University of Cincinnati

Date: 7/16/2013

I, J'ai Watson, hereby submit this original work as part of the requirements for the degree of Master of Science in Industrial Hygiene (Environmental Health).

It is entitled:

Impact of Noise on Nurses in Pediatric Intensive Care Units

Student's name: J'ai Watson

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Impact of Noise on Nurses in Pediatric Intensive Care Units

A thesis submitted to the

Division of Research and Advanced Studies of the University of Cincinnati

In partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in the College of Medicine, Department of Environmental Health,

Division of Environmental and Occupational Hygiene

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by

J'ai Watson

B.S., University of Cincinnati, 2011

Thesis Committee:

Kermit Davis, PhD, Chair

Nancy Daraiseh, PhD

Susan Kotowski, PhD

ABSTRACT

Objective: To measure the impact of noise on nurses' heart rates in pediatric intensive care units.

Design: Cross-sectional study using direct observation techniques.

Setting: The neonatal intensive care unit, the cardiac intensive care unit, and the pediatric intensive care unit at a single urban pediatric hospital.

Subjects: Eighteen registered nurses, six from each unit, were observed.

Methods: Each nurse was observed during patient care for a 4-hr period. Heart rate and sound pressure level were recorded continuously using personal heart rate monitors and dosimeters (personal and hand-held) while stress ratings were collected pre-, mid-, and post-observation. Variables assessed as potential confounders were age, height, weight, BMI, years of nursing experience, caffeine intake, and patient census. Descriptive statistics were computed to determine the mean and standard deviations for the different effects. A repeated measures analysis of variance (ANOVA) with a within-subjects design was utilized to determine if noise and heart rate were impacted by the independent variables with post-hoc test in the form of Tukey honest difference test to determine source of the differences. Kruskal-Wallis Test was utilized to determine any differences resulted from the stress indices across assessments. Correlations between noise and heart rate were computed overall and blocked on the different independent variables.

Main Results: Overall, the average sound pressure level was about 78 dBA, with a range between 50 and 101 dBA. While the overall average heart rate was greater than 75 bmp, some activities and locations had a significant influence on heart rate. The neonatal intensive care unit recorded the highest average sound pressure level as well as heart rate. The maximum distribution of noise recordings were found in patient rooms; during support activities and employee interactions; and caused by staff communication. Mild correlations between noise and heart rate were significant as a function of unit, location, activity, and source.

Conclusions: Overall, the results indicate that intensive care units have high levels of noise which are driven by communication between nurses and patients and in-room equipment. Further, these levels require immediate attention through effective interventions—engineering controls and behavioral changes. While the impact of noise on heart rate is less conclusive, mild correlations were found and may indicate that noise can produce adverse health outcomes (e.g.

elevate cardiovascular risk). The bottom line is that ICUs have significant amount of noise that can adversely impact the nurse as well as the patient.

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TABLE OF CONTENTS

1.0 INTRODUCTION.....	pages 1-5
2.0 METHODS.....	pages 6-12
2.1 <i>Subjects and setting</i>	pages 6-7
2.2 <i>Apparatus and tools</i>	pages 7-9
2.3 <i>Procedures</i>	pages 9-11
2.4 <i>Data Analyses</i>	page 11
2.4 <i>Statistical Analyses</i>	page 11-12
3.0 RESULTS.....	pages 13-33
3.1 <i>Average Noise Levels for Nurses in ICUs</i>	pages 13-14
3.2 <i>Frequency of Noise Recordings for Nurses in ICUs</i>	pages 14-15
3.3 <i>Frequency of 5-minute intervals of Noise Exceeding 75 dBA Thresholds as Identified by handheld dosimeter</i>	pages 15-24
3.4 <i>Frequency of 5-minute intervals of Noise Exceeding 75 dBA Thresholds as Identified by personal dosimeter</i>	pages 24-29
3.5 <i>Average Heart Rate for Nurses in ICUs</i>	pages 30-32
3.6 <i>Correlation between Noise Level and Heart Rate</i>	pages 32-33
3.7 <i>Average Stress Levels for Nurses in ICUs pre-, mid-, and post-observation period</i>	page 33
4.0 DISCUSSION.....	pages 34-40
5.0 CONCLUSIONS.....	pages 41
REFERENCES.....	pages 42-44
APPENDICES	

Appendix A: Investigator Developed Noise Log

LIST OF TABLES AND/OR FIGURES

Table 1. Summary of studies measuring the impact of noise in the hospital setting.

