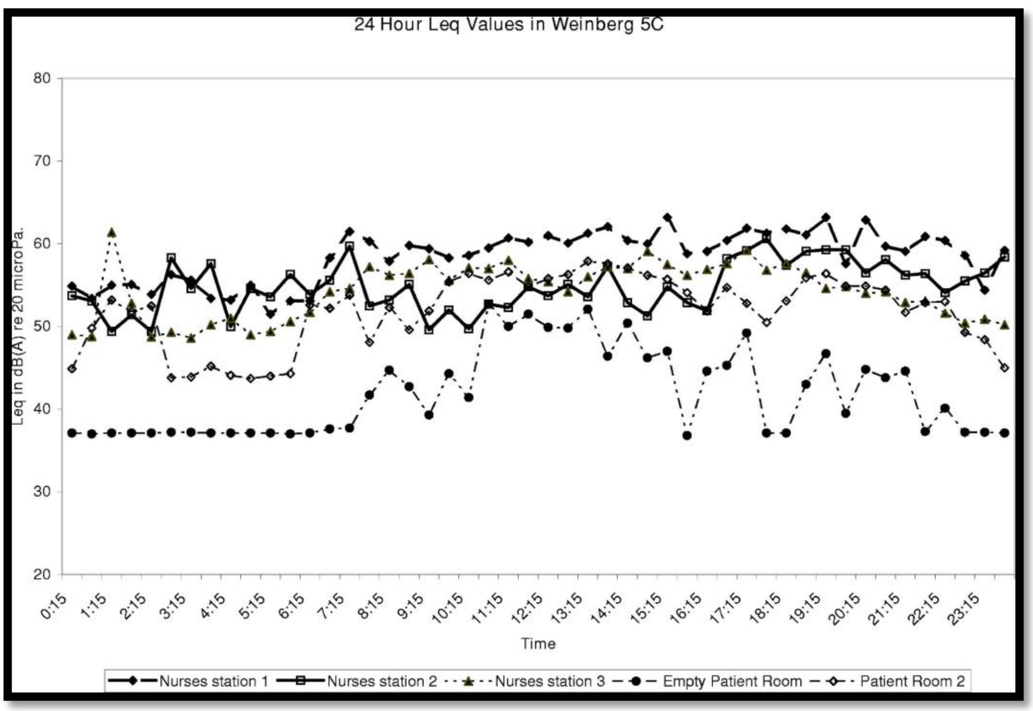

Figure 1: Decibel Levels versus Time for Various Hospital Locations. Johns Hopkins Hospital

From our preliminary background research, we have been able to discover that noise is in fact a very significant problem for patients trying to recover in hospitals. In addition, recent studies have shown that the noise problem has not been getting better, but rather worse. The increased noise levels throughout hospitals, specifically in recovery or intensive/critical care units, suggests that action must be taken in order to improve the living and healing conditions of the millions of patients housed by hospitals every year. Thus, in order to fix the rising problem, the source of the problem must first be discovered. The following paragraphs will expound upon the previously defined problem and attribute sources to the problem…

Most if not all modern day hospitals employ the use of physiological monitors on patients to alert care givers of changes of interest that are abnormal to set parameters; which include cardiac monitors, pulse oximetry monitors, and various other real-time patient health measurements. During an average day, thousands of alarms within the hospital go off, and it is common for a considerable portion of these alarms to be false alarms; also referred to as "nuisance" alarms. In a recent 2010 study by Kelly Graham of the *American Journal of Critical Care*, 1300 health care professionals were interviewed and the following statistics were found: "81% of professionals believed nuisance alarms occurred frequently, roughly 77% of those alarms were disruptive to patient care, and 78% of professionals saw nuisance alarms as "annoying" and were therefore disabled by clinicians." Furthermore, "false alarms produced by physiological monitors result in a change of patient management less than 1% of the time.", therefore suggesting that 99% of the time the alarm is essential useless to patient care and only detrimental to the overall quietness of the ward. Clearly, hospitals experience a number of "nuisance" alarms which are unnecessary and can therefore be significantly improved upon to guarantee patient satisfaction and healthy recovery.

Unit Psychosis is a condition or disorder in which a patient in an intensive care, or similar hospital setting, may experience moderate to severe levels of anxiety, paranoia, agitation, and may additionally become hallucinogenic, disoriented, or even violent. The condition itself is a delirium, or acute brain syndrome, which occurs in patients who are exposed to an over abundant amount of sensory data. Sometimes referred to as "sensory overflow", the influx of a large amount of data through the senses can sometimes lead to an overloading of the subconscious, thereby creating a deprivation of normal brain function. Although the conditions are still being studied rather thoroughly to completely understand the causes of unit psychosis, the overwhelming leading cause seems to be sensory overload from repetitive noisy machines. A recent study by *Medicine.Net* suggests that roughly "one third of every patient who spends more than 5 days in an ICU [or similar hospital setting], experiences some form of psychotic reaction, such as unit psychosis. Similarly as the number of intensive care units and the number of people in them grow, unit psychosis is perforce increasing as a problem." (MedTerms, 2001) As previously mentioned, the largest cause of this "over-simulation" of the mind and other sensory organs is an over abundant amount of noise and repetition of said noise. Alarms such as those produced from readings of pulse oximetry sensors, which are mandatory in every hospital setting across the United States, are very repetitive and annoying to most patients. Hearing the sound over and over again is oddly similar to the basics of Chinese water torture; the subject is tied down to a table while water drips slowly onto his/her forehead causing sensory overload and extreme anxiety. Trying to eliminate some of these sources of noise, especially unnecessary repetitive ones, will be a major improvement to the hospital ward.

The final concern with the numerous alarms that sound in hospitals across the United States is the resulting alarm fatigue for nurses and doctors. Many of the concerns for nurse fatigue stems from the fact that some nurses work eight or even twelve hour shifts and up to forty or fifty hours a week. In addition to long work shifts, nurses receive few breaks away from the hospital setting. Alarms sound almost continuously throughout the hospital, whether in the nurse's station or one of the patients' rooms, sometimes unfortunately causing adverse effects. The major downside from the numerous alarms is that nurses can sometimes become accustomed to them, or worse yet, annoyed by them to the point that they disable / mute them. A recent article by James Welch PhD uncovers the fact that, "nurses in intensive care units stated that the primary problem with alarms is that they are continuously going off and that the largest contributor to the number of false alarms in intensive care units is the pulse oximetry alarm." By deductive reasoning, one can conclude that inaccurate and "nuisance" often times lead to alarm fatigue, a condition that is dangerous for both the caretakers and the patients:

> "Alarm fatigue happens when too many alarms occur in a clinical environment, causing clinicians to miss true clinically significant alarms. Users report that more than 350 alarms per patient per day result from monitoring systems alone in some acute care environments, but less than 5% of these alarms require clinical intervention to avoid patient harm (AAMI, 2011). Nuisance alarms represent the 95% of alarms that do not require a clinical intervention. Reducing the overall occurrence of nuisance alarms is essential in creating and maintaining a safe clinical environment. Furthermore, solving this vexing problem is essential to improve patient safety systems." (Hazards, 2001)

One of the leading sources for nuisance alarms is the pulse oximetry (SP02) sensor, which is generally located in every room of every hospital. Hospitals similar to the VA hospital in Roxbury, Massachusetts set certain threshold parameters for the

SP02 sensor, which determine the exact conditions under which the alarm will sound. Standard parameters for SP02 sensors are an oxygen saturation of 90 or 92 percent and a two or three second time delay. With these conditions, the patient must drop their oxygen sat. below 90/92 percent for at least a sustained 2-3 seconds before the alarm will sound. In the VA Hospital, the current parameter for SP02 sensors is simply an oxygen saturation below 92 percent. Once again relating to a study performed by John's Hopkins University, the hospital was able to reduce the total number of alarms in their ICU by nearly 63 percent by simply reducing the SP02 threshold parameter from 90 to 88%. Obviously, the threshold value has a rather significant effect on the total number of alarms; an interesting "pay-off" of safety versus total number of alarms and alarm fatigue results.

There are many technological factors that weigh in to the accuracy of an Sp02 reading. Proper application of the Sp02 sensor is critical to its functionality. A sensor that has not been fitted properly to the patient cannot be expected to generate actionable alarms. Disposable, single patient use sensors are less prone to create nuisance alarms that lead to alarm fatigue. Second-source recycled sensors might provide a financial savings, but also risk spreading contaminants from patient to patient. The Boston VA healthcare system is currently using disposable, single patient use sensors. In addition, aforementioned alarm settings have a large impact on alarm frequency and modifications made to time delay and Sp02 threshold have been shown to drastically reduce the occurrence of false alarms. The study that James Welch performed, in his article *An Evidence-Based Approach to Reduce Nuisance Alarms*, ultimately created a synthesis of information involving time delays and Sp02 threshold level reduction. Time delay is a very efficient and safe way to regulate the amount of false alarms. A patient that simply holds their breath for an extended period of time can drop their Sp02 level below the threshold level. Any sort of movement can also create spikes in the threshold levels. As a result adding a time delay to the Sp02 alarm would allow the patient a certain duration to recover their Sp02 level, effectively weeding out alarms caused by a single movement spike or the like. On the next page one can see a table showing an array of conditions for varying alarm delays and saturation threshold levels versus the resulting decrease in total number of alarms (in percentage form).

Reduction in Alarm Frequency				
	Alarm Delay			
Low SpO2 Alarm Threshold (%)	0 sec	5 sec	10 sec	15 sec
90	Reference	32%	57%	70%
89	27%	51%	69%	79%
88	45%	64%	78%	85%
87	58%	74%	84%	89%
86	68%	80%	87%	91%
85	75%	85%	87%	91%
84	80%	89%	93%	95%
83	84%	91%	95%	97%
82	87%	93%	96%	97%
81	89%	95%	97%	98%
80	90%	96%	97%	98%

Figure 2: Varying Alarm Delay and Saturation Levels vs. Decrease in Number of Alarms (in Percentage Form)

The effect of threshold and time delay parameters on SP02 sensors on the total number of alarms within any given hospital is enormous. By only decreasing the threshold value from 92 to 90 an estimated 40-50 percent of alarms will be eliminated. Additionally, if only a 5 second alarm delay was added roughly 30 – 40 percent of alarms would be eliminated. Finally, an ideal 90 percent oxygen saturation and a 5 second alarm delay would decrease the total number of alarms by roughly 55 – 65 percent. This enormous change in the total number of alarms could lead to a large decrease in alarm fatigue, a decrease in the overall noisiness of hospital rooms, and an increase in the quality of patient care and recovery.

The growth of the availability and potential possibilities of modern-day technology ensures that the hospital environment can be vastly improved upon. Improving pulse oximetry sensors, utilizing acoustic or noise canceling materials to quiet patient rooms, or wiring remote electronic devices for caretakers to replace loud audible alarms, are all ways that technology can be used to improve the comfort and healing process of patients in hospitals. There comes a time in the natural order of things in which changes need to be made for the better, before they get worse; the time is now.

2.3 Literature Review Conclusions

The literature review for this project was crucial to determine work that has already been done in the field we are researching. Reviewing the work of professionals such as Huisman and Franchi in the fields of risk factors of hospital readmission and the impact of physical environmental factors on patient recovery will play an extremely important role in supporting our own conclusions in chapter 3. Claims have already been made regarding alarm fatigue and sound pollution in the hospital environment in relation to patient recovery rates. Our project would like to put some numbers to these arguments, in an effort to further validate that which has been discussed in many of the papers we have reviewed here. It is made clear in many studies that the quality of sleep in ICU's (of various types) was poor for all patients. It is our mission to track down specific sources of noise within the hospital environment by using various acoustical observation techniques. Evidence obtained from our study will hopefully influence decisions in the hospital environment with acoustical repercussions. By lessening the severity of alarm fatigue and acoustic pollution on patient floors, we hope to promote a decrease in hospital readmission rates which is favorable not only for patients and their families, but also physicians and administration of the health care facility.

CHAPTER 3: METHODOLOGY AND DATA COLLECTION TECHNIQUES

3.1 INTRODUCTION

The aim of this project was to examine the noise present in the West Roxbury VA Hospital's Cardiac Care Unit (CCU) and characterize this noise. To do this, data was taken from several sources. These sources include sound loggers, alarm monitoring software, and nurse schedules. Data was analyzed using Excel spreadsheets based on a variety of factors. Sound levels were sorted in 24 hour stretches, based on night and day, and at three locations. Alarms were categorized by type and severity, location, and quantity.

Extech sound loggers were placed in three locations within the CCU as will be described later. These sound loggers were the largest contributor to the raw data acquired and were used to view trends in noise level based on time of day. The PHILIPS alarm monitoring software logged all yellow and red alarms that went off in the CCU during data collection (does not log blue alarms). This allowed for the correlation of alarm quantity to the overall noise environment within the CCU. Nursing schedules were used to account for human influence on the noise levels within the CCU. This schedule was particularly useful in isolating trends that related to scheduled activities.

The analysis of the sound logger readings was performed using excel. Breakdowns were made based on single days and grouped into two separate observation periods. Averages were taken on an hourly basis and the two testing periods were each averaged to achieve trend lines. Decibel readings were also looked at on the basis of night and day to determine if nighttime conditions within the CCU were within federal guidelines for a community sleeping environment. Sound trends were also isolated based on the location of the logger within the CCU in order to observe the variance between different locations.

Alarm data was sorted by the PHILIPS software by severity and was further sorted into categories based on codes received from the VA hospital. Alarms were sorted into the same locations as the loggers were placed to isolate the effect alarms had on the recorded noise levels. Basic averages were taken to see the quantity of alarms that were present in each part of the CCU on a daily and hourly basis.

The findings gathered from the aforementioned protocols can be used to determine specific noise patterns within the CCU. This means determining precisely how loud the CCU is based on location and time of day, whether this is an acceptable noise level, sources of the noise and changes that may create a quieter environment.

The first piece of information that must be looked at from the testing procedures is the average noise levels based on time of day and location. The average values seen in these basic analysis immediately determine the extent of the problem and can give a foundation for the soundscape of the CCU. The findings can then be compared to various guidelines put forth by regulatory agencies such as the Food and Drug Administration or the World Health Organization. If the values are found to be higher than the recommended levels, as it is expected to be based on background research including previous data taken on site, then further analysis will be required to determine the exact cause of noise events.

For the purposes of this project noise sources can be considered to fall into one of two categories: alarm or human. Alarms can then be classified based on severity into three categories: blue, yellow, and red. Blue alarms are considered inoperative alarms and occur when equipment is not working properly such as a lead that is not attached to a patient. These alarms are not recorded by the PHILIPS software. Yellow alarms are medium priority and sound in the room of the patient whose alarm has been triggered. Red alarms are the most severe and sound in all patient rooms to assure a quick response. These alarms are given codes in the software output based on the specific medical reason for the alarm. This allows for the pinpoint detection of what alarms cause the most disturbance within the ward. Human sounds are less straightforward to categorize. Human sounds can come from guests or patient activities such as watching TV, these noises must all be grouped as background noise. However, some specific trends can be attributed to scheduled ward events performed by the medical staff and provide insight to spikes in decibel level.

