RELATING HOSPITAL ACOUSTICS TO STAFF OUTCOMES IN REAL AND SIMULATED SETTINGS

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RELATING HOSPITAL ACOUSTICS TO STAFF OUTCOMES IN REAL AND SIMULATED SETTINGS

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TABLE OF CONTENTS

Page

CHAPTER

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

$\bar{\alpha}$	Average absorption coefficient
ACLS	Advanced Cardiovascular Life Support
AHA	American Heart Association
ANSI	American National Standards Institute
ANOVA	Analysis of Variance
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
C50_500	Clarity Index at 500 Hz
dB	Decibels
dBA	A-weighted Decibels
dBC	C-weighted Decibels
f_s	Schroeder frequency
HART	Healthcare Acoustics Research Team
HE-BASQ	Healthcare Environments – Baseline Assessment for Safety & Quality
JCQ	Job Content Questionnaire
jnd	Just Noticeable Difference
LAeq	A-weighted Equivalent Sound Pressure Level (dBA)
LAeq_delta	Occupied minus unoccupied dBA level (dBA)
LAmax	A-weighted Maximum Sound Pressure Level (dBA)
LAmax_occup_rate	Percentage of time that occupied LAmax exceeds 80 dBA
LAmax_unocc_rate	Percentage of time that unoccupied LAmax exceeds 80 dBA
LCpeak	C-weighted Peak Sound Pressure Level (dBC)
LCpeak_occup_rate	Percentage of time that occupied LCpeak exceeds 90 dBC
LCpeak_unocc_rate	Percentage of time that unoccupied LCpeak exceeds 90 dBC

L10_L90	L10 minus L90 (dB)
Ln	nth percentile Level (dB)
MCS	Mental health component summary score
MLS	Maximum Length Sequence
NC	Noise Criterion Rating
NC_occup	Noise criteria for occupied spaces (rating)
NC_unocc	Noise criteria for unoccupied spaces (rating)
p	P-value
PCS	Physical health component summary score
RMS	Root Mean Square
RT	Reverberation Time (sec)
RT_500	Reverberation Time at 500 Hz (sec)
S_{tot}	Total surface area
SII	Speech Intelligibility Index
SII_delta	Occupied minus unoccupied SII
T_{60}	Reverberation Time
V	Volume (cubed meters)
WHO	World Health Organization

SUMMARY

The sound environment in hospitals is complex. While there have been several studies that address the acoustic environment in hospitals, there is a limited amount of research done concerning the effect that noise has on staff. This thesis describes two related studies: 1) analysis of the relationships between acoustics and perceptual staff outcomes using an existing dataset collected in real hospitals; 2) development of methodologies to test the relationships between acoustics and hospital staff task performance in a simulated laboratory setting.

In the first study it was found that mental health and perception of noisiness were occupational factors that were related to the sound environment using a variety of acoustic metrics. Only a few acoustic metrics were shown to be statistically significant related to dependent variables (such as mental health) in a direct correlation (e.g., as the acoustic conditions worsened the dependent variable also decreased). However, almost all acoustic metrics tested had a statistically significant relationship with mental health once subjective job strain was considered as a moderating factor. This means that while the direct impact of sound may not be immediately observable, sound may play a more significant role once subjective job strain is taken into account.

In the second study, a new methodology was developed to directly relate staff task performance to noise and beta-tested on a single group of subjects. The methodology development included synthesizing a signal that was acoustically comparable to those heard in real hospitals in order to simulate a realistic noise exposure in a controlled environment. Additionally, objective methods of measuring performance and perception were devised by utilizing task performance scripts already validated in other studies and developing new surveys that could be administered to subjects to garner their perceived task performance and perceptions of the simulation room environment, including noise.

CHAPTER 1

INTRODUCTION

The sound environment in hospitals is complex; it is composed of sounds from several different sources such like alarms, medical equipment and conversations. Noise is often defined as an unwanted sound and it can affect staff communication and concentration. While there have been several studies that address the acoustic environment in hospitals, there is a limited amount of research done concerning the effect that noise has on staff. Because the caregiver’s job is important, not only are their health and job satisfaction a matter of concern, also it is important to consider how a noisy environment might affect their performance.

This thesis describes two related studies: 1) analysis of the relationships between acoustics and perceptual staff outcomes using an existing set of dataset collected in real hospitals (hereafter referred to as the *survey study*); 2) development of methodologies to test the relationships between acoustics and hospital staff task performance in a simulated laboratory setting (hereafter referred to as the *simulation study*).

The survey study involved a deeper analysis to a dataset previously collected in more than 12 units at 3 hospitals, which included both acoustic measurements and staff perceptual survey data. For this thesis, statistical analysis was conducted with this dataset in order to relate more than 15 specific acoustic metrics to occupational factors on caregivers, such as job strain, job satisfaction, organizational commitment and health.

In the simulation study, a new study methodology was developed aiming to relate hospital noise to staff performance. This was conducted in a simulation room, which is a controlled environment that looks like a real hospital and is used to teach several procedures to caregivers.

Taking this into consideration, the goals of this study were:

- To establish relationships between noise environment and the staff occupational factors in real-life hospitals.
- To develop a study methodology to directly measure performance and perception of staff exposed to noise in a realistic, simulated setting.

Previous studies have shown that hospital sound environments can potentially cause severe detrimental impacts on staff. However, the majority of these studies analyzed the hospital acoustical environment using measurement methods that were not sufficiently rigorous. This study will help to provide evidence on how a hospital's soundscape affects staff members, which should be taken into account in future hospital designs.

CHAPTER 2

LITERATURE REVIEW AND BACKGROUND INFORMATION

Noise is often defined as unwanted sound (Harris, 1979). Hospital sound environments are very complex because they are composed of sounds generated by different types of sources. Examples of these sources would be the equipment alarms, human sources as conversations, footsteps and phones, and also the built environment noise from the building, such as the air conditioning system. The variety of sources makes it difficult to measure and describe the complex sound environment.

Studies found in the literature generally report overall noise levels, linear or A-weighted. More detailed noise analyses, such as spectrum analysis and intelligibility measurements are hard to find, which makes it difficult to establish a relationship between noise and its psychological and physiological effect on humans.

There is evidence that sound levels in hospitals have been increasing steadily since the 1960's (Busch-Vishniac, et al., 2005; Ryherd, et al., 2011). Several studies have shown the effect of noisy environments on patients. For example, poor acoustics can hinder recovery among patients (Meyer, et al., 1994), can be related to cardiovascular arousal in certain patients (Baker, et al., 1993), can increase the probability of re-hospitalization (Hagerman, et al., 2005) and can disturb sleep (Freedman, et al., 2001).

Much less research has been done about the impact of the sound environment on staff members. Recent studies suggest that noise in hospitals could affect occupants and contribute to staff errors, as described below. It has been shown that noise affects workers in other environments. For example, in offices it can affect oral communication and performance (Bowden & Wang, 2005; Bradley, 2003; Ryherd & Wang, 2007, 2008; Persson Waye, et al., 2001). All this contributes to the motivation for this study of whether noise affects staff in hospitals. Also, it is clearly important to develop new studies to analyze the effect of a hospital's noise environment on its staff, where extensive acoustic metrics, performance and job strain should be considered.

The effect of job strain in the relationship between noise and staff outcomes

The demand/control hypothesis relies on the idea that two important elements are fundamental to job stress / strain. "(1) The job demands placed on the worker (demand) and (2) the discretion permitted to the worker in deciding how to meet these demands (control)" (Karasek, 1979, 1985). Under a high demand and low control system, workers experience the most strain, and this could directly affect various outcomes such as their job satisfaction and organizational commitment.

Previous research has linked occupational noise to several negative stress, job satisfaction and health effects among office workers. For example, Sundstrom et al. found declining job satisfaction in workers exposed to high noise levels (1994). Leather et al. in 2003 studied how job strain and noise levels affected several job-related variables in office workers, such as organizational commitment, job satisfaction and occupational health. They worked on two specific hypotheses: first that "higher noise levels will be associated with lower job satisfaction, lower organizational commitment and poorer well-being" and second that "Noise exposure and job stress will interact such that lower levels of noise will buffer any negative effect of job strain, organizational commitment and well-being" (Leather, et al., 2003). They showed that lower levels of ambient noise buffered the negative impact of psychosocial job stress upon these three outcomes; in other words, high noise levels amplified the impact of stressful jobs. In this study they measured the background noise of the subject's workstations, including the highest and lowest levels.

Staff performance

In order to understand how noise affects staff performance, it is important to state clearly the variables that are involved and how they were addressed in past studies. The three primary variables are: *the acoustic environment, performance and perception.*

The acoustic environment describes the background noise and room acoustic environment in which subjects are going to be immersed. Researchers need to define if they are going to work in a real environment or a controlled one. In the first case, the acoustic variable is going to be defined by the actual sound environment in the hospital. In the second one, a signal should be played to the subjects in the controlled environment; it could be music or noise. It is important to report the levels and other acoustic metrics that are going to be measured in order to relate the controlled study to reality.

The second variable is the *performance*; it could be difficult to find a way to measure this objectively. Tasks could be realistic (e.g., medical charting, patient diagnoses) or more related to cognitive function (e.g., visual tracking, recall). The third variable is the subject's *perception* and this is usually measured through surveys. The links between these three variables will help explain how noise affects staff performance.

A wide variety of past studies take into account one or more of these variables. Some of them only measured the noise environment in different hospitals (e.g., Busch-Vishniac, et al., 2005). Others have collected staff perceptions of the sound environment through surveys (e.g., Hawksworth, et al., 1997; Moeller, 2012; Mahapatra, 2011). Also, there are some that have addressed the relationship between a noise environment and performance (e.g., Moorthy, et al., 2004; Murthy, et al., 1995; Park, et al., 1994).

With regard to studies that address directly the performance variable, different relationships between noise and hospital staff performance have been found. Some of them show a relationship between these variables. For example, Murthy et al. (1995) studied 20-anesthesia residents, measuring mental efficiency and short-term memory as performance outcomes. Subjects were exposed to a quiet situation (40 dBA) and another with recorded operating room noise at 73 dBA. Their results showed a significant deterioration on all tests in presence of noise.

A larger study asked more than a hundred emergency room physicians, nursing personnel and medical students to hear heart and lung sounds of healthy individuals (Zun & Downey, 2005). Subjects were exposed to 90 dB of pink noise. Nearly half of them reported diminished heart and lung sounds of the healthy patients in the noisy situation. Between 4% and 8% were totally unable to hear the healthy patients' sounds in the noisy situation. It should be noted, however, that the noise exposure on this study (90 dB) was higher than what is usually found in hospitals and that pink noise is a somewhat unrealistic noise exposure.

Other studies show no relationship between noisy environments and hospital staff performance. For instance, one study asked 12 surgeons to perform laparoscopic suturing (Moorthy, et al., 2004). Performance was measured via accuracy and quality of the knot and the number of non-purposeful movements. Subjects were tested in three conditions: quiet, noise at 80-85 dBA and music at self adjusted volume. Their results showed no correlation between noise and suturing performance.

Another study asked 12 anesthetic trainees to perform tasks on a computer while immersed in different sound situations (Hawksworth, et al., 1998). The outcomes measured were vigilance, reaction time and percentage of time on target. The noise exposures were a quiet situation, self-chosen music, classical music, and white noise; all of them at self adjusted volumes. No correlation between sound and performance was found; however, the authors suggested that follow up studies should ask subjects to perform a more realistic task.

Another study asked the subjects about their attitude towards sounds (Park. et al., 1994). They found out that those individuals who favored quieter environments showed reduced performance in the presence of noise, while the performance of those who favored noisy environments was not affected. The study asked 8 radiology residents to detect rib fractures in an x-ray. There were two different noise exposure situations: a quiet one with 43-45 dBA of background noise and a mix of recorded noise from hospitals at 81-84 dBA.

Several variables could be affecting the results on the mentioned previous studies. The effects of noise on performance depend on the type of noise and on the task being performed (Broadbent, 1979; Murthy, et al., 1996). It is important to utilize noise signals that are comparable with real hospital conditions. Also, the task that subjects are asked to perform should be chosen carefully because if it is too simple, some subjects could have an advanced level of expertise on the task, making the effect of sound irrelevant. The task should be directly related to the subjects' jobs in order to get results that represent reality. Additionally, the Park et al. 1994 results indicate that subject acoustic preference can impact results, so it is good to pair surveys with direct performance measures.

CHAPTER 3

SURVEY STUDY

Methodology

The survey study consisted of analyses of the relationships between acoustics and perceptual staff outcomes using an existing set of dataset collected in real hospitals. The existing dataset was from a previous study on "Healthcare Environments – Baseline Assessment for Safety & Quality" (HE-BASQ Report) (US DoD, 2011). This study was the "collection of acoustic and occupant measures in the largest variety of unit types and locations within hospital units published" to that date (Moeller, 2012). The study collected extensive acoustical and perceptual data at four different hospitals. Several units in each hospital were studied in order to adequately characterize hospitals as a whole. The units studied were: Emergency Departments, Intensive Care Units, Medical/Surgical Nursing Inpatient Units, Mother/Baby Units, and Ambulatory Same-Day Surgery Clinics. (US DoD, 2011)

After that study, investigators suggested that additional examination should be done in order to analyze in more depth the effects of noise on hospital occupants. It is specifically stated that "the main (direct) and interaction (indirect) effects of noise levels and job strain on self- reported job satisfaction, organizational commitment, and health needed to be investigated by conducting multiple one-way ANOVA taking into account different acoustic metrics" (Moeller, 2012).

The HE-BASQ study asked staff, patients and visitors to complete surveys about the noise environment in the hospital. Staffs were also asked about their perception of occupational factors (including job strain) and of physical and mental health. A preliminary analysis was done in the HE-BASQ study report (US DoD, 2011). It showed some relationships between noise, job strain and work related variables. These relationships were associated with the two hypotheses tested:

- Hypothesis 1: Higher noise levels will be associated with increased perception of noisiness, lower job satisfaction, lower organizational commitment, and poorer health (main effects). (US DoD, 2011)
- Hypothesis 2: Noise exposure and job strain will interact such that the negative impacts of job strain on job satisfaction, organizational commitment, and health will be greatest under conditions of both higher noise levels and higher strain (moderator effect). (US DoD, 2011)

Acoustic data gathered and calculated

A variety of acoustic metrics were used in the HE-BASQ report, and were chosen because of their common use in acoustics, because they appeared in ANSI/WHO/ASHRAE guidelines, or because they captured characteristics (such as temporal pattern or speech intelligibility) that the investigators hypothesized are important for hospitals. All metrics defined below were measured and calculated in the HE-BASQ study. This thesis goes further by analyzing the relationships between these specific acoustic metrics and staff occupational factors and health. In all measurements, sound level meters were set to a “fast” response time (125 msec) and one-minute averaging intervals (US DoD, 2011). Energy decay measurements were made using the Maximum Length Sequence (MLS) impulse response technique (US DoD, 2011).

