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EVALUATION OF HOSPITAL SOUNDSCAPES TO IMPROVE PATIENT AND STAFF EXPERIENCE

Jay Bliefnick
University of Nebraska, jbliefnick@unomaha.edu

EVALUATION OF HOSPITAL SOUNDSCAPES TO IMPROVE PATIENT AND STAFF EXPERIENCE

by

Jay Michael Bliefnick

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EVALUATION OF HOSPITAL SOUNDSCAPES TO IMPROVE

PATIENT EXPERIENCE

Jay Michael Bliefnick, Ph.D.

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Advisor: Erica E. Ryherd

Hospital soundscapes can be difficult environments to assess acoustically due to the continuous activity within units. Routinely, patients perceive these soundscapes poorly when rating their hospital experience on HCAHPS (Hospital Consumer Assessment of Healthcare Providers and Systems) surveys administered after discharge. In addition, hospital staff can be negatively impacted by the acoustical environments in which they work, affecting both performance and job satisfaction. This doctoral research addressed these issues across three phases by collecting acoustical measurements within three individual hospitals, comparing results with provided patient and staff survey information, and conducting laboratory tests of hospital noise perception.

In the first two phases of this research, 38 patient rooms from 11 units within three hospitals were measured acoustically and correlated with HCAHPS 'Quietness of the Hospital Environment' surveys at room and unit-levels, revealing acoustical metrics linked to patient perceptions of hospital soundscape conditions. Metrics found to be most statistically correlated ($p < 0.05$), included the absolute LA_{MIN} levels in patient rooms, which found significantly higher HCAHPS 'Quietness of the Hospital Environment' scores in units with average LA_{MIN} levels below 35 dBA. Many other standard acoustical metrics (such as LA_{EQ}, LA_{MAX}, LC_{PEAK}, and LA_{90}) were not found to be statistically

correlated between measured acoustical data and HCAHPS ‘Quietness’ patient responses, emphasizing the difficulties faced when evaluating hospital soundscapes.

The third phase of this research involved the creation and administration of a subjective perceptual laboratory test designed to assess the annoyance perception of hospital soundscapes with varying dynamic ranges of noise. It was found that subjects perceived soundscapes with a wider dynamic range of noise and louder peak noise events more negatively than soundscapes with a more consistent sound level.

Taken as a whole, this study provides new insights into the potential relationships between hospital noise and patient and staff satisfaction. The three research phases aimed to address this issue from different perspectives to provide a broad assessment of this very complicated issue. The data gathered and presented could be utilized to more accurately assess hospital soundscapes and ultimately aid in the design process of new hospitals to improve patient and staff satisfaction.

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Chapter 1

Introduction

1.1.1 Background & Motivation

Anyone who has spent time within a hospital can understand that they can present challenging acoustical environments. Staff and patient communication, alarms, paging systems, medical procedures, and mechanical systems are just a few examples of the noise found within hospital units, often leading noise to be a complaint among patients, staff, and visitors. [1, 2] This problem is not new, as noise levels within hospitals have been studied for more than 50 years, and in fact shown to have risen on average more than 15 decibels between 1960 and 2005, for both daytime and nighttime levels. [3]

Complicating these acoustical environments are the transient nature and varying levels of many of the sound sources. Present anywhere within hospitals are both constant noise sources, primarily caused by heating and ventilation equipment (HVAC), and temporary noise sources such as speech, medical procedures, alarms, doors/equipment bangs, bathroom sounds, etc. These two types of noise combine to create soundscapes that include relatively steady background noise levels (BNL) together with unpredictable interjections of sound. Identifying the issues caused by transient noise within hospitals, a new acoustical metric, Occurrence Rate, was developed as an adaptation of standard percentile level metrics to better analyze the variability found in acoustical time-history measurements. [4, 5] As most published research involving hospital acoustics have concentrated on time-averaged noise levels, such as equivalent sound levels (LA_{EQ}) or minimum and maximum measured levels (LA_{MIN} & LA_{MAX}), the Occurrence Rate metric was designed to look at finer details related to the transient nature of sound over time to better assess challenging acoustical environments.

While studying the noise levels within hospitals can be enlightening, measurements alone cannot determine the impact of noise on patients or staff. In an effort to improve patient experience, the Center for Medicare & Medicaid Services published the Hospital Consumer Assessment of Healthcare Providers and Systems survey (HCAHPS, pronounced "H-caps"), the first standardized national and publically reported survey assessing the perspectives of patients' hospital experiences. [6] The survey asks discharged patients 25 questions (in 11 categories) about their recent hospital stay, including but not limited to the overall rating of the hospital, the communication and responsiveness of nurses and doctors, and (most important to this study) the 'Quietness of Hospital Environment'. Since the survey was instituted in 2006, 'Quietness of Hospital Environment' has been consistently one of the two worst rated HCAHPS categories reported, but unfortunately, there has not been research published systematically linking measured sound levels to HCAHPS scores within patient rooms and/or hospital units. This lack of information limits the effectiveness of potential acoustical interventions aimed at helping hospital soundscape conditions and increasing HCAHPS scores to ultimately improve patient care.

1.1.2 Study Outline

The primary purpose of this study was to examine relationships between hospital noise and occupant perception. To accomplish this goal, the study included the following specific objectives across three phases:

Phase I: Relate measured noise levels with HCAHPS patient survey results from 5 units within a large urban hospital

Phase II: Relate measured noise levels with HCAHPS patient survey results as well as staff surveys from 6 units within two smaller, rural hospitals

Phase III: Analyze the perceived annoyance of hospital noise in a subjective perception test in a controlled laboratory setting

To complete Phase I and Phase II of this study, acoustical measurements were conducted in three independent hospitals, from 11 hospital units, totaling 38 patient rooms and 12 nursing stations. In these measurements, a vast array of acoustical metrics were gathered and/or computed for analysis, including the aforementioned LA_{EQ}, LA_{MIN}, LA_{MAX}, and Occurrence Rates. In addition, HCAHPS results were provided by each hospital, which were then correlated against the multitude of acoustical metrics. This analysis between acoustical data and patient satisfaction information was used to identify specific metrics and other important factors that could be utilized to accurately assess hospital soundscape conditions. These findings could potentially be put to use in existing or future hospital environments, with the ultimate goal of improving patient experience.

Phase I of this study was conducted at a large urban hospital, located in Omaha, Nebraska and will be denoted Hospital U1 in this document. Acoustical measurements were collected from five units within the hospital, which were selected based on widely disparate HCAHPS 'Quietness of Hospital Environment' average unit scores. Three patient rooms within each unit were measured for 24 consecutive hours using sound level meters (SLMs) mounted near the patient bedsides. Additionally, the busiest nursing station within each unit was measured for 24 hours. Once all measurements at Hospital U1 were complete, the gathered data were correlated with HCAHPS survey results by room to determine any meaningful correlations. It was found that many averaged acoustical metrics, like LA_{EQ}, were found to not be correlated with 'Quietness of Hospital Environment' results due to the significant noise variability found over the 24 hour measurement periods. Ultimately, a limited number of metrics were found to be correlated with HCAHPS results, including minimum sound levels, specific low frequency ranges, and Occurrence Rates calculated for LC_{PEAK} and LA_{EQ} metrics.

Phase II of this study involved acoustical measurements conducted at two smaller, rural hospitals, also located in Nebraska. Both hospitals, denoted Hospital R1 and Hospital R2, included three units where acoustical measurements were conducted: ICU/Critical Care, Medical/Surgical, and Women & Children's. Within each unit 2 – 5 patient rooms were measured, along with 1 or 2 nursing station(s) for 24 hour periods using the same methods that were employed at Hospital U1. Once again, the collected acoustical data were correlated against HCAHPS 'Quietness of Hospital Environment' survey results to determine potential meaningful correlations. However, the HCAHPS for these hospitals were not delineated by room, so the analysis was limited to hospital-wide values. In addition to the HCAHPS survey, a recently conducted hospital administered staff survey was also available for comparison with measured acoustical data, providing a second form of analysis regarding the perception of noise within the hospitals. These further correlations helped to corroborate some findings from Phase I of this study and substantiate the importance of minimum noise levels and the impact transient sounds can have on hospital patient satisfaction.

Phase III of this study built upon results found in Phase I of the research by creating a more detailed laboratory test of subjective perception. In the Phase I and II hospital measurements, patient rooms with more varied sound levels (as opposed to constant sound levels) were found to be related to higher HCAHPS survey results. This result was interesting, so it was desired to investigate this relationship further. To this end, subjective perceptual tests were designed to have participants rate their annoyance level when presented with hospital sounds in a controlled environment with a varying dynamic range of noise. These tests were conducted in the Nebraska Acoustics Listening Laboratory, located at the Peter Kiewit Institute on the campus of the University of Nebraska in Omaha, Nebraska.

Thirty-three total subjects participated in ~25 minute listening tests where they would hear, analyze, and rate the annoyance of the presented sounds. The sounds were comprised of simulated hospital soundscapes, similar to a unit waiting room or hallway, and controlled in such a way to present subjects with a wide variety of noise levels. The Occurrence Rate range (developed for this research) quantified the span of noise levels during a measurement time period, and was utilized to measure the 'dynamic range' of the created sound signals. In addition, demographic information and noise sensitivity data were collected for each subject. Subject affect was also measured, both before and after the listening portion of testing to determine any potential changes. This collection of data allowed for analysis on the subjective perception of noise, indicating that a more varied soundscape was not necessarily desired, and that subjects found louder noise events to be more annoying on average. The tests also provided insights into the results found in acoustical measurements collected from the three real hospitals.

This Doctoral Dissertation has been divided into six chapters which address all aspects of the study. Chapter 1 has been an introduction to this research and a layout of the remainder of the document. Chapter 2 is a literature review of all prior research regarding the analysis of hospital acoustics, patient satisfaction, and perceptual testing. Chapter 3 details the Phase I acoustical measurements and patient perception study conducted at urban Hospital U1. Chapter 4 discusses the Phase II acoustical measurements, patient perception, and staff perception study conducted at rural Hospitals R1 & R2. Chapter 5 covers the Phase III subjective perceptual tests conducted to analyze the annoyance of varying hospital noise levels. Chapter 6 summarizes the information that is presented in the preceding chapters and offers conclusions, future testing considerations, and general thoughts concerning the research. Figure, table, and equation lists can be found before Chapter 1 with references included after Chapter 6. The Dissertation is concluded with Appendices A, B, and C which include acoustical data for the three study phases.

Chapter 2

Literature Review

2.1.1 Introduction

There is growing evidence that poor hospital soundscapes negatively impact both patients and staff, resulting in hindered recovery and increased communication errors. [1 – 2] It has been found that between 1960 and 2005 the quality of hospital soundscapes have diminished, with noise levels increasing more than 2.5 times (15 dB) over that time period, during both daytime and nighttime. [3] In a review of research between 2005 and 2010, these trends showed little to no improvement, with average daytime levels remaining consistent and average nighttime levels louder than in previous years. [7] These circumstances are not entirely unexpected, given expectations from an expanding population along with the financial requirements needed to operate a hospital in the 21st century. These demands generate an increased flow of patients (as well as doctors, nurses, and staff), creating a more active work environment and thus more noise. Additionally, advances in medical equipment continually bring new types of machinery into hospitals, some to replace existing equipment, others to provide new or better tools. Regardless of the function, though, most hospital equipment generates some type of noise, either through its operation or from alarms and monitoring sensors. It is important to acknowledge these changes to the hospital environment and adjust accordingly to improve soundscape conditions and ultimately improve patient and staff experience.

Poor perceptions of hospital soundscapes are not a new occurrence, as noise within hospitals was identified as being problematic nearly 90 years ago. The first article in the Journal of the Acoustical Society of America (JASA) regarding hospital noise was published in 1930 by Charles Neergaard entitled, “Are acoustical materials a menace in the hospital?” [8] This article was contained within the second volume of the JASA journal, showing just how long acoustics within hospitals have been of interest. In the article, the author recommends the use of absorptive materials in hospital settings to absorb reflected sound, resulting in quieter environments overall. The author also noted the difficulties associated with the application of absorptive materials in healthcare settings, due to cleaning & sterilization requirements, a common concern even today. Some years later in 1942, the same author published more detailed recommendations regarding hospital materials and the impact on acoustics that are still valid:

> “Acoustical material of 70 % absorption in corridors, nurses' stations, visitors' rooms, quiet rooms and nurseries, and all service units where noise originates. Particularly important is the entrance lobby and adjoining waiting and admitting rooms, so whoever enters senses a hushed and quiet atmosphere. In one or two hospitals I have been able to use, in all patients' rooms, a relatively inexpensive material with about 45 percent absorption, with results well worth the cost.” [9]

Further recommendations included installing quiet-closing door hinges and latches, positioning noise sources away from noise sensitive spaces, and installing rubber gaskets or other similar materials to decrease impact noise. Interestingly, the common complaint (at least made by acoustical consultants) of institutions neglecting acoustical concerns was noted, all of which is not uncommon to find even today.

Advances have been made over these past decades to hospital soundscape design, with new requirements emerging, such as in research hospitals where sound isolation rooms might be needed. [10] In the past twenty years or so especially, there have been measures introduced that have increased the awareness of hospital acoustics. In 1999, the World Health Organization (WHO) published its recommended guidelines for daytime and nighttime levels within hospitals. [11] In 2006, the HCAHPS patient satisfaction survey was instituted, which included the 'Quietness of Hospital Environment' acoustics question. [6] Also, in 2010 the Federal Guidelines Institute updated its Guidelines for Design and Construction of Hospitals to include major new sections on acoustics. [12] An increased number of studies regarding hospital acoustics have also been found over the past few decades, with JASA submissions nearly tripling between the 1980s and 1990s and increasing more than 25 % between the 1990s and 2000s, with the trend continuing still. The issues created by poor hospital soundscapes have also been highlighted in more widely distributed publications as well, such as Acoustics Today. [13] It is clear that noise within hospitals is and has been an important issue, but several questions remain: what are the best ways of analyzing hospital noise and how can hospital soundscapes be enhanced to improve patient and staff experience?

2.1.2 Noise Analysis Metrics

Before delving into the details of hospital soundscapes, it is important to describe the acoustical metrics that are implemented to analyze the sound in these environments. Included are metrics that are averaged over time, delineated by time, averaged over frequency, computed by statistics, or calculated using the raw data generated from a time history measurement. All of the following acoustical metrics can be useful for describing sound in hospitals, given the proper understanding and application.

The most commonly utilized acoustical metric in hospital acoustics, and many other environments, is the equivalent sound pressure level, denoted L_{EQ}. Equivalent level is “defined as the steady level that contains the same amount of energy as the actual time-varying level during a given period. The L_{EQ} can be thought of as an average sound pressure level, where the averaging is based on energy.” [14] If a frequency weighting has been associated with the equivalent level (described below), it would be denoted LA_{EQ} (if the value was A-weighted). L_{EQ} is the most common acoustical metric found in hospital acoustics (and most other environments) due to its simplicity of calculation, ease of understanding, and general acceptance of use. For example, if hospital room A had a measured L_{EQ} of 60 dB compared to room B with an L_{EQ} of 70 dB, then it could be concluded that room B was 10 dB louder than room A on average.

Equivalent level can also be averaged across measured frequencies, or pitches, often in 1/1 or 1/3 octave bands. In addition to L_{EQ}, it is also common to measure the associated sound spectra when conducting acoustical measurements, allowing noise to be analyzed for frequency-related effects. This could include low frequency rumble, such as HVAC noise traveling through ductwork, or high frequency hiss, such as that generated by certain electrical equipment. Frequency weightings are also commonly found in acoustics calculations, which represent frequency contours that roughly mirror the sensitivity of human hearing at specific listening levels. The three frequency weightings of interest in hospital acoustics are A, C, and Z weighting [14]. A-weightings roughly represent the 40 phon line and C-weightings roughly represent the 80 phon line. The phon contour lines are dictated by the value of a 1000 Hz tone, so the 40 phon line has a value of 40 dB re 20 μPa at 1000 Hz with the hearing contour associated with that sound level. Z-weighting are un-weighted sound levels.

Along with equivalent level, minimum and maximum sound levels are typically reported in hospital acoustics research. As expected these would be denoted L_{MIN} and

L_{MAX} or LA_{MIN} and LA_{MAX} if frequency weighted (L_{MIN} and L_{MAX} are not generally reported by frequency band) [14]. There are two types of minimum and maximum levels associated with acoustical measurements: averaged and absolute. Averaged minimum and maximum sound levels are computed in the same fashion as L_{EQ}, using logarithmic averaging based on the measurement sample time (described below). These calculated min and max values find the average minimum and maximum values over the measured time period. Absolute minimum and maximum sound levels represent the single quietest and loudest moments measured during the course of a measurement. In addition, peak sound levels are also frequently reported, generally using the C frequency weighting and denoted LC_{PEAK}. Peak values are measured based on the instantaneous level of the SLM and represent more impulsive signals than maximum sound levels, which are calculated through the RMS detector on the SLMs (using the ‘Fast’ setting).

All of the metrics described above, L_{EQ}, L_{MIN}, L_{MAX}, L_{PEAK}, and any spectral components therein are calculated using acoustical time history measurements. Generally these are completed using sound level meters or microphones connected to computer software. These measurements monitor the sound levels at the connected microphone over a specified time period, based on several timing parameters. The first parameter that is determined (by the user) is the time history period. The time history period determines the length of the time window that is used to determine L_{EQ}, L_{MIN}, and L_{MAX} values, thereby determining how often acoustical values are collected. A typical time history period for long term hospital measurements (24 hours or more) would be 1 minute. The second parameter that affects acoustical measurements is RMS detector speed, which determines how often the measurement device is collecting data: Slow (1 second), Fast (125 ms), or Impulse (35 ms). In previously published hospital acoustics measurements, both Slow and Fast detector speeds have been utilized, with Fast being recommended in more recent research, as this was found to better represent fluctuations common to hospital soundscapes. [4]

Statistical sound levels are also calculated in acoustical measurements, which show the level that is exceeded a certain percentage of the time, denoted $L_{\%}$. For example, L_{10} would represent the sound level exceeded 10 % of the time and L_{90} would represent the sound level exceeded 90 % of the time. The L_{90} value also has been associated with the 'ambient' sound level of a space, although research has found that this does not necessarily hold true in hospital environments. [15]

Using the spectral data from an acoustical measurement, it is also possible to calculate two noise criteria ratings. The Room Criteria (RC & RC Mark II) and Noise Criteria (NC) were developed to produce single number ratings to evaluate interior noise. [16] Noise Criteria includes only a loudness number rating; Room Criteria includes both a loudness number rating and a frequency quality indicator: (HF) for high frequency hiss, (LF) for low frequency rumble, or (N) for a neutral spectrum. Both of these metrics are commonly used in building acoustics recommendations, including hospitals, especially concerning HVAC equipment and other common noise sources.

Speech Intelligibility

Speech intelligibility is an important aspect in a hospital acoustics. Doctors and nursing staff must be able to communicate effectively with patients and one another to ensure information is accurately disseminated. The Speech Intelligibility Index (SII) is commonly utilized to assess the speech conditions in indoor environments and has been implemented to analyze speech conditions in hospital soundscapes by several authors. SII has been found to be highly correlated with the intelligibility of speech under a variety of adverse listening conditions, such as noise, filtering, and reverberation, and thus has been widely implemented in human speech recognition. [17 - 19] Other speech associated acoustical metrics have also been utilized in previous hospital noise assessments, such as the Articulation Index (AI). [20, 21]

The ANSI S3.5 (R2007) standard details the SII calculation procedure, which considers speech importance and audibility across 1/3 octave bands from 160 Hz to 8000 Hz. SII takes voice effort (e.g. 'normal' or 'raised') as well as the measured noise spectra into account and can be thought of as a frequency-weighted signal-to-noise metric. [22] It produces a single number value ranging from 0.0 to 1.0 with higher values signifying better speech intelligibility. These figures are then rated on a qualitative scale: SII > 0.75 rating as 'Good', 0.75 < SII < 0.45 rating as 'Marginal' or 'Fair', and SII < 0.45 rating as 'Poor'. Unfortunately for those within most hospital units, speech intelligibility is worse than desired, with many units generating 'Poor' SII ratings. [19]

Occurrence Rate

In addition to the numerous acoustical metrics listed above, a recently developed metric was utilized in this study which assesses the temporal variability within acoustics time history measurements. The metric was first introduced in 2008 by Erica Ryherd, Kerstin Persson Waye, and Linda Ljungkvist [4] and further developed by Selen Okcu in recent years. [23] Occurrence Rates define the percentage of time sound is above a given level over the measured timespan, similar to the aforementioned statistical sound levels. For instance, a plot of the L_{EQ} Occurrence Rates would produce a graph showing the span of measured sound levels sloping from top left corner (representing the sound level exceeded 100 percent of the time) to the bottom right corner (representing the sound level never exceeded). The Occurrence Rate graph depicts an acoustics time history measurement across the measured sound levels, so statistical sound levels (e.g. L_{10} or L_{90}) would be shown individual points on a L_{EQ} Occurrence Rate graph.

It is important to point out that Occurrence Rates can be calculated for any acoustical metric with time history data, not just L_{EQ}. This means that Occurrence Rates could be calculated for L_{MAX} or L_{PEAK}, L_{MIN}, frequency bands, statistical levels, room and noise criteria, or any other acoustical metric that has been measured at every time interval. This is especially important, as it was found in previous studies that Occurrence Rates in hospital environments are applicable using max and peak values, as these present a more accurate representation of the variability in sound levels experienced therein.

It should be noted that all of the acoustical metrics listed above were utilized in the analysis of the measured hospital data in course of this study.

2.1.3 Current State of Hospital Acoustics

Over the past few decades, there has been increasing awareness regarding the impact of hospital noise on both patients and staff. [1, 2] In an effort to address the poor acoustical conditions in healthcare facilities, the World Health Organization published guidelines of recommended hospital noise levels in 1999 for unoccupied spaces: daytime LA_{EQ} less than 35 dBA, nighttime LA_{EQ} less than 30 dBA, and nighttime LA_{MAX} less than 40 dBA. [11] However, numerous studies on hospital noise conducted since this publication have revealed little compliance with these guidelines. [3 – 5, 19, 23 – 30]. In fact, background noise levels found within hospitals are routinely louder than WHO recommended nighttime noise levels. Multiple other institutions have issued noise level recommendations for hospitals in unoccupied spaces, including the Facility Guidelines Institute (FGI), who stated patient rooms should have noise levels below NC 40, RC 40

(N), or 45 dBA, with operating rooms and corridors 5 – 10 dB louder and more noise sensitive spaces (such as NICU sleep areas) 5 – 10 dB quieter. [12] The American National Standards Institute (ANSI) also provided recommendations for hospital noise levels in ANSI S12.2-1995 (R2008), citing Room Criteria levels of 25 – 30 (N) in patient and operating rooms and 5 points higher in more trafficked areas. [16] Note that in both FGI and ANSI publications, neutral frequency spectra are recommended in all hospital spaces, indicating the goal of having no additional low or high frequency noise present.

While recommendations put forth by both FGI and ANSI were less stringent that WHO guidelines, these recommended noise levels are still consistently exceeded. This is true for many different areas of the hospital, including operating rooms, intensive care units, neonatal intensive care units, or standard patient rooms. In operating rooms, where higher noise levels are to be expected, occupied LA_{EQ} levels have been found ranging between 65 dBA and 73 dBA. [24 – 26] In other hospital patient areas, lower average sound levels have been found, ranging from 50 dBA to 65 dBA in ICUs [23, 27], NICUs [28], and general patient rooms. [29, 30] It should also be noted that the majority of published hospital acoustics research utilizes L_{EQ}, L_{MIN}, L_{MAX}, and LC_{PEAK} metrics (and some frequency content). [25 – 28] Fewer incorporate statistical sound levels [15, 24, 28] and fewer still included more advanced metrics, such as Occurrence Rates. [4, 23] Unoccupied noise levels in hospitals have rarely been reported.

Noise Impact on Patients

With noise levels found in hospital patient areas exceeding most if not all recommended guidelines, it should come as no surprise that there have been negative outcomes discovered for patients experiencing these conditions. Noise within hospitals has been found to impact patients in a variety of ways, including sleep disruption, increased stress, extended hospital stay, or even physical symptoms. [1, 31 – 43] A frequently studied repercussion of noise found in hospitals has been sleep disturbance. [32 – 37] Due to the constant and transient noise sources found within hospital units, patients are subject to consistent background noise levels combined with sporadic louder sounds. The implications of these poor soundscape conditions can include poorer sleep efficiency, more difficulty falling or staying asleep, and more difficultly progressing into deeper levels of sleep. [32] There has also been evidence found linking the adverse effects of sleep disturbance on the cognitive development of children. [33]

Interestingly, some studies have found that the majority of sleep arousals are not caused by noise (which was responsible for around 20 – 30 % of arousals), with the remainder caused by other facets of patient care. [34, 35] These numbers are lower than perhaps expected, but still demonstrate clear room for improvement in reducing the final percentage of noise arousals. It has also been shown that significant percentages of noise can be attributed to either the patient (31 %) or staff (39 %), with the remaining percentage being generated by alarms and medical devices (30 %). [38] These noise arousal and alarm noise percentages lend some explanation as to why interventions aimed at decreasing nighttime disturbance by improving soundscape conditions have not always been effective. [36]

In addition to sleep disturbance (or more likely in conjunction with), acoustics within the hospital have been found to have noticeable impacts on health and quality of stay. Studies looking at patient physiology have found hospital acoustics can be related to patient cardiovascular arousal [39] and increased dosages of pain medication. [40] There have also been reported increases in patient stress potentially leading to delirium, indicated by sudden changes or fluctuations in a person's mental status, [37] which could also cause feelings of fear or helplessness. [41] These numerous physiological impacts on patients have also been found to increase re-hospitalization [42] as well as extend hospital stays. [43]

Noise Impact on Staff

While previous research has been primarily interested in the impact that poor hospital soundscape conditions can have on patients, the affect these environments can have on the staff caring for these patients must be acknowledged. Evidence has been found that increased stress and burn-out, short-term memory disruption, staff mental efficiency, higher levels of annoyance, loss of concentration, increased tiredness, and noise-induced hearing loss can all be related to the acoustical environment of a hospital. [7, 44 – 49] It has also been shown that noise in occupational environments can hinder oral communication, task performance, and even job satisfaction. [50 – 54] Due to the noisy conditions found in hospitals and the extended durations staff spend in these environments, it comes as no surprise that adverse effects would be the result.

Being exposed to poor hospital soundscape conditions imposes both constant and transient noise sources onto medical personnel, often leading to annoyance and stress in the workplace. [7, 44 – 47] Stress in general has a rather ubiquitous effect on a person's life, potentially impacting health, physical tasks, mental tasks, or one's emotional state. Stress in hospital environments has been found to correlate with physical health symptoms, such as tachycardia (when a person's heart rate exceeds 100 BPM), [45] headaches in the workplace, higher blood pressure, and diminished respiration. [46, 47] The stress caused in healthcare settings has also been found to lead to disruption of concentration and increased tiredness. [48] Ultimately, the increased stress on employees caused by poor acoustical conditions can also lead to staff burnout. [7]

Noise within hospital environments (and the stress that it can induce) can also cause hospital staff to make additional errors in their work. [7, 44, 48] These findings corroborate with independent studies which have linked poorer task performance with noise exposure. [50 – 52] These additional errors are clearly important in hospital environments, because when dealing with patient health, a single error could mean the difference between life and death. Combined with the evidence linking poor hospital acoustics and the impact on speech intelligibility, these potential staff errors demonstrate the kind of indirect effect noise in hospitals can have on patient health.

Not only can hospital noise affect staff mental state and performance, there can also be direct physical impacts on medical personnel due to noisy equipment. It has been found that workers using orthopedic equipment (bone saws, etc.) were at risk for noise induced hearing loss. [49] This was due to the close proximity of the noise generating tools, the tonal noise they produced, and the extended time that employees were required to spend using the equipment. It has also been found that while staff might be aware of the poor soundscape conditions that they work in, most are not fully versed in the impact that these environments can have on themselves or patients. [54] This indicates more work is needed towards the awareness of hospital noise implications.

Physical Hospital Noise Mitigation

The issues regarding poor hospital soundscapes and the impact on patients and staff have been laid out, so a natural question might be: has anything been done to improve the state of hospital acoustics? From the early days of architectural acoustics, it has been understood that adding absorbing elements to the walls and ceilings in hospital environments can improve the acoustical conditions. [8 – 10] This inclusion of higher amounts of absorption serves to decrease sound reflections, thereby lowering the reverberation time (the time it takes for sound to decay within a room). The additional absorption and lower reverberation times would then lead to quieter overall noise levels.

The inclusion of absorbing wall and ceiling elements has been shown to effectively decrease the sound levels in hospital environments. [55 – 58] In studies where the addition of absorptive treatments was the only change, the average decrease in LA_{EQ} was 5 decibels [55 – 57] A 10 decibel difference equates to an approximate doubling in perceived sound level and a 3 decibel difference is considered 'noticeable' [14] so the 5 decibel decrease in LA_{EQ} levels would be substantial. This perception was demonstrated in staff surveys indicating clear preference for the addition of absorbing elements. [55, 56] More extensive modifications to both the hospital structural composition combined with the addition of absorptive treatments have been found to produce even larger effects of up to 30 decibel decreases in patient room noise. [58]

Alongside the inclusion of absorptive elements, the overall design of hospital units can have an impact on patient health. [59, 60] There are numerous factors that go into hospital unit layout, such as proximity to nursing station(s), visual and auditory access, and adjacency to noise. Physician and nursing requirements for performing standard procedures takes priority in unit design, with acoustical requirements not always being the focus. It has been shown, though, that patient visibility and thereby audibility can impact mortality and length of stay in critically-ill patients. [59]

Other Hospital Noise Interventions

Because physical alterations to hospital units are not always feasible, some healthcare facilities have chosen to address noise issues from an administrative perspective. Many hospitals have implemented a procedure known as Quiet Time in the afternoons and/or early mornings each day, [61 – 64] including numerous units measured in Phase I and Phase II of this study. During Quiet Time hours, patients, visitors, and staff are asked to decrease voice volume, limit cell phone usage, etc. in an attempt to promote a quieter and more relaxing period during the day/night. Depending on the hospital and/or unit, the specific protocols differ: some units simply post Quiet Time signs as the only preventative step while other units implement a starting chime, dim the lights, and alter medical schedules to increase the effectiveness of the protocol.

Studies have shown Quiet Time procedures can potentially lower average noise levels during implemented hours and decrease sleep disturbance. [61 – 64] These changes ultimately led to lower noise perception and increased satisfaction of patients and staff. Also, in at least one study, Quiet Time was positively linked with infant developmental outcomes. [61] It should be noted, while positive physical and psychological impacts have been found for the implementation of Quiet Time hours, challenges have arisen as well. Importantly, dedication is required for Quiet Time procedures to be effective, as all staff must be accountable for the noise they generate. Some hospitals have altered scheduling of rounds and procedures to help facilitate the quiet environment, a factor that has reportedly been difficult for some practitioners to adhere to. [64]

Other approaches in analyzing hospital soundscapes have also been presented in recent years. Simulated hospital environments have been created to analyze the noise sources found in patient rooms and the impact background noise can have on alarm audibility. [65] Also, short-term acoustic forecasting has been employed to try to predict noise generation in an effort to help mitigate the effects. [66]

2.1.4 Patient Satisfaction

It has been shown that poor hospital soundscapes can negatively impact patients and staff in a variety ways, both physically and psychologically. There has also been evidence found that these poor acoustical environments can decrease patient satisfaction. [67 – 72] Given the fact that patient satisfaction is now linked to hospital performance and federal funding, there are numerous incentives to improve these poor soundscape conditions. [6]

Patient satisfaction is most commonly measured using surveys issued in a variety of ways, from a multitude of institutions. For many years, surveys were conducted by hospitals independently, as no nationally recognized surveys assessing patient satisfaction had been published before 2006. Since the introduction of the HCAHPS survey (detailed below), other widely dispersed (although not federally funded) surveys have become available, such as through Press Ganey Associates and the National Research Corporation. These surveys have asked numerous questions regarding hospital environments, and in most cases specific acoustics related questions. It has been found that noise levels within hospitals are correlated with patient satisfaction as well as patients' overall rating of hospitals. [67 – 72]

There are limited numbers of studies that have directly addressed changes in patient satisfaction due to modifications to hospital acoustics. Two such studies were found where physical improvements were undertaken aimed at improving poor soundscape conditions with patient satisfaction surveys collected both before and after acoustical treatments. [68, 69] One study analyzed modifications made to an existing ICU, where large wards with 10 – 14 patient wards were changed to more divided, physically separated rooms. No sound level measurements were conducted in this study, but overall patient satisfaction rose from 63.6 % to 69.6 %, 'Silence ICU' was rated significantly higher ($p < 0.01$) by patients, and 'Silence ICU' was found to be correlated (0.61) with overall patient satisfaction. [68] A second study analyzed the difference in patient satisfaction between a newly opened clinical building and the previous building it replaced. Using patient satisfaction data collected from both HCAHPS and Press Ganey surveys, it was found that the new clinical building rated more than 8 % better in the overall rating of the hospital and more than 14 % better in the 'Quietness of Hospital Environment' measure. [69] These improvements were attributed to the changes made to the acoustical environment: "sound-absorbing features (were placed) in patient care corridors ranging from acoustical ceiling tiles to a quiet nurse-call system." However, no sound level measurements were collected to quantify these changes.

Clearly, acoustics have been identified by many institutions to be an issue in hospital environments and that improvements to the physical properties of the spaces can have dramatic impacts on patient satisfaction. It stands to reason: Why are hospital soundscapes not improving more rapidly? In a recent survey of staff from 241 hospitals, [70] it was found that 87 % of respondents recognized noise as a problem in their workplace. However, only 67 % of these respondents had assessed the acoustical environment, 51 % had developed a noise plan, and only 5 % had completed a noise plan. Obviously, there is work to be done in regards to full implementation of noise control procedures, but strides are being made, especially now that HCAHPS scores are linked to hospital finances. In the survey, it was found that 'HCAHPS Pay for Performance' was the catalyst for 66 % of noise interventions and 57 % reported 'HCAHPS Score Increase' as the positive outcome most desired (both were the highest reported answer for each question). The most important finding from this survey was the commitment needed to improve soundscape conditions, similar to findings in Quiet Time interventions. By fully adhering to good acoustical protocols, through changes in the hospital environment or administrative protocols, it is possible to decrease noise and improve patient satisfaction.

Aside from noise level guidelines, as published by the World Health Organization or Facility Guidelines Institute, some institutions have issued recommendations regarding hospital acoustics in the effort of raising patient satisfaction. The American Hospital Association (AHA), alongside the American Society for Healthcare Engineering, issued a guidebook aimed at improving patient experience across the entire healthcare environment. [71] Highlighted specifically was hospital acoustics, as measured by the HCAHPS 'Quietness of Hospital Environment' question, which included patient and staff actions as well as physical and technological features. Figure 1 displays the 'People, Process, and Place Model' developed to address areas of improvement in the hospital, which compiles many of the identified problems and associated mitigations found in prior hospital acoustics research. In the course of this dissertation research, the efficacy of the recommendations laid out below was consistently proven, as HCAHPS scores and patient/staff satisfaction were found to increase as soundscape conditions improved. Specific actions listed were found to be effective, including staff lead Quiet Time procedures and the use of sound-absorbing materials.

<table>
<tr><th colspan="2">Question</th><th>Improvement Goal</th></tr>
<tr><td colspan="2">How often was the area around your room quiet at night?</td><td>Decrease noise to enable patient sleep and rest and decrease staff stress.</td></tr>
<tr><th colspan="3">Components that Influence the Patient Experience</th></tr>
<tr><th>People/Culture</th><th>Process Reengineering</th><th>Place</th></tr>
<tr><td rowspan="3">Desired end-state
Improved decibel level, HCAHPS score, staff satisfaction about noise

Steps to achieve this
» Establish a sense of urgency for improvement
» Identify target goals
» Develop noise reduction campaign plan:
• Set the stage with research and best practices
• Clarify values, vision
• Measure and reward progress
• Find and tell the best stories</td><td>Staff actions
» Nighttime care guidelines
» Quiet voices
» Resupply and equip-ment movement procedures</td><td>Building features
» Single-patient rooms
» Sound-absorbing materials
» Design to separate noise sources (e.g., ice-making equipment)</td></tr>
<tr><td>Patient actions
» Earplugs
» Television and radio headphones</td><td>Technology features
» Hands-free communication
» Beepers on vibrate
» No overhead paging</td></tr>
<tr><td>Visitor actions
» Orientation to noise reduction
» Cell phone use</td><td>Equipment
» Equipment maintained without squeaks
» Decreased equipment volume, links to hands-free devices</td></tr>
</table>

Source: Eileen Malone, Mercury Healthcare Consulting.

Figure 1: AHA People, Process, & Place Model for Assessing Hospital Soundscape Conditions [71]

HCAHPS Hospital Patient Survey

In an effort to improve patient satisfaction, it has been common practice for individual hospitals to conduct surveys of patients and staff assessing the performance of the hospital. While this type of research can provide valuable information for the hospital in which the survey was conducted, data of this type cannot be compared against surveys administered at other hospitals.

Aimed at allowing valid comparisons to be made across hospitals locally, regionally, and nationally, the Hospital Consumer Assessment of Healthcare Providers and Systems survey was first introduced in 2006 with public reporting of collected data being issued in 2008. The HCAHPS survey was developed by the Centers for Medicare & Medicaid Services (CMS) along with the Agency for Healthcare Research and Quality (AHRQ) and was the first standardized national and publically reported survey assessing the perspectives of patients' hospital experiences. [6, 73, 74] Three primary goals shaped the design of the HCAHPS survey: to produce data regarding patients' perceptions of care received during their hospital stay (allowing objective comparisons between hospitals), to publicly report this data in an effort to improve quality of care, and to enhance hospital transparency and accountability through this available information. [75] According to published literature, "AHRQ carried out a rigorous, scientific process to develop and test the HCAHPS instrument. This process entailed multiple steps, including a public call for measures; literature review; cognitive interviews; consumer testing and focus groups; stakeholder input; a large-scale pilot test and a number of small-scale field tests." [74, 76]

Additionally, financial incentives were attached to HCAHPS performance after enactment of the Deficit Reduction Act in 2005. [77] Hospitals subject to the Inpatient Prospective Payment System must collect and submit HCAHPS survey information, which is included (along with several other factors) in each hospital's Total Performance Score for the Hospital Value Based Purchasing Program. [78, 79] These scores ultimately determine a small portion (2.0%) of the overall Diagnosis-Related Group (DRG) payments received by hospitals each fiscal year. Therefore, patient perspectives of hospitals as reported through HCAHPS surveys can not only have a significant impact on the public perception of a hospital, but also a noticeable financial effect. In subsequent reports, it has been found that HCAHPS results have motivated hospitals to undergo improvements, leading to positive impacts on patient satisfaction. [80]

The HCAHPS survey is administered to patients based on four eligibility requirements: 18 years or older at the time of admission, at least one inpatient overnight stay in the hospital, non-psychiatric MS-DRG/principal diagnosis at discharge, and alive at the time of discharge. Patients qualifying for the survey (and not within several specific exclusionary categories) are included within the subject pool of the discharging hospital to potentially receive the HCAHPS survey. Subjects are randomly selected from these pools on a monthly basis for large hospitals; smaller hospitals potentially need to survey all qualified subjects to meet the minimum number of responses (300 completed surveys over a 12 month period) to satisfy the statistical reliability targets. The survey is administered using four different methods: mail only, telephone only, mail with telephone follow-up (also known as mixed mode), and active interactive voice response (IVR). Based on CMS research, implemented methodology influenced survey responses, with telephone only and IVR procedures producing more positive evaluations. Therefore, CMS developed compensating procedures for factoring out survey mode response differences. [74]

Looking at the construction of the HCAHPS, the survey asks discharged patients 25 questions (plus 7 demographic questions) about their recent hospital stay. The 25 assessment questions are subdivided into 11 categories: communication with doctors, communication with nurses, responsiveness of hospital staff, communication about medicines, pain management, discharge information, cleanliness of hospital environment, quietness of hospital environment, overall rating of hospital, recommendation of hospital, and transition to post-hospital care. All of these categories are important for hospital assessment, but for this research, the most important HCAHPS category was 'Quietness of Hospital Environment'. This category is comprised of a single question on the survey (question number nine): *'During this hospital stay, how often was the area around your room quiet at night?'* Respondents are given four potential responses to the question: (1) 'Never', (2) 'Sometimes', (3) 'Usually', and (4) 'Always'.

HCAHPS survey scores are reported using the Top Box Score, representing the percentage of respondents who selected the best option of 'Always' quiet at night. In national response averages, 'Quietness of Hospital Environment' was consistently the lowest rated category among the 10 original reported until recently, and is now behind only 'Care Transition' which was introduced in the December 2014 Public Report. [81] Limited numbers of studies have been published linking HCAHPS survey performance with underlying factors, such as with admission mortality risk [82], but no studies are available regarding 'Quietness of Hospital Environment' performance. Given the consistently low performance of the category, this was unexpected, but also made this study unique by correlating HCAHPS survey results of patients' noise perceptions with measured acoustical data from 11 units in three hospitals.

2.1.5 Subject Perceptual Testing

The dynamic range of noise has been revealed as an interesting component relevant to human perception through limited previous field studies. A subjective perceptual study was created to more systematically analyze the annoyance caused by listening to hospital soundscapes with varying sound levels. This in turn helped to determine the perceptual differences between hospital soundscapes with constant noise levels and noise with sporadic peaks when normalized to have the same average level.

A perceptual study of this type has not been conducted before, so no references were available for a basis of comparison. However, a body of literature exists on subjective testing and that is the focus of this section. To construct the testing procedures for this phase of the study, sensible stimulus-centered subject testing methods were employed. [83] In these stimulus-centered testing methods, a single metric is of interest

(LC_{PEAK} Occurrence Rate ranges in this research), so all other identifiable variables should be controlled. It is possible to also include other related variables in addition to the primary metric in stimulus-centered testing methods, especially when differences between subject groups are of interest. To limit comparative bias created by potential group discrepancies, each group should be presented a unique combination of variables (i.e. two variables, with two levels would create four subject groups).

Item selection should also be carefully considered, as the presented items need to be of medium difficulty (or annoyance, as in this research) to elicit the largest range of subject responses. This requires questions to not be too extreme in annoyance level, which would then be always perceived as positive or negative. Item ordering and subject starting position need to be considered as well, with individual items and subject starting positions equally dispersing throughout the test. Once testing procedures are created, pilot testing is always recommended, as initial testing can lead to a much more reliable and valid test by indicating which items and ordering methods would more likely produce good data.

Subject selection and placement into testing groups should be randomized to mitigate differences between groups based on the individual subject. Demographic questions can be asked during testing for comparative purposes, such as age and gender, or more specific measures like noise sensitivity and subject affect (detailed below). To analyze the consistency of subject responses, reliability coefficients can be calculated for testing items using Cronbach’s Alpha and split-half methods of reliability estimation. Results can be validated by correlating measured response data with specific item properties, such as comparing perceived annoyance with calculated LC_{PEAK} Occurrence Rate ranges, as in this perceptual study.

Noise Sensitivity

One additional measure that was of interest to this study was the interaction of subject noise sensitivity to the presented stimuli. It has been found that subjects identified as more noise sensitive (either voluntarily or through testing methodologies) are more affected by sources of noise. [84 – 90] The effects noise can present to noise sensitive individuals can range, from higher levels of annoyance, [85, 86] to decreased scholastic ability, [87] to physiological responses such as heart rate, [86] as well as decreased sleep quality and health. [88]

In an effort to identify individuals who might be sensitive to noise, Neil Weinstein published the Weinstein Noise Sensitivity scale in 1978. [87] The scale presents subjects with 21 items regarding their sensitivity to noise, such as 'I am sensitive to noise' or I am easily awakened by noise.' Subjects are asked to rate each item on a 1 – 6 scale from strongly agree (1) to strongly disagree (6), with scores being summed to determine the level of noise sensitivity (higher numbers indicating a more noise sensitive subject). The Weinstein scale was validated to correlate self-reported noise sensitivity with effects caused by noise sensitivity as well as with other metrics analyzing subject sensitivity to noise. [87, 89] Due to the length of the 21 item scale, studies have been conducted on shorter versions of the Weinstein Noise Sensitivity scale, with 10 item versions being found to have high correlation with the full length scale. [89]

Subject Affect

In addition to the subject annoyance rating of the presented stimuli, the effect of hospital noise on subject affect was also of interest. Subject affect assess a person's mood in relation to a presented time frame: 'how do you feel now' or 'how have you felt in the past week', etc. It has been shown previously that increased noise levels can negatively influence subject affect. [90] To measure subject affect, the Positive and Negative Affect Scale (PANAS) was employed [91] which presents twenty items to subjects (such as ‘interested’ or ‘irritable’, etc.). These items are rated 1 – 5 from ‘very slightly/not at all’ to ‘extremely’, with specific items being combined to generate a positive affect score and a negative affect score for each subject. The PANAS scale has been shown to have high reliability and construct validity when measuring subject affect. [91, 92] Additional subject affect scales have also been developed, such as the PANAS-X expanded form [93] or the Negative and Positive Affect Scale (NAPAS). [94]

2.1.6 Study Association

While noise within hospitals has been identified as problematic for nearly a century, it still remains an issue to this day. Numerous research studies have connected the effects of poor hospital soundscapes with diminished patient healthcare, decreased staff productivity, and overall dissatisfaction of the environment. In response, noise level guidelines have been published from multiple institutions, such as the World Health Organization and the Facility Guidelines Institute. Also, the Centers for Medicare & Medicaid Services produced the HCAHPS patient satisfaction survey, which includes one category assessing noise within hospitals: ‘Quietness of Hospital Environment’.

To this point, however, there has been no research published systematically linking acoustical measurements with HCAHPS ‘Quietness of Hospital Environment’ survey responses to determine potential correlations. During Phase I & II, this study aimed to address this issue by conducting sound level measurements within three hospitals, spanning 11 different units, 38 individual patient rooms, and 12 nursing stations. The acoustical data compiled from these numerous measurements were then correlated with collected HCAHPS patient survey results as well as staff survey results, identifying the acoustical metrics most associated with patient satisfaction. The findings from these measurements also initiated further investigation into the subjective perception of varying noise levels in Phase III of this study. The findings from the three phases of this dissertation research have provided direct links between patient and staff satisfaction survey responses and measured acoustical data. This has provided quantifiable information for the assessment of hospital soundscapes, and ultimately can be used to improve patient and staff experience.

Chapter 3

Phase I: Relating Noise and Patient Satisfaction in Urban Hospital U1

Methodology

Phase I of this study was conducted at a large urban hospital, located in Omaha, Nebraska, where acoustical measurements were collected from five units within the hospital, which were selected based on widely disparate HCAHPS 'Quietness of Hospital Environment' average unit scores. Three patient rooms within each unit along with the busiest nursing station within each unit were measured for 24 consecutive hours. Once all measurements at Hospital U1 were complete, the gathered data were analyzed acoustically and ultimately correlated with HCAHPS survey results by room to determine any meaningful connections.

3.1.1 Measured Hospital Units

The five hospital units were selected based on their disparate average unit scores (43.5 % – 65.0 %) for this HCAHPS question. The hope in this selection was to find acoustical reasons behind these significant differences in patient perception. When looking at the unit typology, similarities were found between all, however, variations in unit function, room type, and bed count all differed. All five units were step-down type, designed for recovery from inpatient procedures. This was an important distinction, as

HCAHPS surveys are only sent out for inpatient discharge units. Emergency rooms, for example, would not be under HCAHPS survey purview. Four of the units provided care for patients undergoing medical, surgical, or telemetry procedures; the remaining unit specialized in organ transplant care. Bed counts for the five units ranged from 22 to 48, with higher rated units having less patient rooms. Details on the five measured units from the urban hospital can be found in Table 1.

Table 1: Five Units Measured in Hospital U1

Unit	Unit Type	Room Type	Bed Count	Ceiling Type
Unit H-1	Med / Surg	Private	22	ACT
Unit H-2	Med / Surg	Private	22	ACT
Unit M-1	Med / Surg	Private	40	ACT
Unit M-2	Transplant	Private	48	GWB
Unit L-1	Med / Surg	Semi-Private	45	GWB

In addition to the hospital unit differences described above, interior material differences were found on both the ceilings and floors. Within all units, the patient rooms and hallways included gypsum wall board (GWB) walls, linoleum floors, and acoustical ceiling tile (ACT) ceilings unless specifically stated otherwise. Units M-2 and L-1 included GWB ceilings within the patient rooms. Not surprisingly (based on prior research) these units were perceived the worst in patient perception. Also, Units H-1 and H-2 included 'softer' resilient flooring which absorbed footfalls and cart noises more effectively. The difference in flooring was not investigated further in this study, but noted as a potential contributing factor to these two better performing units.

Figure 2 displays the floor layouts of the five units measured in this study. The units have been arranged from best (top) to worst (bottom) based on the unit average 2016 HCAHPS 'Quietness of Hospital Environment' Top Box Scores. Each unit has been labeled with an ‘H’, ‘M’, or ‘L’ moniker, denoting higher, mid/average, or lower performance. These labels were designated by the author to clearly identify the five units studied: they do not refer to any specific rating system. Patient rooms that were measured within each unit have been marked with a blue circle. Nursing stations that were measured have been marked with a black circle. Patient rooms have been indicated by the tan coloration, so as to differentiate from corridors and staff/maintenance areas.

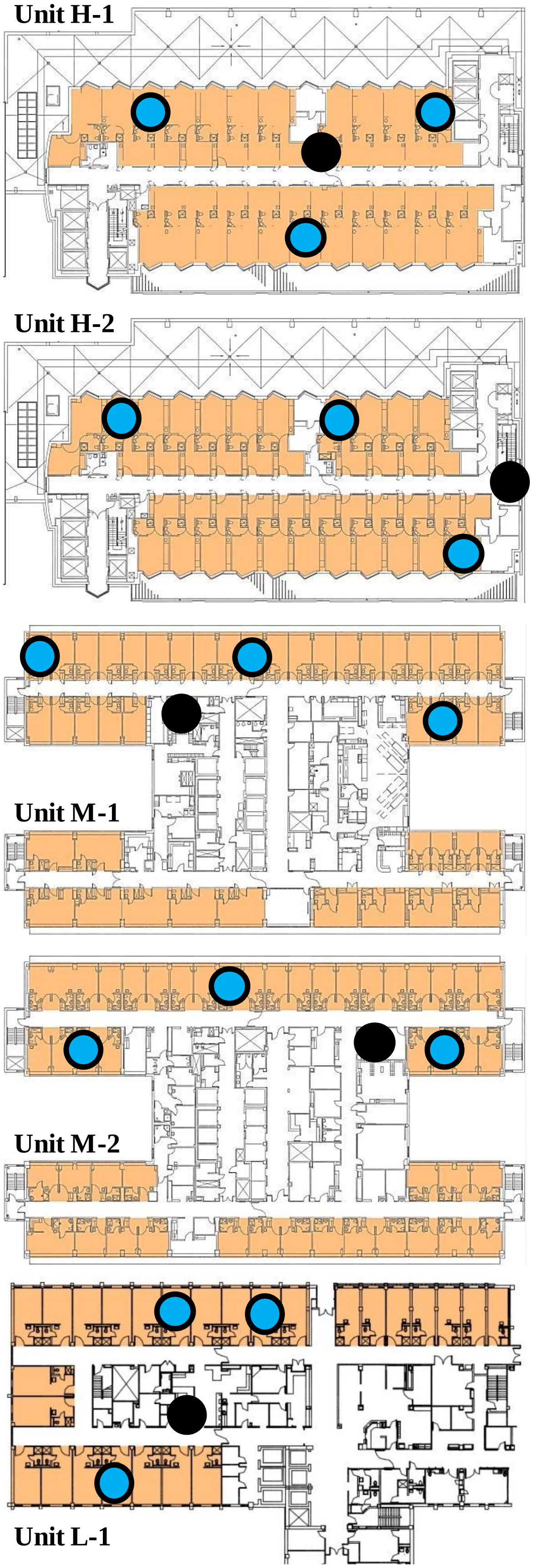

Figure 2: Five Units Measured in Hospital U1 – Ordered By Higher (H), Mid/Average (M), & Lower (L) Performance Using 2016 HCAHPS 'Quietness of Hospital Environment' Survey Data

Patient Rooms Measured
Nurse Stations Measured
Patient Rooms

Units H-1 and H-2 utilized a single corridor design and were located on vertically adjacent floors within the same hospital tower. These units focused primarily on medical, surgical, and telemetry patients. Unit H-1 was designed with a centralized nursing station located at the midpoint of the hallway while also implementing rolling computerized nursing carts. Unit H-2, however, only utilized the rolling nursing carts and did not include a typical nursing station. The patient rooms in both units were designed with long-term care in mind and featured a vestibule entrance where nursing functions could be performed and family members could sleep if needed. The vestibules acted as a natural sound buffer, isolating patients further from hallway noise.

Units M-1 and M-2 were located within a second tower of the hospital campus, separated by several floors. Both units utilized a dual-single corridor design with two independent hallways of patient rooms and four nursing stations, distributed to the wings of each floor. Staff and maintenance areas, including elevators, were limited to areas between these two main corridors. Unit M-1 was a medical surgical unit specializing in orthopedics and general surgery with primarily private rooms (all M-1 rooms measured were private). Unit M-2 was designed for solid organ transplants and included GWB ceilings within the patient rooms (unlike the first three units), which resulted in a noticeable impact on noise levels, as will be discussed.

Unit L-1 was arranged in a rectangular racetrack configuration and provided patient care for a wide range of departments including internal medicine, family medicine, surgery and multiple specialty services. Unlike the others, Unit L-1 featured primarily semi-private, dual occupancy rooms (all rooms measured were semi-private). The ceilings within the patient rooms were GWB, and there was one centralized nursing station within the unit, located between the two parallel corridors.

3.1.2 HCAHPS Patient Survey Ratings

The five units chosen in this study represented a selection of similar units from the same hospital. These step-down units were selected because of their widely varying HCAHPS ‘Quietness of Hospital Environment’ performance. Survey responses to this question were compiled for all measured rooms individually, as well as for each unit overall for the 2016 calendar year. These collected patient perception values were subsequently correlated with measured acoustical data, both on a room-by-room level and utilizing unit-level averaging. Table 2 displays the aggregated unit data for the HCAHPS ‘Quietness of Hospital Environment’ question for the five units in the study ordered from highest (H), to mid/average (M), to lowest (L) performance. The 2016 Top Box Scores are listed in the left column, while the national percentile rank of each unit is listed in the right column. Comparing these units to other hospitals, the national average for ‘Quietness of Hospital Environment’ Top Box Score has consistently been 62 % for the last few years. In 2016, Unit H-1 rated in the 61st percentile, while Unit L-1 rated in the bottom 5th percent. [81] Full compiled ‘Quietness of Hospital Environment’ survey data can be found in Appendix A in Table 20 (individual rooms) and Table 21 (entire units).

Table 2: HCAHPS ‘Quietness of Hospital Environment’ Top Box Score Averages for Units Measured in Hospital U1

	HCAHPS 'Quietness of Hospital Environment' Unit Average	
Unit	2016 Top Box Score (%)	National Hospital Percentile Rank
Unit H-1	65.0	61ST
Unit H-2	58.2	36TH
Unit M-1	52.4	17TH
Unit M-2	52.3	17TH
Unit L-1	43.5	< 5TH

3.1.3 Measurement Setting

The primary data collected in Hospital U1 of this study were 24-hour sound level meter (SLM) measurements collected within a total of 15 patient rooms and 5 nursing stations from the 5 units. Measurements were conducted consecutively over a one week time period, beginning at 8 AM on Monday morning and ending Saturday morning.