The final step is to take the information gathered about the particular noise sources and suggest the means by which to best mitigate their contribution to the overall CCU noise level. Alarm sources can be targeted based on the thresholds that are set by the hospital or based on the equipment itself. Frequent false alarms based on an unnecessarily large safety factor in the alarm's threshold for triggering can be reduced by researching and implementing a more appropriate threshold. Alarms triggered due to faults in the equipment such as poor adherence to the patient, might require a redesign of the equipment or a change to a different provider/manufacturer. Noise trends that can be attributed to ward staff require procedural changes. Though much is already done by the nursing staff to ensure that they do not disturb the patients, certain activities that are linked to increase noise levels can be adjusted in either how or when they are done to make the smallest possible impact on the all-important rest of the patients in the ward. Other recommendations may be made based on further research into sound solutions for healthcare environments.

3.2 Experimental Setup and Procedures

We examined the possible sources of noise within the hospital environment in an attempt to characterize the contribution of the overall noise from medical alarms and equipment. To reach this goal, sound levels were measured from three different locations in the CCU. Medical alarms were tracked by Philips alarm software from the central nurses' station. Excel formulas were developed as an aid to parse and sort data relevant to plotting hourly sound levels and alarm counts. Recurring events in CCU that contributed to overall noise were outlined by the nursing staff and served as a basis for our understanding of the plotted data.

3.2.1 Data Collection

It was necessary to pull sound level samples as often as possible in the hospital environment to get an accurate measure of the average sound level. Because alarms signal periodically, a soundlogger with a short sampling rate was the best choice to capture as much information about alarm noise as possible. The sensors chosen for data collection were Extech SDL-600 Sound Level Meter/Datalogger. Three devices were purchased with the purpose of being able to record in different areas of the CCU simultaneously. The devices have a sampling rate of 1 second and store dB readings in EXCEL (.xls) format via SD card. The manufacturers stated accuracy is $\pm$ 1.4 dB.

Figure 3: Extech SDL-600 Sound Level Instruments (left) and Sensor Housing (right)

Sensor housings were created from thermostat protector boxes to comply with necessary CCU cleaning regulations. It was necessary the sensors were able to be wiped down as part of the CCU patient room cleaning procedure. The devices were installed in three different areas (see floor plan figure below) in the CCU, all approximately 7′ from the floor to avoid tampering. Sensor 1 was placed near the double door entrance to the CCU, which was a suspect for noise pollution on the ward. Sensor 2 was located in the Central Nurses Station and Sensor 3 located in a patient room adjacent to the Central Nurses Station. Sensors were placed as close to the patient beds as possible within the room to measure as accurately as possible the noise levels experienced by patients in the CCU.

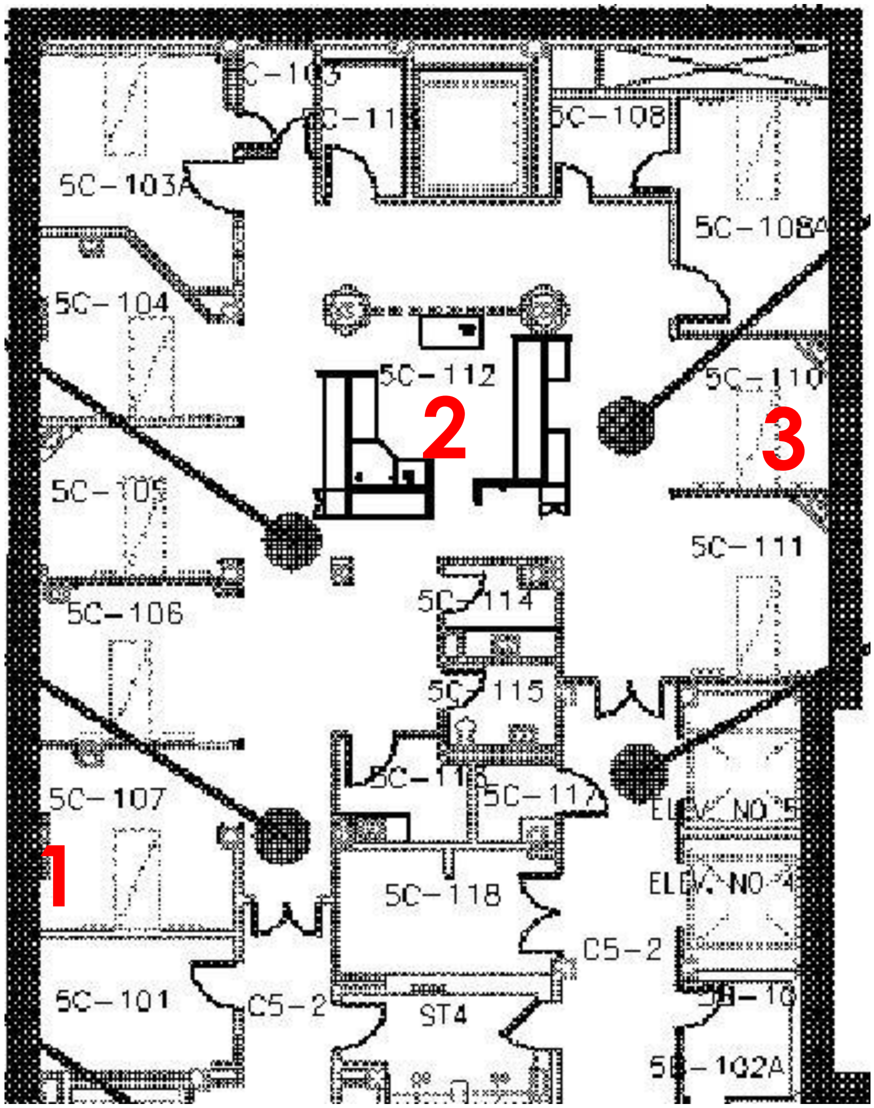

Figure 4: CCU Floor Plan. Sensor 1 Located in Patient Room 1. Sensor 2 Located at Central Nurses Station. Sensor 3 Located in Patient Room 7.

Additionally, alarm tracking software was purchased by the West Roxbury VA that integrated into their current alarm tracking system in the CCU. Data reports generated by the alarm software were to be used to count alarm occurrences and determine the contribution of specific alarm categories to the overall amount of counted alarms. We were provided sorted data from the Biomedical Engineering department at the VA Hospital for Alarms specifically from Patient Rooms 1 and 7 as well as overall alarms from the CCU.

3.2 2 Sound Logger Settings

There were various settings on the soundlogger that needed attention before measurements could be taken. It was necessary to know what time precisely was being measured. The date and time were set to that of the Philips alarm software. This was necessary to make sure that we could easily understand the contribution of alarms to the noise in the patient room. The next setting on the devices was frequency weighting "A" and "C". From the soundlogger user's manual,

> *"Select 'A' or 'C' frequency weighting in the SETUP Mode. With 'A' weighting selected, the frequency response of the meter is similar to the response of the human ear. 'A' weighting is commonly used for environmental or hearing conservation programs such as OSHA regulatory testing and noise ordinance law enforcement. 'C' weighting is a much flatter response and is suitable for the sound level analysis of machines, engines, etc. Most noise measurements are performed using 'A' Weighting and SLOW Response".*

"A" frequency weighting was chosen because it is similar to that "of the human ear" which is useful in an experiment whose purpose is to make a more comfortable hospital environment for humans[1]. The next soundlogger setting that required attention was the response time. The options offered were "Fast" and "Slow", with fast being applicable to situations tracking noise peaks and noises that occur very quickly. We decided to use the fast setting because the duration of alarms we were tracking were

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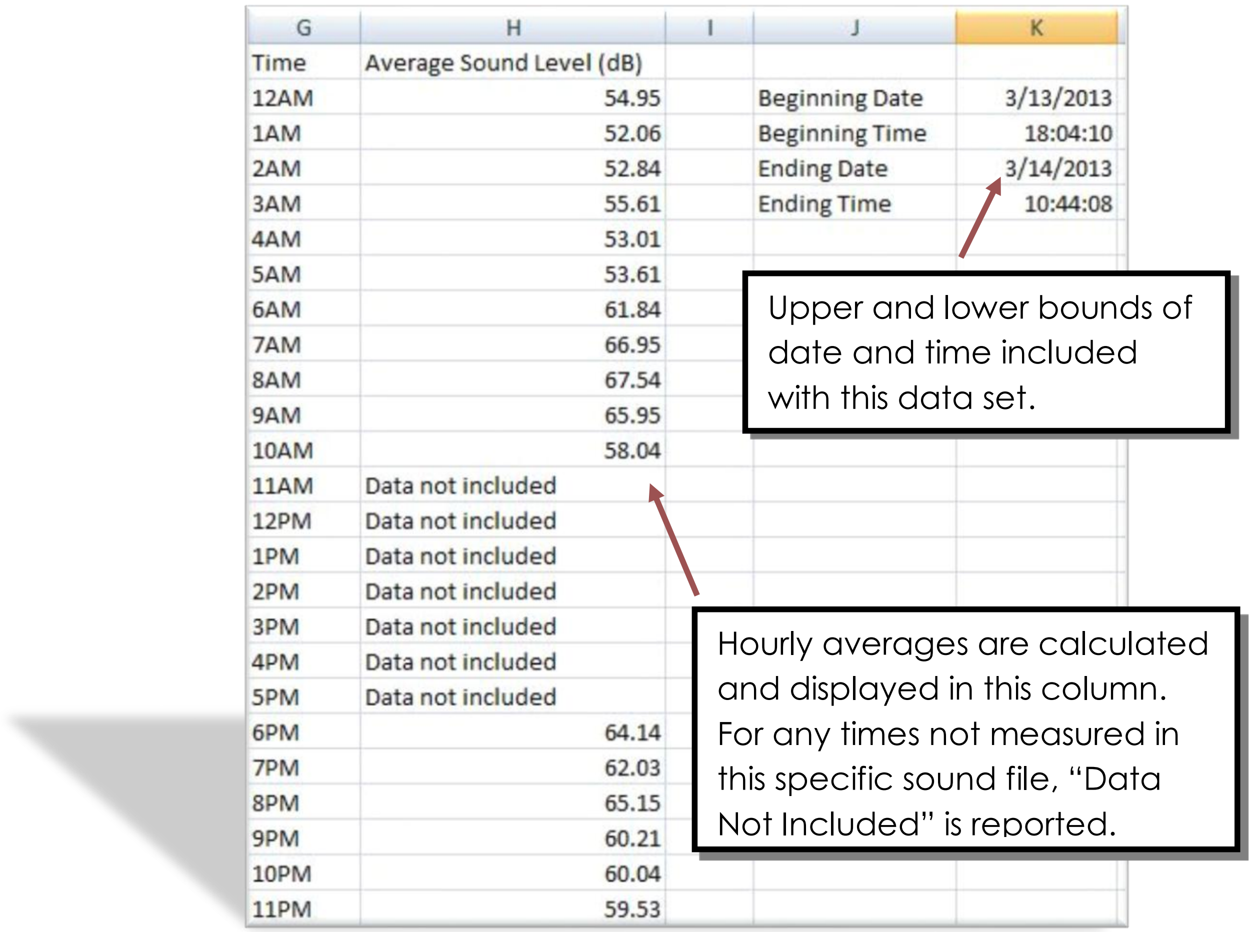
[1] Noise levels are measured using the A-weighted sound level. This is the most commonly used descriptor to quantify the relative loudness of various types of sounds with similar or differing frequency characteristics. (Joseph & Ulrich, 2004)

very short beeps or spikes of noise in comparison to the overall noise of the healing environment. Automatic data logging was used to log data onto an SD memory card that could be removed at any point and the data transferred to a computer for analysis. Every 30,000 samples a new document was created. This fact needed to be accounted for when developing our analysis technique because the data for the same day had the potential to be located on multiple files. We decided early on that the best way to keep track of the data was to create a master hourly average document that all processed data would be pasted into after hourly average techniques were applied.

3.2.3 Analysis Techniques

Sound Loggers

The most usable form of data collected from the soundloggers was hourly averages that could be used to plot graphs. There were over 100 files generated during the measurement period, which represented one second measurements for three sensors at around 2 weeks total per sensor. Individual analysis of these files would represent a significant undertaking. To simplify this problem of data averaging we developed a set of "paste-in" functions in Microsoft EXCEL that would do the averaging for us based on the times contained in the file being measured. Using the fact that each sample taken had a unique time stamp associated with it, AVERAGEIFS functions were used to group data by hour. The figure below represents the block of functions that were pasted into each individual data file generated by the EXTECH soundloggers.



G	H	I	J	K
Time	Average Sound Level (dB)			
12AM	54.95		Beginning Date	3/13/2013
1AM	52.06		Beginning Time	18:04:10
2AM	52.84		Ending Date	3/14/2013
3AM	55.61		Ending Time	10:44:08
4AM	53.01			
5AM	53.61			
6AM	61.84			
7AM	66.95			
8AM	67.54			
9AM	65.95			
10AM	58.04			
11AM	Data not included			
12PM	Data not included			
1PM	Data not included			
2PM	Data not included			
3PM	Data not included			
4PM	Data not included			
5PM	Data not included			
6PM	64.14			
7PM	62.03			
8PM	65.15			
9PM	60.21			
10PM	60.04			
11PM	59.53			

Figure 5: "Paste-In" Analysis Block (*Excel* Generated dB Analysis)

An example of the function employed to average hourly sound data is provided below. The IFERROR wrapper provides error trapping by displaying "Data not included" if an error is encountered. In this situation, an error is encountered when there is no data being fed into an AVERAGEIFS function. This occurs when the hour that the function is attempting to average is not included in the dataset. As stated before, since there is a maximum of 30,000 readings per file (EXCEL limitation) a single 24 hour period of recording was broken up onto 3 files (sometimes 2). The example below averages all of the data readings time stamped by the soundlogger as occurring between 19:00:00 and 20:00:00 (8PM – 9PM). The function averages the values in column D for these time value occurring in column C.

```
=IFERROR((AVERAGEIFS(D:D,C:C,">=19:00:00",C:C,"<20:00:00")),"Data not included")
```

Figure 6: Example of function to average sound readings occurring between two time periods using the AVERAGEIFS function. Error trapping is employed with the IFERROR function if the data is out of the range of the current document (Organization, 2001).