Table 2. A list of independent and dependent variables used for the study.

Table 3. Anthropometric data of the three Intensive Care Units: neonatal intensive care unit (NICU), cardiac intensive care unit (CICU), and pediatric intensive care unit (PICU).

Table 4. Categories of location, source, and activity from investigator developed Noise Log.

Table 3.1 Average Noise levels for each subject (average of the 5 minute interval noise)

Table 3.2. Average Noise levels for ICU Unit (average of the 5 minute interval noise)

Table 3.3. Heart rate averages by unit.

Table 3.4. Correlation between Noise Level and Heart Rate as a Function of Unit, Location, Activity, and Source.

Table 3.5. Pre, mid, and post stress rating by unit (not significant at $p > 0.05$).

Figure 3.1. Average Noise Level as a Function of Location of Noise Source ($p < 0.05$)
(Different Alpha characters indicate significant difference)

Figure 3.2. Breakdown of the distribution of noise recordings as a function of location: a) location group and b) specific location.

Figure 3.3. Breakdown of the distribution of noise recordings as a function of Activity: a) activity group and b) specific activity.

Figure 3.4. Breakdown of the distribution of noise recordings as a function of Source: a) source group and b) specific source.

Figure 3.5. Breakdown of the distribution of hand-held noise recordings above threshold (75 dBA) for each subject.

Figure 3.6. Percentage of hand-held noise recordings above threshold (75dBA) for each unit.

Figure 3.7. Breakdown of the distribution of hand-held noise recordings above threshold (75dBA) for units as function of location a) location group and b) specific location.

Figure 3.8. Breakdown of the distribution of noise recordings above threshold (75dBA) as a function of activities completed by the nurses: a) activity group and b) specific activity.

Figure 3.9. Breakdown of the distribution of hand-held noise recordings above threshold (75dBA) for units as a function of source: a) source group and b) specific source.

Figure 3.10. Breakdown of the distribution of 5-minute interval noise recordings above threshold (75 dBA) for each subject.

Figure 3.11. Breakdown of the distribution of 5-minute intervals of noise recordings above threshold (75dBA) as a function of location: a) location group and b) specific location.

Figure 3.12. Breakdown of the distribution of 5-minute intervals of noise recordings above threshold (75dBA) as a function of Activities of the nurses: a) activity group and b) specific activity.

Figure 3.13. Breakdown of the distribution of 5-minute intervals of noise recordings above threshold (75dBA) as a function of Source: a) source group and b) specific source.

Figure 3.14: Average Heart Rate as a Function of Location of Noise Source ($p < 0.05$)
(Different Alpha characters indicate significant difference)

Figure 3.15: Average Heart Rate as a Function of Activity being Performed by Nurse ($p < 0.05$)
(Different Alpha characters indicate significant difference)

Figure 3.16: Average Heart Rate as a Function of Source of the Noise ($p < 0.05$)
(Different Alpha characters indicate significant difference)

1.0 INTRODUCTION

Over the years, advancements in intensive care medicine have led to a great degree of sophistication. These advancements have not come without a potential cost to healthcare professionals. Many specialty hospital rooms are now equipped with equipment that emit noise while running or sounding alarms. In addition, certain functions of a hospital contribute to elevated sound pressure levels (SPLs), such as ventilation and communication systems. An additional source of noise exists from conversations between staff, patients, and/or families. In the early 1970s, physicians began to measure these hospital noise sources. Table 1 provides Initial surveys discovered SPLs ranging from 70 dBA to 117 dBA¹. Soon after these measurements were made, government agencies began to offer recommendations and guidelines to limit noise produced in the hospital setting.