Within each unit, three occupied patient rooms were selected for study. Rooms were chosen for a variety of factors including proximity to evident noise (nursing stations, operable hallway doors, etc.) with the intent to select a representative sampling of patient rooms within each unit. Additionally, placement of SLMs within patient rooms was at the preference of the nursing staff, taking into consideration the health of the patient and their capacity to participate in the study. Also, the busiest/most active nursing station within each unit was measured for 24 hours. Unit H-2 did not include a central nursing station, so the SLM was placed at end of the corridor, outside the unit manager’s office (a location less trafficked than in the other units).

Finally, additional short-term ‘spot’ SLM measurements were collected from throughout each of the five units in hallways, secondary nursing stations, and other relevant locations. These measurements included 15 minute measurements, to take a short snapshot of the environment, and also one minute measurements to gather background noise levels (BNLs).

3.1.4 Test Setup

The measurements collected in this phase were performed using five Larson Davis 831 sound level meters. All meters implemented fast response times (0.125 s) in both A and C spectral weightings. The 24-hour measurements (and 15 minute measurements) were collected using a one-minute averaging interval.

Within each patient room, SLMs were setup to measure the sound levels experienced by the patient, so the SLM microphone capsules (using extension cables) were attached to unused medical equipment located on the rear walls approximately 1 m behind the patients. (Figure 3) Within Unit L-1, all measurements were collected from the bed closest to the windows (and away from the bathroom) for consistency.

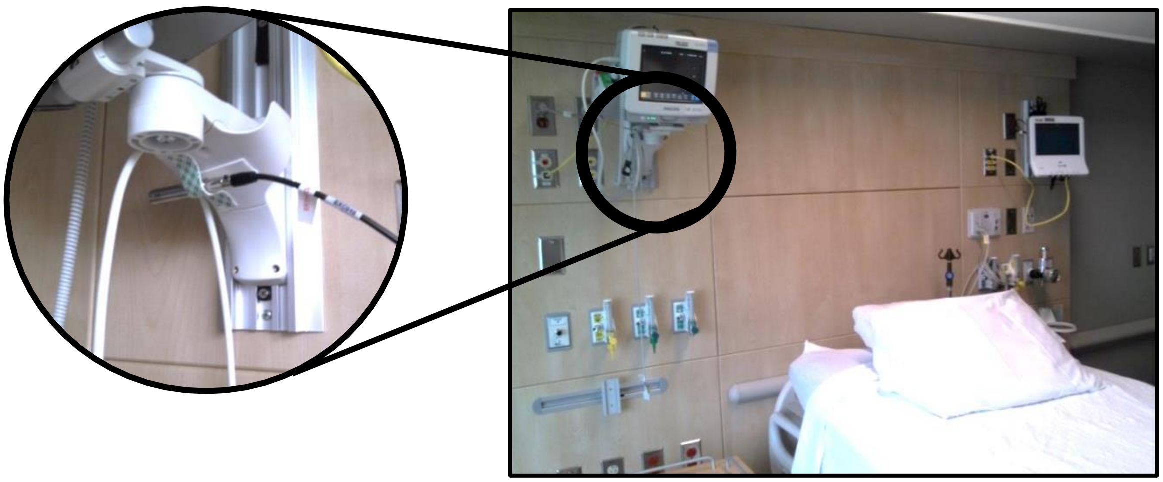

Figure 3: Sound Level Meter Placement within Patient Rooms in Hospital U1

Similar setups were utilized for the nursing stations within each unit. The microphone capsules were positioned above head height within the chosen station, pointing into the hallway. The values collected represented the noise generated from each nursing station within the adjacent hallway.

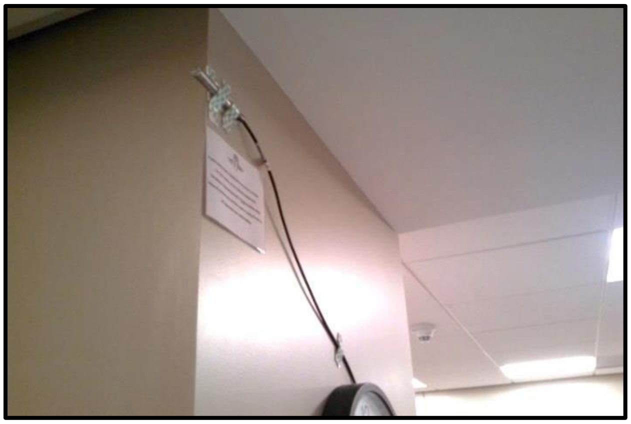

Figure 4: Sound Level Meter Placement within Nursing Stations in Hospital U1

The microphone positioning in close proximity to the walls or equipment might have raised the measured levels slightly due to sound reflections. However, all measurements were conducted with the same conditions to be internally consistent.

Short-term 'spot' measurements were conducted to provide additional information the 24-hour data could not provide. In each unit, measurements (either 15 minutes or 1 minute in duration) were taken from corridors, staff areas, reception areas, and any other position of interest. Within three units (H-1, M-1, & M-2) unoccupied rooms were available for study, so additional background noise level measurements were collected. This included a comparison of opened and closed doors as well as the acoustical impact of drawing the privacy curtain.

3.1.5 Acoustical Metrics

Numerous acoustical metrics were utilized in the analysis of the generated hospital data. Collected in each sample were the A-Weighted Equivalent Sound Pressure Level LA_{EQ}, as well as the min and max (LA_{MIN} & LA_{MAX}) and C-Weighted peak levels (LC_{PEAK}). In addition, 1/1 and 1/3 octave band frequency data and six statistical sound levels (LA_{05}, LA_{10}, LA_{33}, LA_{50}, LA_{90}, and LA_{95}) were collected every minute. All measurements utilized a reference pressure of 20 μPa.

The above 'primary' acoustical metrics were subsequently used to further analyze the hospital soundscapes for speech intelligibility utilizing the Speech Intelligibility Index (SII). Also, RC, RC Mark II, and NC Noise Criteria were calculated for each measurement. The Occurrence Rates for LA_{EQ}, LA_{MIN}, LA_{MAX}, & LC_{PEAK} were studied, allowing temporal differences between rooms and units to be analyzed. Finally, day (7 AM – 10 PM) and night (10 PM – 7 AM) logarithmic energy averages were calculated for all preceding acoustical metrics.

Hospital U1 Measurement Results – 24 Hour Data

3.2.1 Overall Levels

Once acoustical measurements were collected from the five units, compilation of the data were required to determine meaningful differences between the rooms. For each measurement, SLMs generated 24-hour averaged, single number values for a variety of metrics, such as LA_{EQ}, LA_{MIN}, LA_{MAX}, LC_{PEAK}, etc. Full acoustical data can be found in Appendix A in Table 22 (individual rooms) and Table 23 (averaged units). The averaged values were utilized in subsequent analyses and correlations with HCAHPS 'Quietness of Hospital Environment' survey data. Time history values were also collected based on a 1-minute sample time interval, which provided more continuous measurements of all above values. Time history data were utilized in Occurrence Rate analyses and day/night differences, and once again correlated with HCAHPS survey results.

To compute overall noise levels for each unit, the 24-hour acoustical values for the three patient rooms within each unit were averaged together (using log averaging where applicable). Figure 5 displays the averaged 24-hour LA_{EQ} levels within the five measured units, ordered based on HCAHPS scores as before and including error bars showing one standard deviation. There was a wide spread of nearly 10 dBA between the units, ranging from 52 dBA (Unit M-1) to 61 dBA (Unit L-1). To put this into context, 3 decibels is widely considered to be the minimum detectable difference and 10 decibels is often considered perceptually twice as loud [14]. Individual rooms ranged between 51 dBA and 63 dBA. These LA_{EQ} values found within the five units were consistent with levels found in other hospitals. [3 – 5, 19, 23 – 30] However, LA_{EQ} levels did not correspond with patient perception, as the quietest unit measured was the third ranked unit on the HCAHPS survey. Conversely, the top ranked unit on the survey was nearly as loud on average as the fourth ranked unit. As could be expected from this data, LA_{EQ} was not correlated with HCAHPS responses (detailed below in section 3.4.2). As will be shown, LA_{EQ} values alone could not fully describe the acoustics of these environments, and thus further metrics were necessary to provide insights.

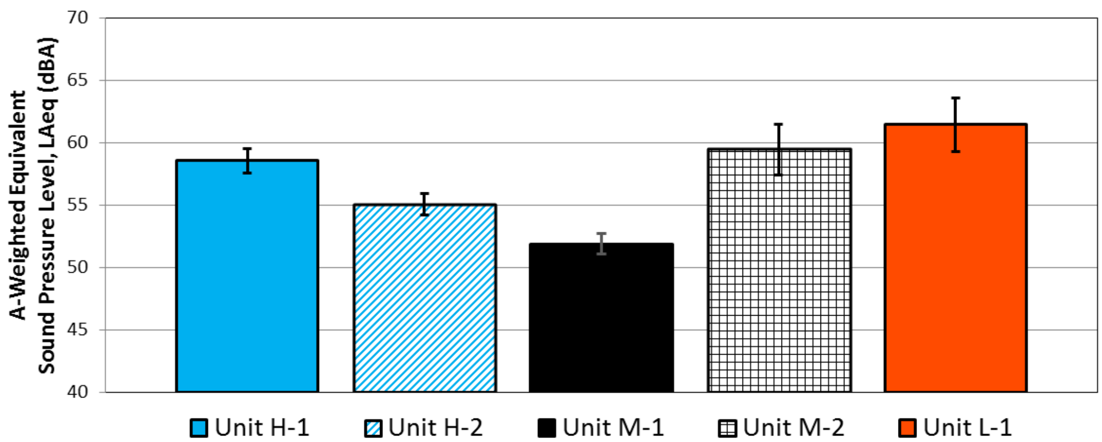

Figure 5: 24-Hour Average LA_{EQ} in Hospital U1 – 5 Unit Patient Room Comparison

The 24-hour LA_{MIN}, LA_{MAX}, & LC_{PEAK} metrics collected within each of the patient rooms were also averaged for the five units. Both time-averaged and absolute values over the measurement time period were collected for the three metrics: time-averaged values provided insight into the min, max, and peak values on a minute-by-minute basis whereas the absolute values described the quietest and the loudest noises measured. Figure 6 shows the absolute LA_{MIN} values collected during the 24-hour measurement periods, averaged by unit and including error bars showing one standard deviation. There was a clear distinction between the five units, with higher performing units on the HCAHPS survey having dramatically lower LA_{MIN} levels than the worst rated units: more than a 12 dBA difference. When analyzed statistically, it was found that LA_{MIN} was significantly correlated with HCAHPS survey results, as rooms with

LA_{MIN} levels below 35 dBA were found to have ‘Quietness of Hospital Environment’ scores 16.2% higher on average (detailed below in section 3.4.2).

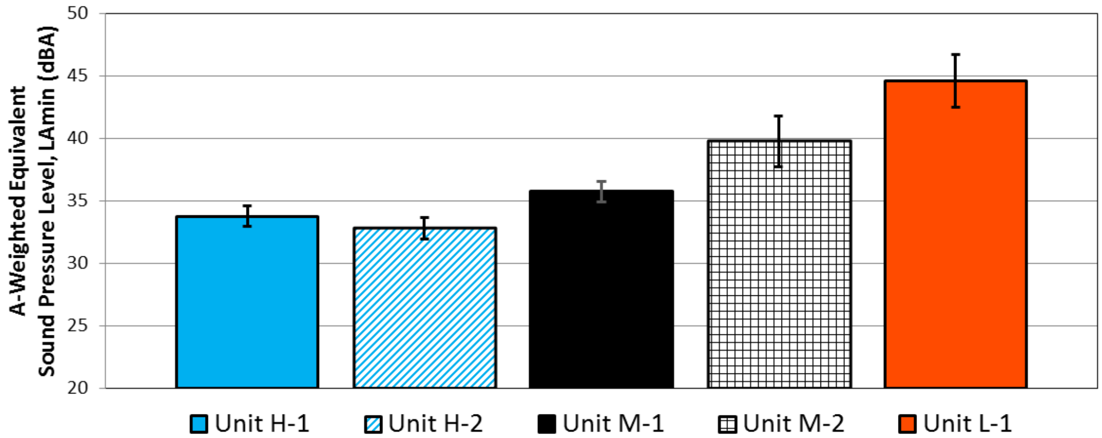

Figure 6: 24-Hour Average LA_{MIN} in Hospital U1 – 5 Unit Patient Room Comparison (Absolute Values Shown)

Figure 7 displays the absolute values found during the 24-hour timespans within the patient rooms of the five units for the LA_{MAX} and LC_{PEAK} metrics. As could be expected with acoustical metrics which analyze transient properties of sound, there was a significant variation between the units and even individual rooms within the units. The one commonality found within the data, as it related to HCAHPS survey performance, was that the worst rated unit also exhibited the loudest LA_{MAX} and LC_{PEAK} levels. However, the quietest unit for these metrics was the third rated unit, M-1, (as with LA_{EQ} levels) and the highest ranked units, H-1 and H-2, were among the louder units. Neither LA_{MAX} nor LC_{PEAK} metrics proved to be correlated with HCAHPS ‘Quietness of Hospital Environment’ survey data (detailed below in section 3.4.2).

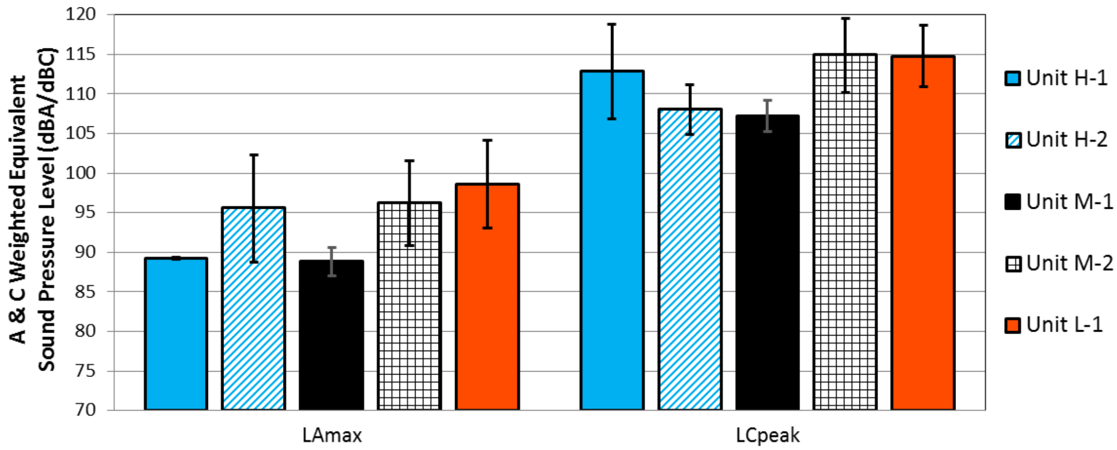

Figure 7: 24-Hour Avg LA_{MAX} & LC_{PEAK} in Hospital U1 – 5 Unit Patient Room Comparison (Absolute Values Shown)

Six statistical sound levels (representing the sound level exceeded a specified percent of the time) were computed for each of the units, calculated using the 24 hour patient room data: LA_{05}, LA_{10}, LA_{33}, LA_{50}, LA_{90}, and LA_{95}. (Figure 8 – LA_{33} was omitted for brevity) As expected, sound levels diminished between the transient noise metrics (LA_{05} & LA_{10}) and the ambient noise metrics (LA_{90} & LA_{95}). Also, the units with higher LA_{EQ} levels (H-1, M-2, and L-1) displayed higher statistical sound levels. However, the progression from LA_{05} to LA_{95} in the statistical sound levels for each unit was different. For example, Unit H-2 was 3 dBA louder than Unit M-1 for LA_{10}, but for LA_{90} the data reversed, with Unit H-2 quieter by 2 dBA. This indicated that while the 24-hour overall LA_{EQ} values shown in Figure 5 were higher for Unit H-2, it was quieter during periods of inactivity within the patient rooms (e.g. nighttime), possibly contributing to discrepancies in HCAHPS data (58 % to 52 %).

Interestingly, the average LA_{EQ} levels most closely equated to the LA_{10} statistical values. This demonstrated the impact of transient noise sources present within the units, with such a density of peak noise events that cumulatively they contain enough energy to shift the LA_{EQ} levels up. This effect was even greater than results in prior research which found LA_{EQ} levels in healthcare settings more closely resembled LA_{33} values. [15]

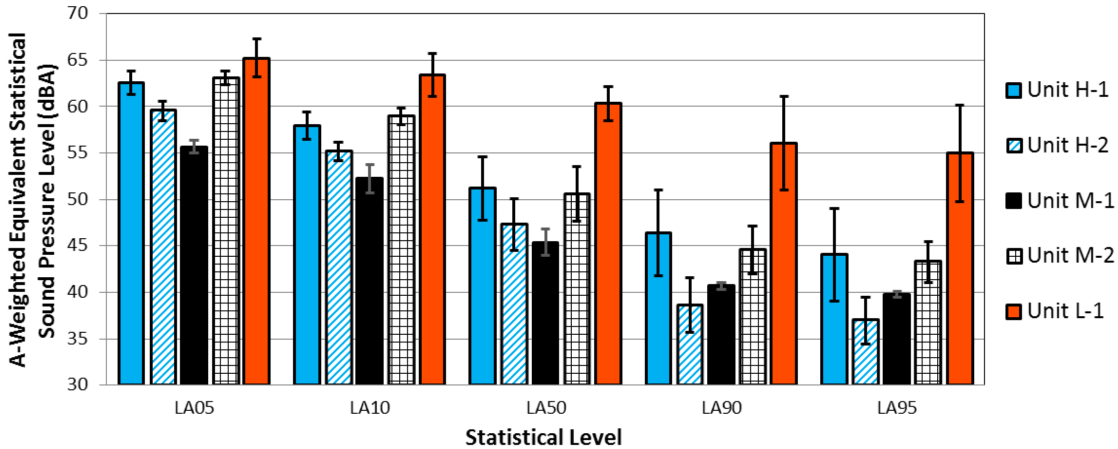

Figure 8: 24-Hour Average Statistical Sound Levels in Hospital U1 – 5 Unit Patient Room Comparison

3.2.2 Speech Intelligibility

The Speech Intelligibility Index (SII) was utilized to assess the speech conditions within the five units in Hospital U1 because it has been found to be highly correlated with the intelligibility of speech under a variety of adverse listening conditions, including correlations with nurse perception of communication in hospitals. [17 - 19] Unit averaged SII values for Hospital U1 are shown in Figure 9, calculated for the 24-hour patient room data. Of the five units, none received a rating of 'Good', three received a rating of 'Marginal', and two were rated 'Poor', which was consistent with results found in prior research. [19] Units M-1 and H-2 rated the best, with scores of 0.65 and 0.55 respectively. Unit H-1, with a value of 0.46, barely exceeded the 'Marginal' threshold but Unit M-2 did not at 0.44. Unit L-1 had the worst speech intelligibility with an SII of 0.36, which made sense as the SII values were inversely related to the overall LA_{EQ} values within each unit.

These SII values were all calculated using occupied patient room conditions and therefore included speech contributions within the noise spectrum. These represented the in-room sound fields experienced by patients and staff but not necessarily the built environment for which building recommendations are made. In three of the units (H-1, M-1, & M-2), unoccupied room measurements were taken (detailed below in section 3.3.3) which were compared with the occupied data. In these unoccupied measurements, the three units received 'Good' SII ratings of 0.91, 0.90, and 0.90 respectively.

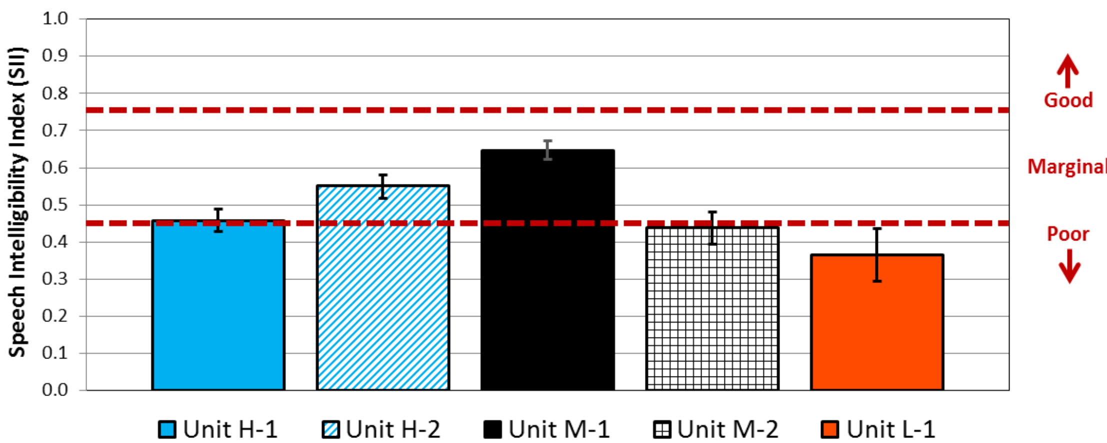

Figure 9: 24-Hour Average Speech Intelligibility Indices (SII) in Hospital U1 – 5 Unit Patient Room Comparison

3.2.3 Spectral Analysis

To further analyze the 24-hour patient room measurements, the average frequency spectra for the five units were plotted. (Figure 10) Overall, expected trends were found between the units, tracking with the average LA_{EQ} values: Unit L-1 was loudest across the spectrum, followed by Units M-2 and H-1. Units H-2 and M-1 showed the lowest levels across frequency overall, but Unit M-1 had significantly more low frequency energy. In comparison, Units H-1 and H-2 had noticeably less low frequency noise, a fact that might have impacted HCAHPS survey scores (detailed below in section 3.4.2).

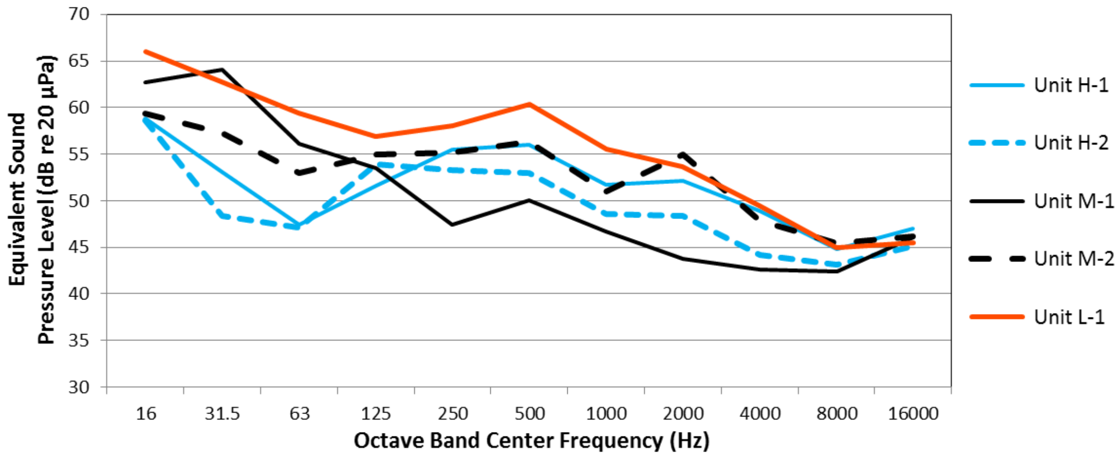

Figure 10: 24-Hour Average Spectra in Hospital U1 – 5 Unit Patient Room Comparison

3.2.4 Occurrence Rates

Using time history data from the 24-hour patient room measurements, a temporal analysis of sound levels was conducted. For this research LA_{EQ}, LA_{MIN}, LA_{MAX}, & LC_{PEAK} data were collected for each 1-minute sample, allowing the fluctuation of all four metrics to be studied. Occurrence Rates define the percentage of time sound is above a given level over the measured timespan. [4, 5, 23]

Figure 11 shows the plot for average LC_{PEAK} Occurrence Rates of the five units with level on the X-Axis (in dBC) and percentage of time on the Y-Axis. Unit L-1 was clearly louder more often when compared with the other four units. Consistent with the LA_{EQ} levels, Unit M-2 showed the second highest LC_{PEAK} Occurrence Rates, followed by H-1, H-2, and M-1 in succession. The latter four units maintained similar progressions of temporal noise (i.e. the 'slope' of the Occurrence Rates), with all gradually transitioning from louder to quieter conditions. This indicated an even distribution of noise across the dynamic range of the measurements. Unit L-1, by comparison, showed a more drastic 'slope' in the LC_{PEAK} Occurrence Rate, indicating consistently louder average sound levels in that unit. Conversely, the five units had similar LC_{PEAK} absolute values, as the difference between the units above 90 dBC was less than 8 % in time and diminished to negligible differences at 95 dBC and 100 dBC.

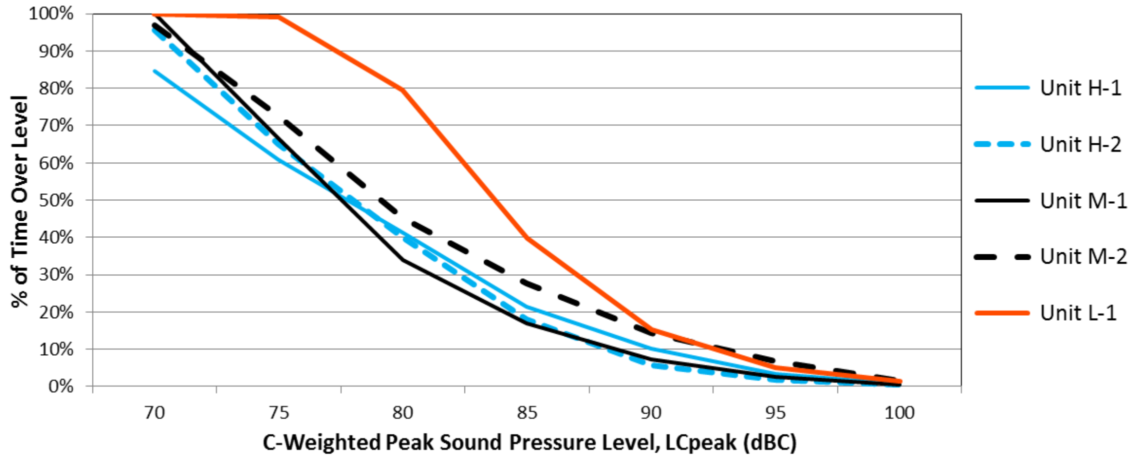

Figure 11: 24-Hour Average LC_{PEAK} Occurrence Rates in Hospital U1 – 5 Unit Patient Room Comparison

3.2.5 Nursing Stations

One nursing station within each unit was measured for 24 hours in addition to the patient rooms. Figure 12 and Figure 13 display the ‘primary’ acoustical metrics collected from the nursing stations within each of the units. LA_{EQ} values ranged between 55 dBA and 59 dBA on average for the four utilized nursing stations. As stated earlier, Unit H-2 did not include a nursing station so the measurements were taken at the end of the hallway and thus showed lower noise levels (50 dBA). Overall, while values were comparable between units, some general trends of higher, average, and lower HCAHPS performance continued, with Unit H-1 showing quieter LA_{EQ} and absolute LA_{MIN}, LA_{MAX}, & LC_{PEAK} values than the other nursing stations. Conversely, while LA_{EQ} levels in Unit L-1 were in line with the other units, absolute LA_{MAX}, and LC_{PEAK} values were significantly higher.

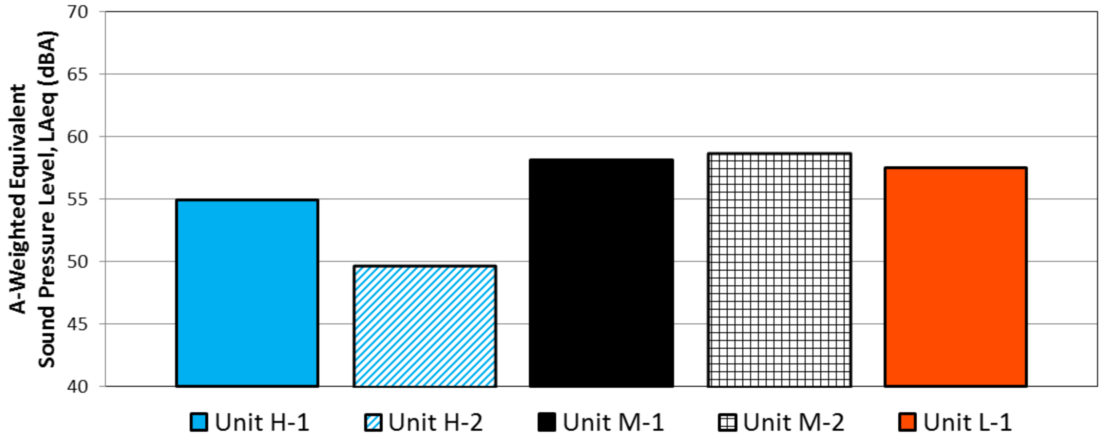

Figure 12: 24-Hour LA_{EQ} in Hospital U1 – 5 Unit Nursing Station Comparison

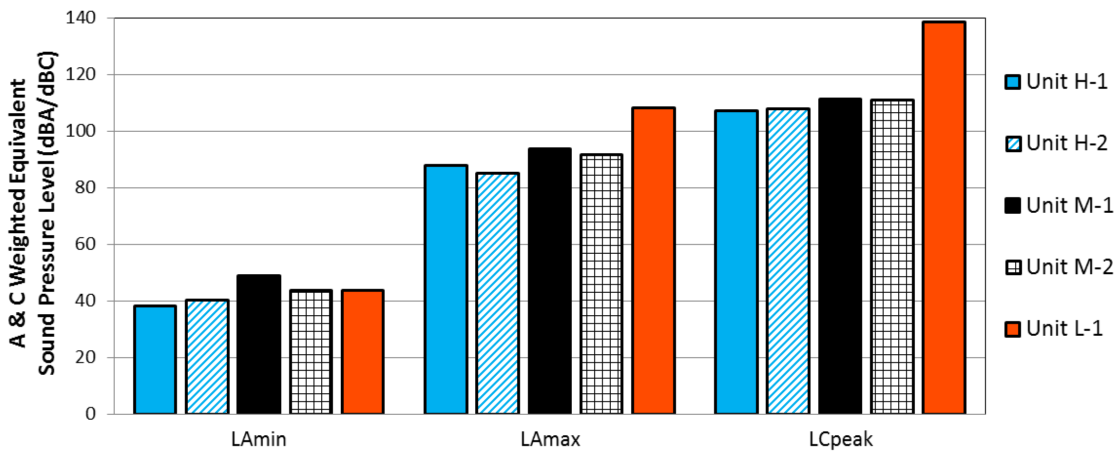

Figure 13: 24-Hour LA_{MIN}, LA_{MAX}, & LC_{PEAK} in Hospital U1 – 5 Unit Nursing Station Comparison (Absolute Values Shown)

Hospital U1 Measurement Results – Other Data

3.3.1 Short Term Measurements

Short-term 'spot' SLM measurements were collected from throughout each of the five units during the field procedures. 15-minute and 1-minute measurements were taken from multiple locations within the units, including hallways, waiting areas, and unoccupied patient rooms. The hallway and nursing station data were found to be consistent with 24-hour sound levels from the nursing stations, with most LA_{EQ} values falling between 50 and 60 dBA: typical office or conversation noise levels.

3.3.2 Unoccupied Patient Rooms

Data from unoccupied patient rooms were used to assess the background noise levels and door isolation properties in three units (Units H-1, M-1, and M-2). Within each room, measurements were collected in 4 scenarios: the hallway door open, the hallway door closed, and the privacy curtain pulled with the door open and closed. In each case the closed door provided good acoustical isolation from hall noise: 6.6 dBA decrease in LA_{EQ} from open conditions on average. While designed for visual privacy primarily, the thin fabric pull-curtains hung on tracks within the patient rooms also provided a noticeable decrease in LA_{EQ} values: 4.0 dBA on average. When used in combination, the curtains did not add any additional isolation to closed doors.

3.3.3 BNL Noise Criteria

To evaluate the background noise levels, conditions within the unoccupied patient rooms with the doors closed were analyzed. Even though the three units were located in different hospital towers, the BNL levels were quite similar. Units H-1, M-1, and M-2 were found to have LA_{EQ} values of 37 dBA, 36 dBA, and 38 dBA respectively. It should be noted that even in unoccupied room conditions, these three units did not meet the WHO occupied recommendations: "For wardrooms in hospitals, the guideline values indoors are 30 dBA LA_{EQ}, together with 40 dBA LA_{MAX} during the night." [11]

ANSI/ASA S12.2-2008 [16] defines the evaluation of room noise, specifically via the Room Criteria (RC) and Noise Criteria (NC) metrics utilized in this study. Table 3 displays the RC and NC values calculated using the unoccupied patient room data. Per ANSI/ASA recommendations, none of the units meet the stated BNL levels for private rooms in hospitals. For RC, a value of 25 – 35 is recommended, with a spectral rating of neutral (5 dB decrease per octave equates to a neutral spectrum). In all three units, the computed levels were within the recommended range, but the spectra were denoted with the hiss (H) classification, as there was additional high frequency noise. Similarly, the measured unit values did not meet the Facility Guidelines Institute (FGI) recommendations of RC 40 (N). [12]

Table 3: Unoccupied Patient Rooms in Hospital U1 – Room & Noise Criteria

Unit	RC	NC
Unit H-1	33 (H)	41
Unit M-1	33 (H)	42
Unit M-2	35 (H)	41

Figure 14 displays the frequency response from the three unoccupied patient room measurements as well as the RC 35 (N) cutoff line. While the low and mid frequency energy (below 2000 Hz) were within recommended levels for all units, there was a significant increase between 4000 Hz and 16000 Hz. This high frequency noise was the cause for the HF objectionable RC Ratings and high NC values. Since the three units had nearly identical spectra in the high frequency region, it was surmised that the source of this noise was system based: either through duct noise or diffuser selection possibly.

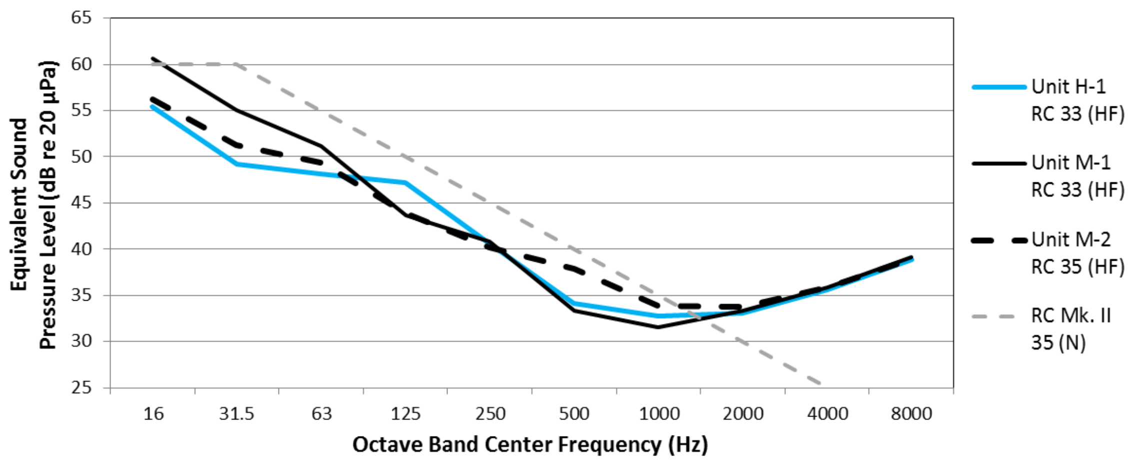

Figure 14: Unoccupied Patient Rooms in Hospital U1 – Frequency Spectra

Hospital U1 Data Analysis

3.4.1 Discussion

Once the acoustical data for the 15 patient rooms and five nursing stations within the five measured units was compiled, it was subsequently analyzed in a number of ways. First, the 2016 HCAHPS survey data provided for both individual patient rooms and unit-wide averages were correlated with all calculated acoustical metrics. These correlations were then utilized to assess which acoustical metrics could accurately assess patient perception of the hospital. In addition, reasons were found as to potentially why some units under or over performed in HCAHPS survey results. Also, the ceiling type installed within each patient room (ACT or GWB) was compared, as well as day and night differences and the Quiet Time hours implemented in each unit.

It should be noted that all measured rooms were included in the subsequent analyses, with no outlier exclusions. This choice was intentional, as a large enough percentage (> 20 %) of patient rooms was found to have values outside of a normal distribution for several acoustical metrics. This might have impacted analysis results by potentially finding different statistically correlated metrics (or not correlated). However, the decision to include all measurements regardless of data distribution was deemed to better represent the measured patient rooms rather than a selected subset of data.

3.4.2 HCAHPS Correlation

In this research, the HCAHPS ‘Quietness of Hospital Environment’ survey results for the 2016 calendar year were compared with acoustical metrics. Using the Top Box Scores for answer ‘Always’ quiet, linear regressions were completed using SAS analytics software, comparing HCAHPS survey results with unit and individual room acoustical data. In the analysis, the probability values (p), F critical values (F), and correlation coefficients (r) were used to evaluate the relationship strength between those datasets.

Unfortunately, Unit H-1 was opened during the 2016 calendar year and as such, received significantly fewer survey responses than the other units, including one room which did not receive any responses at all. This room was subsequently omitted from all further HCAHPS correlations, resulting in a comparison of 14 total rooms. HCAHPS survey response data for the 'Quietness of Hospital Environment' question have been placed in Table 20 (individual rooms) and Table 21 (full units) of Appendix A. Data has been provided for each acoustical metric, the results of which can be found in Appendix A in Table 22 (individual rooms), Table 23 (averaged units), Table 24 (spectral data), Table 28 (daytime), and Table 29 (nighttime). In the tables, statistical values have been located beneath each acoustical value and highlighted yellow if found statistically significant ($p < 0.05$) or orange if found marginally related ($0.05 < p < 0.10$).

Table 2 displays the aggregated HCAHPS unit data for the 2016 calendar year, showing a clear delineation between the higher performing units, H-1 and H-2, as compared with the other three. However, the 24-hour LA_{EQ} values (Figure 5) showed no correlation with HCAHPS scores, using individual room data ($F[1,13] = 0.02$, $p = 0.899$) or aggregated unit data ($F[1,4] = 0.24$, $p = 0.655$). In fact, the 'Best' rated unit had the third loudest noise levels while the quietest unit performing only average in the patient survey. Even though LA_{EQ} levels were not statistically correlated, there was some relationship between LA_{EQ} values and HCAHPS data, as the loudest two units, M-2 and L-1, were also the lowest performing units in the survey. This indicated that while the LA_{EQ} values could partially describe these hospital soundscapes, they could not fully account for the perceived acoustical conditions within the patient rooms.

No corrections were made in the statistical analyses to account for multiple correlations of the same dataset. This analysis was intended to find acoustical metrics that were potentially correlated with HCAHPS patient satisfaction data, so the use of multiple correlations was on purpose. However, analysis corrections might have been applicable in this instance to ensure that significant correlations were indeed representative of related quantities and not a product of random chance correlation.

Looking at the other acoustical metrics listed in Figure 6 and Figure 7, the absolute value of LA_{MIN} was found to be statistically correlated with HCAHPS unit-level survey data ($F[1,4] = 9.91$, $p = 0.050$) and marginally related with room-level data ($F[1,13] = 4.05$, $p = 0.065$). In addition, the two other spectrally weighted absolute minimum values collected were also found to be correlated (or marginally related) with HCAHPS data at a room-level: LC_{MIN} ($F[1,13] = 4.96$, $p = 0.046$) and LZ_{MIN} ($F[1,13] = 3.35$, $p = 0.092$). These minimum absolute values marked the quietest moment during the 24-hour measurement period: essentially the 'noise floor' or an in-situ background noise level within each patient room. These measurements showed that patient rooms capable of achieving quieter conditions were more likely to produce higher HCAHPS 'Quietness of Hospital Environment' results. Units H-1 and H-2 were found to have the quietest LA_{MIN} levels (below 35 dBA on average), and perhaps consequently these units performed best on HCAHPS survey responses. When compared with Unit M-1, LA_{EQ} levels in Units H-1 and H-2 were louder overall, but these two units were perceived more favorably by patients. Examining the LA_{MIN} levels by individual patient room revealed similar results: patient rooms with absolute LA_{MIN} values below 35 dBA scored 16.2 % higher on average (61.1 % vs 49.9 %) for the 'Quietness of Hospital Environment' question than rooms with higher LA_{MIN} levels ($F[1,13] = 5.5$, $p = 0.037$). These results indicated a preference in patient perception, as hospital rooms with minimum sound levels below 35 dBA performed significantly better on HCAHPS surveys.

Looking at the remaining acoustical metrics compared (and listed in Table 22) with HCAHPS data, there were no other values that were found to be correlated with room-level data. Also, when the unit-level data were analyzed, only one other metric was found to be correlated: LZ_{MAX}. As this value was the only 'peak' metric found to be correlated with HCAHPS data, this finding was deemed a random occurrence.

When HCAHPS scores were linearly regressed with 1/1 octave band frequency data (Table 24), it was found that specific low frequency bands were statistically correlated (or marginally related): 16 Hz ($F[1,13] = 4.66$, $p = 0.050$), 31.5 Hz ($F[1,13] = 3.66$, $p = 0.080$), and 63 Hz ($F[1,13] = 8.82$, $p = 0.012$). Nearly identical results were found when the 24-hour data were delineated by daytime and nighttime. Furthermore, the 1/3 octave band spectral data revealed that four specific low frequency bands were statistically correlated: 20 Hz ($F[1,13] = 6.34$, $p = 0.027$), 63 Hz ($F[1,13] = 5.08$, $p = 0.044$), 80 Hz ($F[1,13] = 11.96$, $p = 0.005$), and 100 Hz ($F[1,13] = 5.45$, $p = 0.038$). The results of these statistical tests on the spectral data were considered meaningful, as the range of data between rooms was substantive: 7 – 14 dB depending on the frequency band. Figure 10 displays the average frequency response for each of the five units, with better perceived units (H-1 and H-2) having quieter low frequency levels. Patient perception of Unit M-1 was worse than expected (having the lowest measured average LA_{EQ} levels), but was found to have significant additional low frequency noise. It was suspected that this loud low frequency energy was in part responsible for the poor HCAHPS survey scores for Unit M-1. When looking at the HCAHPS performance of individual patient rooms, it was found that rooms with noise levels below 50 dBA in low frequency bands (20 Hz – 125 Hz) scored on average 11.5 % higher on HCAHPS 'Quietness of Hospital Environment' survey responses. These findings provide another link between low frequency noise and patient perception.

3.4.3 Occurrence Rate Analysis

To further analyze the complicated soundscapes measured in the hospital patient rooms, Occurrence Rate values were calculated for the four 'primary' acoustical metrics: LA_{EQ}, LA_{MIN}, LA_{MAX}, & LC_{PEAK}. A spreadsheet was developed to calculate Occurrence Rate values for any acoustical metric, with resolution down to 1 decibel. To determine whether any of these metrics were correlated with HCAHPS 'Quietness of Hospital Environment' survey data, the Occurrence Rates found for each of the above metrics were tested at all decibel values measured. For example, the LC_{PEAK} Occurrence Rates were linearly regressed with the HCAHPS data at 70 dBC, 75 dBC, 80 dBC, etc. Calculated Occurrence Rate values and statistical correlations can be found in Appendix A in Table 25 (LC_{PEAK}), Table 26 (LA_{EQ} & LA_{MIN}), and Table 27 (LA_{MAX} & Occurrence Rate Range).

Of the four above metrics, only LC_{PEAK} was found to be correlated with HCAHPS survey results when regressed against room-level data. Because of this finding, LC_{PEAK} data were regressed at one decibel increments for a more thorough examination of the range of correlated values. For all values between the range of 71 dBC to 78 dBC, marginal correlation was found, with significant correlations found at 72 dBC ($F[1,13] = 5.18$, $p = 0.042$) and 74 dBC ($F[1,13] = 5.54$, $p = 0.036$). This indicated that there might have been a threshold for LC_{PEAK} values at which it became tangible to patient perception. Based on these results, an LC_{PEAK} level of 74 dBC was found to be the highest correlated quantity and could be considered the most likely value for this dataset.

Looking at the LA_{EQ} and LA_{MAX} Occurrence Rate values, no statistical correlation was found between either metric at any calculated level with the HCAHPS survey data. Similarly, LA_{MIN} Occurrence Rate values were not found to be statistically correlated with HCAHPS data, save the 55 dBA minimum level which was found to be marginally related, thought to be due to a statistical anomaly.

Secondary Occurrence Rate Metrics

To take the analysis of Occurrence Rates a step further, additional metrics were calculated based on the above data for all four metrics. These secondary metrics included the maximum Occurrence Rate slope rate (in %), maximum Occurrence Rate slope level (in dB), Occurrence Rate integration (in dB & Pa), Occurrence Rate range (in dB), and Occurrence Rate 1 % and 99 % levels (in dB). These acoustical metrics have not been calculated in any prior research and developed solely in the course of this research.

Example Occurrence Rate graphs have been included in Figure 15 and Figure 16 to illustrate the calculated values. The 24-hour LA_{EQ} level (marked by a black square) has been included for reference. The 1 % and 99 % Occurrence Rate levels (marked by a black X and a blue diamond respectively) are rather self-explanatory: these were the levels at which the Occurrence Rate exceeded the 1 % and 99 % thresholds. The max slope level (marked by an orange triangle) indicated the 'steepest' slope point found on the graph, which could have been an indication of the shape of the graph (i.e. how fast the Occurrence Rate levels progressed from 100 % to 0 %). Finally, a trapezoidal integration was calculated for the Occurrence Rate values, providing another possible manner of quantifying the total noise level over time (marked with yellow circle).

Values included in the legend of the two figures below are the Occurrence Rate range, which was calculated by subtracting the 99 % level from the 1 % level. Also, the value of the maximum Occurrence Rate slope has been listed: the value associated with the point indicated with the orange triangle. These two values represented the best metrics to describe the 'shape' of the Occurrence Rate graph. It was important to understand the 'shape' of the Occurrence Rate graph, because with this information it was possible to better evaluate the perception of the measured soundscape conditions.

The two graphs below display LA_{EQ} Occurrence Rate values for individual patient rooms in Hospital U1. The room shown Figure 15 exhibited a wide range of sound levels over the course of the measurement period. This can be seen in both the Occurrence Rate range (27 dB) and the maximum slope (12.2 %). The room shown in Figure 16 shows a very narrow range of sound levels during the measurement time, with largely different Occurrence Rate range (11 dB) and the maximum slope (29.2 %) values. The room shown in Figure 16 was consistently loud, whereas the room shown Figure 15 had periods of quiet interspersed with louder noise events. Clearly, the soundscape conditions within these two rooms were quite different, even though the 24-hour LA_{EQ} levels were reasonably similar, with 57 dBA and 61 dBA respectively and thus just exceeding the minimum perceptible difference.

By analyzing the Occurrence Rate values using the Occurrence Rate range and maximum slope rate in this manner, it was possible to produce a single number value to indicate the variability of sound levels in the acoustical time history measurements. In the course of this research the Occurrence Rate range was found to be the most reliable predictor of Occurrence Rate graph 'shape', more than the maximum slope rate. This was due to the wide variety of Occurrence Rate configurations that are possible. In comparison, a fair percentage of the time for the data from Hospital U1, the maximum slope rate produced inconclusive results.

Therefore, the Occurrence Rate range metric, developed in this research, was specifically explored as a means to analyze Occurrence Rate data. It was found to accurately describe the sound level variability within the measured patient rooms, was the easiest new metric to calculate, and was also the most easily understood quantity. It should be noted, when calculating LA_{EQ} Occurrence Rates, the Occurrence Rate range will be the exact same quantity as the statistical value $LA_{01} - LA_{99}$, which is commonly calculated. However, Occurrence Rates can be calculated for any acoustical metric with time history data, so for any other metric (e.g., LA_{MAX}) there is no direct association with commonly reported statistical levels.

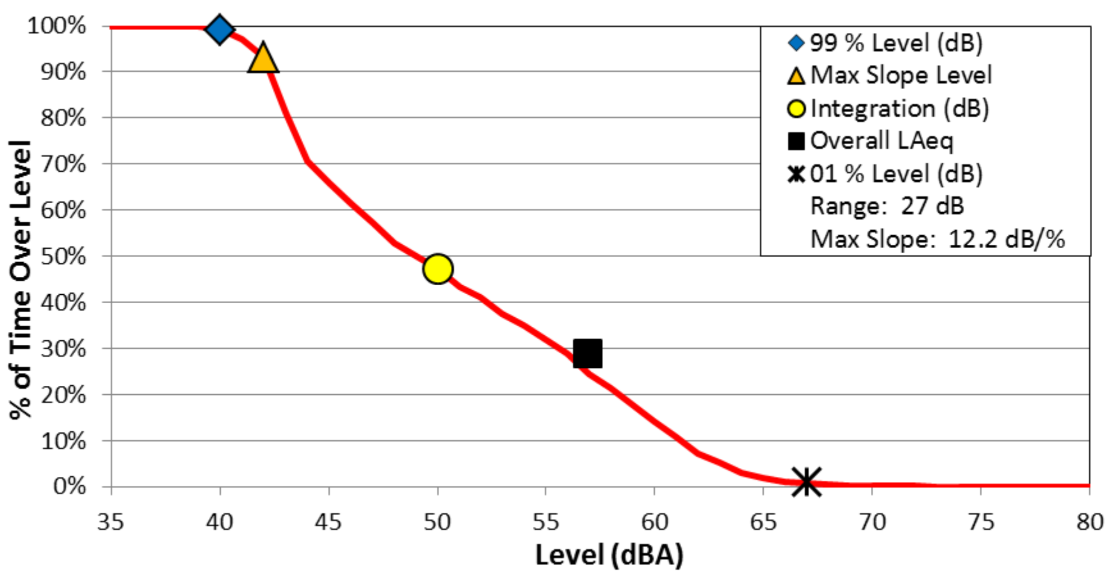

Figure 15: Example Occurrence Rate Graph – Wide Occurrence Rate Range

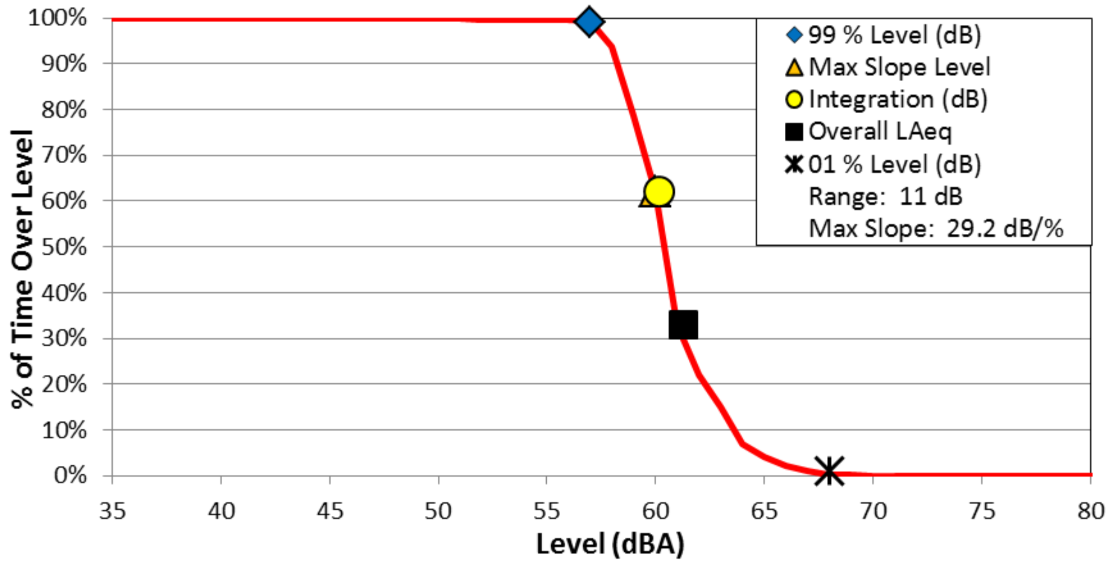

Figure 16: Example Occurrence Rate Graph – Narrow Occurrence Rate Range

As with the Occurrence Rate values, the newly created secondary Occurrence Rate metrics were correlated with HCAHPS 'Quietness of Hospital Environment' survey data. Linear regressions were calculated for the maximum Occurrence Rate range, Occurrence Rate slope rate, maximum Occurrence Rate slope level, Occurrence Rate integration (in dB & Pa), and Occurrence Rate 1 % and 99 % levels. Out of these metrics, only the Occurrence Rate range was found to be statistically correlated (or marginally related) with HCAHPS data for LA_{EQ} ($F[1,13] = 5.00$, $p = 0.045$), LA_{MAX} ($F[1,13] = 3.38$, $p = 0.091$) and LC_{PEAK} ($F[1,13] = 10.55$, $p = 0.007$). (Table 27)

These findings indicated potential connections between the variability in soundscape noise levels and patient perception, as measured using the Occurrence Rate range. In this dataset, having a wider range of noise levels was found to be correlated with higher HCAHPS scores. However, when analyzed further this correlation was found to be linked to a specific component of the noise level variability: the minimum sound levels. Rooms with lower LA_{MIN} levels yielded larger Occurrence Rate ranges and vice versa, thus these two metrics were found to both be correlated for LA_{EQ} and LC_{PEAK} Occurrence rate ranges. Conversely, no relationship was found between Occurrence Rate ranges and LC_{PEAK} levels. This indicated that the Occurrence Rate ranges were being dictated by minimum sound levels primarily. Therefore, while statistical correlation was found between Occurrence Rate ranges and HCAHPS survey data, it is unclear whether the metric can be utilized to accurately assess other hospital soundscape conditions. More research into the Occurrence Rate range metric is required before definitive conclusions can be made, as described later in Chapter 5 of this dissertation.

3.4.4 Comparison of Hospital Units

Upon analysis of the HCAHPS survey data, questions arose as to why certain hospital units rated well and others did not. Why did Unit H-1 rate best on the survey with higher average 24-hour noise levels? Why did Unit M-1 rate poorer on the survey with quieter noise levels overall? The ‘primary’ acoustical metrics described above could not fully address these issues and thus a deeper analysis was necessary.

Unit H-1 was designed to provide suite-style accommodation for patients, with an entrance alcove used for family space and nursing functions, also acting as a natural sound buffer. The unoccupied sound levels measured in the unit revealed a low background noise level of 37 dBA which equated to RC 33 (H). Anecdotally, the unit seemed quiet overall both within patient rooms and in the hallway, so the reason behind the discrepancy between higher 24-hour noise levels and HCAHPS scores was initially unclear. Through analysis, it was found that at least one of the patient rooms measured used an auditory sleep aid (white noise, television, etc.) during the night, thus artificially raising the noise levels. This was surmised because the nighttime LA_{MIN} absolute value was 52.0 dBA within the room in question, which was well above measured background noise levels in the unit. In fact, the LA_{EQ} was actually higher at night than in the daytime. This demonstrated the unpredictability of the hospital soundscapes and could potentially explain why Unit H-1 was perceived as quiet while having higher measured sound levels.

Looking solely at the LA_{EQ} data, Unit M-1 should have rated very well in the HCAHPS survey. However, with a rating of 52.4% on the 2016 ‘Quietness of Hospital Environment’ question, it was the third rated unit of the five. Nearly all of the acoustical metrics pointed to quiet conditions within the unit: LA_{EQ}, LA_{MIN}, LA_{MAX}, LC_{PEAK}, SII, RC, NC, and Occurrence Rates. The average frequency spectrum was the one acoustical quantity that stood out. There was significant low frequency energy concentrated between 30 and 80 Hertz found at all times during the measurement.