Piece by piece, the hourly data averages for all three sensors were pasted into a master document by day. From this master document it was easy to make graphs for hourly sound levels for a given sensor or even multiple sensors on the same graph if need be. The most effective format for the hourly trend graphs was hourly spanning from Midnight → Midnight showing all 24 hourly data points per day with average sound levels on the y-axis in decibels.

We found the COUNTIFS function also suitable to analyze the percentage of readings that occurred after a given time. It was beneficial to be able to classify the amount of time spent above a certain decibel reading at night time, when patients are supposed to be sleeping. The two criteria required for counting were *if the decibel level* *was over 45dB* and *if the time was between 19:00:00 and 7:00:00* (7PM→7AM). The COUNTIF results were divided by the total number of samples taken during the night and multiplied by 100 to calculate the percentage of time during the night that the sound level at each sensor location was over 45dB. We set this 45dB threshold 15dB over the world health organization standard of 30dB (Organization, 2001). In 35 published research studies over the last 45 years, not one published study reported noise levels that complied with the World Health Organization (WHO) guidelines for noise levels in hospitals. (Joseph & Ulrich, 2004)

Hospital Alarms

Characterization of the profile of medical alarms and their impact on the overall noise in the CCU was also one of the goals of our project. Currently the VA hospital uses a PHILIPS alarm monitors that are routed to the central nurse's station. For our project and the benefit of the CCU, the biomedical engineering staff purchased a software package from PHILIPS that allowed medical alarm tracking and cataloging. We were able to export this alarm data in the form of EXCEL documents indicating the type of alarm causing the trigger, the time and date of the alarm, which patient bed triggered the alarm and what the priority of the alarm was. A limitation with this program is that INOP (BLUE) alarms were not recorded. This is unfortunate because the total amount of alarms sounding still remains unknown, and we're unsure how many INOP alarms make up the total alarm profile (yellow and red alarms are known) of the CCU. The data that we were provided to work with for this portion of our experimental procedure was the specific alarm data for patient rooms 1 and 7 as well as the total logged alarm profile pulled at the central nurse's station. It is worthwhile to note at this point that HIGH priority alarms (RED) sound over the entire CCU floor, both in the central nurse's station and in *every* patient room.

In addition to the severity column in the alarm EXCEL sheet, a secondary severity index was developed. The index used asterisks placed before the triggering string with one asterisk representing the lowest severity, two asterisks representing medium severity and three asterisks representing high severity. The figure below is an example of how we will be representing the data.

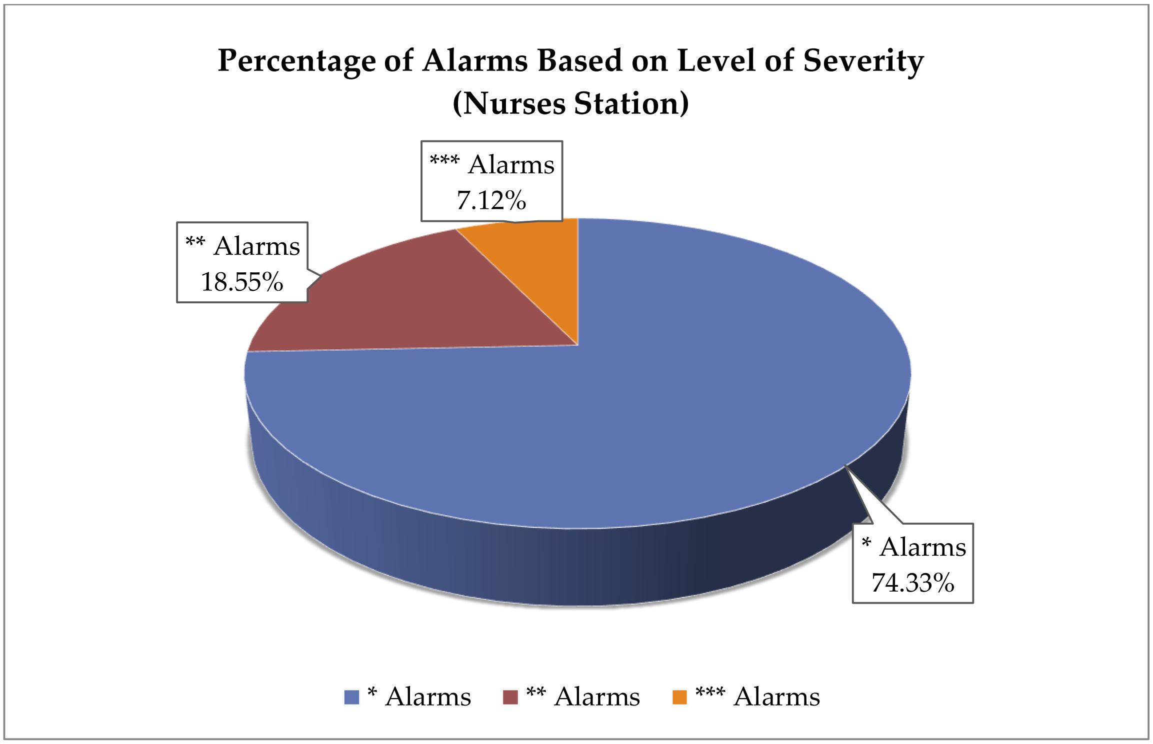


Figure 7: Percentage of alarms sorted by asterisk severity rating (*,,***)**

3.3 Schedule of Recurring Events

Recurring events occurring in the hospital environment have an impact on the daily noise profile of the CCU. Nursing staff, clinicians, doctors, visitors, custodial and other hospital employees may have an impact on how loud the ward can get during different times of the day. Table 1 below summarizes the daily proceedings in the CCU that possibly influence the sound levels in patient rooms.

Time	**Event**
5:00 AM	Labs for patients are taken
7:30 – 8:00 AM	Morning shift change occurs
7:30 - 8:30 AM	Nurses try to get patients out of bed and move around*
9:00 – 10:30 AM	Physician rounds: Talks with nurses about treatment. Occurs in the nurses' station and occasionally in the rooms
12:00 PM	Lunch
1:30 – 2:00 PM	Interdisciplinary rounds: Nutrition/ social work/ etc. and nursing staff meet around central nursing station
5:00 PM	Dinner
7:30 – 8:00 PM	Night shift change occurs

Table 1: Daily CCU Schedule

*Nurses report this being a frequent time for false alarms to occur.

Chapter 4: Results and Conclusions

4.1 Sound Levels

Over the course of two months, sound levels were measured in the Cardiac Care Unit at the West Roxbury Veterans Affairs Hospital. In total two weeks of sound level samples were recorded every second in three different areas of the CCU. All areas were free of acoustical treatments and staff members were instructed to continue with their normal schedule during the data collection period.

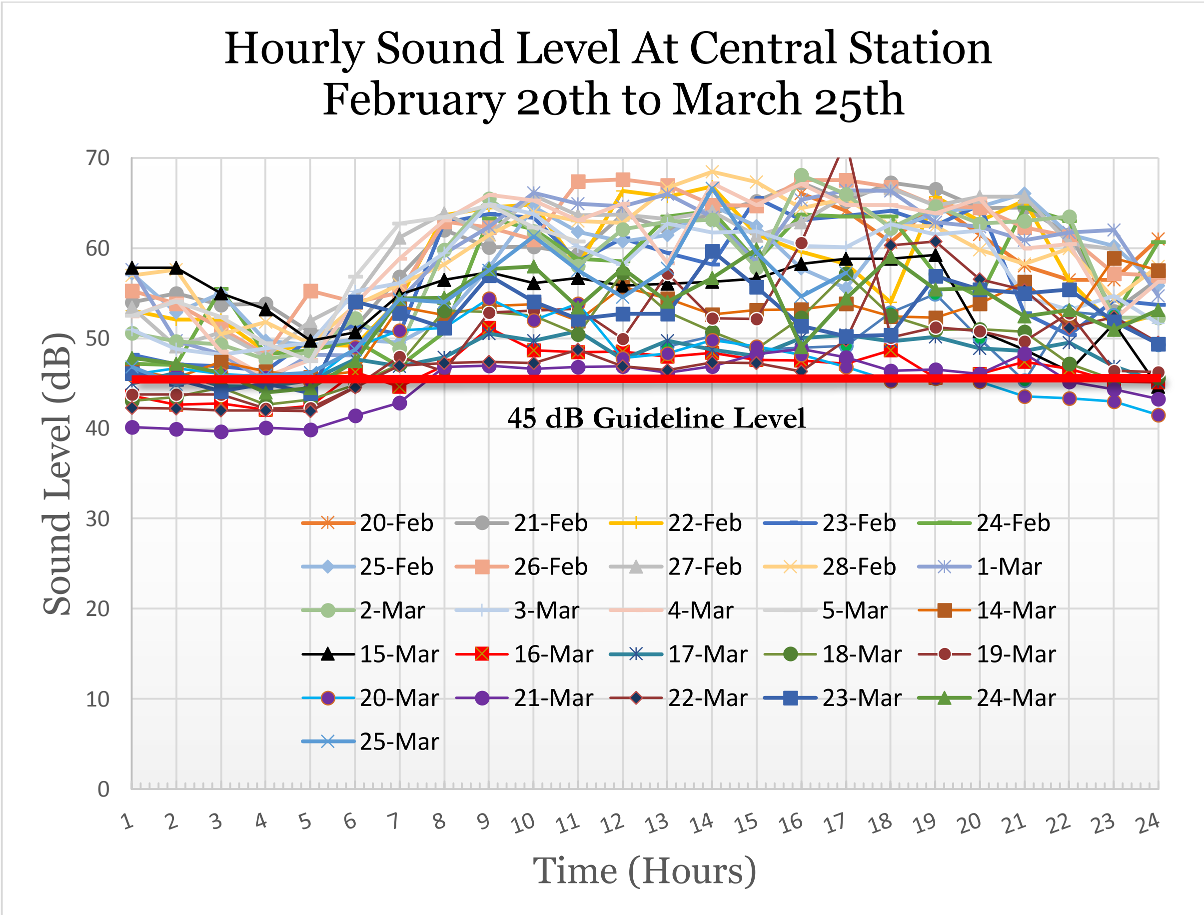


Figure 8: Hourly sound level averages for the recording period February 20th to March 25th at the Central Nurses' Station

Figure 8 above shows the data collected at the central nurses' station between February 20th and March 25th. Data between March 5th and March 14th was not collected due to a power outage that reset the sensors and corrupted the dataset for that period. The x-axis of the graph represents the time of the day in hours, while the y-axis shows the average sound level for that time interval. Average sound levels were calculated using the procedure outlined in the methodology beginning on page 26. A 45dB guideline sound level is overlaid on the graphs for reference to acceptable noise levels in the hospital environment (Organization, 2001). A general trend can be seen from this graph; however an average of daily measurements is a simpler, cleaner way to get a feeling for the noise levels in the CCU.

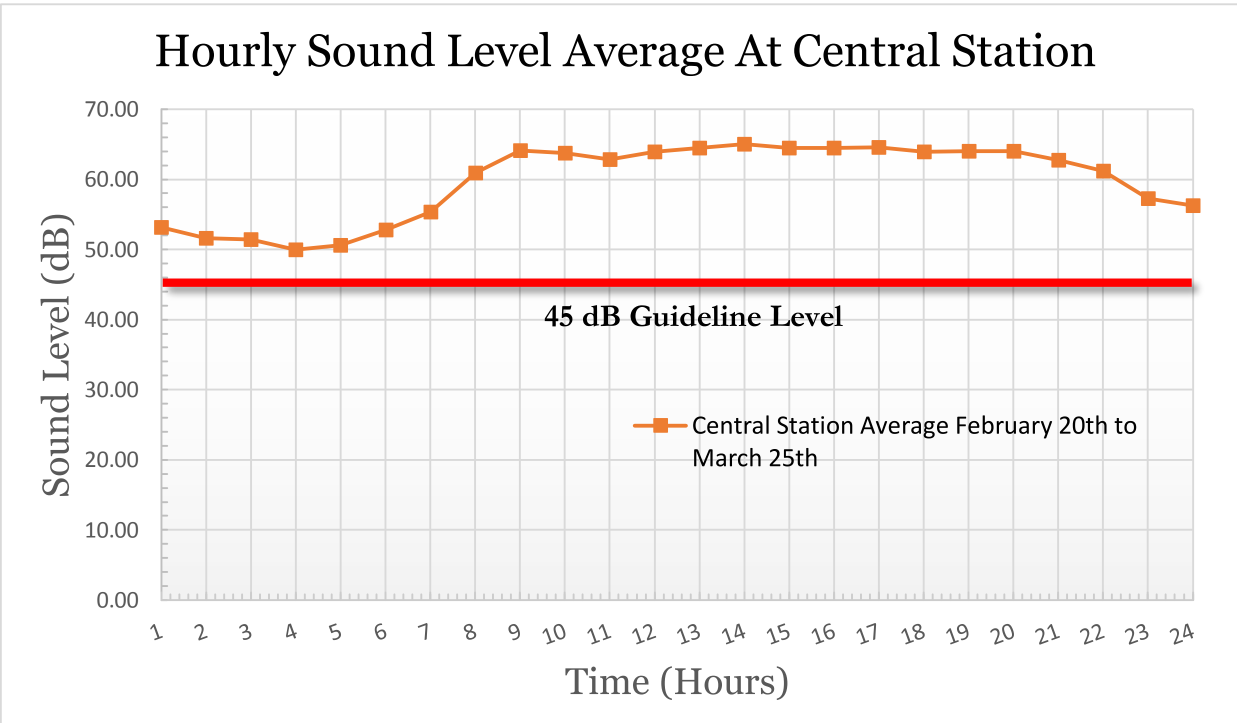


Figure 9: Overall average sound level at Central Nurses' Station

Figure 9 above is a compilation and average of all of the hourly sound averages developed from the logged data sets. The central nurses' station is a notable sensor location because sound generated in this area is most likely a contribution to the sound levels in the patient rooms. Patient room 1 is located nearest to the entrance of the CCU as shown in Figure 4 on page 32. Our data shows that this sensor location is the quietest overall of the three locations measured. Figure 10shows the hourly averages for each day between February 21st and March 25th.