In order to fully characterize the sound environment in hospitals, several key components of the hospital soundscape were measured, from which various acoustic metrics were calculated:

Sound Pressure Levels: to show the overall loudness of the sound environment. Metrics used to reflect sound pressure level were:

- *A-weighted equivalent, maximum, and C-weighted peak sound pressure levels (LAeq, LAmax, LCpeak):* These are used to describe the overall loudness level of background noise (Bies & Hansen, 1996). The A and C filters are used to account for the relative loudness perceived by the human ear. The sound level meter measures several times per second and calculates an average for each second. Then it calculates the average for each minute and also for the whole time span of the measurement. LAeq is the equivalent A-weighted level over time; the total sound energy of the signal will be equivalent to the energy of the calculated equivalent level (LAeq) through that same time period. LAmax is the level of the second with the highest RMS A-weighted level. LCpeak is the highest absolute sound pressure C-weighted value acquired by the sound level meter in the specified period. Peak and max levels are saved for each minute. Higher decibels indicate a louder sound.
- *Noise Criteria (NC):* This is one of the most commonly used criteria for indoor spaces. It is one of the earliest methods, and it is characterized by its simplicity (Beranek, 1957). The method provides a single-number level that is calculated by comparing the frequency content of the measured background noise with some pre-defined NC curves that approximate the relative loudness perceived by the human ear.

Temporal pattern: to indicate how much sound fluctuates over time. Metrics used to reflect temporal pattern were:

- *Percentiles (Ln):* Ln is given in decibels and it represents the sound pressure level that is exceeded n-percentage of the measurement time (e.g., L90 = 40 dB implies 40 dB is exceeded 90% of the measurement time) (Bies & Hansen, 1996).
- *Occurrence Rate:* This represents the percentage of time that LAmax and LCpeak exceed certain decibel value. It is a new metric developed by the Healthcare Acoustics Research Team (HART) (Ryherd, et al., 2011; Okcu, et al., 2011;). It is used to characterize the "peakiness" or define the impulse nature of the background noise. This metric differs from the percentiles levels because it specifically takes into account the maximum and peak levels.

Energy decay: relates to the rate at which sound energy is dissipated over time. Metrics used to reflect energy decay were:

- *Reverberation Time (RT):* A measure of energy decay. Reverberation Time is defined as the time it takes acoustic energy to decay to one-millionth of its initial value once the source is stopped. In other words, it is a measure of how quickly sounds dies out (Metha, et al., 1999).

Speech Intelligibility: relates to how the acoustic environment (i.e., noise, reverberation) impacts the ability of listeners to understand speech. Metrics used to reflect speech intelligibility were:

- *Speech Intelligibility Index (SII):* This is a metric to quantify how easy it is to understand speech. According to ANSI S3.5, the SII is "a physical measure that is highly correlated with the intelligibility of speech under a variety of adverse listening conditions, such as noise, filtering, and reverberation" (American National Standards Institute, 2007). It is a number between 0 and 1; a larger value indicates a more easily understood speech.
- *Clarity Index:* Clarity is related to how distinct individual sounds are from each other (Mehta, et al., 1999). A room with a high degree of clarity indicates that

individual consonants, words, etc. in a speech can be distinctly heard or that the discrete notes in a piece of music can be distinctly heard.

Perceptual data gathered and calculated

As part of the HE-BASQ study, a survey was administrated to hospital staff that worked on the units where the acoustical environment was measured. First, the survey collected the *demographic data* from subjects, including their age, gender, job category, length of time worked in the department, length of nursing career, and typical working hours (US DoD, 2011). Subjects were also asked about their *perceptions of the sound environment*, including questions about overall noise levels, annoyance and ability to communicate.

The *emotional and physical health* of the subjects was also quantified through a set of survey items adapted from previous research (Lim & Fisher, 1999; Ware et al., 1995). Specifically, the 12-item Short-Form (SF-12v2) Health Survey was used (Lim & Fisher, 1999). Several questions assessed the physical and mental health across eight health domains: physical functioning, the role of physical health, bodily pain, general health, vitality, social functioning, the role of emotional health, and mental health. One to two questions were asked per domain and used to calculate two overall health scores per subject: Physical Component Summary (PCS) and Mental Component Summary (MCS). These indices can be directly compared to the mean of the general US population, which is designated to be 50.

Different questions about their job strain, satisfaction and organizational commitment were asked in order to get the staff perception of *occupational factors*. Satisfaction and commitment evaluated with single questions. Job strain was evaluated using the Job Content Questionnaire (JCQ) by Karasek, which utilizes the demand/control hypothesis described in Chapter 2 (Karasek, 1979, 1985; Karasek et al, 1998). The JCQ takes into account the skill discretion, which is measured by the level of skill and creativity needed for the job, the variety of tasks performed, the ability to develop one`s own unique abilities, the need to learn new things and the amount of repetition, pace and difficulty of tasks. This procedure also considers the demands of the job by accounting for the amount of work, the time to complete tasks, and the amount of conflicting demands. The decision authority of the subject is also evaluated, which is the ability of workers to have freedom and say. Responses to the JCQ survey items were used to calculate overall "control" and "demand" scores. These scores were then used to find an overall "job strain" score for each subject, which was calculated as the imbalance between demand and control (US DoD, 2011).

Seventy staff members responded to the survey. 21% were male and 79% were female (US DoD, 2011). Most respondents were 18-29 years old (41%), followed by age 30-39 (23%). The majority of staff had 1-5 years of experience in their current unit (58%). The HE-BASQ study reported that hearing health and noise sensitivity were not significantly related to noise perception, which agrees with the result that 90% of subjects reported "normal" to "very good" hearing. (US DoD, 2011)

Moderator analysis

The original HE-BASQ moderator analysis focused on LAeq only and a limited set of survey items. The current study presents a much more in-depth analysis, where the original two HE-BASQ hypotheses were revisited using additional acoustic metrics and survey items. Recall the hypotheses presented above:

- Hypothesis 1: Higher noise levels will be associated with increased perception of noisiness, lower job satisfaction, lower organizational commitment, and poorer health (main effects). (US DoD, 2011)
- Hypothesis 2: Noise exposure and job strain will interact such that the negative impacts of job strain on job satisfaction, organizational commitment, and health will be greatest under conditions of both higher noise levels and higher strain (moderator effect). (US DoD, 2011)

The HE-BASQ study showed that LAeq and perception of noisiness were related as stated in Hypothesis 1. Also, mental health (MCS) was impacted by the interaction of job strain and LAeq, following Hypothesis 2, but it was not statistically related to LAeq by itself (US DoD, 2011). This result highlights that using LAeq as an acoustic metric, the direct impact of sound was not statistically significant on mental health, but it did play a role once job strain was taken into account. The HE-BASQ study clearly stated the necessity to test this moderator hypothesis with an expanded set of acoustic metrics such as occurrence rates, SII and noise criteria.

In order to study the moderator effect, a median split technique was used in accordance with previous research (Leather et al. 2003); both predictor variables (strain and noise metrics) were converted into dichotomous variables. This resulted in two levels of each factor ("low" = below the median and "high" = above the median).

Results

One-way and two-way Analysis of Variance (ANOVA) was used to find relationships of interest as defined in the two hypotheses. Acoustic metrics and job strain were considered as independent variables and are summarized in Table 3.1. It is important to recall that these variables were measured in each unit where subjects were asked to fill out the subjective survey.

Table 3.1 Independent variables in the survey study.

Variables	Brief explanation
LAeq (dBA)	Overall dBA level
LAeq_delta (dBA)	Occupied minus unoccupied dBA level
SII	Overall Speech Intelligibility Index
SII_delta	Occupied minus unoccupied SII
RT_500 (seconds)	Reverberation time at 500 Hz
C50_500 (seconds)	Clarity Index (50 msec) at 500 Hz
LAmax_unocc_rate (%)	Percentage of time that LAmax exceeds 80 dBA (unoccupied)
LCpeak_unocc_rate (%)	Percentage of time that LCpeak exceeds 90 dBC (unoccupied)
LAmax_occup_rate (%)	Percentage of time that LAmax exceeds 80 dBA
LCpeak_occup_rate (%)	Percentage of time that LCpeak exceeds 90 dBC
L10 (dB)	10% percentile level
L33 (dB)	33% percentile level
L90 (dB)	90% percentile level
L10_L90 (dB)	L10 minus L90
NC_unocc (rating)	Noise criteria (unoccupied)
NC_occup (rating)	Noise criteria
Strain	Job strain as related to perceived demand and control

NOTE: Every variable is for occupied spaces unless labeled otherwise. Median split technique was used for all metrics.

It is important to have in mind that for almost all of the independent variables, a higher number represents a worse scenario. A special case is the Speech Intelligibility Index, in which a higher SII means speech is more intelligible, which is likely a better acoustic situation for staff communication and task performance. Also the delta variables represent the difference between occupied and unoccupied situations. Those variables do not separate between high and low noise situations; they separate between high and low delta between occupied and unoccupied conditions. They should be analyzed as the difference between two situations rather than high and low noise cases as the rest of acoustic variables.

A summary of the values of the independent variables is shown in Table 3.2. It has the maximum and minimum value, average, standard deviation and the median of each independent variable. This table helps to provide further understanding of the statistical analysis that follows.

Table 3.2 Summary of independent variable values.

Input variables	Max value	Min value	Average	Standard Deviation	Median Split
LAeq (dBA)	61.13	54.06	57.10	2.17	56.60
LAeq_delta (dBA)	12.10	-3.20	4.85	5.58	6.10
SII	0.72	0.40	0.58	0.11	0.61
SII_delta	0.36	-0.32	0.12	0.18	0.20
RT_500 (seconds)	0.61	0.31	0.44	0.08	0.47
C50_500 (seconds)	9.31	6.40	7.63	0.90	7.35
LAmax_unocc_rate (%)	3.80	0.00	1.30	1.40	0.30
LCpeak_unocc_rate (%)	74.20	0.80	23.10	26.00	7.70
LAmax_occup_rate (%)	6.80	0.00	2.80	2.40	0.00
LCpeak_occup_rate (%)	93.50	9.10	39.10	29.10	30.00
L10 (dB)	63.05	52.30	57.29	3.53	58.15
L33 (dB)	58.49	45.99	51.63	3.72	52.43
L90 (dB)	53.84	42.42	45.84	2.65	46.45
L10_L90 (dB)	14.84	8.51	11.45	2.00	10.70
NC_unocc (rating)	61.00	35.00	43.20	7.12	39.00
NC_occup (rating)	66.00	39.00	48.59	6.11	49.00
Strain	4.00	0.00	1.15	0.92	0.80

Dependent variables were calculated through the responses of the survey. These variables are summarized in Table 3.3.

Table 3.3 Dependent Variables for survey study.

Variables	Brief explanation
MCS	Mental health score
PCS	Physical health score
Noisiness	Personal perception of noise in unit
Satisfaction	Job satisfaction
Commitment	Organizational commitment
Health	Self perception of overall health from a direct question on the survey
Strain	Job strain as related to perceived demand and control

Table 3.4 shows a summary of the values of the dependent variables. It has the maximum and minimum value, average, standard deviation and the median of each dependent variable

Table 3.4 Summary of dependent variable values.

Variables	Max value	Min value	Average	Standard Deviation	Median Split
MCS	66.20	22.95	51.12	10.29	54.29
PCS	61.85	30.39	51.24	8.25	54.53
Noisiness	4.00	1.00	2.00	0.82	2.00
Satisfaction	5.00	1.00	2.24	0.98	2.00
Commitment	4.00	1.00	3.62	0.67	4.00
Health	5.00	1.00	2.06	0.86	2.00

For MCS and PCS, a higher value represents better health, being 50 the mean of the US population. They were calculated through answers to several questions on the survey, as explained before. The next four dependent variables were answers to a single question answered by subjects. Noisiness was composed of values from 1: “a little noisy” to 4: “extremely noisy”. Satisfaction had values from 1: “extremely satisfied” to 5: “extremely dissatisfied”. Commitment was composed of values from 1: “not at all committed” to 4: “fully committed”. Self-perception of health had values from 1: “excellent” to 5: “poor”.

Hypotheses one and two were tested for every dependent variable, taking into consideration one independent variable at the time. Those that showed statistically significant relationships are analyzed in the next pages.

Strain

Strain was analyzed as a dependent variable for hypothesis one. This means that the direct relationship between acoustic metrics and the perceptual job strain was examined. Of those tested in Table 3.1, only three acoustic variables were found to be statistically significantly related to job strain: LAmax unoccupied occurrence rate, LCpeak occupied occurrence rate and the 90 percentile level (L90). Their relationships are shown in Figure 3.1.

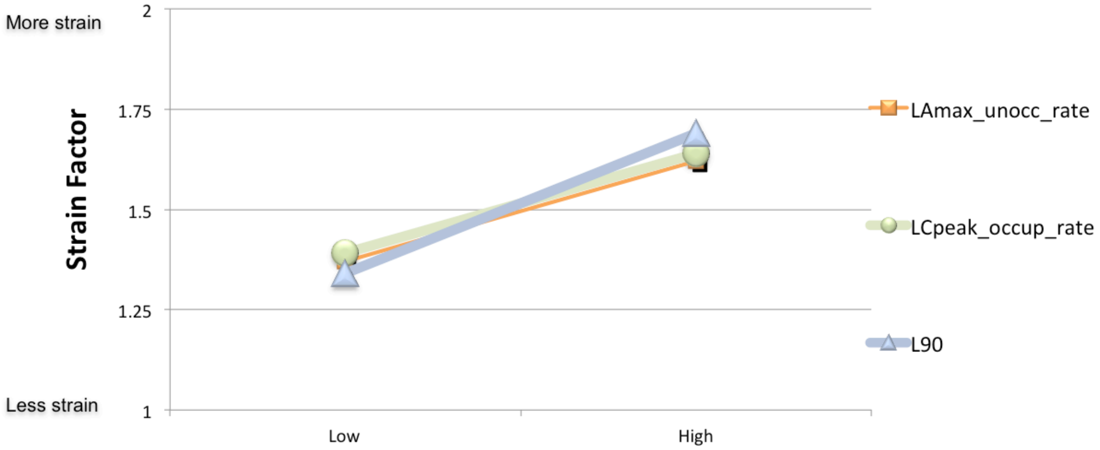

Figure 3.1 Hypothesis 1: Subjective strain versus several acoustic metrics. Perception of strain increased as noise fluctuations increased (LAMax_unocc_rate, LCPeak_occup_rate; *p*<0.05) or baseline conditions became louder (L90; *p*<0.01).