To look at the unit another way, the frequency spectrum for the LA_{90} statistical sound level was plotted, which represented the sound level exceeded 90 percent of the time and could be thought of as the ‘ambient’ noise level within the unit. Figure 17 displays the LA_{90} frequency spectra of Unit M-1 and Unit H-2 for comparison. The discrepancy in low frequency energy was clear: 17 dBA louder at 40 Hz. This unwanted noise, especially at night, was found to be the most likely cause for such low HCAHPS ‘Quietness of Hospital Environment’ results in Unit M-1. While this cannot be confirmed solely from the analysis, the increased low frequency energy was the only acoustical metric which stood out amongst those evaluated. Interestingly, the location of the unit within the hospital campus might have been a factor in the noise, as the unit was positioned on the top floor of a tower, in proximity with rooftop HVAC equipment and three helipads.

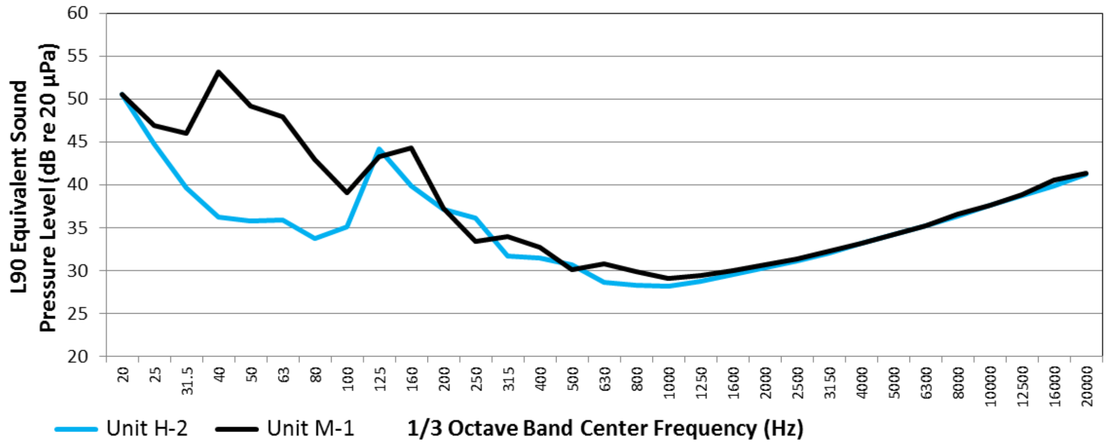

Figure 17: Comparison of Unit M-1 & Unit H-2 in Hospital U1 – L_{90} Frequency Spectra

3.4.5 Low Frequency Noise in Hospitals

The impact of this low frequency noise was not completely unexpected, as the effects of unwanted low frequency noise have been studied for some time. Low frequency sounds are generally from 20 Hz – 125 Hz (sometimes considered up to 250 Hz) and can be described perceptually as 'rumbly' or 'boomy'. Low frequency noise is more capable of passing by or through objects, due to the longer wavelengths, making it more difficult to deal with acoustically. [12] These physical properties are why low frequency noise can be heard transmitted through multiple building levels or over significant distances, as generated by HVAC equipment or wind turbines, for example. Also, because of the mechanics of the inner ear, low frequency sounds can obscure higher frequency sounds due to the upward spread of masking. [95] This can especially interfere with communication, as low frequencies could potentially mask speech regions.

It has been found that low frequency noise has been judged to be louder and more annoying than noise of equal sound pressure level with flat spectral content. [96] Also, buzz and rattle can be generated through low frequency vibrations, further exacerbating annoyance. Additional studies have shown the perception of rumble and roar to be significantly correlated with the subjective perception of loudness and annoyance, meaning that as subjects perceive noise to be more roaring or rumbly, they also perceive it to be louder and more annoying. [97]

Looking beyond the perception of annoyance, low frequency noise has been found to impact individuals physically, potentially leading to sleep-related problems, concentration difficulties, or headaches. [51] Other studies have shown low frequency noise to negatively impact performance, as judged by proof-reading and verbal grammatical reasoning tests. [84] Identified in both of these studies was the additional impact experienced by individuals found to have high noise sensitivity, indicating that while low frequency noise is generally perceived to be negative by the general population, these perceptions are exacerbated in those who are more sensitive to noise.

Helicopter Noise at Hospitals

Hospital Unit M-1 described in the previous section was found to have several potential sources of the low frequency noise, primarily due to the physical location within the hospital complex. The unit was situated on the top floor (9^{th} floor) of a centrally located building on the hospital campus. This placed the unit directly below HVAC equipment located on the roof, capable of generating low frequency noise that could potentially be transmitted through to the floor below.

The unit was also in close proximity to three helicopter pads used for emergency patient transportation. Helicopters generate significant amounts of tonal low frequency noise and have been found to increase annoyance in communities. [98] While on-site during measurements within the unit, multiple helicopters were observed landing and taking off with flight plans directly over the specified unit, so it was hypothesized that they were a source of the low frequency noise measured within the unit. To handle the emergency helicopter patient transportation, Hospital U1 utilizes Bell 407 helicopters for all patient transports. [99]

No acoustical measurements were conducted at the Hospital U1 campus to analyze the helicopter noise on-site due to access limitations. Fortunately, acoustical data has been published documenting the noise levels generated by various helicopters including the Bell 407. [100 – 102] In the most detailed analysis, it was found that the Bell 407 produced significant tonal noise at approximately 40 Hz with secondary peaks at approximately 80 Hz and 120 Hz. [100] These values were consistent with measured noise levels at Hospital U1 and provided a basis for further analysis. It must be stated that the helicopter noise was infrequent, and thus could not be considered the sole cause of the additional low frequency noise, only a contributing factor.

3.4.6 Acoustical Ceiling Tile vs Gypsum Wall Board Ceiling

Between the five measured units, ceiling type was the only disparate architectural element found. Units H-1, H-2, and M-1 featured acoustical ceiling tile while Units M-2 and L-1 had gypsum wall board ceilings. To analyze the data statistically, one-way ANOVA tests were computed between the two ceiling types and the gathered acoustical metrics. Table 4 displays the room averaged acoustical metrics for both ACT and GWB ceiling groups. All values were lower on average in the rooms with ACT, with LA_{EQ}, LA_{MAX}, and LC_{PEAK} levels each 4 – 5 dB quieter. These improvements were consistent with prior research which found a 5 dBA decrease in LA_{EQ} values after the installation of absorptive ceiling panels within a hospital ward. [56] As expected, these acoustical metrics listed were all statistically correlated between the ceiling types, including LA_{EQ} ($F[1,13] = 10.58$, $p = 0.006$), LA_{MIN} ($F[1,13] = 11.03$, $p = 0.006$), LA_{MAX} ($F[1,13] =$

11.81, p = 0.004), LC_{PEAK} (F[1,13] = 15.55, p = 0.002), and SII (F[1,14] = 11.52, p = 0.005). The LA_{MIN} levels in this study were particularly quieter in the rooms with ACT: 10 dBA lower than in rooms with GWB ceilings.

In fact, of all the acoustical metrics calculated for the 24-hour patient room data, only the absolute maximum values (LA_{MAX}, LC_{MAX}, and LC_{PEAK}) were not correlated with the type of ceilings installed. Thus, based on the collected acoustical data a significant decrease in sound levels was found between patient rooms utilizing acoustical ceiling tiles and those appointed with gypsum wall board ceilings.

Table 4: Ceiling Type Comparison in Hospital U1 – ACT vs GWB Ceilings

	LAeq	LAmin	LAmax	LCpeak
Unit	(dBA)	(dBA)	(dBA)	(dBC)
ACT Ceiling	56	45	70	87
Gypsum Ceiling	61	55	74	91

3.4.7 Day/Night Differences

Daytime (7 AM to 10 PM) and nighttime (10 PM to 7) hours were compared acoustically as well. Table 5 displays the average daytime and nighttime LA_{EQ} and LA_{MAX} values for the five units. It was found that nighttime LA_{EQ} levels were 2.6 dBA quieter than in the daytime, with the largest difference being only 4 dBA. These values were in line with day/night differences found previously. [4]

Because the sound level meters utilized in this study were unmanned, the cause of the relatively small differences between daytime and nighttime noise levels was unknown. All rooms were occupied overnight, but the activity level within specific patient rooms or the hallways could have varied widely. Also, some individuals might have preferred to sleep using some sort of aural sleep aid, such as a white noise generator or the radio/television, as suspected in Unit H-1. These types of discrepancies were ultimately included in all averaged values as no further data parsing was possible based on available information.

Table 5: Daytime vs Nighttime Noise Level Comparison in Hospital U1 – LA_{EQ} & LA_{MAX}

	LAeq (dBA)		LAmax (dBA)	
	Daytime	Nighttime	Daytime	Nighttime
Unit	7 AM-10 PM	10 PM-7 AM	7 AM-10 PM	10 PM-7 AM
Unit H-1	59	57	73	68
Unit H-2	56	53	72	67
Unit M-1	53	49	70	65
Unit M-2	60	57	75	70
Unit L-1	62	61	74	73

Full acoustical data as well as HCAHPS statistical correlations can be found in Appendix A in Table 28 (daytime) and Table 29 (nighttime). When the daytime and nighttime acoustical data were regressed with HCAHPS 'Quietness of Hospital Environment' survey data, very few correlations were found. In fact, the only acoustical metric found to be even marginally related with HCAHPS data were LA_{MIN}, both for daytime ($F[1,13] = 4.03$, $p = 0.068$) and nighttime ($F[1,13] = 4.08$, $p = 0.066$). The nighttime findings are especially meaningful, due to the wording of the HCAHPS question: *'During this hospital stay, how often was the area around your room quiet at night?'* Because the question asks specifically about nighttime noise perception, having LA_{MIN} be the only acoustical metric to stand out was an interesting finding.

3.4.8 Quiet Time

All five units measured in the study implemented a Quiet Time procedure for at least one hour every afternoon. These procedures were aimed at providing a quieter, more relaxing environment during the selected hours to improve patient recovery by decreasing the amount of occupant generated noise within the units. Units H-1 and H-2 had two hours of Quiet Time from 1 to 3 PM, Units M-1 and M-2 had two hours of Quiet Time from 2 to 4 PM, and Unit L-1 had one hour of Quiet Time from 3 to 4 PM.

Table 6 displays the LA_{EQ} values for Quiet Times and the overall daytime (7 AM to 10 PM) levels for the patient room averages and nursing stations within each unit. Very little difference was found between the Quiet Time LA_{EQ} values and the daytime levels in both environments: the largest discrepancy being only 1 dBA. Within the patient rooms this result was not surprising, as in-room patient activity would not necessarily change during these hours in the afternoon. At the nursing stations, however, a difference between daytime sound levels and the levels during Quiet Time hours was expected.

Table 6: Quiet Time Noise Level Comparison in Hospital U1 – LA_{EQ} in Patient Rooms & Nursing Stations

	Patient Rooms		Nursing Stations	
Unit	Day LAeq (dBA)	Quiet Time (dBA)	Day LAeq (dBA)	Quiet Time (dBA)
Unit H-1	59	59	56	56
Unit H-2	56	55	51	50
Unit M-1	53	53	59	59
Unit M-2	60	60	59	59
Unit L-1	62	63	57	56

Because there was so little difference seen in LA_{EQ} values, additional metrics were analyzed, including the LC_{PEAK} Occurrence Rates. Figure 18 displays the daytime and Quiet Time LC_{PEAK} Occurrence Rates for Units H-1, M-1, & M-2. Unit H-2 was omitted from the graph for not utilizing a standard nursing station; Unit L-1 was omitted from the graph for having negligible differences between daytime and Quiet Time levels. For the three units shown, a significant decrease in LC_{PEAK} Occurrence Rates was found during Quiet Time between 75 dBC and 85 dBC: levels were 20% to 30% less frequent on average. This indicated that while overall LA_{EQ} noise levels were not significantly affected by Quiet Time procedures, the quantity of louder transient events were being decreased by these measures (e.g. staff/patient communication and other occupant generated noise). As hospital staff contribute approximately 57 percent of noise within a unit not generated by patients [86], it is reasonable to conclude that Quiet Time procedures had a positive effect on staff noise levels within Units H-1, M-1, & M-2. Conversely, the similarity between Quiet Time and daytime LC_{PEAK} Occurrence Rates found in Unit L-1 indicated a potential lack of effectiveness of the intervention procedures, possibly attributable to the short one hour duration.

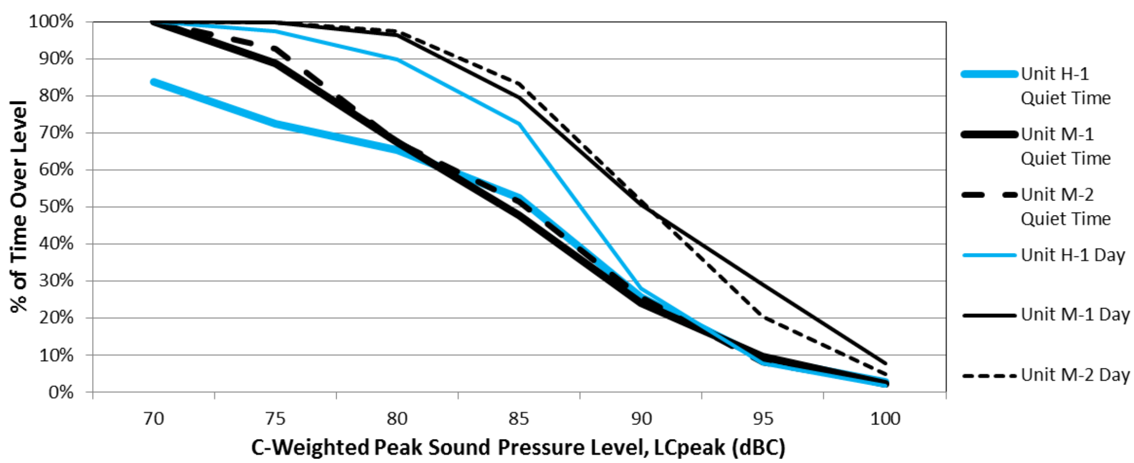

Figure 18: Quiet Time Noise Level Comparison in Hospital U1 – LC_{PEAK} Occurrence Rates from 3 Nursing Stations

Hospital U1 Conclusions

In Phase I of this research, the sound levels of patient rooms and nursing stations within five similar-type units were measured in an urban hospital, providing information on the acoustical performance of step-down recovery units currently in service. The 24-hour average LA_{EQ} values of the five units within the patient rooms was found to be between 52 dBA and 61 dBA, while the absolute minimum LA_{MIN} ranged from 33 dBA to 45 dBA, and the absolute maximum LA_{MAX} spanned from 89 dBA up to 99 dBA. All five of the units failed to achieve SII ratings of 'Good', with all either receiving 'Marginal' or 'Poor' grades. Occupied noise, such as speech, was the dominant spectral contributor, with most of the noise concentrated between 250 Hz and 4000 Hz, although some units (M-1 in particular) had low frequency issues. Unoccupied patient rooms in three of the units were measured, revealing relatively acceptable unoccupied noise levels (36 dBA – 38 dBA), although too much high frequency energy was present to meet ANSI/ASA or FGI patient room noise recommendations.

Additionally, the measured acoustical data were correlated with 2016 HCAHPS 'Quietness of Hospital Environment' survey responses, rating patients' perceptions of in-room noise conditions. Of all the acoustical metrics, the absolute minimum values measured LC_{MIN} was found to be the statistically correlated with HCAHPS survey information, with LA_{MIN} and LZ_{MIN} marginally related. A clear preference of patient perception was found, as hospital rooms with LA_{MIN} levels below 35 dBA scored 16.2 % higher on average than rooms that measured above this minimum sound level. These results show that even though LA_{MIN} values were found to only be marginally related with HCAHPS data when linearly regressed, the relationship between minimum sound levels and patient satisfaction is still evident. Low frequencies between 20 Hz and 125 Hz also generated significant correlations with HCAHPS data, finding patient rooms with levels below 50 dBA in these frequency bands scoring on average 11.5 % higher than those above this level. These findings established links between patient room minimum sound levels, low frequency noise, as well as the occurrence of peak noise events with patient perception, providing additional clues into the motivation of patients and how they evaluate hospital soundscapes.

Other metrics, LA_{EQ} for example, showed some association (as the loudest unit was also the worst rated in the survey) but not enough to be statistically correlated ($p > 0.05$). This incongruity between average noise levels and HCAHPS data were likely due to the unpredictable nature of the hospital soundscapes. The best rated unit (H-1) performed poorer than expected acoustically, potentially due to in-room patient noise at night (such as an auditory sleep aid). Conversely, the quietest unit (M-1) was rated as average on the HCAHPS survey, likely due to significant low frequency noise found within the unit.

The five units selected also provided the opportunity to compare patient room ceiling types, as three units had ACT installed while two utilized GWB ceilings. The patient rooms with ACT ceilings were found to be 5 dBA quieter on average than the GWB rooms. This again demonstrated the significant difference in acoustical performance between acoustical ceiling tile and gypsum wall board ceilings and likely explained the differences in HCAHPS survey performance between the two ceiling types: 58.5 % on average for ACT rooms and 47.9 % for rooms with GWB ceilings.

More research is required detailing the correlation with HCAHPS 'Quietness of Hospital Environment' survey data. Absolute LA_{MIN} noise levels, specific low frequency

1/1 & 1/3 octave bands, and LC_{PEAK} Occurrence Rate values were some of the very few acoustical metrics found to be correlated with HCAHPS data. These findings indicated a preference in patient perception for hospital rooms with BNL levels below 35 dBA with minimal low frequency or peak level noise: design goals that may be applicable to any hospital. However, additional testing in more patient rooms for longer durations is necessary to confirm these findings and determine whether any other acoustical metrics are potentially related. This would allow further correlations between the acoustical data to further understand hospital soundscapes and ultimately improve patient experience. To that end, additional acoustical measurements were collected at two rural hospitals and analyzed using HCAHPS survey data as well as staff survey data, detailed in the following chapter.

Chapter 4

Phase II: Relating Noise, Patient, and Staff Satisfaction in Rural Hospitals R1 & R2

Methodology

Phase II of this study involved acoustical measurements conducted at two smaller, rural hospitals, also located in Nebraska. Both hospitals included three units where acoustical measurements were conducted: ICU/Critical Care, Medical/Surgical, and Women & Children's. Within each unit 2 – 5 patient rooms were measured, along with 1 or 2 nursing station(s) for 24 hour periods using the same methods that were employed at Hospital U1. Once again, the collected acoustical data were correlated against HCAHPS 'Quietness of Hospital Environment' survey results to determine potential meaningful correlations. However, the HCAHPS for these hospitals were not delineated by room, so the analysis was limited to hospital-wide values. In addition to the HCAHPS survey, a recently conducted hospital administered staff survey was also available for comparison with measured acoustical data, providing a second form of analysis regarding the perception of noise within the hospitals and helped to corroborate some findings from Phase I of this study.

4.1.1 Measured Hospital Units

Both hospitals in Phase II were designed by the same architectural engineering (AE) firm (who also helped facilitate this phase of the study), and as such included many similar design elements. However, differences had been found in both patient and staff perceptions between the two hospitals, regarding centralized/de-centralized nursing stations and building environment conditions, especially concerning acoustics. In response to these findings, an investigation was launched by the two hospitals in conjunction with the AE firm to assess the perception of these issues, including a staff survey and physical environment measurements. Due to Dr. Ryherd's association with the AE firm, it was agreed to conduct the acoustical measurements at the two rural hospitals as part of this dissertation research. In doing so the noise issues within the hospital units were analyzed while also furthering the understanding of noise of within hospital units begun in Phase I. This provided an opportunity to expand upon Phase I in two ways: to investigate the Phase I methodologies and metrics in two different, rural hospital settings, and expand the project to include investigations of staff perception.

Both Hospitals R1 & R2 included a single four or five-story tower with units separated by floor. Acoustical measurements were collected from three units within both hospitals: ICU, Medical/Surgical, and Women & Children's (birthing units). When looking at the unit typologies, similarities were found between all units, which were expected given the same AE firm. For example, all rooms within the six units were private, all included ACT on the ceiling, and all had GWB installed on the walls. It should also be noted, even with the varying unit functions, all units were still technically step-down type, and thus subject to HCAHPS patient surveys, which were utilized in the analysis during this study. No Quiet Time hours were observed in either hospital. Details on the six measured units from the two rural hospitals can be found in Table 7.

Table 7: Five Units Measured in Hospitals R1 & R2

Hospital	Unit	Room Type	Bed Count	Ceiling Type
R1	ICU	Private	6	ACT
R1	Med / Surg	Private	26	ACT
R1	Women / Child	Private	20	ACT
R2	ICU	Private	32	ACT
R2	Med / Surg	Private	32	ACT
R2	Women / Child	Private	24	ACT

Hospital R1 was the smaller of the two hospitals, and as such located the three units on only two floors. Figure 19 shows the layout of the two main floors of Hospital R1, which was comprised of the ICU and Medical/Surgical units on the 3rd floor with the Women & Children's unit on the 4th floor. The floors were laid out in a 'T', with the main nursing station located at the crossing of the hallways. Each of the hallway legs included two parallel halls, separated by offices/storage. These close parallel halls could have led to some acoustical reflection anomalies (discussed below in section 4.4.6). A second nursing station was located on each floor, but was generally unmanned. The ICU and the Medical/Surgical units were not physically separated by anything: the ICU simply included the six patient rooms located nearest to the main nursing station (denoted by the dashed line in Figure 19) with the remaining 26 rooms on the 3rd floor being designated as Medical/Surgical. In addition to nursing station proximity, the ICU rooms also included more extensive medical equipment and further capabilities for in-room procedures. The Women & Children's unit was populated primarily with women giving birth, and according to the nursing staff, has had significant occupant fluctuation due to the unpredictability of birth. When measured, the unit (which included 20 patient rooms in total) had only six patients and the rest of the unit was empty. When extremely busy, the Medical/Surgical unit uses the unused rooms on the 4^{th} floor as overflow.

Hospital R2 was slightly larger than its counterpart, and as such had the ICU, Medical/Surgical, and Women & Children's units located each on separate floors. Figure 20 shows the layout of the three units measured in this study, with Women & Children's on the 2^{nd} floor, ICU on the 3^{rd} floor, and Medical/Surgical on the fourth floor. Each of the floors incorporated dual-corridor designs with staff facilities between the two hallways. The ICU and Medical/Surgical units both included 32 rooms in total and were identical in layout of patient and staff facilities. The Women & Children's unit was slightly different in layout (not shown due to unavailable building plans), as the lower, left hallway was cordoned off to house the neo-natal intensive care (NICU) patients in an isolated space.

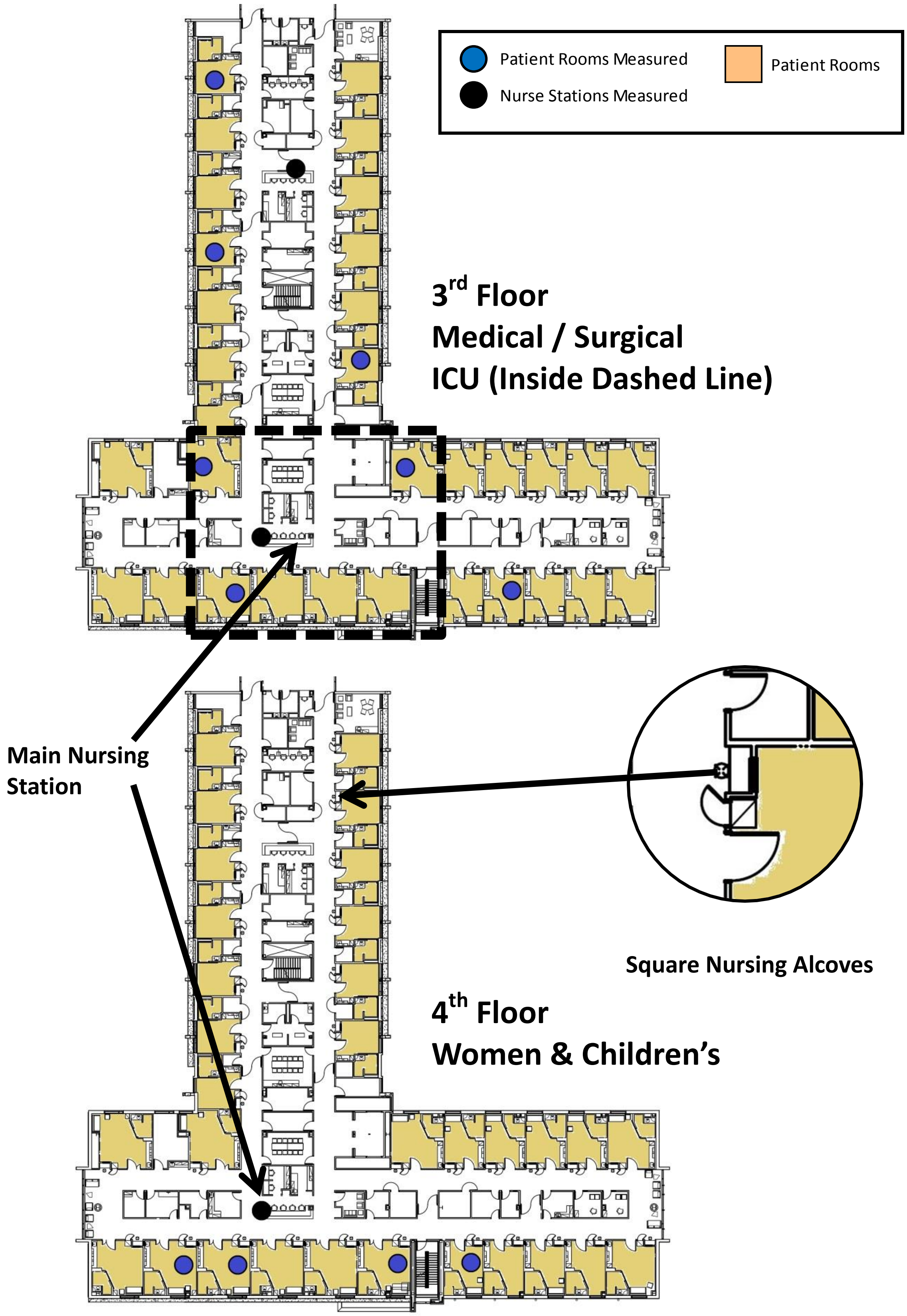

Figure 19: Three Units Measured in Hospital R1

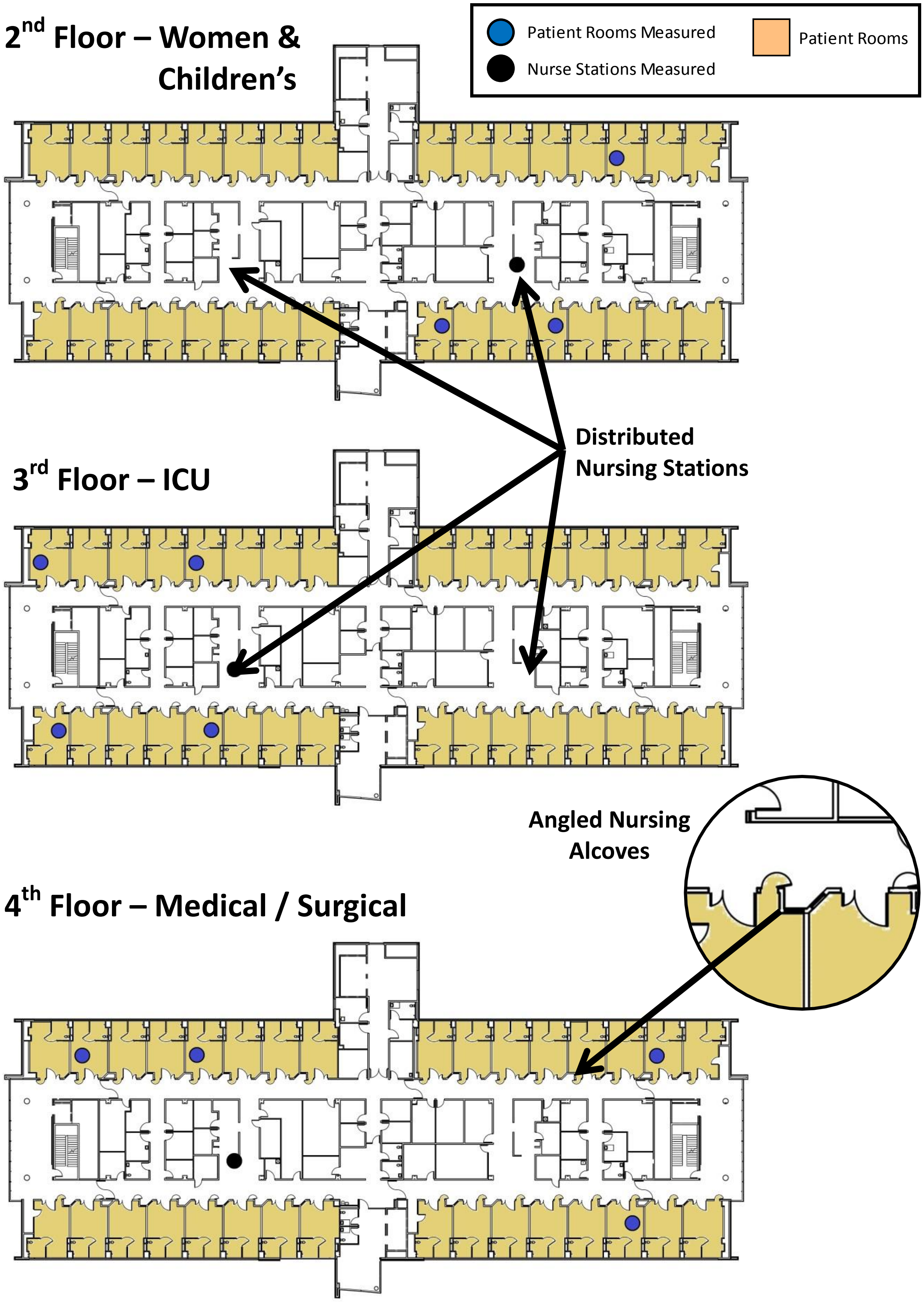

Figure 20: Three Units Measured in Hospital R2

The principal difference between the two hospitals was the utilization of the nursing stations. Hospital R1 used a centralized nursing station for most operations on both floors, while Hospital R2 employed multiple de-centralized nursing stations on all three floors. The study of centralized/de-centralized nursing stations in function was beyond the scope of this research. However, these two types of nursing stations can have an impact on unit acoustics, both in overall level and dispersion of noise, which was import to this study. In addition, the nursing alcoves were also a point of interest between the two hospitals, as Hospital R1 included square alcoves and Hospital R2 had angled alcoves, detailed in the figure insets above. While innocuous in appearance, the sharp corners that the square alcoves created could reflect sounds in unwanted and unexpected ways, potentially contributing to acoustical issues noted by staff.

A few other physical differences were found between the two hospitals which were of note (each hospital was consistent internally). First, the floors installed within the hallways of the two hospitals were slightly different. Both were some type of rolled, resilient flooring, but the floors in Hospital R2 were slightly softer feeling underfoot, which resulted in less footfall and cart noise. It was unclear the specific difference in material (underlayment thickness, etc.), but the effect was tangible. The second difference found was the inclusion of ACT in positive pressure rooms in Hospital R2. Hospital R1 utilized GWB ceilings in these few rooms (2 – 4 per floor), which did result in higher background noise levels (detailed in section 4.3.2).

4.1.2 HCAHPS Patient Survey Ratings

Unlike Hospital U1 (which included numerous hospital units with HCAHPS data which to select from) Hospitals R1 & R2 only had three units available for study: ICU, Medical/Surgical, and Women & Children’s. As such, all units were measured acoustically and used to compare with HCAHPS patient survey data. Unfortunately, the same level of detail was not available for HCAHPS data for either Hospital R1 or R2 as was provided for Hospital U1. For the Hospital R1, HCAHPS survey data were aggregated by hospital and by month, so all survey responses for each hospital were lumped together each month, regardless of room or unit. Hospital R2 was compiled even further, with only hospital-wide data available for the 2014 and 2016 calendar years.

This lack of specificity was due to the layers of management used to administer the HCAHPS surveys to patients. The hospitals used a third party company to administer the surveys to patients after discharge. This company only provided the hospital (and thus in turn the AE firm and ultimately this research) with aggregated survey data. In a way this makes sense for the hospital, as aggregated data would be easier to analyze and draw conclusions from. However, because the hospital did not have room-level data on file, and the third party company was unavailable to contact, this meant that room-level HCAHPS data were not available for comparison with acoustical measurement data. Therefore HCAHPS survey data were not correlated by room or unit with acoustical data. Instead, an analysis was completed based on the hospital-level HCAHPS information, in conjunction with the staff surveys administered by the architectural engineering firm.

Hospital R1 HCAHPS Data

The HCAHPS patient survey data that was available for study of Hospital R1 was compiled by hospital, delineated by month. The data provided included five questions rating patient hospital perception: ‘Quietness of Hospital Environment’, ‘Received Help When Needed’, ‘Overall Hospital Rating’, ‘Would Recommend Hospital’, and ‘Family Allowed to be with Patient’. Response data for these five questions can be found in Table 8. Included was data over the past five years (July 2013 was the first month recorded), divided by pre and post-move dates. During January 2015, the units measured in this study were moved from a different location in the same city. No data were available regarding specific differences in unit typology or features for the pre-move conditions.

Table 8: HCAHPS Patient Survey Response Data in Hospital R1

		Pre-Move (July 2013-December 2014)		Post-Move (January 2015-March 2018)	
Questions	Positive Response	Total patients	Positive N (%)	Total patients	Positive N (%)
Quietness of Hospital Environment	Always	516	298 (57.8)	980	720 (73.5)
Received Help When Needed	Always	448	313 (69.9)	857	514 (60.0)
Overall Hospital Rating	9 or 10	503	378 (75.2)	962	762 (79.2)
Would Recommend Hospital	Definitely	501	359 (71.7)	950	720 (75.8)
Family Allowed to be With Patient	Always	477	437 (91.6)	925	845 (91.4)

In total, approximately 500 patients responded to the five survey questions (448 – 516 responses per question) before the move and approximately 950 patients responded after the move (857 – 980 responses per question). This equated to approximately 25 patient responses per month for the entire hospital, consistent both pre and post-move. For HCAHPS results, the Top Box Score is most commonly utilized metric to analyze response data, listed as 'N (%)' for each question above, and corresponds to positive response percentages listed for both before and after moving. For one question, 'Quietness of Hospital Environment', a marked increase was seen between pre and post-move conditions: 57.8 % vs 73.5 %. For another question, a decrease was found as time progressed: 'Received Help When Needed' lowered from 69.9 % to 60.0 %. The other three questions showed marginal increases over time, if any at all.

The monthly response data for the ‘Quietness of Hospital Environment’ question for Hospital R1 has been displayed in Figure 21. Denoted is the pre and post-move time periods during January 2015. A steady increase in patient positive patient responses can be seen over the entire timeframe, producing statistically significant positive linear trends (F[1,56] = 33.24, p = < 0.0001). Looking at the pre and post-move time periods actually resulted in a non-significant trend pre-move (F[1,17] = 0.54, p = 0.473) but still a significant trend post-move (F[1,38] = 5.92, p = <0.020). It was concluded that patient perception of the ‘Quietness of Hospital Environment’ improved post-move, and continued to improve for at least six months. After July 2015, however, the positive trend of improvement tailed off, producing non-significant positive linear regressions of decreasing effect size. This resulted in average monthly ‘Quietness of Hospital Environment’ response rate to be approximately 77 % over the last two and a half years.

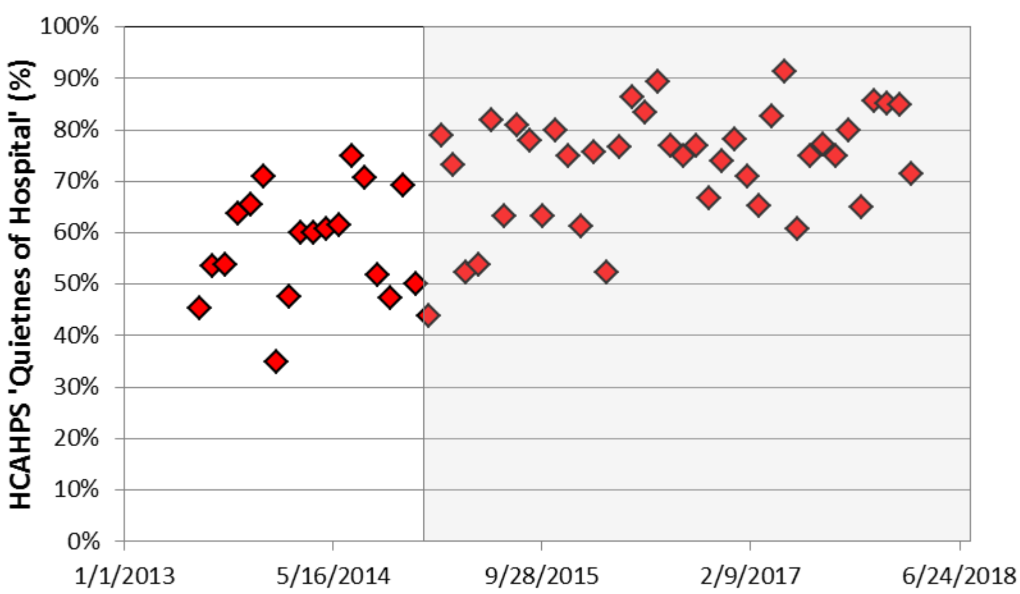

Figure 21: HCAHPS 'Quietness of Hospital Environment' Data in Hospital R1 – Pre/Post Move Monthly Averages

The HCAHPS patient response data for the ‘Overall Hospital Rating’ question for Hospital R1 produced similar results as with the ‘Quietness of Hospital Environment’ question, although with less dramatic effects. (Figure 22) A positive linear trend was found for the entire timespan of analysis (F[1,56] = 10.43, p = <0.002). Just as before, no statistical trend was found before the move (F[1,38] = 2.00, p = <0.176), but a statistically significant positive increase was found post-move (F[1,38] = 5.16, p = <0.029). Once again, six months into the post-move unit there was no longer an increasing linear trend found, with average 'Overall Hospital Ratings' remaining steady at 81 % over the past two and a half years. Data from the remaining three HCAHPS questions provided was beyond the scope of this research and has thus been omitted.

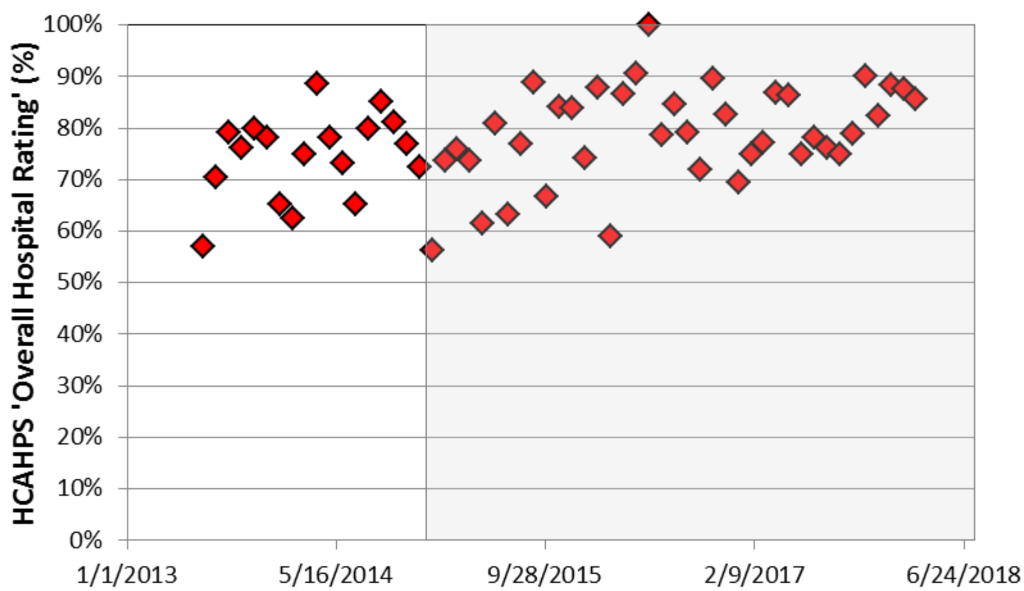

Figure 22: HCAHPS 'Overall Hospital Rating' Data in Hospital R1 – Pre/Post Move Monthly Averages

Hospital R2 HCAHPS Data

The HCAHPS patient survey data provided for Hospital R2 was compiled for the entire hospital for the 2014 and 2016 calendar years. The data which was provided included all 31 HCAHPS questions rating patient hospital perception, including 'Quietness of Hospital Environment', 'Overall Hospital Rating', amongst many others. Response data for all 31 questions can be found in Table 30. Included was data for the

2014 and 2016 calendar years, the survey response totals, national averages from 2014 and 2016, and the differences found between the two years for Hospital R2. On average, approximately 535 patients responded to the five survey questions in 2014 (321 – 599 responses per question) and approximately 495 patients responded in 2016 (278 – 558 responses per question). This equated to an average of 44 patient responses per month for the entire hospital in 2014 and just slightly less in 2016 at 41 responses per month.

Looking at the primary HCAHPS question of interest, ‘Quietness of Hospital Environment’, a marked increase was seen between 2014 and 2016: 58.1 % vs 76.3 % for a difference of 18.2 %. In 2015, Hospital R2 opened a new patient tower (the site of measurements conducted in this study) which was assumed to precipitate these dramatic improvements. Conversely, the national averages for the ‘Quietness of Hospital Environment’ question remained very consistent during this time, decreasing slightly from 60.0% to 59.9%.

Out of the remaining questions on the HCAHPS survey, there were a handful that showed relatively large increases in patient satisfaction between 2014 and 2016. The ‘Overall Hospital Rating’ question showed an increase of 5.5 % and the ‘Would Recommend Hospital’ question rose by 3.5 %. These two questions evaluated the hospital as a whole, and as such would be influenced by the performance of other factors (such as the ‘Quietness of Hospital Environment’). Other specific questions found to have marked increases included room ‘Kept Clean During Stay’, ‘Excellent Flavor’, and ‘Right Temperature’, which displayed increases of 8.6 % to 10.2 % between 2014 and 2016. It would be fair to surmise that the improvements found in these four HCAHPS categories had at least some effect on the ‘Overall Hospital Rating’ questions. Furthermore, it would be reasonable to conclude that the ‘Quietness of Hospital

Environment' improvements might have had the most influential impact of any specific HCAHPS factor, due to the significant increase in performance. Therefore, while the data provided for Hospital R2 did not allow the depth of analysis completed for Hospitals U1 & R1, meaningful relationships between the 'Quietness of Hospital Environment' and Overall hospital rating questions were found, corroborating similar results found in the other two hospitals.

4.1.3 Hospital Staff Survey Results

In response to anecdotal evidence of multiple issues being observed within both Hospitals R1 & R2, the hospital leadership involved the architectural engineering firm responsible for the design of both hospitals in the administration of a staff survey. The first goal of this survey was to determine whether changing from a centralized to a decentralized nursing unit model were associated with key adult inpatient outcomes. Secondly, it was desired to quantitatively and qualitatively explore nurse perspectives of the decentralized nursing model, collaboration, satisfaction, organizational factors and change. Finally, facility performance was to be evaluated using physical measurement devices. An identical survey was given in both Hospitals R1 & R2, administered in the third quarter of 2017 for both hospitals.

For Hospital R1, 73 staff members responded to the survey, with 59 % of participants being RNs and 70 % involved in inpatient care. In the Figure 23 on the right, the units highlighted red were those under investigation. The average work experience for these employees was 11.23 years, with more than 58 % of survey participants having more than 10 years of experience. The left figure below shows the percentage of respondents divided by employment tenure.

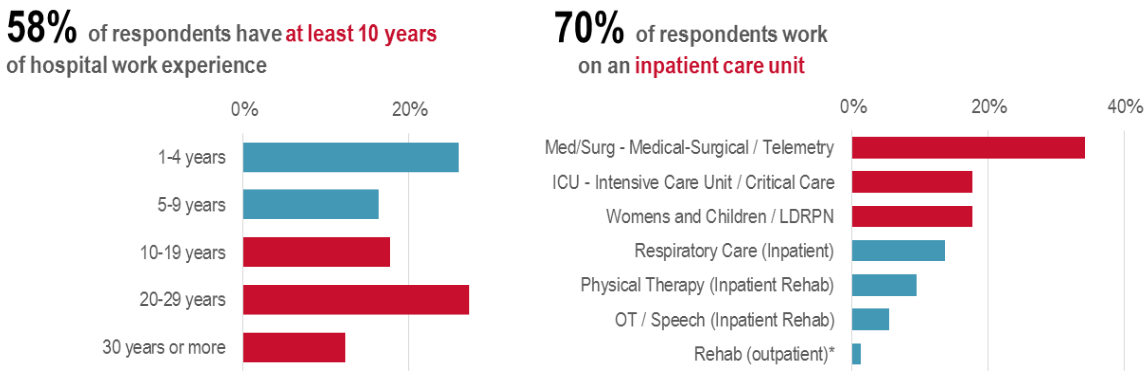

Figure 23: Hospital Staff Survey Response Data in Hospital R1 – Years Employed & Unit Worked

For Hospital R2, 227 staff members responded to the survey, with 53 % of participants being RNs and 67 % involved in inpatient care. In Figure 24 on the right, the units highlighted in red were those under investigation. Of note was the significant decrease in the percentage of respondents from the units of interest. Hospital R2 included a greater variety of hospital facilities (such as for research or out-patient care) than did Hospital R1, and thus had more survey responses from units other than those studied. The average work experience for the employees in the survey was 8.69 years, with more than 40 % of survey participants having more than 10 years of experience. The left figure below shows the percentage of respondents divided by employment tenure.

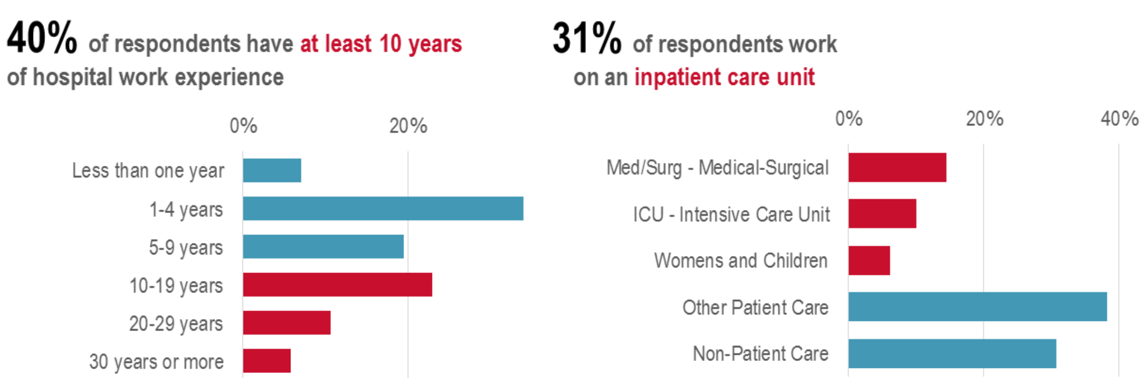

Figure 24: Hospital Staff Survey Response Data in Hospital R2 – Years Employed & Unit Worked

The survey administered to the staff of both hospitals included numerous questions regarding the perception of hospital performance in multiple areas. For example, job satisfaction was assessed along with the functionality of the nursing stations and associated design features. The impact of building aesthetics and design was analyzed as well as temperature, air quality, and lighting quality within the hospitals. Most importantly to this research, though, was the effect the acoustical environment had on the perception of the hospital environment to the staff. Thankfully, a significant number of questions regarding the hospital soundscape conditions were posed to survey participants, including ‘Does the acoustical environment support your ability to perform your job functions?’ and ‘What are the primary sources of noise within your unit?’

Hospital R1 Staff Survey Data

The first survey item of interest was the job satisfaction rating for Hospital R1, which was assessed using a validated 10-questions scale to assess working and interpersonal satisfaction among nurses (Chang 2015; Chang et al. 2011). Figure 25 displays the job satisfaction ratings of the three units measured in Hospital R1 on a 10-point positive-negative scale. The ICU and Medical/Surgical units were not statistically different, however, the Women & Children’s unit was clearly perceived more favorably, with nearly double the satisfaction rating.

Looking at the acoustical environment questions, the ‘Acoustical environment supports job functions’ question showed clear differences between the three units within Hospital R1 (Figure 26). Please note, the ICU and Medical/Surgical units were located on the same floor, only designated by location within the 3rd floor. As with the job satisfaction ratings, the Women & Children’s unit was perceived more favorably than the other two units, with no respondents disagreeing with the 'Acoustical environments ability to support job functions' question.

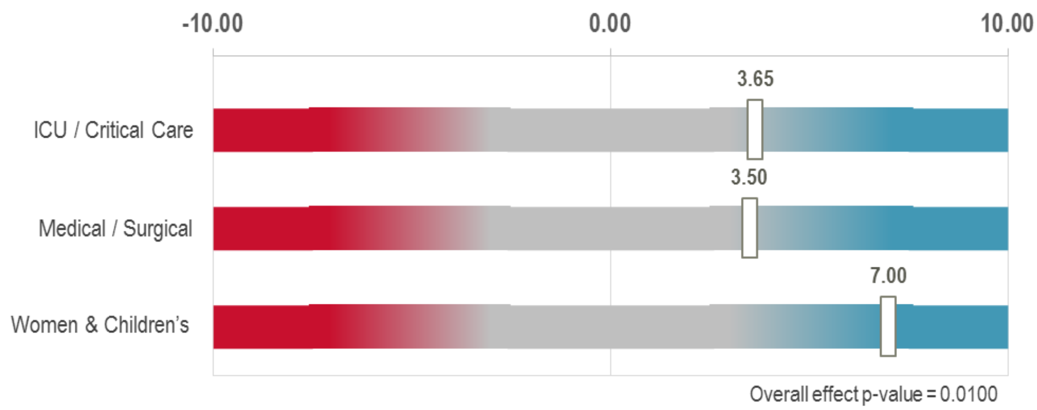

Figure 25: Survey Responses by Unit in Hospital R1 – Job Satisfaction

Similar trends were found for both 'Noise disrupts patient rest and recuperation' and 'Noise disrupts my work' questions (Figure 73 & Figure 74 in Appendix B) with the Women & Children's unit rated highest in all three survey questions and the Medical/Surgical and ICU units second and third. Interestingly, however, when assessing the satisfaction of the overall workplace environment, the Women & Children's unit within Hospital R1 was the worst perceived (Figure 69 in Appendix B). The reasoning behind this anomaly was unclear, as all other environment survey measures (temperature, air quality, and lighting) did not reveal any obvious causes for the lower overall ratings.

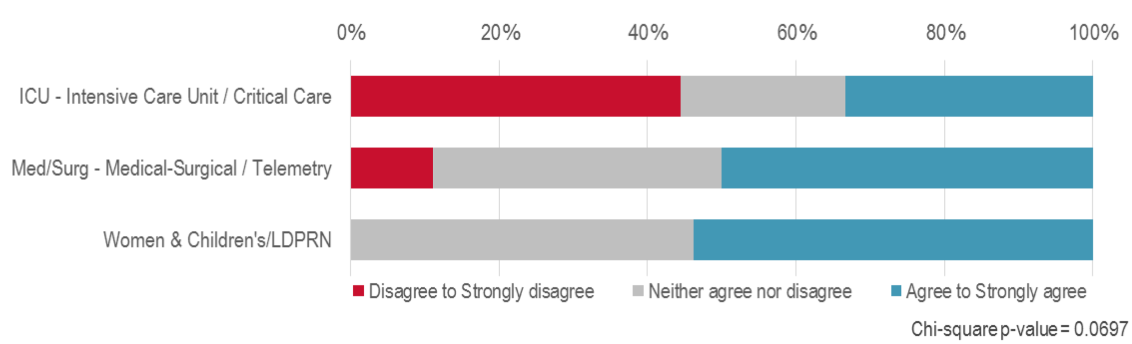

Figure 26: Survey Responses in Hospital R1 – Acoustical Environment Supports Ability to Perform Job Functions

Hospital R2 Staff Survey Data

Looking at the job satisfaction ratings for Hospital R2 (Figure 27) reveals very similar (non-significant) differences between the ICU, Medical/Surgical, and Women & Children's units. Hospital R2 produced higher job satisfaction than the ICU or Medical/Surgical units in Hospital R1, but the Women & Children's unit was not perceived as favorably, lower by some 2.5 points.

Once again, of the acoustical environment questions, the 'Acoustical environment supports job functions' question showed very little differences between the three units within Hospital R2 (Figure 28). All three units displayed nearly 70 % agreement with this question, higher than any unit within Hospital R1. These values also corresponded well with the perception of job satisfaction, again showing very similar survey results between units. Looking at the differences between Hospitals R1 & R2 revealed moderately better survey results overall, with disagreement values lower and agreement values markedly increased (Figure 29).

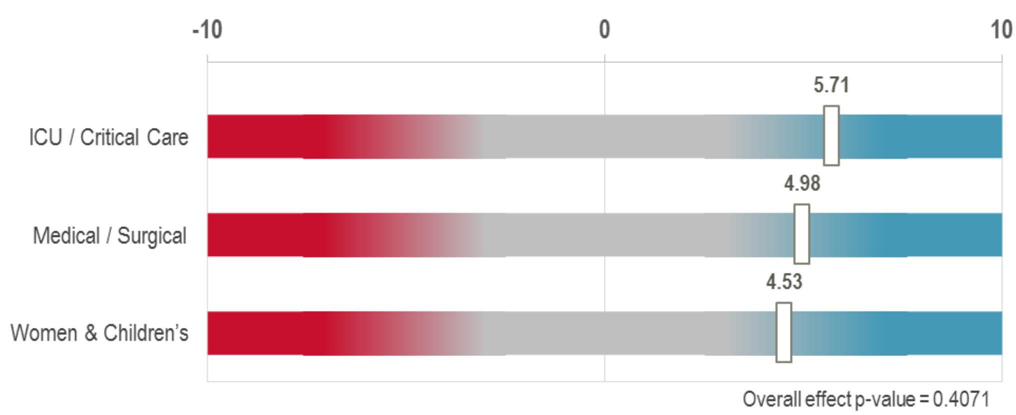

Figure 27: Survey Responses by Unit in Hospital R2 – Job Satisfaction

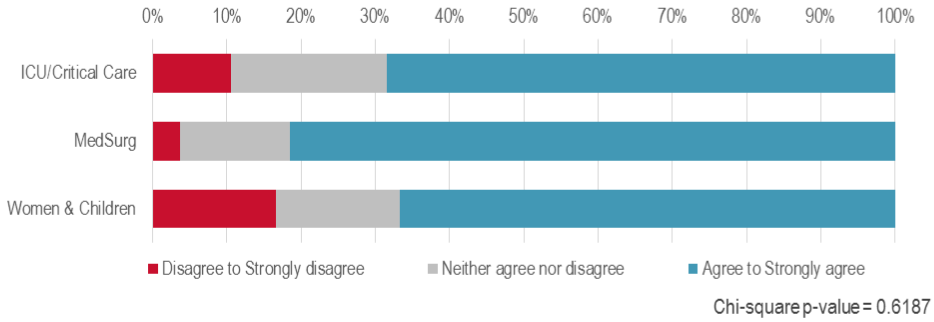

Figure 28: Survey Responses in Hospital R2 – Acoustical Environment Supports Ability to Perform Job Functions

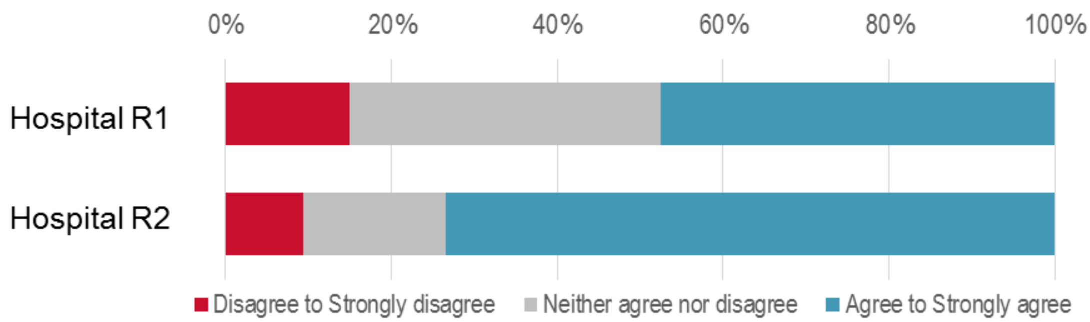

Figure 29: Survey Responses in Hospitals R1 & R2 – Acoustical Environment Supports Ability to Perform Job Functions

In the 'Noise disrupts patient rest and recuperation' and 'Noise disrupts my work' questions (Figure 73 & Figure 74 in Appendix B), very little differences were found between the three units, similar to the 'Ability to perform job functions' question. Comparable results were found for the satisfaction of the overall workplace environment within Hospital R2, with marginal differences found between the perceptions of the three units (Figure 71 in Appendix B). In all units for both hospitals, alarm noises were the dominant noise source, followed by phone calls, conversation noise, and equipment noise (in varying orders depending on unit).