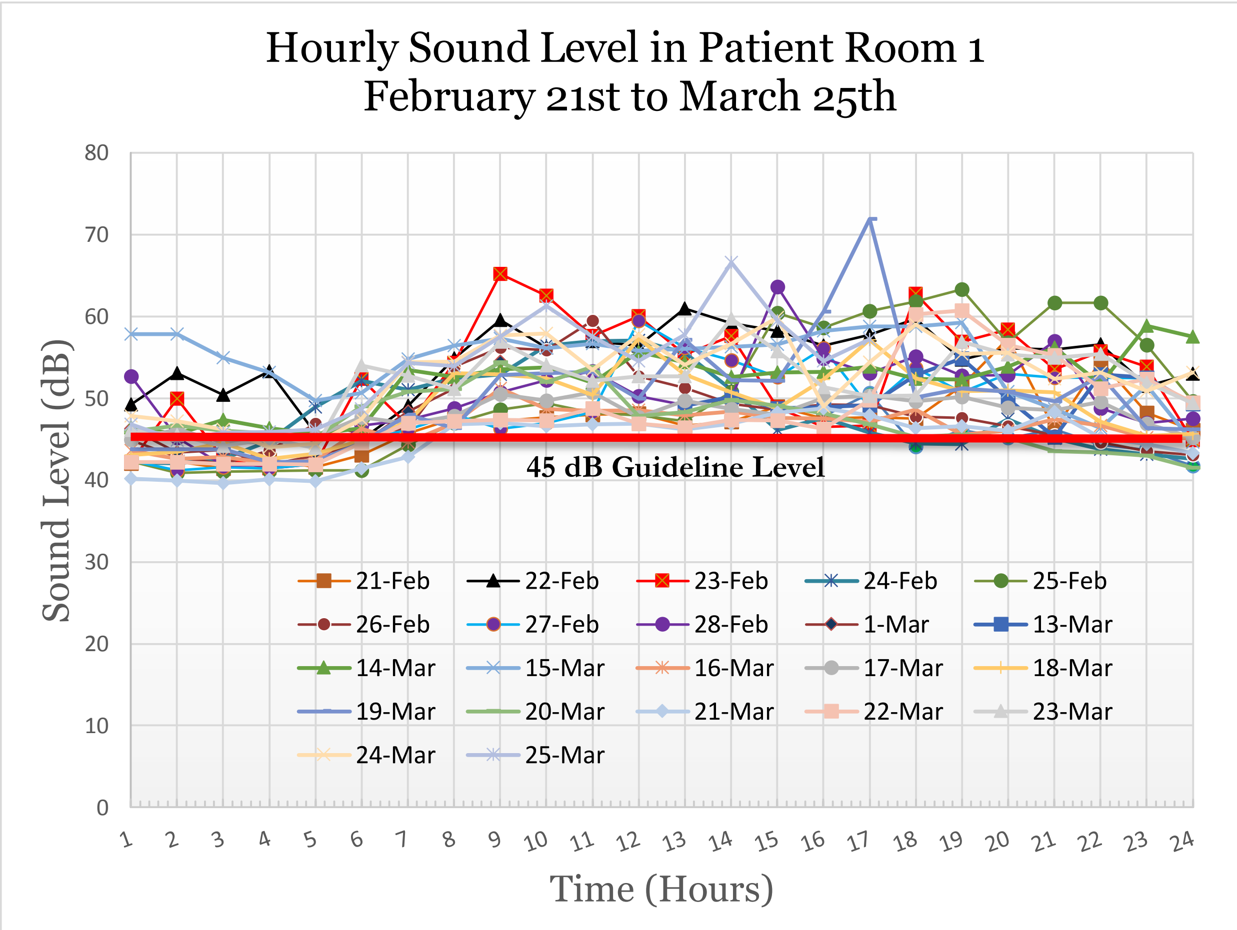


Figure 10: Hourly sound level averages for the recording period February 21st to March 25th at Patient Room 1 (CCU Entrance)

Sound levels for Patient Room 1 were the lowest we measured. The fact that the room was located near the entrance of the CCU led us to believe that we would see increased sound levels at this location due to a higher level of traffic in and out. Our results disprove this claim and show the opposite thought is true.

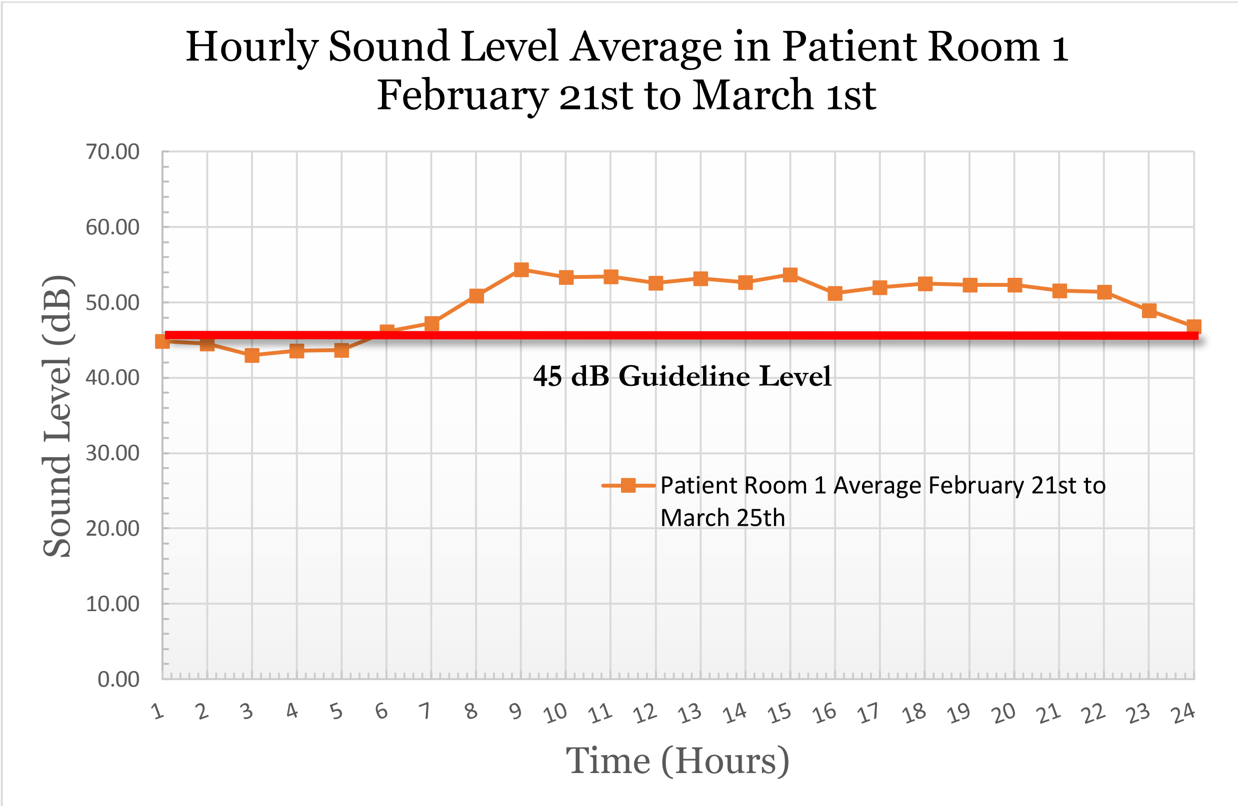


Figure 11: Overall average sound level at Patient Room 1

Again, the overall average trend for Patient Room 1 is shown above. There is a brief period between midnight and 5AM that the average dips below the 45 dB guideline sound level. This is the only point during our study that we noticed an acceptable sound level during the night. This 45 dB sound level is still over the documented guideline noise level for a hospital environment set by the World Health Organization.

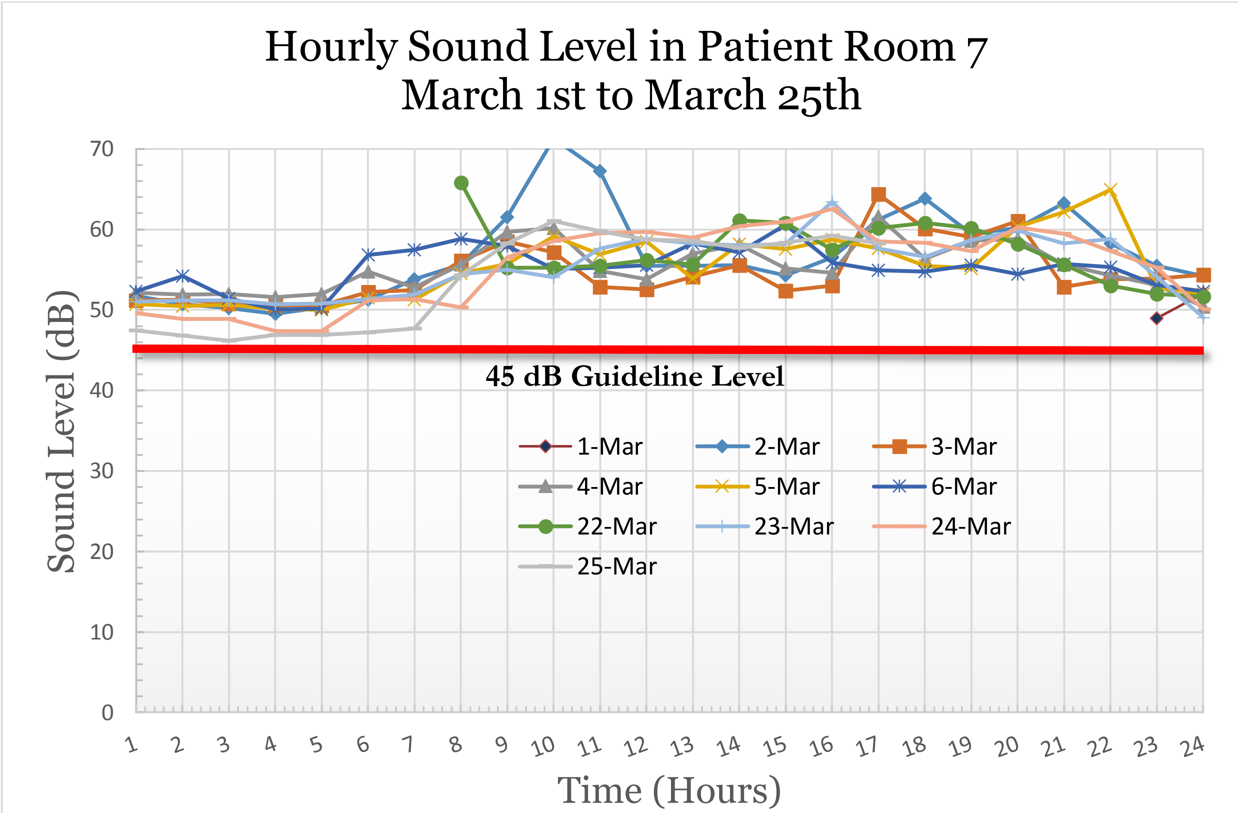


Figure 12: Hourly sound level averages for the recording period February 21st to March 25th at Patient Room 1 (CCU Entrance)

In patient room 7, an overall elevated noise level was noticed in comparison to patient room 1. On average, readings in patient room 7 were 5 dB higher than that in patient room 1. This can mainly be attributed to the fact that patient room 7 is directly adjacent to the central nurses' station. Figure 4 on page 32 shows that patient room 7 is less than half the distance from the central nurses' station compared to patient room 1. Given the elevated noise levels of the nurses' station as shown in Figure 9, it follows that patient room 7 would exhibit an increased overall average compared to patient room 1.

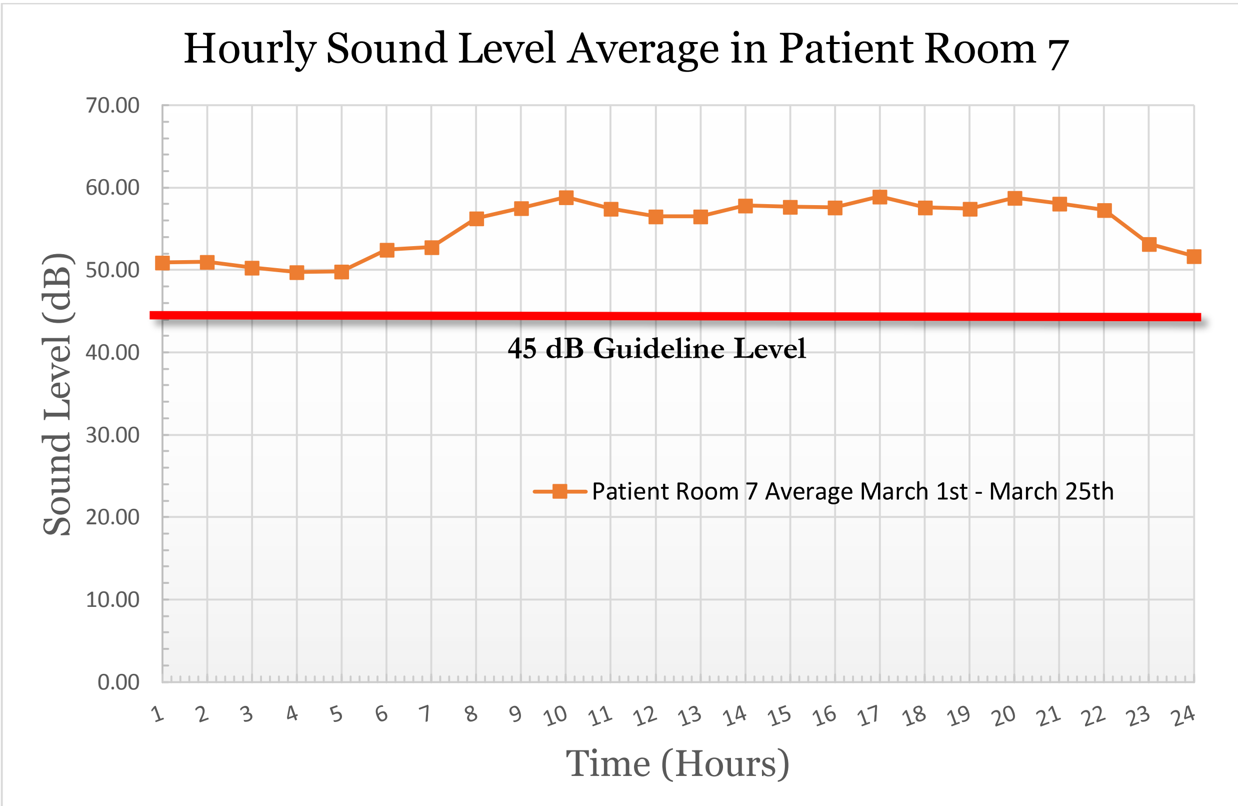


Figure 13: Overall average sound level at Patient Room 7

Table 2: Summary of percent of time spent above acceptable sound levels during the evening for both patient rooms studied

Location	Percentage of Time Spent Above 45 dB	Sample Size (# Readings)
CCU Room #1	55.25 %	489,682
CCU Room #7	99.61 %	361,081

4.2 Medical Alarms

Having recorded an ample amount of noise level data using our three decibel sensors, it was necessary to attempt to attribute alarms to the overall source of noise. Utilizing a packaged group of PHILIPS software, collectively known as IntelliVue Information Center, the group was able to collect, record, characterize, and attribute the various forms of alarms from the Cardiac Care Unit (CCU) at the West Roxbury VA Hospital in Massachusetts. Furthermore, data recovered from the IntelliVue package was thoroughly analyzed to provide the best possible feedback to the hospital board in terms of sources of noise, regularity of alarms throughout the ward, and possible options for the future to reduce the number of alarms and therefore improve the quality of care for patients by reducing noise levels.

