INVESTIGATION OF NOISE IN HOSPITAL EMERGENCY DEPARTMENTS

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NOMENCLATURE

ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CDU	Clinical Decision Unit
dBA	A-weighted Decibels
dBC	C-weighted Decibels
EASERA	Impulse Response Measurement Software
ED	Emergency Department
EDT	Early Decay Time
EMT	Emergency Medical Technicians
ICU	Intensive Care Unit
IR	Impulse Response
L33	Decibel Level that is exceeded 33% of the time
L90	Decibel Level that is exceeded 90% of the time
LAeq	A-weighted Equivalent Sound Pressure Level
LAmin	A-weighted Minimum Sound Pressure Level
LAmax	A-weighted Maximum Sound Pressure Level
LCpeak	C-weighted Peak Sound Pressure Level
Main ED	Main Urgent Care Area of Emergency Department
MHS	Military Health System
MLS	Maximum Length Sequence
NIOSH	National Institute of Occupational Safety and Health
NP	Nurse Practicioners
RC	Room Criterion Rating
SII	Speech Intelligibility Index
SLM	Sound Level Meter
SNR	Signal-to-Noise Ratio
TDGF	Time-Domain Green’s Function
WHO	World Health Organization

SUMMARY

The hospital sound environment is complex. Emergency Departments (EDs), in particular, have proven to be hectic work environments populated with diverse sound sources. Medical equipment, alarms, and communication events generate noise that can interfere with staff concentration and communication. In this study, sound measurements and analyses were conducted in six hospitals total: three civilian hospitals in Atlanta, Georgia and Dublin, Ohio, as well as three Washington, DC-area hospitals in the Military Health System (MHS). The equivalent, minimum, and maximum sound pressure levels were recorded over twenty-four hours in several locations in each ED, with shorter 15-30 minute measurements performed in other areas. Acoustic descriptors, such as spectral content, level distributions, and speech intelligibility were examined. The perception of these acoustic qualities by hospital staff was also evaluated through subjective surveys. It was found that noise levels in both work areas and patient rooms were excessive. Additionally, speech intelligibility measurements and survey results show that background noise presents a significant obstacle in effective communication between staff members and patients. Compared to previous studies, this study looks at a wider range of acoustic metrics and the corresponding perceptions of staff in order to form a more precise and accurate depiction of the ED sound environment.

CHAPTER 1

INTRODUCTION

The hospital sound environment is complex. Medical equipment, alarms, and communication events generate noise that can interfere with staff concentration and communication. This problem is readily seen in Emergency Departments (EDs), in particular. While this acoustic environment is thought to be both complex and intriguing, a limited amount of research has been done focusing on EDs. While previous studies have investigated noise levels in various hospital settings and employees' perceptions of noisy workplaces, extremely limited information is currently available for EDs. This lack of information is attributable to the difficulty in collecting data – the prototypical ED is chaotic, unpredictable, difficult to acquire research access to, and fully operational at all times of the day.

The goal of this study is two-fold – to measure and quantify the acoustic environment of EDs and to investigate the potential effects of noise on ED staff member's perception of their work environment. The first portion involves quantitative, objective analysis of six EDs. By measuring background noise levels in several locations and measuring the room impulse response, a greater understanding of the acoustic environment is achieved. However, current methods for gathering the room impulse response are considered invasive in an ED setting. Therefore, this study also sought to investigate a new, "passive" method for determining the room impulse response, using only ambient room noise as a source. The second portion of the project involved the administration of anonymous surveys given to hospital staff in order to relate perceptions of their work environment to the objective measurements taken. By examining these two areas, a greater understanding of the effect of noise on ED staff members is gathered. While this study does not seek to prove any sort of causation, it provides the first steps in developing relationships between a unique acoustic environment and the corresponding subjective perception.

CHAPTER 2

LITERATURE REVIEW AND BACKGROUND

2.1 Noise Levels in Hospital Environments

The standards for safe noise levels in work environments, namely hospitals, are established by the World Health Organization (WHO) (World Health Organization 1999). However, several studies have shown that the noise in healthcare settings regularly exceeds recommended levels. A 2005 study showed that A-weighted equivalent sound pressure levels (LAeq) in certain hospitals, specifically patient rooms, range between 50 – 60 dBA – well above the WHO recommendation of 30 dBA. Additionally, these LAeq values have been steadily increasing over the past 40 years (Busch-Vishniac et al. 2005).

The noise levels in Emergency Departments (EDs), specifically, have also been documented and found similar results. A study of Phoenix, AZ, EDs found average LAeq levels between 66 and 73 dB (Buelow 2001). Two more recent ED studies in Chicago, IL, and Baltimore, MD, found LAeq levels of approximately 57 dB (Zun and Downey 2005) and 65 dB (Orellana, Busch-Vishniac and West 2007), respectively. These studies have reported the average, maximum, and minimum levels as well as the frequency content. However, other relevant acoustic metrics, such as speech intelligibility, percentile levels, occurrence rates, and reverberation times have not been examined. The measurement of these other characteristics is crucial in understanding the total acoustic landscape of an ED.

Speech intelligibility, the measure of how accurately a listener can understand speech, is important to the communication between members of the hospital staff. A communication error can quickly translate to a medical error in a fast-paced ED setting. Percentile levels are a measure of the percent of time the overall, continuous sound level exceeds certain thresholds, and provide an indication of the general variance of sound over time. The measurement of occurrence rates is related;

it is the measure of how often the LAmax and LCpeak levels exceed a certain value, will give a numerical value to the “impulsiveness” of an ED. Reverberation time is a measurement of how long it takes for sounds to decay. This can describe which sounds are sustained the longest in the ED and thus contribute to LAeq levels the most.

2.2 Effects of Workplace Noise

Previous research has shown that noise in the workplace can have significant effects on employees. For example, work noise exposure (Bies and Hansen 1996, Cesana, et al. 1982, Cook and Wall 1980, Cottington, et al. 1983, Karasek 1979)has been correlated with an increased risk of heart attacks in men of various occupations between the ages of 30-65.(Ising, et al. 1997). In recent years, researchers in environmental health have linked occupational noise exposure to a variety of negative stress, job satisfaction, and health effects for non-hospital workers. For example, Sundstrom et al. (1994) found declining job satisfaction from workers exposed to increased noise. Another example is found in Leather et al. (2003), which presented important findings related to noise and job stress for office workers. Their results showed:

> “…no direct effect of ambient noise levels upon job satisfaction, well-being, or organizational commitment. However, lower levels of ambient noise were found to buffer the negative impact of psychosocial job stress upon these same three outcomes. Psychosocial job stress is, therefore, seen as a valuable heuristic in operationalizing the context of sound events at work.”

Further, it appears that in order to understand the true effect of occupational noise on occupants, one must gather more than just perceptual physical environment information (e.g., how loud or annoying?) from subjects. Several studies have shown that the negative effects of occupational noise exposure are contingent upon features of the broader work context. For example, the interactive effect of occupational noise exposure and shiftwork demands on various health outcomes is well documented, e.g. (Nurminen and Kurppa 1989, Cesana, et al. 1982, Ottman, et al. 1987). In one study, Nurminen and Kurppa (1989) found that pregnancy complications for women working in noisy environments were exacerbated if they were also subjected to additional shiftwork demands. Other studies have found that workers' blood pressure levels were impacted by an interaction of noise and job stress (Cottington, et al. 1983) or noise and social support (Lercher, Hortnagl and Kofler 1993).

Additionally, it has been shown that increased noise in a healthcare setting can have an adverse effect on hospital staff. Doctors in operating rooms were found to have diminished short-term memory in noisy environments (Murthy, et al. 1995) and higher levels of stress were found in staff in a pediatric ICU (Morrison, et al. 2003). Other studies have shown that hospital noise may affect burnout (Topf and Dillon 1988), hearing loss (Holmes, et al. 1996), task performance, and concentration. Although some potential negative impacts on staff have been documented, no studies have specifically examined the correlation between noise and staff response in an ED.

CHAPTER 3

METHODS

3.1 Overview

Two different types of measurements were taken during the study: objective acoustic measurements, consisting of sound level meter (SLM) and room impulse response (IR) measurements and subjective measurements consisting of information collected through anonymous questionnaires administered to ED staff. These two different types were conducted to relate acoustic measurements of the environments to the perception of the staff members within them. The acoustic data was collected in all six study sites, and the survey data was collected in two of the sites, as described below.

3.2 Study Sites

The EDs in six hospitals were included in this study: three civilian hospitals in Atlanta, Georgia and Dublin, Ohio, as well as three Washington, DC-area hospitals in the Military Health System (MHS).

The EDs of the first two hospitals contain a main, urgent care area (Main ED) and a smaller, secondary care area known as the Clinical Decision Unit (CDU). The remaining four consist of only one area. Figure 1 through Figure 7 show the ED floor plans and measurement locations for all hospitals. Figure 3 shows a more detailed view of the main Nurse's Station in Hospital 2. In each floor plan, squares denote 24-hour measurements, circles denote measurements between 15-30 minutes, and diamonds denote impulse response measurement locations.