4.1.4 Alarm Identification Issues in Hospital R1

Anecdotally, one of the most commonly heard complaints regarding either of the two rural hospitals centered on the ICU/Medical/Surgical 3rd floor nursing station of

Hospital R1. Many nurses and staff members commented on the fact that it was difficult to identify where alarms and other loud noise were being generated from within the unit. This has led staff members to have to search for the location of the alarm noise, thus wasting time potentially leading to physical health concerns for the patients. The exact cause of this phenomenon was unclear to the hospital, and thus it was intended for study. As part of this research, the issue of alarm identification within the 3rd floor of Hospital R1 was investigated through the use of long-term and short-term SLM measurements, in addition to the implementation of impulse response analyses.

4.1.5 Measurement Setting

As with Phase I, the primary data collected from Hospitals R1 & R2 of the study were 24-hour sound level meter (SLM) measurements, collected within a total of 23 patient rooms and 7 nursing stations from the 6 total units. Measurements were conducted consecutively over two three-day time periods, beginning at 8 AM on the Wednesday mornings and ending on the following Saturday mornings.

Within each unit, two to five occupied patient rooms were selected for study. Rooms were chosen first for occupancy (both hospitals were at less than half capacity while being measured acoustically) and then for potential acoustical issues, with the intent to select a representative sampling of patient rooms within each unit. In addition, placement of SLMs within patient rooms was at the preference of the nursing staff, taking into consideration the health of the patient and their capacity to participate in the study. Also, the busiest/most active nursing station within each unit was measured for 24 hours, with the main nursing station on the 3rd floor of Hospital R1 being measured twice.

4.1.6 Test Setup

The measurements collected in Phase II study were very consistent with those performed in Phase I, using five Larson Davis 831 sound level meters. All meters implemented fast response times (0.125 s) in both A and C spectral weightings. The 24-hour measurements (and 15 minute measurements) were collected using a 1-minute averaging interval. Within each patient room, SLMs were setup to measure the sound levels experienced by the patient, so the SLM microphone capsules (using extension cables) were attached to unused medical equipment located on the rear walls approximately 1 m behind the patients. (Figure 30) Similar setups were utilized for the nursing stations within each unit. The microphone capsules were positioned above head height within the chosen station, pointing into the hallway. (Figure 31) As before, the mounting of the microphone capsules to close to reflecting surfaces was not ideal, but all measurements were conducted using the same setup so all values collected were internally consistent with one another.

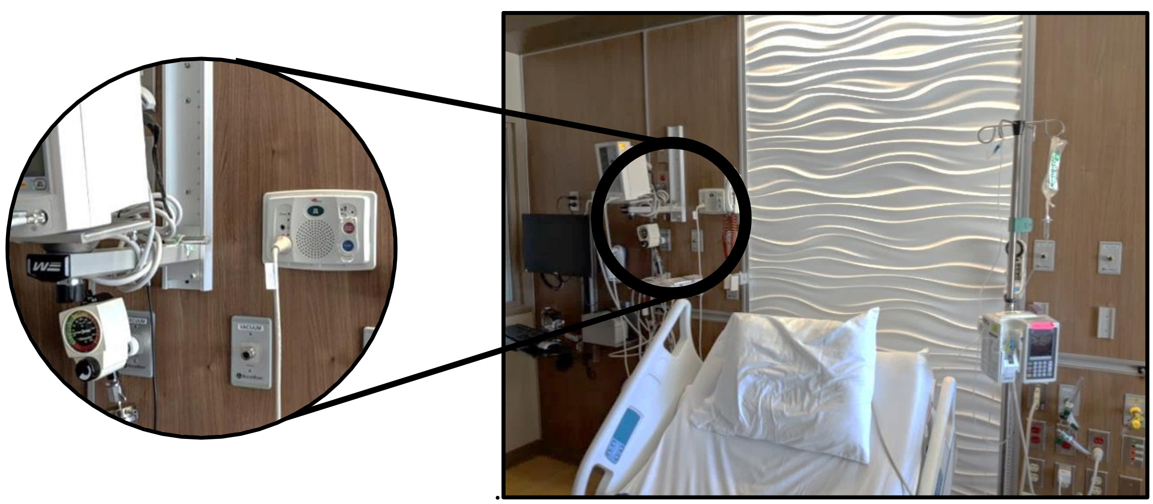

Figure 30: Sound Level Meter Placement within Patient Rooms in Hospitals R1 & R2

Figure 31: Sound Level Meter Placement within Nursing Stations in Hospitals R1 & R2

Short-term 'spot' measurements were conducted to provide additional information the 24-hour data could not provide. In Hospital R1, 15 minute measurements were taken from the corridors surrounding the main nursing station to analyze that soundscape more in depth. In addition, background noise level measurements were collected numerous rooms from all units within both hospitals: 11 rooms from Hospital R1 and 6 rooms from Hospital R2. This provided a comparison of background noise levels between patient rooms from a wide assortment of unoccupied patient rooms.

Finally, impulse response measurements were collected from the hallways within both hospitals. This procedure was completed using a popped balloon as the impulse source and measured on a Larson Davis SLM, using the impulse response module. The balloon-pop method was chosen due to the inability to produce sound signals with a loudspeaker within the hospital units. Using this data, the reverberation times within the hospital hallways was assessed, as well as several physical environment properties, such as the impact of the square and angled nursing alcoves. These impulse response measurements also helped shed light as to the cause of the alarm identification issues experienced in Hospital R1.

The same variety of acoustical metrics was utilized in the analysis of the hospital data, as in Phase I. Collected in each sample were the A-Weighted LA_{EQ}, LA_{MIN}, & LA_{MAX} as well as the C-Weighted LC_{PEAK}. Also, 1/1 and 1/3 octave band frequency data, six statistical sound levels (LA_{05}, LA_{10}, LA_{33}, LA_{50}, LA_{90}, and LA_{95}), the Speech Intelligibility Index, RC, RC Mark II, and NC Noise Criteria were all calculated for each measurement. Finally, Occurrence Rates for LA_{EQ}, LA_{MIN}, LA_{MAX}, & LC_{PEAK} were studied, along with day (7 AM – 10 PM) and night (10 PM – 7 AM) averages all preceding acoustical metrics. All measurements utilized a reference pressure of 20 μPa. Where applicable, error bars displaying one standard deviation plus/minus are shown on results graphs.

Hospitals R1 & R2 Results – 24 Hour Data

4.2.1 Overall Levels

As before, the acoustical measurement data were collected from the 6 units in Hospitals R1 & R2 and compiled to determine meaningful differences between the rooms. 24-hour averaged, single number values were generated for a variety of metrics, such as LA_{EQ}, LA_{MIN}, LA_{MAX}, LC_{PEAK}, etc. Full acoustical data can be found in Appendix B in Table 32 (individual rooms) and Table 33 (averaged units) for Hospital R1 as well as Table 37 (individual rooms) and Table 38 (averaged units) for Hospital R2. Time history values were also collected based on a 1-minute sample time interval, which provided continuous measurements of all above values. Time history data were utilized in Occurrence Rate analyses and day/night differences.

To compute overall noise levels for each unit, the 24-hour acoustical values for the patient rooms within each unit were averaged together (using log averaging where applicable). Figure 32 displays the averaged 24-hour LA_{EQ} levels within the six measured units. There was a smaller spread (in relation to Hospital U1) of approximately 6 dBA between the unit averages, ranging from 54 dBA (Hospital R2 Women & Children's) to 60 dBA (Hospital R1 ICU). Individual rooms ranged between 52 dBA and 61 dBA: values very consistent with levels found in Hospital U1. In comparison with the findings of Phase I, LA_{EQ} levels corresponded better with perception of noise within the units, at least as it related to the staff survey, as both Women & Children's units were the quietest units measured and quietest as perceived by survey respondents.

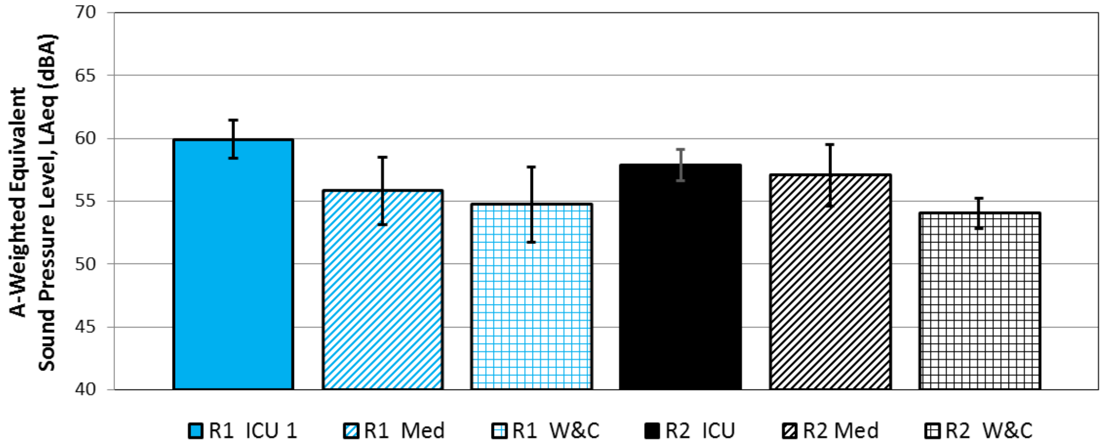

Figure 32: 24-Hour Average LA_{EQ} in Hospitals R1 & R2 – 6 Unit Patient Room Comparison

The 24-hour LA_{MIN}, LA_{MAX}, & LC_{PEAK} metrics collected within each of the patient rooms were also averaged for the six units. Both time-averaged and absolute values over the measurement time period were collected for the three metrics. Figure 33 shows the absolute LA_{MIN} values collected during the 24-hour measurement periods, averaged by unit. There was a clear difference in performance between the units, with nearly a 9 dBA difference found between the units and an almost 20 dBA difference between the individual patient rooms.

Unfortunately, there was no specific pattern to be found as to the distribution of the minimum values shown in Figure 33, when solely analyzing the LA_{MIN} values. The two quietest units (Hospital R1 Women & Children's and Hospital R2 Medical/Surgical) were from two different hospitals and two different unit types. Similar results were observed for the loudest rooms and units. As it happened, the numerous background noise level measurements that were conducted in both hospitals were able to shed some insight as to the sporadic differences found in the LA_{MIN} levels. Some patient rooms simply exhibited significantly louder unoccupied noise levels than others, most prominently due to the HVAC systems.

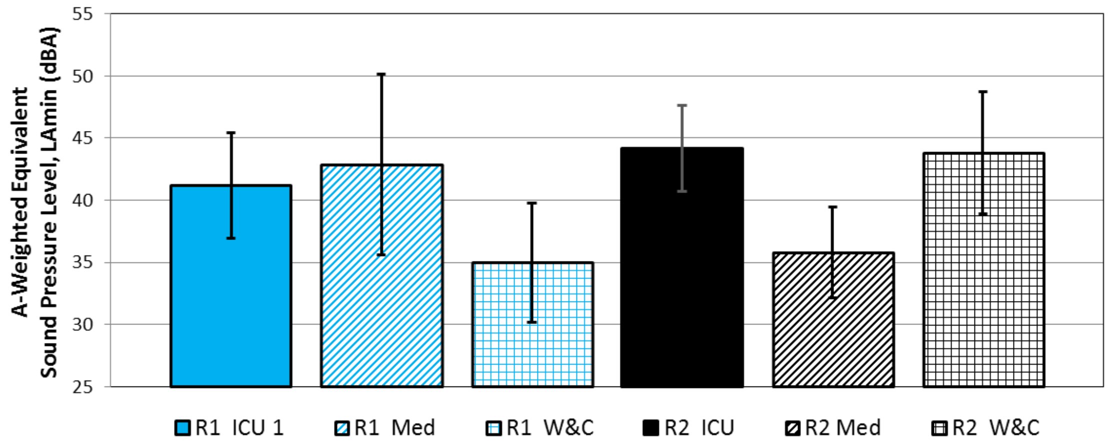

Figure 33: 24-Hour Average LA_{MIN} in Hospitals R1 & R2 – 6 Unit Comparison (Absolute Values Measured Shown)

Figure 34 displays the absolute values (averaged across measured patient rooms for each unit) found during the 24-hour timespans within the six units for the LA_{MAX} and LC_{PEAK} metrics. For the LA_{MAX} metric, very consistent levels were found between all six units of both hospitals: unit averages ranged between 90 dBA and 93 dBA, with individual rooms ranging 87 dBA to 96 dBA. The LC_{PEAK} levels saw a bit more variation, with Hospital R2 Medical/Surgical levels measuring significantly higher than the other units. After a bit more investigation, it was found that one measurement was skewing results (of 124 dBC) and if removed from the dataset, put the Hospital R2 Medical/Surgical unit back in line with other LC_{PEAK} unit averages.

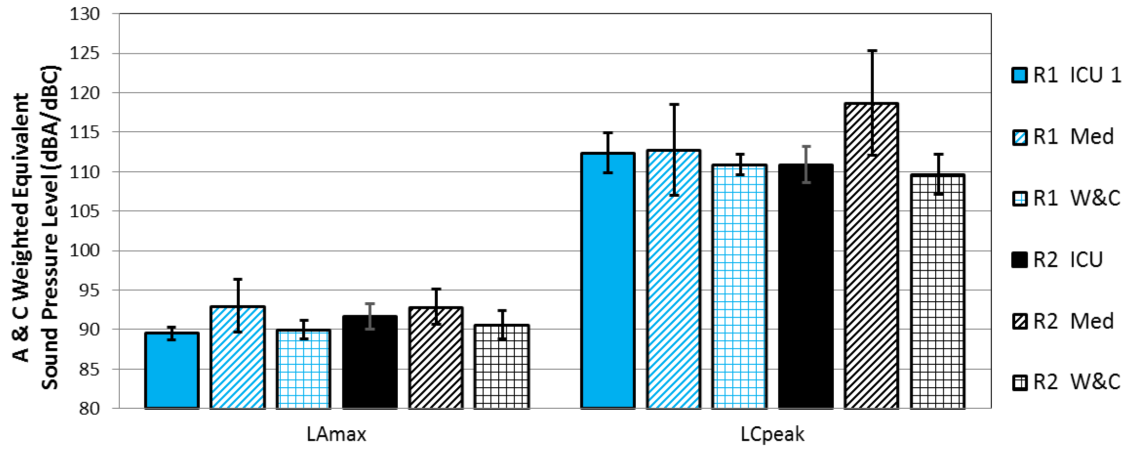

Figure 34: 24-Hour Absolute LA_{MAX} & LC_{PEAK} in Hospitals R1 & R2 – 6 Unit Comparison

Six statistical sound levels were again computed for each of the units: LA_{05}, LA_{10}, LA_{33}, LA_{50}, LA_{90}, and LA_{95}. (Figure 35 – LA_{33} was omitted for brevity) Sound levels diminished as expected between the transient noise metrics (LA_{05} & LA_{10}) and the ambient noise metrics (LA_{90} & LA_{95}) with the units with higher LA_{EQ} levels (Hospital R1 ICU and Hospital R2 ICU & Medical/Surgical) displaying higher statistical sound levels. It was interesting to see how the ICU in Hospital R1 was consistently louder than all of the other units, having LA_{90} & LA_{95} levels of 52 dBA, while not being significantly louder overall (based on average LA_{EQ} levels). Conversely, the Medical/Surgical unit in Hospital R2 had LA_{05} & LA_{10} levels that were nearly as loud as the Hospital R1 ICU, however, showing almost the lowest LA_{90} & LA_{95} levels of 41 dBA. Looking back to the data from the LA_{MAX} & LC_{PEAK} values for the Medical/Surgical unit in Hospital R2 and the influence of at least one very loud event can be seen in the LA_{05} & LA_{10} metrics.

Interestingly, when comparing statistical sound levels between Hospitals R1, R2, & U1 reveal very similar results (Figure 8). This included LA_{90} values (ranging between 39 and 46 with two outliers), often considered as the ambient noise level.

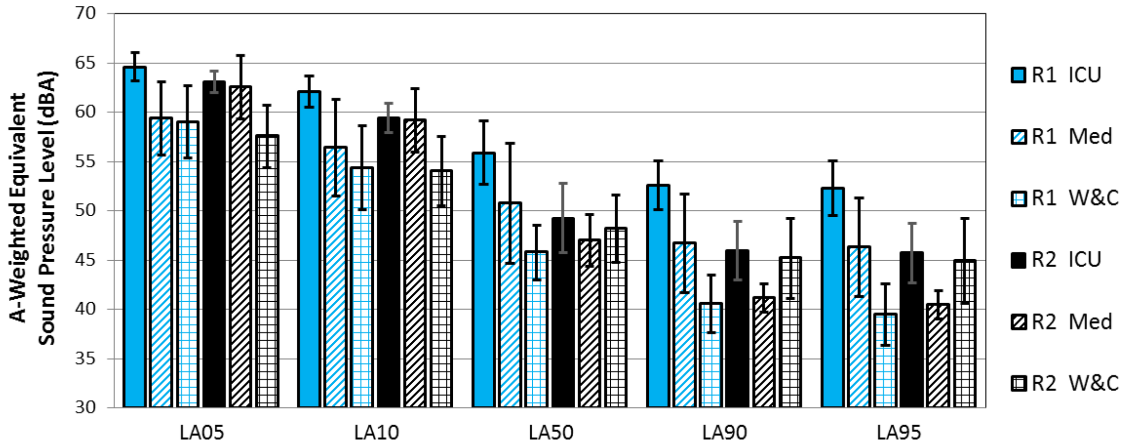

Figure 35: 24-Hour Average Statistical Sound Levels in Hospitals R1 & R2 – 6 Unit Patient Room Comparison

4.2.2 Speech Intelligibility

The Speech Intelligibility Index (SII) was utilized to assess the speech conditions within the six units in Hospitals R1 & R2. Unit averaged SII values for Hospitals R1 and R2 are shown in Figure 36, calculated for the 24-hour patient room data. Of the six units, none received a rating of 'Good', five received a rating of 'Marginal', and one was rated 'Poor'. The two Women & Children's units rated the best, with scores of 0.59 and 0.58 respectively. Hospital R1 ICU had the worst speech intelligibility with an SII of 0.39, which made sense as this unit displayed the highest overall LA_{EQ} values and statistical noise levels of any measured unit.

These SII values were all calculated using occupied patient room conditions and therefore included speech contributions within the analyzed spectrum. This resulted in SII values that were quite low, and not necessarily representative of the actual speech intelligibility of the rooms. This metric is more usefully used in unoccupied room conditions, where it was found that all six units within both hospitals (detailed below in section 4.3.2) received 'Good' SII ratings between 0.85 and 0.87 when unoccupied.

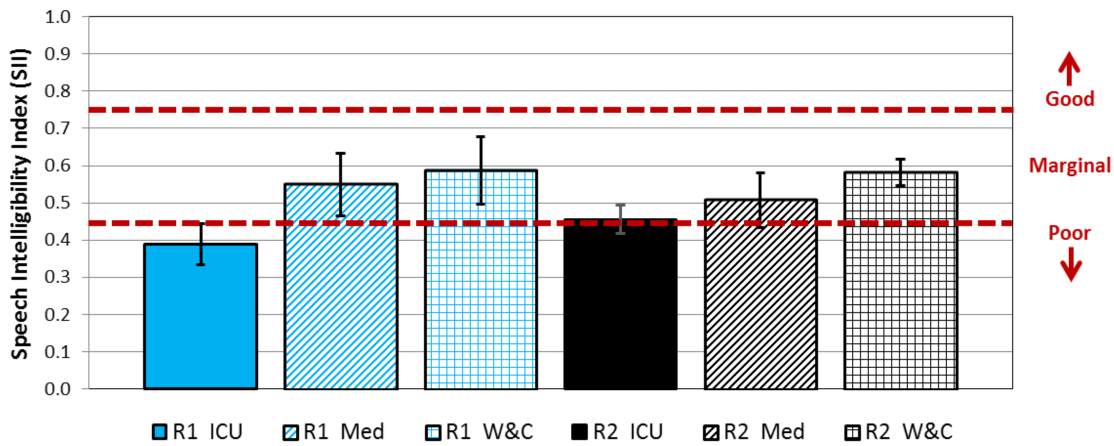

Figure 36: 24-Hour Average Speech Intelligibility Indices in Hospitals R1 & R2 – 6 Unit Patient Room Comparison

4.2.3 Spectral Analysis

To further analyze the 24-hour patient room measurements, the average frequency spectra for the five units were plotted. (Figure 37) Spectral data for individual patient rooms can be found in Appendix B for Hospitals R1 (Table 34) and R2 (Table 39). Overall, expected trends were found between the units, tracking with the average LA_{EQ} values: the ICU in Hospital R1 was loudest across the spectrum, followed by Hospital R2 ICU and Medical/Surgical units. The Medical/Surgical unit in Hospital R1 had peaks at 125 Hz and 250 Hz, but quieter high frequency levels which resulted in lower overall LA_{EQ} values. The Women & Children's units in both hospitals again showed the lowest levels across all frequency. In comparison with Hospital U1, no units exhibited significant low frequency noise. However, none of the six units in Hospital R1 or R2 were located on the top floor of a tower, near multiple helicopter pads as was the specific unit in Phase I.

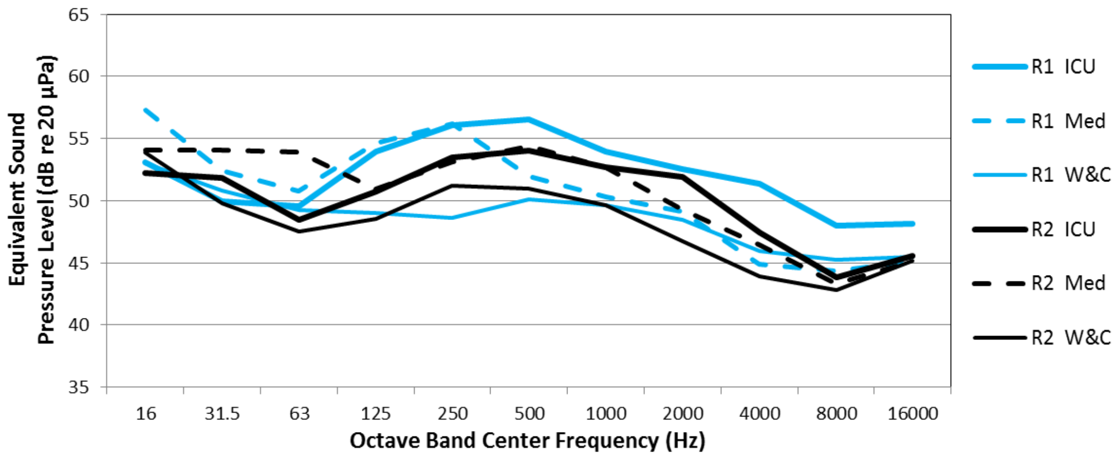

Figure 37: 24-Hour Average Spectra in Hospitals R1 & R2 – 6 Unit Patient Room Comparison

4.2.4 Occurrence Rates

Using time history data from the 24-hour patient room measurements, a temporal analysis of sound levels was conducted. For this research LA_{EQ}, LA_{MIN}, LA_{MAX}, & LC_{PEAK} data were collected for each 1-minute sample, allowing the fluctuation of all four metrics to be studied. Figure 38 shows the plot for average LC_{PEAK} Occurrence Rates of the six units with level (in dBC) on the X-Axis and percentage of time on the Y-Axis. As with most other acoustical metrics, the ICU in Hospital R1 was louder more often when compared with the other five units. Consistent with the LA_{EQ} levels, Hospital R2 ICU and Medical/Surgical units as well as the Hospital R1 Medical/Surgical unit were slightly less for the measured LC_{PEAK} Occurrence Rates. Once again, the Women & Children's units were quieter more often than the other four units. All of the six units maintained similar progressions of temporal noise (i.e. the 'slope' of the Occurrence Rate), with gradual transitions from louder to quieter conditions. Occurrence Rate ranges calculated for all 'primary' acoustical metrics in individual patient rooms can be found in Appendix B for Hospital R1 (Table 35) and Hospital R2 (Table 40).

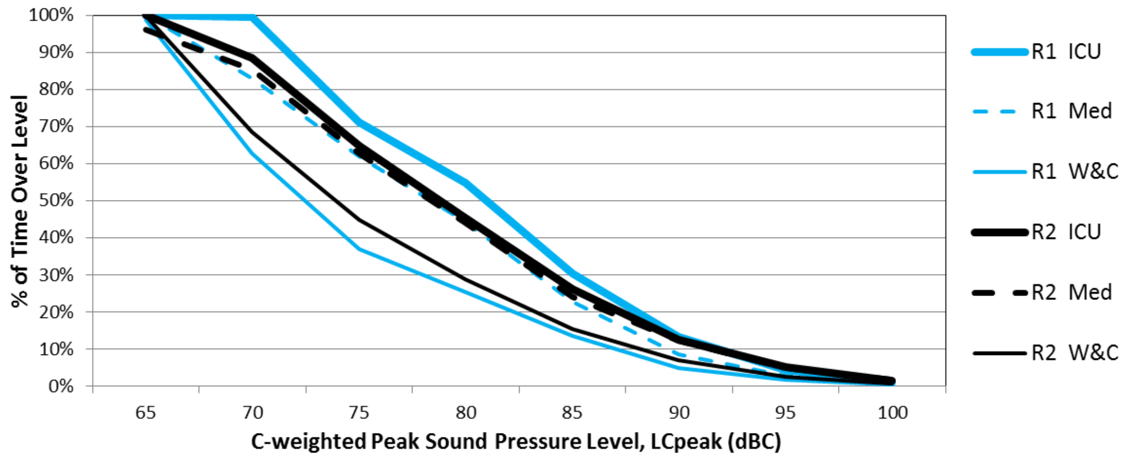

Figure 38: 24-Hour Average LC_{PEAK} Occurrence Rates in Hospitals R1 & R2 – 6 Unit Patient Room Comparison

4.2.5 Nursing Stations

At least one nursing station within each unit was measured for 24 hours during each measurement day in addition to the patient rooms. Figure 39 and Figure 40 display the 'primary' acoustical metrics collected from the nursing stations within each of the units. Nursing station data can be found in Appendix B for Hospital R1 (Table 36) and Hospital R2 (Table 41). LA_{EQ} values were quite consistent, ranging between 52 dBA and 58 dBA on average for the seven measured stations. As stated earlier, the ICU nursing station in Hospital R1 was measured twice, as the ICU and Medical/Surgical units were located on the same floor, and thus two entries have been made on the graph below.

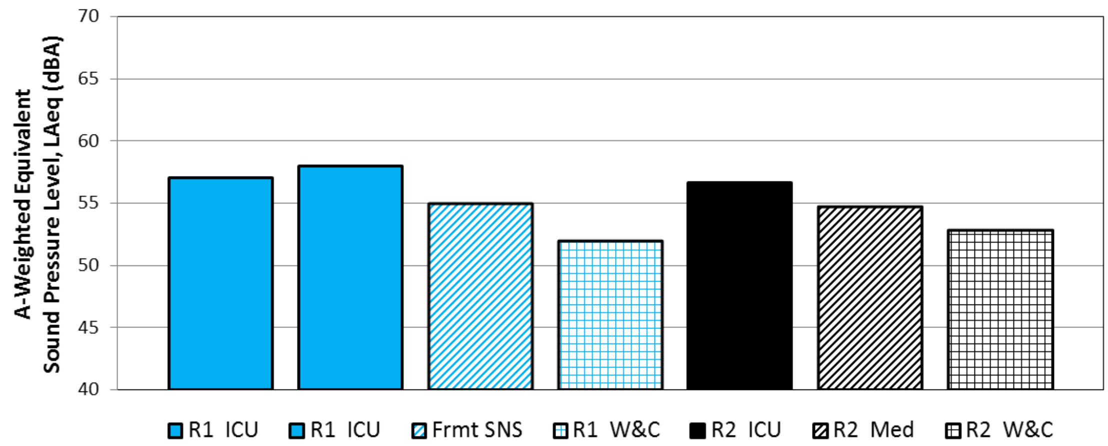

Figure 39: 24-Hour LA_{EQ} in Hospital U1 – 5 Unit Nursing Station Comparison

Minimum, maximum, and peak level values were also very comparable between units, especially for Hospital R1 (Figure 40). Absolute LA_{MIN}, LA_{MAX}, & LC_{PEAK} values were all within 4 dB between the four nursing stations measured in Hospital R1. This demonstrated very consistent acoustical soundscape conditions between the different common areas of Hospital R1.

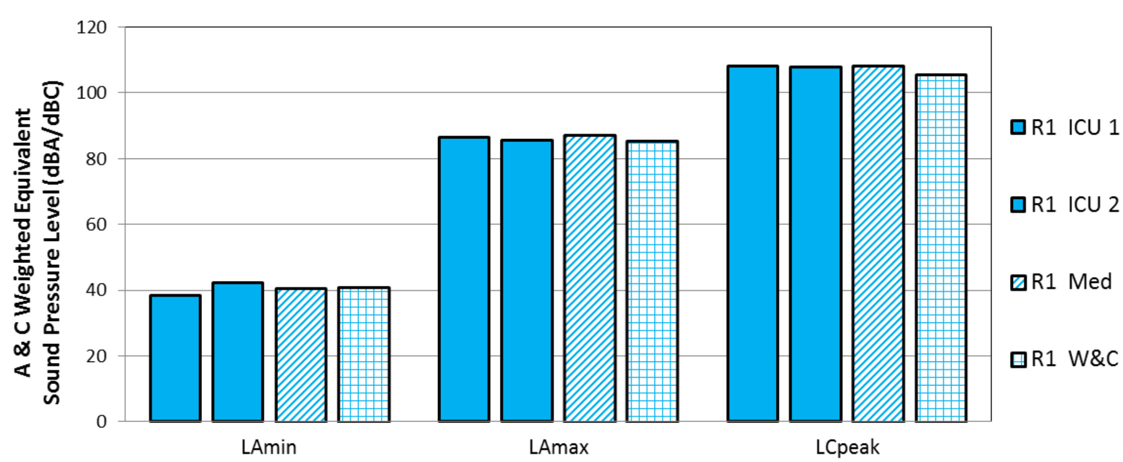

Figure 40: 24-Hour Absolute LA_{MIN}, LA_{MAX}, & LC_{PEAK} in Hospital R1 – 3 Unit Nursing Station Comparison

Hospital R2 displayed slightly more variation between the three nursing stations measured, especially in the minimum sound levels. (Figure 41) A spread of nearly 12 dBA was observed between the absolute LA_{MIN} values collected from the three nursing stations over the 24-hour measurement timeframe. Absolute LA_{MAX} and LC_{PEAK} levels were more consistent, however, with spreads of 2 dBA and 5 dBC, respectively.

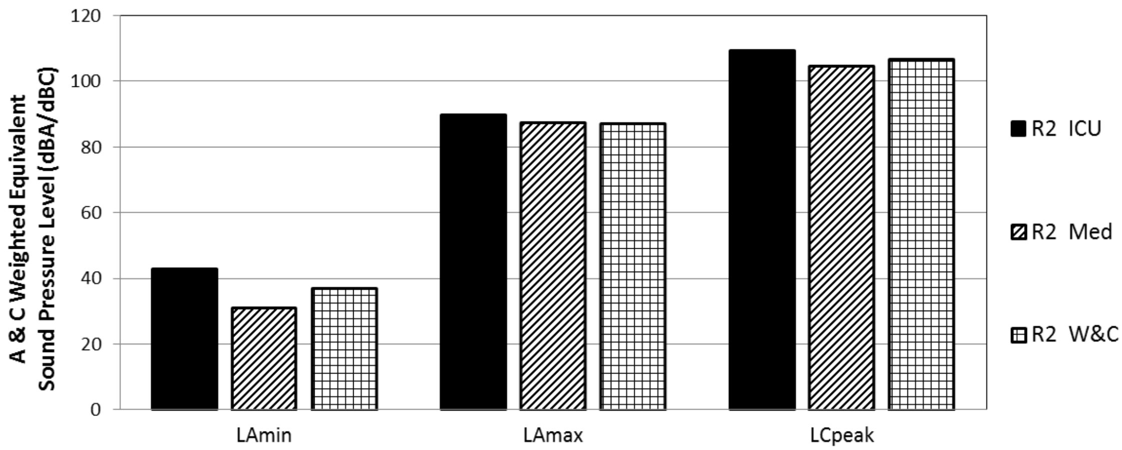

Figure 41: 24-Hour Absolute LA_{MIN}, LA_{MAX}, & LC_{PEAK} in Hospital R2 – 3 Unit Nursing Station Comparison

Hospitals R1 & R2 Results – Other Data

4.3.1 Short Term Measurements

Short-term 'spot' SLM measurements were collected from specific locations within each of the six units during the field procedures. 15 minute measurements were taken from multiple locations around the main nursing station on the 3rd floor of Hospital R1 to further assess the alarm identification issues experience by the staff. The data gathered from these short term measurements was found to be consistent with 24-hour sound levels from the nursing stations, with most LA_{EQ} values falling between 52 and 61 dBA. Therefore, specific data taken from these measurements will not be presented.

4.3.2 Unoccupied Patient Rooms

Acoustical measurements from unoccupied patient rooms were used to assess the background noise levels in all six units studied. Unlike urban Hospital U1, where all the measured units were nearly at capacity, the units within both rural hospitals were only about half full with patients. Therefore, a large number of BNL measurements were able to be completed: 11 rooms in Hospital R1 and 6 rooms in Hospital R2. Within each room, measurements were collected in a single scenario: with the hallway door closed.

The background noise levels were first analyzed using unit averaged data and on the whole looked consistent with levels found in Phase I of the study. LA_{EQ} levels ranged between 40 dBA and 43 dBA for the six unit averages. Once again, in unoccupied room conditions, these units did not meet the WHO occupied guidelines of 30 dBA LA_{EQ} and 40 dBA LA_{MAX} during the night. [11]

Table 9 displays the RC and NC values calculated using the unoccupied patient room data, averaged by unit. Per ANSI/ASA recommendations, none of the units meet the stated BNL levels for private rooms in hospitals of RC 25 – 35, with a spectral rating of neutral. In all six units, the computed levels were both slightly above the recommended range and denoted with the hiss (H) classification, as there was additional high frequency noise. Similarly, the measured unit values did not meet the Facility Guidelines Institute (FGI) recommendations of RC 40 (N). [12]

Table 9: Unoccupied Patient Rooms in Hospitals R1 & R2 – Room & Noise Criteria

Unit	RC	NC
R1 ICU	36 (H)	43
R1 Med / Surg	35 (H)	43
R1 W & C	36 (H)	43
R2 ICU	37 (H)	43
R2 Med / Surg	38 (H)	43
R2 W & C	37 (H)	43

Figure 42 displays the frequency response from the unoccupied patient room measurements, averaged for each hospital, as well as the RC 35 (N) cutoff line. While the low and mid frequency energy (below 2000 Hz) were within recommended levels for all units, there was a significant increase between 2000 Hz and 8000 Hz. This high frequency noise was the cause for the HF objectionable RC Ratings and high NC values. Since the six units had nearly identical spectra in the high frequency region, it was surmised that the source of this noise was system based: either through duct noise or diffuser selection, although looking at the individual rooms revealed more information. While the measured spectra in Hospital R1 & R2 were very similar, the same SLMs were utilized in Phase I of the research, producing different levels and spectra, so these findings were deemed to be accurate even with the unlikely similarities in results.

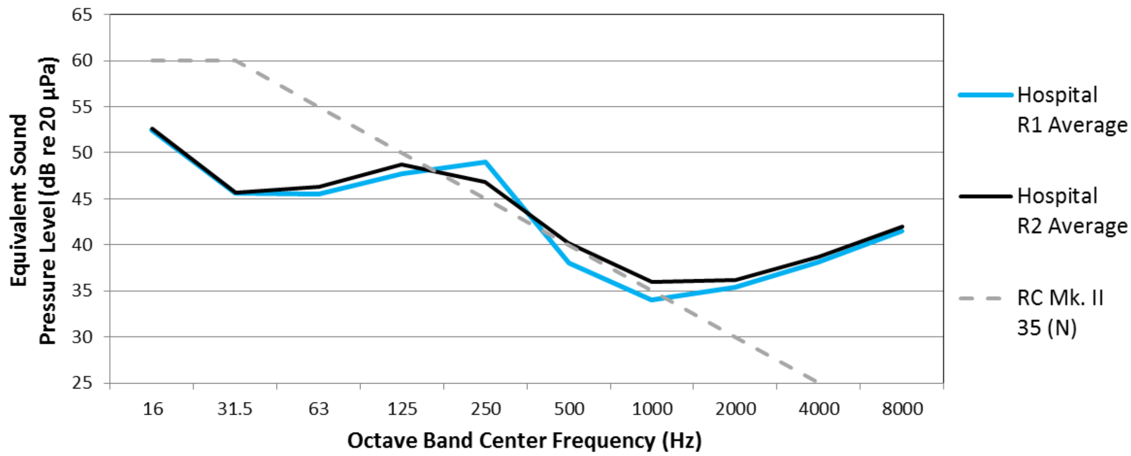

Figure 42: Unoccupied Patient Rooms in Hospitals R1 & R2 – Frequency Spectra

Figure 43 and Figure 44 display the LA_{EQ} values for the individual unoccupied patient rooms measured within Hospitals R1 & R2. Of note is the significant variation, especially in Hospital R1 (Figure 43), which was found to have a range of nearly 12 dBA in background noise levels on the same floor. The dispersion of noise within the patient rooms did not show any discernable pattern, as quiet and loud rooms were found adjacent to one another and sporadically spread throughout the units within both hospitals. The most dominant noise source observed during the BNL measurements was the air being distributed through the HVAC system, and some rooms were noticeably louder than others. Because of this wide variation in unoccupied patient room noise levels, the source of the additional noise was suspected to be related to the diffuser selection and/or setup that could have caused unwanted turbulence to the air being introduced to specific patient rooms. Similarly, noise generated within the ducts themselves, such as from variable air volume (VAV) boxes, could have contributed to the noise found in the unoccupied rooms. It was clear, however, that the background noise levels were not consistent between the patient rooms of Hospitals R1 & R2, and might not be in other hospital environments as well.

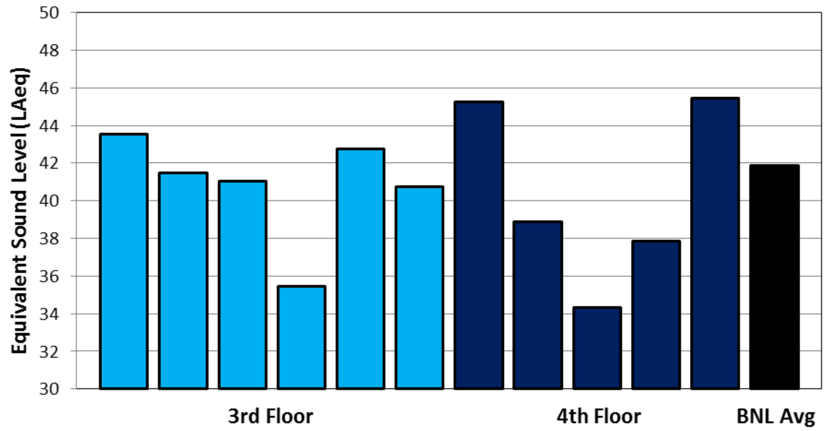

Figure 43: Unoccupied Patient Rooms Measured in Hospital R1 – LA_{EQ}

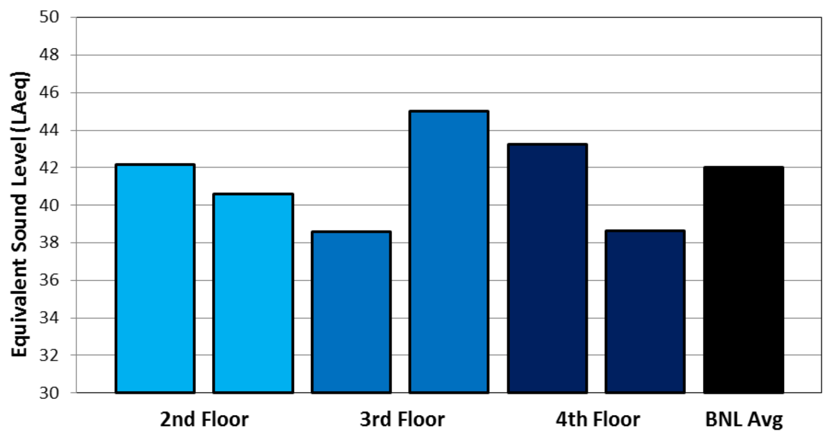

Figure 44: Unoccupied Patient Rooms Measured in Hospital R2 – LA_{EQ}

4.3.3 Impulse Response Measurements

In addition to the measurements detailed above using the standard SLM features on the Larson Davis 831 meters, impulse response measurements were collected from hallways within Hospitals R1 & R2. A popped balloon was utilized as the impulsive noise source to generate sound throughout the hallways, triggering the SLM to begin the impulse measurement (Figure 45). A time length of 4 seconds was set for the maximum decay and the measurement time interval was set at 5 ms (which was too large, as was found).

Hospital R1

Hospital R2

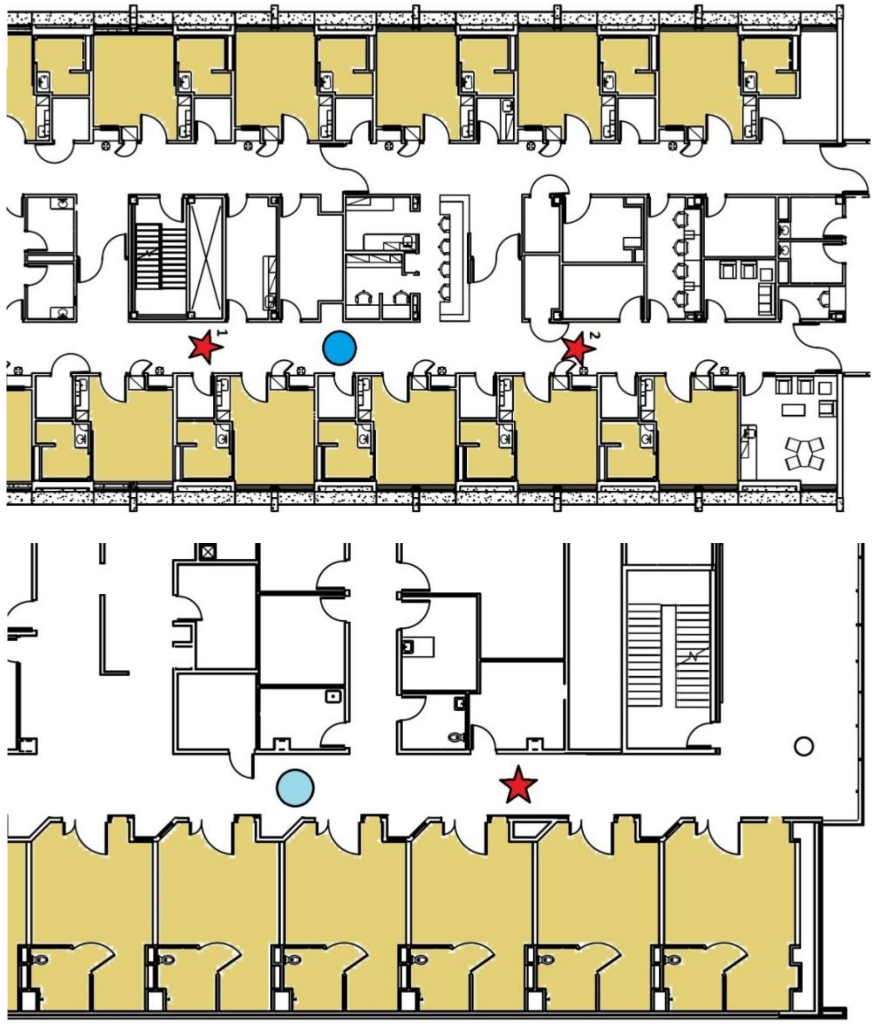

Figure 45: Layout of Impulse Response Measurements Collected from Hospitals R1 & R2 (Star – Source, Circle – SLM)

The impulse response measurements produced graphs of sound decay within the hallways, as seen in Figure 46. The graph below displays the decay of one impulse response measurement from Hospital R1 at 1600 Hz, and revealed four distinct reflections at 0.24, 0.38, 0.60, and 0.74 seconds. Similar graphs were produced for frequencies between 1250 Hz and 5000 Hz, as reflections could easily be discerned within the impulse data, primarily concentrated at the four timing peaks listed above. When these time values associated with the reflection peaks were compared with the CAD drawings from Hospital R1, meaningful relationships emerged. The timespans between reflection peaks corresponded with the total length of the measured hallway, so these peaks were being generated by sound bouncing back and forth between the two ends of the hallway. From these results, it can be concluded that the straight hallways with closed ends (from a closed doorway or connecting hallway) created an architectural situation where sound could reflect unencumbered from one end of the unit to the other in a flutter echo pattern. This in turn, could have contributed to unwanted noise traveling throughout the unit resulting in higher overall noise levels and potentially a worse perception of soundscape conditions.

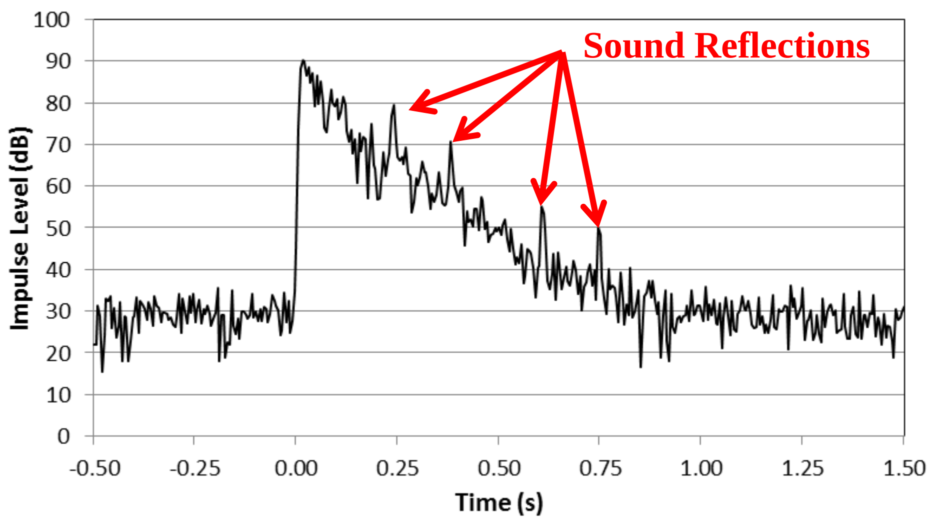

Figure 46: Impulse Response Graph from Hospital R1 – Reflections at 1600 Hz

The impulse response measurements also generated the reverberation times within the hallways measured, by calculating the time it would take for sound to decay 60 decibels in the space (using T20 and T30 parameters). Figure 47 displays the reverberation times across frequency measured within the hallways of Hospitals R1 & R2. Similar values were found for both hospitals, with each generating reverberation times around 0.6 seconds across the spectrum. This was expected, given the similarities in hallway size and interior materials (GWB walls, ACT ceilings, & resilient flooring).

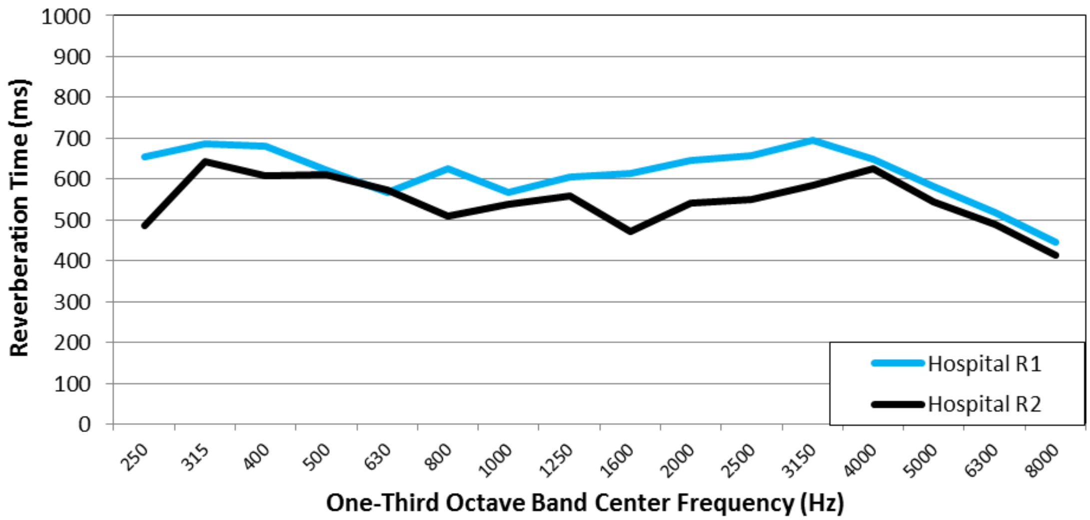

Figure 47: Reverberation Times Measured in Hospitals R1 & R2

Hospitals R1 & R2 Analyses

4.4.1 Acoustical Data Analysis

Once the acoustical data for the 23 patient rooms and 7 nursing stations within the six measured units was compiled, it was subsequently analyzed in a number of ways. First, the HCAHPS survey data provided for both hospitals was compared with measured acoustical data. In addition, the hospital staff survey administered to both hospitals was utilized to assess staff perception of soundscape conditions within individual units. Furthermore, physical differences found between the two hospitals which could have impacted acoustical conditions were analyzed, including the influence these features might have had on impulse response measurements and the alarm identification issues experienced in the third floor of Hospital R1.

4.4.2 HCAHPS Patient Survey

When beginning acoustical measurements at Hospitals R1 & R2, the intended goal was to analyze the collected data as was accomplished for Hospital U1: correlating room-level HCAHPS data with the measured acoustical metrics. Unfortunately, the HCAHPS patient survey for these hospitals did not provide information at a room-level, so correlations (as were completed in Phase I) were not possible in Phase II of this study. The HCAHPS data that was available for this phase of the study was aggregated by month for each hospital, providing performance results for soundscape conditions over time. Again this did not provide adequate data for correlation, as there was only one measurement time period collected for each hospital. Therefore, a comparison between HCAHPS results and acoustical metrics with Hospital U1 was completed.

The HCAHPS patient survey data for Hospital R1 over the last two and a half years showed an average Quietness of Hospital Environment score of 77 %. This placed Hospital R1 above the average for hospitals in Nebraska (68 % to 72 % over that time period) and placed it near the 90th percentile in national ratings. In contrast, the five units measured from Hospital U1 scored between 43 % and 65 % which corresponded to the 5th and 65th percentile ratings, respectively. With these results, it was expected to find dramatically different acoustical results between the rural and urban hospitals.

Looking at measured LA_{EQ} values within the patient rooms of each unit (Figure 5 for Hospital U1 and Figure 32 for Hospitals R1 & R2) revealed very little differences between the average 24-hour sound levels. Eight of the eleven units measured in all three hospitals had average patient room LA_{EQ} levels between 55 dBA and 60 dBA during the measurement periods. With all units included, the LA_{EQ} ranged between 52 dBA and 62 dBA. Similar results were found between other acoustical metrics, such as LA_{MIN}, LA_{MAX}, LC_{PEAK}, SII, Spectra, Occurrence Rates, and at nursing stations. There was more variability with measured acoustical data observed in Hospital U1, but not enough to draw tangible conclusions from.

With such similar acoustical measurement results, it begged the question: Why did these hospitals perform so differently on the HCAHPS Quietness of Hospital Environment patient survey question? It is important to note that these three hospitals were located in two disparate environments, in an urban city and in two rural areas of Nebraska. In turn, the hospitals themselves and the occupancy within the units were comparable in size to their locales. This resulted in Hospital U1 having 20 or more step-down type units on its campus, all continually at near full-capacity, as opposed to the two rural hospitals, which each contained three step-down type units, usually at around half to two-thirds patient occupancy. It was possible that the differences in HCAHPS performance was to the perceived ‘hustle and bustle’ of the busier units found in the urban hospital environment, despite the similarity of overall average noise levels. A more constant activity level would have the potential to raise average levels, but the measured sound levels specifically within patient rooms were more attributed to each room and the noise generated therein and less to the activity throughout the units. The more constant activity level could anecdotally be perceived negatively by patients, and thus could lead to differences in HCAHPS survey results, as was found between the urban and rural hospitals in Phase I and Phase II of this study, even without differences in acoustical metrics.

4.4.3 Hospital Staff Survey

The hospital staff survey administered by the AE firm at the hospital’s behest provided a number of indications as to the acoustical performance of each of the units within the two rural hospitals. With the measured acoustical data, it was possible to evaluate these findings and lend reasoning behind the staff perception of the soundscapes.

When looking at the survey results from the six units measured in Hospitals R1 & R2, the Women & Children’s unit from Hospital R1 stood out positively in all related acoustical questions: ‘Acoustical environment supports ability to perform job functions’, ‘Frequency noise disrupts patient rest & recuperation’, job satisfaction, etc. It was found that this unit had the second lowest average LA_{EQ} levels, the lowest LA_{MIN} levels and LC_{PEAK} Occurrence Rates in patient rooms as well as the lowest LA_{EQ} values of any of the nursing stations. With this assemblage of data, it was logical to see why the Women & Children’s unit in Hospital R1 was rated more favorably by staff, especially considering that it was typically the unit with the lowest occupancy of the six units tested.

At the opposite end of the spectrum was the ICU in Hospital R1, having the worst perceived acoustical conditions of the six hospital units surveyed. This unit proved to be the most distracting for ‘Acoustical environment supports ability to perform job functions’ and ‘Noise disrupts my work’ questions, and second worst (only to the Medical/Surgical unit in Hospital R1) for ‘Frequency noise disrupts patient rest & recuperation’. While LA_{EQ} levels were not substantially higher (2 – 3 dBA) for the ICU in Hospital R1 than in the other units (Figure 32), the statistical levels (Figure 35) and LCPEAK Occurrence Rates (Figure 38) indicated that the patient rooms in the unit were consistently louder than any other unit. Also, the main nursing station showed the highest LA_{EQ} levels than the other measured units, lending further reasoning behind the perceived staff differences.

The other four hospital units measured displayed similar results, both in the staff survey responses to the associated acoustical questions as well as the acoustical metrics. Of note was the performance difference between hospitals for the ‘Acoustical environment supports ability to perform job functions’ question, with Hospital R2 receiving significantly more ‘agree to strongly agree responses’ than in Hospital R1. These results lent substation to the alarm identification issues reported in Hospital R1, and provided further evidence of the impact of this problem.