Understanding the PHILIPS IntelliVue software to the fullest was a quintessential aspect of the data acquisition period. By extracting all of the data to an excel spreadsheet, the group was able to quickly and easily view the type of alarm and the level of its severity, the location where the alarm originated (patient room), and the exact date and time that the alarm was initiated. Additionally, the data could be extracted in such a way that the group could create a separate spreadsheet for each patient room (specifically patient rooms 1 and 7 – where two of the sensors were placed) and one general spreadsheet for the nurses' station (where alarms from all of the patient rooms were amalgamated). By analyzing the PHILIPS data for alarm regularity, as well as the level of severity of the numerous alarms that occur day in and out, the group was able to more accurately explain sources of noise within the VA CCU.

The first step in the data acquisition and analysis process was to "pull" the data from the PHILIPS monitors within the Cardiac Care Unit; for the specific study being performed by the group it was only necessary to pull the collaborative nurse's station data as well as patient rooms 1 and 7 data. Once all of the necessary software was installed, including the required computer drivers, the data could easily be removed and copied into excel spreadsheet format for the group's use. With the help of Jaspreet Mankoo, a graduate student studying Clinical Engineering at the West Roxbury VA Hospital, the team was able to assemble all of the necessary data and begin the actual analysis portion of the report.

The primary concern with the PHILIPS data was to analyze the number of alarms, and subsequently the severity / category of the aforementioned alarms. The process for this analysis was conducted separately for each of the three locations where decibel sensors were mounted (patient room 1, patient room 7, and the nurse's station [which was an amalgamation of all patient room data]). An example of several rows of the excel spreadsheet, shown below in Table 2, illustrates the parameters given by the PHILIPS software: alarm name, date, time, and priority of alarm.

Name	Date	Time	Priority
*** PAUSE**	2/21/2013	7:07:49 PM	Medium
*** PAUSE**	2/21/2013	7:13:12 PM	Medium
****RR 3 < 8**	2/21/2013	7:13:57 PM	Medium
****RR 7 < 8**	2/21/2013	7:19:16 PM	Medium
*******	2/22/2013	8:30:45 AM	High

Table 3: Sample of PHILIPS Data Gathered

As you can see in the table above, there are two distinct *priority levels*, which indicate the severity and the protocol required for the given alarm. Medium alarms are common in the Cardiac Care Unit, require nurse attention, but are limited to sounding in the patient room in which they occurred and the nurse's station. High alarms are much more serious however; they require <u>immediate</u> attention for nurses/doctors and subsequently sound an alarm throughout the unit to notify caregivers of the situation. As one might imagine, high alarms are a rather large contributor to overall noise levels in the CCU because of the fact that they sound on every monitor in every patient room (as well as the nurse's station). To understand the total number of alarms that sound on a typical day in each of the two patient rooms being studied, as well as the nurse's station (where <u>all</u> alarms record and sound), the following table was created…

Location	Total # Alarms per	# Medium Alarms per	# High Alarms per
Patient Room	57.17	51.97	5.20
Patient Room	122.03	115.96	6.07
Nurse's Station	562.26	522.24	40.02

Table 4: PHILIPS Alarm Data for Various Sensor Location

Information from the table above is very telling of the overall noisiness of the Cardiac Care Unit (CCU). The unit experiences numerous numbers of alarms per day, including just over 40 high alarms; which sound throughout every patient room. The number of alarms can be broken down further to generate the following three graphs which depict the overall average number of alarms per hour per day in CCU room #1, room #7, and the general nurses' station…

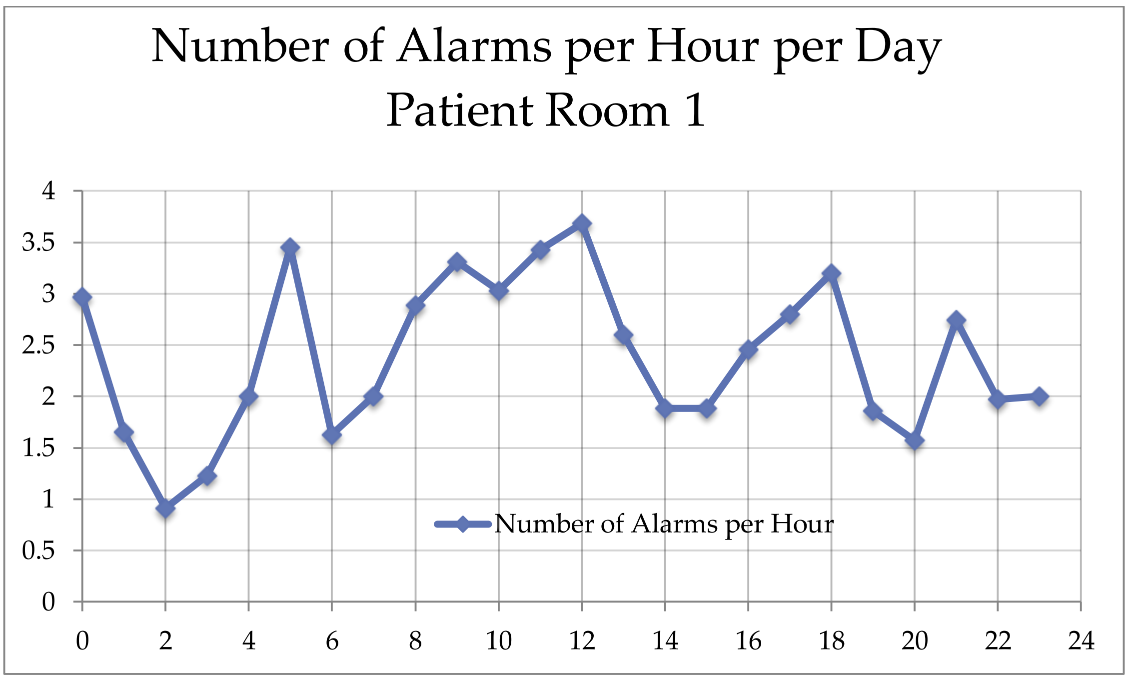


Figure 14: Number of Alarms per Hour per Day (Patient Room #1)

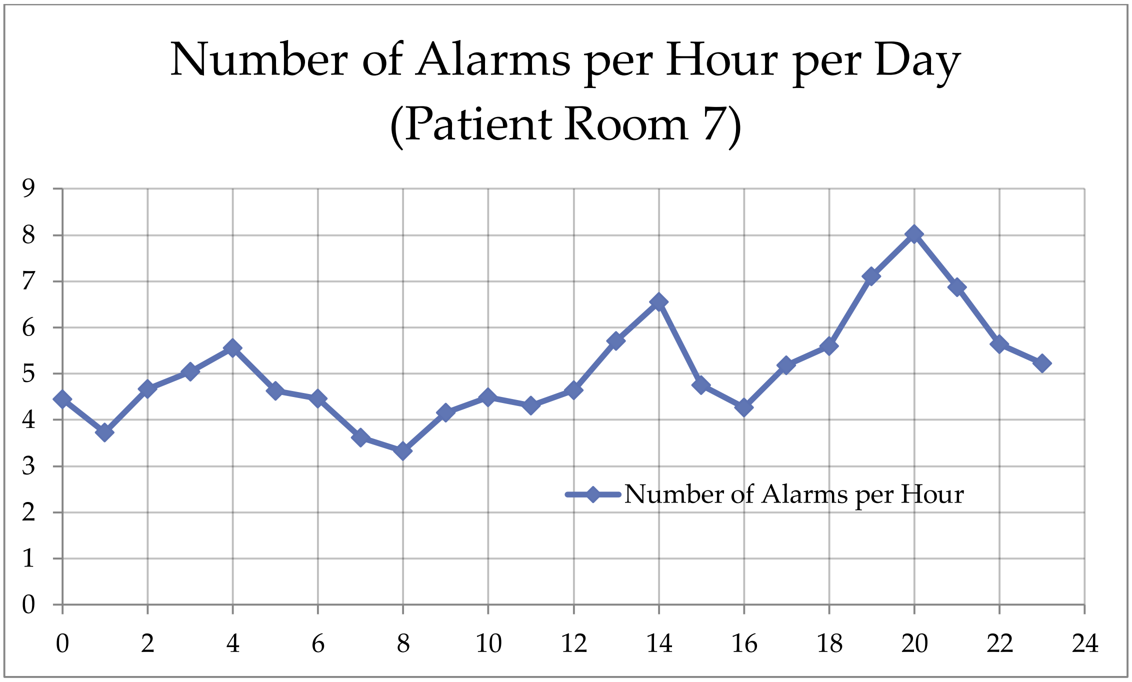


Figure 15: Number of Alarms per Hour per Day (Patient Room #7)

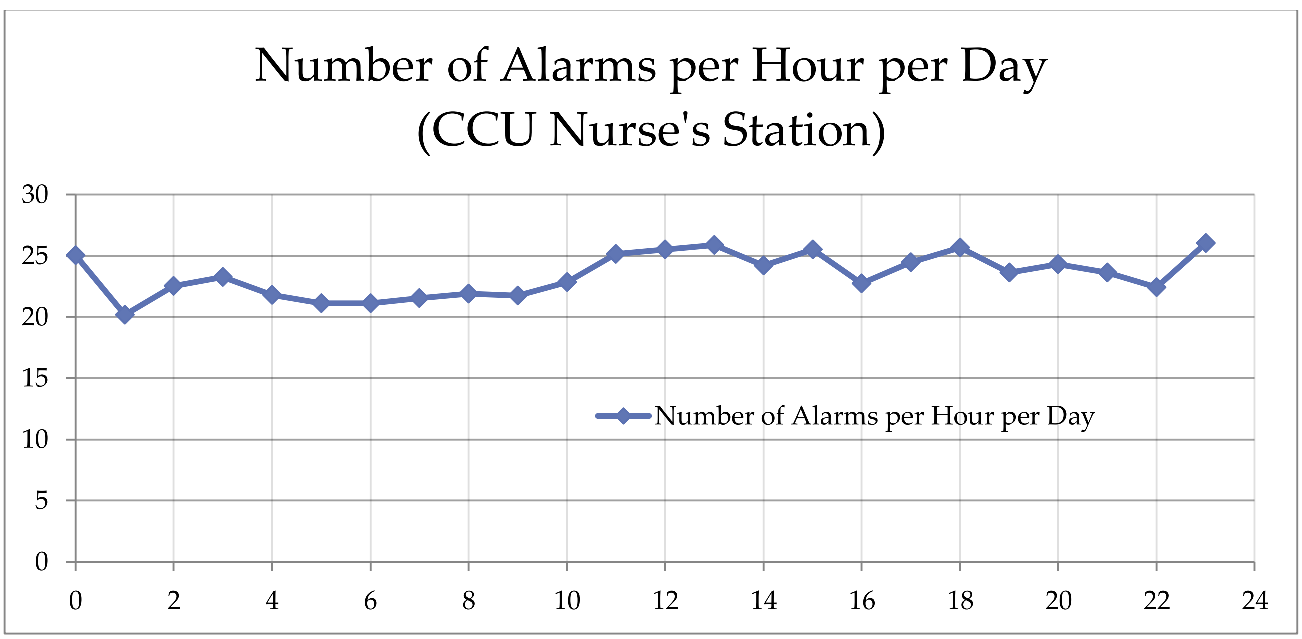


Figure 16: Number of Alarms per Hour per Day (Nurse's Station)

As shown in the figures above, the general number of alarms per hour per day follows little to no organization or trend. This discovery furthermore suggests that the total number of alarms does not decrease during the night hours, but instead proposes a nearly steady amount of alarms even during regular/routine sleeping hours. As one might expect, alarms that occur during normal sleeping hours are a significant source of disturbance for otherwise lower overall ambient noise levels. To better understand the number of alarms that occur during sleeping hours the group was able to isolate the data from a range of 7pm to 7am and recreate the table previously shown in Table 4.

Location	Total # Alarms per	# Medium Alarms per	# High Alarms per
Patient Room	24.00	21.03	2.97
Patient Room	65.38	62.67	2.71
Nurse's	275.04	258.22	16.82

Table 5: PHILIPS Alarm Data for Various Sensor Locations at Night

As previously speculated, the PHILIPS IntelliVue data proved that the number of alarms (more importantly that the number of high alarms) does not decrease during sleeping hours. The adverse effect that alarms have with the overall quietness of the CCU causes the quality of care, and the quality of a healthy healing environment, to diminish. As studied earlier in the literature review section of this report, a desired noise level during the night (necessary for a quiet and healthy night sleep) is around 35 – 40 dB. In addition, the *World Health Organization (WHO)* suggests the maximum noise level to never exceed 45 dB; otherwise the quality of care, the availability for the patient to heal, and the general comfort of that patient is put in jeopardy.

The array of alarm types that occur within the CCU during any given day is extremely sizeable and copious. To better understand the number of alarms under each severity category, ranging from Medium/Yellow alarm to High/Red alarm, we had to isolate the excel spreadsheets further (*Note that the Low/blue and INOPT alarms are not analyzed here since the PHILIPS software is not able to record such alarms). The PHILIPS IntelliVue software breaks alarms up based on severity, giving each alarm type a ranking from one to three asterisks (three being severe and one being not as severe). The group was able to extract the data from each of the three sensor/monitor locations and generate the table of data shown below of the percentage of alarms that fall into each category.