As can be seen in Figure 3.1, higher perception of job strain is associated with the high acoustic conditions for these three metrics. Specifically, perception of job strain increased as noise fluctuations increased (via LAMax_unocc_rate or LCPeak_occup_rate; *p*<0.05) or baseline conditions became louder (via L90; $p<0.01$). These relationships demonstrate the importance of considering the strain factor in hypothesis 2. The subjective perception of job strain can have a statistically significant relationship with the sound environment, and it could be affecting other dependent variables.

Table 3.5 provides a summary of the statistical analysis. The L90 percentile level was significant at a slightly more stringent level ($p<0.01$), which could imply that it has a stronger relationship with strain than the other acoustic metrics have.

Table 3.5 Strain analysis summary.

Acoustic Metric	Hypothesis 1
RT_500 (seconds)	ns*
LAmax_unocc_rate (%)	F(1,66)=4.34, $p<0.05$, r=0.25
LCpeak_occup_rate (%)	F(1,66)=4.38, $p<0.05$, r=0.25
L90 (dB)	F(1,66)=8.61, $p<0.01$, r=0.34

NOTE: ns* means that $0.05<p<0.1$ but it was considered non-significant for this study

Mental Component Summary (MCS)

Mental health was one of the dependent variables that showed relationships with several acoustic variables in both hypotheses, as described in the following sections. It is possible that mental health was found to be statistically significant related to several acoustic metrics because annoyance is a common response to undesired sounds. These findings indicate that mental health could be a good variable to study in future attempts to describe the effect of noisy environments on staff.

Hypothesis 1

The three independent variables that were related to MCS were: strain, LAmax unoccupied occurrence rate and reverberation time. The first two showed a logical relationship and are shown in Figure 3.2.

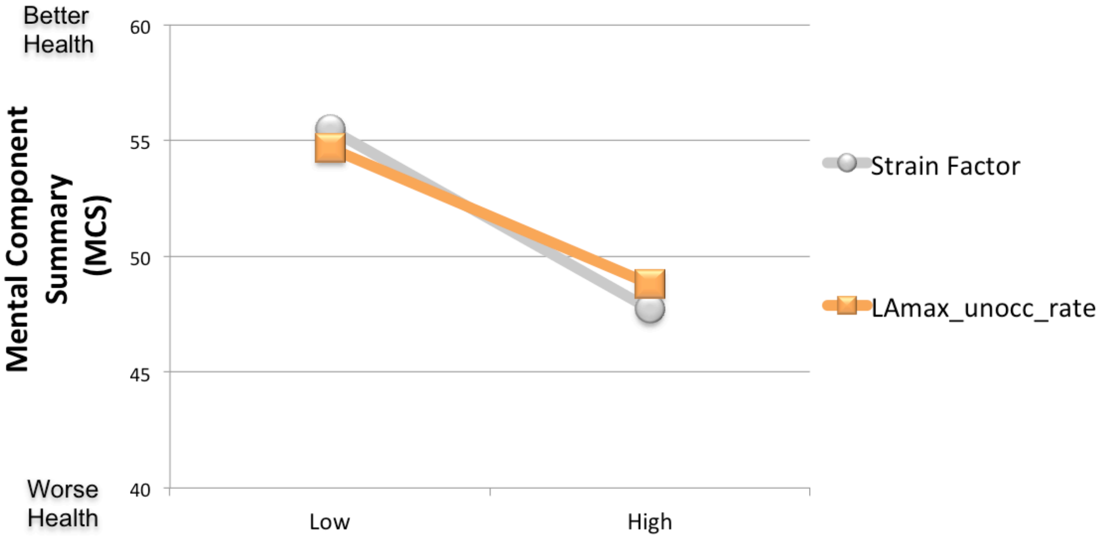

Figure 3.2 Hypothesis 1: MCS versus subjective strain and LAmax_unocc_rate. Mental health decreased as perception of strain increased (*p*<0.05) or noise fluctuations increased (LAMax_unocc_rate; *p*<0.01).

As can be seen in Figure 3.2, lower mental health is associated with the high acoustic and high strain conditions. Specifically, mental health (MCS) decreased as noise fluctuations increased (via LAMax_unocc_rate: $p<0.01$) or perception of job strain increased ($p<0.05$). The other variable that was found to be significant was RT 500, but mental health decreased as reverberation time decreased. This is not intuitive because it is expected that for poorer acoustic situations poorer health should be found, as stated in hypothesis one. A logical explanation for this is that there was a limited range of RT 500 values measured in these hospitals. The minimum and maximum reverberation time measured in this study were 0.31 and 0.61 seconds (Table 3.2). Even though a change in

5-10% in reverberation time is the just noticeable difference (jnd) (Meng, et al., 2006), all measurements are relatively low and can be characterized as dry environments. This makes that values in the low and high RT 500 variable had very close numbers for reverb time. Maybe subjects working on places with higher RT 500 (e.g., greater than 1 second) would show lower MCS. Another hypothesis could be that because the median split number for RT was at 0.47 seconds (Table 3.2); subjects immersed in a low RT 500 environment could be more affected as very low reverb time could cause annoyance. Further research should be done in order to relate reverberation time to mental health or other dependent variables among hospital staff.

Hypothesis 2

For the moderator analysis all the acoustic metrics were found to interact with strain to affect mental health. The metrics that showed the greatest effect were: LAmax unoccupied occurrence rate and L10 minus L90, both with $p<0.01$ and possibly showing a greater effect on MCS under high perceptual strain than other independent variables. Figure 3.3 illustrates the moderator analysis for LAmax unoccupied occurrence rate.

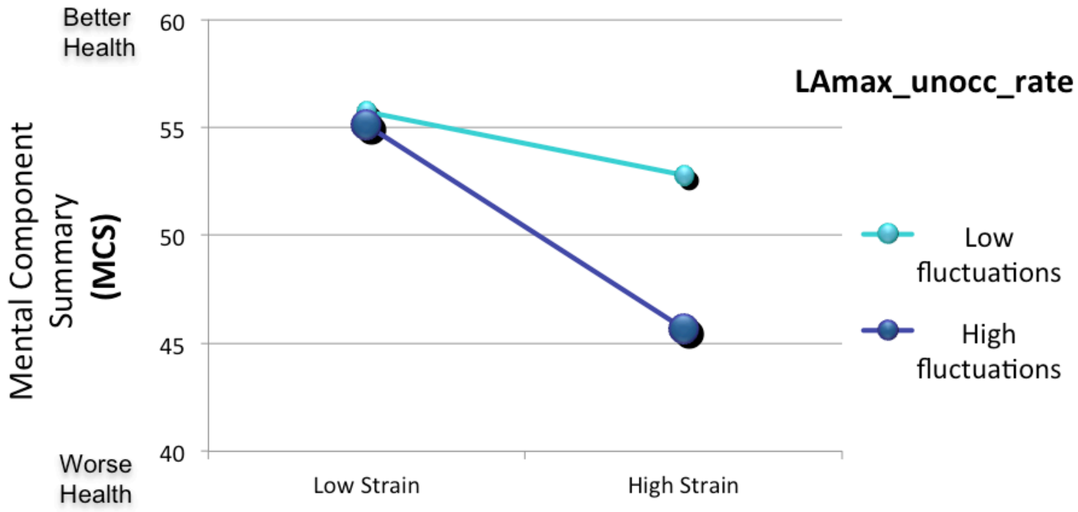

Figure 3.3 Hypothesis 2: Noise exposure and subjective job strain interact such that mental health is lowest under conditions of high fluctuations (via LAMax_unocc_rate) and high strain (*p*<0.01).

As shown in Figure 3.3, mental health for low strain conditions was found to be in the same order of magnitude for both low and high fluctuations. But when high subjective strain conditions were analyzed, mental health was found to decrease as occurrence rate increased (*p*<0.01). For the LAmax unoccupied occurrence rate, a statistically significant relationship was found in both hypotheses; it should be a good variable to take into account in future research. L10 minus L90 has the same type of relationship as does the LAmax unoccupied occurrence rate, meaning that the graph for the former looks similar to the graph for the latter (and also *p*<0.01).

In both cases the difference in mental health for high perceptual strain conditions is important, where noise is interacting with the job strain and a decrease in mental health is found as both strain and noise increase. Note that L10 minus L90 was not significantly related to MCS for hypothesis one. These results imply that while the direct impact of sound (L10 minus L90) on MCS was not statistically significant, noise did play a role once perceptual job strain was taken into account. Again, this highlights the importance of the job strain moderator analysis.

Several other acoustic metrics were found to be important, though the differences in mental health for high noise and perceptual strain conditions were not as large as those shown in Fig 3.3. These include LAeq, LCpeak occupied and unoccupied occurrence rates, LAmax occupied occurrence rate, and L90 ($p<0.05$); and L10, L33 and occupied NC ($p<0.01$). Figure 3.4 illustrates this relationship taking as example LAeq.

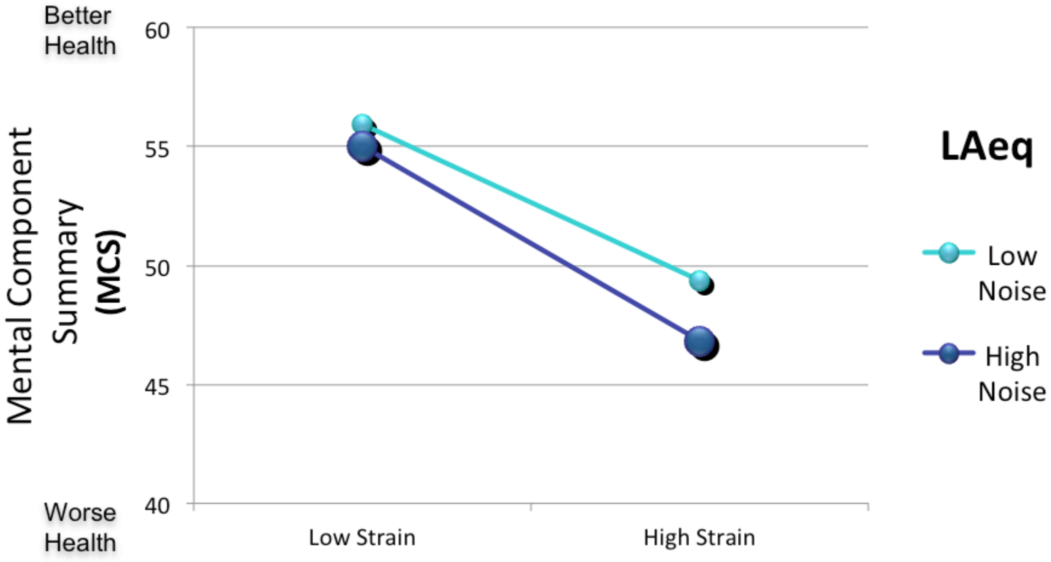

Figure 3.4 Hypothesis 2: Noise exposure and subjective job strain interact such that mental health is lowest under conditions of high noise (via LAeq) and high strain ($p<0.05$).

As shown in Figure 3.4, mental health for low strain conditions was found to be in the same order of magnitude for both low and high noise. But when high subjective strain conditions were analyzed, mental health was found to decrease as noise level increased ($p<0.01$). However, the difference between MCS for high strain jobs in Figure 3.4 is less than those found in Figure 3.3. This could imply that that the acoustic metrics represented by Figure 3.3 have a slightly stronger effect on MCS when perceptual strain is taken into consideration than do those represented in Figure 3.4. This should be confirmed in future research.

Occupied NC had the same behavior than the one showed in Figure 3.4: as NC values and perception of strain increased, MCS decreased ($p<0.05$). In the case of unoccupied NC, mental health also decreased as perception of strain increased; but for high strain situations when NC values increased mental health also increased, which is non intuitive. This behavior is shown in Figure 3.5.

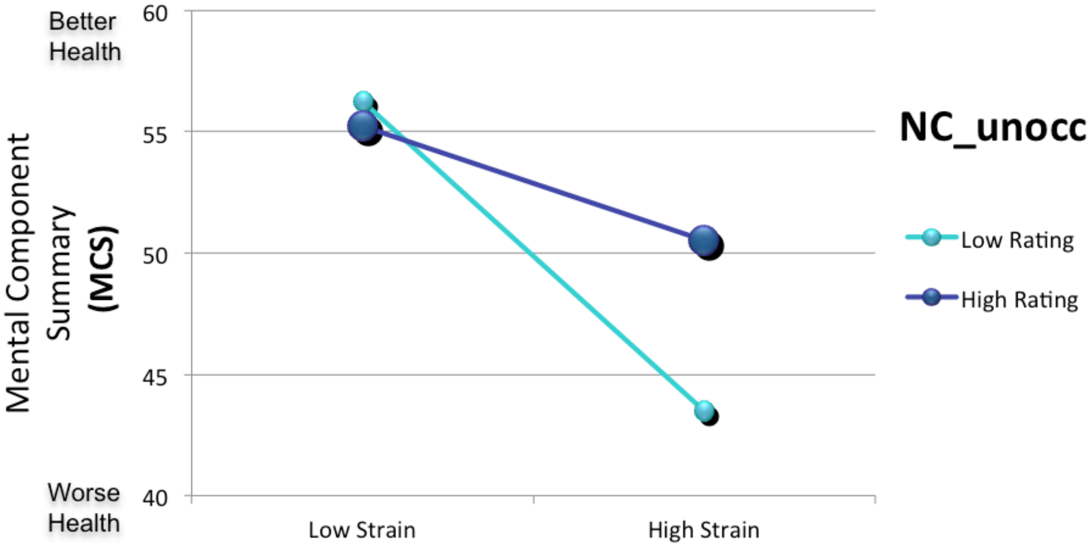

Figure 3.5 Hypothesis 2: Noise criteria and subjective job strain interaction shows a non-intuitive result. For high strain situations MCS increased as NC values increased.

Further analysis should be done to understand these results and try to relate NC values to independent variables.

The delta variables showed an important relationship with mental health. The moderator analysis graph for Delta SII is presented in Figure 3.6. The moderator analysis for Delta LAeq had the same behavior.