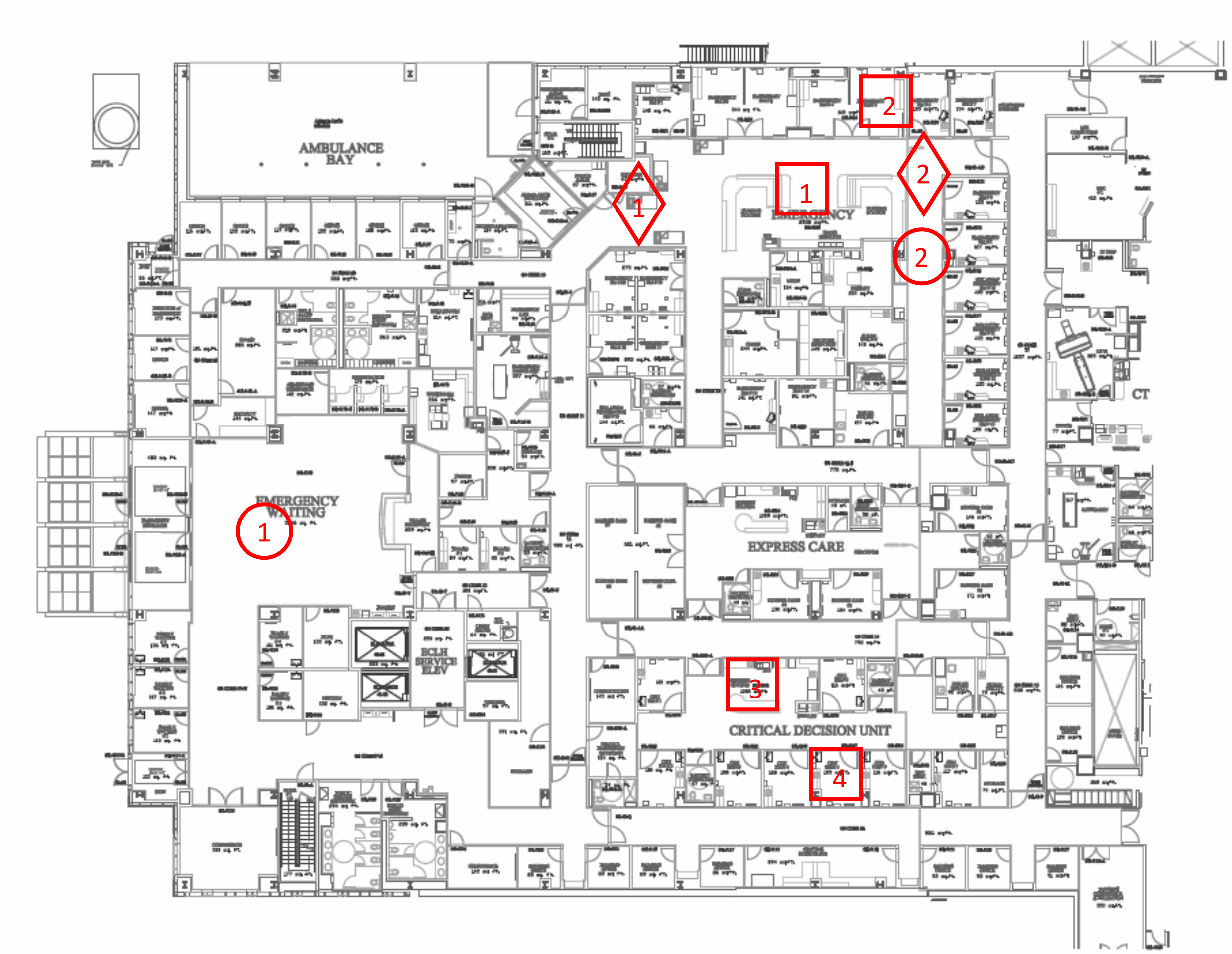

Figure 1. Floor Plan and Measurement Locations for Hospital 1

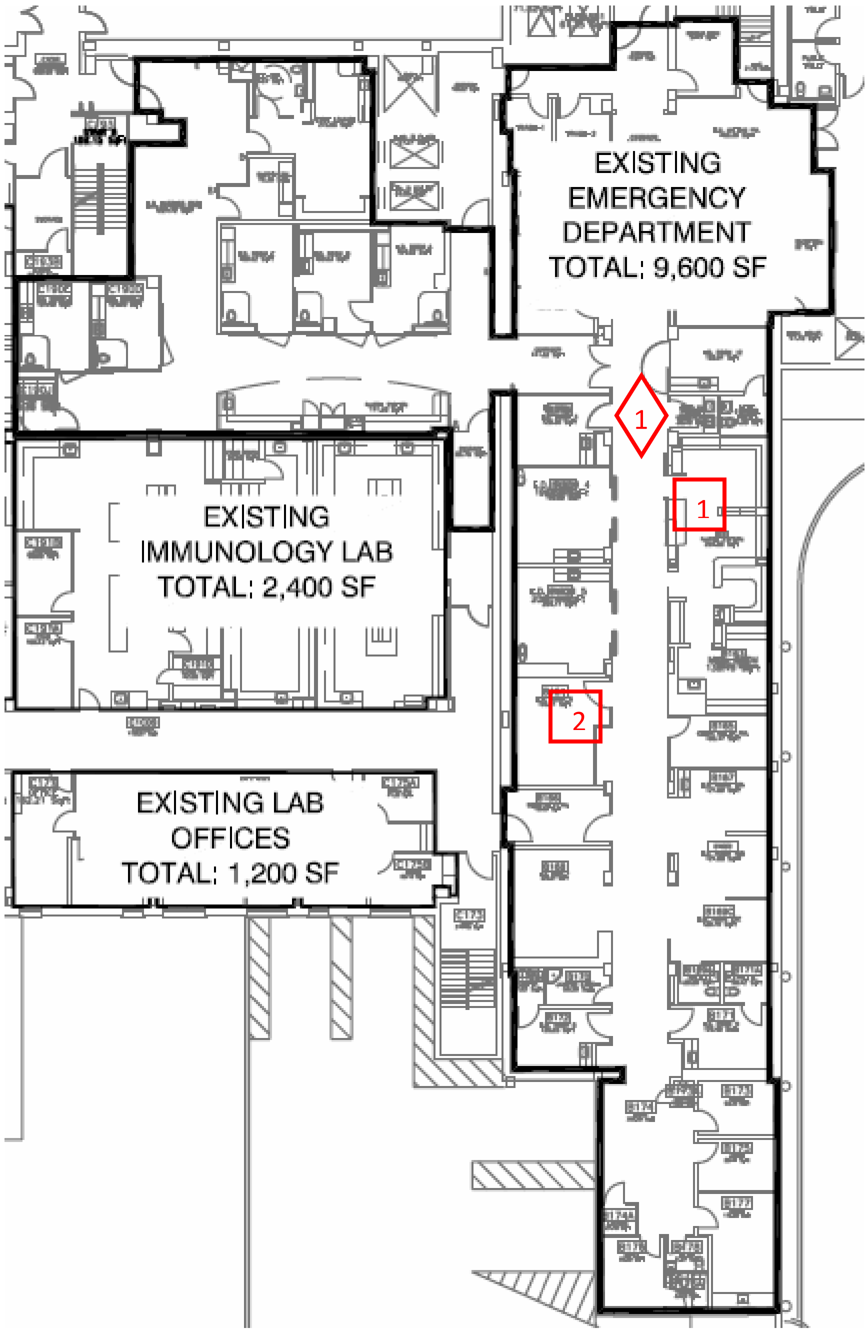

Figure 2. Main ED Floor Plan and Measurement Locations for Hospital 2

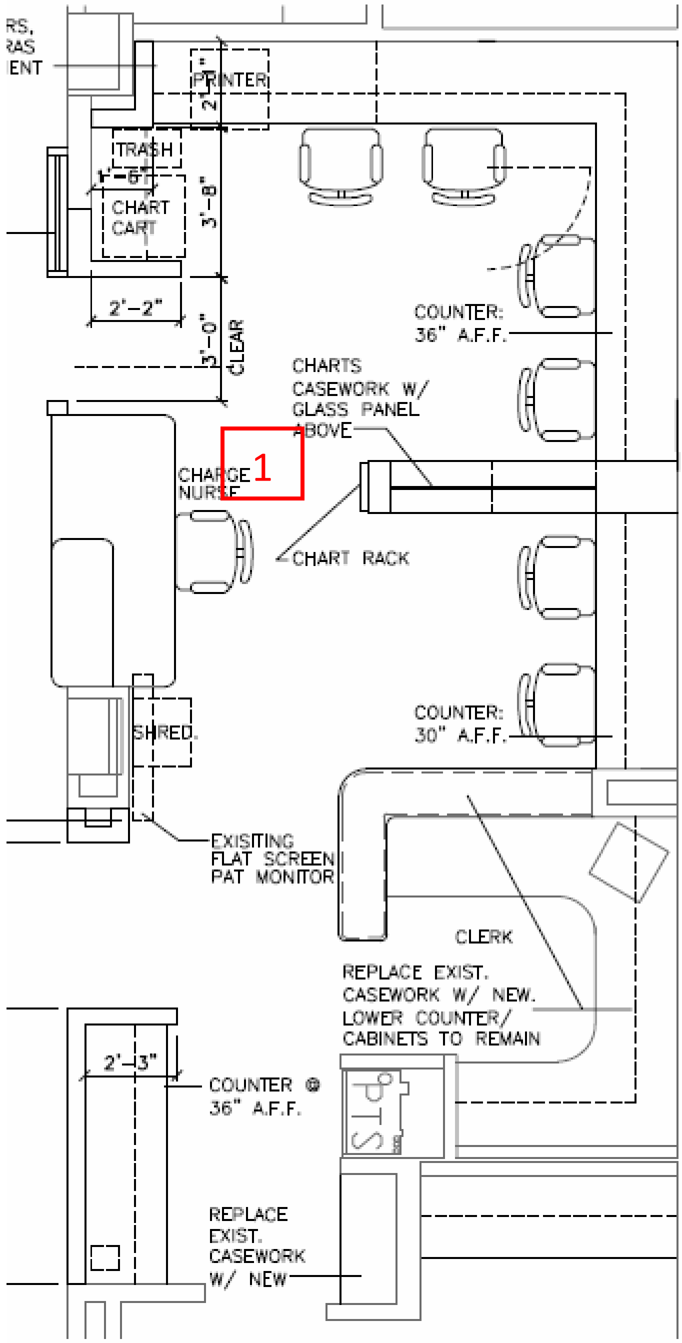

Figure 3. Main Nurse's Station in Hospital 2

Figure 4. Floor Plan and Measurement Locations for Hospital 3

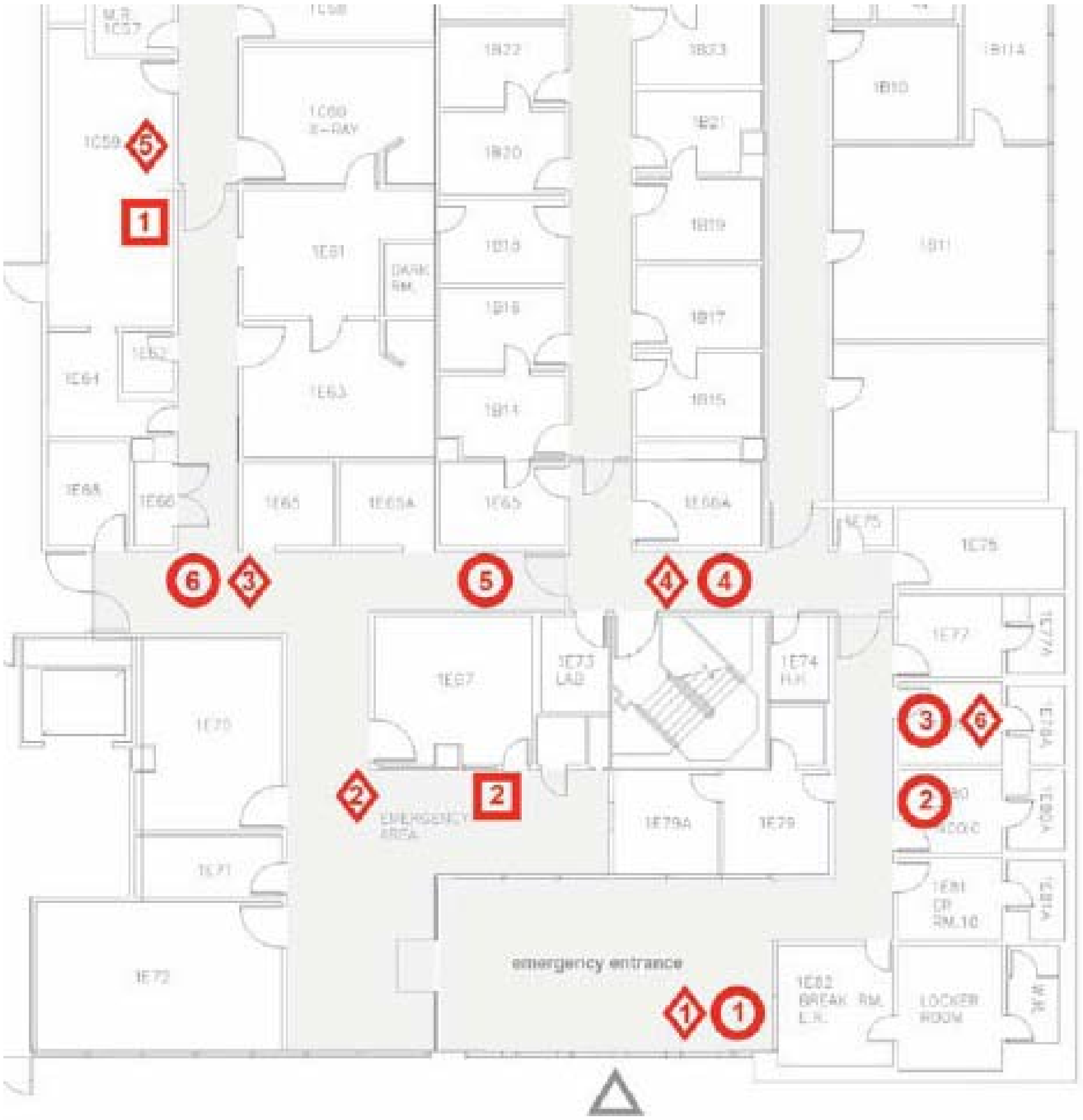

Figure 5. Floor Plan and Measurement Locations for Hospital 4

Figure 6. Floor Plan and Measurement Locations for Hospital 5

Figure 7. Floor Plan and Measurement Locations for Hospital 6

3.3 Objective Acoustic Measurements

In each hospital, methodologies were as similar as possible. However, some differences existed due to site access, logistics, and preferences of the hospital administrators and unit staff. In all 6 hospitals, SLM measurements were conducted using two different time lengths: longer term measurements (24-hour) and shorter term measurements (15- to 30-minutes). The specific locations for the longer and shorter term measurements conducted in each hospital are shown in Table 2. The longer term (24-hour) measurements were taken at main nursing stations and patient rooms, while the shorter term (15- to 30-minute) measurements were taken at other "high traffic" areas in the ED – e.g., waiting areas and main corridors. The shorter term measurements typically took place during daytime hours (7 am – 7 pm).

Table 1. Locations where longer (24-hour) and shorter (15- to 30-minute) sound level meter measurements were conducted in each hospital.

Measurement Locations	Hospital					
	1	2	3	4	5	6
Nurse Station	24 h	24 h	24 h	24 h	24 h	24 h
CDU Nurse Station	24 h	24 h				
Occupied Patient Room	24 h	24 h	30 m	30 m	30 m	30 m
CDU Occupied Patient Room	24 h	24 h				
Unoccupied Patient Room			24 h		30 m	24 h
Visitor Waiting Area	15 m		30 m	24 h	24 h	30 m
Ambulance Bay				30 m	30 m	30 m
Main Corridor	15 m		30 m	30 m	30 m	30 m

Larson-Davis Model 824 Sound Level Meters and Larson Davis Utility software were used for all measurements and analysis. Microphones were vertically hung approximately two feet below ceiling level or stand mounted on tripods depending upon access. One-minute averaging intervals and a fast response time were used for equivalent, maximum, and minimum levels.

For all of the SLM measurements, the A-weighted equivalent, minimum, and maximum (LAeq,LAmin, LAmax) sound pressure levels were recorded across one-third octave bands. The C-weighted peak (LCpeak) sound pressure level was also recorded in Hospitals 3 through 6.

Additionally, various percentile levels were recorded (Ln, defined as the decibel level that is exceeded n percent of the measurement time), including L90 and L33(Bies and Hansen 1996).

Occurrence rates were also calculated. The "occurrence rate" is a newer measure defined as the percentage of time that maximum and peak sound pressure levels exceed certain decibel values (Ryherd, et al. 2011, Ryherd, Persson Waye and Ljungvist 2008, Kracht, Busch-Vishniac and West 2007, Williams, van Drongelen and Lasky 2007). The occurrence rate metric differs from the percentile level metric because occurrence rate is specifically for maximum and peak sound pressure levels. Thus, the occurrence rate is a measure of the "peakiness" or impulsive-nature of the background noise environment. Further, percentile levels measurements are usually collected by SLM programming before measurements are taken. Occurrence rates, on the other hand, are obtained after measurements have completed in a laboratory setting, allowing more freedom in analysis that can be tailored after a basic knowledge of the soundscape is known.

The Speech Intelligibility Index (SII) was calculated at each location, as well, based on the background noise measured by the SLMs (ANSI 1997 r2007). SII values were calculated for normal, raised, and loud speech levels. A SII rating above 0.75 is considered "good," a rating between 0.45 and 0.75 is marginal, while a rating below 0.45 qualifies as "poor" Intelligibility (ANSI 1997 r2007).

3.4 Hospital Staff Surveys

Subjective measurements were collected via anonymous surveys distributed to physicians, nurses, and other medical staff within the EDs of hospitals 1 and 2. The goal of the surveys was to gather pilot data for a descriptive view of staff perception in the ED, as opposed to a strict comparison of different areas or amongst different types of staff members. The survey can be split into four general categories: subject demographics, perception of sound environment, perception of occupational factors, and perception of physical and emotional health. A full copy of the survey can be found in Appendix A.

The ***demographic*** questions were asked to gather subject age, gender, job category (e.g., physician, nurse), length of time they have worked in the ED, and typical working hours.

Several different types of questions were asked in order to measure staff ***perception of the sound environment***. This included questions about overall noise levels, annoyance due to noise at specific locations (e.g., nurse stations, triage), and ability to communicate. They were also given a series of noise sources (e.g., conversation noise, alarms) and asked to what degree these sources affected their work concentration.

Staff ***perception of occupational factors*** was garnered through a series of questions about their job stress and job satisfaction. These survey items are adapted from previous research that included validation for internal consistency. The job stress questions ask about perceived job creativity, challenge, variety, pace, decision making, and demands (Sale and Kerr 2002, Karasek 1979). The job satisfaction questions ask about overall satisfaction and organizational commitment (Warr et al. 1979, Cook and Wall 1980).

The ***emotional and physical health*** of survey respondents was gathered through a set of survey items adapted from previous research (Lim and Fisher 1999, Ware et al. 1995). These survey items asked about level of activity, overall physical and psychological health, overall hearing ability, and noise sensitivity.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Objective Measures

4.1.1 Sound Pressure Levels

The LAeq and LAmax for all eight primary locations are shown below.

Table 2. LAeq for Nurse's Stations and Patient Rooms

Hospital Number	Main ED Nurse Station	CDU Nurse Station	Main ED Patient Room	CDU Patient Room
1	62	59	63	53
2	62	60	60	51
3	64		58	
4	61		51[1]	
5	61		56	
6	59		54	

[1] Denotes space was unoccupied due to the unavailability of occupied space

Table 3. LAmax for Nurse's Stations and Patient Rooms

Hospital Number	Main ED Nurse Station (dBA)	CDU Nurse Station (dBA)	Main ED Patient Room (dBA)	CDU Patient Room (dBA)
1	101	89	100	95
2	102	92	104	89
3	114		89	
4	88		79[1]	
5	108		85	
6	91		87	

The background noise levels measured in all hospitals are consistent with levels measured in other recent ED studies, which ranged from 45 to 70 dBA (Buelow 2001, Zun and Downey 2005, Orellana, Busch-Vishniac and West 2007). The locations in the CDUs of both hospitals 1 and 2 were found to be significantly quieter than the Main ED areas – this is concordant to their purpose as a smaller, more intimate care location. It can also be seen that in all hospitals, the differences in LAeq between Main ED work areas and in occupied patient rooms are relatively small (1 to 5 dBA), but likely noticeable to the average observer (Pierce 1983). In CDU locations, the differences between the nurse station and patient rooms are definitely noticeable, as levels varied as much as 9 dBA.

Across the entire 24-hour period, the LAeq levels in all work areas exceed 50 dBA, a value that the National Institute of Occupational Safety and Health (NIOSH) deem "not desirable for work.” LAmax values exceeding 100dBA in work areas and 85 dBA in patient rooms highlight a potential risk for hearing impairment, according to the same standard (NIOSH 1998). However, the exact physiological ramifications of these short-duration loud impulsive noises are not entirely known.

Figure 8 and Figure 9 show the LAeq levels of daytime (7am-7pm) vs. nighttime (7pm-7am) hours for locations in Hospitals 1 and 2, respectively. Only one location (CDU Station in Hospital 2) showed a day-night difference greater than 5 dBA. This finding is similar to Ryherd et al (2008) (2008) which found similar differences between day and night LAeq levels in a neurological intensive-care unit. It is especially concerning that background noise levels in patient rooms remain elevated even at times when patients are normally resting. This shows that the ED sound environments are active 24 hours a day.