Location	Percentage of * Alarms	Percentage of ** Alarms	Percentage of *** Alarms
Patient Room	69.57	21.34	9.10
Patient Room	84.81	10.22	4.97
Nurse's	74.33	18.55	7.12

Table 6: Percentage of Alarms Based on Severity for Various Locations

Table 5 above shows the general partition of alarms based on severity from a rating of one asterisk to three (three being the highest level of severity). The categorization of alarms based on the level of severity helps give a better understanding to the overall percentage of critical alarms that occur. In a very similar manner, the group was challenged with the task of dividing alarms up based on the biological counterpart that they affected. For example, the team divided alarms up into groups dealing with:

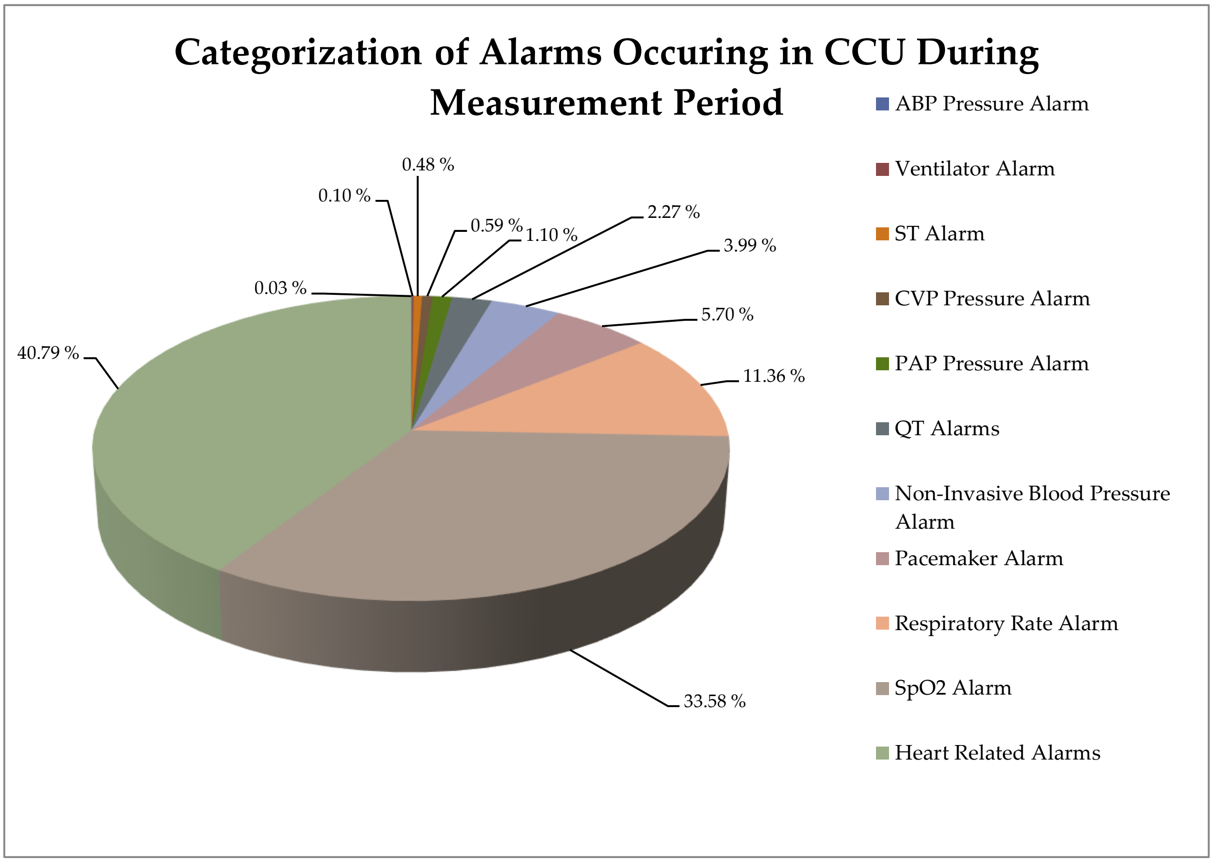


Figure 17: Breakdown of medical alarms by category, shown as percentage of total alarms pulled from nurses' station.

4.3 Discussion

The results of this project give rise to several important observations related to the noise pollution present within the CCU. Noise levels broken down by hour show a clear trend of descending decibel levels at night that rise in the early morning. Alarm data shows the large volume alerts present each day even within the individual rooms. The data also shows many alarms remain present during the night and constitute a disruption to patient sleep. Comparison of noise levels attained through testing with regulatory guidelines on patient sleep environments shows that the soundscape of the CCU is not conducive to restful patient sleep.

There is a clear trend of noise present in the CCU over the course of each 24 hour period. The graphs showing the average sound level by hour for each location within the ward each show a similar shape. These values are visible in Figures 8, 10 and 12. This shape suggests that peak noise level is attained each day in the midafternoon as might be expected. However, this trend can prove detrimental to rest that is normally attained through napping at this time of day. Napping can be an effective way for patients to catch up on rest and speed up recovery time. Thus making it highly desirable to have some period of quiet within the afternoon hours. At this time, the evidence suggests that there is no good afternoon period for patients to attain rest. The trends on these graphs also show a drop in overall decibel level during nighttime hours.

This drop is sustained for several hours before rising again in the early morning. Though the general trend of quieting by about 10-15 decibels that can be seen during this time is a good sign, it is not necessarily sufficient. It seems to be sustained for only a few hours, well below the amount that would be optimal for a full night's rest. Though the general trend is the same there is an offset visible between the three locations. The evidence shows a marked increase in noise at the sensor at the nurses' station there are two likely causes for this outcome. The first is that there is more human activity throughout the day at the nurse's station including rounds. This will obviously lead to increased noise levels as there are more people, more movement and more communication here. The second reason is that all alarms triggered within the CCU sound at the central station along with on the monitor that they are triggered from. This means every alarm triggered throughout the day sounds at the central station leading to more noise on average. The next observation is that patient room 7 which is directly next to the nurses' station shows higher noise averages than patient room 1 which as at a far corner of the ward. Patient room 7 is on average 5-10 decibels louder than patient room 1, as visible in Figures 11 and 13. This difference suggests that the activity and increased noise levels at the nurses' station can have a significant influence on the noise levels of adjacent patient rooms.

Alarms are a serious issue when dealing with noise pollution. The alarms constitute spikes that are easily capable of waking a patient. The other issue from alarms is the psychological effects they have on patients and staff. Both of these problems are suggested by the alarm data recorded within the CCU. Guidelines suggest that noise levels in a sleeping environment should not peak over 45 dB, well below the level that alarms create in the ward. This suggests that any alarms that take place in a patient room or in proximity to a patient room can be expected to have a detrimental effect on sleep patterns. The data shows that there are clearly alarms present during the night. The change in alarms from hour to hour is almost random with not statistically significant decrease visible for nighttime hours, as shown in Figures 14, 15 and 16. The data shown in Table 4 suggests that even the quieter of the two patient rooms experienced an average of 24 alarms per night or about 2 per hour during the night. This would make sleep extremely difficult, let alone an environment like patient room 7 which experienced an average of 65 alarms per night which would be over 5 per hour. Though it is impossible to prevent patients from triggering alarms during the night this evidence clearly suggests that some change to alarm signaling should be made to eliminate the need for these loud alarms through sleeping hours. The other issue that excess alarms presents is alarm fatigue. Nurses are most susceptible to this affliction since they are in the ward for hours each day and are responsible for all the alarms that go off within the ward while they are present. An overwhelming number of alarms can cause anybody to become overly stressed or experience some sort of breakdown from sensory overload. The evidence presented in Table 3 shows that a patient would experience an average of between 50-120 alarms per day, and a nurse may experience closer to 550 alarms per day which is approximately 23 alarms per hour or one every 3 minutes. The data collected suggests that there is significant risk to staff and patient alike of experiencing such a difficulty.

The most important factor in looking at this data is whether or not the CCU is in compliance with recommendations made by the FDA. The FDA suggests that during the hours of 7am to 7pm there should be no spikes in noise level above 45 dB (Organization, 2001) as these are likely to disrupt sleep. The data shown in Figures 8, 10 and 12 clearly shows that for much of the night, on most days tested, the noise did not drop below this guideline value. Further analysis showed that for patient room 1, the noise level was above 45 dB during the night 55% of the time. Worse, patient room 7 was determined to be above 45 dB greater than 99% of the time during the night. This information can be seen in Table 2. These values indicate that current conditions are woefully out of accordance with FDA suggestions. This means that noise within the CCU constitutes a serious crux on restful sleep.

4.4 Recommendations

These recommendations reflect possible ways that the noise levels in the CCU could be reduced in order to create a more calm and restful environment for the patients present. Many of these recommendations could be used or easily adapted for use in a variety of care wards not only in the West Roxbury VA hospital but in other healthcare facilities. These recommendations include sound absorbent ceiling tiles that are already commercially available, curtains that provide better sound dampening than those employed by the hospital, the addition of a partition that would block the empty gap between curtain rod and ceiling at the entrance of each CCU room, the use of a centralized alarm system and pagers that transmit alarms to specific caregivers instead of omnidirectionally through the ward, procedural changes to nurse activities and scheduling could also benefit patient sleep habits.

There are a variety of options for sound absorbing ceiling tiles on the market today. There are certain limitations, however, for any material to be used in a hospital environment. A key requirement is that any material put into the ward must be washable. Armstrong™ is a company that creates a variety of ceiling products including acoustically absorbent products. Some of these products, such as the Optima Health Zone™ product are specifically designed for use in hospital environments.

These products are marketed as being completely washable (Armstrong). This makes them ideally suited for this application and should be strongly considered. A comprehensive guide to the planning, design and implementation of such sound absorbent was produced by the Ceilings & Interior Systems Construction Association (CISCA) and outlines the various factors that must be considered when undertaking such a remodeling plan (CISCA).

Another option for using sound absorbent material within a ward would involve the implementation of new curtains that can satisfy the role of existing curtains within the ward while also dampening sounds from travelling into the patient's room from the body of the ward. Products like the Hush Curtain™ have been used in hospitals before and may provide a solution (Hush Curtain). Further research would be required to ensure they fulfill the necessary roles for a curtain within the ward including being easily cleaned and easily moved by staff and patients. These products have potential to considerably lower noise in patient rooms as testing has shown that the alarms present in the ward's central station contribute significantly to increased noise levels in nearby patient rooms and the curtain is currently the only barrier between these areas.

Another limitation of current curtain barriers within the CU is that they are mounted on curtain rods that approximately a foot below the ceiling itself. This means that even if any sound is absorbed by the curtain, there is still a considerable amount of space for noise to travel over the curtains and into the patient rooms completely unhampered. There are two main remedies that were determined. Either the curtain rods could be moved to reach the ceiling and longer curtains added or partitions made that fit in the existing gap. The latter was determined to be the more favorable option as it does not require any significant construction but instead could be made to snap in place without permanent fixtures. This course of action would also avoid the need to switch curtains to a nonstandard size. This partition does not necessarily need be a dampening material as it only needs to act as a solid barrier. Using a sound mitigating shape or a dampening material could help minimize reverberations. This technique used in tandem with sound absorbent curtains would help to isolate the patient rooms from the central part of the ward which means more patient privacy and comfort.

Alarms are obviously one of the most significant noise irritants in the hospital environment. This is because of the way the monitors currently broadcast an alarm. The standard form for an alarm is for a speaker in the patient room and a speaker in the nurses' station to emit a loud sound that alerts nearby personnel to the existence of a problem and its exact nature. There has been work to change this broad alert system into a more personalized paging system. This would mean that instead of emitting a noise to the entire area, the alarm would be sent directly to nursing staff via a pager device. This device could use vibration along with or instead of sound to effectively alert necessary personnel without alarming or discomforting patients or other staff. Most of this is overviewed or directly managed by one or more watchers who can make sure information reaches the proper hands and that the situation is in fact addressed. These watchers also provide an opportunity to manually filter out alarms that would normally sound and have to be handled by caregivers before the alarm would cease (ECRI Institute). The pagers would be capable of transmitting more information than simple alarm sounds and it could pass on the information in a more efficient and patient friendly means.

Results from this project showed that in several cases, increases in noise could be linked to activities performed by the nursing staff over the entire ward. Events like taking labs and doctor visits can increase the noise level on the ward. These events cannot be eliminated from the CCU's daily schedule. There is also little that can be done by the staff to reduce noise during these interactions. This means the best way to combat these disruptions is by adjusting them to the times of day where they will least disrupt rest. This means avoiding nighttime hours and periods in the middle of the day where patients commonly nap. The two ways of going about this are to do many activities at the same time such that they may increase noise significantly but for only a short time. The opposite course of action could also be used by spreading interactions out as much as possible to try and avoid the creation of noise spikes. The exact nature of any procedural changes would have to be determined by the medical staff themselves as there must be a priority on proper patient treatment and only they can know what protocols can be changed and in what way without compromising patient care.

Any or all of these recommendations could be executed to significantly reduce noise levels within the CCU or within many hospital environments. Many of these recommendations rely on products that are designed specifically for use in the hospital environment and are commercially available. Solutions not outlined in detail could be the subject of further research by students or professionals. These recommendations are designed only as a starting point and are by no means a comprehensive list of all possible solutions or products available. Further analysis based on the exact needs of the hospital and the particular ward should be done in order to determine the exact effect of any of the recommended courses of action.

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APPENDIX A: LITERATURE REVIEW DOCUMENTS

An Evidence-Based Approach to Reduce Nuisance Alarms and Alarm Fatigue

James Welch

Key Terms

1. **Actionable Alarms**: Alarms that require a response to bedside and therapeutic intervention to avoid an adverse event
2. **Alarm Fatigue**: Failure to recognize and respond to true alarms that require bedside clinical intervention as a result of high occurrence of alarms
3. **False Alarms**: Alarms due to artifact that produce false data
4. **Non-Actionable Alarms**: True alarms that do not require patient therapeutic intervention
5. **Nuisance Alarms**: The high occurrence of clinically non-actionable alarms.

The occurrence of false and nuisance alarms in the hospital environment has continually been ranked one of the "Top 10" technology hazards by the ECRI institute. A link has been found between the occurrence of false alarms and a decline in clinician attentiveness to the alarms (L., 2010). Decreasing the amount of alarm fatigue in the hospital environment is a responsibility taken on by not only clinicians, but also biomedical engineers and industry leaders. In a study conducted by one emergency department, less than 1% of alarm occurrences were clinically actionable. The current strategies being applied to the problem of alarm fatigue are optimization of the signal path, technology innovation and examination of alarm policies. Technological innovations in the field of signal processing and analysis have significantly reduced the number of alarms in the recent past.

Another method to reduce alarm fatigue that is becoming popular is the reduction of the Sp02 alarm thresholds from the standard 90%. A reduction of this threshold obviously can have some dangerous effects. Part of why we are summarizing these articles is to prove to the Veterans Affairs hospital that doing so is a viable option for them. John's Hopkins Hospital reduced pulse oximetry alarms by nearly 63% in a study that they conducted by reducing The Sp02 threshold from 90% to 88%. The Veteran's Affairs hospital that is sponsoring our project is looking to decrease their threshold to these same levels. There are many more alarm optimization techniques that are applicable to this situation. Each method has its own pros and cons that must be considered individually to determine the effectiveness it will have when implemented at a specific hospital.

There are many technological factors that weigh in to the accuracy of an Sp02 reading. Proper application of the Sp02 sensor is critical to its functionality. A sensor that has not been fitted properly to the patient cannot be expected to generate actionable alarms. - Disposable, single patient use sensors are less prone to create nuisance alarms that lead to alarm fatigue. Second-source recycled sensors might provide a financial savings, but also risk spreading contaminants from patient to patient. The Boston VA healthcare system is currently using disposable, single patient use sensors. There are many sensors currently on the market, and one of our final goals is to develop and design a more cost effective and reliable disposable Sp02 sensor.