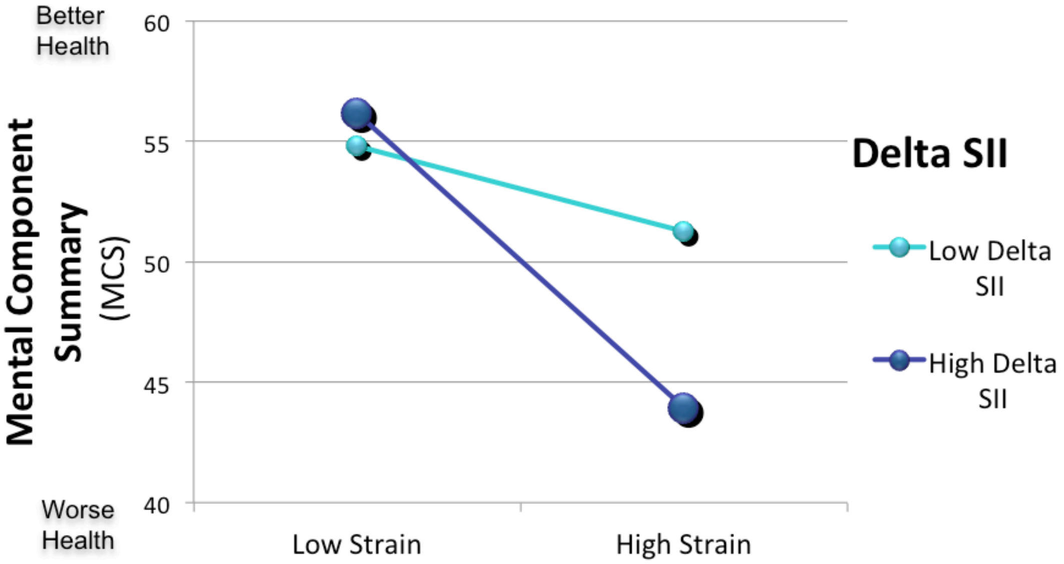

Figure 3.6 Hypothesis 2: Noise exposure and subjective job strain interact such that mental health is lowest under conditions of high Delta SII (via SII_delta) and high strain (*p*<0.05).

It is important to recall that a delta variable indicates a difference in the metric between occupied and unoccupied situations. Low delta means that there is a small difference in the sound environment between occupied and unoccupied situations. This could occur in places with a quiet sound environment that does not change a lot when it is occupied. Also, it could occur in places with noisy sound environments that do not change a lot with the addition of human noise. A high delta value means that the difference between occupied and unoccupied cases is larger, meaning that human activity noise significantly affects the sound environment. In this case it may be expected to find lower MCS in high strain conditions, because the fluctuations in sound environment may have an effect on subjects.

As shown in Figure 3.6, under the low strain condition, the high Delta SII curve is slightly above the low Delta SII one. But when high subjective strain jobs were analyzed, MCS values decreased as Delta SII increased. As the environment changes between occupied and unoccupied situations (spatially or over time) it is more disruptive for subjects. Therefore, MCS is lowest under high strain and high delta conditions.

The clarity index showed a statistically significant relationship on the second hypothesis, but both low and high conditions graphs where practically the same line (superposed to each other) as it can be seen in Figure 3.7

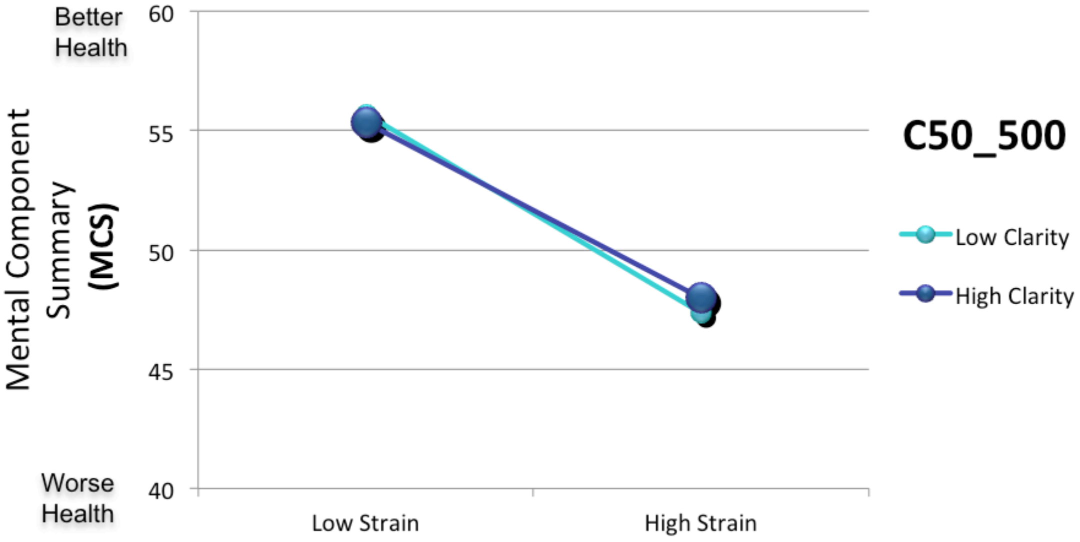

Figure 3.7 Hypothesis 2: Interaction between Clarity and subjective job strain.

Figure 3.7 shows that subjective strain is affecting MCS but between low and high clarity conditions mental health is not varying, this could imply that clarity is not affecting mental health of subjects

Summary

Table 3.6 is provided as a summary of the analysis for mental health concerning the two hypotheses. The LAmax occurrence rate for unoccupied spaces is the only acoustic metric that showed a logical and statistically significant relationship for both hypotheses ($p<0.05$ and $p<0.01$). RT 500 had the inverse direction of what it is expected in both hypotheses. As reverberation time increased, mental health increased in both hypotheses. The reason for these results was already analyzed. Also the unoccupied NC showed an inverse relationship, suggesting that when NC values increased MCS increased. Clarity did not affect MCS on both subjective strain conditions. All other metrics with statistically significant relationships showed trends in the expected directions.

Table 3.6 MCS analysis summary.

Acoustic Metric	Hypothesis 1	Hypothesis 2
LAeq (dBA)	ns	F(3,65)=3.76, $p<0.05$, $r^2=0.15$
LAeq_delta (dBA)	ns	F(3,65)=4.84, $p<0.01$, $r^2=0.19$
SII	ns	F(3,65)=5.70, $p<0.01$, $r^2=0.22$
SII_delta	ns	F(3,65)=3.71, $p<0.05$, $r^2=0.15$
RT_500 (seconds)	F(1,67)=4.05, $p<0.05$, r=0.24	F(3,65)=4.23, $p<0.01$, $r^2=0.17$
C50_500 (seconds)	ns	F(3,65)=3.54, $p<0.05$, $r^2=0.15$
LAmax_unocc_rate (%)	F(1,67)=5.63, $p<0.05$, r=-0.28	F(3,65)=5.14, $p<0.01$, $r^2=0.20$
LCpeak_unocc_rate (%)	ns	F(3,65)=3.60, $p<0.05$, $r^2=0.15$
LAmax_occup_rate (%)	ns	F(3,65)=3.86, $p<0.05$, $r^2=0.16$
LCpeak_occup_rate (%)	ns*	F(3,65)=3.77, $p<0.05$, $r^2=0.15$
L10 (dB)	ns*	F(3,65)=4.16, $p<0.01$, $r^2=0.17$
L33 (dB)	ns*	F(3,65)=4.16, $p<0.01$, $r^2=0.17$
L90 (dB)	ns*	F(3,65)=3.80, $p<0.05$, $r^2=0.16$
L10_L90 (dB)	ns*	F(3,65)=4.64, $p<0.01$, $r^2=0.18$
NC_unocc (rating)	ns	F(3,65)=5.41, $p<0.01$, $r^2=0.21$
NC_occup (rating)	ns	F(3,65)=3.87, $p<0.05$, $r^2=0.16$
Strain	F(1,65)=10.91, $p<0.01$, r=-0.38	Not Applicable

NOTE: ns* means that $0.05<p<0.1$ but it was considered non-significant for this study

Perception of noisiness

The survey asked subjects how noisy they considered their department; in their responses, they were able to choose between these four options: a little noisy, moderately noisy, quite noisy and extremely noisy.

Perception of noisiness was the dependent variable that was related with more independent variables in hypothesis one. It also showed a significant relationship concerning hypothesis two with almost all acoustic metrics. This could have been expected because the perception of noisiness is gathered through a direct question to subjects about the sound environment, and the analysis is linking their perception of the sound environment with the actual noise level.

Hypothesis 1

The following independent variables showed a statistically significant relationship with perception of noisiness as stated in hypothesis one: LAeq, SII, RT 500, LAmax unoccupied and occupied occurrence rate, LCpeak occupied occurrence rate, L10, L33, L90, L10 minus L90, occupied NC and strain factor. It is important to say that almost all of the relationships had a $p<0.01$. Only LAeq had a higher value of p, but it was less than 0.05.

Most of the variables had a behavior similar to the one shown in Figure 3.8, where for low case in the independent variable, subjects rated less noisy their work environment.

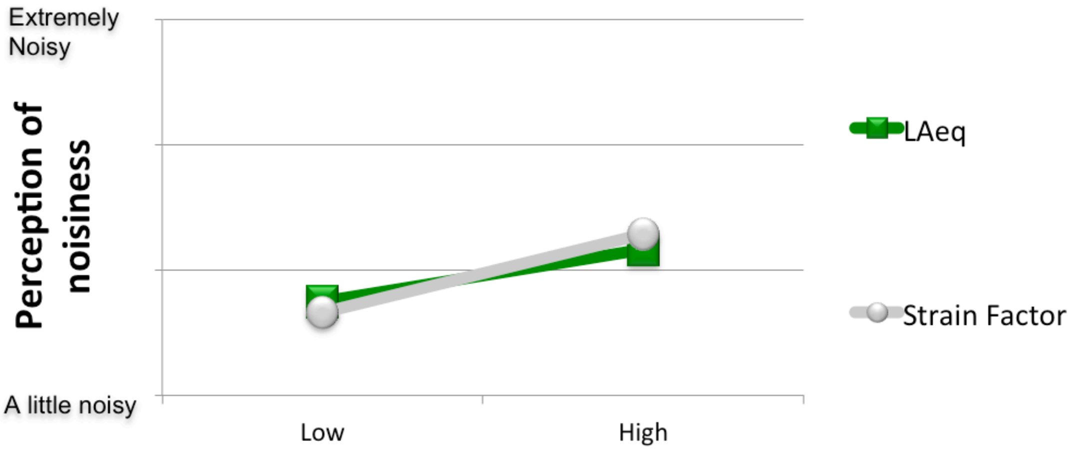

Figure 3.8 Hypothesis 1: Perception of noisiness versus subjective strain and LAeq. Perception of noisiness increased as perception of strain increased (Strain factor; *p*<0.01) or overall noise level increased (LAeq; *p*<0.05).

In the case of SII, the graph would be a decreasing line, because low speech intelligibility indicates more noise. For RT 500 the relationship does not make sense because the results shows that as reverberation time increases perception of noisiness decreases, which is non intuitive. The possible reasons for these results were explained before.

Hypothesis 2

For the moderator analysis almost all the acoustic metrics were found to interact with subjective strain to affect perception of noisiness. Only LAeq had a p value higher than 0.05 for the interaction, but it is important to say for future studies that it was less than 0.1. Interaction of subjective strain with LCpeak unoccupied occurrence rate, LAmax occupied occurrence rate and NC occupied had a p less than 0.05; all the other interactions between independent variables and strain had a p less than 0.01. Figure 3.9 shows the moderator analysis for LAmax occurrence rate for unoccupied spaces.

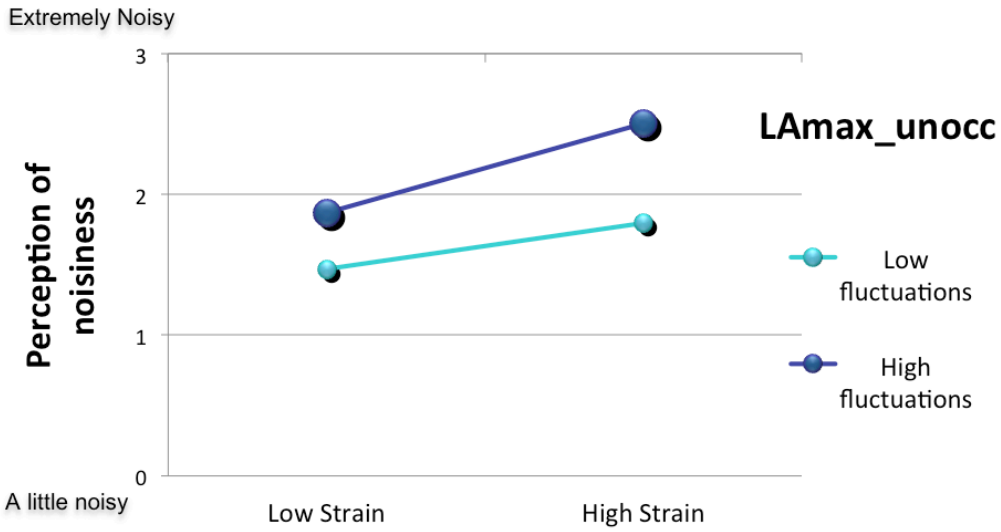

Figure 3.9 Hypothesis 2: Noise exposure and subjective job strain interact such that perception of noisiness is highest under conditions of high fluctuations (via LAmax_unocc_rate) and high strain (*p*<0.01).

Perception of noisiness increased as acoustic fluctuation increased in the environment for low and high subjective strain jobs. But the slope of the high fluctuation curve is steeper than the one of low fluctuations. Meaning that noise exposure and subjective job strain are interacting such that perception of noisiness is highest under conditions of high fluctuations and high strain (via LAmax_unocc_rate: *p*<0.01). The graph for LCpeak occupied occurrence rate and L10 minus L90 looks similar to the one on Figure 3.9.