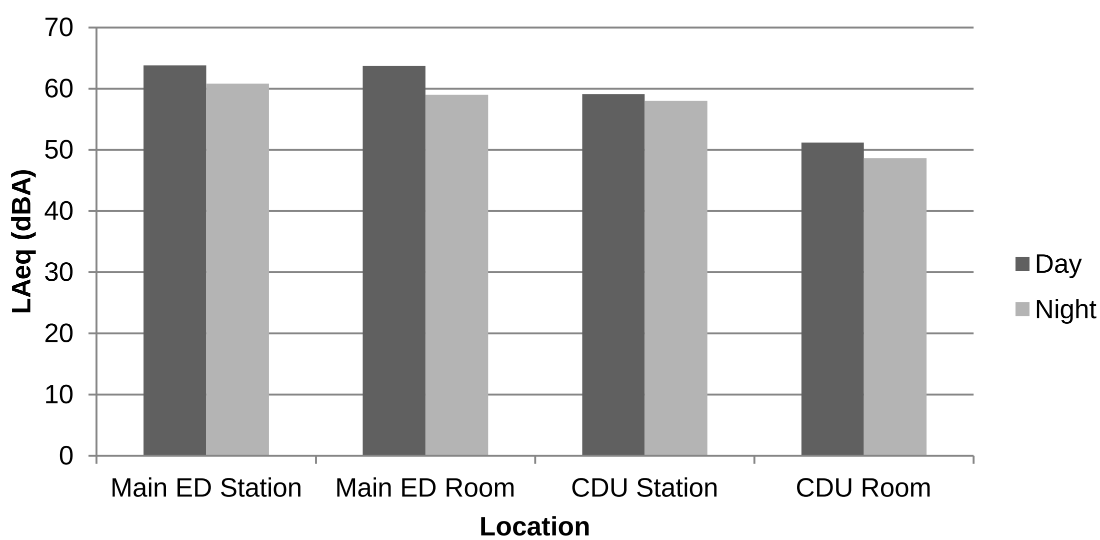

Figure 8. Day vs. Night LAeq for Hospital 1

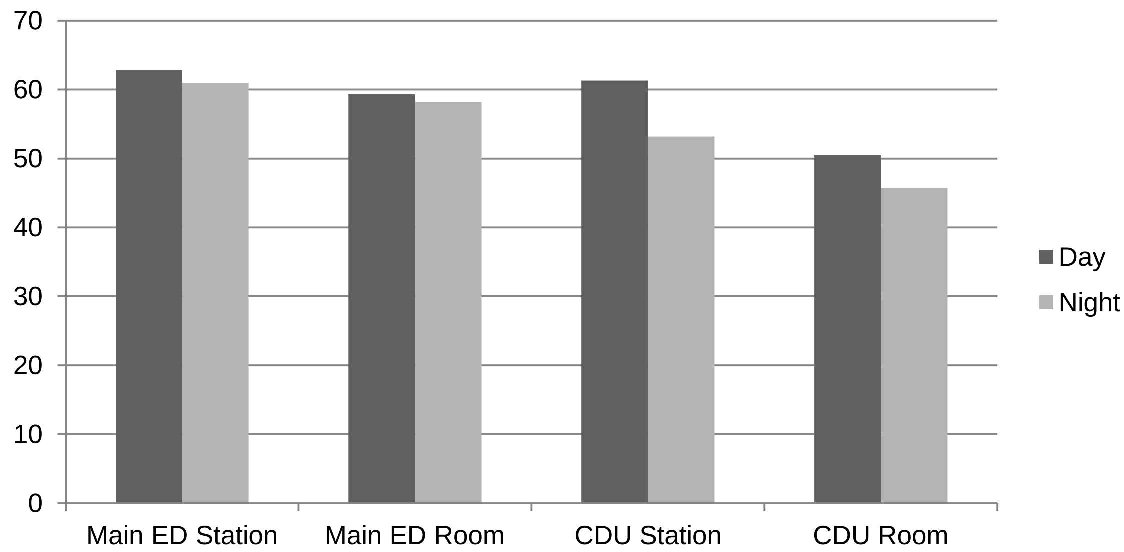

Figure 9. Day vs. Night LAeq for Hospital 2

4.1.2 Percentile Levels

Values for L90 and L33 were compared to LAeq values and are shown in below. Interestingly, the values for LAeq more closely resemble those for L33, as seen in Figure 10.

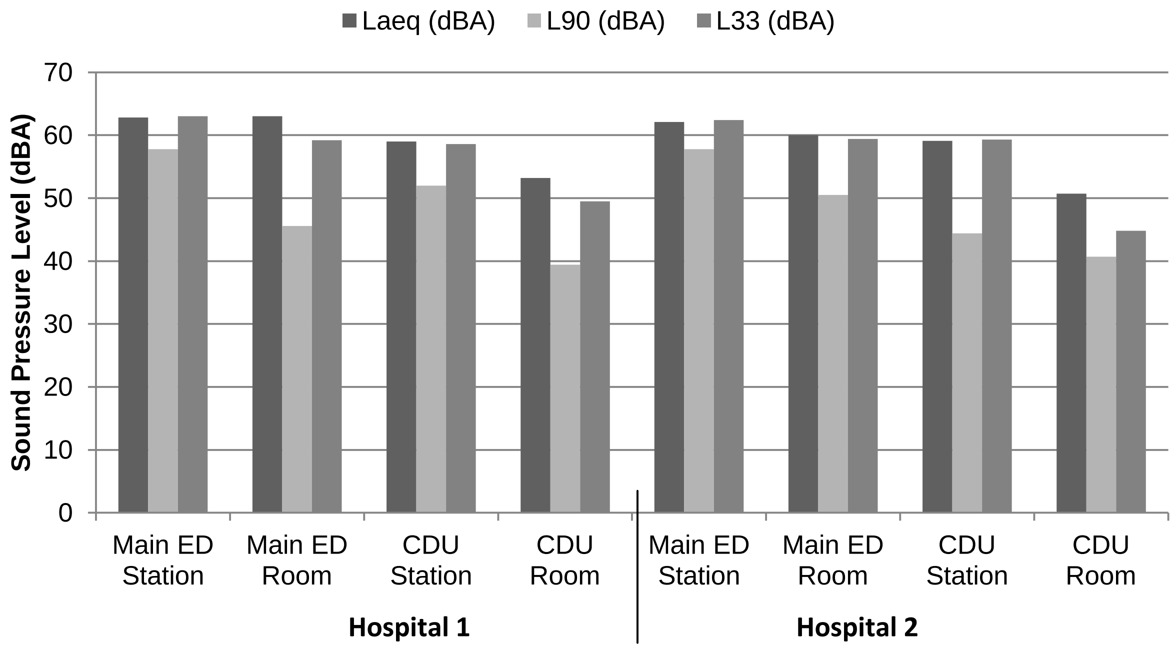

Figure 10. LAeq, L90, and L33 for Hospital 1 and 2 Measurement Locations

The LAeq values more closely equate to L33 than to L90. This finding is of particular interest, as the LAeq and L33 values have been documented to be approximately equal in situations "when free-flowing traffic is the dominant noise source," (ATS Consulting 2010) and at motor speedway during a nighttime NASCAR race (Johnson and Menge 2009). While the background noise level of EDs are not similar to those found in these two extreme situation, it is troubling that levels of fluctuations in the EDs studied are more representative of a chaotic sound environment than a normal workplace. In most environments, L90 is accepted as approximately equal to the background noise level (Cassafe 2011). This finding presents an objective description of the "impulsiveness" of the ED sound environment that has not been found in previous studies, to date.

4.1.3 Occurrence Rates

Occurrence rates were calculated for LAmax and LCpeak values at the locations shown below from Figure 11 to Figure 18.

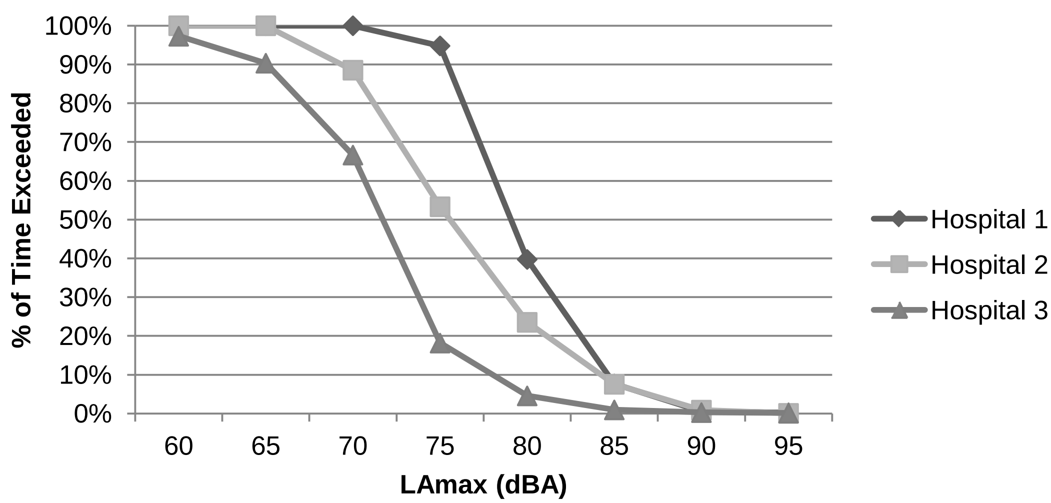

Figure 11. LAmax Occurrence Rates for Main ED Nurse's Station in Civilian Hospitals

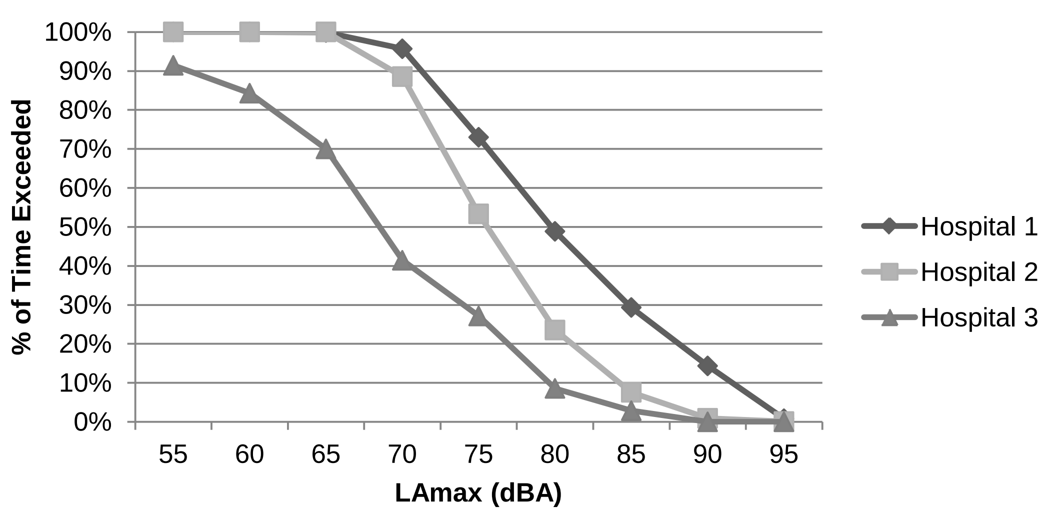

Figure 12. LAmax Occurrence Rates for Main ED Patient Rooms in Civilian Hospitals

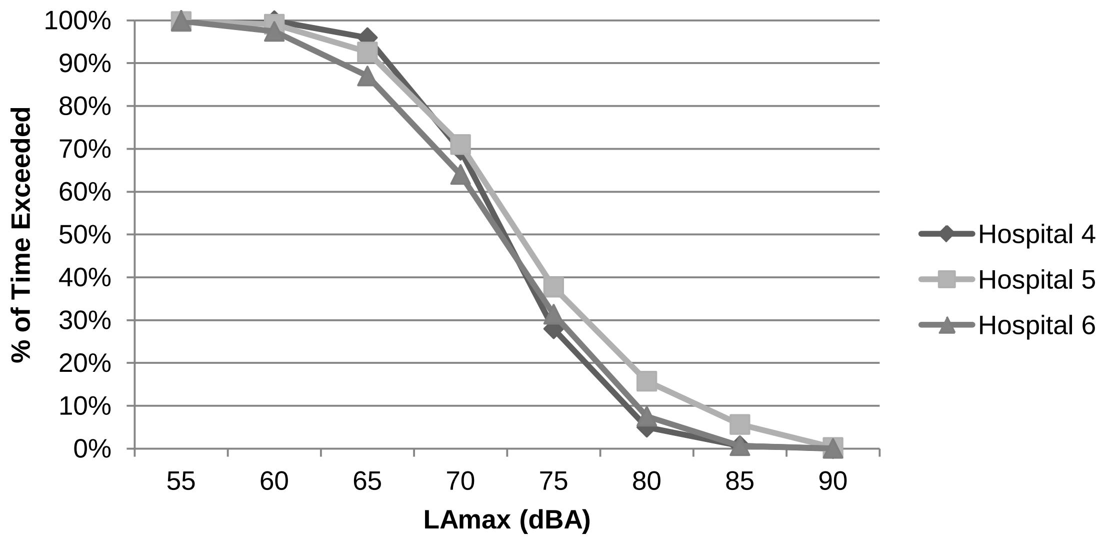

Figure 13. LAmax Occurrence Rates for Main ED Nurse's Station in Military Hospitals

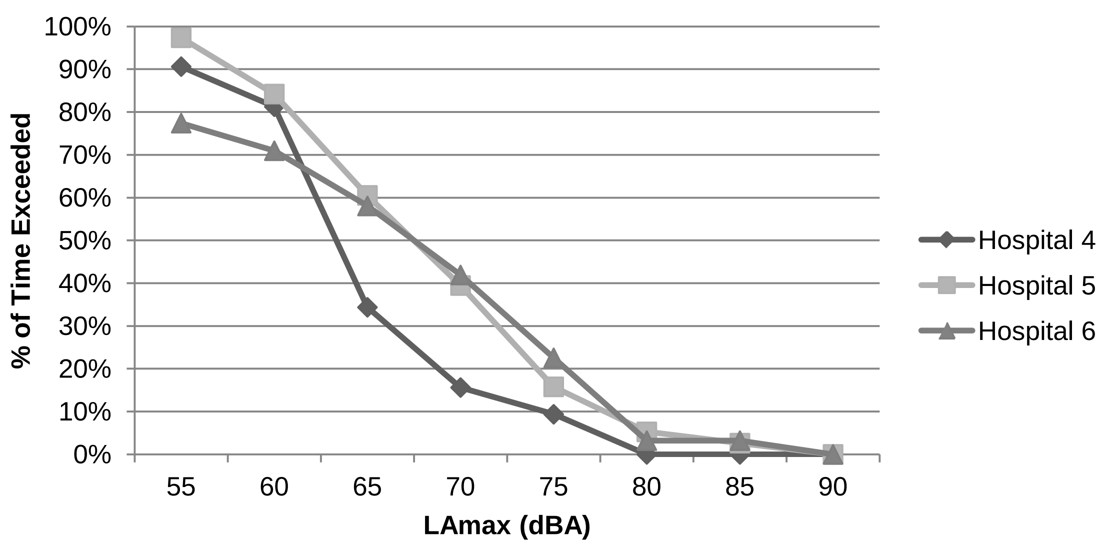

Figure 14. LAmax Occurrence Rates for Main ED Patient Rooms in Military Hospitals