Signal processing is another field that has experienced many innovations recently. Reducing alarms due to false data is essential to an alarm management strategy (Welch, Spring 2011). Sp02 sensors are most accurate and reliable on immobile patients. Measurements that are being taken on active, mobile patients are often unreliable and incorrect. It is common that pulse oximetry readings can freeze, zero out or falsely alarm during patient motion.

Alarm settings have a large impact on alarm frequency and modifications made to time delay and Sp02 threshold have been shown to drastically reduce the occurrence of false alarms. The study that Welch performed ultimately created a synthesis of information involving time delays and Sp02 threshold level reduction. Time delay is a very efficient and safe way to regulate the amount of false alarms. A patient that simply holds their breath for an extended period of time can drop their Sp02 level below the threshold level. Any sort of movement can also create spikes in the threshold levels. As a result adding a time delay to the Sp02 alarm would allow the patient a certain duration to recover their Sp02 level, effectively weeding out alarms caused by a single movement spike or the like.

Reduction in Alarm Frequency				
	Alarm Delay			
Low SpO_2 Alarm Threshold (%)	0 sec	5 sec	10 sec	15 sec
90	Reference	32%	57%	70%
89	27%	51%	69%	79%
88	45%	64%	78%	85%
87	58%	74%	84%	89%
86	68%	80%	87%	91%
85	75%	85%	87%	91%
84	80%	89%	93%	95%
83	84%	91%	95%	97%
82	87%	93%	96%	97%
81	89%	95%	97%	98%
80	90%	96%	97%	98%

Figure 18: This table demonstrates how a combination of Sp02 threshold reduction and alarm delay can produce a decrease in false alarms.

Again, combining alarm delays and lowering the Sp02 threshold is the most effective way to decrease the occurrence of false alarms. The application of both of these changes will not only produce a significant amount of alarm reduction but will also preserve the integrity of actionable alarms. Another effective strategy that can be employed by biomedical engineers is to introduce an alarm averaging filter to the Sp02 alarm. For nearly the same reason as why adding an alarm delay is beneficial, alarm averaging will limit the number of false alarms due to movement spikes. By adding an alarm averaging setting to the Sp02 system, the reported values actually represent an averaged Sp02 level over a user defined time period. Accordingly, the system will not respond just to spikes, but only to an averaged Sp02 level that will produce a meaningful, actionable alarm. (Welch, Spring 2011).

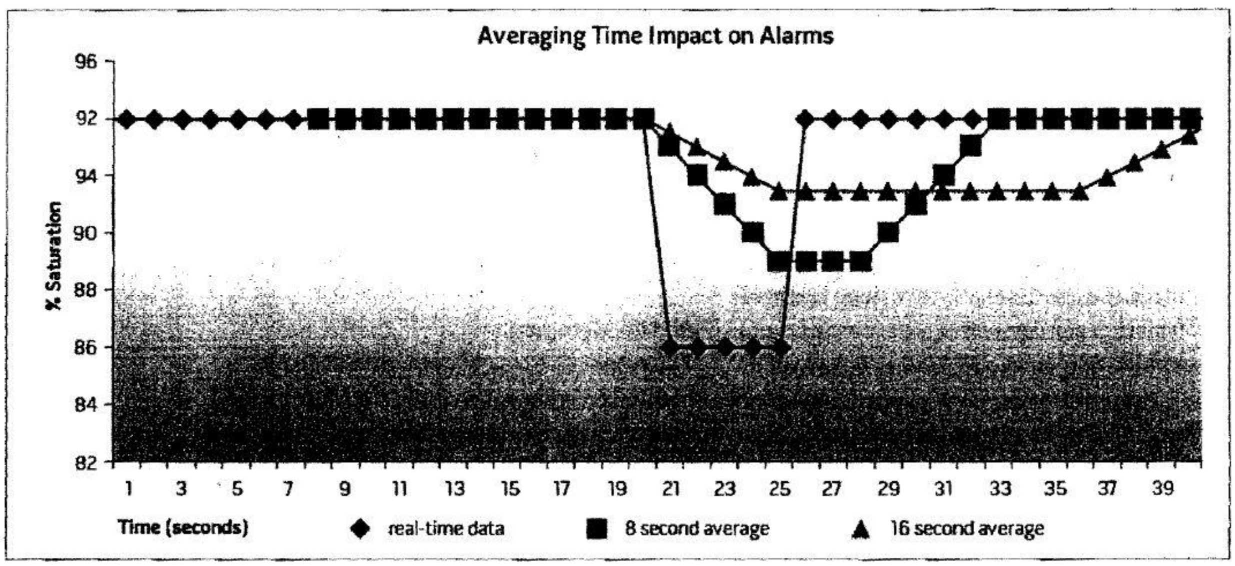

Figure 19: This graph demonstrates how the addition of an alarm averaging strategy can decrease the number of false alarms due to Sp02 spikes.

The clinicians at the VA hospital have the final say in any sort of policy change in regards to alarm settings. We hope to assist their decision making process by analyzing how current trends apply to their situation specifically. A balance is sought between patient safety and an acceptable amount of alarms. In an ideal situation, the only alarms that sounded would be actionable alarms that required bedside assistance. Because of physiological uncertainties and many variables that affect sensor readings, the best we can hope for is a reduction in false alarms. The choice of sensor threshold limits will not simple be based on research evidence alone, because factors such as patient to nurse ratio must be considered as well. General care areas will make better use of a systems approach because nurses are typically not immediately available when an alarm sounds. Frequency of alarms, especially false alarms, disrupt the rest cycle of recovering patients and leads to alarm fatigue on the ward. Optimization of alarm behavior can be achieved by a combination of research findings and observed trends in the specific hospitals setting.

Noise Levels in Johns Hopkins Hospital

Ilene J Busch-Vishniac et. Al

Over the past 45 years there has been a significant increase in sound levels apparent in hospitals around the nation. To add to this problem, it has been discovered that "many units exhibit little if any reduction of sound levels in the nighttime."[2] In response to the rising sound levels in local hospitals Florence Nightingale, in 1859, published an article suggesting that "…unnecessary noise, is the most cruel absence of care which can be inflicted either on sick or well [patients]."[3] Overall, noise complaints are the largest source of lack of comfort within hospital environments; clearly something has to be done to alleviate this complication…

The levels of noise apparent in the hospital environment may be detrimental to patients and care givers in more than one way. "There is evidence that the high sound levels in hospitals contribute to stress in hospital staff and a suggestion from one study that noise contributes to staff burn-out. Further, there is some evidence that noise negatively affects the speed of wound healing."[1] These arguments are very valid, and

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[2] Busch-Vishniac, Ilene J., James E. West, Colin Barnhill, Tyrone Hunter, Douglas Orellana, and Ram Chivukula. "Noise Levels in Johns Hopkins Hospital." *The Journal of the Acoustical Society of America* 118.6 (2005): 3629. Print.

[3] Florence, Nightingale, *Notes on Nursing* (Dover, New York, 1969).

furthermore some may argue that the elevated sound levels may contribute to *medical errors* – instrument noise may interfere with communication attempts by caregivers, causing safety hazards from the inability to accurately comprehend what was being said. Overall, the sound levels in hospitals have several detrimental causations, which lead many professionals to argue for a more efficient system for the future.

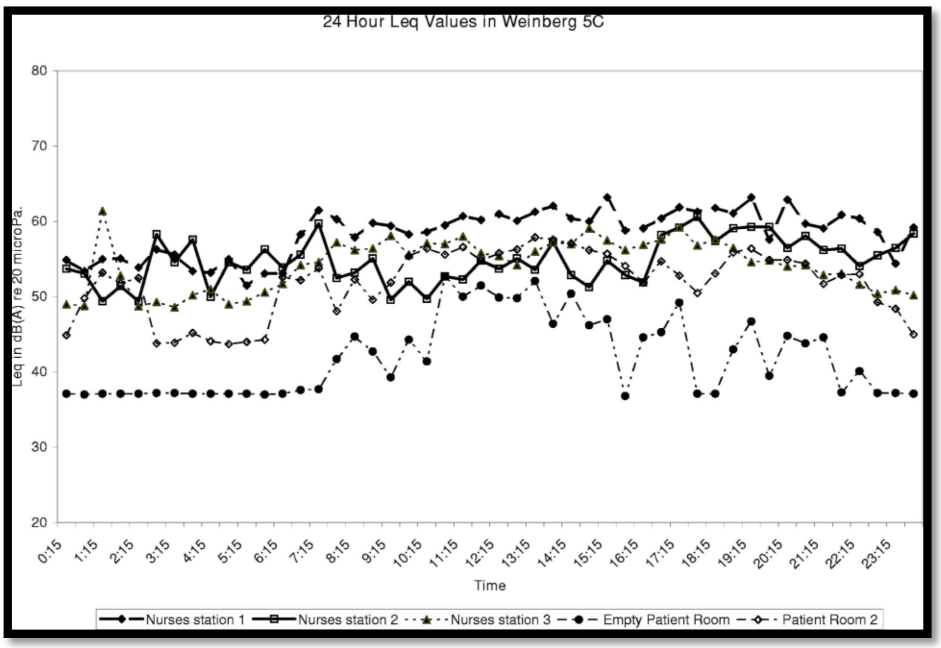

Figure 20: Graph of Decibel Levels vs. Time of Day (Military Time)

As you can see in the graph above, sound decibel level vs. time of day, there is no <u>real decline</u> in decibel readings within the patient's rooms, nurse's station, and hallway during the night. The graph shows that for the most part, with a small exception for the hours of 1AM to 5AM, the sound level is constant at around 50-60 dB max and 40-52 dB average throughout the day. "A straight line fit to the data shows an increase, on average, of .38 dB per year for daytime levels, and .42 dB per year for the nighttime levels [since 1960]…"[4] The increase in sound levels in hospitals over the past 50 years suggest that the problem is getting worse, rather than better.

The *World Health Organization* published an article in 1995 entitled *Guidelines for Community Noise*, which attempted to regulate the "allowable" sound levels for hospitals…

"[*Guidelines for Community Noise*] recommended an Lmax of no more than 40 dB at night. They also suggest a patient room Laverage of no more than 35 dB during the day and 30 dB at night…"[3]

The suggestions made by the (WHO) are extremely relevant to our own project at the VA Hospital in West Roxbury, MA. It is our ultimate goal to find the operating noise levels in the hospital and then <u>trace</u> where the noise is coming from. In addition, we hope to use several other articles similar to this one to establish the largest cause of noise; at this point we suspect that the source is largely due to false alarms, non-

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[4] Busch-Vishniac, Ilene J., James E. West, Colin Barnhill, Tyrone Hunter, Douglas Orellana, and Ram Chivukula.

responsive alarms, and SP02 Sensor alarms. We hope that by identifying the source of the problem, we will be able to further pursue a solution. At this point of our studies, we hope to gather information regarding noise and SP02 Sensor technology to be able to regulate new changes to the way in which hospitals standardize their operation; this may eventually lead to the adjusting of “cut-off” points and/or delay times for the Pulse Oximetry Sensors (all of this will be discussed in later reports).

Hospital noise pollution: an environmental stress model to guide research and clinical interventions

Margaret Topf

This article sets out to create a model for how noise contributes to stress in a hospital and particularly CCU setting. The model takes a step by step look at the factors that contribute to stress and how this stress can be alleviated. The article starts by looking at the concept of ambient stressors. Then they examine deeply the subjective reaction to these stressors and how this creates actual physical stress. They then explore the effects such subjective stress can have on the body. The article starts by looking at the concept of ambient stressors. Then they examine deeply the subjective reaction to these stressors and how this creates actual physical stress. They then explore the effects such subjective stress can have on the body. Finally they examine some ways that stress could be minimized at each stage of the model.

The first topic is the idea of ambient stressors. An ambient stressor is any environmental factor that can contribute to stress in an individual. For the purpose of this article they focus on the concept of noise pollution within the hospital as a stressor. They present data that indicates that noise is in fact a major stressor that is found in most, if not all, hospital CCUs. The article stresses that though stressors are an objective observation of the environment they have strong links to subjective feelings of stress.

This means that noise is characterized as a stressor objectively by observing that it is loud, this does not necessarily indicate that people are stressed by it, just that the high noise levels exist. The article notes that data recorded from hospitals as found noise in CCUs to range from 60 to 80 dB or so, about the noise level of heavy traffic. This certainly indicates an ambient stressor.

Once noise is identified as an ambient stressor the article investigates the correlation between this stressor and the subjective feeling of stress. The article finds that there is significant correlation between people who indicate that the noise level is high and those report a high level stress. This relates a clear picture that noise does have an effect on some patients. The article indicates that demographics have been seen to be particularly susceptible to this stress. For instance it was shown that the women are more likely than men to suffer stress from the high noise levels, it was also discovered that elderly patients were likely to have more stress induced by the loud noise. An interesting relationship was that patients in more pain or under heavier medication also showed a higher disposition to be affected by noise. This is particularly relevant in a CCU setting were a significant amount of the patients are there for critical reasons and are likely to be under medical duress. Even though certain factors make patients more susceptible to stress, stress is fundamentally an individual response. It is unlikely that the two individuals will feel exactly the same when presented with the same stressors even if they fall into similar demographics. There are too many variables to take into account, such as personal issues, the level of sound they are acclimated to, or if a particular sound or rhythm affects them more than others. A significant factor in deciding whether or not a person is caused stress by an environmental factor is how much control they feel they have over it. A subject is able to easily cope with a stressor if they have the power to exert some control over it, in the case of noises in a hospital this is often not the case. Regulations keep issues of noise and alarms largely out of the hands of the patient. A particularly powerful example of this is when an alarm goes off in a patient's room as they often have no idea what the alarm means and are powerless to fix it until a doctor or nurse arrives. Only through individual attention can exact stress levels for a patient be understood.

The stress created by excessive noise has been linked to significant physical and mental ailments sometimes experienced by patients. The easiest way noise can have an impact on patients is through the effect on sleep. The FDA recommends that noise levels during the night in a hospital setting not exceed 45 dB but data taken from a hospital showed that noise levels never dropped below 50 dB throughout the night and even spiked as high as 80 dB . Studies have shown that under simulated CCU noise subjects have a significantly harder time falling asleep than subjects who slept under normal residential noise levels. Sleep is essential in a CCU where patients may be recovering from serious procedures. Sleep contributes to the healing of tissues and cell regeneration. Without proper rest patients can experience significantly impaired healing rates along with normal side-effects of sleep deprivation like low attentiveness and lethargy. Along with these extensive physical problems come serious mental issues that have been tied lack of sleep and excessive stress. Mental issues can include irritability, social withdrawal, disorientation, delusion or even hallucinations. Such serious physical and mental traumas are the precise opposite of the intent of a hospital and are counterproductive to proper patient care.