Speech Intelligibility Index also showed an interaction effect with subjective strain that affected perception of noisiness (*p*<0.01). The graph looks very similar to the one on Figure 3.9, but in this case the low condition line is above the high one, because low SII means poorer acoustical conditions (Figure 3.10)

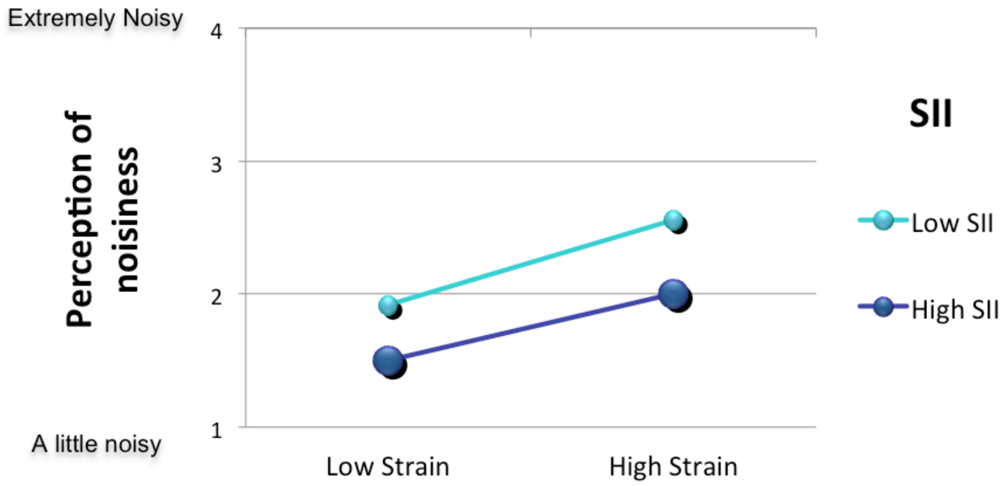

Figure 3.10 Hypothesis 2: Noise exposure and subjective job strain interact such that perception of noisiness is highest under conditions of low speech intelligibility (via SII) and high strain (*p*<0.01).

Several other acoustic metrics were found to be important, although the curves for low and high conditions were parallel in contrast with the ones shown in Figure 3.9 and Figure 3.10.

As it can be seen in Figure 3.11, curves for both high and low baseline conditions of noise (L90) are almost parallel, but the first one is well above of the latter. Other independent variables that had the same behavior as the one shown in Figure 3.11 were: LAmax occupied occurrence rate (*p*<0.05) and L10, L33 and NC occupied (*p*<0.01).

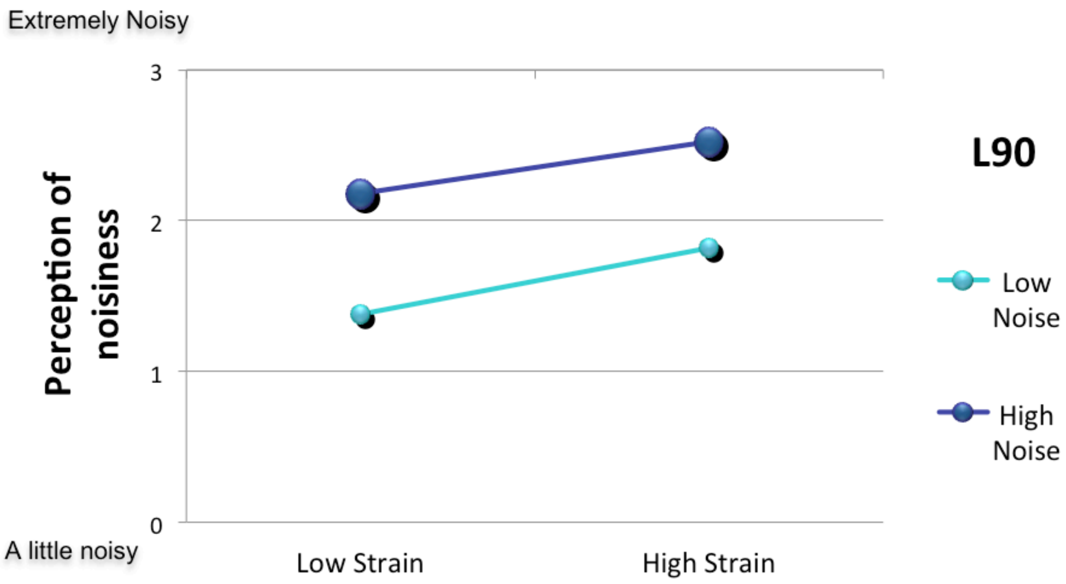

Figure 3.11 Hypothesis 2: Noise exposure and subjective job strain interact such that perception of noisiness is highest under louder baseline conditions (via L90) and high strain (*p*<0.01).

Again, perception of noisiness increased as subjective job strain increased and baseline conditions of noise became louder. Subjects rated noisiest the spaces where subjective strain was high and also noise conditions were worse (in the case of Figure 3.11, where baseline conditions of noise were louder).

Both delta variables showed a statistically significant relationship concerning hypothesis 2 (*p*<0.01). High and low delta lines were parallel to each other, similar to Figure 3.11 but closer to each other, as it can be seen in Figure 3.12.

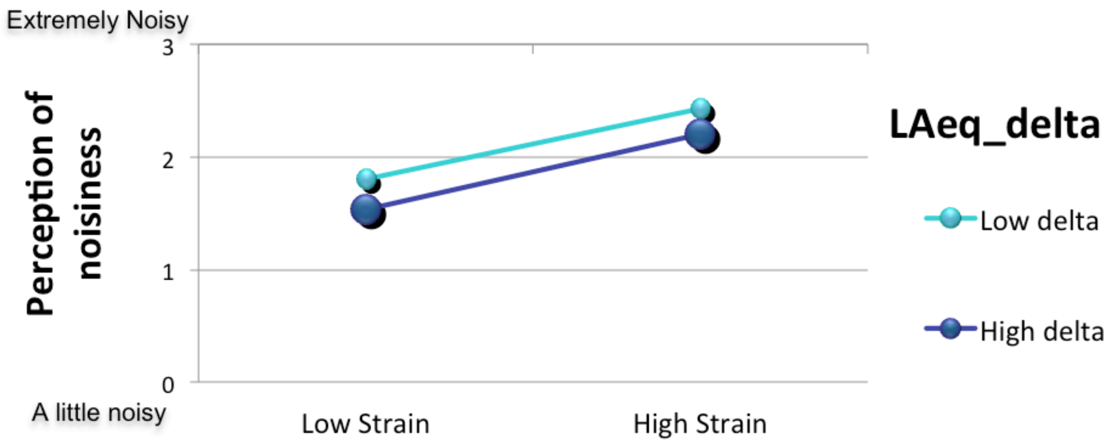

Figure 3.12 Hypothesis 2: Noise exposure and subjective job strain interact such that perception of noisiness is highest under lower noise differences between occupied and unoccupied spaces (via LAeq_delta) and high strain (*p*<0.01).

Again, the analysis of the delta variables should be done carefully. High delta means that there is a large change between occupied and unoccupied conditions, meaning that subjects may be working on changing conditions and may have to adapt several times.

The graph for SII delta looks very similar to the one on Figure 3.12 (*p*<0.01). The graphs for clarity (*p*<0.01), LCpeak occurrence rate for unoccupied spaces (*p*<0.05) and unoccupied NC (*p*<0.05) also look like the one on Figure 3.12, but with the high condition curve on top.

The graph for RT 500 looks very similar to Figure 3.12. But it is non intuitive because the low reverberation curve is above the high reverberation one. The possible reasons for this result were already discussed.

Summary

Table 3.7 is provided as a summary of the analysis for perception of noisiness concerning the two hypotheses. Several independent variables were found to be statistically significant related to perception of noise through both hypotheses. The ones with a stronger effect on perception of noisiness were: LAmax unoccupied occurrence rate, LCpeak occupied occurrence rate and L10 minus L90.

Table 3.7 Perception of noisiness analysis summary.

Acoustic Metric	Hypothesis 1	Hypothesis 2
LAeq (dBA)	F(1,68)=4.58, $p<0.05$, r=0.25	ns*
LAeq_delta (dBA)	ns	F(3,65)=4.28, $p<0.01$, $r^2=0.17$
SII	F(1,68)=7.66, $p<0.01$, r=-0.32	F(3,65)=5.24, $p<0.01$, $r^2=0.20$
SII_delta	ns*	F(3,65)=6.39, $p<0.01$, $r^2=0.24$
RT_500 (seconds)	F(1,68)=8.04, $p<0.01$, r=-0.33	F(3,65)=5.51, $p<0.01$, $r^2=0.21$
C50_500 (seconds)	ns	F(3,65)=4.17, $p<0.01$, $r^2=0.17$
LAmax_unocc_rate (%)	F(1,68)=12.78, $p<0.01$, r=0.40	F(3,65)=7.03, $p<0.01$, $r^2=0.25$
LCpeak_unocc_rate (%)	ns	F(3,65)=4.00, $p<0.05$, $r^2=0.16$
LAmax_occup_rate (%)	F(1,68)=9.78, $p<0.01$, r=0.36	F(3,65)=6.64, $p<0.05$, $r^2=0.24$
LCpeak_occup_rate (%)	F(1,68)=12.13, $p<0.01$, r=0.39	F(3,65)=7.70, $p<0.01$, $r^2=0.27$
L10 (dB)	F(1,68)=18.37, $p<0.01$, r=0.46	F(3,65)=9.21, $p<0.01$, $r^2=0.31$
L33 (dB)	F(1,68)=18.37, $p<0.01$, r=0.46	F(3,65)=9.21, $p<0.01$, $r^2=0.31$
L90 (dB)	F(1,68)=25.59, $p<0.01$, r=0.53	F(3,65)=10.36, $p<0.01$, $r^2=0.34$
L10_L90 (dB)	F(1,68)=12.06, $p<0.01$, r=0.39	F(3,65)=7.32, $p<0.01$, $r^2=0.26$
NC_unocc (rating)	ns	F(3,65)=3.73, $p<0.05$, $r^2=0.15$
NC_occup (rating)	F(1,68)=12.43, $p<0.01$, r=0.40	F(3,65)=7.11, $p<0.01$, $r^2=0.26$
Strain	F(1,68)=11.22, $p<0.01$, r=0.39	NA

NOTE: ns* means that $0.05<p<0.1$ but it was considered non-significant for this study

Other dependent variables

Self-perception of Health

The survey asked subjects how would they rate their health; in their responses, they were able to choose between these five options: excellent, very good, good, fair and poor.

Only two independent variables were found to be statistically significant related to self-perception of health in hypothesis one, and none were found to have an interaction with strain as stated in hypothesis two. A summary of these relationships can be found in Table 3.8.

Table 3.8 Self-perception of Health analysis summary.

Acoustic Metric	Hypothesis 1	Hypothesis 2
LAeq_delta	F(1,67)=5.10, $p<0.05$, r=0.27	ns*
NC_unocc	F(1,67)=5.31, $p<0.05$, r=-0.27	ns*
Strain	ns*	Not applicable

NOTE: ns* means that $0.05<p<0.1$ but it was considered non-significant for this study

As LAeq delta increased, self-perception of health decreased, which means that for higher delta LAeq, self-perception of health was lower. It is important to remember the fluctuations in the sound environment may have an effect on subjects, and these results are showing that. Further analysis should be done in order to relate the delta variables to several dependent variables.

The relationship with NC unoccupied was non logical because it indicated that as noise criteria increased, self-perception of health was better.

Satisfaction

The survey asked subjects how satisfied were they with their job; in their responses they were able to choose between these five options: extremely satisfied, satisfied, neutral, dissatisfied and extremely dissatisfied.

Only NC for unoccupied spaces showed a statistically significant relationship according to hypothesis 2 with subjective strain and job satisfaction (with $F(3,66)=2.12$, $p<0.05$, $r^2=0.13$). But the graph showed the low and high NC curves crossing each other, which does not make sense. Further analysis should be done in order to determine the relationship between job satisfaction and independent variables.

Organizational commitment

The survey asked subjects about the level of commitment with their current job; in their responses they were able to choose between these five options: not at all committed, slightly committed, moderately committed and fully committed. None statistically significant relationship was found with any dependent variable taking into account both hypotheses.

Physical Component Summary (PCS)

Physical health was calculated through the responses of several questions as described in previous sections. It did no show any statistically significant relationship in any of the two hypotheses with dependent variables.

Summary

Self-perception of health, job satisfaction and organizational commitment were calculated only from one question in the subjective survey. Almost no important relationship with independent variable was found with these dependent variables. Further research should be done to analyze better ways to gather these dependent variables.

PCS did not show any significant relationship with the independent variables. PCS was calculated with a similar procedure as MCS (Mental health) was. MCS did show several significant relationships with almost all independent variables on both hypotheses. Mental health could reflect annoyance on subjects and noise may affect that easily. In the case of PCS, physical health should change in subjects in order for this index to vary, and it may be difficult for only noise to cause this change quickly.

CHAPTER 4

SIMULATION STUDY

Methodology

This study was designed taking into consideration the previous studies mentioned in Chapter 2; also evidence shown in Chapter 3 states that noise affects hospital staff and that specific acoustic metrics could help to describe their relationship. From Chapter 2 it is clear that a new study is needed in order to relate noise with staff performance. This study should ask subjects to perform a real task from their jobs and should immerse them in a realistic hospital noise environment. The purpose of this portion of the research is therefore to develop and pilot test a methodology to relate hospital noise to staff performance in a realistic setting.

A simulation center is a place in hospitals or universities that is used to train healthcare staff. It is designed to be as realistic as possible, it has functional medical equipment and it looks like a real hospital. It is equipped with mannequins that look like a real people and have basic physiological functions including pulse and breath rhythm. An operator is located behind a one-way glass partition and can control the response of the mannequins based on the caregiver's performance (e.g., send the mannequin into cardiac arrest). These elements can be seen in Figure 4.1.

Figure 4.1 A Simulation room with a mannequin and glass partition.

Taking all into account, the simulations are meant to mimic real life medical situations, making them ideal spaces to test the impact of noise on staff performance without compromising the health or safety of live patients.

General description of the study

For this study subjects were asked to complete perception surveys and perform realistic patient-care tasks while the sound environment in the room was manipulated. Two different noise conditions were used, a quiet one and a noisy hospital environment. Two iterations of the tasks were used, which are described below. The order of the two noise conditions and the performance tasks were randomized between groups.

Demographic data was collected before starting the study and subjects were asked to fill out a survey about their impressions after each scenario. This way data concerning the relationship between noise environment, perception and performance was gathered.

The noise environment

A signal was synthesized in order to be played in the simulation room during the noisy scenario. It is composed of audio files that sound like real hospital noise but do not contain any identifiable patient data. It has several components that are heard in a healthcare facility, like conversations, equipment alarms, doctor paging, footsteps and an air conditioning system. The whole signal length is 30 minutes, even though each simulation lasts 15 minutes maximum, including the time to fill the survey. This way the signal did not end unexpectedly during a simulation.

Different acoustical metrics were used to compare the signal with real hospital data; that way the noise environment in which subjects performed is acoustically as close as possible to a real life situation. Several measurements were taken inside the simulation room with the signal playing. The collected data helped as an input to decide where and how to change the frequency content and some peaks in the signal through signal processing softwares (ArtemiS® V10.0 and GarageBand® 11 V6.0.4).