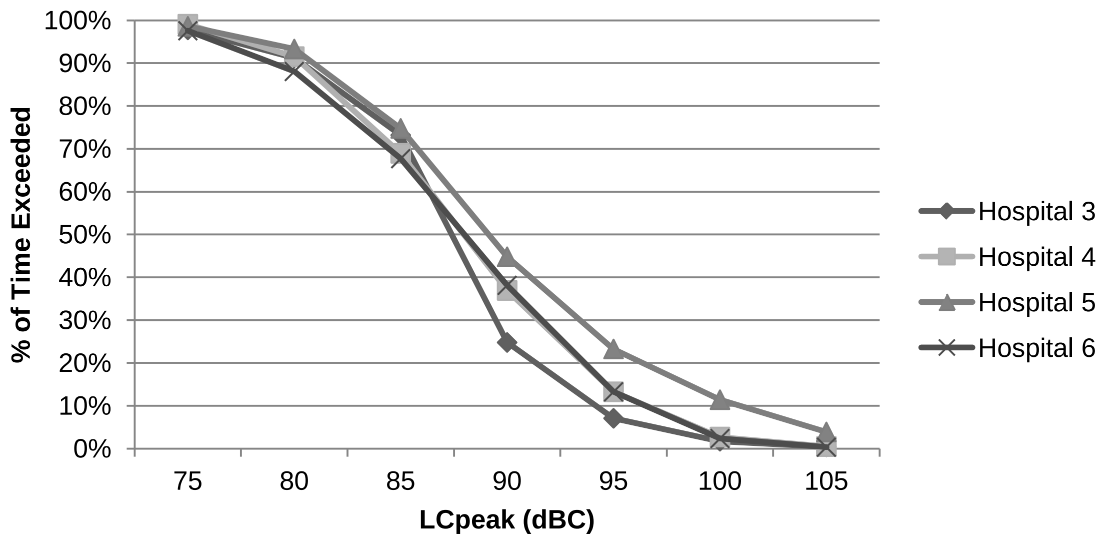

Figure 15. LCpeak Occurrence Rates for Main ED Nurse's Station in Hospitals 3-6

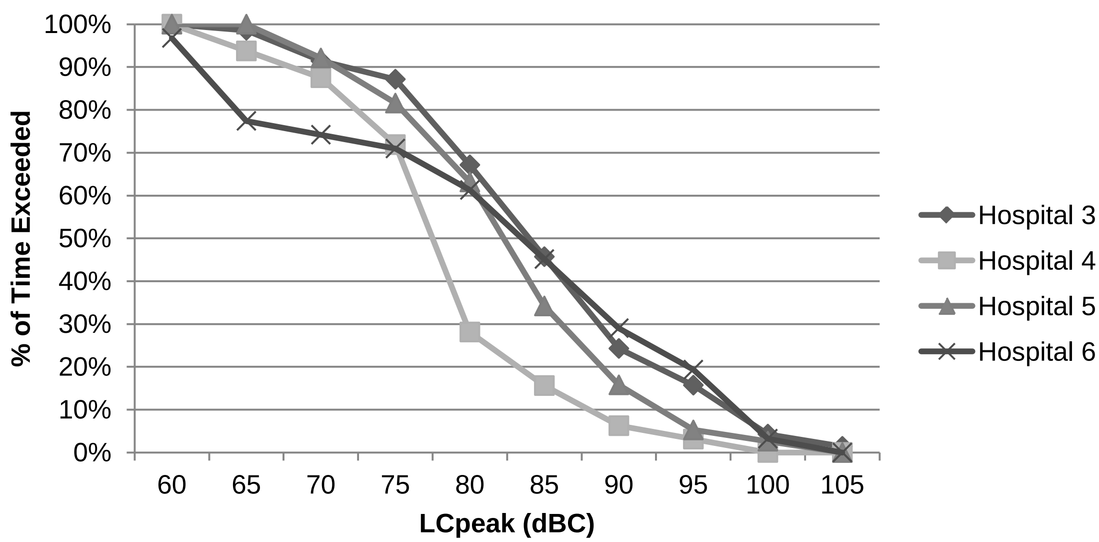

Figure 16. LCpeak Occurrence Rates for Main ED Patient Roms in Hospitals 3-6

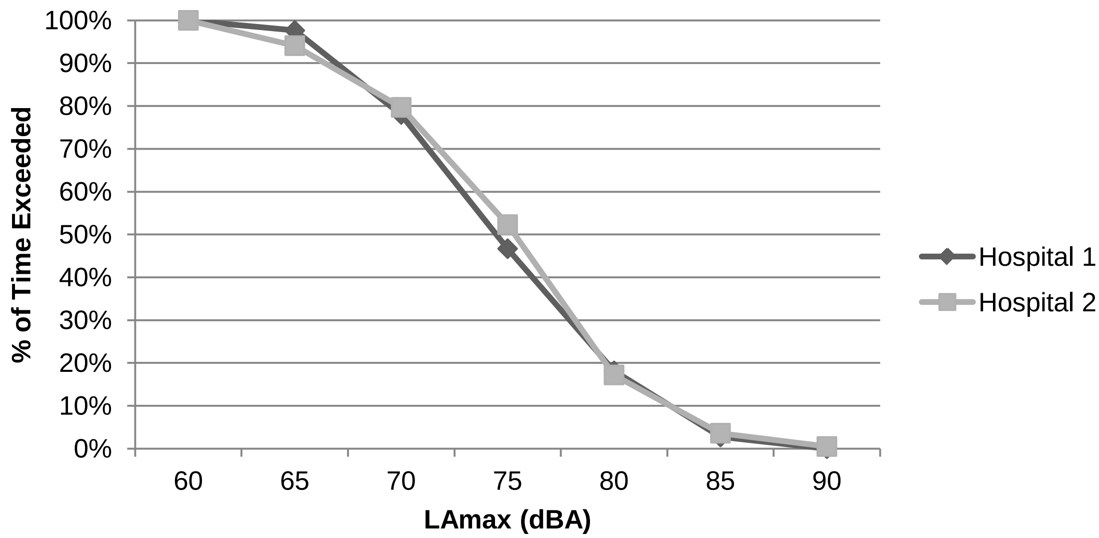

Figure 17. CDU Nurse's Station LAmax Occurrence Rates

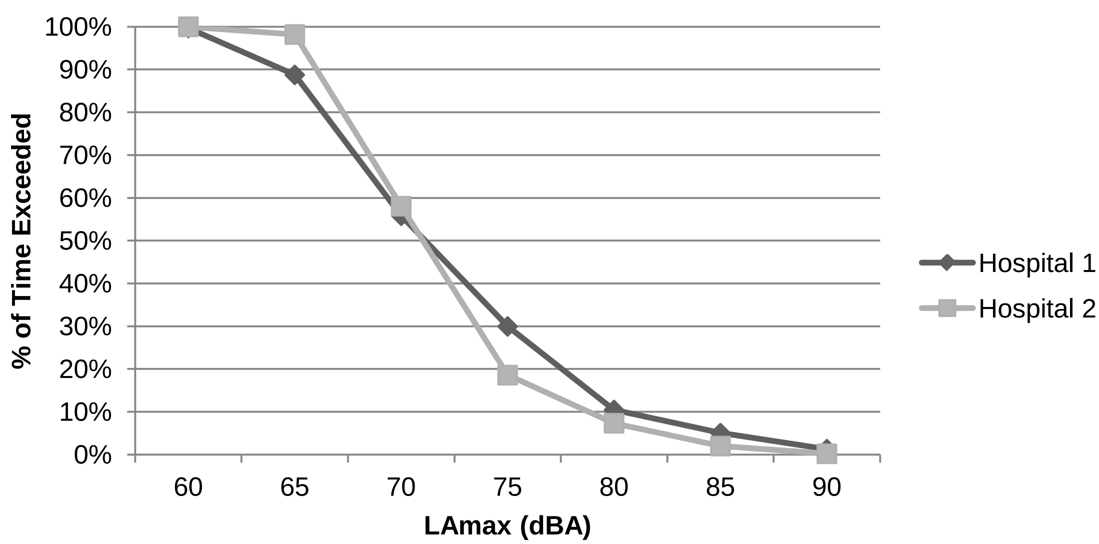

Figure 18. CDU Patient Room LAmax Occurrence Rates

Measurement of the occurrence rates show that LAmax exceeds 85 dBA 5-10% of the time at work areas in some of the EDs studied. While the LAmax was recorded to exceed 100 dBA in several work stations and patient rooms, the occurrence rate graphs show that these levels occur extremely rarely (< 5% of the time). The higher LAmax levels were exceeded less often in patient rooms than at work areas, on average. Further, in military hospitals, work areas saw LAmax levels exceeding 70 dBA approximately 60-75% of the time. The patient rooms in the same EDs experienced this occurrence (LAmax > 70 dBA) approximately 15-40% of the time. It is also clear that peak noise levels exceed 90 dBC a significant amount – up to 40% of the time in work areas and up to 30% of the time in patient rooms. These results imply that the work areas are more "peaky" than the patient rooms, which makes sense based on the types of activities occurring in these spaces. For example, the reduction of "peakiness" in patient rooms could be attributed to the absence of telephones and the lower amount of alarms and conversations. Finally, it appears that differences in occurrence rates between hospitals' work areas are more evident in civilian EDs than in military EDs. For example, the range of occurrence rates between Hospitals 1-3 (Figure 11) is much wider than the range seen in Hospitals 4-6 (Figure 13). In general, the range of occurrence rates in patient rooms was significantly larger than that of work areas.

It was also found that in patient rooms, LAeq exceeded 30 dBA 100% of the time and 40 dBA at least 80% of the time, or approximately 19 hours of a 24 hour measurement. This finding clearly exceeds the recommendation of the WHO for the LAeq to remain below 30 dBA in rooms and 35 dBA in treatment areas (World Health Organization 1999). Additionally, the Main ED and CDU Work Stations exhibited Room Criterion (RC) ratings between RC 54 and RC 59. A "hissy" descriptor (indicating excessive high frequency noise) was attributed to 2 of the 3 civilian hospitals, while 2 of 3 military hospitals showed a "vibrational" quality (indicating low frequency noise excessive enough to potentially induce vibration). The American Society of

Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) recommend a range of RC 30 to RC 35 for hospital wards (ASHRAE 1995). However, it should be noted that the WHO and ASHRAE guidelines were more intended for unoccupied spaces and several of the patient rooms measured in this study were occupied most of the time. There are no existing guidelines for recommended occupied levels. From examining the data, it is difficult to deduce when these rooms were unoccupied – taking an “unoccupied sample” out of the 24-hour data is not possible. However, three measurements of unoccupied rooms were possible in Hospitals 3, 5, and 6. These spaces were found to have RC ratings between 35 and 50, with “vibrational,” “neutral,” or “hissy” qualities, respectively. This implies that the RC ratings may vary widely between different hospitals, although a larger sample size may be required. Similar to the occupied rooms, these unoccupied spaces also exceeded a background noise level of 40 dBA at least 80% of the time.

4.1.4 Speech Intelligibility

The SII for all locations where 24-hour measurements took place are shown below, for “normal,” “raised,” and “loud” speech levels, which have total sound pressure levels of 62, 68, and 74 dB, respectively. The black lines in each SII graph represent the ANSI-defined levels of “good” SI (>0.75) and “poor” SI (<0.45) (ANSI 1997 r2007). The civilian hospitals are presented first, followed by the military hospitals.

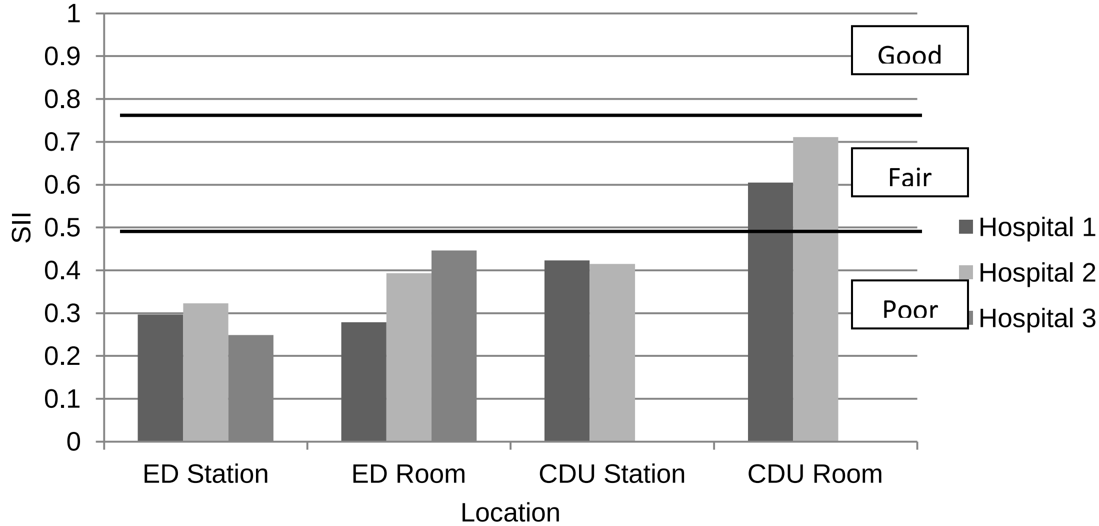

Figure 19. Civilian Hospital SII vs. Location (Nurse Station or Patient Room) for Normal Speech Level

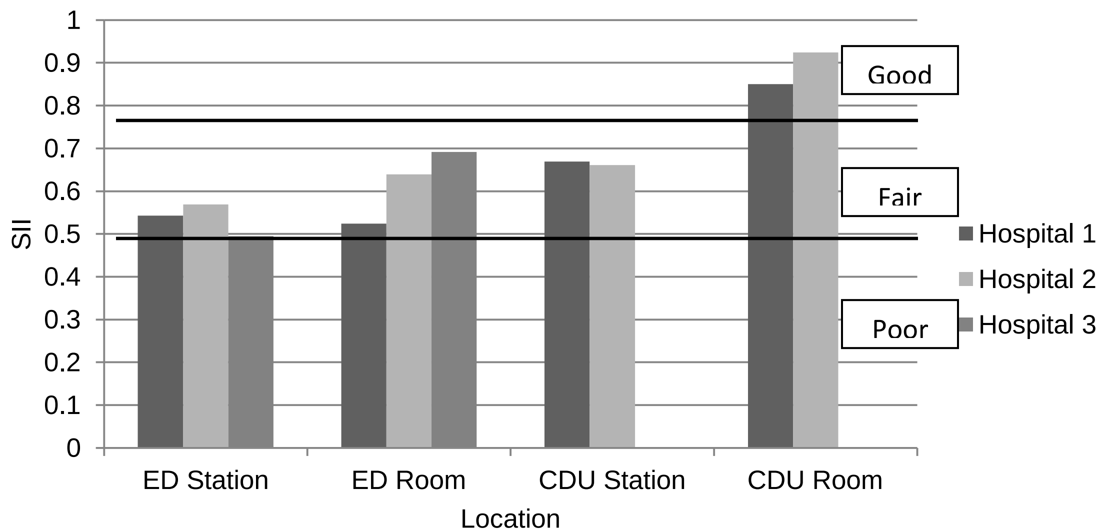

Figure 20. Civilian Hospital SII vs. Location (Nurse Station or Patient Room) for Raised Speech Level

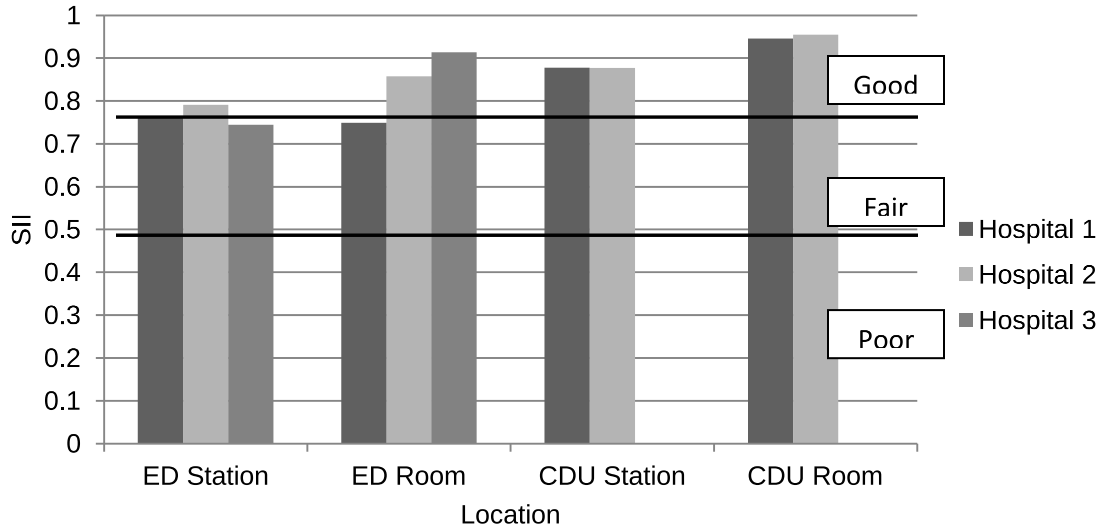

Figure 21. Civilian Hospital SII vs. Location (Nurse Station or Patient Room) for Loud Speech Level

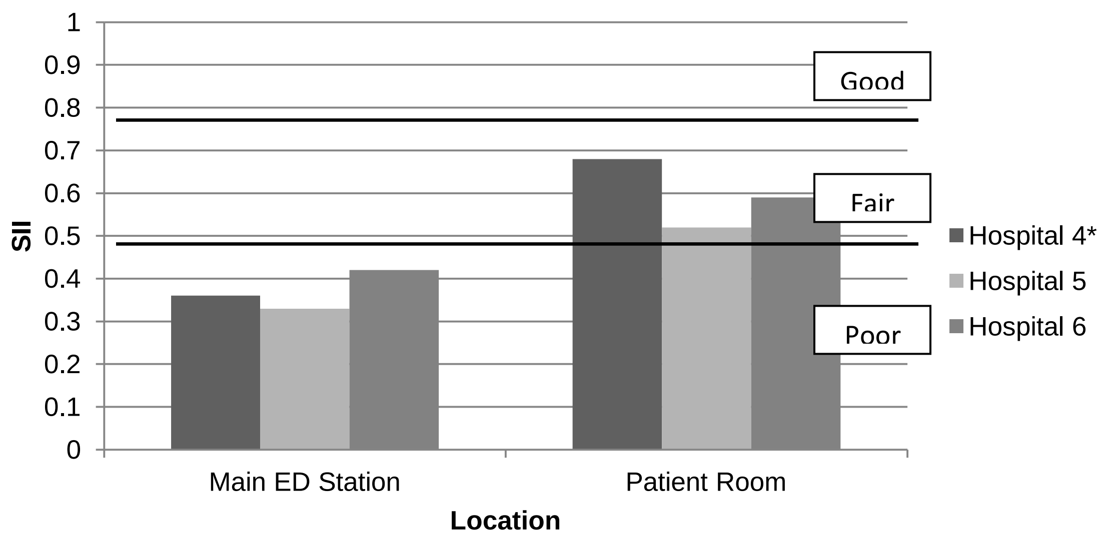

Figure 22. Military Hospital SII vs. Location (Nurses Station or Patient Room) for Normal Speech Level