The questions on the staff survey related to acoustical issues were also linearly regressed with measured acoustical data. This resulted in a large number of correlations completed for five staff survey questions: ‘Job satisfaction’, ‘Acoustical environment supports ability to perform job functions’, ‘Noise disrupts my work’, ‘Noise disrupts patient rest and recuperation’, and ‘Satisfaction with overall physical workplace environment’. This survey data were correlated against measured acoustical values for patient rooms and nursing stations, averaged by unit (to provide analogous data to the survey). ‘Job satisfaction’ was reported using a 10-point positive-negative scale, while all other survey questions utilized three levels of answer percentages, such as ‘agree or strongly agree’, ‘neither agree or disagree’, and ‘disagree or strongly disagree’. The numerical values for staff survey responses can be found in Table 31 of Appendix B. Each level of response (positive, neutral, negative) was correlated with each acoustical metric separately. This resulted in 13 survey response values regressed with 18 acoustical metrics for patient room data, totaling 468 correlations.

The results from this regression analysis were somewhat unpredictable, which was understandable given the small sample size of six units. Looking at the correlations between acoustical data and ‘Job satisfaction’ produced very little agreement, with no patient room metrics found to be significantly correlated ($p < 0.05$). (Table 42) Similar results were found for ‘Satisfaction with overall physical workplace environment’, with no significant correlations found between this survey question and measured acoustical data. (Table 43, Table 44, & Table 45) These findings indicated that unit averaged acoustical values measured in Hospitals R1 & R2 could not statistically be linked with ‘Job satisfaction’ or for ‘Satisfaction with overall physical workplace environment’.

The ‘Acoustical environment supports ability to perform job functions’ question produced a few statistically significant results, for the ‘disagree or strongly disagree’ response for patient room data. (Table 46, Table 47, & Table 48) The correlated acoustical metrics were all statistical levels: LA_{33} ($F[1,5] = 3.06$, $p = 0.038$), LA_{50} ($F[1,5] = 5.34$, $p = 0.006$), LA_{90} ($F[1,5] = 5.40$, $p = 0.006$), and LA_{95} ($F[1,5] = 5.02$, $p = 0.007$). This indicated that disagreement to the ‘Acoustical environment supports ability to perform job functions’ question was linked in some way to these four statistical levels.

Unlike the preceding three staff survey questions, the ‘Noise disrupts my work’ question proved to be highly linked with acoustical data. (Table 49, Table 50, & Table 51) Specifically, the ‘rarely to never’ response to this question produced 9 of 18 statistical correlations ($p < 0.05$) with measured patient room acoustical metrics including LA_{EQ} ($F[1,5] = 3.67$, $p = 0.021$). The significantly correlated metrics for patient rooms also included LAE, LA_{05}, LA_{10}, LA_{33}, RC, NC, SII (Normal), and SII (Raised). Additionally, correlations were found for the ‘often to very frequently’ response, for the LA_{50}, LA_{90}, and LA_{95} metrics. Clearly, there were significant relationships between the soundscape conditions of both the patient rooms with the perceptions of the staff. These findings indicated that the ‘Noise disrupts my work’ survey question elicited accurate perceptions of soundscape conditions when compared with acoustical values.

Similarly, the ‘Noise disrupts patient rest and recuperation’ question produced numerous statistically significant correlations with measured acoustical data. (Table 52, Table 53, & Table 54) For both ‘rarely to never’ and ‘sometimes’ responses, many correlations were found with acoustical metrics: 19 out of 72 regressions were significantly correlated ($p < 0.05$) and 19 were marginally related ($0.05 < p < 0.1$). No corrections for multiple correlations were completed for this dataset, indicating that some of these correlations might have been due to random chance correlation. Unlike the previous question, however, the acoustical metrics that were found to be correlated were sporadically distributed. The LA_{EQ} was not correlated for any patient room data. Again, these findings established links between measured acoustical values and the ‘Noise disrupts patient rest and recuperation’ survey question, indicating the efficacy of using this question in the perception of soundscape conditions. This question and the ‘Noise disrupts my work’ survey question proved to be the most correlated with measured acoustical data, validating the use of these two questions in the assessment of hospital soundscapes.

4.4.4 Physical Unit Differences

Even though Hospitals R1 & R2 were designed by the same architectural engineering firm and were opened within five years of one another, there were still differences found in the architectural design of the Hospitals. Hospital R2 was servicing a larger community and thus required a larger medical facility, so the fact that it was built one story taller than Hospital R1 was not surprising. However, the two hospitals were designed with significantly different unit and hallway layouts, with Hospital R1 having dual parallel corridors arranged in a ‘T’ and Hospital R2 having two long hallways separated by some distance (~50 feet or more). This layout difference resulted in number of consequences, most notably in the manner in which nursing stations were distributed. Hospital R1 utilized a centralized nursing station at the crossing of the ‘T’ within each unit, while Hospital R2 had two nursing stations per floor: one on each side of the unit. Functionally, both the centralized and de-centralized nursing station designs exhibited positive features. The main nursing station in Hospital R1 had the benefit of being centrally located, within close proximity to ICU patients and equidistant with most Medical/Surgical rooms further down the hallways. The distance between patient rooms and the nursing stations in Hospital R2 was not as close with specific ICU patients as in Hospital R1, but was more equidistant to a larger number of patient rooms.

The nursing station design decision had acoustical consequences as well, with the main nursing station in Hospital R1 on the ICU/Medical/Surgical floor exhibiting poorer soundscape conditions than any nursing stations in Hospital R2. The average LA_{EQ}

levels in this unit were the highest among nursing stations tested. The unit was also rated the poorest on the hospital staff survey, corroborating the measured acoustical data. Quickly looking at some of the other staff survey responses, Collaboration Experience (12-question validated scale, Hua 2010) was lower in the centralized nursing environment in the Hospital R1 ICU/Medical/Surgical floor, with scores of 2.27 and 1.98 respectively, versus 4.9 and 3.39 in the analogous units in Hospital R2. Clearly, nursing station design within units had an impact on a number of factors for both patients and staff.

Beyond the differences in the overall layouts, Hospitals R1 & R2 were built with several design features that deserved mentioning as they related to acoustics. The first difference observed was in the nursing station alcoves located along the hallways between patient rooms which allowed immediate access to patient records for staff members. In Hospital R1, these nursing alcoves were square (Figure 19); in Hospital R2, one wall of the nursing alcoves was angled (Figure 20). This could have resulted in differing reflection patterns for sound within the hallways, potentially creating acoustical anomalies. Also, the floors installed within the hallways of the two hospitals were slightly different; the floors in Hospital R2 felt slightly softer underfoot which resulted in less footfall and cart noise. This effect was only evident anecdotally, as no tapping tests (or similar acoustical measurements) were conducted to substantiate these observations. No other differences were found in building materials utilized in the hallways and other common areas (such as wall or ceiling types).

The one difference found in the patient rooms was within rooms equipped with positive pressure capabilities: Hospital R1 used GWB ceilings, while Hospital R2 had ACT ceilings. The BNL for the last individual patient room in Figure 43 was the only patient room measured with GWB ceilings in any of the measurements for either hospital.

It showed an unoccupied noise level of 45.5 dBA: the highest BNL of any tested. While onsite, it was reported from a patient in one of these rooms with GWB ceilings, “I can’t hear the television in the room well. It sounds noisy when it is on and if I turn up the volume, it just sounds even noisier.” These poor acoustical findings for patient rooms with GWB ceilings were consistent with results found in Phase I.

4.4.5 Impulse Response Analysis

The impulse response measurements were a unique addition to this research, and one that was not expected to be accomplished within the two rural hospitals. Generally, these measurements involve making loud, impulsive noise using a speaker within a room which produces a decay of sound that is subsequently measured using sound level meters or other acoustical equipment. In a hospital environment, creating loud noises is quite often frowned upon, for obvious reason of patient disturbance. Luckily, the Women & Children’s unit in Hospital R1 (which was the first site measured) was 75 % empty during the acoustical measurements, with one long hallway having no occupants. Once conferring with the nursing staff, they agreed to allow the popping of several balloons to complete the impulse response measurements. The Women & Children’s unit in Hospital R2 was also selected for measurement, as it was the least occupied (at around 50 % capacity) of the three units measured. The staff within Hospital R2 was less thrilled with the balloons being popped within the unit, but allowed the measurements to commence.

For each hospital, reverberation times were calculated using the decay data from each hospital hallway, generating times of 0.5 to 0.6 seconds across the frequency spectrum (Figure 47). These values were computed using the T20 parameter; T30 values were consistent with those presented, except where signal-to-noise ratio issues rendered reverberation times invalid. No recommendations have been given regarding hospital hallway reverberation time values, but the measured values are in line with recommended values for spaces utilized for speech, such as classrooms and meeting rooms.

The impulse response measurements also provided an analysis of reflection patterns within the hospital hallways between 250 Hz and 5000 Hz. Unfortunately, as the impulse response measurements were unexpected, the settings utilized in the sound level meters used were set improperly for a full analysis. The time value which determined the regularity of acoustical data points was set to 5 milliseconds, which sounded like a proper timeframe, but simply did not provide the time resolution desired. Figure 46 shows an example impulse response graph for a specific frequency for a measurement within Hospital R1. It was desired to zoom in on the first 100 ms, for example, to see how the initial sound reflected around the area close to the source and receiver. For this level of detail, a time value in the microseconds would have been required, as is generated when using a 44.1 kHz sample rate (commonly used for impulse response measurements).

Therefore, the key finding from the impulse response measurements was the fact that hospital units with long, straight hallways can have sound travel the length of the hall many times in a flutter echo pattern before decaying. Within both Hospitals R1 & R2, reflections were found in the impulse response graphs that corresponded with the physical lengths of the units (in association with the speed of sound), indicating that the noise from the popped balloons was traveling back and forth between the end walls in the units. Given the lengths of each of these hallways (200+ feet in Hospital R1 and 300+ feet in Hospital R2) plus the fact that ACT was on the entire hallway ceiling, this result was illuminating.

The author of this research was not the only student involved in research connected with the three hospitals measured in this study. Also working with Dr. Ryherd was undergraduate student Stephanie Ahrens who analyzed differences between the hallways within Hospitals R1 & R2 using Odeon computer modeling software. The author was not involved in any part of the modeling research: the graphics below were provided for dissemination by Ms. Ahrens in this dissertation, as they illustrate the soundscape conditions measured by the impulse responses.

Figure 48 displays computer models generated for Hospital R1 (left) and Hospital R2 (right). The blue lines are tracing rays generated from a single source point (as was with the popped balloon), which were then allowed to propagate throughout the hallways. The rays generated were random with regard to origination direction. Of note are the square and angled nursing station alcoves for the two units. Within Hospital R1, sound tended to build up around the source location, as opposed to in Hospital R2, where the sound was allowed to more readily travel throughout the unit. It was possible that the difference between the square and angled nursing alcoves in the hallways played an influence in these results. It was also possible that these models created anomalous findings, with source/receiver positing that produced the figures below. This was why having more detailed impulse response data would have been very helpful to analyze the early reflection pattern of the sound, but this level of resolution was just not available.

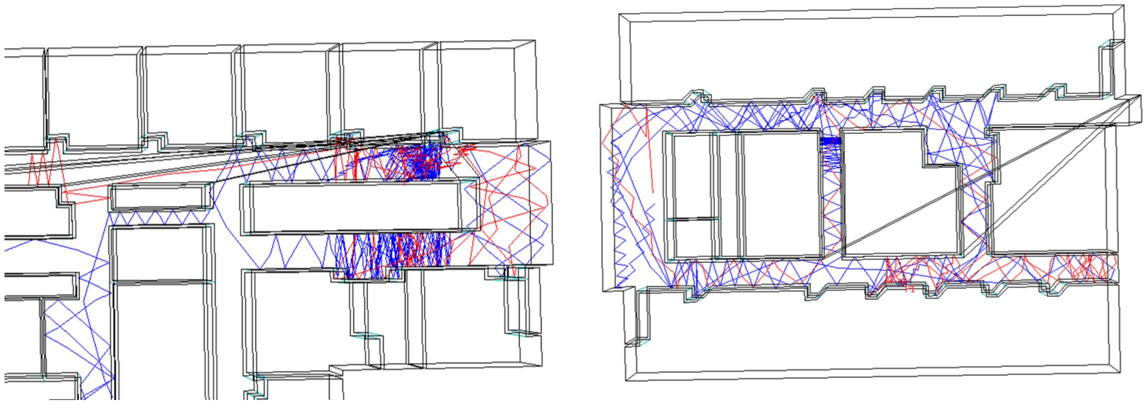

Figure 48: Odeon Acoustical Models of Nursing Alcoves in Hospitals R1 & R2 (Images Courtesy of Stephanie Ahrens)

4.4.6 Alarm Identification Analysis

One of the main issues reported by the hospital administration was the difficulty in identifying the direction and/or location of alarm sounds within the ICU and Medical/Surgical units in Hospital R1. Similar complaints were not being generated by the staff in Hospital R2, so it was reasonable to assume that there was a cause associated with the Hospital R1 environment. Various reasons behind this problem have been alluded to in the acoustical data and survey information presented thus far, but tying things together revealed a multi-pronged situation with no single solution.

The main culprit for the alarm identification issues was likely due to the physical layout of the units in Hospital R1, but not necessarily caused by the centralized nursing station. Instead, the fact that these units utilized two parallel hallways in close proximity to one another was surmised to be causing odd reflection patterns. These parallel hallways were 12 – 15 feet apart (wide enough to house a single row of small offices) with connecting passages every 30 – 40 feet. This resulted in an interconnected hallway design which facilitated passage for patients and staff, but also allowed sound to travel throughout the unit in multiple directions. Therefore, when alarms were sounded, the noise could potentially travel down a number of pathways, which could make it seem as if the sound was coming from a different direction.

The flooring and the small differences in reverberation times could have also played a small role in this issue, but with acoustical data so close the impact was not thought to be substantial. The square versus angled nursing alcoves could have played a role in the alarm identification issues, however. As illustrated in Figure 48, a greater buildup of sound was potentially possible with the square nursing alcoves as opposed to the hallways with the angled design. In certain instances, these buildup effects could have resulted in unexpected reflection patterns. Combined with the dual corridor layout of the units in Hospital R1 these issues could have potentially created alarm sounds from unknown directions.

It was also important to look at the source of noise at the main nursing station in question to see if any sound generated in Hospital R1 was in part responsible for the alarm identification issues. The overall levels measured at the ICU/Medical/Surgical nursing station in Hospital R1 were the highest on average between the units measured, but were not significantly louder. Looking at the other acoustical metrics revealed discrepancies in the frequency spectrum measured at the nursing station of interest. A significant peak was observed at 500 Hz for the ICU/Medical/Surgical nursing station in Hospital R1 (Figure 49) during both measurement days. This spectral peak was not seen in any other nursing station in either hospital. Clearly, some noise source was constantly present at this nursing station, enough to raise the level at 500 Hz as well as the overall LA_{EQ}. The cause of this peak was unknown, but given the narrow frequency range accentuated, the noise was not caused by speech (as that noise would be much more broadband). It was likely caused by one or more communication systems (alarms, ringing phones, paging equipment, etc.) constantly present at the nursing station.

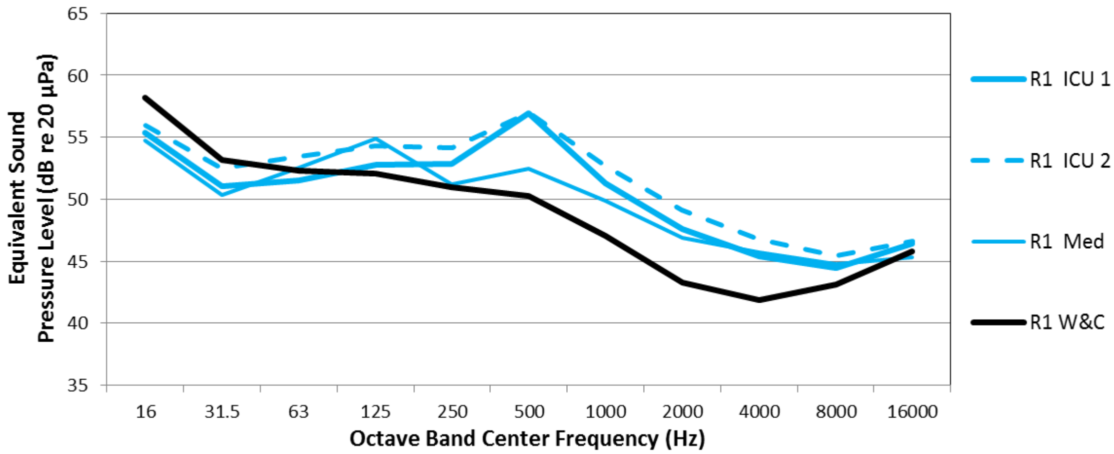

Figure 49: 24-Hour Average Spectra in Hospital R1 – Nursing Station Comparison

The ultimate cause of the issues in alarm identification by staff in the Hospital R1 ICU/Medical/Surgical unit could not be isolated to a single cause, but was the result of several architectural design decisions coalescing into an acoustical problem. The very close dual corridor design together with the square nursing alcoves likely caused odd sound reflection patterns, creating alarm direction identification issues to occur. It was possible that the narrow frequency range of noise at the main nursing station exacerbated this situation, due to many sounds being generated at a similar frequency, potentially causing hearing confusion. In the end, the mitigation of this problem was beyond the scope of this research. Strategically placed absorption panels around the main nursing station could have the effect of minimizing the unwanted reflections within the unit, but the topic would require additional study to craft a more specific solution.

Hospitals R1 & R2 Conclusions

In Phase II of this research, the sound levels of patient rooms and nursing stations within six similar-type units were measured in two rural hospitals, providing the comparison between two additional hospitals and the analysis of various acoustical issues. The 24-hour average LA_{EQ} values of the six units within the patient rooms was found to be between 54 dBA and 60 dBA, while the absolute minimum LA_{MIN} ranged from 35 dBA to 44 dBA, and the absolute maximum LA_{MAX} spanned from 85 dBA up to 90 dBA. All six units failed to achieve SII ratings of 'Good', with all either receiving 'Marginal' or 'Poor' grades. Unoccupied patient rooms in the six units were measured, revealing relatively acceptable unoccupied noise levels in some rooms (34 dBA – 46 dBA), although too much high frequency energy was present to meet ANSI/ASA or FGI patient room noise recommendations. The large range of levels measured within the unoccupied patient rooms was of note, with numerous rooms displaying markedly higher background noise levels than others. Impulse response measurements were also collected within the two rural hospitals, generating reverberation time values for the unit hallways and providing novel information as to how sound decayed in those environments.

The measured acoustical data were utilized in conjunction with HCAHPS patient survey data and hospital staff survey results to analyze the differences in soundscape perception of the six units. It was shown that the worst perceived unit (Hospital R1 ICU) in the hospital staff survey was also the loudest within the patient rooms, both for the overall LA_{EQ} and consistently during all periods in the statistical sound levels and LC_{PEAK} Occurrence Rates. It was also found that the best perceived unit (Hospital R1 Women & Children's) had the lowest overall noise levels across many of the measured acoustical metrics, also including LC_{PEAK} Occurrence Rates. Additionally, it was observed that other topics on the hospital staff survey related with the perception of unit soundscape conditions, with job satisfaction and staff collaboration measures being found to be higher in the best perceived unit and lower in the worst perceived unit. It was also identified that the 'Noise disrupts patient rest and recuperation' and 'Noise disrupts my work' survey questions were the most correlated with measured acoustical data, validating the use of these two questions in the assessment of hospital soundscapes.

The issue of alarm identification was recognized by the hospital administration and thus analyzed during this research. It was surmised that these directional perception issues were caused by several architectural elements incorporated into the design of the hospital. Having parallel corridors in close proximity to one another allowed sound multiple paths in which to travel and combined with the square nursing alcoves generated unexpected reflection patterns. These patterns could have in turn potentially created false sonic images, causing difficulties in identifying alarm location.

At the start of the Phase II research, it was intended to correlate HCAHPS 'Quietness of Hospital Environment' survey data at a patient room-level, as was accomplished in Phase I. Unfortunately, this level of detail was not available for the HCAHPS patient survey data provided and thus a more general approach was adopted for the analysis procedures with acoustical measurement data. It would still be beneficial to analyze additional hospital patient rooms in a room-level analysis with HCAHPS data at other hospital sites (or if this data becomes available for Hospitals R1 & R2) to further corroborate correlations found in Phase I of the study as well as related hospital characteristics found in Phase II.

Chapter 5

Phase III: Perceptual Tests on the Dynamic Range of Noise

Perceptual Test Background

In Phase 1 of this study, a significant correlation was found between HCAHPS 'Quietness of Hospital Environment' survey results and several calculated Occurrence Rate metrics. Specifically, LC_{PEAK} Occurrence Rate range was found to be correlated with patient perception of noise, which indicated a potential preference toward soundscapes with lower minimum sound levels, even when this resulted in a wide range of sound levels as opposed to a very narrow range of sound levels. This result was interesting, as no research had been found linking human perception with the dynamic range of noise, so it was desired to investigate this situation further. In the Phase I analysis, it was found that the absolute LA_{MIN} levels were highly correlated with the LC_{PEAK} Occurrence Rate range, while the absolute LC_{PEAK} levels were not correlated. This indicated that the relationship between patient perception and the LC_{PEAK} Occurrence Rate range was dependent on the minimum sound levels (and not the peak levels) for the data from Hospital U1. Whether this was a meaningful connection or a statistical anomaly required further study to address.

A subjective perceptual test was created to study the annoyance of noise with varying dynamic ranges of noise. These tests helped to determine the perceptual differences between hospital soundscapes with constant noise levels versus ones with sporadic peaks. The results also helped to illuminate the findings from Phase I, which linked higher patient perception with soundscapes having lower minimum sound levels even if when this resulted in a wider range of sound levels.

5.1.1 Sound Masking in Hospitals

The subjective perception of noise with varying sound levels is an important topic, as the understanding of how humans perceive dynamic noise is limited. A constant noise level might be perceived more favorably because you can 'tune out' the noise more so than in a quiet environment with occasional distracting noise. Conversely, the benefit of a quieter overall soundscape might be perceived more favorably despite having more impulsive noise events. The answer to this question was unknown, but specifically related to one topic that has arisen over the past few decades in hospital acoustics: sound masking systems in hospital units and patient rooms.

A sound masking system is a dedicated sound system that generates low-level, neutral-spectra noise, such as white, pink, or brown noise. This broadband noise produces a constant background noise level that has been raised above the ambient noise floor of the room. The theory behind sound masking systems is that providing a constant sound level will eliminate a certain amount of transient noise, thus creating a less distracting and more pleasing acoustic environment. Sound masking can have a positive impact on work environments by increasing speech privacy, [103] important in medical and communication offices. It has also been found that memory task performance decreases in the presence of intelligible speech, the effects of which would be diminished with the addition of a sound masking system. [104] Negative impacts of sound masking have been found as well, such as subjects reporting obscuring of nearby conversations. This interference can potentially be judged to be more annoying than the noise those conversations might generate. [105]

Masking systems have been making their way into hospital environments over the past 10 – 20 years, as better and more advanced products have been offered. Based on manufacturers' published information, hundreds of hospitals implement some form of sound masking system. [106 – 108] Unfortunately, there has been no published research advocating or discouraging the utilization of these systems within hospitals. This is not entirely surprising, as conducting a proper study of this magnitude would entail a significant commitment from both the hospital and manufacturer. However, sound masking systems do have the potential to improve patient rest and recuperation, as stated by one manufacturer, "Studies show that patients in rooms with sound masking find that it helps to shorten the time it takes to fall asleep and prevents unwanted noises from disrupting their sleep." [106]

The fact is that there has been no research linking sound masking systems in hospitals with improved patient satisfaction or wellbeing: the only evidence has been anecdotal. While this research has not involved the use of sound masking systems in any of the acoustical hospital measurements conducted, certain acoustical metrics could be used to evaluate associated properties. For example, absolute minimum sound levels might indicate how quiet a patient room could get in the absence of outside noise, as was found in Phase I. The LA_{MIN} levels were positively correlated with patient satisfaction, indicating a preference towards quieter background noise levels, potentially contradictory to the premise behind sound masking systems. Therefore, in addition to increasing the understanding of human perception of noise, this study has the potential to provide information, at least indirectly, as to the appropriate use and design of sound masking systems in hospital environments.

5.1.2 Subjective Perceptual Tests

This phase of the research involved the creation of a subjective perceptual test to be administered on people with normal hearing to determine their annoyance level to soundscapes with varying dynamic ranges of noise. Specifically, the impact of hospital-related noise was of interest to this study. Numerous audio files were prepared from simulated hospital soundscapes that were equivalent in average level, but differed in the quantity of transient noise events. The goal was for subjects to listen to each hospital soundscape and rate how annoying they found it on a seven point Likert scale, from not annoyed at all (1) to unbearably annoying (7). Annoyance was chosen because it was a universal emotion that every subject would understand and relate to, and was thought to be the best way to rate the perceptual differences between the hospital soundscapes.

Subjects listened to these audio files in a controlled testing environment where they would be able to concentrate on the differences between the soundscapes. In addition to the annoyance data, age, gender, and noise sensitivity demographics were also collected. These provided confounding variables that illuminated the relationships between annoyance and the various groups of people. PANAS subject affect schedules were also administered before and after the test and heart rates were collected during the test for a select number of subjects. Together these two measures provided external quantifications of the impact that half an hour of hospital noise had on subjects.

Once the subjects completed all testing procedures, the perceptual annoyance data were correlated against the acoustical properties of the presented test item audio files. Specifically, the range of dynamic noise, as measured by LC_{PEAK} Occurrence Rate range, was of interest, as well as the level of peak noise events. The perceptual annoyance data were also used in correlations with subject demographics, and the impact of hospital noise on subject affect and heart rate were also analyzed. In total, these tests helped provide new information into the perceptual preference between soundscapes with constant noise levels versus soundscapes with numerous sporadic peaks.

5.1.3 IRB Application

To conduct the subjective perception tests, approval was required from the University of Nebraska Institutional Review Board (IRB) to determine whether the study was safe to conduct on human subjects. This process required submission of an application which stated the intended goals of the study, the potential risks involved to any participants, the information that was hoped to be gathered, the methodology that would be used, and any associated documentation from the study. The forms were submitted for the author, Jay Bliefnick, under the advisement of Dr. Erica Ryherd. The information provided to the IRB was essentially a condensed version of the goals and procedures outlined in this document. Also included were copies of the pamphlets that advertised the study to potential volunteers, the subject email contact template, the participant questionnaire (asking age, gender, noise sensitivity, and subject affect), as well as the informed consent form that subjects were required to sign, which spelled out the process of their involvement with the study. Once all information was provided to the IRB and the review process was completed, the subjective testing commenced.

Perceptual Test Construction

5.2.1 Subjective Perception Test Construction Goals

A perceptual study of this type had not been conducted before, so no references were available for a basis of comparison. To construct the testing procedures for this phase of the study, sensible stimulus-centered subject testing methods were employed. The primary intention was to construct a fair testing procedure that measured the desired value (the dynamic range of noise in this instance) and was not influenced by external factors or testing errors. For example, if test items were constructed improperly, it could have resulted in universal annoyance or non-annoyance from subjects, which would not have revealed any meaningful relationships.

It was desired to test the perceptual differences between noises with varying dynamic ranges, as these quantities were found to be related in Phase I of this research. To quantify these differences, the LC_{PEAK} Occurrence Rate range was selected for use, as this value was determined by the dynamic range of LC_{PEAK} levels. Audio files were created that varied in the LC_{PEAK} Occurrence Rate range while maintaining equivalent average sound levels to 'normalize' presented soundscapes. The audio file presentation order was pseudo-randomized to equally distribute the various soundscapes throughout the testing procedure. All of these measures were instituted in order to minimize the impact of factors other than the dynamic range of noise, which was being tested.

The audio files were divided into two groups determined by average LA_{EQ} level: 65 dBA and 55 dBA. Two subject groups were formed to determine whether level of presented noise influenced annoyance levels. All other facets of testing were identical between the two subject groups, including the testing of annoyance perception data and the collection of demographic, subject affect, and heart rate information.

During testing procedures, each subject listened to 30 individual audio files comprised of simulated hospital soundscapes that lasted 30 seconds each. The total testing time was around 30 minutes for each subject, after including the time spent signing the informed consent form and filling out the demographic and subject affect questionnaires. This testing time was selected in an effort to minimize subject distraction and fatigue, common with tests of longer testing times. The final result of these numerous testing procedure decisions was a subjective perceptual test that was specifically designed to analyze the differences between noises with varying dynamic ranges. All reasonable steps were taken to isolate the acoustical quantity of interest and to test its impact, free from any external perceptual influences.

5.2.2 Item Creation

The first step in the creation of the subjective perceptual tests was to produce the audio files being used to present to subjects. This process required the choice of how these sound files were going to be created, where the sound files would come from, and in what manner they were to be altered to form a meaningful collection of data. It was possible that real, recorded hospital soundscapes could have been used, or simulated hospital soundscapes could have been created in a number of ways. In the end, it was determined that simulated hospital soundscapes (equivalent to those found in real hospital environments) would serve as test items, as recorded hospital soundscapes would have carried far too many other issues (such as privacy concerns). The simulated soundscapes also provided a more ‘uniform’ collection of audio content, which proved important.

The simulated hospital soundscapes were downloaded from a website, SoundSnap.com, which featured thousands of audio sound files representing numerous different environments. To start, around 40 unique audio files were downloaded and evaluated for content, quality of recording, etc. This list was eventually whittled down to a smaller list of three audio files which were used to create the presented perceptual test audio files. Ultimately, only one downloaded 'master' file was used in the creation of the audio files used in the perceptual test. It was concluded that using multiple master audio files would represent a completely separate grouping of tests, requiring an entirely separate group of subjects. Therefore it was determined to utilize one downloaded master audio file from which to generate all presented test items.

Item selection was also carefully considered, as the presented audio files needed to be 'annoying' enough to elicit a range of subject responses, but not 'too annoying' to be consistently perceived as extremely negative. To that end, the master audio file with less 'aggressive' sounding noise was selected for use in the perceptual tests. The other two originally downloaded soundscapes were simulating emergency room and operating room environments, respectively, and were considered considerably more annoying when pilot tested (detailed below in section 5.2.6). The master audio file selected produced a wide range of subject response values in pilot tests, and was chosen as the best candidate for item creation.

The selected master audio file was approximately 2 minutes and 45 seconds in duration, and featured aural content similar to what would be found in a hospital waiting room or hallway. There were rolling carts, alarm noises, clanks & bangs, muffled (unintelligible) voices, etc. There was no discernable speech, loud wailing, or any 'extreme' sounds which were found to elicit consistent negative reactions in pilot testing.

Figure 50 displays the visual representation of the master audio file used to create the presented testing items. From this audio file, individual 30-second audio files were generated using a 10-second offset time. The pattern of audio file creation is highlighted by the bars above Figure 50. This resulted in 15 individual audio files created from the original master file, each with a unique starting position. This also meant that there was a certain amount of content overlap between the presented audio files. This was deemed to be beneficial as opposed to detrimental, as the continuity of sounds between the test items could only further reinforce the concentration on the dynamic range of noise.

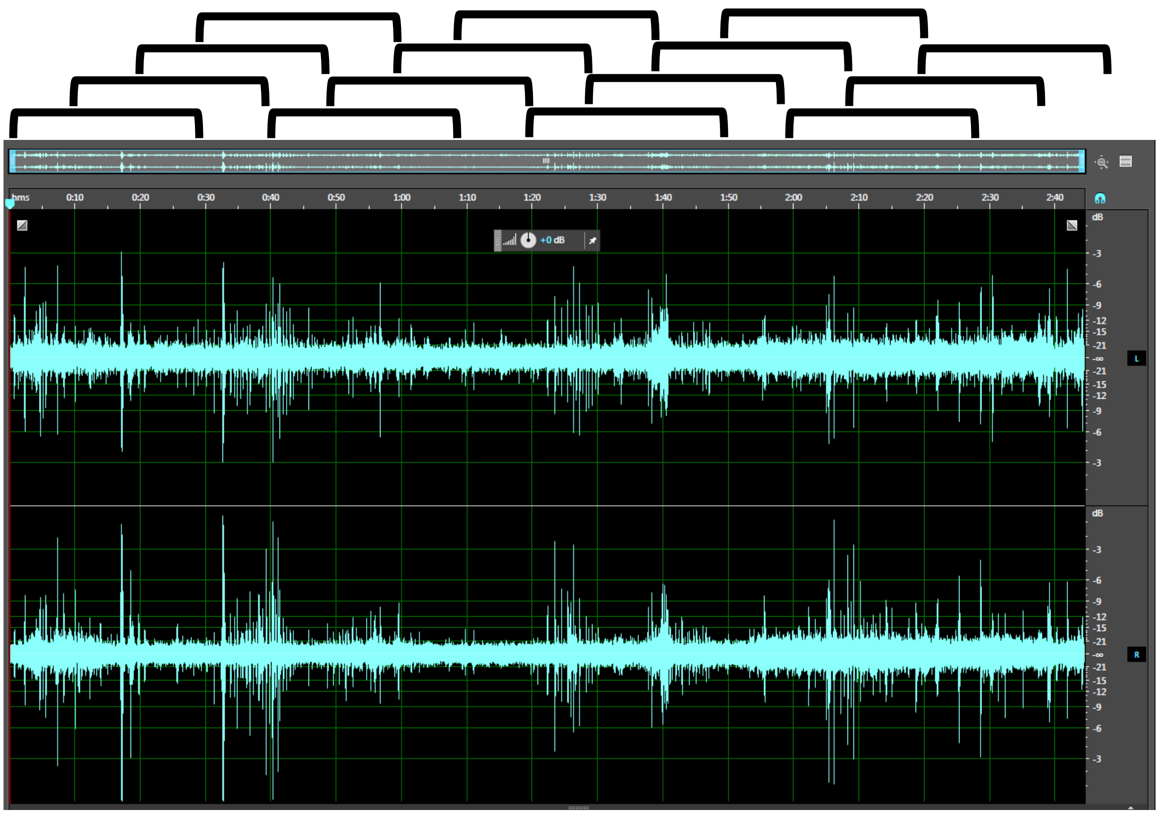

Figure 50: Perceptual Test Item Creation – Entire 2 Minute 45 Second Audio File

Once the 15 individual test item audio files were generated, they needed to be edited in such a way to create the range of dynamic noise necessary for the perceptual testing. All of the files were nearly identical to start (not surprising as they all came from the same master file), but alterations were needed to achieve the desired spread of presented audio levels. Figure 51 and Figure 52 display the result of audio editing to the presented audio files. Figure 51 was an audio file test item designed to have a low dynamic range of noise. This effect was created using Adobe Audition sound editing software, by implementing a noise limiter to eliminate the peaks in the audio file. The level was subsequently raised to bring the overall average level (LA_{EQ} over the 30-second audio file length) equivalent with all other audio file test items. By condensing the signal into a narrow band of sound levels, the range of dynamic noise was minimized, producing a very constant sound level within this audio file without changing the content.

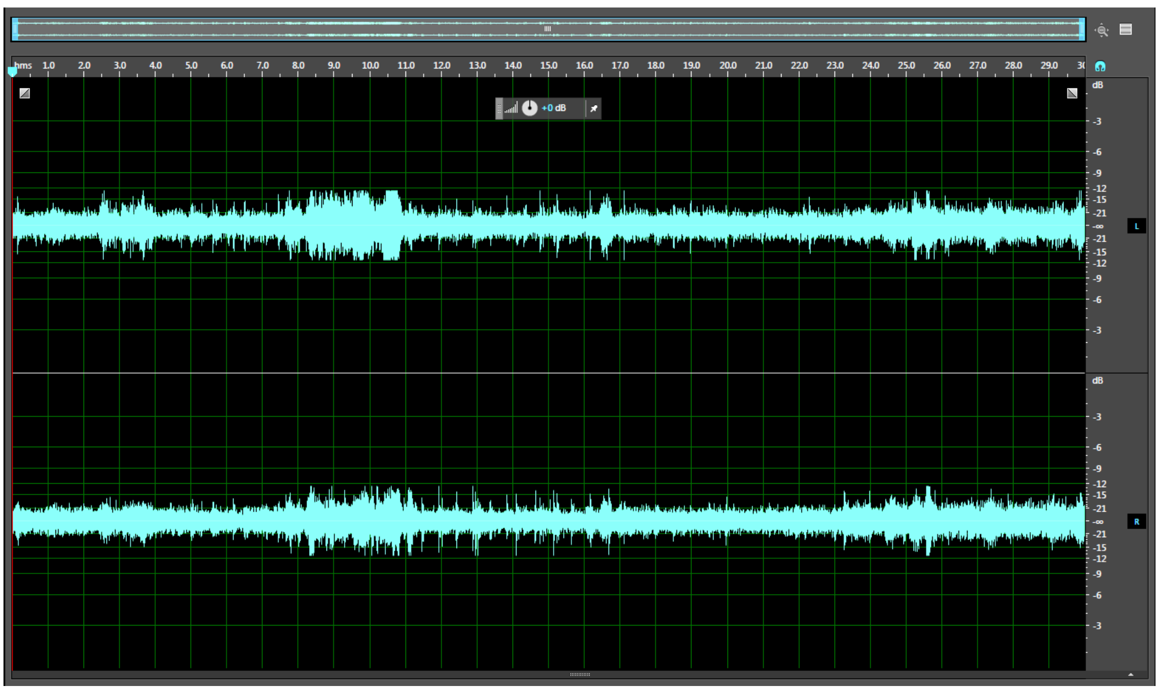

Figure 51: Perceptual Test Item Creation – Example of Presented Audio File – Low Dynamic Range of Noise

Figure 52 displays an audio file test item designed to have a high dynamic range of noise. For this audio file, the original waveform was not limited as before, but the individual peak events were accentuated, raising these levels to the highest possible values without distortion. Also, the 'quiet' sections had the volume lowered in specific time intervals. This resulted in the widest possible range of dynamic noise from these simulated hospital soundscapes, and thus represented an environment with a significantly varied range of sound levels. Once again, overall average levels were adjusted to make each test item LA_{EQ} values equivalent with all other audio file test items.

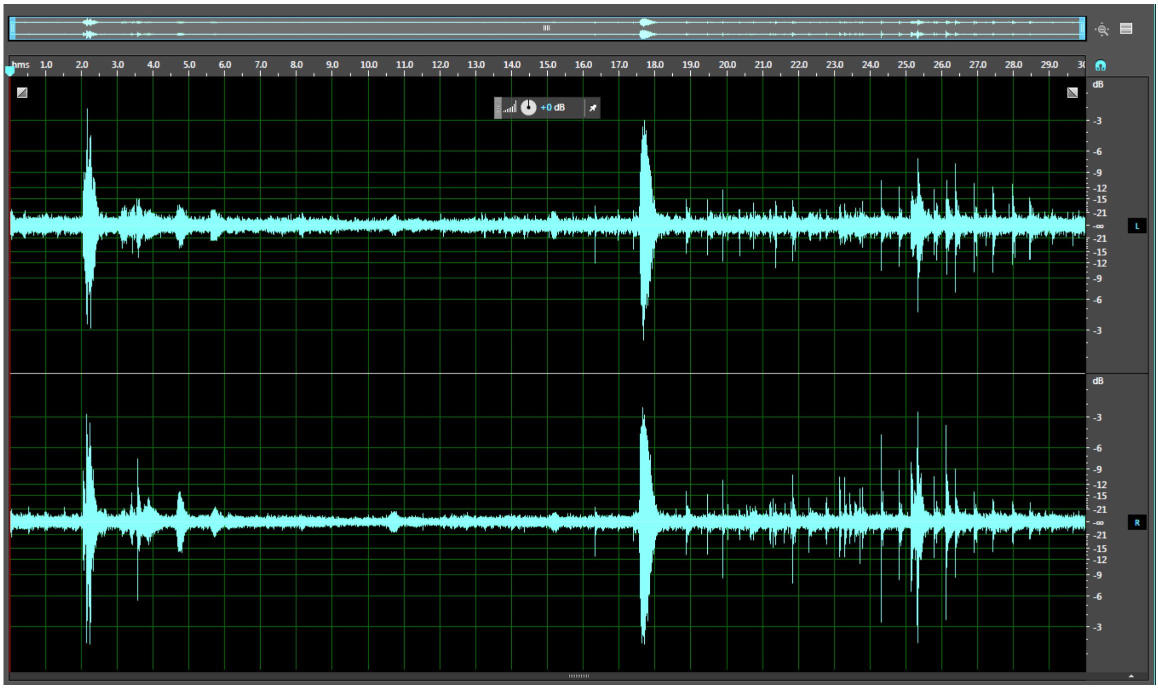

Figure 52: Perceptual Test Item Creation – Example of Presented Audio File – High Dynamic Range of Noise

To quantify the differences between the created audio files, each test item was played through the same speaker system, using the same level parameters. Each audio file was measured with a sound level meter for the 30-second duration of the file, using a 1-second sampling interval. Using this methodology, the overall LA_{EQ} levels for each audio file were normalized to within one decibel of 65 dBA. The 15 test item audio files were analyzed for their LC_{PEAK} Occurrence Rate ranges, with the goal of ultimately producing a wide spectrum of values. Table 10 shows the 15 test items, along with their measured LA_{EQ} and Occurrence Rate ranges. The LC_{PEAK} Occurrence Rate ranges were highlighted, as these were how the dynamic range of noise was quantified. From this data, six groupings (labeled as Occ Group A – F) were formed based on the measured Occurrence Rate ranges: red for audio files with a low dynamic range of noise, yellow for a high dynamic range.

Table 10: Perceptual Test Item Creation – Audio File Acoustical Verification Data

			Occurrence Rate Range (dB)				
Audio Order	Occ Group	2016	LAeq	LAmin	LAmax	LApk	LCpk
HS 3 - 1 - 1	E	65.6	20.0	13.0	23.0	28.0	24.0
HS 3 - 1 - 2	E	65.2	23.0	10.0	26.0	29.0	26.0
HS 3 - 1 - 3	F	65.5	22.0	27.0	27.0	29.0	25.0
HS 3 - 2 - 1	F	65.1	26.0	14.0	29.0	29.0	29.0
HS 3 - 2 - 2	D	65.5	17.0	31.0	22.0	26.0	23.0
HS 3 - 2 - 3	B	64.7	10.0	25.0	15.0	13.0	11.0
HS 3 - 3 - 1	D	66.1	17.0	31.0	21.0	27.0	24.0
HS 3 - 3 - 2	C	65.7	12.0	29.0	15.0	22.0	18.0
HS 3 - 3 - 3	B	65.6	13.0	34.0	14.0	14.0	13.0
HS 3 - 4 - 1	A	64.9	10.0	32.0	10.0	10.0	8.0
HS 3 - 4 - 2	D	64.8	17.0	29.0	19.0	22.0	21.0
HS 3 - 4 - 3	C	64.9	10.0	28.0	13.0	17.0	14.0
HS 3 - 5 - 1	A	65.1	7.0	29.0	9.0	8.0	7.0
HS 3 - 5 - 2	C	64.8	11.0	29.0	15.0	16.0	16.0
HS 3 - 5 - 3	B	65.2	8.0	16.0	11.0	12.0	9.0

Occ Group
A
B
C
D
E
F

The six groupings of audio file test items (A – F) each included two or three test item audio files and ranged between 7.0 dB for the LC_{PEAK} Occurrence Rate range (for group A) to up to 29.0 dB (for group F). Each grouping was separated by about 4 – 5 dB, creating a smooth sampling across a wide dynamic range of noise. Groupings E and F were more closely bunched due to audio editing limitations, with slight overlap between the second and third audio file (the LC_{PEAK} values for these audio files were actually reversed during the item creation process). The LC_{PEAK} levels (as opposed to LA_{MIN} levels) were the controlling factor in determining the LC_{PEAK} range, as this found to be a more effective way to create the audio files. These groupings were utilized in determining the order of presented test items, with the desired intention to equally distribute all audio file groupings throughout the testing procedure. (Described below in section 5.2.7)

5.2.3 Verification of Measurement Methods

One important step in the verification process in assessing the efficacy of these perceptual tests was the establishment of comparable data between sound level time history measurements using different sampling times. Most acoustical measurements collected in real environments utilize a sampling time of 1-minute (as was the case in Phase I & II). Because the audio files used in the perceptual tests were less than one minute, a shorter sampling time was necessary to evaluate the acoustical properties of the test item audio files. Therefore, two small tests were conducted to determine the relationships between sound level meter measurements using different sampling times: one in a testing chamber using simulated noise soundscapes and one in a public gym.

Figure 53 shows the testing setup within the isolated testing chamber using three sound level meters positioned with the microphone capsules as close together as possible. A simulated soundscape audio file (not one used in the perceptual tests) that was approximately 30 minutes long was measured for the entirety of its duration. The sound level meters were setup using five different sampling times: 1s, 5s, 10s, 30s, and 60s. The procedure was repeated to measure the additional sampling times.

Figure 53: Perceptual Test Item Creation – Audio File Acoustical Verification Setup

Figure 54 displays the results for the LC_{PEAK} Occurrence Rates across five different sampling times from the sound level meter measurements in the test chamber. All five measurements have very similar Occurrence Rate profiles, i.e. how they transition from 100% to 0% on the graph. The primary differences were in the absolute levels of LC_{PEAK} Occurrence Rates between the five sampling times: the 1-second sampling time data showed much lower values than the 60-second sampling time data. This was not unexpected, as the 60-second sampling times would have one data point during this time span (as opposed to 60 data points for the 1-second sampling time). As this metric was determined by peak levels, by definition these longer sampling times would produce levels greater than shorter sampling times.

Of note was the lack of smoothness found in the 30 and 60-second sampling times. This was due to the simulated soundscape audio file, which included repeated sections of around 5 minutes. This created sections of identical measurements from the sound level meters, and as there were a limited number of data points available for the longer sampling times, a more stepped graph of LC_{PEAK} Occurrence Rate ranges was generated.

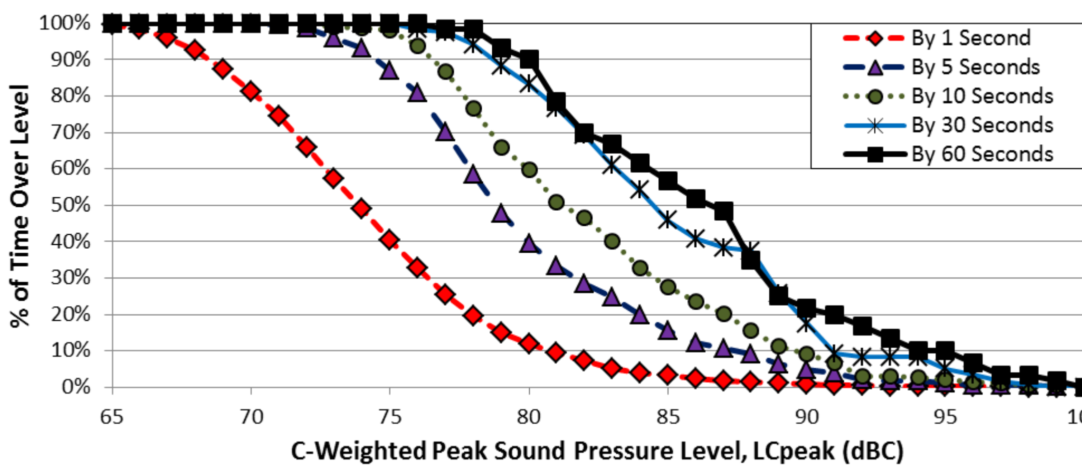

Figure 54: Perceptual Test Item Creation – Audio File Verification Data – Sample Time Analysis – Test Chamber Occurrence Rates

The important finding from this test was the continuity between LC_{PEAK} Occurrence Rate ranges measured for the five different sampling times. The values for LA_{EQ}, LA_{MIN}, LA_{MAX}, and LC_{PEAK} ranges are shown in Figure 55. LA_{EQ} and LA_{MIN} Occurrence Rate ranges were found to vary considerably between the five sampling times (LA_{EQ} values between 9 dBA and 22 dBA and LA_{MIN} values between 10 dBA and 15 dBA). LA_{MAX} ranges varied less (between 22 dBA and 26 dBA) than the prior two metrics, but still showed measureable discrepancies between the different sampling times. The LC_{PEAK} ranges displayed the most similar spread (only 3 dBC) between the five sampling times, corroborating the metric's usefulness in assessing the dynamic range of noise.

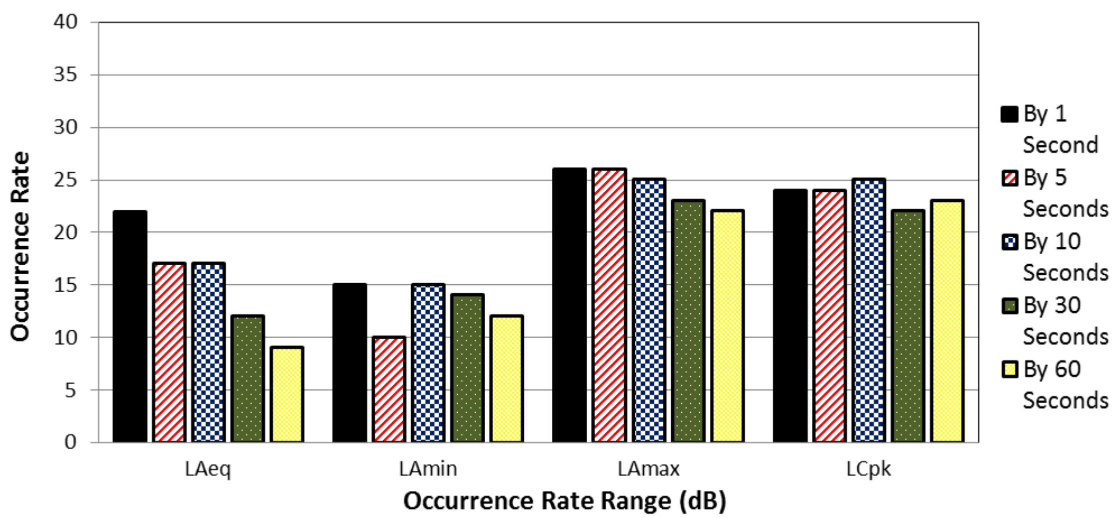

Figure 55: Perceptual Test Item Creation – Audio File Verification Data – Sample Time Analysis – Test Chamber Acoustical Metrics

To further verify these findings, a second test measurement was conducted in a real environment for a longer duration. Three sound level meters were used to measure the ambient conditions within a local gym: the specific environment was somewhat irrelevant to this analysis; it simply needed to have numerous impulsive noise events. As before, a selection of sampling times was used on the three different meters: 1s, 5s, and 60s. Figure 56 shows the results from these testing procedures, with the LC_{PEAK}

Occurrence Rates plotted for the three different sampling times. As before, the absolute level between the three measurements was different, but the overall shape of the graph remained very similar. Consequently, the LC_{PEAK} Occurrence Rate ranges were nearly identical between the three measurements, with only a 1 dB difference found. These results confirmed the findings from the first round of tests using the simulated soundscapes that LC_{PEAK} Occurrence Rate ranges remain consistent between sound level measurements using different sampling times.

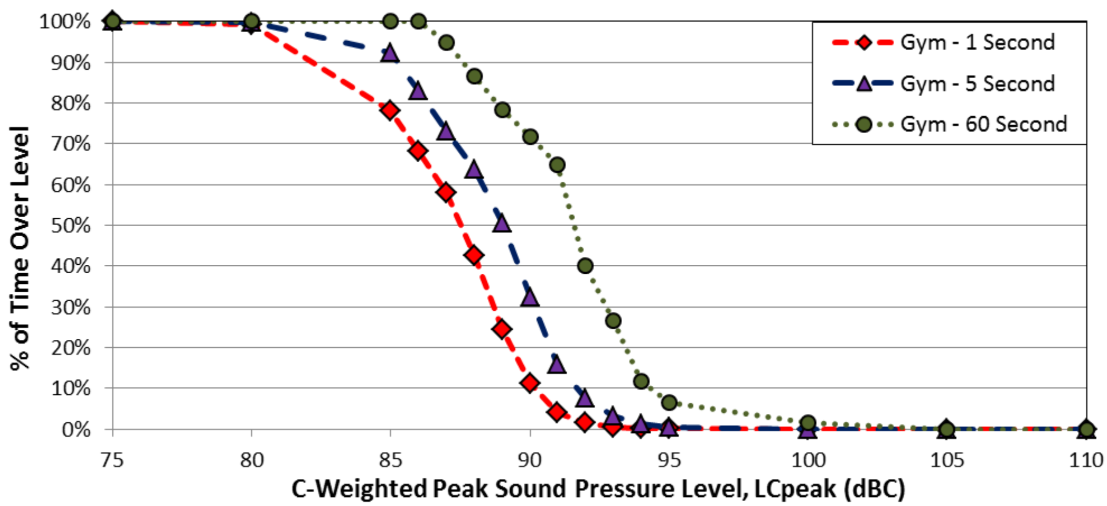

Figure 56: Perceptual Test Item Creation – Audio File Verification Data – Sample Time Analysis – Gym Occurrence Rates

In completing these two small tests, it was confirmed that LC_{PEAK} Occurrence Rate ranges remain consistent between sound measurements using different sampling times. Therefore, it can be assumed that findings from the subjective perceptual tests (which used a 1-second sampling time) would be relatable to the LC_{PEAK} Occurrence Rate range findings from the Hospital U1, R1, & R2 (which used a 60-second sampling times). The test item audio files were also created with LC_{PEAK} Occurrence Rate ranges similar to those measured in the hospital environments, providing another comparable element between the datasets. The goal was to create a subjective perceptual test, the findings from which could be applied to realistic hospital settings. By these tests, it was at least verified that the methodologies used in measuring the dynamic range of noise and the subsequent audio file item creation were analogous between the simulated audio files presented to subjects and real measured soundscapes.

5.2.4 Test Item Verification

With the test item audio file creation complete, the presented audio files required measurement within the testing chamber utilized in the perceptual tests. A similar setup as shown in Figure 53 was used in the test item verification process, only using one sound level meter. The 15 presented audio files were measured for the duration of the 30-second timeframes, using a 1-second sample time. The data measured in this process can be found in Table 55 of Appendix C. Of note were the very consistent LA_{EQ} levels (less than 1 dBA difference between test items) and the measured LC_{PEAK} Occurrence Rate ranges. The LA_{MIN} and LC_{PEAK} values were each found to have an approximate spread of 10 dB between the 15 test items, which indicated a relatively equal importance of minimum and peak levels dictating the resulting LC_{PEAK} Occurrence Rate ranges. This was slightly different from Phase I data, where only minimum sound levels controlled the LC_{PEAK} Occurrence Rate ranges. These measured values were the acoustical metrics ultimately correlated with subject annoyance data (including LA_{MIN} with and without the first second of data).

5.2.5 Testing Setup & Interface

The subjective perception testing was conducted at the University of Nebraska Acoustic Listening Laboratory, located in the Peter Kiewit Institute in Omaha, Nebraska. The room was isolated and windowless with approximately 150 sq. ft. of floor area. With minimal background noise and few distracting elements, it allowed subjects to concentrate on the given tasks, namely listening to auditory stimuli. The space also had multiple absorptive elements, including two corner bass traps, wall absorption panels, and acoustical ceiling tiles to control room reverberation. The room was appointed with a centrally located chair, a computer monitor, and several different speaker setups. Figure 57 shows the testing chamber used in the subjective perceptual tests. Subjects were instructed to maintain positioning within the room to ensure all subjects experienced the same acoustical conditions. The speakers shown in the photo were used in the presentation of the audio file test items, reproducing the simulated hospital soundscapes in stereo. The subjects then utilized the wireless mouse and graphical computer interface to operate the testing program and input annoyance perception ratings.