Because of logistical issues it was difficult to access the simulation center each time a change was made in the signal. Therefore an anechoic chamber was used to test the signal several times before final measurements were conducted in the simulation center.

ArtemiS® V10.0 was used to analyze the frequency content as a function of time. Taking into account the first occurrence rates measured, some frequency peaks were boosted in order to get the desired ones. Also the overall frequency content was analyzed and compared with real hospital data. Bands that were low in the simulation room with the signal playing were boosted.

After all the changes and several trials in the anechoic chamber, a final signal was developed. It was tested in the simulation room to account for the naturally occurring noise in that space. The final signal (as measured in the simulation room) was once again compared to real-life conditions to verify the acoustic realism of the noise environment in which the subjects were asked to perform.

Other Hospital data

A set of 4 units was chosen from previous research to compare the synthesized signal to real hospital data. All measurements from real units and the ones made on this study were taken with a fast response setting, one minute averaging intervals and using the same sound level meters (LarsonDavis 824). This data of real units was taken from different locations that could be compared with the place that the simulation room is trying to recreate. Unit 1 and 2 are occupied patient rooms in emergency departments (from Mahapatra, 2011). Unit 3 is an occupied urgent room in an emergency department (from Mahapatra, 2011). Lastly, unit 4 is an occupied room in a same day surgery unit (from US DoD, 2011).

Setup in the simulation room

The simulation room was arranged in such a way that no acoustic equipment was easily visible. That way subjects would not place undue attention on the changes in the acoustic environment during their simulations, potentially resulting in biased results.

Two speakers were used, a JBL® EON 510 and a JBL® EON15 G2. They were connected to a computer that had the digital signal through stereo 1/8" cables. The speakers were behind medical privacy screens as shown in Figure 4.2.

Figure 4.2: Privacy screens in the simulation center.

A floor plan of the simulation room is provided in Figure 4.3. The speakers are located on the top corners. The triangles are the microphone locations for different measurements.

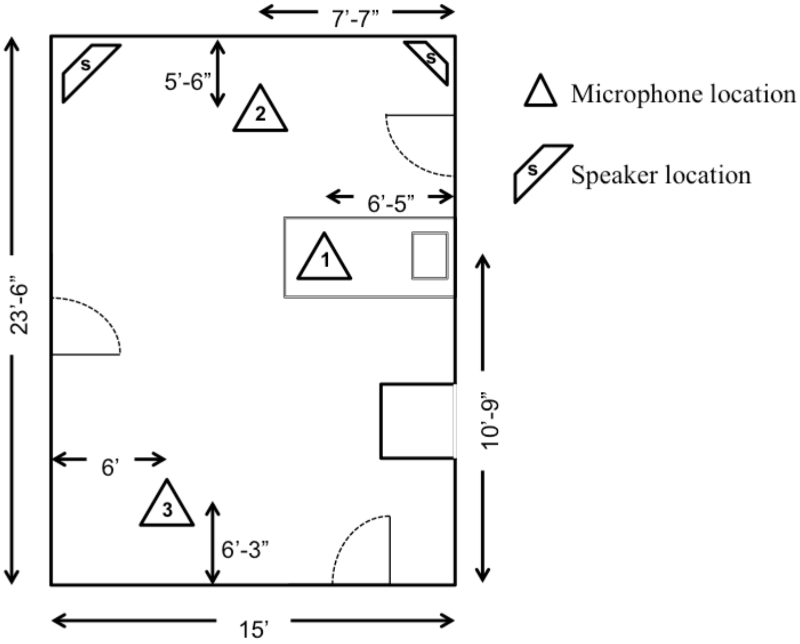

Figure 4.3 Simulation room floor plan, showing microphone and loudspeaker locations.

In order to set up and calibrate the signal, all the acoustic equipment was installed in the room, and the signal was played while a LarsonDavis 824 sound level meter measured the sound environment (on location 1). The microphone was at 5 feet height and just above the bed, where subjects are most of the time during the simulation (location 1). Location 2 and 3 were measured using tripods with microphones at 4 feet height. All measurements were taken at location 1 unless otherwise specified.

The volume of the signal was varied in order to get 62.5 dBA, which is in the mid-range of what has been found in real hospitals (from 56 to 71 dBA; US DoD, 2011; Mahapatra, 2011; Moeller, 2012). Once this level was achieved, the same signal was measured in different locations simultaneity to see if there was a difference between locations. During the simulations no acoustic data was collected. That way there was no sound level meter or microphone to hide inside the room.

The survey

Subjects were asked to fill out a survey about their perception after each simulation. This survey collected their impressions about the room environment (e.g., lighting, temperature, noise) and their perceived performance. It also asked them if they thought the noise affected the communication between team members. This way data concerning the relationships between perception-noise environment and perception-performance were gathered. The survey was anonymous. All team members (leader + two assistants) were asked to complete the survey in order to see if there was a difference between the assistant and team leaders answers. The survey can be found in Appendix A.

The collected surveys were scanned into electronic format. Results were then tabulated into spreadsheet format using Remark Office Optical Mark Recognition (OMR) v.7.0 software.

The task performance measure

The simulation centers are used to train and certify healthcare staff on a variety of medical and patient care procedures. Usually procedures that can be modeled with algorithms (step-by-step procedures) are taught in simulation centers. A commonly tested procedure is the Advanced Cardiovascular Life Support (ACLS) procedure, which tests staff on clinical interventions needed for urgent treatment of cardiac arrest, stroke, and other cardiopulmonary emergencies. The ACLS utilizes a systematic approach (a.k.a. algorithm) to test staff on a variety of skills, such as advanced airway management, pharmacological intervention, defibrillation / external pacing, acute coronary syndrome, acute ischemic stroke, cardiac rhythm disturbances, and post resuscitation care (Sinz, et al., 2011). The tests are designed for personnel working in emergency response or in emergency, intensive care, and critical care types of hospital settings.

Several categories of hospital staff, including physicians, pharmacists, midlevel practitioners, respiratory therapists, nurses, paramedics, and other emergency responders are required to get an ACLS certification every two years depending on their medical institution's requirements (Sinz, et al., 2011). Certification is typically completed in the form of a course that includes a theory and a practice part. The first part is where the algorithms are explained and taught to subjects. The second part is usually held in a simulation center where the caregivers perform some of the algorithms (which are also called megacodes) and their performance is evaluated. A number of different standardized algorithms (i.e., megacodes) are available (American Heart Association, 2012).

Instructors have a checklist for each megacode; that way they can objectively evaluate students, as they need a minimum grade in order to get certified. Usually the instructor speaks as if he or she were the patient. Sometimes the instructors are behind mirror windows in the simulation room so that subjects cannot see them; that way the simulation is more real. The ACLS megacodes are usually performed in groups composed by one team leader and two assistants. The team leader makes the decisions and is the one being certified.

Previous studies have used the ACLS megacodes as a method to measure performance and compare different situations. Lo et al. in 2011 studied the difference in performance between two different teaching methods in order to compare them and test if one of them was better. They found out that in the initial testing subjects from one method performed significantly better than the others. Nevertheless, after a year from their respective training there was not a significant difference in their performances (Lo, et al., 2011).

Therefore, in the current study subjects are asked how long it has been since their last certification and this variable can be treated as a potential confounding factor.

The study protocol

Each group of subjects was asked to perform two simulations (corresponding to the noise and quiet conditions) for this research study that would not count for any certification process. All of them should complete the same two megacodes in a randomized order, one of them with the signal playing and the other one without it (i.e., the quiet environment).

Consent was collected before starting the first simulation in accordance with Institutional Review Board procedures. Subjects were asked to stay outside the room while “the room environment is set up”. If they were going to perform the noisy simulation, the signal was turned on, and then the investigator let them in. If they were going to perform the quiet simulation, the investigator just entered the room, waited a few seconds and then let them in. That way both simulations were treated the same way. Between the two simulations subjects were asked to leave the room for the same reason.

After each megacode, subjects were asked to fill out the survey inside the room; that way they were immersed in the same noisy or quiet environment as they experienced during the simulation they were evaluating.

Behind the one-way glass in the simulation room was the person who ran the simulation and spoke as if he or she were the patient. The simulations were taped; that way a doctor could watch it later and grade the performance with the checklist.

Results

The room acoustic environment

The background LAeq level for the unoccupied simulation room without the signal was 37.7 dBA. The Schroeder frequency was calculated to better understand what frequencies should be included in the signal analysis and characterization. The sound environment can be assumed to be sufficiently diffuse above the Schroeder frequency such that microphones are not located in modes. Therefore, the sound pressure level on a room should not depend as much on the location if the considered frequency band is above the Schroeder frequency. Acoustic modes can appear below the Schroeder frequency, making the sound pressure level more dependent on the location.

Measurements were taken in three different locations in the simulation room once the final signal was synthesized. Also, an approximate value of the Schroeder frequency was calculated from the dimensions of the room and the estimated sound absorption coefficients of the floor, walls and ceiling.

The Schroeder frequency can be calculated using Equation 4.1, where T_{60} is the reverberation time (in seconds) and can be approximated by Equation 4.2. The volume of the room is represented by V (in meters cubed).

$$f_s = 2000 * \sqrt{\frac{T_{60}}{V}}$$

Equation 4.1 Schroeder frequency (Kuttruff, 2000).

$$T_{60} = \frac{0.16 * V}{S_{tot} * \bar{\alpha}}$$

Equation 4.2 Reverberation time (Bies & Hansen 1996).

The surface areas of the room are accounted in S_{tot}, which is the total area of the room including floor, walls and ceiling. The alpha bar value ($\bar{\alpha}$) is the average absorption coefficient of the room and is calculated using Equation 4.3.

$$\bar{\alpha} = \frac{\sum S_i * \alpha_i}{S_{tot}}$$

Equation 4.3 Average absorption coefficient (Bies & Hansen 1996).

Equation 4.3 accounts for all the surfaces and their specific acoustic absorption coefficients in the summation. It then divides by the total surface area of the room, making $\bar{\alpha}$ an average absorption coefficient.

The reverberation time using these formulas was 0.6 seconds at 500 Hz and the Schroeder frequency was 155 Hz. It is important to state clearly that these are approximate values. The sound absorption coefficients for surface areas can be easily found in the literature. The walls in the simulation center were gypsum board, and acoustic ceiling tiles composed the ceiling. The dimensions of the simulation room can be found above in Figure 4.3, the height of the room is 10 feet.

Figure 4.4 shows the frequency content of the background (quiet) noise condition in the simulation room measured at location 1 indicated on the floor plan in Figure 4.3. Also an average from all 4 units of real hospitals is shown for comparison. The average was taken at each one-third octave band across the data set of the four units.

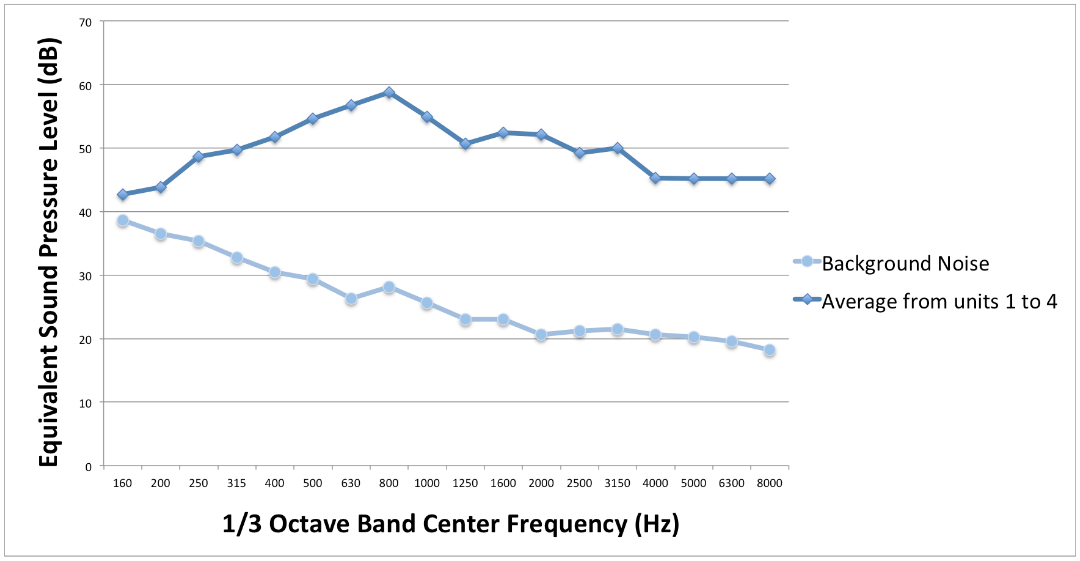

Figure 4.4 Frequency content for background noise and other real units. (Units 1-4: Mahapatra, 2011; US DoD 2011)

The background noise is way lower than the average levels found in other hospitals (units 1 to 4), which suggest the importance of synthesizing a signal to recreate a real-hospital sound environment. Also, the LAmax occurrence rates for the background noise are shown in Figure 4.5, which are definitely well below the ones found in units 1 through 4, as is exposed in the next few pages (Figure 4.6 and Figure 4.9).

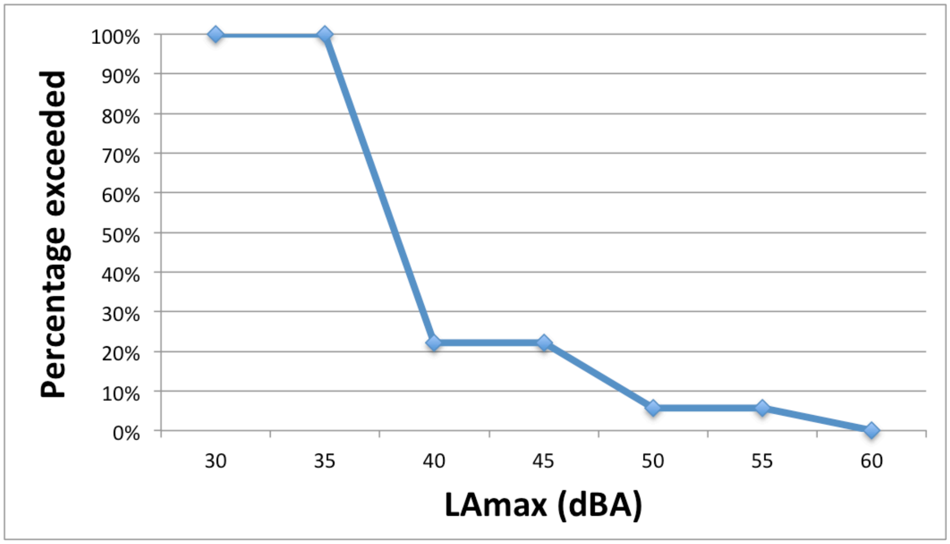

Figure 4.5 LAmax occurrence rate for background noise in simulation room.