*An unoccupied room was analyzed for Hospital 4 due to the unavailability of an occupied room

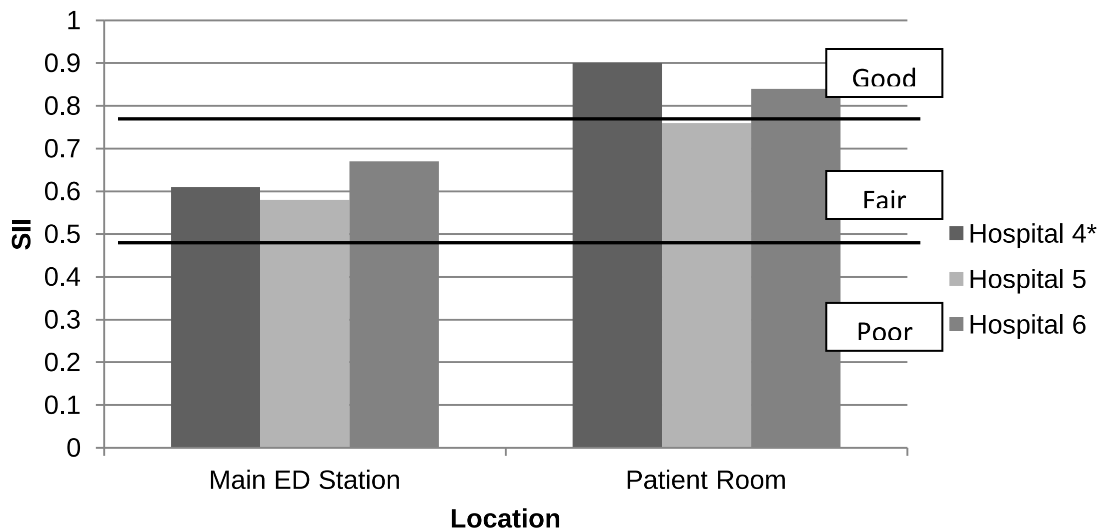

Figure 23. Military Hospital SII vs. Location (Nurses Station or Patient Room) for Raised Speech Level

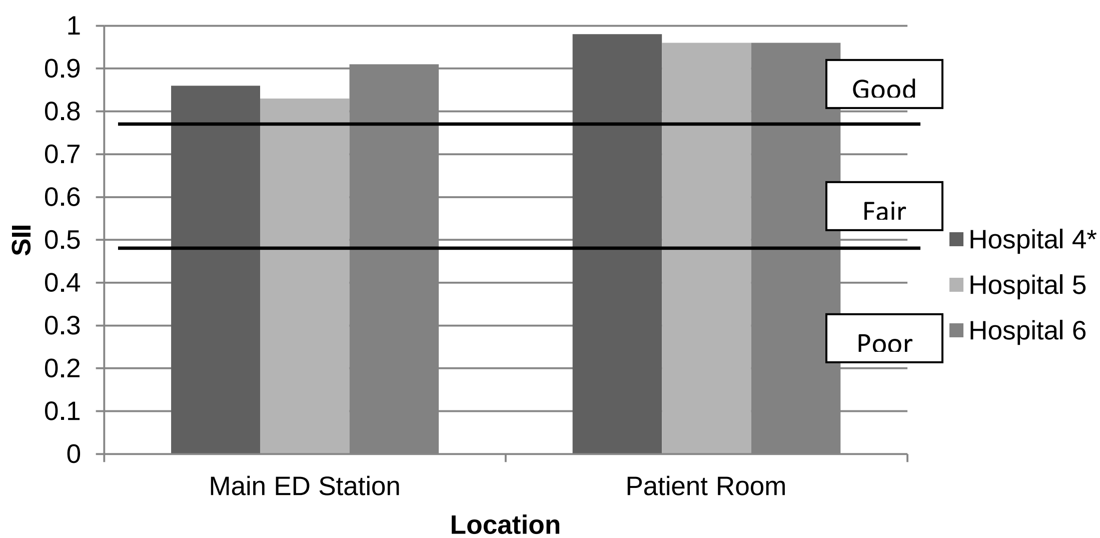

Figure 24. Military Hospital SII vs. Location (Nurses Station or Patient Room) for Loud Speech Level

As seen in Figure 19, the SII is "poor" for normal speech in all civilian locations except the patient room in both hospitals' CDU. Figure 21 shows that a loud speech level is necessary to ensure good speech intelligibility. In military hospitals, nurse's stations had similar SII levels as civilian hospitals, while military patient rooms showed significantly higher speech intelligibility than their civilian hospital counterparts. It has been shown that “loud speech, conglomerate noise, and tasks requiring attention” can combine to a lower tolerance for frustration (Rotton, et al. 1978). As all three of these elements are present in an ED setting, it presents a significant problem for staff members. Additionally, previous studies show that an increased loudness of speech can cause “differences in the formant frequencies and short-term spectra of vowels” (Summers, et al. 1988). One source indicates that the format frequencies, along with the fundamental frequency, are “probably the most important concepts in speech synthesis and also in speech processing in general” (Lemmetty 1999).

4.2 Subjective Measures

4.2.1 Staff Demographics

A total of 65 staff members responded to the anonymous online survey executed at the two Atlanta-area civilian hospitals (10 at Hospital 1 and 55 at Hospital 2). Despite repeated attempts to increase response rate at Hospital 1, the overall number remained low; thus, the results shown below are a compilation of both hospitals. Due to the low number of respondents in Hospital 1, it was not possible to run comparative statistics; however, a descriptive analysis is presented below to provide an overall impression of the staff’s perceptions of the ED environment.

Of the 65 respondents, 68% work at a variety of hours, 12% worked mostly in the morning, 8% worked mostly in the afternoon, and the remaining 12% worked mostly at night. It is shown in Figure 8 and Figure 9 that noise levels do not change significantly between 7am and

7pm in a vast majority of locations examined. Therefore, it can be assumed that hospital staff members experience approximately the same sound levels during their work hours. The job categories, genders of staff members, and average weekly hours worked are shown in Table 5. The “other” job category includes nurse practicioners (NPs), emergency medical technicians (EMTs), and patient relations staff. The age distribution and time working in the EDs are presented from Figure 22 to Figure 24.

Table 4. Gender and Work Hours by Job Category

Job Category	Physicians	Nurses	Other
Male Employees	14	7	0
Female Employees	10	18	10
Total Employees[2]	26	28	11
Average Weekly Hours	25.6	33.4	34.7

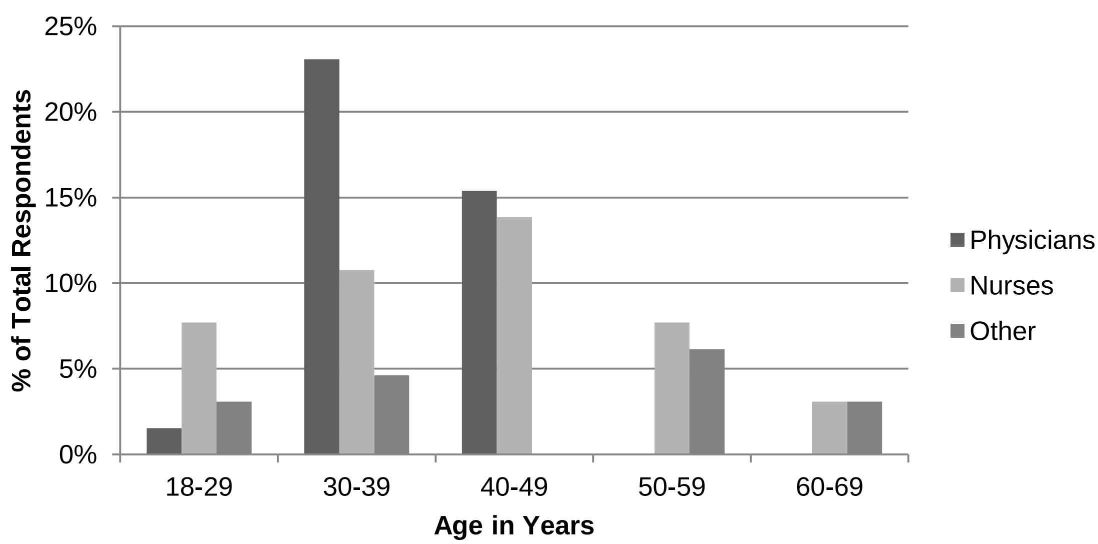

Figure 25. Age Distribution of Survey Respondents

[2] Six employees elected to withhold their gender from survey responses.

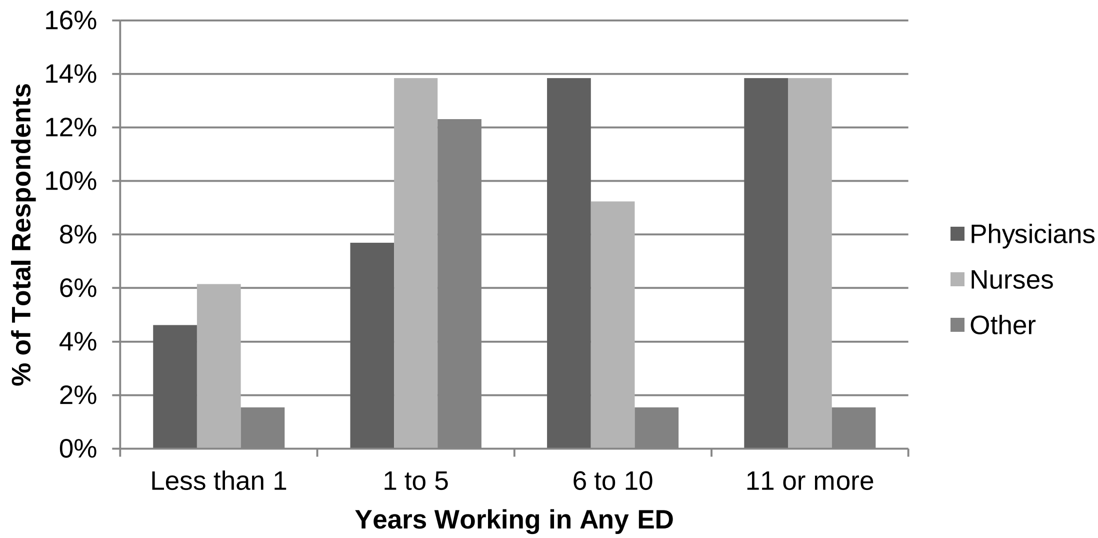

Figure 26. Survey Respondents' Experience in Any ED

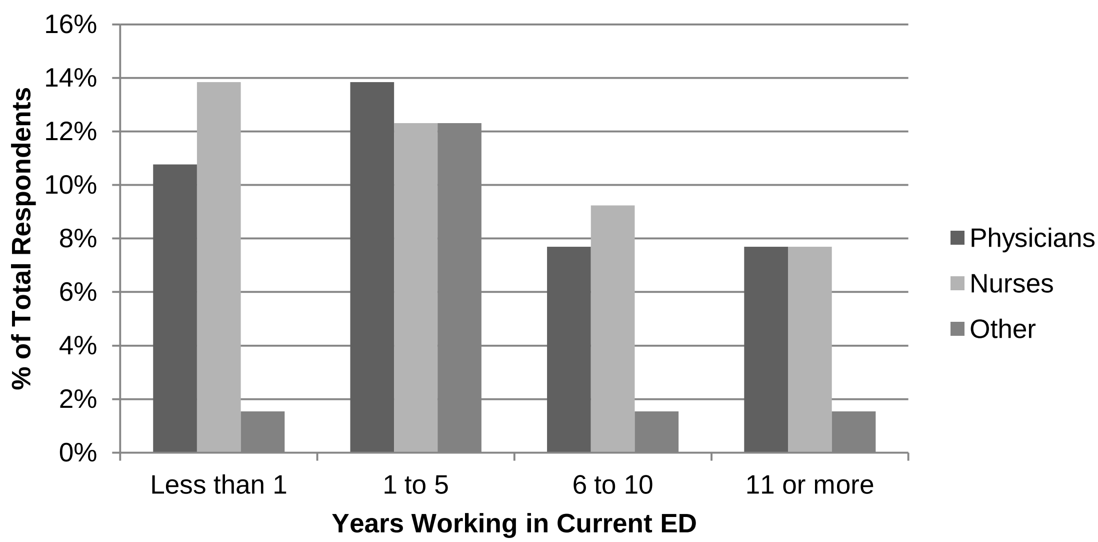

Figure 27. Survey Respondents' Experience in Current ED

Approximately two-thirds of survey respondents were female. About 65% of survey respondents were between 30-49 years of age, with approximately 55% having 6 or more years of experience working in any ED setting. However, over 60% of respondents have only been in their current ED for no more than 5 years. It is also interesting to note that no physician in the survey was above the age of 49. However, the length of time they have worked in EDs is comparable to that of the nursing staff. Additionally, a majority of "other" staff members have worked between 1 to 5 years in their EDs and have not spent a significant amount of time in other EDs. Nurses and Other staff members, on average, worked 8-9 more hours per week than physicians and are therefore exposed to the acoustic environment of the ED more often.

4.2.2 Perception of Sound Environment

First, respondents were asked "how noisy is your workplace?" With 96% of physicians, 89% of nurses, and 91% of other staff indicating between "somewhat" and "extremely" noisy. The next two questions asked about the level of annoyance caused by noise in staff work areas and in occupied patient rooms and are shown in Figure 25.

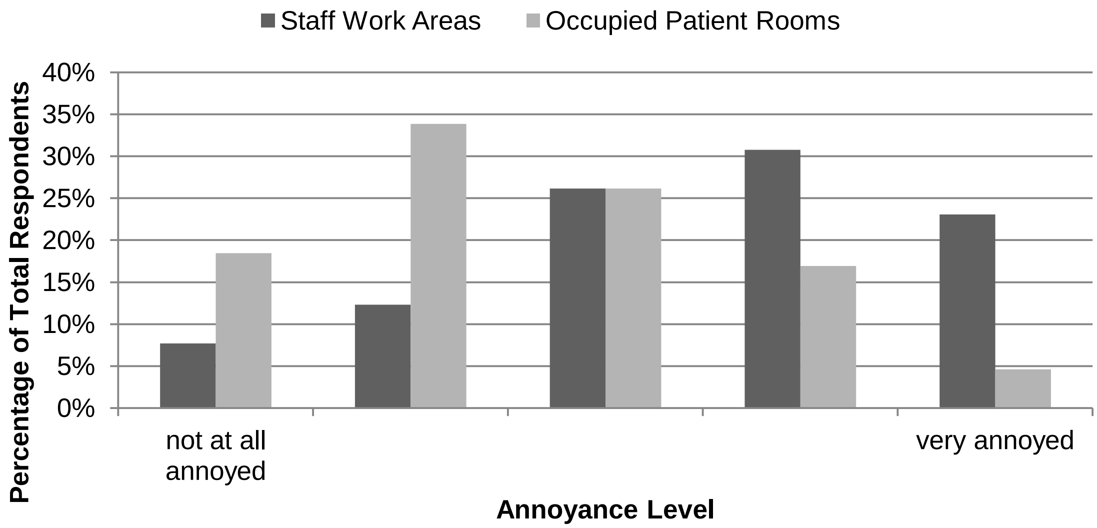

Figure 28. Annoyance Due to Noise in Two Areas

It is clear that employees find the noise in their ED to be bothersome. A significantly higher number of staff members reported annoyance due to noise at work stations than in patient rooms - almost one-quarter of staff members were very annoyed by work area annoyed versus only 5% measuring the same annoyance in patient rooms. This conforms to the higher background noise levels at work areas than in patient rooms shown in Table 3.

Approximately half (49%) of staff stated that they “agree” or “strongly agree” that they have trouble communicating with other staff because of the noise levels, while 35% of staff responded similarly for communicating with patients because of the noise levels. Since staff members primarily communicate with patients within the patient rooms, this conforms nicely to the SII values shown in Figure 19 to Figure 21 – the speech intelligibility was found to be higher in patient rooms than in work areas, on average.