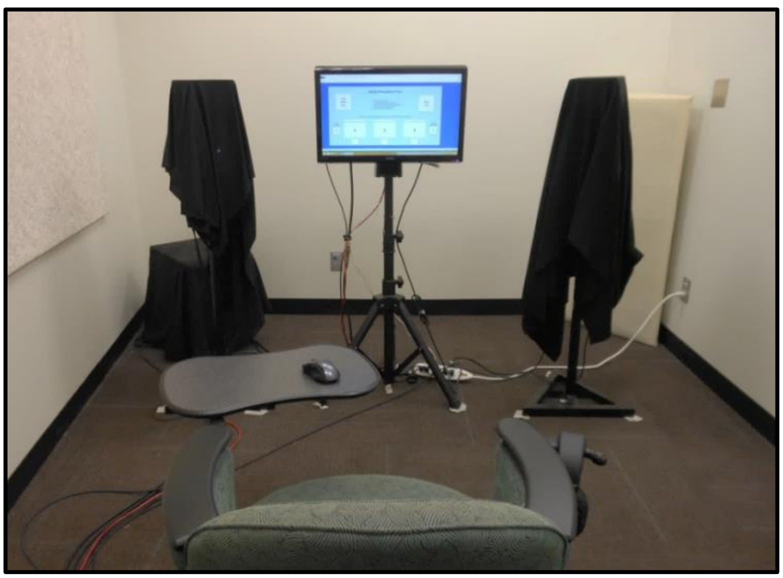

Figure 57: Perceptual Test – Nebraska Acoustics Listening Laboratory

Figure 58 displays the graphical user interface that was presented to subjects in the perception trials. The layout was quite simple in design to minimize any confusion of participants. The users were presented with two buttons and a slider: Play Audio Files, Next Test, and a slider ranging from 1 to 7. One corresponded to the ‘Not annoying at all' response, whereas seven corresponded to the 'Unbearably annoying' response. The subjects were instructed to press the Play Audio Files button when ready, beginning the 30-second audio file test item. They were instructed to rate how annoying they found the presented audio file, based on the range of annoyance response options given.

The program was designed in such a way to force subjects to listen to the entire audio file before moving on to the next test item, and they could not listen to the audio files a second time. Once the Next Test button was pressed, the answer chosen by the subject was recorded and the program would move on to the next trial with a new audio file. Error correction measures were also built into the program to ensure that the audio files could not be played twice or that the Next Test button could not be selected until an annoyance rating had been made.

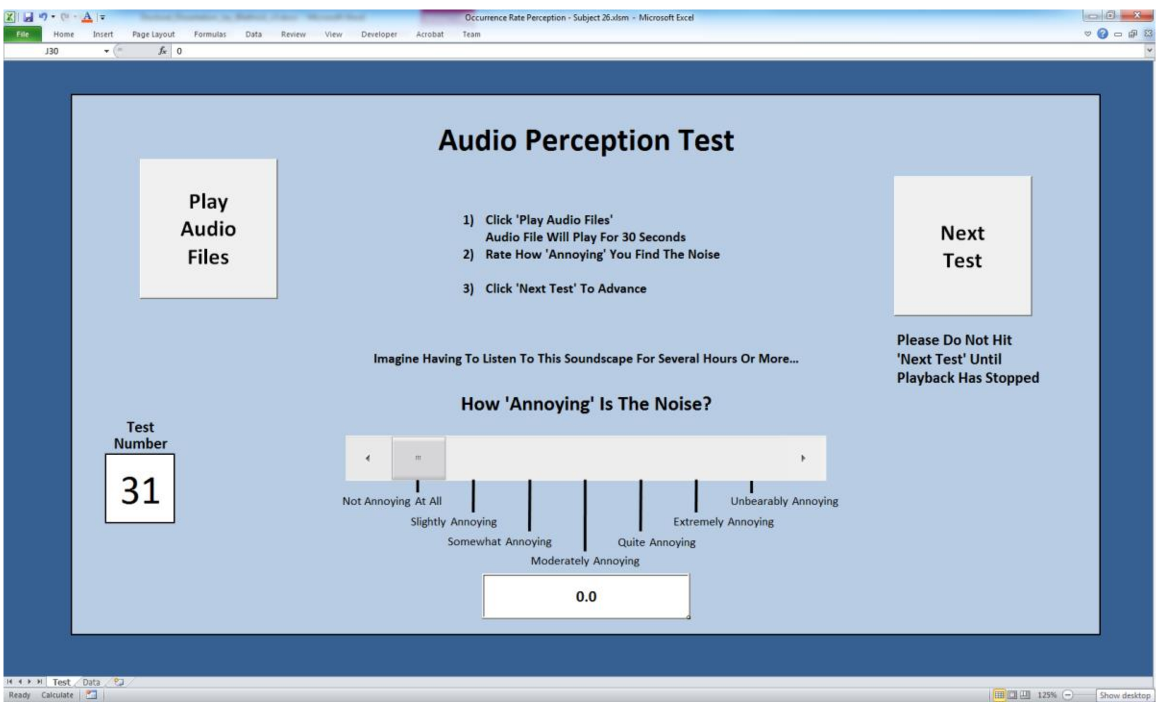

Figure 58: Perceptual Test – Subject Computer Interface

The data generated by the Excel graphical user interface worksheet was tables listing all of the trials completed by the subject for the given tests, the order in which the trials were presented, the audio files used for each presentation, and the annoyance rating made by the participant. This collection of data made it very easy to determine how well each subject performed on the tests and allowed the data to be quickly transferrable to the master data spreadsheet, which compiled the results for all testing subjects into a single file for analysis.

5.2.6 Pilot Tests

An initial round of subjective perceptual tests was completed for a limited number of participants to identify any problems with the testing procedures. The results of these pilot tests were very beneficial to the selection of the test item master audio file, the manner in which the presented audio files were manipulated, and the order in which the testing commenced.

The initial setup of the perceptual test included three different master audio files that were used to create the audio files presented in the tests, before the consequences of these decisions were understood. By adding a second set of audio files, an entirely separate group of subjects would have been required, something that was not logistically feasible. Therefore, a single master audio file was selected, and the pilot tests illuminated which audio file would produce the ‘best’ results. In this instance, the term ‘best’ meaning that the average perception of the audio files landed around the midpoint of the scale (4 on the 1 to 7 scale) with a wide distribution of responses. Two of the master audio files were found to be perceived consistently as very annoying (lots of 6 & 7 responses) in the pilot tests. Because of these results, these two master audio files were removed from the perceptual test procedures. The third master audio file was found to have an average annoyance rating of between 3 and 4, with plenty of variance in responses, so it was selected for use in all subjective testing from this point on.

The pilot tests also identified the importance of minimizing the magnitude of audio editing used on the test item audio files. If too many ‘effects’ were used to manipulate the presented audio files, distortions were generated that could be heard by subjects. It was therefore important to limit the amount of audio editing used to create the test items, while still trying to maximize the spread of LC_{PEAK} Occurrence Rate ranges: not an entirely easy thing to do.

Also, it was noticed that the ordering of presented test items was a factor in subject responses in the pilot tests. When test items of similar LC_{PEAK} Occurrence Rate ranges or audio content were presented sequentially, the effects were noticeable to subjects as a distracting element, and subsequently it was possible that the perception of those particular items could change. In all, the pilot tests were very useful in identifying several testing factors that would have detrimentally altered the perceptual testing.

5.2.7 Test Item Order

Using knowledge of the item construction and multiple iterations of pilot testing eventually led to a much more reliable and valid test, by indicating which audio sources and ordering methods would more likely produce good data. It was found that sequentially presented test items which were similar in content (being clipped from similar timeframes in the master audio file) elicited different responses than otherwise found. Similarly, sequential test items with equivalent LC_{PEAK} Occurrence Rate ranges were found to exacerbate subject annoyance responses. Clearly, a methodology to randomize the presented tests items was required to ensure a consistent distribution of audio files throughout the tests.

This process began by identifying the test item audio files and dividing them into groups which could be distributed. Table 11 displays the 15 test items, ordered from 1 to 15 as they appeared on the master audio file. In addition to noting the temporal location of each audio file, the LC_{PEAK} Occurrence Rate range was listed as well. These values translated into the creation of six groupings of Occurrence Rate ranges: identified A – F originally in Table 10. Together, the temporal identification and the dynamic range of noise assessments were combined to determine the perceptual tests item ordering.

The ordering was chosen in a pseudo-random fashion, with the goal of equally dispersing items throughout the test, using both temporal and dynamic level measures. The method of ordering chosen was a cycle, using a four item skip for the first 15 test items and a five item skip for the second 15 test items. Table 12 shows the final test item ordering used for the subjective perceptual tests. For example, the sequence started with audio file 1, and then went to 5, 9, and 13. The cycle then began again at 2, 6, and so on. Since there were only 15 test item audio files available, and the overall subjective perceptual test length was intended to be twice the duration, the same 15 test item audio files were reordered and presented a second time. For this sequence, a five test item skip was selected, resulting in a cycle of 1, 6, 11, 2, 7, and so on. This ordering ensured a different orientation than the first cycle presentation, while maintaining a significant distance between identical test item audio files. Each subject began their test at a different starting point in the sequence, using a Latin Square Design implementation. The results from these ordering procedures created a subjective perceptual test that minimized errors caused by item creation or test construction, and maximized the potential to measure meaningful data from subject annoyance responses.

Table 11: Perceptual Test Items – Audio Order & Associated Occurrence Rate Ranges

Item Index	Audio Order	Occurrence Rate Range	Occurrence Rate Group
1	1-1	24	E-1
2	1-2	26	E-2
3	1-3	25	F-1
4	2-1	29	F-2
5	2-2	23	D-1
6	2-3	11	B-3
7	3-1	24	D-2
8	3-2	18	C-1
9	3-3	13	B-2
10	4-1	8	A-1
11	4-2	21	D-3
12	4-3	14	C-3
13	5-1	7	A-2
14	5-2	16	C-2
15	5-3	9	B-1

Table 12: Perceptual Test Items – Example of Presented Order to Subjects

1	5	9	13	2	6	10	14	3	7	11	15	4	8	12
1	6	11	2	7	13	4	9	14	5	10	15	8	3	12

5.2.8 Additional Perceptual Survey Measures

In addition to the perceptual testing of annoyance ratings, external measures of noise on subjects were also explored. First, subject affect was identified as a potential way of quantifying the effects of listening to 30 minutes of hospital noise on subjects. The Positive and Negative Affect Scale (PANAS) [91] was chosen to measure subject affect due to its strong reliability and validity, as well as the speed of administration. The

PANAS survey included 20 words describing different emotions, such as interested, upset, inspired, or nervous. (Table 57) Subjects were instructed to rate how strongly they felt these emotions on a five point scale, from very slightly / not at all to extremely. The same survey was administered immediately before listening to the audio files and after as well, so subjects were instructed to rate the emotions 'At this moment' when filling out the PANAS form. This allowed a comparison between before and after listening to the test item audio files, determining any differences to be found.

The PANAS form produced two values: positive and negative affect scores. Positive affect scores were calculated using PANAS items 1, 3, 5, 9, 10, 12, 14, 16, 17, and 19, with higher scores representing higher levels of positive affect. The average subject affect reported in prior testing was 33.3 (SD ± 7.2). Conversely, negative affect scores were calculated using PANAS items 2, 4, 6, 7, 8, 11, 13, 15, 18, and 20, with lower scores representing lower levels of negative affect. The average subject affect reported in prior testing was 17.4 (SD ± 6.2). [91] For each perceptual test subject, a positive and negative affect score was generated for both pre and post-test time periods. Therefore, individual correlations were completed for both PANAS scores, providing clues as to the impact of hospital noise on subject affect.

The PANAS questionnaire was not the only external measure utilized in the procedures of the subjective perceptual tests. Subject heart rate was also monitored for approximately half of the subjects who participated in the tests. A pulse oxiometer (fingertip pulse monitor) was used on consenting subjects by placing the monitor on the non-dominant middle finger before entering the testing chamber. The oxiometer was wirelessly connected, so the data from the unit was recorded on the lab computer automatically for the entire testing duration. Once testing was completed, the oxiometer was removed from the finger of the subject and the data were downloaded. The data produced was a record of heart rate activity throughout the perceptual tests, and these measurements indicated whether a physical reaction occurred in subjects while listening to the hospital noise for 30 minutes.

It should be noted that several factors precluded a detailed analysis of the heart rate data. First, approximately half of all subjects had their heart rates monitored. Some subjects declined to use the oxiometer, whereas for the initial subjects the device was not available until the fourth subject due to shipping issues. Also, the data produced by the specific oxiometer utilized was not detailed enough to accurately assess subject heart rate on a second-by-second basis, which decreased the analysis capabilities. These factors did limit the analysis of the subject heart rate data, but as this was a tertiary measure of the impact of hospital noise on subjects, the lack of a full dataset was not deemed significant.

Test Subject Demographics

5.3.1 Testing Procedures & Subject Selection

The subjective perception testing procedure began with subjects reading and signing the Informed Consent document, described in the IRB section above, which detailed the steps involved in the testing. They then filled out the subject questionnaire asking their age, gender, and noise sensitivity, as well as the first PANAS form. Next, the subjects took a hearing screening to ensure that they had hearing thresholds less than 25 dB HL. This was completed using the UNL hearing threshold test equipment in the controlled environment of the laboratory testing chamber where background noise was very low. In this procedure, subjects heard pure tones at frequencies between 125 Hz and 8000 Hz starting at 0 dB HL. The level was raised until they could hear the tones, at which point they would press the supplied trigger button. This was completed on both ears to ensure participants had 'normal' hearing before testing proceeded.

Once the hearing screening was passed, subjects moved on to a set of preliminary tests, which was a set of 12 test item audio files using the testing interface described above. The purpose of this grouping was to allow subjects to familiarize themselves with the subjective testing methodology, the interface being used, and the types of auditory stimuli that would be employed. The results from these tests were recorded but not included in the final data assessment. The hearing screening and the preliminary testing procedure, along with the signing of paperwork, was completed in the first 10 to 15 minutes of the testing session.

After subjects were familiarized with the process of the perception testing, the primary acoustic test items were presented. The primary tests were approximately 15 minutes long, and were comprised of 30 individual test items. The final step in the perceptual tests was the second PANAS form, administered after listening to and rating the annoyance of the audio files. This resulted in a total testing time of around 30 minutes, which seemed to be a good duration for the subjective perception testing, as sitting and concentrating for any longer became tiresome for most subjects. After completing the session, the participants were paid for their time with a $10 Amazon gift card and asked to sign a release form stating they received payment. Finally, answers provided by each subject were assimilated into the master spreadsheet of subjective perception testing data where they were analyzed with the entire dataset.

The subjects recruited for the study (using flyers distributed around campus) were any individuals with ‘normal’ hearing, identified by having hearing thresholds less than 25 dB HL between 125 Hz and 8000 Hz. No delineation was made for age or gender, although a roughly even split between genders was desired (and achieved). Also, while noise sensitivity was measured as part of the demographic questionnaire, these values were only utilized in post-testing analyses, and not used in subject grouping. A total of 33 participants were tested in the study, providing a sufficient subject pool to achieve adequate statistical power in the analyses. Two subject groups were formed using two different levels of test item audio files: 65 dBA and 55 dBA. Each group included 15 subjects, randomly selected from the overall subject pool. Three subjects were eliminated due to response acquiescence (judging all test items as ‘not annoying at all’).

5.3.2 Subject Pool Demographics

Three simple demographic questions were asked during testing for comparative purposes: age, gender, and noise sensitivity. Table 13 displays the demographic information for all subjects in the study. The gender split was 16 male and 14 female, with the age range from 19 to 56 and a 25.5 year average. A significant number of subjects were college students from both undergraduate and graduate levels, but numerous non-university subjects were also tested. The noise sensitivity rating was measured using the Weinstein Noise Sensitivity [87] short-form scale (Table 56), which included 10 questions quantifying the sensitivity to noise for each subject. The noise sensitivity questionnaire found a minimum value of 24, a maximum value of 52, and an average rating of 40.8 for all subjects. Indicated below are the subject placement into 65 dBA and 55 dBA testing groups. As can be seen, no specific ordering system was employed to place subjects into groups.

Table 13: Perceptual Test Data – Subject Demographics – All Subjects

Demographics	Subject ID																
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Gender	F	F	F	M	F	M	F	F	M	M	M	M	M	M	M	M	M
Age	26	20	19	21	19	27	25	26	24	20	19	24	29	25	23	19	25
Noise Sensitivity	46	29	34	38	49	38	35	51	45	28	46	39	46	44	40	35	47
Testing Group	65	65	65	X	55	55	55	65	X	X	55	65	65	65	55	55	55

	18	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**
Gender	M	M	F	F	M	M	M	F	F	M	F	M	F	F	F	M
Age	28	23	24	20	21	21	25	21	29	56	23	29	29	20	26	35
Noise Sensitivity	45	45	24	40	32	52	40	45	45	46	47	40	48	37	41	33
Testing Group	65	65	55	55	55	55	55	65	55	55	55	65	65	65	65	65

Overall Totals	
Gender	
Male: 16	**Female: 14**
Age	
Min: 19	**Max: 56**
Average: 25.5	
Noise Sensitivity	
Min: 24	**Max: 52**
Average: 40.8	

5.3.3 65 dBA Group Demographics

Because the 65 dBA and 55 dBA testing groups were comprised of completely different test item audio files, the subject groups needed to be wholly separate from one another. Table 14 shows the aggregated demographic data for the 65 dBA testing group. The split between males and females was as close as was possible: seven male versus eight female. The age range was slightly condensed, with a minimum of 19, a maximum of 35, and an average subject age of 25.3 years old. Noise sensitivity was consistent between the 65 dBA subject grouping and the overall pool of subjects, having a range of 29 to 51 and an average noise sensitivity of 41.5.

Table 14: Perceptual Test Data – Subject Demographics – 65 dBA Testing Group

Gender	
Male: 7	Female: 8

Age	
Min: 19	Max: 35
Average: 25.3	

Noise Sensitivity	
Min: 29	Max: 51
Average: 41.5	

5.3.4 55 dBA Group Demographics

Table 15 shows the aggregated demographic data for the 55 dBA testing group. The split between males and females was larger in this testing group: nine male versus six female. The age range was also larger, with a minimum of 19, a maximum of 56, and an average subject age of 25.1 years old. Once again, noise sensitivity was consistent between the 55 dBA subject grouping and the overall pool of subjects, having a range of 24 to 52 and an average noise sensitivity of 41.1.

Table 15: Perceptual Test Data – Subject Demographics – 55 dBA Testing Group

Gender	
Male: 9	Female: 6

Age	
Min: 19	Max: 56
Average: 25.1	

Noise Sensitivity	
Min: 24	Max: 52
Average: 41.1	

Of note was the similarity in demographic information between the 65 dBA and 55 dBA testing groups. This was desired in the testing procedures, but as the data were collected during the tests and not analyzed until after, there was no way of predicting the demographic differences between the two testing groups. As it turned out, the age difference between the 65 dBA and 55 dBA testing groups was only 0.2 years and the noise sensitivity difference was 0.4 points. This was a remarkably small discrepancy, and a very fortuitous result. Because of these findings, both age and noise sensitivity were statistically insignificant and deemed equivalent on average between the testing groups, partially removing those variables in the analysis of the perceptual annoyance ratings of the subjects between the test groupings.

Subjective Perception Data

5.4.1 Individual Subject Data

The subjective perceptual listening tests produced subject annoyance ratings for all 30 test item audio files. Each 30-second test item audio file was rated on a 1 – 7 Likert scale, based on the question 'How 'annoying' is the noise?' The responses ranged from 'Not at all', 'Slightly annoying', 'Somewhat annoying', 'Moderately annoying', 'Quite annoying', 'Extremely annoying', to 'Unbearably annoying'. Each subject response was recorded sequentially so to evaluate any possible trends in subject response patterns. Figure 59 shows the response pattern for a subject picked at random. The rather random and chaotic responses were anticipated and desired. Based on the pseudo-randomization procedure of the test item order, the similarities of level and audio content were distributed throughout the test, so this type of 'messy' response pattern was expected. Because a vast majority of the subjects displayed similar randomized response patterns, the ordering procedure was deemed an acceptable step in the procedure.

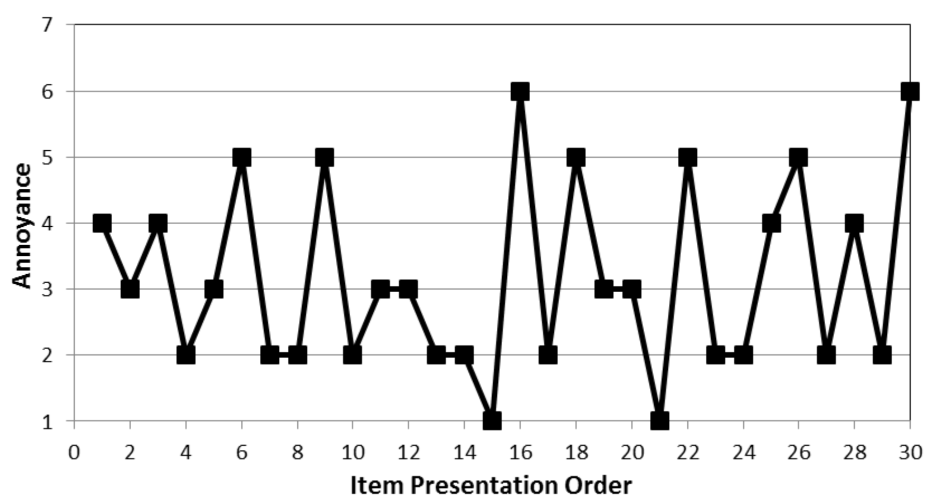

Figure 59: Perceptual Test Data – Example Subject Responses – Through Testing Cycle

Once the individual subject annoyance responses were collected from each test they were compared against the acoustical metrics of interest. For example, the LC_{PEAK} Occurrence Rate range was utilized to define the dynamic range of noise present in the 30 test item audio files. Figure 60 displays the comparison between annoyance responses from a single subject compared with the LC_{PEAK} Occurrence Rate ranges associated with the test items. For this subject, a clear correlation was found, with lower LC_{PEAK} Occurrence Rate ranges indicating lower annoyance ratings and higher ranges predicting higher annoyance ratings. This meant that for the example subject, a soundscape with a steady noise level was preferred over a soundscape with a wide range noise levels, as measured by the LC_{PEAK} Occurrence Rate ranges.

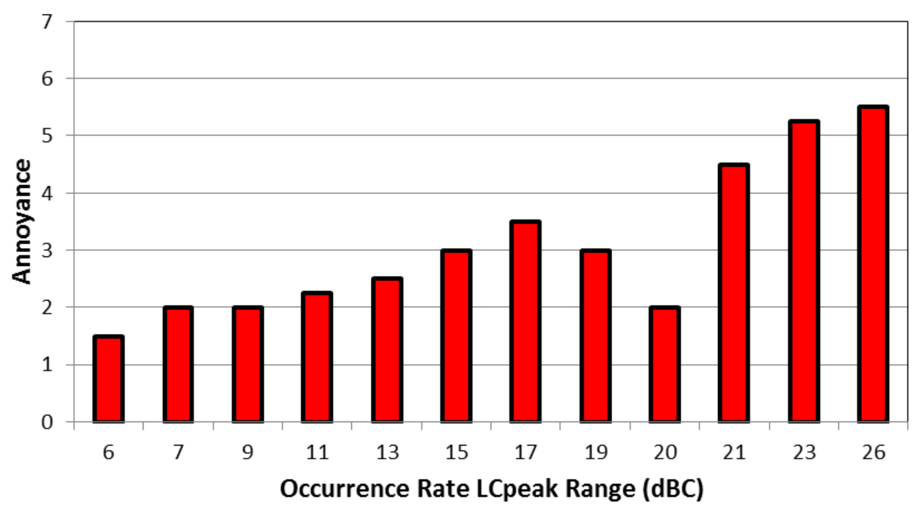

Figure 60: Perceptual Test Data – Example Subject Responses – Ordered By Test Item Occurrence Rate Range

The annoyance response data for each subject, along with associated test item audio file information, were ultimately transferred into a master spreadsheet for analysis. This resulted in the response data from 30 test items measured during the primary test and 12 test items measured during the preliminary testing procedures. For all analyses, the response data for the primary 30-item test comprised the subject pool: the preliminary testing data were not utilized.

5.4.2 65 dBA Testing Group Data

For the 65 dBA testing group, an overall average annoyance response of 3.9 was found. This was based on a range between 2.8 and 4.7 of average annoyance response by item. The general trend displayed in Figure 60 of increasing annoyance values with increasing LC_{PEAK} Occurrence Rate ranges remained consistent with the 65 dBA testing group and these values were found to be significantly correlated (detailed in section 5.5.1 and Figure 61).

5.4.3 55 dBA Testing Group Data

The average for all 15 subjects within the 55 dBA testing group was computed and an average annoyance response of 3.2 was found. The data ranged between 1.9 and 4.7 of average annoyance response by item, slightly larger than the 65 dBA testing group. As before, the trend of increasing annoyance values with increasing LC_{PEAK} Occurrence Rate ranges remained consistent. These values were also found to be significantly correlated (detailed in section 5.5.2 and Figure 63). Of note was the difference in average subject annoyance responses between the 65 dBA and 55 dBA testing groups, with the louder test item audio files eliciting the higher subject annoyance responses.

Based on the results of both the 65 dBA and 55 dBA testing groups, the test item creation, including master audio file selection and audio editing, were deemed acceptable. Both subject testing groups were found to have group means near the midpoint of potential response values (4.0 in this case) of 3.9 for the 65 dBA testing group and 3.2 for the 55 dBA testing group. Also, the range of subject responses were found to be large enough to generate comparable data, with ranges of 1.9 and 2.8 annoyance points found for the 65 dBA and 55 dBA testing groups, respectively. These results signified the creation of a valid testing procedure, producing comparable subject annoyance response values for audio files of varying dynamic ranges of noise.

5.4.4 PANAS Survey Results

The subjective perceptual testing procedures also produced positive and negative PANAS scores for each subject both before and after the listening portion of the test. Table 16 displays the minimum, maximum, and average subject response values for positive and negative PANAS scores before and after the listening tests. Included were difference scores calculated for both positive and negative PANAS scores. Table 58 in Appendix C displays the individual subject responses for positive and negative PANAS surveys for before, after, and difference values. An average positive PANAS score before the test was found to be 32.3 with the average after the test dropping to 25.3, for a negative difference of 7.03. The negative PANAS results showed similar, though less dramatic, reactions to the hospital soundscapes. Before listing to the test item audio files, an average negative PANAS score of 13.2, and rising to 15.1 after the listening portion, for a positive difference of 1.85. In both the positive and negative PANAS scores, subject affect was negatively affected by experiencing the hospital audio sounds and found to be statistically significant (detailed in section 5.5.6).

Table 16: Perceptual Test Data – PANAS Survey Results – Before, After, & Differences

	Before Totals		After Totals		Difference Totals	
Positive PANAS	Min: 16	Max: 50	Min: 12	Max: 42	Min: -18	Max: 6
	Average: 32.3		Average: 25.3		Average: -7.03	
Negative PANAS	Min: 10	Max: 20	Min: 10	Max: 26	Min: -6	Max: 11
	Average: 13.2		Average: 15.1		Average: 1.85	

Breaking down the overall subject testing group into the 65 dBA and 55 dBA individual testing groups revealed similar reactions between the two. Table 17 and Table 18 show the positive and negative PANAS response values the minimum, maximum, and average difference totals for the two testing groups from before and after the listing trials. A positive PANAS decrease was found for both 65 dBA and 55 dBA testing groups: 8.0 and 7.0 points lower, respectively. The louder 65 dBA testing group was found to have the larger positive PANAS decrease. For the negative PANAS differences, the quieter testing group was found to have a slightly larger increase in negative PANAS scores: 1.73 for the 65 dBA group and 2.53 for the 55 dBA group. This was a slightly unexpected result, but these response values were also similar enough to not be significantly different statistically.

Table 17: Perceptual Test Data – PANAS Survey Difference Results – 65 dBA Testing Group

Difference Totals

Positive PANAS	
Min: -16	Max: -1
Average: -8	

Negative PANAS	
Min: -6	Max: 11
Average: 1.73	

Table 18: Perceptual Test Data – PANAS Survey Difference Results – 55 dBA Testing Group

Difference Totals

Positive PANAS	
Min: -18	Max: 6
Average: -7	

Negative PANAS	
Min: -3	Max: 11
Average: 2.53	

5.4.5 Heart Rate Results

In addition to the annoyance response values and the PANAS survey results, heart rate monitor data were recorded for 18 subjects out of the overall subject pool. The oxiometer was unavailable for use for numerous subjects, and others chose not to have their heart rate monitored as described earlier. Table 19 displays the heart rate differences from before and after listening procedures, with more detailed heart rate data provided in Table 59 of Appendix C. It was found that an average heart rate increase of 0.5 bpm was found for subjects before and after listening. It was observed that the heart rate data produced by the oxiometer was very sporadic and lacking in high enough resolution to compare at specific times. A more accurately measuring oxiometer might have improved the heart rate monitoring results, but this unit was the only device available at the time of testing. Because of these shortcomings, and the lack of full subject participation, the heart rate monitoring was not analyzed further.

Table 19: Perceptual Test Data – Heart Rate Results – All Subjects

HR Difference	
Min: -5	Max: 7
Average: 0.5	

Subjective Perception Analysis

5.5.1 Correlations of Subjective Perception Data – 65 dBA Group

Once all subjective perceptual data had been compiled, comparisons between subject annoyance ratings and test item acoustical data were completed. Specifically, individual and group subject annoyance responses were correlated with the acoustical metrics associated with each test item. Test item acoustical data can be found in Table 55 of Appendix C. These comparisons were completed in two ways: first using linear regressions on the aggregated data and second by transforming the individual subject correlations and analyzing the transformed values. The analyses were completed independently for both the 65 dBA and 55 dBA subject testing groups.

The perceptual responses and measured acoustical data were first analyzed using linear regressions between the average subject annoyance responses and the test item acoustical data. Of primary concern were correlations between the LC_{PEAK} Occurrence Rate ranges of the test items, as this was the primary metric used to define each test item audio file. In the 65 dBA testing group, it was found that subject annoyance responses were positively and significantly correlated with LC_{PEAK} Occurrence Rate ranges ($F[1,14] = 4.29$, $p = 0.0138$). Figure 61 displays subject annoyance responses graphed against the test item LC_{PEAK} Occurrence Rate ranges with error bars showing one standard deviation. A steady increase in subject annoyance was found as the Occurrence Rate ranges rose. This indicated subjects perceived test item audio files with higher LC_{PEAK} Occurrence Rate ranges more negatively than those with lower ranges. In other words, subjects in this study preferred an acoustic environment that had a steadier noise level, as opposed to one with a wider dynamic range of noise as measured by LC_{PEAK} Occurrence Rate ranges.

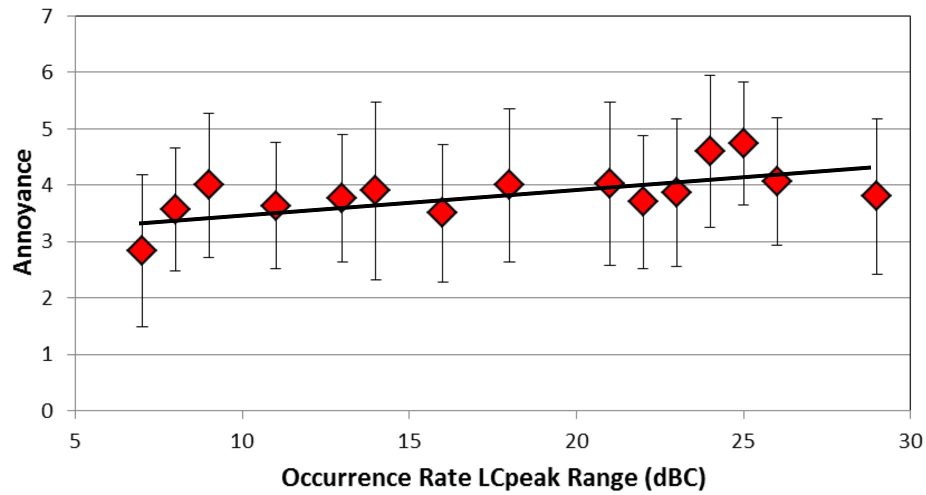

Figure 61: Perceptual Test Analysis – Subject Annoyance vs LC_{PEAK} Occurrence Rate Range – 65 dBA Testing Group

All other measured acoustical metrics measured for the test item audio files were linearly regressed against the subjective annoyance responses. It was found that many were significantly correlated, including LA_{MAX} ($F[1,14] = 3.76$, $p = 0.0229$), LA_{MIN} ($F[1,14] = 6.40$, $p = 0.0022$), and LC_{PEAK} ($F[1,14] = 3.76$, $p = 0.0228$). Figure 62 shows the comparison between subject annoyance responses and measured test item LC_{PEAK} levels. A similar trend was found as before with the LC_{PEAK} Occurrence Rate ranges, with subject annoyance increasing as measured LC_{PEAK} levels rose. This indicated that subjects were more annoyed by test items with louder peak level events than those with fewer loud sounds.

The continuity between the LC_{PEAK} Occurrence Rate range data and the measured LC_{PEAK} data were not surprising. In fact, all of the min, max, and peak metrics were intrinsically linked by the manner in which the test items were created. In other words, LC_{PEAK} Occurrence Rate range was positively and significantly correlated with LA_{MIN}, LA_{MAX}, and LC_{PEAK} metrics. Because the original (unedited) audio files were systematically manipulated in level to both minimize and maximize the LC_{PEAK}

Occurrence Rate ranges, these acoustical metrics were aligned for the test items. This meant that if one min, max, or peak acoustical metric was correlated with the subject annoyance responses, all of the metrics would be (as was found). Conversely, the LA_{EQ} values measured were not found to be significantly correlated with subject annoyance responses. As this variable was controlled in the test item creation process (with less than a one decibel difference between test items), this finding was expected.

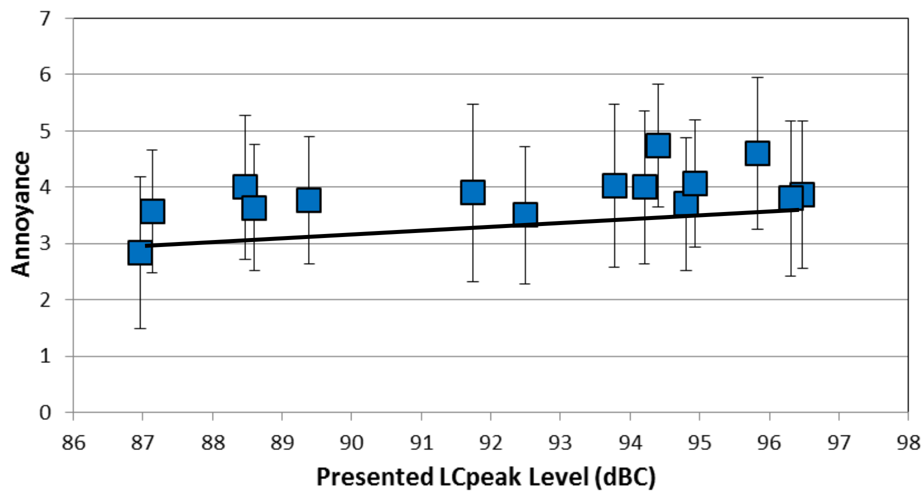

Figure 62: Perceptual Test Analysis – Subject Annoyance vs LC_{PEAK} Measured Level – 65 dBA Testing Group

The linear regressions between subject annoyance responses and the measured test item acoustical metrics provided a rough estimate for the correlation strength between the variables, but a more accurate method of analysis was needed to correctly quantify these strengths. To that end, a second method of statistical analysis was completed on the datasets. This method involved transforming the correlations between individual subject annoyance responses and the measured test item acoustical metrics, using Fisher's Z-Transformation. The transformed data were then tested to determine whether the new values were significantly different from zero. If a significant difference was found, it could then be concluded that subjective annoyance responses were correlated with the acoustical metric being tested.

When the annoyance responses for the 65 dBA subject testing group were transformed and correlated with test item acoustical data, many significant correlations were found. Full reporting of statistical correlations can be found in Table 62 of Appendix C. It was found that LC_{PEAK} Occurrence Rate ranges ($F[1,14] = 12.49$, $p = 0.0037$), LA_{MAX} ($F[1,14] = 8.81$, $p = 0.0109$), LA_{MIN} ($F[1,14] = 17.46$, $p = 0.0011$), and LC_{PEAK} ($F[1,14] = 9.83$, $p = 0.0079$) values were all significantly correlated with subject annoyance responses. These findings were consistent with the linear regression method of analysis, confirming the previous results. It was therefore concluded that the 65 dBA testing group perceived hospital soundscapes with a more varied dynamic range of noise more negatively than those with a more steady noise level.

5.5.2 Correlations of Subjective Perception Data – 55 dBA Group

The 55 dBA subject testing group was analyzed in the same manner as the 65 dBA testing group, both using linear regression analyses and by transforming the individual subject response data. The results of these statistical tests were very consistent between the 65 dBA and 55 dBA testing groups. When the subject annoyance responses for the 55 dBA testing group were correlated with measured test item acoustical metrics, significant correlations were found for LC_{PEAK} Occurrence Rate ranges ($F[1,14] = 5.36$, $p = 0.0052$) as well as levels for LA_{MAX} ($F[1,14] = 5.31$, $p = 0.0055$), LA_{MIN} ($F[1,14] = 7.29$, $p = 0.0011$), and LC_{PEAK} ($F[1,14] = 3.94$, $p = 0.0192$). Figure 63 and Figure 64 display the comparison between subject annoyance responses and the test item LC_{PEAK} Occurrence Rate ranges and measured test item LC_{PEAK} values, respectively. This again indicated that subjects preferred an acoustic environment that had a steadier noise level, as opposed to one with a wider dynamic range of noise.

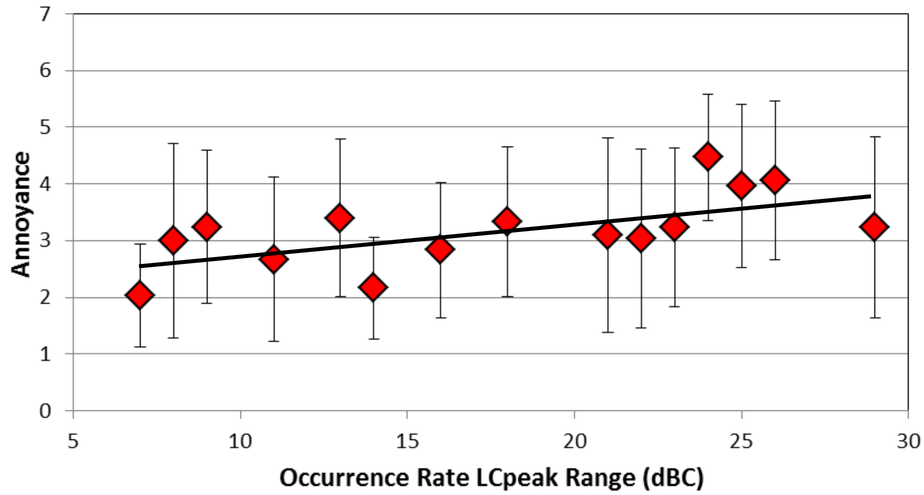

Figure 63: Perceptual Test Analysis – Subject Annoyance vs LC_{PEAK} Occurrence Rate Range – 55 dBA Testing Group

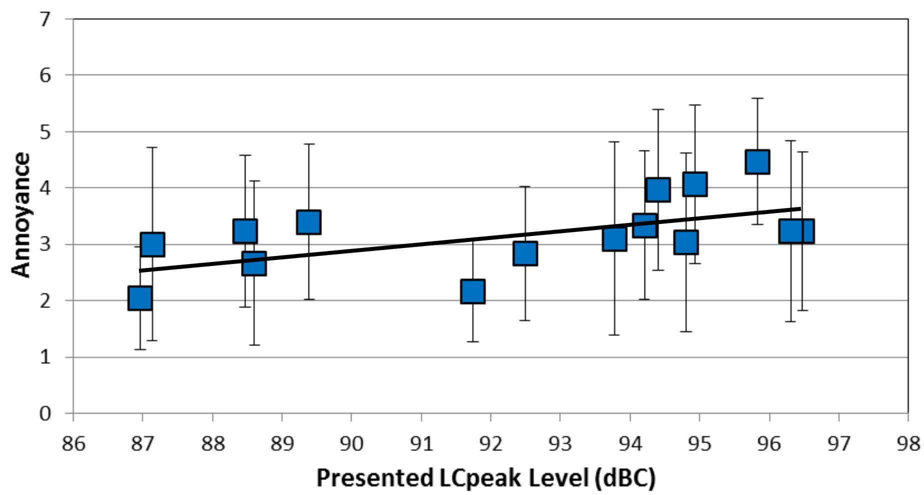

Figure 64: Perceptual Test Analysis – Subject Annoyance vs LC_{PEAK} Measured Level – 55 dBA Testing Group

The data for the 55 dBA subject testing group was also transformed and correlated with test item acoustical data. Full reporting of statistical correlations can be found in Table 63 of Appendix C. Very consistent results were found, with LC_{PEAK} Occurrence Rate ranges ($F[1,14] = 8.29$, $p = 0.0129$), LA_{MAX} ($F[1,14] = 10.13$, $p = 0.0072$), LA_{MIN} ($F[1,14] = 9.77$, $p = 0.0080$), and LC_{PEAK} ($F[1,14] = 5.59$, $p = 0.0334$) all being significantly correlated with subject annoyance responses.

5.5.3 Comparison Between 65 & 55 dBA Testing Groups

When the 65 dBA and 55 dBA were compared, statistical differences were found distinguishing subject annoyance responses with the level of presented test item audio files. On average, the 65 dBA testing group had an overall annoyance response of 3.9, while the 55 dBA testing group scored an average of 3.2. Table 64 displays the statistical tests completed relating subject annoyance responses with the associated 65 dBA or 55 dBA testing group. The basic one-way ANOVA model between the two testing groups found significant correlations ($F[1,29] = 4.99$, $p = 0.0337$) predicting higher subject annoyance with higher sound levels in presented hospital soundscapes.

In this basic model analysis, the responses from each subject were summed to generate their annoyance value, but this summation represented a within subjects design that needed to be accounted for statistically. Therefore, a one-way within-subjects ANOVA model was utilized to more thoroughly analyze the comparison between the 65 dBA and 55 dBA subject groups. Similar results were found as in the basic model, with the between-subjects component finding significant differences separating the two testing groups ($F[3,27] = 4.90$, $p = 0.0352$). The within-subjects component of the analysis found strong correlations ($F[3,27] = 7.06$, $p = 0.0001$), indicating individual subject responses were related to one another. This finding was not unexpected, but was necessary to account for in the statistical analysis. Primarily, because statistically significant results were found in both the basic ANOVA model and the within-subjects ANOVA model, it was concluded that as the level of hospital soundscapes presented to subjects increased, their annoyance ratings would increase as well.

Looking at the subject response data from the two testing groups graphically revealed some interesting patterns related to the statistically significant differences found. Figure 65 and Figure 66 show the response rates for the 65 dBA and 55 dBA testing groups, respectively. The difference between the overall group averages becomes immediately clear when looking between the two graphs. The 65 dBA testing group had a most common response value of ‘3’, although closely followed by ‘4’ and ‘5’. The number of responses outside these three values decreased sharply for the 65 dBA testing group. For the 55 dBA group, the dominant response value was ‘2’, with ‘3’ and ‘4’ also receiving numerous responses.

The graphical representations also show the near normal response distribution of the two datasets. The 65 dBA testing group was found to have a normal distribution, although a more precise testing scale (say using a 9 or 11 point Likert scale) would have likely presented an even better spread of data. The 55 dBA testing group was found to have a skewed distribution, indicating lower average annoyance values than would be normally distributed. Subject response values were distributed well throughout the breadth of the possible 7-point scale and the low level of the presented test item audio files were the cause of the data skew. Therefore the deviation from a fully normally distributed dataset for the 55 dBA testing group was disregarded. Similar to the 65 dBA testing group, though, using a testing scale with a higher precision would have likely created a more normalized dataset. There were simply too few response options for subjects to judge the test items with a higher degree of accuracy than was found.

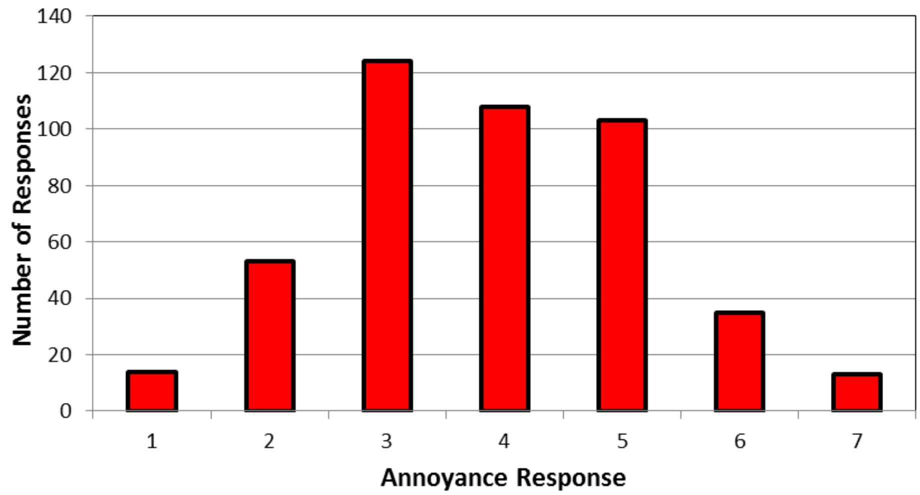

Figure 65: Perceptual Test Analysis – Subject Annoyance Response Rate – 65 dBA Testing Group

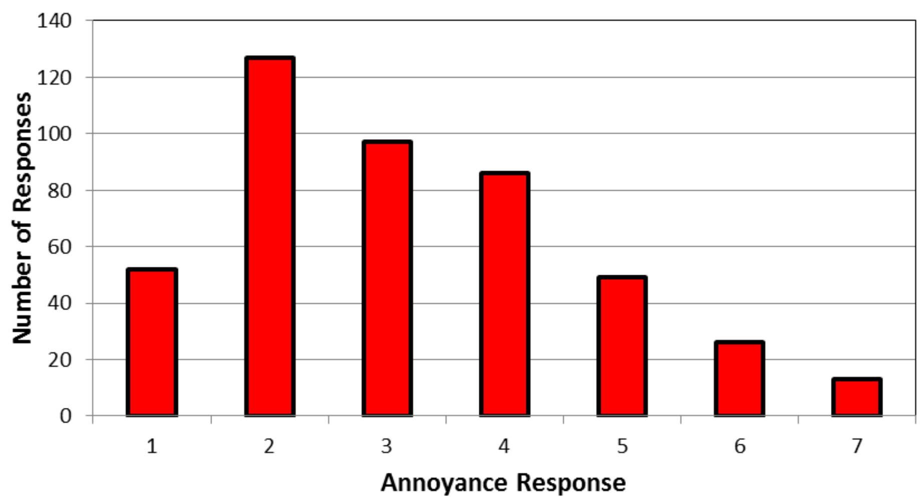

Figure 66: Perceptual Test Analysis – Subject Annoyance Response Rate – 55 dBA Testing Group

5.5.4 Subject Response Rate Over Time

One area of interest was how subject annoyance response rate changed over time as subjects took the test. If increasing or decreasing subject annoyance was found, this would have indicated that the experience of listening to the presented hospital soundscapes had a more significant impact the longer it was listened to. Both the 65 dBA and 55 dBA testing groups were analyzed separately to determine whether the first 15 testing items were statistically more or less annoying than the second 15 testing items.

Figure 67 displays the overall average of the 30 test items, the average of the first 15 test items, and the average of the second 15 test items for the 65 dBA subject testing group. Figure 68 shows the same information for the 55 dBA testing group. In both groups, no statistical differences were found between the first 15 test items and the second 15 test items. For the 65 dBA testing group, only a 0.2 difference (3.8 to 4.0) in subject annoyance response was found between the first 15 test items and the second 15 test items. The 55 dBA grouping showed only a slightly larger difference of 0.3 (3.0 to 3.3) in subject annoyance response between the first and second test item groups. The preliminary testing items showed very similar subject annoyance response ratings as with the primary testing data, with the 65 dBA and the 55 dBA testing groups having average preliminary subject responses of 3.6 and 3.0, respectively.

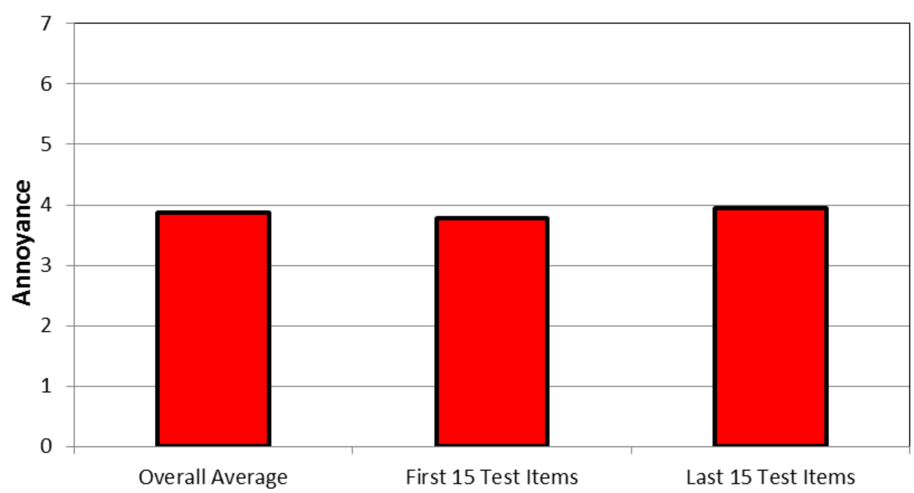

Figure 67: Perceptual Test Analysis – Subject Annoyance Responses Over Time – 65 dBA Testing Group

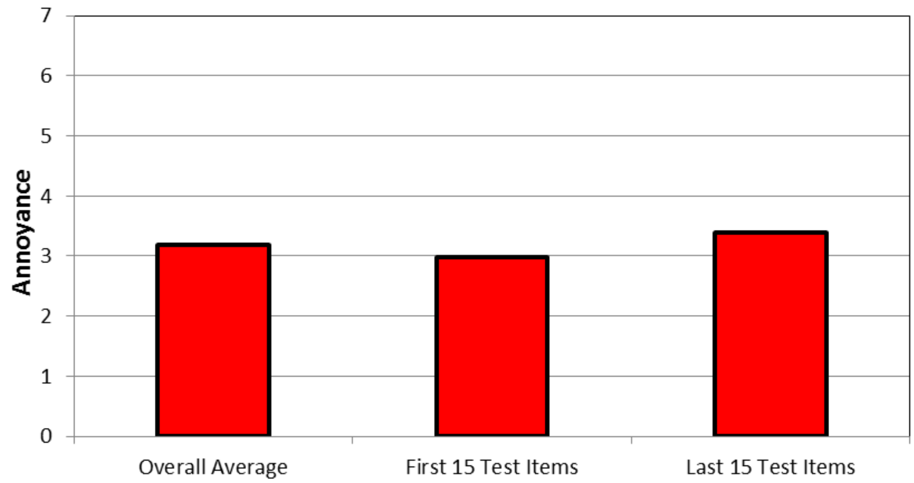

Figure 68: Perceptual Test Analysis – Subject Annoyance Responses Over Time – 55 dBA Testing Group

5.5.5 Subject Demographics Analysis

The influence of subject demographics was of interest to the study, such as whether factors of gender, age, or noise sensitivity significantly impacted the annoyance response ratings of subjects. As with the 65 dBA versus 55 dBA testing group statistical analyses, basic one-way ANOVA / linear regression models and more accurate one-way within-subjects ANOVA models were computed between the subject demographic and annoyance response data.

When gender was statistically correlated with subject annoyance response, no statistical correlations were found in the basic analysis or the between-subjects ANOVA component (relating gender with subject annoyance). These findings were true for both the 65 dBA and 55 dBA testing groups. As before, significant correlations were found for the within-subjects components for both the 65 dBA testing group ($F[3,12] = 2.28$, $p = 0.0069$) and the 55 dBA testing group ($F[3,12] = 3.68$, $p = 0.0001$), indicating individual subject responses were related to one another, as was found in the above analyses. Statistical data for correlations between subject annoyance and gender can be found in Table 65 of Appendix C for the 65 dBA testing group and Table 66 of Appendix C for the 55 dBA testing group.

Age showed similar trends with gender when statistically correlated with subject annoyance response data. No statistical correlations were found between subject age and annoyance in either the basic statistical tests or the between-subjects ANOVA components of the 65 dBA or 55 dBA testing groups. A histogram for the age of all subjects can be found in Table 60, which shows a large concentration of subjects between ages 19 and 29, with two outliers at age 35 and 56. As with the test item audio level and gender comparisons, significant correlations were found for the within-subjects components for both the 65 dBA testing group ($F[3,12] = 2.68$, $p = 0.0034$) and the 55 dBA testing ($F[3,12] = 3.12$, $p = 0.0006$). The correlation data between subject age and annoyance response can be found in Table 65 and Table 66 of Appendix C for the 65 dBA and 55 dBA testing groups, respectively.

Noise sensitivity was found to have no statistical correlation with subject annoyance response, as with the other demographic variables. No correlations were found between subject noise sensitivity and annoyance in either the basic statistical tests or the between-subjects ANOVA components of the 65 dBA or 55 dBA testing groups. A histogram for the noise sensitivity of all subjects can be found in Table 61, which shows a relatively even distribution between 24 and 52, with higher concentrations of subjects at 40, 45, and 46. For the within-subjects components, the 55 dBA testing group was found to have significant correlations ($F[3,12] = 2.3$, $p = 0.0117$), but the 65 dBA testing group was not found to be statistically correlated. The result for the 65 dBA testing group was slightly unexpected, but this finding could have been an anomaly. The correlation data between subject noise sensitivity and annoyance response can be found in Table 65 and Table 66 of Appendix C for the 65 dBA and 55 dBA testing groups, respectively. It was found that none of gender, age, or noise sensitivity was correlated with subject annoyance response, and thus could not be utilized in predicting subject perception of noise.

5.5.6 Positive & Negative PANAS Analysis

In addition to the subject annoyance response data, positive and negative PANAS survey information was collected both before and after the listening portion of the testing procedures. In these analyses, it was determined whether there were statistically significant differences found between subject PANAS scores before and after the test. Also, statistical differences between the 65 dBA and 55 dBA testing group PANAS scores were studied. In these analyses, one-way within-subjects ANOVA models were computed for the subject PANAS data to determine these relationships.

For the positive PANAS comparison, a significant correlation was found in the within-subjects ANOVA component ($F[3,27] = 48.81$, $p = 0.0001$), which tested the difference between subject annoyance responses before and after the listening portion of the testing procedures. The statistical analyses were computed on the full 30-subject dataset, and indicated a significant decrease in positive PANAS scores in subjects after the listening portion of the test, with an average drop of 7.03 points in positive subject affect. The between-subjects ANOVA component found marginal correlation ($F[3,27] = 3.62$, $p = 0.0675$) comparing differences of positive PANAS scores for the 65 dBA and 55 dBA testing groups. A slight difference of 1.0 PANAS points was found between the groups (8.0 versus 7.0), but not enough to be considered statistically significant. Correlation data for positive PANAS scores can be found in Table 67 of Appendix C.

Negative PANAS comparisons found a similar significant correlation in the within-subjects ANOVA component ($F[3,27] = 6.39$, $p = 0.0174$). This was a much less significant correlation than the positive PANAS results, but with an average increase of 1.85 points in negative subject affect, the difference was not surprising. The between-subjects ANOVA component found no correlation comparing differences of negative PANAS scores for the 65 dBA and 55 dBA testing groups. Correlation data for negative PANAS scores can be found in Table 70 of Appendix C.