There are many options that can help with the alleviation of the noise pollution stemming from different parts of the stress model. Starting with the ambient stressor itself noise could be reduced. The article suggests many ways that this could be achieved. Some are simple like laying carpet in high traffic areas to reduce footsteps while others are more complicated like replacing audible alarms with pagers that indicate alerts. On the subjective level, personal interventions may help with the subjective factors that create stress. This means interview or screening to help identify when stress is likely or has started to occur. This may also mean trying to give patients some control over their noise level in order to ease the stress caused by lack of control. Sometimes it is enough to explain certain noises to patients to put their mind at ease but in other cases it may even be possible to give patients the ability to turn off alarms themselves.

In summary, the article is a step-by-step evaluation of how noise levels contribute to patient health within a CCU. This model examines and dissects the mechanisms by which noise induced stress can manifest into a tangible medical ailment. The first part of this model examined the concept of noise as an ambient stressor and concluded that there is sufficient evidence to consider noise a significant environmental stressor within a hospital. The model then analyzes the means by which such a stressor can contribute to an individual's subjective stress level and the effects of personal control on such a contribution. The model is then able to attribute physicals problems such as sleep loss to these elevated noise and stress levels which allows one to see that noise can eventually lead to serious sleep-deprivation related conditions. Once the article has traced the creation of noise to its armful side-effects on the patients exposed to it, it concludes with suggestions on how one might improve a traditional CCU to provide alleviation of stress, and ultimately the problems that go along with it, at each level of the model. This model creates a good standard by which to categorize factors that relate to high noise levels within hospitals. The model is practical and thorough in its separation of factors into concise categories that help in the identification, prevention or correction of serious noise related traumas to patients while staying in a CCU.

Decreasing Alarm Fatigue: Standardizing Use of Physiological Monitors Decreasing Nuisance Alarms

Graham, C. K., & Cvach, M.

Most if not all modern day hospitals employ the use of physiological monitors on patients to alert care givers of changes of interest that are abnormal to set parameters. These include cardiac monitors and pulse oximetry monitors. It is common for the vast amount of monitors to have false alarms also referred to in the article as "nuisance" alarms. The article took a survey of 1300 health care professionals to which they obtained the following "nuisance alarms occur frequently (81%), disrupt patient care (77%), and can reduce trust in alarms, causing clinicians to disable them (78%)." These statistics clearly show that false alarms are having an adverse effect on medical professionals overall care for the patients. The article also stated that "a high percentage of false positive alarms produced by physiological monitors, which result in a change of patient management less than 1% of the time." The drop off in overall care for patients can be attributed to a condition known as alarm fatigue, in which the nurses are subjected to so many alarms and alerts that they are eventually desensitized to the alarms.

It is apparent that the reason for many false alarms is due to the high sensitivity of the machines being used, in which a change off 1% could result in an alert. Nurses eventually become accustomed to these alarms for which an alert went off due to natural fluctuations in human beings. This results in care givers ignoring or disabling alarms which potentially has adverse effects for the patients. It has been reported according to the article that "nurses in intensive care units stated that the primary problem with alarms is that they are continuously going off and that the largest contributor to the number of false alarms in intensive care units is the pulse oximetry alarm." This is due to the parameters set by pulse oximetry sensors being set very high in some cases and due to natural fluctuations in people's 0_2 stats.

The authors of the article performed several tests to discover the legitimacy of the problem of alarms and alarm fatigue. The results showed that often the parameters set by the hospital are inappropriate and that many alarms go off due to inappropriate parameters. They suggest that the staff addresses these alarm parameters and discuss whether they should be adjusted to a more appropriate level. The article also suggested moving the alarms parameters to more actionable levels in which there would be a decrease in the number of false-positives and increase the probability of the alarms occurring in actionable ranges. Nurses should also be trained in how to individualize alarms and finally institutions should also have institution wide standards.

Impact of Pulse Oximetry Surveillance on Rescue Events and Intensive Care Unit Transfers

Taenzer, A. H., & Pyke, J. B

The major concern of the article is that of post-operative care. They explain that during a procedure there is much focus on reducing risk factors and improving morbidity and mortality. Much less emphasis is placed on that of postoperative period. In the article they explain that after an operation there are many complications that arise due to deterioration after surgery. This is due to the fact that there is very little constant monitoring of the patients post-op. This means that often nurses intervene when it is too late and the patient is past the point of no permanent damage. This could have been prevented if they had had more post-op attention and constant detection of patient deterioration. The team in the article implements a patient surveillance system (PSS) post operatively to try and monitor post op deterioration. The device was a continuous pulse oximetry monitor that would be wirelessly hooked up to a pager which the nurse would carry at all times in hopes that if the patient were to have significant deterioration the nurses would be alerted immediately

They expressed several issues with post op care that was a major cause for the necessity of implementing one of these devices. First of they realized that nurses often have many monitors to look after and that the nurse could experience alarm fatigue in which they begin ignoring or disabling alarms due to constant false alarms. Secondly they noted that often the ratio of nurses to patients is quite low. Often this means a nurse's workload can be too great and often patients are affected due to periodic monitoring instead of constant monitoring of the patient's health.

In general the standard hospital care has intermittent observation of vital signs and only increased care for those who have already been classified as high risk for adverse side effects. They found that by using the device they were able to significantly reduce rescue calls from 3.4 to 1.2 per 1,000 patients. The device worked by using a "detection of physiological deterioration based on field triage algorithms" which allowed the device to provide continuous care to the patient assisting the nurses in environments where constant care is unavailable. The device they implemented also addressed the alarm fatigue by adjusting the devices parameters according to standards they felt were more relevant. This all resulted in improved patient care overall and satisfaction by nurses who used the device as well.

Risk Factors for Hospital Readmission of Elderly Patients

Carlotta Franchi, Alessandro Nobili, Daniela Mari

European Journal of Internal Medicine, July 2012

Key Terms:

Hospital Readmission: Patients were readmitted to the hospital within three months after discharge. 19% of patients studied were readmitted at least once within 3 months after discharge.

Adverse Events (AEs): Events patients encountered during their hospital stay that can be seen to prolong the healing period or contribute to increased likeliness for **Hospital Readmission.**

A decrease in hospital readmission rates is favorable amongst hospital staff as well as patients and their families. It is important in order to improve the quality of care and reduce overall costs associated with patient stays. Healthcare physicians are often prompted by hospital administration to minimize the length of patient stays, as well as decrease the likelihood of patient readmission. In this study, nearly 1200 patients aged 65 years or more were studied to pinpoint risk factors that could be used to predict the likelihood of that patient to be readmitted to the hospital within a 30 or 60 day period. Logistic regression (statistical method) was used to evaluate the association of certain risk factors with hospitalization rates.

The variables that were focused on in this study were as follows. Demographic data, relating to age, sex, education, marital status, BMI and lifestyle habits were not included. Clinical Variables described as the length of patient stay and previous hospital readmission records and the number of diagnoses and prescribed drugs at time of discharge. The patient's depression status as well as their ability to perform basic activities of daily living (using the Barthel Index). In order to document patient details and make data collection simple, an internet form was created for clinicians to document the above factors. Patients were followed up with three months after being discharged to collect more information on new diagnoses, hospital readmission status, drug regiment and additional AEs that occurred post-discharge.

The re-hospitalization rate was calculated for patients that were successfully contacted for a follow up and had a well-documented stay at the hospital via the internet form. Statistical analysis methods were used to develop models that were used to study the association of selected variables with the presence of re-hospitalization. A table was created from the analysis software used that can be used to view the presence of certain risk factors with the re-hospitalization status of patients (page 3 of the study). The rate of hospital readmission within 3 months from discharge was found to be 19% of the patients studied. According to the background literature of this study, the factors that might be related to the risk of readmission of elderly people are Functional Status

Score, Illness Severity, Co-Morbidity and Polyphamacy. Readmitted patients suffered more chronic illness with a higher severity index, consumed more drugs, developed an AE during their primary hospitalization and were often hospitalized in the 6 months prior to their primary hospitalization. There was no significant associated found between the likelihood of readmission with age, gender, marital status, education, living arrangement, BMI, smoking or alcohol consumption.

Healing Environment: A Review of the impact of physical environmental factors on users

E.R.C.M. Huisman

Building and Environment, May 2012

Key Terms:

Healthcare Facility (HCF): Traditional and institutionally designed health care facilities including hospitals.

Patients and their families (PF)

Evidence-Based Design: Design of Healthcare Facilities based on scientific evidence and research findings.

The study conducted in this paper was conducted to show the effects on PF and healthcare staff from the perspective of various aspects of physical environmental factors of HCF. This study is very important because a total of 798 papers were identified that fit the inclusion criteria. Out of those papers, 65 articles were chosen to be reviewed and their findings and evidence pulled together to support the research. Papers that did not include enough physical evidence. Many of the outcomes of these papers indicated that evidence of staff outcomes was insufficiently substantiated. As such, the primary focus of the study was to highlight relevant findings pertaining to the design and construction of HCF. Design features to consider for future designs were found to be single patient rooms, identical rooms and lighting. The main area that we are concerned with was in relation to acoustic analysis of HCF and how it pertains to our own study.

In recent years, a growing interest has been seen in outfitting healing environments with technology as part of the holistic treatment of patients. Important discussions were indicated linking technology with patient care. Evidence based design has become standard, where healthcare facilities are designed around scientific research linking certain design principles or building features with an increased likelihood of patient recovery. Our project should be viewed as one of the studies trying to quantify a phenomena (HCF acoustics) to be used as evidence for evidence based design. The outcomes of our study may not have as many direct implications on the HCF as we would like, but it should give an indication of how design principles may be utilized to maximize acoustic comfort in the HCF, ultimately leading to an increase in patient comfort and decrease in recovery time.

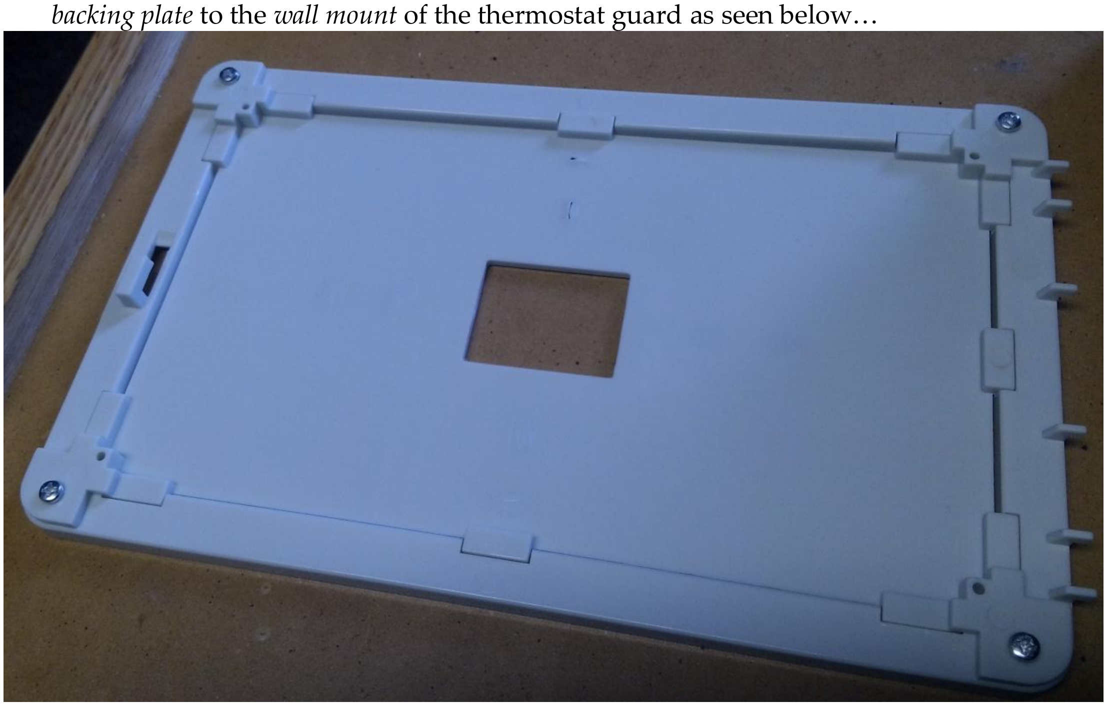
The study of acoustics in this research was not very in depth, but rather directed us to papers and other studies concerning acoustical phenomena in relation to patient comfort and recovery rates. That is the crucial link that needed to be found. Without any substantiated evidence showing that patient recovery rates and comfort can be linked to acoustic levels or sound pollution in the healing environment, our study would have produced meaningless evidence. By drawing similarities between our acoustical analyses of the hospital we are studying, we can discuss how design principles addressing these acoustics can therefore lead to an increase in patient comfort. ‘

The study noted by this paper conducted by Blomkvist et al. indicated that the improved acoustics had affected the psychosocial environment in the HCF. The study also showed that improved acoustic conditions in the healing environment reduced the risk of conflicts and errors, which translates to a better healing environment not only for PF but also for healthcare staff. The most important acoustic parameters were found to be sound pressure level and reverberation time. Sound pressure analysis was also conducted in the Johns Hopkins hospital paper included in this literature review. One of the major findings was that the main repercussion of a high noise level is the effect on patient’s quality and quantity of sleep. Quality of sleep is crucial to patient’s recovery, and many patients never experience a full sleep cycle while in the hospital environment. The findings of these articles documenting sleep trends vs. noise levels will also be extremely helpful when analyzing the results of our own findings.

Sensor Case Construction

1. Product #G0457466 was ordered from ZOROTOOLS.com. The thermostat guard had dimensions 8-11/16 x 5-3/16 x 3-1/2 (Height x Width x Depth)

2. 4 x 3/8″ bolts and nuts were purchased from a local hardware store and utilized to secure the *backing plate* to the *wall mount* of the thermostat guard as seen below…



3. A round hole in the top of the guard was cut to accommodate the microphone portion of the sensor previously purchased from *Extech*.
    a. Utilizing a 1-1/4″ diameter diamond dusted hole saw we cut a hole in the middle-dead-center of the top face of the thermostat guard (opposite the key mechanism).
    b. Using 150+ grit sand paper we smoothed the edges to prevent cracking or sharp edges.

4. The thermostat guard was reassembled and locked with the supplied key

5. In order to mount the sensor we utilized 3M adhesive Velcro, enabling the sensor to be removed from the Plexiglas box easily (in order to withdraw the SD card and obtain the data it had collected while operating).

6. Similar to step (5) we used 3M adhesive Velcro to attach the thermostat box to the wall of the CCU at the VA hospital in order to avoid drilling/screwing into the wall (which required approval from hospital engineers).