The next set of questions focused on various noise sources. Subjects were asked to rate how much various noise sources typically disturbed their work concentration on a scale from “not at all” to “extremely.” The items that most often generated responses between “moderately” and “extremely” disturbing are shown in Figure 26. A majority of the most bothersome noise sources are mechanisms related to the treatment of patients (e.g., alarms, monitoring devices). Also, the majority of these sources were mechanical; only two were human generated (staff conversation noise and visitor noise). Other sources included on the questionnaire that averagely generated responses between “not at all” and “somewhat” disturbing were visitor conversation noise, patient sounds (e.g., coughing, gagging), emergency procedures, operational sounds of medical equipment (e.g., breathing machines), noise from rolling medicine carts or beds, ventilation systems, cleaning equipment, door sounds, falling objects, toilets flushing, televisions, footsteps, and road traffic.

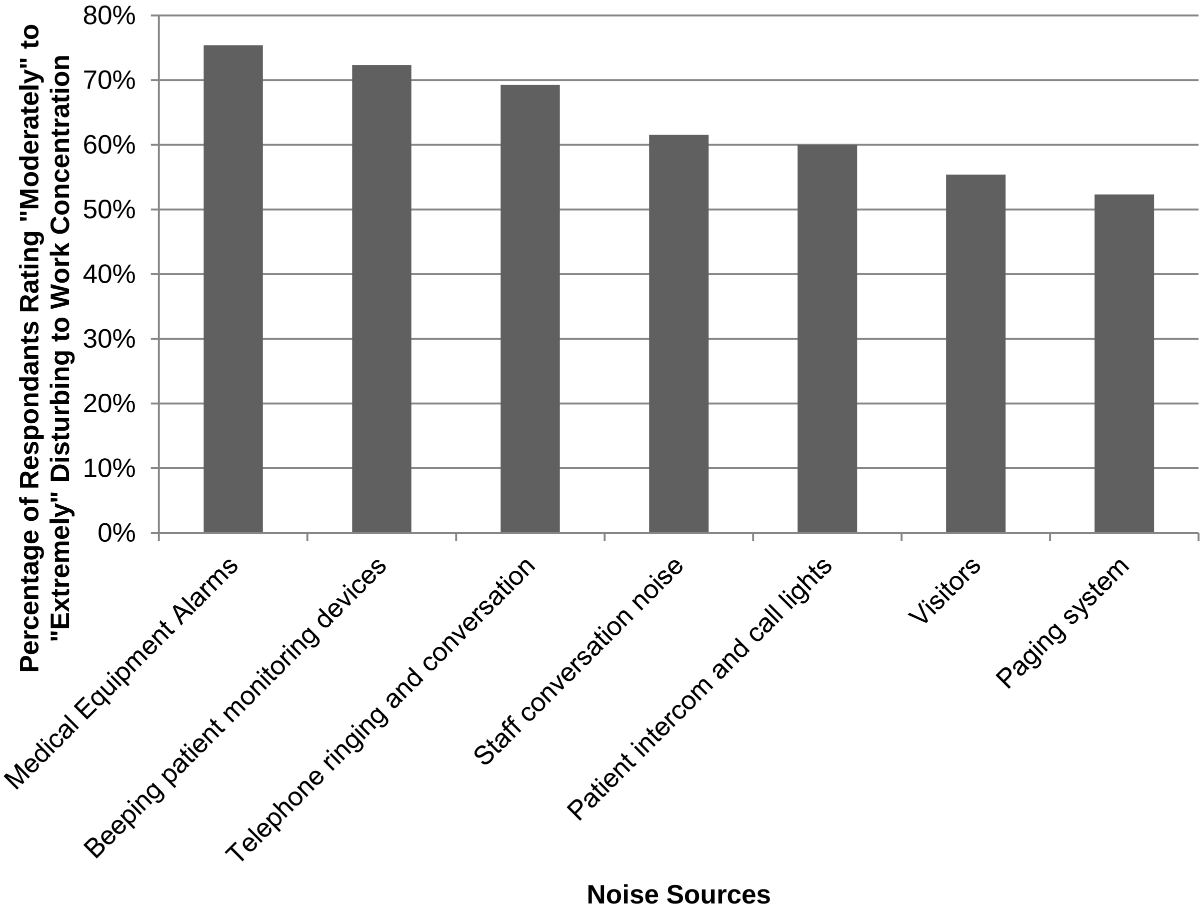

Figure 29. Amount of Work Concentration Disturbance due to Various Noise Sources

It is interesting to note the locations where these highly disruptive noise sources are normally found. While alarms for medical equipment and patient monitoring may be heard in patient rooms as well as work areas, ringing telephones, staff conversation, and noise from the patient intercom are found primarily near nurse's stations. The identification of sources and their locations are necessary in order to improve the acoustic environment of the ED.

Based on the responses of Figure 30, several steps can be taken to reduce disturbance of work concentration. The two largest sources of disturbance – medical equipment alarms and patient monitoring devices – can be replaced by non-auditory systems. One recent study found that over 60% of hospital staff thought that audible alarms could be replaced with visual alarms (Ryherd, Persson Waye and Ljungvist 2008). Additionally, another study found that a majority of test subjects would prefer using a vibro-tactile alarm instead of an auditory type because the "alarm communicated effectively in a noisy environment" (Ng, et al. 2005). Some action can also be taken for ringing telephones, staff conversation, and overhead paging systems. Quieter or less annoying ring tones may be used for phones, while staff conversation noise can be reduced with the installation of absorptive ceiling tiles in work areas. While many of these tiles are porous and cannot be used in hospitals due to their ability to harbor bacteria, new products are being released that have thin membranes that protect against bacteria and effectively absorb sound (Barnhill, et al. 2010, Hsu, et al. 2010). These panels may also be used in hallways to reduce noise from visitors. Additionally, previous studies have tested personal communication systems that can replace a majority of messages that normally come from overhead paging systems. These devices noticeably reduced the noise levels of the tested pediatric intensive care unit (Busch-Vishniac, et al. 2005). The inclusion of absorptive panels and wireless communication systems may allow for a higher degree of work concentration in ED staff.

4.2.3 Perception of Occupational Factors

An overwhelming majority of the respondents (an average of 97%) either "agreed" or "strongly agreed" with 7 of the next 8 statements, which focus on their feelings toward their current job, and are presented in Table 4.

Table 5. Respondent Answers to Statements About Current Job

Statement	% indicating "agree" or "strongly agree"		
	Physicians	Nurses	Other
My job requires that I learn new things	100	100	100
My job requires me to be creative	96	100	100
My job requires a high level of skill	100	96	91
I get to do a variety of different things in my job	100	100	100
I have an opportunity to develop my own abilities	96	86	100
My job involves a lot of repetitive work	96	96	82
My job allows me to make a lot of decisions on my own	100	89	91
I have a lot to say about what happens on my job	69	71	55

A lower percentage, however still a majority, of respondents agreed that they have a lot to say about what happens on their respective jobs. Sale and Kerr (2002), which administered the same survey questions to employees at a teaching hospital in Ontario, CA, found that agreement with this "Say" question has a moderate positive correlation ($r \geq 0.29$) with 5 of the other 7 statements presented in Table 5. In this study, a statistically significant positive correlation with the "Say" question was found in only 2 of the other 7 statements – "I have an opportunity to develop my abilities" and "My job allows me to make a lot of decisions on my own."

A number of questions measuring the psychological demands of staff were presented next. As shown in Table 6 and Table 7, a majority of employees thought they are required to work very fast and hard, are asked to do an excessive amount of work, do not have enough time to get things done, and are given conflicting demands by others.

Table 6. Agreement with Psychological Demand Statements

Statement	% indicating "Strongly Agree"
My job requires working very fast	60
My job requires working very hard	68

Table 7. Disagreement with Psychological Demand Statements

Statement	% indicating "Disagree" or "Strongly Disagree"
I am not asked to do an excessive amount of work	65
I have enough time to get the job done	63
I am free from conflicting demands that others make	78

Despite these findings, which indicate employees feel they are subjected to a high amount of psychological demands, 83% indicated they are “somewhat” to “extremely” committed to their present job and 60% are “somewhat” to “extremely” satisfied with their job.

4.2.4 Perception of Physical and Emotional Health

Questions about respondents’ physical and emotional health were presented next. The average respondent rated their general health as very good, with only two respondents indicating a score less than good. Approximately 13% reported being limited by their physical health at least some of the time. A slightly greater amount (22%) stated they accomplished less than they would like at least some of the time due to their emotional problems. 17% of respondents reported pain interfering with their normal work to at least a moderate extent. Approximately 85% indicated that they are calm, peaceful, and have a lot of energy some to all of the time. To the same degree, about one-fifth felt downhearted and depressed and had physical or emotional problems interfere with social activities.

In all questions relating to physical and emotional health, ED staff reported significantly better health, on average, than the general US population. (Johnson and Coons 1998) This may be due to the respondents’ status as health care professionals – due to their training and work, employees are more educated aware of their health than the general population. The staff’s hearing ability was also gathered, with 92% reporting a “normal” hearing ability or higher. Additionally, 86% reported that they were between “not at all” and “moderately” sensitive to noise. Due to these answers, it was assumed that the staff’s perception of their work environment would not be significantly distorted by their health.

4.2.5 Statistical Analysis

A Pearson correlation test was run between the survey questions that focused on staff members' perception of their work environment using IBM SPSS v19.0 software. While the sample size of 65 respondents was not ideal, there were still a handful of statistically significant correlations that were extracted from survey data.

The first interesting observation was that the average weekly hours worked hardly correlated to any of the other perception-related questions. Only one significant correlation appeared – staff members who worked more hours tended to perceive the ED as less noisy ($r = 0.247$, $p < 0.05$). While this is not a particularly strong correlation, it may be attributed to staff members getting acclimated to the types and levels of noise in their workplace as they spend more time exposed to their respective environments. A number of correlations were found between the perception of noise overall and job elements. The correlations to the responses of the question "How Noisy is your Workplace" are shown in Table 9.

Table 8. Correlation to Perception of Overall Noise in Workplace

Question	Correlation (r-value)	Statistical Significance (p-value)
My job requires me to be creative	0.318	.010
My job allows me to make a lot of decisions on my own	0.338	.006
I am not asked to do an excessive amount of work	-0.304	.014
I have enough time to get the job done	-0.369	.003
I am free from conflicting demands that others make	-0.285	.022

Moderate correlations were also found between increased job satisfaction and level of agreement with the last three statements of Table 9, with r-values of 0.373, 0.524, and 0.460, respectively ($p < 0.01$). Additionally, staff members who felt more satisfied with and committed to their jobs also agreed to a greater extent that they do a variety of different things as well as have an opportunity to develop their abilities. These findings suggest that a higher amount of employee satisfaction and commitment in the ED environment is correlated to a decrease of certain psychological job demands and an increase in “decision latitude,” as defined by Kerasek (1979).

Very few correlations were found between respondents’ perception of noise and perception of their physical and emotional health. It was found that respondents’ who perceived a higher amount of annoyance due to noise in triage areas were more likely to state their physical health limited them in the kind of work they did ($r = 0.335$, $p < 0.01$) and in moderate activities, such as bowling, playing golf, or pushing a vacuum cleaner ($r = 0.474$, $p < 0.01$). It is interesting to note that no correlation was found between a higher perception of noise and a decrease in emotional health, as increased noise has been shown to cause mental strain (Topf and Dillon 1988, Ryherd, Persson Waye and Ljungvist 2008).

CHAPTER 5

FUTURE RESEARCH: PASSIVE METHOD FOR CALCULATING ROOM IMPULSE RESPONSE

5.1 Motivation

The impulse response (IR) of a room is considered the “acoustic fingerprint” of the space. Also known as the Time-Domain Green's Function (TDGF), the IR can be used to extract numerous acoustic parameters of the room, such as reverberation time, clarity, and frequency response. A reverberation time metric known as Early Decay Time (EDT) is also often extracted. In a healthcare setting, recording the acoustic parameters of a space can help facilitate design changes that may be made to improve the acoustic environment.

However, the quality of the IR measurement is dependent on several factors of the space, most importantly the Signal-to-Noise Ratio (SNR) – the signal's sound pressure level must be significantly high relative to the background noise level in order to get reliable, accurate results. This restriction causes the measurement to be disruptive to any occupants of the space and requires a source powerful enough to produce the signal at high amplitude without distortion. An additional restriction is that the presence of people close to the measurement location may cause a significant change in the measured reverberation time (ISO 2008).

While this problem is normally solved by performing the measurement when the space is unoccupied or at an otherwise “low-traffic” time period, a busy healthcare setting does not provide such luxury – emergency departments in particular. As previous studies have shown, the LAeq in healthcare settings can reach 65 dBA (Busch-Vishniac, et al. 2005), requiring an excessively loud signal that may disrupt medical communications, procedures, or resting patients at any given time. For this reason, the development of alternative methods for measuring the IR of a room would be beneficial in understanding the acoustic environment of a healthcare setting.

5.2 Previous Research

5.2.1 Current Methods for Measuring Room Impulse Response

Measurement of the IR is usually performed by playing a known signal through a source and measuring the signal's behavior with the use of one or more receivers. Most commonly, both the source and receiver are connected to a laptop computer and controlled by software specifically designed for IR measurements, such as EASERA. The two most common signals are known as Sine Sweep and Maximum Length Sequence (MLS). The Sine Sweep signal plays through the full audible range, starting from a low frequency with the signal logarithmically increasing in frequency over time. The signal is played several times and the room response is averaged by the computer software. The MLS signal is comprised of a broadband, pseudo-randomly generated signal at a constant level over time and has been shown to be more accurate in the presence of non-white noise, such as hospital environments (Stan, Embrechts and Archambeau 2002).For both signals, ISO standards dictate the signals be played at a level considerably higher than the background noise level (ISO 2008). Both signals use their respective algorithms to calculate the Green's Function between the source and the receiver.

5.2.2 Passive Impulse Response Measurements in Non-Air Media

Previous research has been successful in finding the Green's function between two points using ambient noise of the environment (Roux and Kuperman 2004, Sabra et al. 2005). However, none of these studies were done in an air medium. One study used ambient ocean noise to calculate an estimate for the TDGF between two receivers (Roux and Kuperman 2004). Another study used ambient seismic noise to calculate the same function between two seismic recording stations (Sabra, et al. 2005). A mathematical examination of the methods in use in these studies shows that ambient noise in a sufficiently diffuse medium can produce an estimate of the TDGF (Roux, Sabra and Kuperman 2005). Using this assumption, it can be proposed that the IR between two receivers in an air-filled medium can be calculated using the ambient noise of the space, provided the space can be modeled as a diffuse environment.

5.3 Pilot Lab Test of Passive Method

Testing was done in a Reverberation Chamber at the Integrated Acoustics Laboratory (IAL) at the Georgia Institute of Technology, which was assumed to be sufficiently diffuse. The room impulse response was first calculated using active methods, in a setup shown in Figure 27. Two separate trials were conducted, one with an MLS source signal, and the other with a Sine Sweep signal which was generated using EASERA v1.1 software. The results of the two trials were used as the baseline data for passive measurement and are shown in Table 8. The results of the two methods were reasonably similar with a maximum difference of 5.1%, which occurred at 125 Hz.

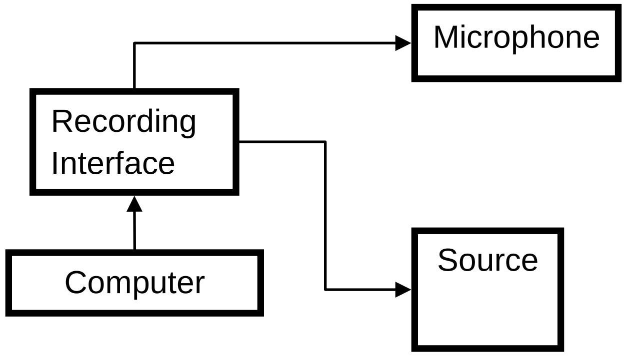

Figure 29. Experimental Setup of Active Impulse Response Measurement

Table 9. Reverberation Chamber T60 Times from Active Methods

Octave Band Center Frequency (Hz)	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
MLS (sec)	3.28	3.81	4.01	4.12	3.43	1.90	1.03
Sine Sweep (sec)	3.12	3.77	3.94	4.04	3.34	1.90	1.03

For the passive test, two Larson-Davis 2560 1/2" Random Incidence Microphones were connected to 2 Larson-Davis PRM900C Preamplifiers. The microphones were placed parallel to the ground at a height of 1.5 meters on separate microphone stands. Both were connected through a Larson-Davis 2200C amplifier which was then connected to a Presonus EASERA Gateway as an interface between the receivers and the laboratory computer. A diagram of the setup is shown in Figure 28. Both microphones were calibrated and test signals were used to ensure there was a negligible difference in both amplitude and frequency response. For the first set of testing the passive method, a steady, white-noise source was used to create a known background noise. Additionally, a human voice was used as a source in a second trial to ensure the method worked a signal of non-uniform frequency distribution. The source and two receivers were arranged in the reverberation chamber according to Figure 29. The resulting signal was recorded on both microphones simultaneously using Adobe Audition v3.0.