When correlated as a confounding variable with the subject annoyance response data, only one statistical correlation was found between subject PANAS data and annoyance in either the basic statistical tests or the between-subjects ANOVA components of the 65 dBA or 55 dBA testing groups. Only the simple one-way ANOVA model for positive PANAS in the 65 dBA testing group was found to be statistically correlated ($F[1,14] = 13.18$, $p = 0.0030$). This indicated that positive PANAS scores could possibly be related with subject annoyance response to hospital noise. As with the other confounding variables, significant correlations were found for the within-subjects components for both the 65 dBA and 55 dBA testing groups for both positive and negative PANAS scores. The correlation data between subject PANAS results and annoyance response can be found in Table 68, Table 69, Table 71, and Table 72 of Appendix C for the 65 dBA and 55 dBA testing groups and positive and negative PANAS scores, respectively.

Overall, it was found that listening to approximately 30 minutes of simulated hospital soundscapes within a controlled testing environment negatively affected subject affect. Significant differences were found in positive and negative PANAS scores measured before and after the listing part of the testing procedures. This showed that the experience of listening to hospital noise for an extended period time could have a noticeable impact on the subject affect of the listener.

It should be noted that differences found in subject affect before and after testing could have been influenced by the mood of the subject as they were coming into the test. Large variations between subjects as they filled out the first PANAS could have resulted in unintended results in the computed difference scores. This effect could have been minimized through the implementation of a pre-test waiting period to equalize subject mood. However, because this was not introduced in the testing procedures, this type of change would need to happen in future round of study.

5.5.7 Item Ordering Change Comparison

The first 11 subjects who participated in the subjective testing procedures were given a test item ordering that was different than described in the preceding section. For these subjects, the first 15 test items had the same ordering as the second 15 test items. During the doctoral comprehensive examination, it was brought up that this ordering scheme was incorrectly designed and could introduce unwanted error into the analyses. It was therefore necessary to change the ordering procedure for all future testing subjects (12 through 33) to the scheme that was described above.

It was also necessary to analyze the data produce from the first 11 testing subjects to determine whether significant differences were found based on the order of the presented test item audio files. It was found that no statistical differences were found between the first 11 testing subjects and the last 19 testing subjects for either the 65 dBA or 55 dBA testing groups. The average subject annoyance response for the first 11 subjects was 3.8 and 3.1 for the 65 dBA and 55 dBA groups, respectively. Comparing these values with the group averages for the testing pool as a whole (3.9 and 3.2) revealed very consistent response rates for all subjects. Similar results were found regarding the minimum and maximum subject annoyance values and the differences between the first 15 test items and the second 15 test items. These findings indicated that the alterations in test item ordering did not significantly impact subject annoyance response values, and could thus be analyzed as a single homogenous pool of subjects.

Subjective Perception Conclusions

In Phase III of this research, a subjective perception test was created and administered, aimed at assessing the perceived annoyance of hospital soundscapes with varying ranges of dynamic noise. These tests were inspired by results from Phase I of this research, where it was found that the dynamic range of noise was significantly correlated with patient satisfaction. In that analysis, patients in rooms with a wider dynamic range of noise rated their perception of hospital noise more favorably than patients who experienced a more narrow range of sound levels. This result was investigated in this phase of the study under controlled laboratory conditions.

A new subjective perception test was generated for this study, which involved subjects listening to and rating the annoyance of sounds with varying dynamic noise ranges. Numerous 30-second audio files were created using simulated hospital soundscapes. The audio properties of these files were altered (using limiting and leveling techniques) to create a group of test items with very similar content, but widely varying ranges of dynamic noise. The test items were measured to quantify their individual acoustical properties, and then utilized in the subjective testing procedures. This process of item creation and test development served to isolate the specific comparison between the various dynamic noise ranges of the test items as much as was possible.

Thirty-three subjects participated in the perceptual listening tests over the six week testing period. In addition to the annoyance rating portion of the test, subjects were asked to provide demographic information, including age, gender, and noise sensitivity ratings, as well as fill out subject affect assessment surveys before and after listening to the audio files. The subject pool was separated into two distinct groups, determined by the presented level of the test item audio files. The first grouping of 15 subjects listened to the test items at an average level (as measured at the subject listening position) of 65 dBA. The second grouping of 15 subjects listened to the test items at an average level of 55 dBA. This split provided useful information in determining whether results were consistent for a range of presented audio levels.

It was found that subjects perceived hospital soundscapes with a wider range of dynamic noise (as quantified by the LC_{PEAK} Occurrence Rate range metric) more negatively than soundscapes with a more consistent sound level. These findings were consistent for both 65 dBA and 55 dBA testing groups, indicating results were not dependent on presented sound level. The 65 dBA test items were perceived more negatively on average than the 55 dBA test items: 3.9 versus 3.2 annoyance rating for the two testing groups, respectively. No significant correlations were found regarding subject response rate over time or with any comparisons with demographic information. Subject affect comparisons revealed significant changes in both positive and negative PANAS scores before and after listening portions of the test.

The results of the subject perception tests were contrary to finding from Phase I of this research. The cause of this discrepancy was due to the audio content (in a manner of speaking) for both circumstances. As detailed in Chapter 3, the correlation in the hospitals between patient satisfaction and the dynamic range of noise was due to the low minimum sound levels, and that the peak levels were consistent between patient rooms. In the perceptual tests, the annoyance ratings of the dynamic range of noise were dictated by the peak level events, and not the minimum sound levels. This created a situation opposite of the conditions experienced in the hospital. This discovery was not uncovered until after the testing and analysis procedure was completed. Had this information been know, the test item audio file creation process would have been adjusted slightly to further vary the differences of the minimum sound levels. This finding should not discount the results from the perceptual testing, but rather lend credence to the effects that the dynamic range of noise can have on human perception and annoyance. In both Phase I and Phase III of this study, significant correlations were found linking perception of noise with the dynamic range of noise, although through different mechanisms.

In this phase of the study, it was found that subjects perceived hospital environments with varying dynamic noise ranges more negatively than soundscapes with more consistent sound levels. This result was found to be consistent for two audio file presentation levels. It was also found that listening to 30 minutes of simulated hospital soundscapes negatively impacted subject affect. Please note that these results represented the annoyance ratings of a limited number of subjects under controlled testing conditions using generated test item audio files. More tests using a larger subject pool and new test items are required to verify these results and further establish the preference of a steadier acoustic environment over one with a wider dynamic range of noise.

Chapter 6

Summary & Conclusions

6.1.1 Study Scope

This doctoral research aimed to improve patient satisfaction of hospital environments by measuring the acoustical properties of numerous patient rooms in multiple units of three distinct hospitals. This collected data were compared with patient and staff satisfaction information using both individual room level data and aggregated hospital values. These analyses revealed that many traditional acoustical metrics were insufficient to accurately assess the perceived hospital soundscape conditions, although several metrics were identified that correlated well with satisfaction measures. In addition to the hospital measurements, a subjective perceptual test was created and administered to further analyze the perception of hospital soundscapes with varying dynamic ranges of noise. Together, the three phases of this research have provided new and unique information on the perception of noise in hospital environments and means of assessing these soundscapes to ultimately improve patient experience.

6.1.2 Phase I – Acoustical Measurements at an Urban Hospital

In Phase I of this research, the sound levels of patient rooms and nursing stations within five similar-type units were measured in an urban hospital. The 24-hour average LA_{EQ} values of the five units within the patient rooms was found to be between 52 dBA and 61 dBA, while the absolute minimum LA_{MIN} ranged from 33 dBA to 45 dBA, and the absolute maximum LA_{MAX} spanned from 89 dBA up to 99 dBA. All five of the units failed to achieve SII ratings of ‘Good’, with all either receiving ‘Marginal’ or ‘Poor’ grades. Unoccupied patient rooms in three of the units were measured, revealing unoccupied noise levels between 36 dBA and 38 dBA, although too much high frequency energy was present to meet ANSI/ASA or FGI patient room noise recommendations.

The measured acoustical data were correlated with 2016 HCAHPS ‘Quietness of Hospital Environment’ survey responses, rating patients’ perceptions of in-room noise conditions. Of all the acoustical metrics, the absolute minimum values measured (LA_{MIN}, LC_{MIN}, & LZ_{MIN}) were found to be the most statistically correlated metrics with survey information. A clear preference of patient perception was found, as hospital rooms with LA_{MIN} levels below 35 dBA scored 16.2 % higher on average than rooms that measured above this minimum sound level. Low frequencies between 20 Hz and 125 Hz also generated significant correlations with HCAHPS data, finding patient rooms with levels below 50 dBA in these frequency bands scoring on average 11.5 % higher than those above this level. These findings established links between patient room minimum sound levels, low frequency noise, as well as the occurrence of peak noise events with patient perception, providing additional clues into the motivation of patients and how they evaluate hospital soundscapes. Other metrics, LA_{EQ} for example, showed some association (as the loudest unit was also the worst rated in the survey) but not enough to be statistically correlated. This incongruity between average noise levels and HCAHPS data were likely due to the unpredictable nature of the hospital soundscapes.

The five units selected also provided the opportunity to compare patient room ceiling types, as three units had ACT installed while two utilized GWB ceilings. The patient rooms with ACT ceilings were found to be 5 dBA quieter on average than the

GWB rooms. This again demonstrated the significant difference in acoustical performance between acoustical ceiling tile and gypsum wall board ceilings and likely explained the differences in HCAHPS survey performance between the two ceiling types: 58.5 % on average for ACT rooms and 47.9 % for rooms with GWB ceilings.

6.1.3 Phase II – Acoustical Measurements at Two Rural Hospitals

In Phase II of this research, the sound levels of patient rooms and nursing stations within six units were measured in two rural hospitals, providing the comparison between two additional hospitals and the analysis of various acoustical issues. The 24-hour average LA_{EQ} values of the six units within the patient rooms was found to be between 54 dBA and 60 dBA, while the absolute minimum LA_{MIN} ranged from 35 dBA to 44 dBA, and the absolute maximum LA_{MAX} spanned from 85 dBA up to 90 dBA. All six units failed to achieve SII ratings of 'Good', with all either receiving 'Marginal' or 'Poor' grades. Unoccupied patient rooms in the six units were measured, revealing a wide range of unoccupied noise levels (34 dBA – 46 dBA). Impulse response measurements were also collected within the two rural hospitals, generating reverberation time values for the unit hallways and providing information as to how sound decayed in those environments.

The measured acoustical data were utilized in conjunction with HCAHPS patient survey data and hospital staff survey results to analyze the differences in soundscape perception of the six units. It was shown that the worst perceived unit (Hospital R1 ICU) in the hospital staff survey was also the loudest within the patient rooms, both for the overall LA_{EQ}, consistently during all periods in the statistical sound levels, as well as LC_{PEAK} Occurrence Rate analyses. It was additionally found that the best perceived unit (Hospital R1 Women & Children's) had the lowest overall noise levels across many of the measured acoustical metrics including LC_{PEAK} Occurrence Rate levels. Also, it was observed that other topics on the hospital staff survey related with the perception of unit soundscape conditions, with job satisfaction and staff collaboration measures being found to be higher in the best perceived unit and lower in the worst perceived unit. It was also identified that the 'Noise disrupts patient rest and recuperation' and 'Noise disrupts my work' survey questions were highly correlated with measured acoustical data, validating the use of these two questions in the assessment of hospital soundscapes.

Hospital administration identified the issue of alarm identification within Hospital R1 which was analyzed during this research. It was surmised that directional perception issues were caused by several architectural elements incorporated into the design of the hospital. Having parallel corridors in close proximity to one another allowed sound multiple paths in which to travel and combined with the square nursing alcoves generated unexpected reflection patterns. These patterns could have in turn potentially created false sonic images, causing difficulties in identifying alarm direction.

6.1.4 Phase III – Perceptual Tests on the Dynamic Range of Noise

In Phase III of this research, a subjective perception test was created and administered, aimed at assessing the perceived annoyance of hospital soundscapes with varying ranges of dynamic noise. These tests were inspired by results from Phase I of this research, where it was found that the dynamic range of noise was significantly correlated with patient satisfaction. This result was investigated with a new subjective perception test generated for this study. The test involved subjects listening to and rating the annoyance of sounds with varying dynamic noise ranges. Numerous 30-second audio files were created using simulated hospital soundscapes. The audio properties of these files were altered to create a group of test items with very similar content, but widely varying ranges of dynamic noise.

Thirty-three subjects participated in the perceptual listening tests over a six week period. In addition to the annoyance rating portion of the tests, subjects were asked to provide demographic information, including age, gender, and noise sensitivity ratings, as well as fill out subject affect assessment surveys before and after listening to the audio files. The subject pool was separated into two distinct groups, determined by the presented level of the test item audio files: 65 dBA and 55 dBA.

It was found that subjects perceived hospital soundscapes with a wider range of dynamic noise (as quantified by the LC_{PEAK} Occurrence Rate range metric) more negatively than soundscapes with a more consistent sound level, contradicting results found in Phase I. These findings were consistent for both 65 dBA and 55 dBA testing groups, indicating results were not dependent on presented sound level. The 65 dBA test items were perceived more negatively on average than the 55 dBA test items: 3.9 versus 3.2 annoyance rating for the two testing groups, respectively. No significant correlations were found regarding subject response rate over time or with any comparisons between demographic information. Subject affect comparisons revealed significant changes in both positive and negative PANAS scores before and after listening portions of the test.

These results could have implications to the use of sound masking discussed in section 5.1.1. By increasing the minimum sound levels, the dynamic range of noise would decrease and serve to minimize some amount of transient noise events. This in turn might help to improve the perception of the soundscapes, although this application would in part be contradictory to finding from Phase I, where quieter minimum sound levels were found to be correlated with higher patient satisfaction.

6.1.5 Primary Study Conclusions

Over the course of the three phases of this doctoral research acoustical measurements were collected from three hospitals and compared with patient and staff satisfaction information. Additionally, a subjective perceptual test was created and administered to further study the perception of hospital noise.

In Phase I, it was found that patients clearly preferred rooms with low minimum sound levels, as hospital rooms with LA_{MIN} levels below 35 dBA scored 16.2 % higher on average than rooms that measured above this minimum sound level. Low frequencies between 20 Hz and 125 Hz also generated significant correlations with HCAHPS data, finding patient rooms with levels below 50 dBA in these frequency bands scoring 11.5 % higher on average. Conversely, LA_{EQ} and many other traditional metrics were not correlated with patient satisfaction data, due primarily to the unpredictable nature of the hospital soundscapes.

In Phase II, it was shown that the worst perceived unit (Hospital R1 ICU) in the hospital staff survey was also the loudest within the patient rooms, and that the best perceived unit (Hospital R1 Women & Children's) had the lowest overall noise levels across many of the measured acoustical metrics. Additionally, it was found that job satisfaction and staff collaboration measures being found to be higher in the best perceived unit and lower in the worst perceived unit.

In Phase III, it was found that subjects perceived hospital soundscapes with a wider range of dynamic more negatively than soundscapes with a more consistent sound level, for both 65 dBA and 55 dBA testing groups, differing from Phase I results. The 65 dBA test items were perceived more negatively on average than the 55 dBA test items, and subject affect comparisons revealed significant changes in both positive and negative PANAS scores before and after listening portions of the test.

Together the three phases of this research provided new details into the perception of hospital noise from patients, staff, and under controlled listening conditions. This information can be utilized to more accurately assess hospital soundscapes and also aid in the design process in building new hospitals to ultimately improve patient satisfaction.

6.1.6 Limitations & Suggestions for Future Testing

In the course of this research, acoustical measurements were collected from numerous patient rooms in three individual hospitals, providing significant breadth in the measured acoustical data. However, the correlation data that was available for comparison was not consistent between all of the sites and therefore was not fully analogous throughout. More research is required detailing the correlations of individual patient room acoustical data with HCAHPS ‘Quietness of Hospital Environment’ survey responses to more thoroughly examine the significant correlations found. The distribution of noise data could be analyzed further, as the correlations completed from Phase I & II included all measured patient rooms, regardless of levels. Exclusion of outlier data points might improve the strength of analysis and ultimately the quality of results by minimizing uncommon noise levels. Also, corrections for multiple correlations could be implemented to ensure the strength of correlations found. Using the level of analysis completed for Hospital U1 on other hospital sites would help to establish whether the findings of Phase I are consistent between hospitals or unique to this one site.

It would also be useful for the HCAHPS survey to be updated to include additional noise related questions. The current survey has not changed in format or included questions since its inception (other than the addition of the ‘Care Transition’ category question). This is likely due to the time and money it would entail to revalidate a new survey, but given the importance that the 'Quietness of the Hospital Environment' category has been found to have, inclusion of additional more detailed noise related questions would be prudent. The introduction of a federally mandated staff survey would also provide useful information and potentially a different view than those of patients.

While the data provided from Hospitals R1 & R2 provided similar findings as in Hospital U1, the lack of detailed HCAHPS patient survey data limited analysis capabilities. Staff surveys indicated connections between unit soundscape properties and staff satisfaction, but as with the patient data, more information from additional hospital sites is needed to verify these findings, including specific responses that could be more rigorously tested statistically.

The subjective perceptual tests helped to further the understanding of perceived annoyance of hospital soundscapes with varying dynamic noise ranges. These tests utilized one master audio file for test item creation, which isolated the dynamic range of noise variable but also limited the presented audio content. Additional tests under similar conditions using different test item audio files are necessary to verify the results from these tests, as results were highly dependent on source files. The inclusion of a pre-test waiting period could have improved subject affect consistency. Also, by utilizing a more sensitive heart rate oximeter, subject physiological data could be studied in greater detail on a second-by-second basis, which could identify if loud transient noise events directly impacted subject heart rate. This would provide a further understanding of how individuals perceive hospital soundscape noise, which in turn could be utilized in hospital environments to ultimately improve patient experience.

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Appendix A: Hospital U1 Data

A.1 Hospital U1 HCAHPS Survey Data

Table 20: Hospital U1 2016 HCAHPS Survey Data – Responses from Measured Rooms

		Always		Usually		Sometimes		Never	
Unit	**Room**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
H-1	**1**	4	80.0	1	20.0	0	0.0	0	0.0
	2	0	0.0	0	0.0	0	0.0	0	0.0
	3	4	57.1	2	28.6	1	14.3	0	0.0
	Totals	8	68.6	3	24.3	1	14.3	0	0.0
H-2	**1**	7	58.3	4	33.3	0	0.0	1	8.3
	2	8	44.4	7	38.9	3	16.7	0	0.0
	3	11	64.7	5	29.4	0	0.0	1	5.9
	Totals	26	55.8	16	33.9	3	5.6	2	4.7
M-1	**1**	12	42.9	14	50.0	2	7.1	0	0.0
	2	8	40.0	10	50.0	1	5.0	1	5.0
	3	6	50.0	5	41.7	1	8.3	0	0.0
	Totals	26	44.3	29	47.2	4	6.8	1	1.7
M-2	**1**	13	61.9	6	28.6	1	4.8	1	4.8
	2	8	80.0	2	20.0	0	0.0	0	0.0
	3	5	50.0	4	40.0	1	10.0	0	0.0
	Totals	26	64.0	12	29.5	2	4.9	1	1.6
L-1	**1**	11	39.3	14	50.0	2	7.1	1	3.6
	2	10	29.4	14	41.2	8	23.5	2	5.9
	3	10	43.5	8	34.8	3	13.0	2	8.7
	Totals	31	37.4	36	42.0	13	14.5	5	6.1

Table 21: Hospital U1 2016 HCAHPS Survey Data – Aggregated Responses from Measured Units

	Always		Usually		Sometimes		Never	
Unit	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
H-1	52	65.0	26	32.5	2	2.5	0	0.0
H-2	145	58.2	78	31.3	18	7.2	8	3.2
M-1	356	52.4	229	33.7	74	10.9	21	3.1
M-2	207	52.3	147	37.1	32	8.1	10	2.5
L-1	243	43.5	206	36.9	79	14.2	30	5.4
Totals	1003	51.1	686	34.9	205	10.4	69	3.5

A.2 Hospital U1 Acoustical Data & HCAHPS Correlation

Table 22: Hospital U1 Measured Acoustical & HCAHPS Correlation Data – 24-Hour Patient Room Values

24-Hour Overall

Measurement		2016	24 Hour Averages LAeq	LAmax	LAmin	LCpeak	Absolute Values LAmax	LAmin	LCpeak	SII (Norm)	SII (Rsd)
H-1	1	80.0	57.1	70.3	48.8	86.1	89.2	34.7	103.1	0.50	0.74
	2	-	58.9	71.5	51.3	88.9	89.1	33.7	117.1	0.44	0.69
	3	57.1	59.4	72.6	43.4	88.7	89.3	32.7	106.6	0.43	0.68
H-2	1	58.3	56.0	69.9	37.1	85.0	87.0	32.6	106.8	0.51	0.76
	2	44.4	53.9	67.9	38.9	84.3	84.5	34.5	103.2	0.59	0.83
	3	64.7	55.0	72.2	36.8	87.4	100.0	30.4	110.8	0.54	0.79
M-1	1	42.9	53.0	68.4	40.6	85.2	87.1	33.7	104.7	0.61	0.86
	2	40.0	51.5	69.0	40.1	88.0	90.9	37.3	109.3	0.65	0.90
	3	50.0	51.0	67.8	40.3	85.2	87.2	35.4	106.4	0.67	0.91
M-2	1	61.9	61.7	74.1	50.3	89.7	89.9	40.1	108.5	0.38	0.62
	2	80.0	56.9	75.3	41.1	93.4	100.4	34.8	118.8	0.48	0.73
	3	50.0	58.3	72.1	48.7	88.5	88.1	41.8	109.3	0.45	0.70
L-1	1	39.3	61.3	73.3	58.2	90.8	94.2	41.1	111.0	0.35	0.60
	2	29.4	58.2	70.2	54.7	88.1	89.2	42.3	109.4	0.46	0.70
	3	43.5	63.4	75.1	58.9	92.0	102.6	47.5	118.4	0.28	0.53
HCAHPS	F*		0.02	1.68	1.37	0.26	0.81	4.05	0.07	0.01	0.01
2016	PRE/R^2		0.001	0.118	0.103	0.021	0.063	0.252	0.006	0.001	0.001
Analysis	p		0.899	0.229	0.264	0.621	0.386	0.065	0.797	0.941	0.939

Measurement		2016	LCeq	LCmax	LCmin	LZeq	LZmax	LZmin	LC-LA	LAE
H-1	1	80.0	60.9	91.6	48.6	67.7	100.8	54.8	4	106
	2	-	61.6	88.7	47.9	71.5	97.5	54.9	3	108
	3	57.1	61.9	91.8	47.5	67.1	102.1	53.6	3	109
H-2	1	58.3	59.6	90.5	46.3	69.2	103.0	52.2	4	105
	2	44.4	59.7	87.3	49.2	69.3	103.0	54.7	6	103
	3	64.7	59.6	99.9	44.7	67.4	99.9	54.1	5	104
M-1	1	42.9	59.6	91.5	52.0	69.9	106.7	57.8	7	102
	2	40.0	63.7	95.1	55.7	75.4	104.5	62.9	12	101
	3	50.0	62.0	92.8	53.7	67.9	103.9	59.1	11	100
M-2	1	61.9	63.7	93.5	54.0	71.9	108.5	58.4	2	111
	2	80.0	62.2	99.8	50.0	75.5	109.0	56.8	5	106
	3	50.0	63.0	90.6	54.1	71.9	106.5	58.0	5	108
L-1	1	39.3	67.4	97.1	54.2	75.3	110.7	61.3	6	111
	2	29.4	63.6	88.9	52.8	71.4	101.3	56.6	5	108
	3	43.5	68.3	102.5	57.7	72.5	107.1	62.1	5	113
HCAHPS	F*		2.01	0.72	4.96	0.67	0.11	3.35	2.51	0.02
2016	PRE/R^2		0.143	0.056	0.293	0.053	0.009	0.218	0.173	0.002
Analysis	p		0.182	0.414	0.046	0.429	0.746	0.092	0.139	0.896

Measurement		2016	LAF5	LAF10	LAF 33	LAF50	LAF90	LAF95	RC	NC
H-1	1	80.0	60.7	55.8	51.1	50.5	48.9	48.1	52	52
	2	-	62.9	58.0	54.7	53.9	46.7	38.3	52	54
	3	57.1	63.6	59.3	47.7	45.5	38.2	36.8	54	55
H-2	1	58.3	60.6	53.6	44.9	42.6	35.5	35.0	51	51
	2	44.4	59.6	56.0	50.3	48.5	41.7	39.7	49	49
	3	64.7	58.0	55.5	51.6	48.6	35.4	33.9	50	48
M-1	1	42.9	56.3	53.7	49.3	47.1	41.2	39.9	48	47
	2	40.0	55.8	52.3	46.3	44.4	40.6	40.0	47	45
	3	50.0	54.7	50.0	45.0	43.9	40.3	39.3	46	45
M-2	1	61.9	63.5	57.8	53.2	52.5	46.1	43.8	55	59
	2	80.0	62.0	58.7	50.0	45.6	40.3	39.6	52	51
	3	50.0	63.5	60.0	52.7	51.1	45.4	44.8	53	54
L-1	1	39.3	64.4	63.1	60.8	60.1	57.6	57.1	56	56
	2	29.4	62.4	59.8	58.1	57.6	46.9	45.6	53	54
	3	43.5	67.4	65.5	63.2	62.1	57.7	55.9	58	59
HCAHPS	F*		0.00	0.26	1.51	2.09	1.14	1.09	0.01	0.00
2016	PRE/R^2		0.000	0.022	0.112	0.148	0.087	0.083	0.001	0.000
Analysis	p		0.952	0.617	0.243	0.174	0.306	0.318	0.933	0.973

Linear Regression Statistics Shown for All Completed Tests – Statistically Significant ($p < 0.05$) Values Highlighted in Yellow, Marginally Significant ($0.05 < p < 0.10$) Values Highlighted in Orange

Table 23: Hospital U1 Measured Acoustical & HCAHPS Correlation Data – 24-Hour Unit Average Values

24-Hour Overall

Measurement		2016	24 Hour Averages LAeq	LAmax	LAmin	LCpeak	Absolute Values LAmax	LAmin	LCpeak	SII (Norm)	SII (Rsd)
H-1		65.0	58.6	71.6	48.9	88.1	89.2	33.8	112.8	0.46	0.70
H-2		58.2	55.1	70.4	37.7	85.8	95.5	32.8	108.0	0.55	0.79
M-1		52.4	51.9	68.4	40.3	86.3	88.8	35.7	107.2	0.65	0.89
M-2		52.3	59.5	74.0	48.1	91.1	96.2	39.8	114.8	0.44	0.68
L-1		43.5	61.4	73.3	57.6	90.6	98.6	44.6	114.8	0.36	0.61
HCAHPS 2016 Analysis	F*		0.24	0.30	0.89	1.00	2.07	9.91	0.27	0.33	0.28
	PRE/R^2		0.075	0.092	0.229	0.250	0.408	0.768	0.083	0.099	0.085
	p		0.655	0.620	0.415	0.391	0.246	0.050	0.638	0.607	0.635

Measurement		2016	LCeq	LCmax	LCmin	LZeq	LZmax	LZmin	LC-LA	LAE
H-1		65.0	61.5	69.2	49.1	70.2	100.6	54.7	3.0	107.94
H-2		58.2	59.6	68.7	48.9	68.4	102.3	54.6	4.6	104.42
M-1		52.4	62.1	72.3	57.5	72.4	104.1	62.3	10.0	101.27
M-2		52.3	63.0	73.5	53.0	73.1	107.0	57.7	4.0	108.84
L-1		43.5	66.9	73.4	55.2	72.7	108.1	60.2	5.5	110.81
HCAHPS 2016 Analysis	F*		5.78	6.98	3.86	2.70	20.59	3.65	0.06	0.27
	PRE/R^2		0.658	0.699	0.563	0.474	0.873	0.549	0.171	0.081
	p		0.096	0.078	0.144	0.199	0.020	0.152	0.489	0.642

Measurement		2016	LAF5	LAF10	LAF 33	LAF50	LAF90	LAF95	RC	NC
H-1		65.0	62.6	57.9	52.1	51.2	46.4	44.0	52.7	53.67
H-2		58.2	59.5	55.1	49.7	47.3	38.6	37.0	50.0	49.33
M-1		52.4	55.7	52.3	47.3	45.4	40.7	39.7	47.0	45.67
M-2		52.3	63.1	58.9	52.2	50.6	44.6	43.2	53.3	54.67
L-1		43.5	65.2	63.4	61.2	60.3	56.1	55.0	55.7	56.33
HCAHPS 2016 Analysis	F*		0.18	0.82	1.59	1.33	1.36	1.90	0.30	0.13
	PRE/R^2		0.057	0.215	0.346	0.307	0.312	0.388	0.091	0.042
	p		0.698	0.431	0.297	0.333	0.328	0.262	0.623	0.741

Table 24: Hospital U1 Measured Spectral & HCAHPS Correlation Data – 24-Hour Patient Room Values

24-Hour Spectral Data

24 Hour Averages

Measurement		2016	8	16	31.5	63	125	250
H-1	1	80.0	68.8	60.1	49.1	45.4	51.0	54.8
	3	57.1	69.4	56.8	49.2	50.0	53.0	55.2
H-2	1	58.3	69.3	56.7	50.2	48.0	53.1	51.3
	2	44.4	68.6	60.4	46.1	45.4	54.3	53.5
	3	64.7	68.0	58.1	47.9	47.7	54.2	54.6
M-1	1	42.9	66.1	62.7	60.0	51.6	49.9	47.2
	2	40.0	71.6	63.5	66.6	57.5	51.3	47.4
	3	50.0	65.5	61.6	63.0	57.0	56.5	47.8
M-2	1	61.9	67.5	59.6	56.8	50.2	54.9	57.6
	2	80.0	73.2	60.4	57.2	52.0	53.6	52.9
	3	50.0	66.5	57.6	57.7	55.2	56.0	53.0
L-1	1	39.3	74.0	68.9	64.2	58.7	57.4	57.8
	2	29.4	71.1	62.9	57.5	59.9	53.4	53.9
	3	43.5	68.5	63.6	63.9	59.5	58.5	60.4

HCAHPS 2016 Analysis	F*	[redacted]	0.01	4.66	3.66	8.82	0.62	0.17
	PRE/R^2		0.001	0.280	0.234	0.424	0.049	0.014
	p		0.933	0.050	0.080	0.012	0.445	0.692

Measurement		2016	500	1000	2000	4000	8000	16000
H-1	1	80.0	56.4	52.0	47.6	44.5	43.5	45.4
	3	57.1	56.6	52.1	54.8	44.7	44.6	45.3
H-2	1	58.3	53.4	49.6	50.5	44.9	43.3	44.8
	2	44.4	53.2	46.7	45.6	42.9	43.0	45.1
	3	64.7	52.4	49.0	47.7	44.6	43.2	45.5
M-1	1	42.9	51.3	47.5	44.4	44.8	42.4	46.6
	2	40.0	49.9	46.2	43.9	40.9	42.6	46.0
	3	50.0	48.5	46.4	42.7	40.8	42.3	45.5
M-2	1	61.9	55.1	51.2	58.9	48.4	45.9	46.7
	2	80.0	55.4	50.9	48.9	46.4	46.1	46.6
	3	50.0	57.9	50.7	49.9	48.6	44.0	45.2
L-1	1	39.3	59.7	56.0	53.4	48.6	45.9	46.4
	2	29.4	57.5	51.8	50.3	46.5	43.1	44.2
	3	43.5	62.4	57.1	55.6	51.6	45.4	45.5

HCAHPS 2016 Analysis	F*	[redacted]	0.05	0.00	0.06	0.02	1.19	0.87
	PRE/R^2		0.004	0.000	0.005	0.002	0.090	0.068
	p		0.826	0.983	0.806	0.883	0.296	0.368

Table 25: Hospital U1 Measured Occurrence Rate & HCAHPS Correlation Data – LC_{PEAK} vs Level

Occurrence Rate Analysis

LCpeak (%)

Measurement		2016	65	70	71	72	73	74	75	76
H-1	1	80.0	100.0%	87.4%	80.2%	73.8%	68.3%	62.7%	58.3%	50.6%
	2	-	100.0%	98.8%	98.5%	97.2%	91.2%	81.5%	76.0%	71.5%
	3	57.1	99.9%	67.4%	61.9%	57.4%	54.4%	51.0%	48.2%	45.7%
H-2	1	58.3	100.0%	100.0%	99.2%	83.3%	67.2%	62.1%	59.4%	56.9%
	2	44.4	100.0%	96.9%	93.8%	89.6%	84.5%	77.1%	69.2%	60.6%
	3	64.7	98.5%	90.2%	88.7%	86.7%	83.8%	77.3%	66.7%	57.4%
M-1	1	42.9	100.0%	100.0%	95.8%	84.2%	68.9%	59.0%	49.9%	43.1%
	2	40.0	100.0%	100.0%	100.0%	100.0%	100.0%	95.3%	76.2%	62.7%
	3	50.0	100.0%	100.0%	100.0%	99.9%	96.9%	88.9%	74.0%	56.5%
M-2	1	61.9	100.0%	100.0%	99.5%	99.0%	95.1%	79.8%	71.5%	64.6%
	2	80.0	100.0%	90.7%	85.8%	82.1%	78.5%	74.2%	70.9%	67.6%
	3	50.0	100.0%	100.0%	99.9%	97.1%	89.2%	81.9%	75.2%	67.6%
L-1	1	39.3	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	2	29.4	100.0%	100.0%	99.9%	99.6%	99.0%	98.8%	97.4%	96.7%
	3	43.5	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
HCAHPS 2016 Analysis	F*		0.67	3.18	4.50	5.18	4.40	5.54	4.42	3.61
	PRE/R^2		0.053	0.209	0.273	0.301	0.268	0.316	0.269	0.231
	p		0.430	0.100	0.055	0.042	0.058	0.036	0.057	0.082

LCpeak (%)

Measurement		2016	77	78	79	80	85	90	95	100
H-1	1	80.0	45.8%	39.1%	32.7%	30.0%	16.7%	7.6%	3.2%	0.6%
	2	-	68.5%	63.1%	57.2%	55.7%	19.2%	9.6%	2.3%	0.2%
	3	57.1	43.4%	42.2%	39.9%	37.8%	28.1%	13.7%	4.7%	1.6%
H-2	1	58.3	55.3%	52.8%	48.1%	45.1%	22.8%	5.3%	1.3%	0.1%
	2	44.4	54.4%	49.2%	45.6%	41.4%	14.5%	4.4%	1.3%	0.2%
	3	64.7	49.9%	43.1%	37.0%	33.3%	16.5%	7.8%	2.7%	1.0%
M-1	1	42.9	37.5%	34.0%	31.3%	28.1%	14.9%	6.8%	2.0%	0.3%
	2	40.0	56.3%	52.0%	46.9%	40.6%	19.3%	9.4%	3.9%	0.8%
	3	50.0	47.8%	43.2%	37.8%	33.2%	16.7%	6.0%	1.7%	0.5%
M-2	1	61.9	59.2%	53.3%	47.6%	43.3%	29.4%	15.0%	5.8%	1.9%
	2	80.0	63.8%	60.5%	57.1%	53.8%	29.2%	15.8%	10.0%	1.8%
	3	50.0	58.3%	49.7%	43.2%	38.8%	24.5%	12.6%	4.4%	1.3%
L-1	1	39.3	99.9%	97.6%	90.8%	79.9%	47.2%	17.9%	5.2%	1.9%
	2	29.4	94.9%	89.1%	76.3%	66.5%	27.8%	10.8%	3.7%	0.6%
	3	43.5	100.0%	99.4%	97.6%	92.0%	44.7%	17.4%	6.0%	1.5%
HCAHPS 2016 Analysis	F*		3.27	3.29	2.90	2.17	0.58	0.00	1.50	0.54
	PRE/R^2		0.214	0.215	0.195	0.153	0.046	0.000	0.111	0.043
	p		0.096	0.095	0.114	0.166	0.462	0.991	0.245	0.478

Table 26: Hospital U1 Measured Occurrence Rate & HCAHPS Correlation Data – LA_{EQ} & LA_{MIN} vs Level

Occurrence Rate Analysis

			LAeq (%)						
Measurement		2016	40	45	50	55	60	65	70
H-1	1	80.0	100.0%	100.0%	78.3%	17.8%	7.8%	2.6%	1.0%
	2	-	97.2%	94.4%	93.4%	41.7%	13.7%	2.3%	1.0%
	3	57.1	83.0%	66.2%	39.1%	31.9%	16.2%	5.4%	1.5%
H-2	1	58.3	79.7%	48.8%	27.1%	22.4%	12.6%	3.0%	0.1%
	2	44.4	99.9%	92.6%	49.7%	20.7%	5.3%	0.3%	0.0%
	3	64.7	89.3%	81.7%	69.4%	17.4%	4.7%	0.8%	0.1%
M-1	1	42.9	99.9%	89.3%	42.0%	11.9%	3.5%	0.3%	0.0%
	2	40.0	99.9%	59.1%	28.5%	10.1%	2.0%	0.2%	0.0%
	3	50.0	98.1%	48.2%	21.1%	9.2%	1.6%	0.5%	0.0%
M-2	1	61.9	100.0%	96.4%	91.7%	27.2%	16.3%	6.9%	2.7%
	2	80.0	99.3%	65.9%	47.3%	31.9%	14.2%	1.9%	0.3%
	3	50.0	100.0%	97.0%	66.0%	37.1%	16.2%	4.2%	0.5%
L-1	1	39.3	100.0%	100.0%	99.9%	99.6%	62.0%	4.0%	0.1%
	2	29.4	100.0%	99.9%	86.0%	71.6%	13.3%	1.3%	0.0%
	3	43.5	100.0%	100.0%	100.0%	99.5%	80.3%	14.1%	0.7%

HCAHPS 2016 Analysis	F*		0.67	0.42	0.10	2.51	0.82	0.00	2.04
	PRE/R^2		0.053	0.034	0.008	0.173	0.064	0.000	0.145
	p		0.427	0.527	0.762	0.139	0.384	0.961	0.179

					LAmin (%)		
Measurement		2016	35	40	45	50	55
H-1	1	80.0	99.9%	92.7%	92.2%	13.5%	0.0%
	2	-	94.9%	87.0%	87.0%	61.2%	0.6%
	3	57.1	94.4%	64.6%	22.9%	0.4%	0.0%
H-2	1	58.3	65.1%	6.3%	0.1%	0.0%	0.0%
	2	44.4	99.4%	18.3%	0.8%	0.0%	0.0%
	3	64.7	51.9%	8.1%	1.3%	0.0%	0.0%
M-1	1	42.9	98.9%	43.2%	2.8%	0.0%	0.0%
	2	40.0	100.0%	39.2%	0.1%	0.0%	0.0%
	3	50.0	100.0%	55.6%	0.2%	0.0%	0.0%
M-2	1	61.9	100.0%	100.0%	80.0%	64.3%	0.0%
	2	80.0	99.9%	30.6%	4.5%	1.3%	0.0%
	3	50.0	100.0%	100.0%	61.9%	27.9%	3.4%
L-1	1	39.3	100.0%	100.0%	98.5%	98.5%	95.6%
	2	29.4	100.0%	100.0%	74.9%	58.5%	56.5%
	3	43.5	100.0%	100.0%	100.0%	98.4%	75.8%

HCAHPS 2016 Analysis	F*		0.86	0.62	0.12	1.98	4.49
	PRE/R^2		0.067	0.049	0.010	0.141	0.272
	p		0.373	0.446	0.731	0.185	0.056

Table 27: Hospital U1 Measured Occurrence Rate & HCAHPS Correlation Data – LA_{MAX} vs Level & Occurrence Rate Range for Each Calculated Metric

Occurrence Rate Analysis

Measurement		2016	LAmax (%) 45	50	55	60	65	70	75	80
H-1	1	80.0	100.0%	100.0%	56.8%	43.8%	25.0%	15.5%	6.7%	2.1%
	2	-	99.6%	97.5%	95.4%	52.6%	35.9%	21.6%	10.4%	3.0%
	3	57.1	91.9%	67.9%	51.5%	41.5%	34.3%	26.4%	15.3%	5.1%
H-2	1	58.3	100.0%	100.0%	66.3%	33.2%	28.3%	23.8%	12.8%	0.6%
	2	44.4	100.0%	97.6%	75.9%	46.3%	31.9%	15.7%	2.7%	0.9%
	3	64.7	96.7%	90.3%	84.7%	49.9%	25.4%	15.3%	6.3%	1.9%
M-1	1	42.9	100.0%	97.5%	80.8%	42.2%	22.7%	13.8%	5.7%	1.0%
	2	40.0	100.0%	90.8%	56.2%	40.6%	26.7%	13.2%	4.9%	1.4%
	3	50.0	99.5%	81.5%	51.5%	36.5%	23.0%	11.1%	3.7%	1.1%
M-2	1	61.9	100.0%	98.7%	93.4%	49.1%	37.2%	27.0%	16.4%	7.6%
	2	80.0	99.4%	77.8%	65.6%	53.8%	40.9%	27.4%	12.6%	4.0%
	3	50.0	100.0%	82.3%	64.0%	53.1%	35.6%	23.8%	13.2%	3.4%
L-1	1	39.3	100.0%	100.0%	100.0%	95.3%	55.9%	29.6%	11.4%	3.9%
	2	29.4	100.0%	99.7%	92.8%	59.1%	40.4%	23.1%	7.6%	1.0%
	3	43.5	100.0%	100.0%	100.0%	99.7%	73.3%	43.7%	14.8%	2.5%
HCAHPS 2016 Analysis	F*		0.48	1.06	2.08	1.34	0.91	0.04	0.65	1.48
	PRE/R^2		0.038	0.081	0.148	0.101	0.070	0.003	0.052	0.110
	p		0.503	0.324	0.174	0.269	0.360	0.851	0.435	0.247

Measurement		2016	Occurrence Rate Range (dB) Leq	Lmin	Lmax	Lpk	Lpk
H-1	1	80.0	22	15	32	36	30
	2	-	32	20	37	38	29
	3	57.1	36	14	44	46	36
H-2	1	58.3	28	7	26	26	26
	2	44.4	21	10	31	37	28
	3	64.7	30	11	43	46	35
M-1	1	42.9	22	12	32	37	27
	2	40.0	20	6	34	39	26
	3	50.0	22	6	35	38	24
M-2	1	61.9	32	12	37	42	31
	2	80.0	27	15	40	47	36
	3	50.0	24	15	37	41	30
L-1	1	39.3	11	20	26	30	25
	2	29.4	20	18	30	35	26
	3	43.5	14	14	21	25	24
HCAHPS 2016 Analysis	F*		5.00	0.02	3.38	2.81	10.55
	PRE/R^2		0.294	0.002	0.220	0.190	0.468
	p		0.045	0.890	0.091	0.119	0.007

Table 28: Hospital U1 Measured Acoustical & HCAHPS Correlation Data – Day (7 AM – 7 PM) Patient Room Values

Day Measurement		2016	LAeq	24 Hour Averages LAmax	LAmin	LCpeak	Absolute Values LAmax	LAmin	LCpeak	SII (Norm)	SII (Rsd)
H-1	1	80.0	58.7	72.0	49.0	87.3	89.2	35.2	102.6	0.45	0.70
	2	-	58.0	72.0	49.2	90.4	89.1	33.7	117.1	0.46	0.71
	3	57.1	60.8	74.1	43.6	90.2	89.3	34.1	106.6	0.39	0.63
H-2	1	58.3	56.0	70.2	38.1	85.3	84.0	33.4	99.9	0.51	0.76
	2	44.4	55.2	69.3	39.2	85.5	84.5	34.5	101.9	0.55	0.79
	3	64.7	56.3	73.8	37.5	88.7	100.0	31.7	110.8	0.50	0.75
M-1	1	42.9	54.1	70.0	40.6	86.8	87.1	35.3	104.7	0.58	0.82
	2	40.0	52.4	69.7	40.3	88.8	86.0	37.5	109.3	0.63	0.87
	3	50.0	52.3	69.3	40.3	86.6	87.2	35.4	106.4	0.63	0.88
M-2	1	61.9	62.1	75.1	49.4	90.9	89.9	40.1	108.5	0.36	0.60
	2	80.0	58.2	77.0	40.9	95.0	100.4	34.8	118.8	0.44	0.69
	3	50.0	59.9	73.2	50.0	89.4	87.7	41.8	109.3	0.40	0.65
L-1	1	39.3	61.7	74.7	58.1	92.3	94.2	41.1	111.0	0.34	0.58
	2	29.4	58.0	71.5	52.9	88.8	89.2	42.3	106.8	0.46	0.70
	3	43.5	63.5	74.4	57.1	91.6	93.3	47.5	111.5	0.27	0.52

HCAHPS 2016 Analysis	F*		0.19	2.83	1.21	0.53	2.50	4.03	0.36	0.15	0.09
	PRE/R^2		0.015	0.191	0.092	0.043	0.172	0.251	0.029	0.012	0.007
	p		0.672	0.118	0.292	0.479	0.140	0.068	0.562	0.708	0.776

Measurement		2016	LAF5	LAF10	LAF 33	LAF50	LAF90	LAF95	RC	NC
H-1	1	80.0	63.8	60.5	54.2	52.3	50.6	50.0	54	55
	2	-	62.7	61.1	55.0	53.3	47.9	40.1	52	52
	3	57.1	66.3	64.5	57.7	49.9	39.2	38.6	56	56
H-2	1	58.3	62.7	61.3	48.6	46.0	42.0	40.8	51	51
	2	44.4	61.0	59.3	54.3	50.8	47.2	45.9	50	50
	3	64.7	60.9	58.9	53.2	51.9	44.2	39.9	51	49
M-1	1	42.9	60.2	57.8	51.4	49.8	44.8	43.7	49	48
	2	40.0	58.1	56.0	50.8	48.1	43.9	43.3	48	46
	3	50.0	58.2	56.1	49.1	46.1	42.7	41.6	47	46
M-2	1	61.9	66.8	64.4	55.3	53.1	47.2	44.5	56	60
	2	80.0	63.6	62.0	56.6	52.6	42.8	41.3	53	53
	3	50.0	65.9	63.6	58.3	54.9	50.8	46.8	54	56
L-1	1	39.3	65.4	64.2	61.8	60.5	58.0	57.9	57	57
	2	29.4	63.7	61.8	57.9	56.2	48.2	47.7	53	53
	3	43.5	67.4	66.3	63.9	62.4	58.7	57.0	59	58

HCAHPS 2016 Analysis	F*		0.23	0.05	0.42	0.76	1.17	1.64	0.11	0.35
	PRE/R^2		0.019	0.004	0.034	0.060	0.089	0.120	0.009	0.029
	p		0.638	0.826	0.531	0.400	0.302	0.225	0.745	0.563

Table 29: Hospital U1 Measured Acoustical & HCAHPS Correlation Data – Night (7 PM – 7 AM) Patient Room Values

Night			24 Hour Averages				Absolute Values				
Measurement		2016	LAeq	LAmax	LAmin	LCpeak	LAmax	LAmin	LCpeak	SII (Norm)	SII (Rsd)
H-1	1	80.0	51.2	63.3	48.4	83.0	80.6	34.7	103.1	0.68	0.91
	2	-	60.2	70.5	53.4	84.0	85.7	52.0	97.2	0.43	0.67
	3	57.1	54.9	67.9	43.2	83.5	84.5	32.7	101.2	0.58	0.82
H-2	1	58.3	56.0	69.3	34.3	84.2	87.0	32.6	106.8	0.53	0.77
	2	44.4	50.2	63.1	38.4	81.1	81.9	35.0	103.2	0.71	0.91
	3	64.7	51.1	66.2	35.4	83.7	85.0	30.4	103.9	0.66	0.87
M-1	1	42.9	50.0	62.7	40.4	79.4	80.4	33.7	95.5	0.71	0.93
	2	40.0	49.7	67.5	39.9	86.1	90.9	37.3	106.5	0.71	0.93
	3	50.0	47.2	62.8	40.3	81.0	81.4	36.8	98.3	0.78	0.94
M-2	1	61.9	61.1	71.4	51.4	86.4	85.5	49.3	103.8	0.44	0.69
	2	80.0	53.2	68.4	41.4	87.5	86.8	36.0	108.8	0.59	0.84
	3	50.0	52.6	69.3	44.8	86.5	88.1	42.5	105.1	0.63	0.87
L-1	1	39.3	60.5	69.1	58.4	85.8	85.1	51.7	103.1	0.38	0.63
	2	29.4	58.5	66.3	56.7	86.5	82.4	54.3	109.4	0.47	0.72
	3	43.5	63.1	76.1	60.8	92.6	102.6	48.6	118.4	0.32	0.57

HCAHPS 2016 Analysis	F*		0.45	0.03	1.47	0.04	0.28	4.08	0.06	0.48	0.74
	PRE/R^2		0.036	0.003	0.109	0.003	0.022	0.254	0.005	0.039	0.058
	p		0.516	0.858	0.249	0.854	0.609	0.066	0.817	0.500	0.406

Measurement		2016	LAF5	LAF10	LAF 33	LAF50	LAF90	LAF95	RC	NC
H-1	1	80.0	54.5	53.1	50.2	50.0	49.4	49.1	46	46
	2	-	63.5	60.5	58.0	55.2	54.2	54.1	53	56
	3	57.1	59.0	55.8	47.1	45.7	38.0	35.5	49	52
H-2	1	58.3	65.2	61.6	43.2	40.1	38.7	38.5	51	51
	2	44.4	54.6	51.7	50.3	48.7	44.4	43.3	44	45
	3	64.7	55.2	53.1	51.8	50.9	36.9	34.3	45	45
M-1	1	42.9	54.2	52.7	49.8	48.8	44.9	43.6	46	45
	2	40.0	55.4	51.9	45.2	44.4	42.6	42.1	45	45
	3	50.0	49.2	46.4	44.7	44.2	40.9	40.1	41	44
M-2	1	61.9	64.1	60.9	53.2	52.9	52.2	52.0	53	59
	2	80.0	60.5	57.7	46.5	43.7	42.2	41.9	48	47
	3	50.0	59.5	56.9	47.1	46.5	45.1	44.9	47	48
L-1	1	39.3	62.2	61.5	60.8	60.5	59.1	58.6	56	55
	2	29.4	60.3	59.1	58.3	58.1	57.8	57.7	54	55
	3	43.5	64.3	64.0	63.4	63.1	60.2	59.8	57	60

HCAHPS 2016 Analysis	F*		0.00	0.06	2.18	2.43	2.49	2.29	0.87	0.70
	PRE/R^2		0.000	0.005	0.154	0.168	0.172	0.160	0.068	0.055
	p		0.967	0.809	0.165	0.145	0.140	0.156	0.370	0.421

Appendix B: Hospitals R1 & R2 Data

B.1 Hospital R2 HCAHPS Data

Table 30: Hospital R2 2014 & 2016 HCAHPS Survey Data – Responses from Entire Hospital

	Jan 2014 to Dec 2014			Jan 2016 to Dec 2016			
	NRC Avg	2014 GPH HCAHPS		NRC Avg	2016 GPH HCAHPS		GPH Diff
Questions by Units	Positive	Positive	n Size	Positive	Positive	n Size	2014 - 2016
HCAHPS: Did everything to help your pain	80%	83%	461	80%	83%	389	0.4%
HCAHPS: Drs explained things understandably	77%	78%	599	77%	79%	556	1.5%
HCAHPS: Drs listened carefully to you	80%	82%	597	80%	83%	554	0.5%
HCAHPS: Got help as soon as wanted	64%	68%	512	64%	63%	485	-5.9%
HCAHPS: Help going to bathroom when wanted	71%	76%	347	70%	79%	339	2.4%
HCAHPS: Nurses explained things well	75%	81%	596	76%	77%	558	-4.0%
HCAHPS: Nurses listened carefully to you	76%	82%	599	76%	81%	558	-1.5%
HCAHPS: Pain well controlled during stay	65%	67%	458	65%	69%	389	2.2%
HCAHPS: Quiet around room at night	60%	58%	599	59%	76%	553	18.2%
HCAHPS: Rate hospital	72%	70%	591	74%	75%	548	5.5%
HCAHPS: Received info re: sympt. to look for	90%	95%	558	91%	95%	512	-0.3%
HCAHPS: Room kept clean during stay	73%	69%	595	73%	80%	555	10.2%
HCAHPS: Staff described med side effects	51%	53%	321	51%	54%	278	0.3%
HCAHPS: Staff took preferences into account	45%	51%	575	45%	46%	539	-4.9%
HCAHPS: Talked about help you would need	85%	89%	555	86%	90%	507	0.7%
HCAHPS: Told what medicine was for	78%	78%	324	78%	80%	280	2.6%
HCAHPS: Treated w/courtesy/respect by Drs	87%	90%	598	87%	90%	554	0.5%
HCAHPS: Treated w/courtesy/respect Nurses	86%	90%	596	86%	90%	552	-0.6%
HCAHPS: Understood managing of health	54%	60%	580	54%	58%	544	-2.7%
HCAHPS: Understood purpose of medications	62%	62%	457	63%	61%	427	-1.0%
HCAHPS: Would recommend hospital to family	74%	73%	586	76%	77%	548	3.5%
IP: Family allowed to be with patient	88%	94%	571	88%	95%	535	0.6%
IP: Staff verified name/date of birth	0%	93%	577	0%	94%	544	0.9%
IP-A: Received discharge phone call	0%	80%	538	0%	73%	504	-7.5%
IP-A: Visit from nursing leader during stay	0%	94%	516	87%	90%	478	-3.6%
IP-A_AN: Anesthesiologist courtesy/respect	91%	91%	180	90%	92%	47	0.9%
IP-A_AN: Anesth. discussed pain management	74%	73%	177	76%	81%	47	8.0%
IP-A_AN: Anesthesiologist explained things	85%	87%	176	82%	92%	47	4.6%
IP-A_AN: Anesthesiologist listened carefully	84%	82%	176	85%	89%	47	7.6%
IP-A_DS: Excellent flavor	34%	41%	552	36%	51%	516	10.1%
IP-A_DS: Right temperature	59%	51%	559	58%	60%	536	8.6%

B.2 Hospital R1 Staff Survey Data

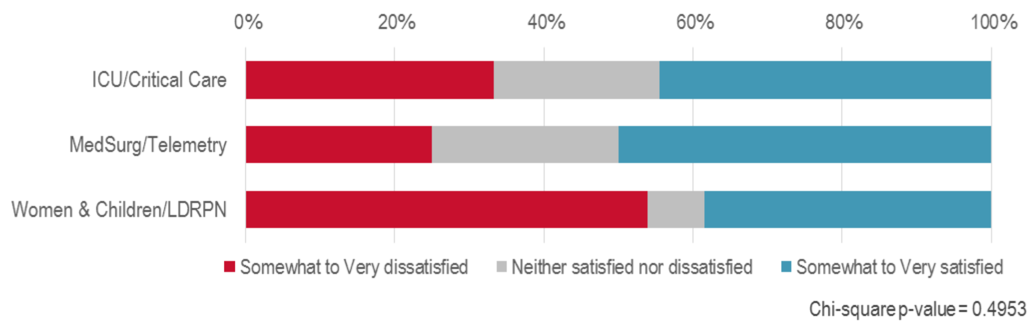


Figure 69: Hospital R1 Survey Response Data – Satisfaction with Overall Physical Workplace Environment