In 1974, the United States Environmental Protection Agency's (EPA's) Office on Noise Abatement and Control stated that noise could produce serious physical and psychological stress. To protect patients and healthcare professionals, the EPA recommended hospital SPLs not exceed 45 dBA during the day and 35 dBA during the night¹. Another document released by the World Health Organization (WHO) provides similar limits for hospital SPLs, stating that average values, for an 8-hour time-weighted average, not exceed 30 dBA with peaks not exceeding 40 dBA². Even with these recommendations and guidelines, studies completed intensive care units (ICUs) have found SPLs to range from 35 dBA to greater than 120 dBA, clearly above the guidelines and recommendations³⁻⁶

Although ICU noise has been classified as being excessive when compared to recommendations and guidelines set by the US EPA and WHO, it is not clear if and how noise contributes to negative health outcomes amongst nurses. Examples of potential adverse health

outcomes are decreased mental efficiency and short term memory; increased stress and burnout, and hearing loss⁷. An additional byproduct of these adverse health effects is a potential for more medical errors¹⁴. Links between high SPLs and heart health effects such as increased blood pressure, arrhythmias, and increased heart rate have also been considered potential health outcomes as seen in the study done by Morrison, et al at Johns Hopkins pediatric intensive care unit (PICU)^{6,8}.

The primary purpose of the study done by Morrison, et al⁶ was to measure hospital noise and determine whether high levels of noise related to high stress—measured by a questionnaire, salivary amylase, and heart rate. Eleven nurse volunteers were observed for a three hour period during patient care. During this time, heart rate and SPLs were recorded continuously; saliva samples and stress/annoyance ratings were collected every 30 minutes. It was found that the average daytime and nighttime SPLs were 61 dBA and 59 dBA, respectively. Additionally, the higher SPLs were found to be related to higher heart rates. Other significant predictors of higher heart rates were higher caffeine intake, less nursing experience, and daytime shift. Salivary amylase measurements showed a large variability and were not significantly affected by SPLs. These results suggest a significant correlation between high SPLs and increased heart rate, which may contribute to stress and annoyance amongst nurses. This also may suggest the possibility of long term health consequences for nurses such as hypertension and heart disease⁶. Linking noise and heart rate on an individual ICU only depicts a small part of the bigger picture as there should be equivalent measures made on each specialty ICU.

Another research group led by Ryherd, et al⁷ also investigated how noise contributes to a negative work environment by conducting sound measurements and occupant evaluations in a neonatal intensive care unit (NICU) for a five day period at patient and staff locations. Results

showed that during 90% of the observed time, SPLs exceeded 50 dBA. This research also found 91% of nurses felt that noise in general could negatively affect them in their routine work environment; 66% of nurses felt irritated and fatigued; 43% of nurses admitted concentration problems; and 40% of nurses experienced tension headaches as a result of high SPL. While documenting noise and psychosocial work demands was helpful, it is also important to determine whether baseline SPLs versus high SPLs are linked to be disruptive to patients and staff⁷.

Darcy and associates⁸ did exactly this by examining the baseline acoustic environment in several mid-Atlantic region NICUs and perceived factors contributing to SPLs. The study collected two hours of data during day and night shifts on three NICUs. The mean SPL ranged from 53.9 dBA to 60.6 dBA for both shifts (not a significant difference). SPLs on all three NICUs were above recommended guidelines; however, nurses did not perceive the sound levels to be high. These results were in direct contradiction of Carvalho and associates⁹, which discovered the most significant levels of noise resulted from conversations among the staff in the PICU. This study continuously monitored for 24 hours a day for six days. Reported results for baseline SPLs between 60 dBA and 70 dBA with a maximum of 120 dBA⁹. This was the first study to link staff behavior and conversations to the noise levels, which may be one source where interventions may be effective in controlling the noise level.