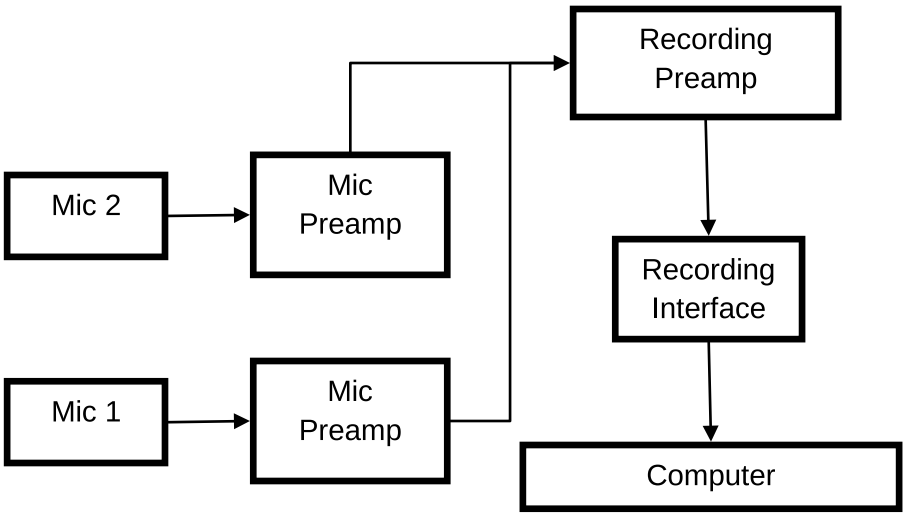

Figure 30. Experimental Setup of Passive Impulse Response Measurement

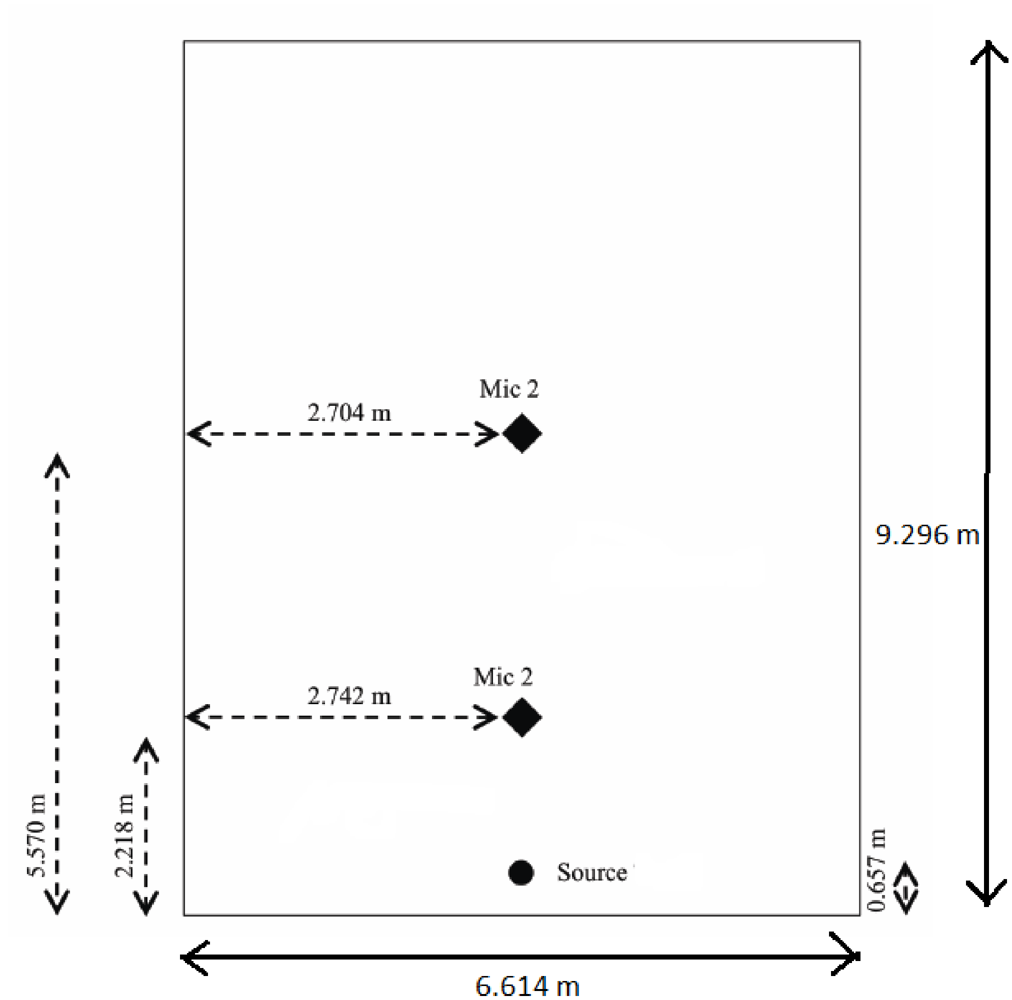

Figure 31. Source and Microphone Arrangement for Passive Impulse Response Tests

The recorded 15-second signals from both microphones were saved as a two-channel ".wav" file. The .wav files were then input into a script developed previously (Roan, et al. 2009) for passive IR measurements. The script first converts the files into a numerical matrix of amplitudes, with each column of the matrix being an individual time-step. The script then extracts coherence and correlation functions between the two signals. The full MATLAB script can be found in Appendix B. Because the correlation function serves as an estimate of the TDGF (Roux, Sabra and Kuperman 2005), it was then converted back to a .wav file and input into the EASERA software. The software then extracted the appropriate acoustic metrics in the same fashion as an active measurement.

The first test of the passive method (white noise as a source) yielded the correlation function seen in Figure 25 – a plot of the correlation of the two microphones versus time. A correlation "spike" is seen at approximately 0.01 seconds, which corresponds to the time it takes for sound to travel between the two microphones in a direct path. Figure 26 shows the correlation vs. time for the second test (human voice as a source) and shows the same correlation spike at 0.01 seconds, but at a higher amplitude than the white noise trial. Both figures show the correlation for times less than zero – this data is produced due to reflected sound that reaches microphone 2 before microphone 1. Only data for positive time was used for processing in EASERA. The impulse response charts created in EASERA for the two tests are shown in Figure 27 and Figure 28.

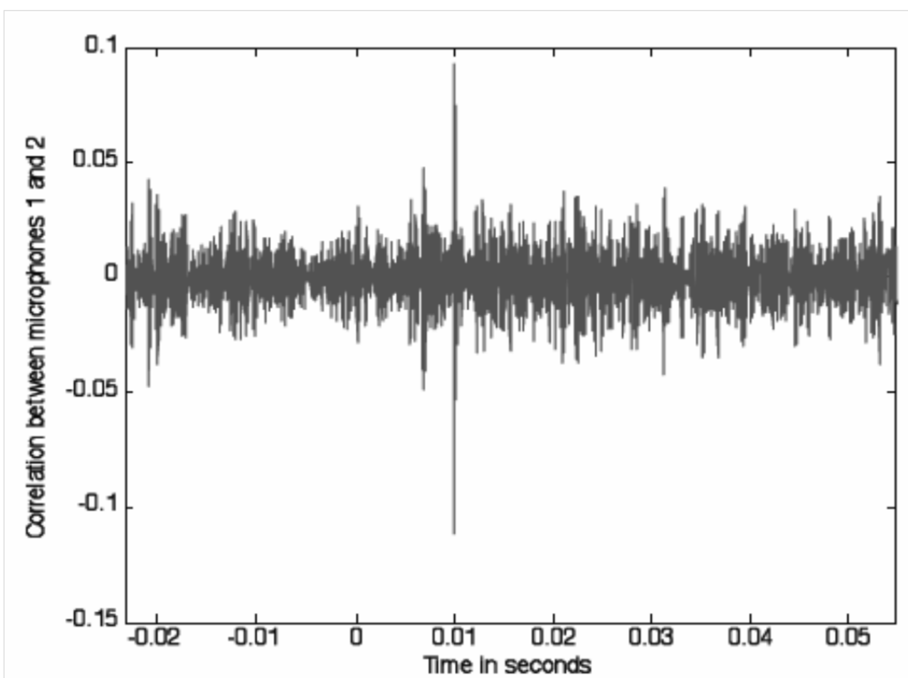

Figure 312. Correlation vs. Time for White Noise

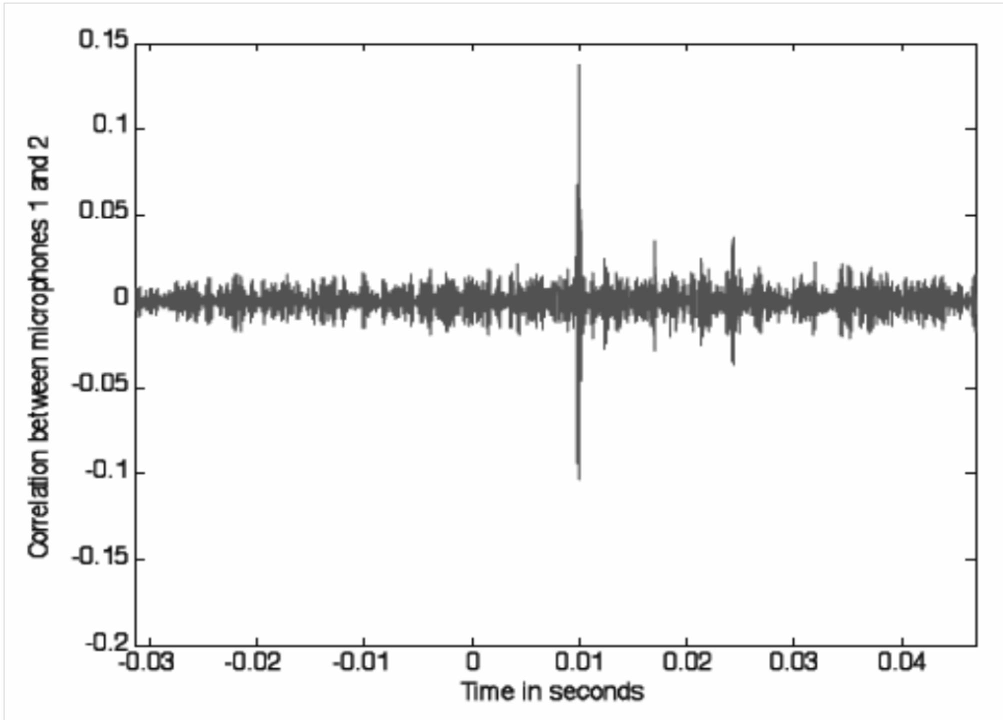

Figure 323. Correlation vs. Time for Human Voice

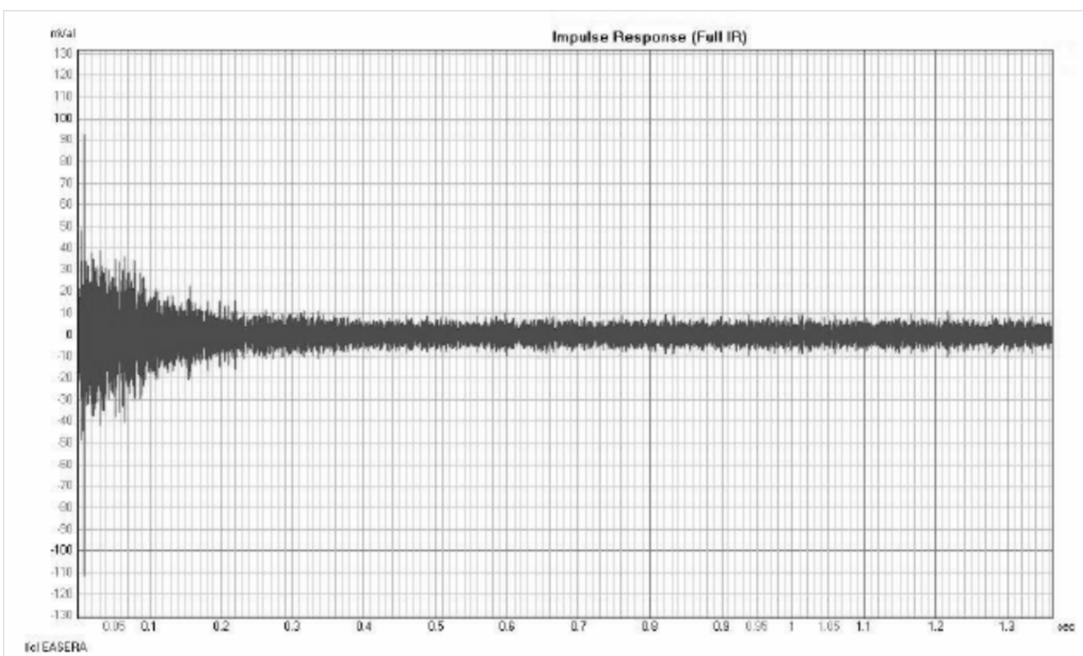

Figure 334. Passive Method Impulse Response from White Noise

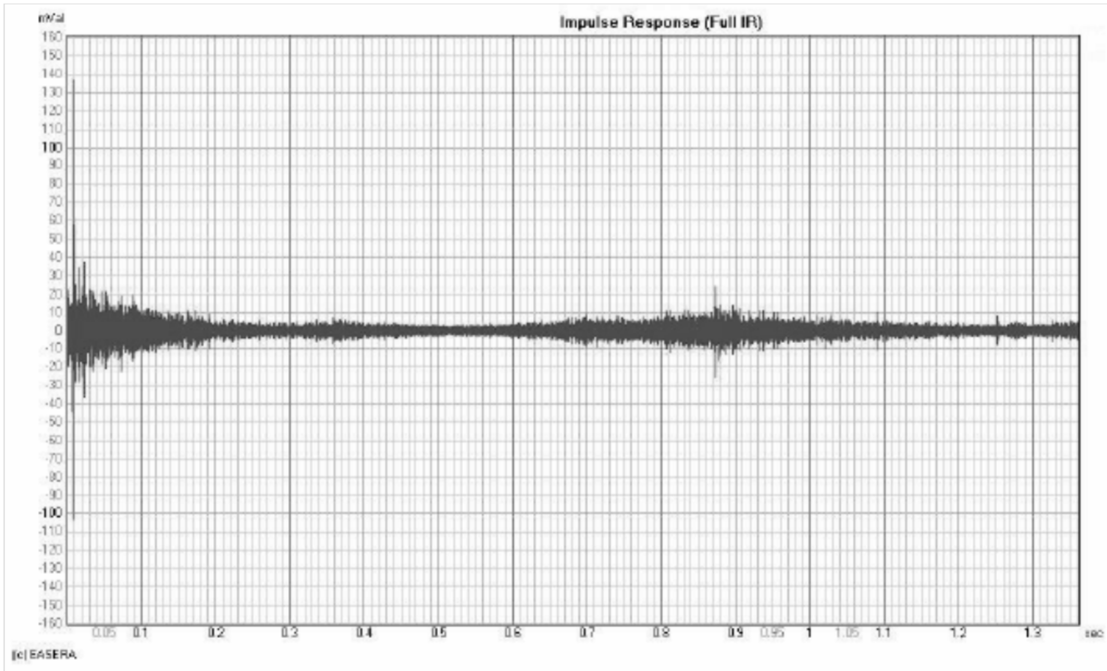

Figure 345. Passive Method Impulse Response from Human Voice

Although the location of the correlation spike in both trials was appropriate, the decay of the correlation amplitude over time produced unreliable results. The EDT's extracted from the passive measurements were excessive in some octave bands and sometimes exceeded 30 seconds – an impossible characteristic for the room volume in question. This error was more prevalent in frequencies below 1000 Hz.