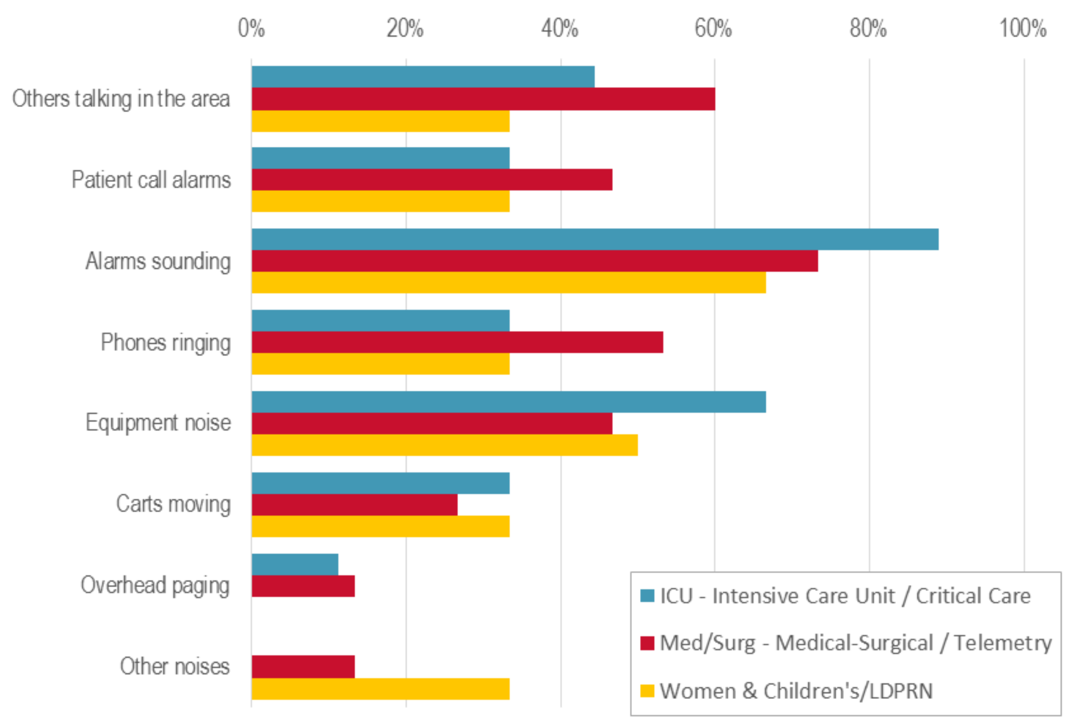


Figure 70: Hospital R1 Survey Response Data – Primary Sources of Noise

B.3 Hospital R2 Staff Survey Data

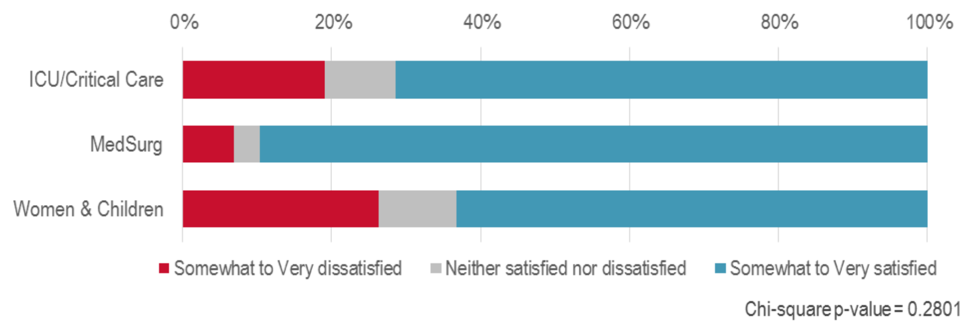


Figure 71: Hospital R2 Survey Response Data – Satisfaction with Overall Physical Workplace Environment

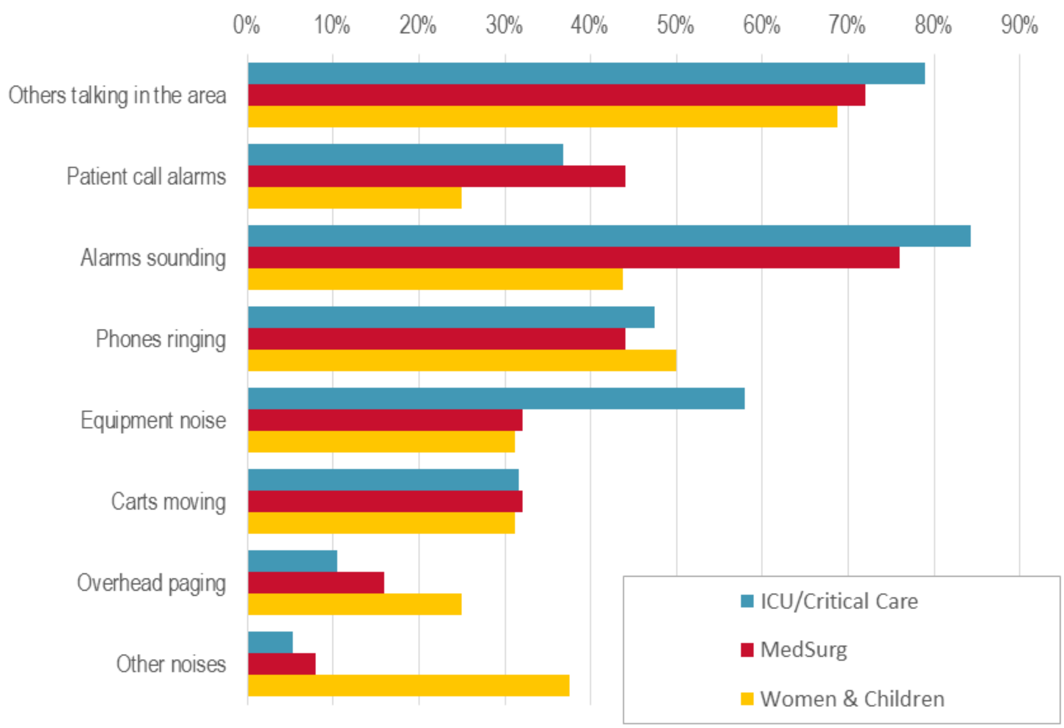


Figure 72: Hospital R2 Survey Response Data – Primary Sources of Noise

B.4 Hospitals R1 & R2 Staff Survey Comparison Data

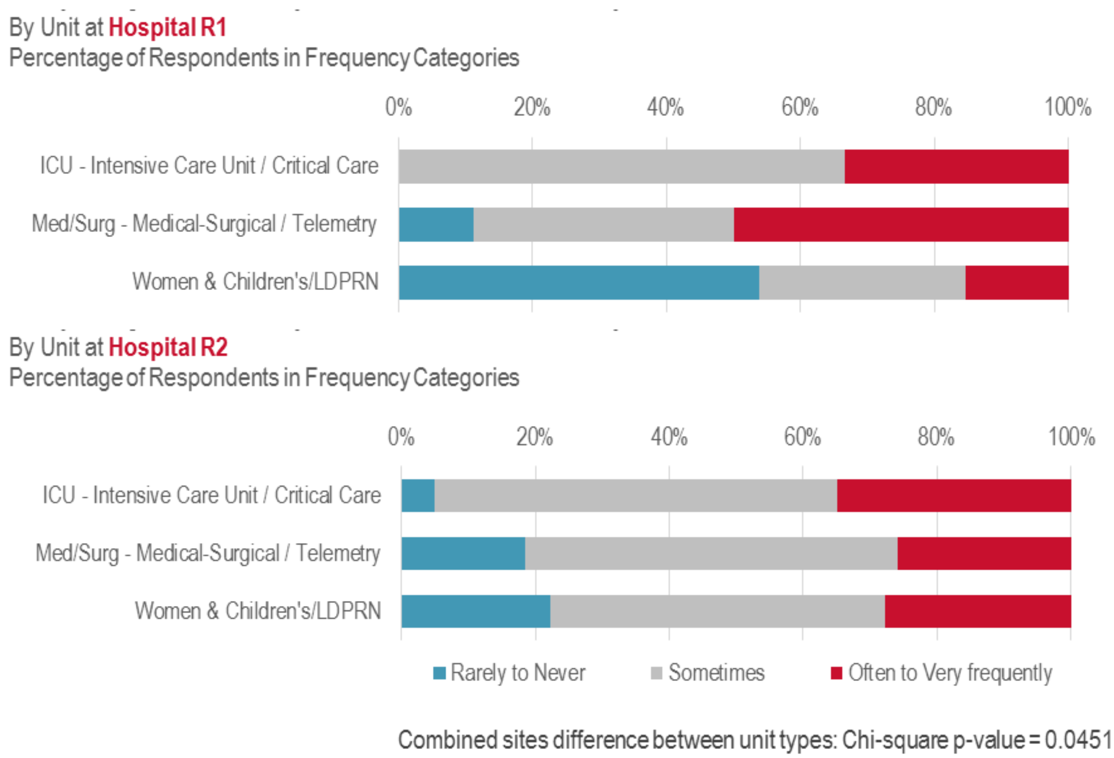


Figure 73: Hospitals R1 & R2 Survey Response Data – Frequency Noise Disrupts Patient Rest & Recuperation

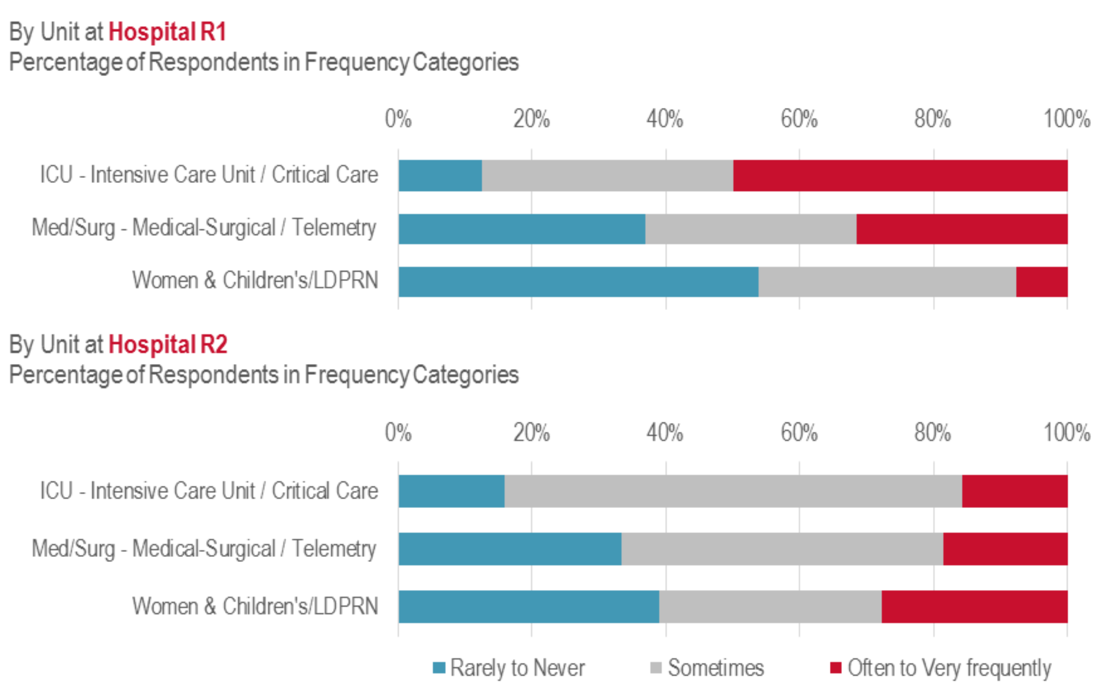


Figure 74: Hospitals R1 & R2 Survey Response Data – Frequency Noise Disrupts My Work

Table 31: Hospitals R1 & R2 Survey Response Data – Numerical Values

		Noise Disrupts Work			Noise Disrupts Patients		
Staff Survey Data	**J Sat**	**Rarely**	**S.times**	**Often**	**Rarely**	**S.times**	**Often**
Fremont ICU	3.65	12.50%	37.50%	50.00%	0.00%	66.67%	33.33%
Fremont Med-Surg	3.50	36.84%	31.58%	31.58%	11.11%	38.89%	50.00%
Fremont Women	7.00	53.85%	38.46%	7.69%	53.85%	30.77%	15.38%
GPH ICU	5.71	15.79%	68.42%	15.79%	5.00%	60.00%	35.00%
GPH Med-Surg	4.98	33.33%	48.15%	18.52%	18.52%	55.56%	25.93%
GPH Women	4.53	38.89%	33.33%	27.78%	22.22%	50.00%	27.78%

	Supports Job Functions			Sat. of Environment		
Staff Survey Data	**Agree**	**Neither**	**Disagree**	**Satisfied**	**Neither**	**Dissat.**
Fremont ICU	33.33%	22.22%	44.44%	44.44%	22.22%	33.33%
Fremont Med-Surg	50.00%	38.89%	11.11%	50.00%	25.00%	25.00%
Fremont Women	53.85%	46.15%	0.00%	38.46%	7.69%	53.85%
GPH ICU	68.42%	21.05%	10.53%	71.43%	9.52%	19.05%
GPH Med-Surg	81.48%	14.81%	3.70%	89.66%	3.45%	6.90%
GPH Women	66.67%	16.67%	16.67%	63.16%	10.53%	26.32%

B.5 Hospital R1 Acoustical Data

Table 32: Hospital R1 Measured Acoustical Data – 24-Hour Patient Room Values

Hospital R1 Overall — **Absolute Values**

Measurement		LAeq	LAmax	LAmin	LCpeak	LCeq	LZeq	LC-LA	LAE	SII (Norm)	SII (Rsd)
ICU	1	61.2	90.2	35.1	114.2	63.7	68.3	2.5	110.5	0.33	0.58
	2	58.1	88.6	43.6	109.1	61.2	68.8	3.1	107.5	0.44	0.69
Medical / Surgical	1	59.1	92.3	49.2	118.5	65.6	71.5	6.6	108.4	0.42	0.67
	2	53.3	94.8	30.1	103.7	59.3	72.4	6.0	102.7	0.59	0.83
	3	52.3	86.9	29.3	104.1	57.8	67.6	5.5	101.7	0.65	0.89
	4	57.1	95.9	34.9	111.9	60.2	68.3	3.1	106.5	0.48	0.73
	5	52.8	89.5	39.4	105.4	58.3	66.6	5.5	102.1	0.60	0.84
Women & Child	1	57.8	91.5	27.7	113.6	59.2	66.6	1.4	107.2	0.46	0.70
	2	51.9	89.3	30.3	110.6	56.0	65.6	4.1	101.2	0.64	0.88
	3	51.1	88.8	38.9	104.0	57.6	66.4	6.5	100.5	0.66	0.89
	4	43.7	69.6	39.2	98.6	56.9	69.4	13.2	93.1	0.88	0.96

Measurement		LAF5	LAF10	LAF 33	LAF50	LAF90	LAF95	RC	NC	Daytime 7A-10P	Nighttime 10P-7A
ICU	1	65.8	63.4	59.9	58.0	54.4	54.2	56	56	61.6	57.9
	2	62.9	60.2	53.1	51.6	49.5	48.7	53	52	60.3	52.8
Medical / Surgical	1	62.7	61.5	58.7	57.1	52.5	52.1	53	53	60.0	58.4
	2	55.9	50.7	45.1	44.4	43.0	42.6	48	48	55.9	49.8
	3	56.1	51.1	45.5	44.7	42.8	42.2	47	48	48.0	53.0
	4	61.6	56.5	41.9	39.3	37.3	36.9	52	54	55.9	54.9
	5	53.0	47.7	44.0	42.5	41.3	41.0	48	48	57.4	42.4
Women & Child	1	62.5	58.1	51.6	48.7	41.6	39.3	52	54	58.9	56.8
	2	55.3	50.2	42.8	42.2	35.7	34.3	47	46	57.2	46.6
	3	54.2	48.3	44.5	43.6	42.1	41.8	46	46	48.9	46.8
	4	44.7	44.2	43.4	43.0	41.7	41.4	37	41	43.3	43.7

Table 33: Hospital R1 Measured Acoustical Data – 24-Hour Unit Average Values

Hospital R1 Averages — **Absolute Values**

Measurement	LAeq	LAmax	LAmin	LCpeak	LCeq	LZeq	LC-LA	LAE	SII (Norm)	SII (Rsd)
ICU	59.9	89.5	41.2	112.4	62.6	68.5	2.8	109.3	0.39	0.63
Medical / Surgical	55.8	93.0	42.9	112.8	61.4	69.9	5.5	105.1	0.55	0.79
Women & Child	54.7	90.0	35.0	110.9	57.8	66.2	4.5	104.1	0.59	0.82

Measurement	LAF5	LAF10	LAF 33	LAF50	LAF90	LAF95	RC	NC	Daytime 7A-10P	Nighttime 10P-7A
ICU	64.6	62.1	57.7	55.9	52.6	52.3	55	54	61.0	56.1
Medical / Surgical	59.3	56.4	52.3	50.8	46.7	46.3	50	50	56.8	54.2
Women & Child	59.0	54.4	48.1	45.8	40.6	39.4	48	49	55.4	51.8

Table 34: Hospital R1 Measured Spectral Data – 24-Hour Patient Room Values

Hospital R1 Spectral Data

Measurement		31.5	63	125	250	500	1000	2000	4000	8000	16000
ICU	1	50.3	50.0	55.3	56.9	57.6	55.1	54.1	52.9	48.9	48.0
	2	49.7	49.0	52.0	55.0	55.3	52.4	50.0	49.1	46.8	48.3
Medical / Surgical	1	51.3	52.5	60.2	61.7	55.5	52.4	51.6	48.3	45.8	45.6
	2	53.3	49.2	50.4	52.0	48.2	49.4	46.1	43.4	43.2	45.0
	3	49.5	48.7	50.6	51.6	48.6	49.0	42.9	40.6	41.1	43.2
	4	54.3	50.9	48.3	52.2	52.9	51.5	52.1	44.8	46.0	45.2
	5	52.3	51.6	49.5	51.4	49.8	47.2	45.9	43.9	43.7	46.0
Women & Child	1	51.6	50.3	44.2	46.0	52.0	52.6	52.0	49.4	47.2	45.5
	2	51.9	46.5	47.1	46.0	49.3	48.0	44.1	41.9	42.9	45.0
	3	48.0	49.9	52.0	51.4	48.1	45.1	44.1	41.8	44.6	46.1
	4	52.9	48.7	51.2	49.5	40.0	34.7	34.9	36.4	39.4	42.8

Table 35: Hospital R1 Measured Occurrence Rate Ranges for Each Calculated Metric

Hospital R1 Occurrence Rate Ranges

Measurement		Leq	Lmin	Lmax	Lpk	Lpk
H-2	1	14	22	28	32	29
	2	19	10	29	31	31
Medical / Surgical	1	14	7	30	36	29
	2	22	10	37	40	29
	3	25	11	34	39	30
	4	30	6	43	47	34
	5	25	6	39	42	33
Women & Child	1	26	11	33	39	33
	2	29	11	42	45	34
	3	19	4	34	38	29
	4	5	3	21	25	18

Table 36: Hospital R1 Measured Nursing Station Data – 24-Hour Values

Hospital R1 Nursing **Absolute Values**

Measurement	LAeq	LAmax	LAmin	LCpeak	LCeq	LZeq	LC-LA	LAE	SII (Norm)	SII (Rsd)
ICU 1	57.1	86.4	38.4	108.3	61.3	65.2	4.2	106.4	0.50	0.74
ICU 2	58.0	85.6	42.3	108.0	62.3	66.0	4.3	107.4	0.46	0.70
Medical / Surgical	55.0	87.1	40.6	108.2	60.1	64.9	5.2	104.3	0.54	0.78
Women & Child	51.9	85.3	40.9	105.7	59.3	67.8	7.4	101.3	0.64	0.89

Measurement	LAF5	LAF10	LAF 33	LAF50	LAF90	LAF95	RC	NC	Daytime 7A-10P	Nighttime 10P-7A
ICU 1	63.2	60.5	53.2	49.9	44.3	43.5	52	50	56.8	55.8
ICU 2	63.9	61.1	54.1	50.8	46.5	46.0	53	51	56.3	56.3
Medical / Surgical	59.9	57.0	49.9	47.1	42.8	42.4	50	49	55.4	52.8
Women & Child	57.0	53.1	45.7	44.7	43.3	42.9	47	46	48.5	48.7

B.6 Hospital R2 Acoustical Data

Table 37: Hospital R2 Measured Acoustical Data – 24-Hour Patient Room Values

Hospital R2 Overall — Absolute Values

Measurement		LAeq	LAmax	LAmin	LCpeak	LCeq	LZeq	LC-LA	LAE	SII (Norm)	SII (Rsd)
ICU	1	59.0	94.1	48.2	113.3	61.6	68.5	2.6	108.4	0.41	0.65
	2	58.2	90.7	42.6	111.2	60.6	67.2	2.4	107.5	0.46	0.70
	3	55.7	90.4	38.7	107.0	59.2	68.1	3.5	105.0	0.51	0.76
	4	58.1	90.1	41.1	109.9	60.8	68.2	2.7	107.5	0.44	0.69
Medical / Surgical	1	56.3	89.6	33.2	109.2	62.1	72.2	5.8	105.7	0.52	0.76
	2	59.7	95.5	36.8	124.3	63.2	71.6	3.5	103.2	0.40	0.65
	3	52.7	91.1	29.1	108.7	57.4	67.0	4.7	102.1	0.61	0.85
	4	56.9	93.0	38.8	109.1	60.0	66.9	3.1	106.3	0.51	0.75
Women & Child	1	52.1	93.0	36.1	112.5	57.3	69.2	5.2	101.5	0.63	0.86
	2	53.5	90.6	47.0	105.4	57.3	66.8	3.8	102.8	0.59	0.84
	3	54.4	88.7	37.1	109.8	58.8	66.1	4.4	103.8	0.57	0.82
	4	55.3	88.6	45.7	108.1	58.0	65.9	2.7	104.7	0.53	0.78

Measurement		LAF5	LAF10	LAF 33	LAF50	LAF90	LAF95	RC	NC	Daytime 7A-10P	Nighttime 10P-7A
H-2	1	62.4	58.5	52.3	50.4	49.4	49.3	54	54	62.0	57.0
	2	63.9	58.6	51.9	48.2	44.5	44.3	53	55	57.0	48.5
	3	61.5	57.7	44.3	42.5	41.1	40.8	51	51	57.0	51.0
M-1	1	64.1	61.7	55.0	51.6	44.6	44.0	53	53	56.6	56.3
	2	62.3	59.1	50.3	45.6	42.1	41.1	51	50	58.7	47.6
	3	65.4	62.0	54.5	50.5	40.5	39.5	54	55	0.0	0.0
M-2	1	56.5	53.1	46.7	44.1	38.7	38.3	48	48	55.1	44.6
	2	62.1	58.4	48.2	44.2	42.4	42.0	52	50	59.3	47.8
	3	51.8	47.4	42.3	41.5	38.4	38.1	47	47	47.4	49.7
L-1	1	55.7	52.8	49.3	49.0	48.2	48.0	49	48	53.6	53.4
	2	60.1	57.3	51.2	50.7	40.6	39.4	49	48	57.3	53.8
	3	58.7	53.6	47.6	47.2	46.7	46.6	50	50	58.8	55.7

Table 38: Hospital R2 Measured Acoustical Data – 24-Hour Unit Average Values

Hospital R2 Averages — Absolute Values

Measurement	LAeq	LAmax	LAmin	LCpeak	LCeq	LZeq	LC-LA	LAE	SII (Norm)	SII (Rsd)
ICU	57.9	91.6	44.2	110.9	60.6	68.0	2.8	107.3	0.46	0.70
Medical / Surgical	57.1	92.9	35.8	118.7	61.2	70.1	4.4	104.6	0.51	0.75
Women & Child	54.0	90.6	43.8	109.7	57.9	67.2	4.1	103.4	0.58	0.82

Measurement	LAF5	LAF10	LAF 33	LAF50	LAF90	LAF95	RC	NC	Daytime 7A-10P	Nighttime 10P-7A
ICU	63.1	59.4	52.2	49.3	45.9	45.7	53	53	58.8	54.5
Medical / Surgical	62.6	59.2	51.0	47.0	41.2	40.5	51	51	58.0	46.9
Women & Child	57.6	54.0	48.6	48.2	45.2	44.9	49	48	56.0	53.6

Table 39: Hospital R2 Measured Spectral Data – 24-Hour Patient Room Values

Hospital R2 Spectral Data

Measurement		31.5	63	125	250	500	1000	2000	4000	8000	16000
H-2	1	50.2	49.2	51.3	54.5	55.8	53.8	52.1	49.4	44.9	46.7
	2	54.0	48.6	50.3	52.5	53.0	51.4	53.8	45.9	44.1	45.2
	3	51.0	48.8	50.6	52.2	52.2	50.8	49.4	45.3	43.5	46.1
	4	51.2	46.9	50.6	54.2	54.2	53.8	51.2	48.0	42.7	43.6
Medical / Surgical	1	52.8	57.6	53.4	54.0	54.7	51.4	47.6	45.0	43.9	45.6
	2	57.8	54.8	51.6	54.3	54.7	56.1	52.3	49.7	44.1	45.2
	3	51.7	47.6	48.1	50.6	50.6	46.6	46.4	43.4	43.1	45.9
	4	49.3	46.5	48.4	52.7	55.9	51.6	48.3	44.9	41.9	43.5
Women & Child	1	52.8	49.1	48.9	49.5	46.4	48.3	45.8	43.0	42.9	45.7
	2	46.7	43.5	48.0	51.9	51.1	48.4	46.5	43.5	42.6	45.0
	3	49.5	48.5	50.2	52.4	52.6	49.8	45.9	43.8	41.5	43.2
	4	47.3	47.2	46.3	50.3	51.7	51.3	48.3	45.0	44.1	46.2

Table 40: Hospital R2 Measured Occurrence Rate Ranges for Each Calculated Metric

Hospital R2 Occurrence Rate Ranges

Measurement		Leq	Lmin	Lmax	Lpk	Lpk
H-2	1	20	6	37	38	33
	2	23	8	38	42	34
	3	25	9	37	41	34
	4	22	11	36	42	38
Medical / Surgical	1	24	13	39	45	37
	2	30	16	39	46	41
	3	25	10	40	42	34
	4	26	6	40	44	35
Women & Child	1	27	5	40	40	31
	2	15	1	31	38	31
	3	23	13	39	44	35
	4	20	2	36	40	35

Table 41: Hospital R2 Measured Nursing Station Data – 24-Hour Values

Hospital R2 Nursing

Absolute Values

Measurement	LAeq	LAmax	LAmin	LCpeak	LCeq	LZeq	LC-LA	LAE	SII (Norm)	SII (Rsd)
ICU	56.6	89.9	42.8	109.2	60.9	68.1	4.3	106.0	0.51	0.76
Medical / Surgical	54.7	87.4	31.1	104.7	60.0	68.4	5.3	104.1	0.56	0.81
Women & Child	52.9	87.3	37.1	106.8	58.2	63.7	5.4	102.2	0.61	0.86

Measurement	LAF5	LAF10	LAF 33	LAF50	LAF90	LAF95	RC	NC	Daytime 7A-10P	Nighttime 10P-7A
ICU	61.5	57.9	51.5	48.3	44.8	44.5	51	51	58.4	55.8
Medical / Surgical	60.3	57.0	49.1	45.6	41.4	41.1	50	48	51.7	50.9
Women & Child	57.5	54.3	46.7	42.6	39.1	38.8	48	47	52.1	49.3

Table 42: Hospital R1 & R2 Staff Survey Correlations – Job Satisfaction

Patient Room Data	LAeq	LAmax	LAmin	LCeq	LZeq	LC-LA	LAE	LCpeak	LA05
F*	0.52	0.21	1.59	2.85	3.10	0.02	0.53	0.10	0.13
PRE/R^2	0.11	0.05	0.28	0.42	0.44	0.00	0.12	0.03	0.03
p	0.511	0.674	0.276	0.166	0.153	0.900	0.506	0.765	0.733

	LA10	LA33	LA50	LA90	LA95	RC	NC	Normal	Raised
F*	0.63	2.68	4.77	4.33	4.66	0.59	0.41	0.61	0.57
PRE/R^2	0.14	0.40	0.54	0.52	0.54	0.13	0.09	0.13	0.12
p	0.471	0.177	0.094	0.106	0.097	0.485	0.559	0.478	0.493

Table 43: Hospital R1 & R2 Staff Survey Correlations – Satisfaction of Environment – Satisfied

Patient Room Data	LAeq	LAmax	LAmin	LCeq	LZeq	LC-LA	LAE	LCpeak	LA05
F*	0.03	2.52	0.00	0.10	1.38	0.03	0.12	2.50	0.25
PRE/R^2	0.01	0.39	0.00	0.02	0.26	0.01	0.03	0.38	0.06
p	0.875	0.188	0.993	0.768	0.306	0.875	0.742	0.189	0.645

	LA10	LA33	LA50	LA90	LA95	RC	NC	Normal	Raised
F*	0.21	0.08	0.49	0.53	0.41	0.10	0.03	0.03	0.02
PRE/R^2	0.05	0.02	0.11	0.12	0.09	0.03	0.01	0.01	0.00
p	0.670	0.792	0.523	0.507	0.559	0.763	0.862	0.871	0.898

Table 44: Hospital R1 & R2 Staff Survey Correlations – Satisfaction of Environment – Neither Satisfied nor Dissatisfied

Patient Room Data	LAeq	LAmax	LAmin	LCeq	LZeq	LC-LA	LAE	LCpeak	LA05
F*	0.40	0.02	1.35	1.46	0.36	0.03	1.19	0.29	0.03
PRE/R^2	0.09	0.00	0.25	0.27	0.08	0.01	0.23	0.07	0.01
p	0.561	0.902	0.310	0.293	0.581	0.869	0.337	0.617	0.873

	LA10	LA33	LA50	LA90	LA95	RC	NC	Normal	Raised
F*	0.22	2.75	6.79	6.56	6.10	0.28	0.45	0.41	0.41
PRE/R^2	0.05	0.41	0.63	0.62	0.60	0.07	0.10	0.09	0.09
p	0.660	0.173	0.060	0.063	0.069	0.622	0.541	0.558	0.559

Table 45: Hospital R1 & R2 Staff Survey Correlations – Satisfaction of Environment – Dissatisfied

Patient Room Data	LAeq	LAmax	LAmin	LCeq	LZeq	LC-LA	LAE	LCpeak	LA05
F*	0.31	4.33	0.31	1.15	5.94	0.01	0.01	2.40	0.52
PRE/R^2	0.07	0.52	0.07	0.22	0.60	0.00	0.00	0.38	0.12
p	0.609	0.106	0.607	0.344	0.071	0.918	0.925	0.196	0.509

	LA10	LA33	LA50	LA90	LA95	RC	NC	Normal	Raised
F*	0.75	0.13	0.00	0.00	0.01	0.51	0.36	0.32	0.26
PRE/R^2	0.16	0.03	0.00	0.00	0.00	0.11	0.08	0.07	0.06
p	0.434	0.735	0.953	0.979	0.917	0.516	0.583	0.604	0.634

Table 46: Hospital R1 & R2 Staff Survey Correlations – Supports Job Functions – Agree

Patient Room Data	LAeq	LAmax	LAmin	LCeq	LZeq	LC-LA	LAE	LCpeak	LA05
F*	0.58	1.97	0.11	0.43	0.11	0.10	1.87	0.82	0.11
PRE/R^2	0.13	0.33	0.03	0.10	0.03	0.02	0.32	0.17	0.03
p	0.490	0.233	0.761	0.548	0.761	0.771	0.243	0.417	0.758
	LA10	LA33	LA50	LA90	LA95	RC	NC	Normal	Raised
	0.23	2.27	4.96	4.29	3.51	0.36	0.46	0.58	0.63
	0.05	0.36	0.55	0.52	0.47	0.08	0.10	0.13	0.14
	0.656	0.206	0.090	0.107	0.134	0.581	0.537	0.488	0.471

Table 47: Hospital R1 & R2 Staff Survey Correlations – Supports Job Functions – Neither Agree or Disagree

Patient Room Data	LAeq	LAmax	LAmin	LCeq	LZeq	LC-LA	LAE	LCpeak	LA05
F*	0.54	0.05	0.41	0.32	0.49	1.41	0.15	0.42	0.78
PRE/R^2	0.12	0.01	0.09	0.07	0.11	0.26	0.04	0.10	0.16
p	0.505	0.838	0.556	0.603	0.522	0.301	0.722	0.551	0.428
	LA10	LA33	LA50	LA90	LA95	RC	NC	Normal	Raised
	1.00	0.25	0.13	0.19	0.27	1.21	0.51	0.91	0.86
	0.20	0.06	0.03	0.05	0.06	0.23	0.11	0.19	0.18
	0.374	0.642	0.733	0.684	0.633	0.332	0.513	0.393	0.407

Table 48: Hospital R1 & R2 Staff Survey Correlations – Supports Job Functions – Disagree

Patient Room Data	LAeq	LAmax	LAmin	LCeq	LZeq	LC-LA	LAE	LCpeak	LA05
F*	3.00	1.51	0.85	1.74	0.04	1.99	5.21	0.15	1.33
PRE/R^2	0.43	0.27	0.17	0.30	0.01	0.33	0.57	0.04	0.25
p	0.158	0.287	0.409	0.258	0.856	0.231	0.085	0.721	0.314
	LA10	LA33	LA50	LA90	LA95	RC	NC	Normal	Raised
	2.37	9.36	28.49	29.16	25.17	3.75	2.40	4.49	4.62
	0.37	0.70	0.88	0.88	0.86	0.48	0.38	0.53	0.54
	0.199	0.038	0.006	0.006	0.007	0.125	0.196	0.101	0.098

Table 49: Hospital R1 & R2 Staff Survey Correlations – Noise Disrupts My Work – Rarely

Patient Room Data	LAeq	LAmax	LAmin	LCeq	LZeq	LC-LA	LAE	LCpeak	LA05
F*	13.44	0.02	1.51	5.37	0.65	5.90	13.33	0.02	8.87
PRE/R^2	0.77	0.00	0.27	0.57	0.14	0.60	0.77	0.00	0.69
p	0.021	0.908	0.286	0.081	0.465	0.072	0.022	0.900	0.041
	LA10	LA33	LA50	LA90	LA95	RC	NC	Normal	Raised
	13.78	9.55	5.22	5.38	5.90	33.27	26.40	27.28	24.69
	0.77	0.70	0.57	0.57	0.60	0.89	0.87	0.87	0.86
	0.021	0.037	0.084	0.081	0.072	0.004	0.007	0.006	0.008

Table 50: Hospital R1 & R2 Staff Survey Correlations – Noise Disrupts My Work – Sometimes

Patient Room Data	LAeq	LAmax	LAmin	LCeq	LZeq	LC-LA	LAE	LCpeak	LA05
F*	0.77	0.16	0.05	0.11	0.00	2.04	0.50	0.04	1.65
PRE/R^2	0.16	0.04	0.01	0.03	0.00	0.34	0.11	0.01	0.29
p	0.430	0.708	0.833	0.755	0.953	0.227	0.520	0.843	0.268
	LA10	**LA33**	**LA50**	**LA90**	**LA95**	**RC**	**NC**	**Normal**	**Raised**
	0.88	0.02	0.10	0.07	0.05	1.06	1.56	0.83	0.80
	0.18	0.00	0.02	0.02	0.01	0.21	0.28	0.17	0.17
	0.402	0.900	0.766	0.807	0.839	0.362	0.280	0.413	0.421

Table 51: Hospital R1 & R2 Staff Survey Correlations – Noise Disrupts My Work – Often

Patient Room Data	LAeq	LAmax	LAmin	LCeq	LZeq	LC-LA	LAE	LCpeak	LA05
F*	1.66	0.26	0.97	2.70	0.60	0.30	2.30	0.00	0.60
PRE/R^2	0.29	0.06	0.19	0.40	0.13	0.07	0.37	0.00	0.13
p	0.268	0.637	0.381	0.176	0.482	0.612	0.204	0.957	0.480
	LA10	**LA33**	**LA50**	**LA90**	**LA95**	**RC**	**NC**	**Normal**	**Raised**
	1.50	7.70	24.99	18.80	17.69	1.82	1.19	2.10	2.09
	0.27	0.66	0.86	0.82	0.82	0.31	0.23	0.34	0.34
	0.288	0.050	0.007	0.012	0.014	0.249	0.337	0.221	0.222

Table 52: Hospital R1 & R2 Staff Survey Correlations – Noise Disrupts Patients – Rarely

Patient Room Data	LAeq	LAmax	LAmin	LCeq	LZeq	LC-LA	LAE	LCpeak	LA05
F*	4.08	0.21	3.26	7.33	2.58	1.06	3.80	0.09	2.58
PRE/R^2	0.51	0.05	0.45	0.65	0.39	0.21	0.49	0.02	0.39
p	0.113	0.669	0.145	0.054	0.183	0.361	0.123	0.782	0.184
	LA10	**LA33**	**LA50**	**LA90**	**LA95**	**RC**	**NC**	**Normal**	**Raised**
	4.87	6.69	5.40	5.73	6.74	6.07	5.66	5.46	5.03
	0.55	0.63	0.57	0.59	0.63	0.60	0.59	0.58	0.56
	0.092	0.061	0.081	0.075	0.060	0.069	0.076	0.080	0.088

Table 53: Hospital R1 & R2 Staff Survey Correlations – Noise Disrupts Patients – Sometimes

Patient Room Data	LAeq	LAmax	LAmin	LCeq	LZeq	LC-LA	LAE	LCpeak	LA05
F*	6.71	0.06	0.64	2.61	0.52	6.96	4.15	0.17	6.58
PRE/R^2	0.63	0.01	0.14	0.40	0.11	0.64	0.51	0.04	0.62
p	0.061	0.822	0.469	0.181	0.512	0.058	0.111	0.698	0.062
	LA10	**LA33**	**LA50**	**LA90**	**LA95**	**RC**	**NC**	**Normal**	**Raised**
	9.01	4.05	2.42	2.41	2.65	14.70	6.77	11.65	11.05
	0.69	0.50	0.38	0.38	0.40	0.79	0.63	0.74	0.73
	0.040	0.115	0.195	0.195	0.179	0.019	0.060	0.027	0.029

Table 54: Hospital R1 & R2 Staff Survey Correlations – Noise Disrupts Patients – Often

Patient Room Data	LAeq	LAmax	LAmin	LCeq	LZeq	LC-LA	LAE	LCpeak	LA05
F*	0.30	1.44	3.54	2.35	2.94	0.11	0.50	0.00	0.06
PRE/R^2	0.07	0.26	0.47	0.37	0.42	0.03	0.11	0.00	0.02
p	0.616	0.296	0.133	0.200	0.162	0.752	0.520	0.991	0.815

	LA10	LA33	LA50	LA90	LA95	RC	NC	Normal	Raised
	0.30	1.28	1.71	1.87	2.08	0.29	0.56	0.29	0.26
	0.07	0.24	0.30	0.32	0.34	0.07	0.12	0.07	0.06
	0.612	0.322	0.261	0.243	0.223	0.618	0.494	0.618	0.640

Appendix C: Perceptual Test Data

C.1 Test Item Verification Data

Table 55: Perceptual Test Audio File Verification Data – Measured in Nebraska Acoustics Listening Laboratory

Measurement	LAeq	LAmax	LAmin	LCeq	LZeq	LC-LA	LAE	LCpeak	LCpeak Range	LAF 5	LAF 10	LAF 50	LAF 90	LAF 95	
HS 3 - 1 - 1	65.6	80.0	52.4	67.1	71.9	1.5	80.4	95.8	24	70.7	68.2	61.9	55.4	54.7	dB
HS 3 - 1 - 2	65.2	81.9	52.4	66.6	72.8	1.4	80.0	94.9	26	67.5	65.2	59.1	54.7	54.0	dB
HS 3 - 1 - 3	65.5	81.4	51.0	66.8	71.9	1.3	80.2	94.4	25	70.2	67.2	58.9	54.2	53.0	dB
HS 3 - 2 - 1	65.1	82.8	49.8	66.4	72.1	1.3	79.9	96.3	29	68.4	65.1	58.3	52.5	51.8	dB
HS 3 - 2 - 2	65.5	79.2	55.8	67.6	72.3	2.1	80.3	94.8	23	71.6	69.3	61.7	57.1	56.6	dB
HS 3 - 2 - 3	64.7	76.1	59.3	67.4	72.2	2.7	79.5	88.6	11	69.3	67.1	63.0	60.3	60.0	dB
HS 3 - 3 - 1	66.1	78.5	55.8	68.2	72.9	2.1	80.9	96.5	24	72.5	70.4	61.1	57.6	57.1	dB
HS 3 - 3 - 2	65.7	75.8	58.6	68.1	73.0	2.4	80.5	94.2	18	70.9	69.1	62.7	59.8	59.3	dB
HS 3 - 3 - 3	65.6	74.7	58.8	68.1	72.8	2.5	80.4	89.4	13	70.8	69.0	62.9	60.0	59.7	dB
HS 3 - 4 - 1	64.9	72.8	58.8	67.9	72.6	3.0	79.6	87.1	8	69.3	67.6	63.3	61.0	60.4	dB
HS 3 - 4 - 2	64.8	77.0	55.0	67.6	72.4	2.7	79.6	93.8	21	70.4	67.0	62.0	57.5	56.5	dB
HS 3 - 4 - 3	64.9	74.8	58.6	68.0	72.9	3.1	79.7	91.7	14	69.2	66.8	63.7	60.9	59.9	dB
HS 3 - 5 - 1	65.1	72.3	61.8	68.2	73.0	3.2	79.8	87.0	7	68.5	67.0	64.1	62.6	62.4	dB
HS 3 - 5 - 2	64.8	77.0	58.5	67.9	72.7	3.1	79.6	92.5	16	70.0	67.2	62.5	60.1	59.6	dB
HS 3 - 5 - 3	65.2	73.5	59.1	68.0	72.8	2.8	80.0	88.5	9	70.3	68.2	63.5	61.7	61.4	dB
Minimum	64.7	72.3	49.8	66.4	71.9	1.3	79.5	87.0	7	67.5	65.1	58.3	52.5	51.8	dB
Average	65.3	78.4	57.5	67.6	72.6	2.4	80.0	93.4	22.2	70.2	67.9	62.2	59.2	58.7	dB
Maximum	66.1	82.8	61.8	68.2	73.0	3.2	80.9	96.5	29	72.5	70.4	64.1	62.6	62.4	dB

C.2 Participant Questionnaire

Table 56: Perceptual Test Participant Questionnaire – Included Age, Gender, & Weinstein Noise Sensitivity Scale

Participant Questionnaire

Subject ID:

Age:

Gender: MALE FEMALE

Weinstein Noise Sensitivity Scale

Instructions:
Circle the number corresponding to how well you agree or disagree. Don't be disturbed by the reversals of order from one line to another.

1	No one should mind much if someone turns up his stereo full blast once in a while.	AGREE	1	2	3	4	5	6	DISAGREE
2	I am easily awakened by noise.	AGREE	6	5	4	3	2	1	DISAGREE
3	I get annoyed when my neighbors are noisy.	AGREE	6	5	4	3	2	1	DISAGREE
4	I get used to most noises without much difficulty.	AGREE	1	2	3	4	5	6	DISAGREE
5	Sometimes noises get on my nerves and get me irritated.	AGREE	6	5	4	3	2	1	DISAGREE
6	Even music I normally like will bother me if I'm trying to concentrate.	AGREE	6	5	4	3	2	1	DISAGREE
7	I find it hard to relax in a place that's noisy.	AGREE	6	5	4	3	2	1	DISAGREE
8	I'm good at concentrating no matter what is going on around me.	AGREE	1	2	3	4	5	6	DISAGREE
9	I get mad at people who make noise that keeps me from falling asleep or getting work done.	AGREE	6	5	4	3	2	1	DISAGREE
10	I am sensitive to noise.	AGREE	6	5	4	3	2	1	DISAGREE

C.3 Positive and Negative Affect Scale

Table 57: Perceptual Test Participant Positive & Negative Affect Scale – Identical Forms Presented Before & After Listening to the Audio Files

Subject ID:

Positive and Negative Affect Schedule (PANAS-SF)

Indicate the extent you feel right now, at this moment.

		Very slightly or not at all	A little	Moderately	Quite a bit	Extremely
1	Interested	1	2	3	4	5
2	Distressed	1	2	3	4	5
3	Excited	1	2	3	4	5
4	Upset	1	2	3	4	5
5	Strong	1	2	3	4	5
6	Guilty	1	2	3	4	5
7	Scared	1	2	3	4	5
8	Hostile	1	2	3	4	5
9	Enthusiastic	1	2	3	4	5
10	Proud	1	2	3	4	5
11	Irritable	1	2	3	4	5
12	Alert	1	2	3	4	5
13	Ashamed	1	2	3	4	5
14	Inspired	1	2	3	4	5
15	Nervous	1	2	3	4	5
16	Determined	1	2	3	4	5
17	Attentive	1	2	3	4	5
18	Jittery	1	2	3	4	5
19	Active	1	2	3	4	5
20	Afraid	1	2	3	4	5

C.4 Raw Data – PANAS Survey

Table 58: Perceptual Test Data – PANAS Survey Results – All Subjects

Before Test — Subject ID

	1	2	3	5	6	7	8	11	12	13	14	15	16	17	18
Positive PANAS	43	26	16	32	34	28	31	35	38	50	27	39	25	42	39
Negative PANAS	19	14	19	10	11	12	11	16	20	10	11	18	13	15	19

	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Positive PANAS	37	27	27	33	23	22	32	26	37	21	42	35	42	41	36
Negative PANAS	10	11	20	11	10	10	12	14	13	10	10	13	14	16	11

After Test — Subject ID

	1	2	3	5	6	7	8	11	12	13	14	15	16	17	18
Positive PANAS	42	17	13	14	22	24	24	25	32	34	20	34	25	37	26
Negative PANAS	18	17	13	14	14	17	22	13	15	13	15	26	13	12	22

	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Positive PANAS	36	16	23	17	12	28	18	12	36	21	28	25	39	34	27
Negative PANAS	10	13	17	15	13	18	12	15	11	21	21	15	10	19	13

Difference — Subject ID

	1	2	3	5	6	7	8	11	12	13	14	15	16	17	18
Positive PANAS	-1	-9	-3	-18	-12	-4	-7	-10	-6	-16	-7	-5	0	-5	-13
Negative PANAS	-1	3	-6	4	3	5	11	-3	-5	3	4	8	0	-3	3

	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Positive PANAS	-1	-11	-4	-16	-11	6	-14	-14	-1	0	-14	-10	-3	-7	-9
Negative PANAS	0	2	-3	4	3	8	0	1	-2	11	11	2	-4	3	2

Positive Difference: Increase in PANAS (Larger After)

Negative Difference: Decrease in PANAS (Larger Before)

C.5 Raw Data – Subject Heart Rate

Table 59: Perceptual Test Data – Subject Heart Rate – All Tested Subjects

Start of Test	
Min: 55	Max: 105
Average: 71.3	

End of Test	
Min: 56	Max: 105
Average: 72.7	

C.6 Raw Data – Subject Histograms

Table 60: Perceptual Test Data – Subject Age Histogram – All Tested Subjects

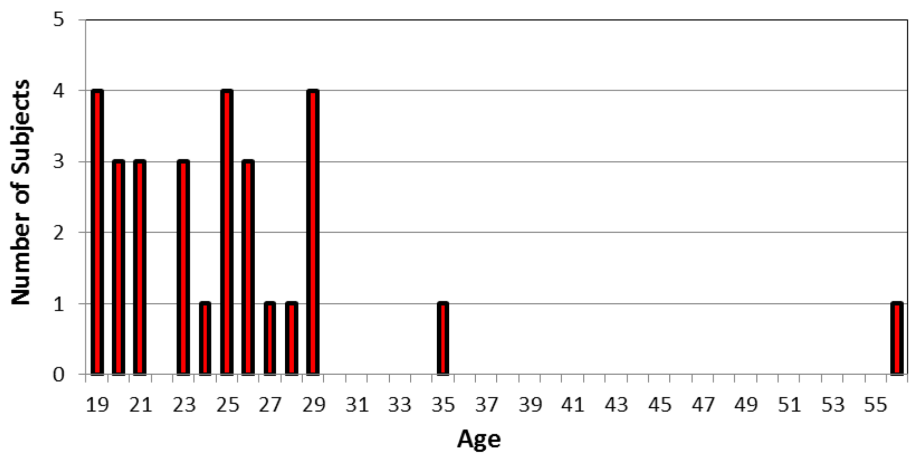
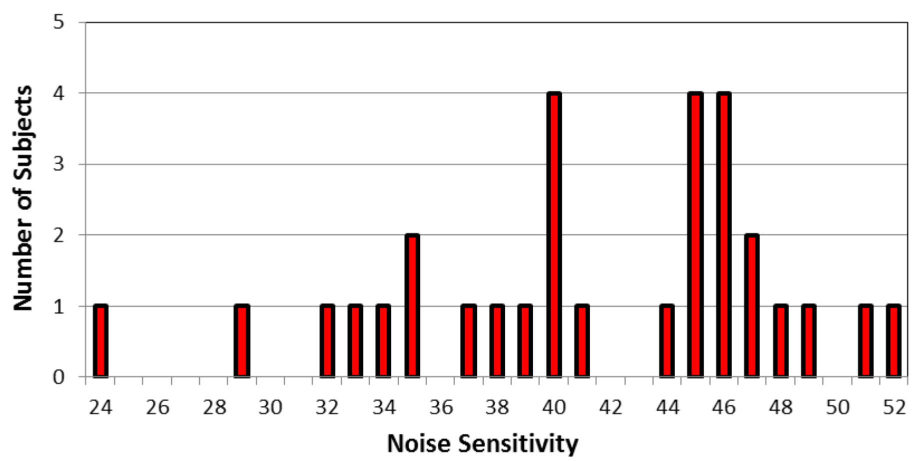


Table 61: Perceptual Test Data – Subject Noise Sensitivity Histogram – All Tested Subjects



C.7 Perceptual Test Correlations – 65 dBA Testing Group

Table 62: Perceptual Test Data – Correlations of Subject Annoyance – 65 dBA Testing Group

65 dBA Level	Occ Range	LAeq	LAmax	LAmin	LCeq	LZeq	LC-LA
F*	12.49	17.82	8.81	17.46	8.20	8.95	9.94
PRE/R^2	0.4716	0.5601	0.3862	0.5551	0.3695	0.3900	0.4151
p	0.0037	0.0010	0.0109	0.0011	0.0133	0.0104	0.0076

	LAE	LCpeak	LAF 05	LAF 10	LAF 50	LAF 90	LAF 95
F*	17.82	9.83	27.62	28.45	9.16	13.63	16.53
PRE/R^2	0.5601	0.4125	0.6636	0.6702	0.3954	0.4933	0.5415
p	0.0010	0.0079	0.0002	0.0001	0.0097	0.0027	0.0013

C.8 Perceptual Test Correlations – 55 dBA Testing Group

Table 63: Perceptual Test Data – Correlations of Subject Annoyance – 55 dBA Testing Group

55 dBA Level	Occ Range	LAeq	LAmax	LAmin	LCeq	LZeq	LC-LA
F*	8.29	6.72	10.13	9.77	10.57	7.75	6.09
PRE/R^2	0.3719	0.3244	0.4197	0.4109	0.4301	0.3563	0.3031
p	0.0129	0.0223	0.0072	0.0080	0.0063	0.0155	0.0283

	LAE	LCpeak	LAF 05	LAF 10	LAF 50	LAF 90	LAF 95
F*	6.72	5.59	20.20	13.41	10.91	8.82	8.03
PRE/R^2	0.3244	0.2852	0.5906	0.4893	0.4380	0.3865	0.3645
p	0.0223	0.0344	0.0006	0.0029	0.0057	0.0109	0.0141

C.9 Perceptual Test Correlations – 65 dBA vs 55 dBA

Table 64: Perceptual Test Data – Correlations of Subject Annoyance – 65 dBA vs 55 dBA Testing Groups

		1-Way ANOVA Within Subjects Design		
	1-Way ANOVA	Bet (55 vs 65)	Within (Ind Resp)	Within (Item*Grp)
F*	4.99	4.9	7.06	1.4
PRE/R^2	0.1513			
p	0.0337	0.0352	0.0001	0.08

C.10 Perceptual Test Correlations – Confounding Variables – 65 dBA

Table 65: Perceptual Test Data – Correlations With Confounding Variables – 65 dBA Testing Group

		1-Way ANOVA Within Subjects Design		
Gender	1-Way ANOVA	Bet (M vs F)	Within (Ind Resp)	Within (Item*Grp)
F*	0.10	0.21	2.28	1.01
PRE/R^2	0.0080			
p	0.7515	0.652	0.0069	0.4411

Age	1-Way ANOVA	Between (Age)	Within (Ind Resp)	Within (Item*Grp)
F*	1.18	0.34	2.68	1.11
PRE/R^2	0.0830			
p	0.2977	0.9245	0.0034	0.3171

Noise Sensitivity	1-Way ANOVA	Between (NS)	Within (Ind Resp)	Within (Item*Grp)
F*	0.08	0.32	1.33	0.66
PRE/R^2	0.0065			
p	0.7759	0.931	0.2307	0.9625

C.11 Perceptual Test Correlations – Confounding Variables – 55 dBA

Table 66: Perceptual Test Data – Correlations With Confounding Variables – 55 dBA Testing Group

		1-Way ANOVA Within Subjects Design		
Gender	1-Way ANOVA	Bet (M vs F)	Within (Ind Resp)	Within (Item*Grp)
F*	1.79	0.04	3.68	1.10
PRE/R^2	0.1211			
p	0.2037	0.8403	0.0001	0.3597

Age	1-Way ANOVA	Between (Age)	Within (Ind Resp)	Within (Item*Grp)
F*	0.07	3.60	3.12	0.94
PRE/R^2	0.0052			
p	0.7989	0.068	0.0006	0.6224

Noise Sensitivity	1-Way ANOVA	Between (NS)	Within (Ind Resp)	Within (Item*Grp)
F*	0.67	0.35	2.3	0.91
PRE/R^2	0.0489			
p	0.4284	0.917	0.0117	0.6844

C.12 Perceptual Test Correlations – Subject Affect – Positive PANAS

Table 67: Perceptual Test Data – Correlations With Positive PANAS – All Subjects

Positive PANAS	1-Way ANOVA Within Subjects Design		
Comparison	Bet (55 vs 65)	With (Bef vs Aft)	Within (Item*Grp)
F*	3.62	48.81	0.22
PRE/R^2			
p	0.0675	0.0001	0.645

Table 68: Perceptual Test Data – Correlations With Positive PANAS – 65 dBA Testing Group

Positive PANAS	1-Way ANOVA	Bet (PP Delta)	Within (Ind Resp)	Within (Item*Grp)
F*	13.18	2.95	2.26	1.27
PRE/R^2	0.5035			
p	0.0030	0.1024	0.0115	0.1227

Table 69: Perceptual Test Data – Correlations With Positive PANAS – 55 dBA Testing Group

Positive PANAS	1-Way ANOVA	Bet (PP Delta)	Within (Ind Resp)	Within (Item*Grp)
F*	1.01	0.43	2.94	0.66
PRE/R^2	0.0724			
p	0.3322	0.8701	0.0021	0.9748

C.13 Perceptual Test Correlations – Subject Affect – Negative PANAS

Table 70: Perceptual Test Data – Correlations With Negative PANAS – All Subjects

Negative PANAS	1-Way ANOVA Within Subjects Design		
Comparison	Bet (55 vs 65)	With (Bef vs Aft)	Within (Item*Grp)
F*	0.32	6.39	0.22
PRE/R^2			
p	0.5766	0.0174	0.6393

Table 71: Perceptual Test Data – Correlations With Negative PANAS – 65 dBA Testing Group

Negative PANAS	1-Way ANOVA	Bet (NP Delta)	Within (Ind Resp)	Within (Item*Grp)
F*	0.56	0.6	2.15	0.95
PRE/R^2	0.0414			
p	0.4673	0.7549	0.0168	0.6003

Table 72: Perceptual Test Data – Correlations With Negative PANAS – 55 dBA Testing Group

Negative PANAS	1-Way ANOVA	Bet (NP Delta)	Within (Ind Resp)	Within (Item*Grp)
F*	1.25	1.17	2.12	0.55
PRE/R^2	0.0880			
p	0.2829	0.4531	0.0208	0.9981