Synthesizing the signal

The process to create a signal that recreated a noisy environment comparable with a real hospital had several steps as stated before. The signal is 30 minutes long, but only the first 15 minutes are used in the metric calculations, as those are the minutes that subjects hear. The synthesized signal was calibrated against the 4 units of real hospital data using these metrics: overall LAeq, LAmax occurrence rate, and frequency content. This process is described below.

Occurrence rates

On Figure 4.6 is possible to see the comparison between the LAmax occurrence rates for the first signal that was synthesized, measured in the simulation room. The occurrence rate for the background (quiet) noise condition is overlaid for comparison.

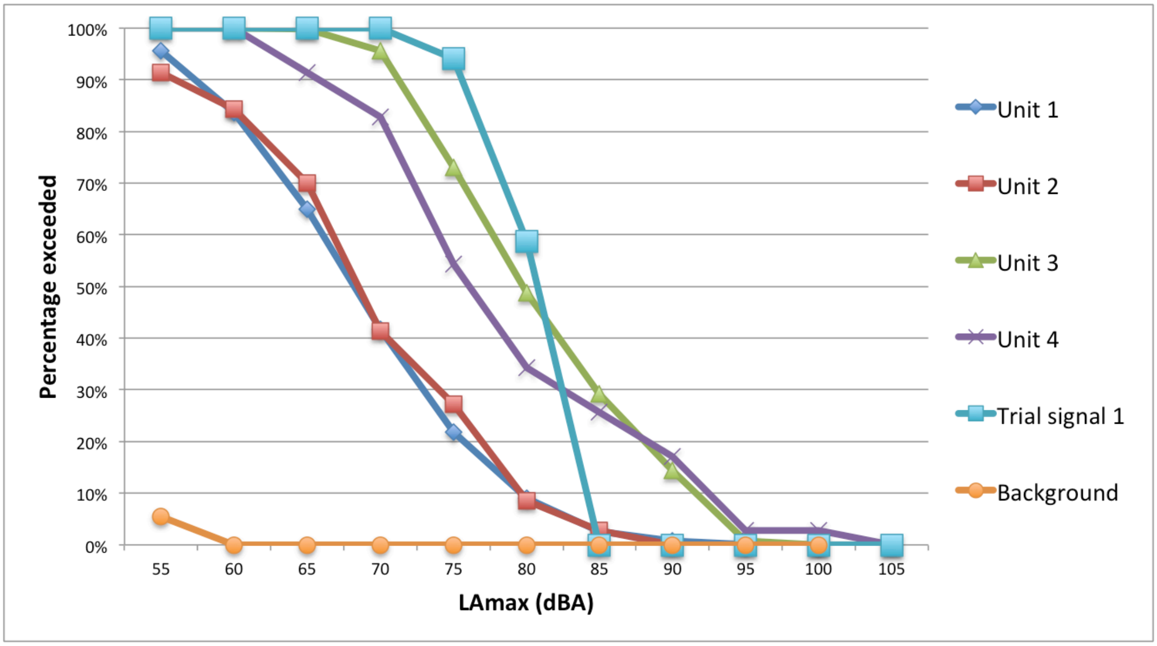

Figure 4.6: LAmax occurrence rates comparison for Trial signal 1. (Units 1-3: Mahapatra, 2011; Unit 4: US DoD 2011)

As can be seen, the first signal was not in the boundaries of data from other units collected in the past. Also, the overall A-weighted level was 68 dBA. Taking this into account the equivalent level was taken down to 62.5 dBA, which is in the mid-range of what has been measured previously in real hospitals (56 to 71 dBA: US DoD, 2011; Mahapatra, 2011). This change shifted the LAmax occurrence rate curve to the left, creating trial signal 2.

Next, the higher amplitude peaks needed to be boosted to match the form of the other graphs. Artemis ® software V10.0 was used to analyze the signal level over time in order to spot the higher amplitude peaks (Figure 4.7). Eight peaks evenly distributed along the 30-minute signal were altered. Those peaks represented more than 25% of the minutes. One-third octave band levels were plotted for each of those peaks in order to determine which band to boost. One example could be found in Figure 4.8. This way the signal does not sound unreal or altered because only the bands that generate the peak are boosted.

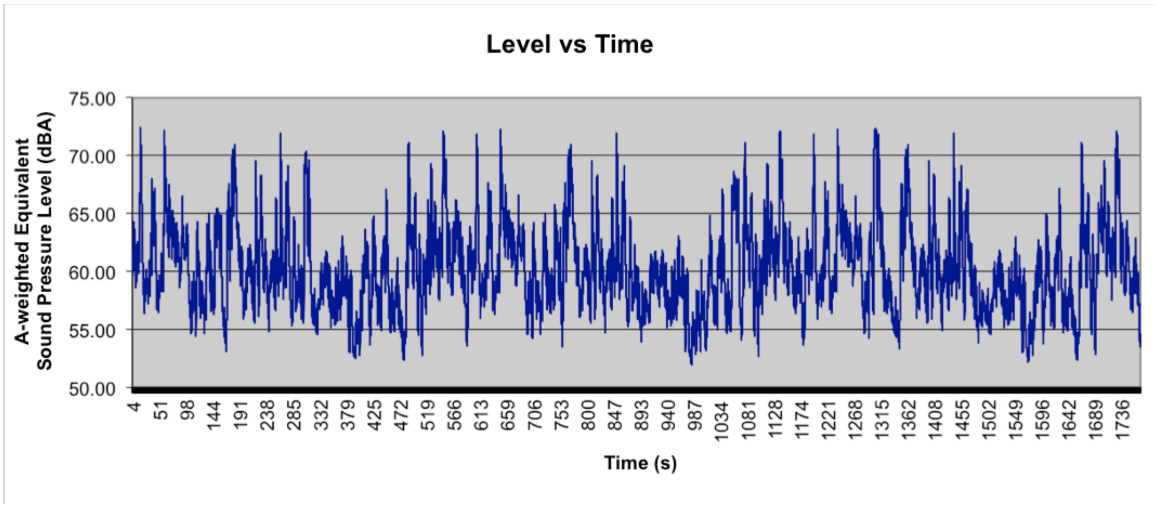

Figure 4.7: Signal level versus time for Trial Signal 2.

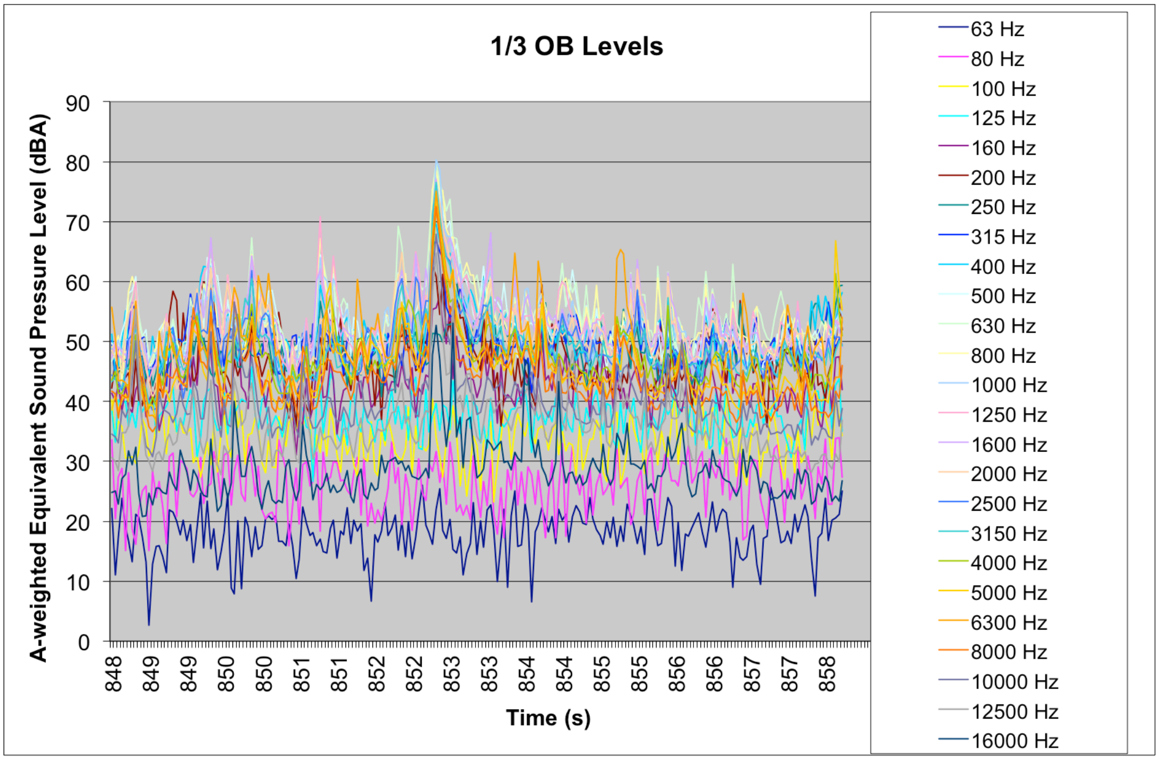

Figure 4.8: One-third octave band levels versus time for Trial Signal 2.

The peaks were altered step by step, with measurement in an anechoic chamber in between. After an acceptable signal was acquired, the final measurements were held inside the simulation room. The LAmax occurrence rates for the final signal are shown in Figure 4.9.

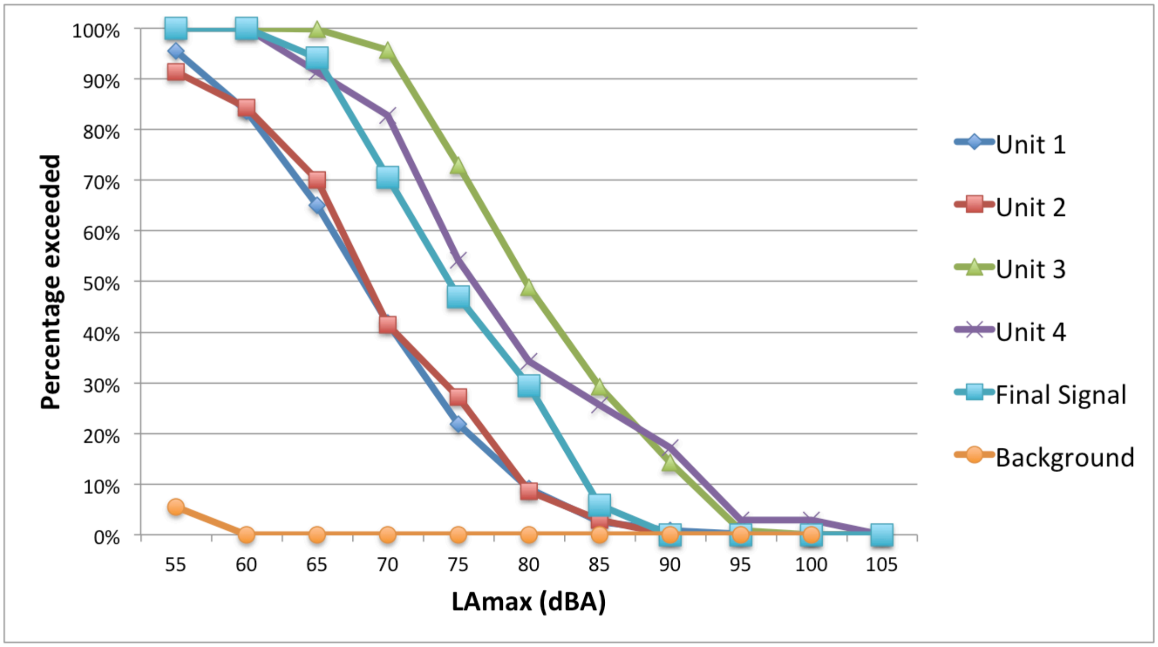

Figure 4.9: LAmax occurrence rates comparison for Final Signal. (Units 1-3: Mahapatra, 2011; Unit 4: US DoD 2011)

As can be seen, the new occurrence rates in the simulation room are inside the values measured in the real units. Again, the background (quiet) noise condition is overlaid for comparison.

Frequency content

Frequency content in the simulation room was measured while the final signal was played; it was then compared with data from units 1 to 4 in Figure 4.10. The maximum and minimum values were calculated for each one-third octave band across the 4 units. The background (quiet) condition is overlaid for comparison.

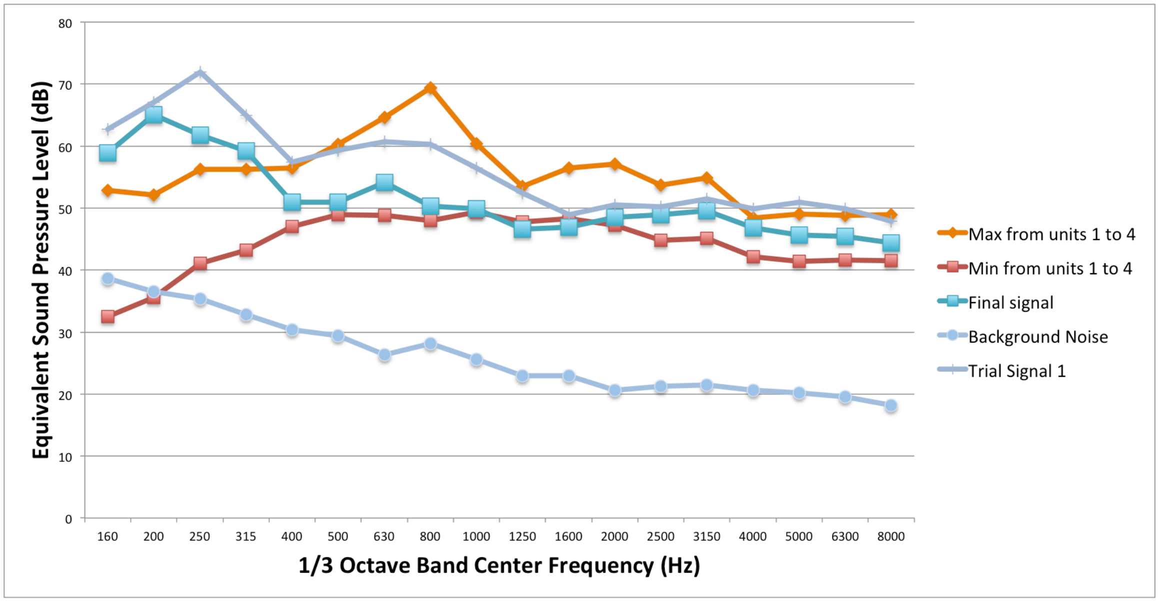

Figure 4.10 Final signal frequency content compared to other hospitals. (Units 1-4: Mahapatra, 2011; US DoD 2011)

It can be seen that above the 400 Hz band the frequency content on the simulation room is generally between the maximum and minimum levels found in other hospitals. The final signal is somewhat higher in low frequency content (160 – 400 Hz) than found in other hospitals. This was caused because the signal had more low frequency content on those third octave bands than what is found in real hospitals; additional filtering of the test signal made it sound too artificial. The background noise in the simulation room is also shown; this background noise is generally quieter than the background noise measured in other hospitals.