5.4 Pilot in-situ ED Test of Active Methods

The MLS method for calculating the IR was tested at three Nurses Stations where background noise measurements were taken in Hospitals 1 and 2. A JBL EON 510 speaker was placed in an open area near the main nurse's station to avoid interfering with medical operations. An omnidirectional Goldline TEF04 microphone was then placed at least 2 meters from the sound source at a height of 63 inches. The source and receiver were connected to the EASERA Gateway and connected to a signal-generating laptop running EASERA v1.1, which recorded the impulse response. In all 3 environments, the maximum signal-to-noise ratio (SNR) that ED staff allowed was used and is presented in Table 6. The test in Hospital 2 saw an additional constraint of a high volume of ED staff near the measurement location.

Table 10. Signal-to-Noise Ratio at Impulse Response Measurement Locations

Location		Signal-to-Noise Ratio
Hospital 1	Main ED Nurses Station	6.0
	CDU Nurses Station	11.3
Hospital 2	Main ED Nurses Station	6.3

Table 11 shows that all sets of measurements have a suitable SNR for accurate measurements. However, the SNRs observed in all Main ED tests were the maximum allowable levels as hospital staff requested that the volume of the test signal was disruptive and must cease.

Table 11. Early Decay Times from Impulse Response Tests

Frequency (Hz)	Hospital 1		Hospital 2
	Main ED Nurses Station	CDU Nurses Station	Main ED Nurses Station
125	0.18	0.37	0.22
250	0.25	0.49	0.28
500	0.18	0.50	0.14
1000	0.26	0.45	0.11
2000	0.27	0.50	0.20
4000	0.25	0.54	0.10
8000	0.16	0.47	0.21

As shown in Table 12, EDT values are particularly low in the Main ED areas compared to the CDU. While the SNR for each set of tests would allow for relatively accurate measurements, the reverberation times for Main ED areas are much lower than expected. In both Main EDs, there was an absence of any type of absorptive materials – all walls and surfaces were smooth and rigid. Additionally, these spaces were significantly larger than the CDU measured, which should, in theory, cause them to be more reverberant. One possible reason for this discrepancy is the higher amount of occupants in the Main EDs. The additional staff members in the area of the test "can have a strong influence on the reverberation time"

(ISO 2008). While the possibility remains to conduct tests at night, when the number of people in the ED is much lower, it would cause a significant disruption to the sleep of patients. Thus, further investment into the development of a passive method for measuring the IR in EDs is warranted.

5.5 Next Steps for Passive IR Method Development

A number of steps must be taken before a passive method for calculating IR can be implemented. The main concern is achieving accurate amplitude decay in microphone correlation over time. While previous research has shown this can be achieved in certain non-air environments, it has become clear that additional adjustments must be made to apply the same concepts to the medium of air. One possible solution is to examine if there is pattern of error between the correlation function and the measured IR. If so, the correlation function may be scaled to increase accuracy. Additionally, the algorithms used to determine EDT's and other metrics should be investigated. Although the way to extract metrics from a given IR is known, EASERA's extraction process itself may not be optimal due to format of the correlation data.

After improvements are made to the passive method, it is essential that it be trained in a more realistic environment (other than the reverberation chamber used in the pilot study) and for a variety of different sources (other than the white noise and human voice sources used in the pilot study). Because this method is to be used in hospital areas, it should be tested with a wide range of frequencies and types of noise, as seen in hospital environments. An additional concern of this method is its ability to compromise privacy – the two microphones record signals in a .wav file format, meaning they could be replayed by any personal computer. A solution to this problem would be adjusting the input to save only the amplitude data, though this would take additional software expertise.

While the investigation into the passive method of calculating a room impulse response has yielded numerous insightful results, it remains to be seen if it can be developed into a reliable method to extract EDT's and other acoustic metrics in hospital environments.

CHAPTER 6

CONCLUSIONS

It is clear that acoustic environment of EDs has a great deal of room for improvement. The trend of increasing background noise levels in hospital settings was confirmed in this study, along with the finding that speech intelligibility is poor in many locations. A majority of ED staff have reported trouble communicating with both patients and other staff members, as well as identifying several sources that are disruptive to their work concentration. These findings present a significant problem for staff members who hope to optimize the quality of healthcare for their patients.

The environment of EDs could benefit greatly from a variety of future studies. One area of investigation could look at how staff perception changes if background noise levels are changed. This study did not focus on that due to the similar noise levels between the two hospitals. Another area would be measuring the impulse response of these environments in order to determine clarity and definition, among other metrics. Finally, the effect of altering noise sources could be examined, such as eliminating overhead paging systems. While this type of study has been done in other hospital environments, the unique nature of emergency medicine may require adjusting the protocol for these changes.

This investigation into EDs provided a more accurate view of both the acoustic environment and staff perception of a unique healthcare space that has yet to be fully examined. However, a great deal more can be learned through future research. Additional knowledge in this area could allow for an improved workplace experience and a higher standard of patient care.

APPENDIX A. STAFF SURVEY USED IN ED STUDY

Noise Study- Emory University Hospital

You are being asked to volunteer in a research study.

This study will examine how various characteristics of the emergency department sound environment impact perceptions of staff members about the qualities of their current jobs. This survey is being distributed to physicians and nurses in the emergency department in which you work.

If you decide to participate, you will be asked to fill out an electronic survey about your current job and various aspects of the sound environment at your workplace. The survey will take approximately 20 minutes to complete, and you should plan to fill out the entire survey in one sitting. It does not necessarily need to be filled out while you are at work; however, you may complete this survey at work if you so choose. You may decide to complete the survey during working hours, but you will not receive additional compensation for your participation.

Thank you!

Research Consent Form

Dear Caregiver,

You are being asked to volunteer in a research study.

Purpose:

This study will examine how various characteristics of the emergency department sound environments can impact the perceptions of staff members about the qualities of their current job. This survey is being distributed to surgeons and nurses in the emergency

*** Statement of consent**

☐ I have read this information form and I have been given the chance to ask questions about it. By checking this box, I agree to be a volunteer in this research study.

* Indicates Response Required

Gender

Male / Female

What is your age?

18-29 / 30-39 / 40-49 / 50-59 / 60-69 / 70 years or older

*** Which job category describes you?**

- Full time nurse
- Part time nurse
- Physician
- Clerk
- If other, please describe

What are your normal working hours?

Mostly mornings / Mostly afternoons / Mostly nights / Combination of morning, afternoon and night

In an ordinary week, how many total hours do you work?

How many years have you worked at your ED?

Less than 1 year / 1 to 5 years / 6 to 10 years / 11 or more years

*** How many years have you worked in an ED in your entire career?**

Less than 1 year / 1 to 5 years / 6 to 10 years / 11 or more years

*** Overall, how noisy is your workplace?**

1 (Not at all) / 2 / 3 / 4 (Somewhat) / 5 / 6 / 7 (Extremely)

* Indicates Response Required

*** Please describe how annoyed you typically are due to noise levels at the following locations in your workplace:**

	not at all annoyed 1	2	3	4	very annoyed 5
Physician/nurse work areas	○	○	○	○	○
Occupied patient rooms	○	○	○	○	○
Corridors	○	○	○	○	○
Triage	○	○	○	○	○
Waiting room	○	○	○	○	○

* Indicates Response Required

*** Please rate your level of agreement with the following statements, describing how you <u>typically</u> experience the sound environment in your workplace:**

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I have to raise my voice in order to communicate with others.	○	○	○	○	○
I have trouble communicating with other staff because of the noise levels.	○	○	○	○	○
I have trouble communicating with the patients because of the noise levels.	○	○	○	○	○
The background noise helps keep my conversations from being overheard by others.	○	○	○	○	○

* Indicates Response Required

*** Please describe how much the following noise sources typically disturb your work concentration in your workplace:**

	not at all	somewhat	moderately	quite a bit	extremely
Visitor conversation noise					
Staff conversation noise					
Visitors					
Patient sounds (e.g. coughing, gagging, snoring)					
Emergency procedures (e.g. cardiac arrest)					
Operational sounds of medical equipment used for patients (e.g. suction, breathing machines)					
Beeping patient monitoring devices					
Alarms on medical equipment					
Patient intercom and call lights					
Paging system					
Telephone ringing and conversation					
Noise from rolling medicine/ linen carts					
Noise from beds (e.g. squeaking, air pumping)					
Ventilation and air conditioning system					
Cleaning equipment (e.g vacuum cleaners)					
Door opening, closing, slamming					
Falling objects					
Toilets flushing					

* Please descibe how much you agree with the following statements when you consider your current job:

	Strongly disagreee	Disagree	Agree	Strongly agree
My job requires that I learn new things.	◯	◯	◯	◯
My job requires me to be creative.	◯	◯	◯	◯
My job requires a high level skill.	◯	◯	◯	◯
I get to do a variety of different things in my job.	◯	◯	◯	◯
I have an opportunity to develop my own abilities.	◯	◯	◯	◯
My job involves a lot of repetitive work.	◯	◯	◯	◯
My job allows me to make a lot of decisions on my own.	◯	◯	◯	◯
I have a lot to say about what happens on my job.	◯	◯	◯	◯
On my job, I have very little freedom to decide I do my work.	◯	◯	◯	◯
My job requires working very fast.	◯	◯	◯	◯
My job requires working very hard.	◯	◯	◯	◯
I am not asked to do an excessive amount of work.	◯	◯	◯	◯
I have enough time to get the job done.	◯	◯	◯	◯
I am free from conflicting demands that others make.	◯	◯	◯	◯

*
Taking everything into consideration, how satisfied are you with your job as a whole?

◯ 1 (Extremely dissatisfied) ◯ 2 ◯ 3 ◯ 4 (Neutral) ◯ 5 ◯ 6 ◯ 7 (Extremely satisfied)

*
Overall, what is your level of commitment to your present job?

◯ 1 (Not commited) ◯ 2 ◯ 3 ◯ 4 (Neutral) ◯ 5 ◯ 6 ◯ 7 (Extremely commited)

* Indicates Response Required

The remaining questions are not necessarily specific to your department. Fill out these questions based on your experience in everyday life.

*** In general, would you say your health is:**

◯ excellent ◯ very good ◯ good ◯ fair ◯ poor

*** The following questions are about activities you might do during a typical day. Does your health now limit you in these activities? If so, how much?**

	yes,limited a lot	yes,limited a little	no, not limited at all
Moderate activities, such as moving a table, pushing a vacuum cleaner, bowling, or playing golf	◯	◯	◯
Climbing several flights of stairs	◯	◯	◯

*** During the past 4 weeks, how much of the time have you had any of the following problems with your work or other regular daily activities as a result of your physical health?**

	All of the time	Most of the time	Some of the time	A little of the time	None of the time
Accomplished less than you would like	◯	◯	◯	◯	◯
Were limited in the kind of work or other activities	◯	◯	◯	◯	◯

*** During the past 4 weeks, how much of the time have you had any of the following problems with your work or other regular daily activities as a result of any emotional problems (such as feeling depressed or anxious)?**

	All of the time	Most of the time	Some of the time	A little of the time	None of the time
Accomplished less than you would like	◯	◯	◯	◯	◯
Did work or activities less carefully than usual	◯	◯	◯	◯	◯

*** During the past 4 weeks, how much did pain interfere with your normal work (including both work outside the home and housework)?**

◯ Not at all ◯ A little bit ◯ Moderately ◯ Quite a bit ◯ Extremely

*** These questions are about how you feel and how things have been with you during the past 4 weeks. For each question, please give the one answer that comes closest to the way you have been feeling. How much of the time during the past 4 weeks...**

	All of the time	Most of the time	Some of the time	A little of the time	None of the time
Have you felt calm and peaceful?	◯	◯	◯	◯	◯
Did you have alot of energy?	◯	◯	◯	◯	◯
Have you felt downhearted and depressed?	◯	◯	◯	◯	◯

*** During the past 4 weeks, how much of the time has your physical health or emotional problems interfered with your social activities (like visiting friends, relatives, etc.)?**

◯ All of the time ◯ Most of the time ◯ Some of the time ◯ A littel of the time ◯ None of the time

* Indicates Response Required

Do you have any known hearing impairments?

◯ Yes ◯ No ◯ I don`t know ◯ If yes, what type

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

◯ Yes ◯ No

*** How do you think your hearing is?**

◯ Very Bad ◯ Bad ◯ Normal ◯ Good ◯ Very Good

*** In general how sensitive are you to noise?**

◯ Not at all ◯ A little ◯ Moderately ◯ Considerably ◯ Extremely

"Noise disturbace" questions are adapted from:
*Topf M, Dillon E. (1988). Noise-induced stress as a predictor of burnout in critical care nurses. Heart & Lung, 17(5), 567-574.

"Job stress" questions are adapted from:
*Sale JEM, Kerr MS. (2002). The psychometric properties of Karasek`s demand and control scales within a single sector: data from a large teaching hospital. International Archives of Occupational and Environmental Health, 75, 145-152.
*Karasek RA. (1979). Job demands, job decision latitude and mental strain: implications for job redesign. Administrative Science Quarterly, 24, 285-308.

"Job satisfaction" questions are adapted from:
*Warr PB, Cook JD, Wall TD. (1979). Scales for the measurement of some work attitudes and aspects of psychological well-being. Journal of Occupational Psychology, 52, 129-148.
"Job commitment" questions are adapted from:
*Cook J, Wall TD. (1980). New work attitude measures of trust, organizational commitment and personal need non-fulfillment. Journal of Occupational Psychology, 53, 39-52.

"General health" survey questions are adapted from:
*Lim LLY, Fisher DJ. (1999). Use of the 12-item short from (SF-12) health survey in an Australian heart and stroke population. Quality of Life Research, 8, 1-8.
*Ware JE, Kosinki M, Keller SD. (1995). A 12-item short form health survey-construction of scales and preliminary tests of reliability and validity. Medical Care, 34, 220-233.

* Indicates Response Required

APPENDIX B. MATLAB CODE FOR PASSIVE IMPULSE RESPONSE MEASUREMENTS

```
[w,freq,nbits] = wavread('success.wav');

data = [w(:,2),w(:,1)];
time=1/freq:1/freq:(length(data(:,1)))/freq;
% Frequency Domain
N=length(time);
Ts=1/freq;
Faxis=(0:N-1)/N/Ts;
[B,A] = butter(2,22e3/(freq/2),'low');
C=filtfilt(B,A,data(:,1:2));

figure
plot(Faxis,20*log10(abs(fft(C))))
title('Recorded Data in Frequency Domain')
xlabel('Frequency in Hz')
ylabel('Magnitude')

% Time Domain
figure
plot(time,C)
title('Recorded Data in Time Domain')
xlabel('Time in Seconds')
ylabel('Signal Amplitude')

%% 2-Channel Coherence Function
% figure
[ZZ,W] = mscohere(data(:,1),data(:,2),1100,[],[],freq);
% plot(W,smooth(ZZ,10),'k')
% title('Coherence Between Microphones 1 and 2')
% xlabel('Frequency in Hz')
% ylabel('Coherence values')
freqmin=6300;
freqmax=14300;
```

```
%% Filter and Generate Correlation Function
new_freq_int=[freqmin  freqmax];  % Sets frequency inverval for
filter
[BB,AA]=butter(3,new_freq_int/freq*2); % Creates Butterworth
bandpass filter for data
for j=1:2
    data(:,j)=filtfilt(BB,AA,data(:,j));
end
tcorr=(-(length(time)-1):length(time)-1)/freq;
CORR=xcorr(data(:,1),data(:,2),'coeff');    % Determine which
mic's data is first
plot(tcorr,CORR)
xlabel('Time in seconds')
ylabel('Correlation between microphones 1 and 2')

%% Save data to file.

ZZ1 = ZZ; %Change number to corresponding test run so data name
is unique
CORR1 = CORR; %Change number to corresponding test run so data
name is unique
save DATA_2_1.mat CORR1 W ZZ1; %Change number to correspond to
test run
```

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ANSI. "Methods for Calculation of the Speech Intelligibility Index." *American National Standards Institute*, 1997: S3.5.

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