Figure 4.11 shows the frequency content of the background (quiet) noise condition in the simulation room measured simultaneously at the three microphone locations indicated on the floor plan in Figure 4.3.

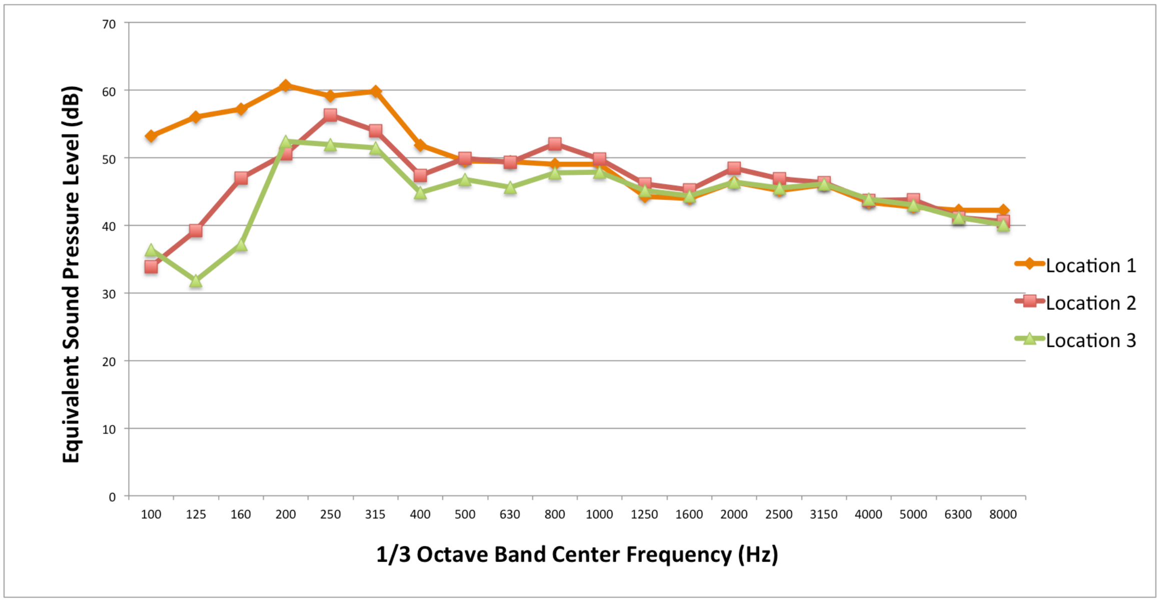

Figure 4.11 Final Signal frequency content in different locations

It is clear that below the 160 Hz band (Schroeder frequency) the sound pressure level varies, which is likely due to the modal room response (i.e., dependent on the microphone location). Between 160 and 400 Hz there is still up to 10 dB difference in microphone location, which is likely due to spatial distribution of ambient sound sources in the room (e.g., air diffusers). Above the 400 Hz band the frequency content is much more similar across locations. Between those bands, the measured levels may differ slightly in each location but they have the same trend.

Simulation study preliminary results

A single group of subjects was beta-tested to verify the functionality and ease of the study protocol. A spreadsheet was constructed to analyze the gathered data, which included analysis of demographic data and differences in subjective responses for the team leader and the assistants. Due to the small sample size (one group or three participants), this analysis is not included in this thesis but the spreadsheet template can be used in future work with a larger sample size.

CHAPTER 5

CONCLUSIONS

The purpose of this thesis was to study the effect that the acoustic environment has on the staff that works in hospitals. Two objectives were clearly stated to guide development of the study:

- To establish relationships between noise environment and the staff occupational factors in real-life hospitals.
- To develop a study methodology to directly measure performance and perception of staff exposed to noise in a realistic, simulated setting.

Survey study

A deeper analysis of the data set gathered in the HE-BASQ study was done in this thesis. More than 15 acoustic metrics and 6 occupational factors were examined in order to establish relationships between them.

Mental health and perception of noisiness are the occupational factors that were related to more acoustic metrics; this should be taken into account in future studies. The following acoustic variables were shown to have a statistically significant relationship with several dependent variables: LAeq, SII, occupied and unoccupied occurrence rates (LAmax and LCpeak) and percentiles levels. All of these acoustic variables are relatively easy to calculate from the data gathered by a sound level meter, making it possible to take them into account in future research.

Other independent variables, like RT 500, C50 and Noise Criteria showed statistically significant relationships with occupational factors in some cases. But sometimes the direction of the connection was not logical, indicating that as noise increased better occupational factors were measured.

It is crucial to state the importance of the second hypothesis; the interaction between subjective strain and independent variables affected significantly dependent variables. For example, MCS: only 2 acoustic variables had a statistically significant relationship as stated in hypothesis 1 (direct relationship); which could imply that MCS is not a good variable to measure staff outcomes. However, once hypothesis 2 was taken into account, all acoustic metrics had a statistically significant relationship with MCS. These results imply that while the direct impact of sound on MCS was not statistically significant (hypothesis 1), noise did play a role once perceptual job strain was taken into account (hypothesis 2).

Simulation study

The goal for this study was to develop a methodology that could directly measure performance and perception of staff exposed to noise in a realistic, simulated setting. It was successfully completed; the methodology was established and tested for the first group of subjects. A signal was synthesized to reproduce a noise environment that was comparable to the ones heard in real hospital units in order to have a realistic condition in a controlled environment. Additionally, objective methods of measuring performance and perception were devised by utilizing task performance scripts already validated in other studies. A survey was developed and administered to subjects in order to garner their perceived task performance and perceptions of the simulation room environment, including noise. The whole methodology was shaped to be as simple as possible, which was confirmed after the first group of subjects completed the process.

Future research

Concerning the survey study, further analysis should be done before associating dependent variables as: RT 500, C50 and Noise Criteria to occupational factors. It would be important to find a better way to gather job satisfaction and commitment, using more that one question in the survey, in order to get results that may represent better the reality. Further analysis could be done to the data set, for instance it could be interesting to compare between units that have the same LAeq level but differ in the dichotomous perceptual strain variable to see if there is a relationship with some independent variables. Also, noise could be treated as a continuous variable instead of using the median split, it would be important to take into account the size of the data set for this analysis. Additional metrics may be tested; also further use of developed methodology for the analysis and collected data can produce on insightful results. Future studies should be aimed to determine thresholds in the occupational factors and relate them to the acoustic metrics in order to establish maximum levels for the design of hospital acoustics (e.g., what SII, RT, or LAmax unoccupied Occurrence Rate values are appropriate for different types of spaces in hospitals?).

Regarding the simulation study, it would be helpful to improve the synthesized signal to match even more the data from real hospital units, specifically the lower frequencies (between 160 and 400 Hz). The whole methodology was developed to be as simple as possible, that way the gathering of future data could be delegated in order to study more subjects and have more data variance. A spreadsheet was built to analyze gathered future data. It could be interesting to analyze the subjective responses of the team leaders and compare it with the ones of the assistants once a substantial amount of data is gathered. Concerning the signal level, additional field measurements should be conducted to determine levels during most stressful times in urgent care (that could be louder). Then, a third signal could be possibly included with greater LAeq. About the effect that noise has on staff, it could be interesting to measure physiological stress responses of staff concurrent with simulation task performance, in order to understand in a better way how stress impacts task performance in noise.

Overall summary

This study helped to understand how sound environments in hospitals affect staff outcomes, such as mental and physical health and performance. The survey study showed that MCS and perception of noisiness were related to a variety of acoustic metrics. It was important to take into account subjective job strain in order to get the relationships between acoustics metrics and staff outcomes. On the simulation study, a methodology was developed to test task performance of staff on a realistic simulated environment and a signal was synthesized comparable to real hospital sound environments. This methodology was tested on a pilot group. This thesis helps to advance knowledge on the hospital acoustics field by providing evidence on how a hospital's soundscape affects staff members.

APPENDIX A

SURVEY USED IN SIMULATION STUDY

The assigned Report Control Symbol is
DD-HA(AS)2263
with an approval expiration date of
April 30, 2014.

Dear Participant,

You are being asked to volunteer in a performance improvement study.

This study will examine how various characteristics of the hospital environment affect the performance of caregivers.

If you decide to participate, you will be asked to fill out a general survey about yourself and your job. The survey will take approximately 10 minutes to complete.

Then you will be asked to complete two ACLS mega-codes. After each one, you will be asked to complete a questionnaire about your perception of the simulation center environment.

Please return your survey to the person in charge of the simulation center.

Thank you!

Healthcare Environments Simulation Study
Emory University
General Survey

Please fill in the bubbles completely.

Your responses to this survey will be de-identified (coded with a sequential respondent number), remain confidential, and will not be used in a manner that could identify you in the future. Your name will not be collected in this survey and any other fact that might point to you will not appear when results of this study are presented or published.

1. Gender

○	Male	○	Female

2. How old are you?

_____________ years

3. Which job category best describes you?

○	Medical Student	○	Resident
○	Fellow from Emory	○	If other, please describe: ____________________________

4. In an ordinary week, how many total hours do you spend at work?

○	0 – 20 hours	○	20 – 39 hours
○	40 hours	○	More than 40 hours

5. To which type of department are you primarily assigned?

○ Intensive Care (ICU) ○ Med/Surg Nursing ○ Emergency (ED)

○ Ambulatory Care ○ Labor & Delivery

○ Other, please describe:

6. When was your last ACLS certification?

○ Less than 2 months ○ 2 to 6 months

○ 7 to 12 months ○ More than 12 months

7. For how long have you been certified in ACLS?

○ Less than 1 year ○ 1 to 3 years

○ 4 to 5 years ○ More than 5 years

8. How long have you been in your current job?

○ Less than 1 year ○ 1 to 5 years

○ 6 to 10 years ○ More than 10 years

9. Do you have any known hearing impairments?

○ Yes ○ No ○ I don’t know

If yes, what type?

10. In everyday life, do you have difficulties understanding speech in an environment where there are several others talking at the same time?

○ No, not at all ○ Somewhat ○ Yes, definitely

11. How do you think your hearing is?

Very Poor	Poor	Normal	Good	Very Good
○	○	○	○	○

12. In general, how *sensitive* are you to the following:

	Not at all Sensitive 1	A little Sensitive 2	Moderately Sensitive 3	Quite Sensitive 4	Extremely Sensitive 5
Light	○	○	○	○	○
Noise	○	○	○	○	○
Temperature	○	○	○	○	○
Odors	○	○	○	○	○

13. How many hours do you usually sleep during a normal night

○ Less than 6 ○ 6 to 8 ○ More than 8

14. How many hours did you sleep last night?

○ Less than 6 ○ 6 to 8 ○ More than 8

15. When was your last work shift?

○ Today ○ Yesterday ○ 2 days or more ago

FIRST SIMULATION. SPECIFIC QUESTIONS.

After your first simulation, please complete the following questions.

1. During the most recent simulation I had to raise my voice in order to communicate with others

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

2. During the most recent simulation I had trouble communicating with other simulation participants because of the sound environment

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

3. During the most recent simulation the sound environment was a distraction

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

4. During the most recent simulation I had trouble concentrating because of the sound environment

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

5. During the most recent simulation I found the sound environment to be annoying

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

6. Please rate your impressions of the conditions in this room during the most recent simulation based on the following attributes:

Lighting Overall	○	○	○	○	○
	Too Dark	*Somewhat Dark*	*Just Right*	*Somewhat Bright*	*Too Bright*
Loudness of Background Noise	○	○	○	○	○
	Too Quiet	*Somewhat Quiet*	*Just Right*	*Somewhat Loud*	*Too Loud*
Temperature	○	○	○	○	○
	Too Cold	*Somewhat Cold*	*Just Right*	*Somewhat Hot*	*Too Hot*
Air Freshness	○	○	○	○	○
	Too Fresh	*Somewhat Fresh*	*Just Right*	*Somewhat Stale*	*Too Stale*
Odor	○	○	○	○	○
	Unpleasant	*Somewhat Unpleasant*	*No smell (Neutral)*	*Somewhat Pleasant*	*Pleasant*

7. During the most recent simulation I would rate my overall performance as:

Very Poor	Poor	Marginal	Good	Very Good
○	○	○	○	○

SECOND SIMULATION. SPECIFIC QUESTIONS.

After your second simulation, please complete the following questions.

1. During the most recent simulation I had to raise my voice in order to communicate with others

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

2. During the most recent simulation I had trouble communicating with other simulation participants because of the sound environment

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

3. During the most recent simulation the sound environment was a distraction

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

4. During the most recent simulation I had trouble concentrating because of the sound environment

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

5. During the most recent simulation I found the sound environment to be annoying

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

6. Please rate your impressions of the conditions in this room during the most recent simulation based on the following attributes:

Lighting Overall	○	○	○	○	○
	Too Dark	*Somewhat Dark*	*Just Right*	*Somewhat Bright*	*Too Bright*
Loudness of Background Noise	○	○	○	○	○
	Too Quiet	*Somewhat Quiet*	*Just Right*	*Somewhat Loud*	*Too Loud*
Temperature	○	○	○	○	○
	Too Cold	*Somewhat Cold*	*Just Right*	*Somewhat Hot*	*Too Hot*
Air Freshness	○	○	○	○	○
	Too Fresh	*Somewhat Fresh*	*Just Right*	*Somewhat Stale*	*Too Stale*
Odor	○	○	○	○	○
	Unpleasant	*Somewhat Unpleasant*	*No smell (Neutral)*	*Somewhat Pleasant*	*Pleasant*

7. During the most recent simulation I would rate my overall performance as:

Very Poor	Poor	Marginal	Good	Very Good
○	○	○	○	○

THANK YOU VERY MUCH FOR YOUR TIME AND INPUT

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