One such intervention is a behavioral change where staff members adhere to a focus on noise reduction. Kahn et al.,⁵ studied SPLs in the medical intensive care unit (MICU) for three weeks at a 720-bed teaching hospital in Providence, Rhode Island investigating sources of high noise levels and identifying potential interventions. SPLs greater than 80 dBA were measured and were found to be based on staff member's behavior. The authors recommended modifying behavior to reduce exposures, such as adjusting the television, turning beepers on vibrate,

adhering strictly to visiting hours and number of visitors at patient's bedsides, and by decreasing or eliminating loud or unnecessary conversation⁵. However, changing the behavior long-term has proven to be a challenge on its own.

Moore, et al¹⁰ confirmed this difficulty through research on interventions aimed at reducing decibel levels on patient care units with interventions consisting of education of nursing and physician staff and closing patient room doors. They found that closing a patient's door could expose the patient to more noise since most noise originates from equipment within the room. Further, the three 1-hour education sessions were not effective in changing behavior. However, the authors still thought a different approach to education was the best solution for behavior modification¹⁰. Elander and Hellstrom's³ study found similar results to the Moore study¹⁰. In a study evaluating an intervention program for noise at a southern Sweden children's surgical ward, researchers reported simple interventions such as presentations, video tapes, and various care activities, were effective in reducing SPLs without additional costs³.

Many studies have reported high levels of noise in hospitals and particularly in ICUs (see Table 1). As seen in Table 1, many of the units have excessive levels, many above recommended levels of exposure. Only two have examined the physiological and psychological health effects of noise on pediatric ICU nurses, and none were found to compare noise across different types of ICUs^{6,11}. Thus, the objective of this study was to measure noise on three different specialty ICUs in a freestanding pediatric medical center to determine the impact noise has on heart rate and psychological health of registered nurses (RNs). It was hypothesized that noise is related to heart rate and that the sources of noise and activities will influence the relationship between noise and heart rate.

Table 1. Summary of studies measuring the impact of noise in the hospital setting.

Study	Setting/Yr	Sample Size	Noise Levels
Bentley et al. ¹²	ICU/1977	N/A	Average 42-53 dBA Peaks >70 dBA
Meyer et al. ¹³	ICU/1994	N/A	Peaks reaching 83.6 dBA
Meyer-Falcke et al. ¹⁴	SICU/1994	N/A	Average >65 dBA Peaks >110dBA
Elander et al. ³	Surgical Ward/1995	52 Nurses	Range 35-84 dBA
McLaughlin et al. ¹⁵	CSICU/1996	N/A	Average 58-77 dBA Peak 101 dBA
Tsiou et al. ¹⁶	ICU/1998	10 Patients	Average 60-67 dBA Peak 83-90 dBA
Kahn et al. ⁵	RICU & MICU/1998	All ICU staff during the study period	Peaks >80 dBA
Morrison et al. ⁶	PICU/2003	11 RNs	Daytime Average 60.6 dBA Nighttime Average 58.8 dBA Range 43-96 dBA
Johnson et al. ⁴	NICU/2003	Not noted in the Study	Averages 56.29-64 dBA
Carvalho et al. ⁹	PICU/2006	N/A	Basal noise level 60-70 dBA Max of 120 dBA
Ryherd et al. ⁷	NICU/2008	47 NICU staff	Range 53-58 dBA Peaks >70 dBA
Cordova et al. ¹⁷	BICU/2012	N/A	Averages 60.9-65.9 dBA

Acronyms: Intensive Care Unit (ICU), Surgical Intensive Care Unit (SICU), Cardiac Surgical Intensive Care Unit (CSICU), Resident Intensive Care Unit (RICU), Medical Intensive Care Unit (MICU), Prenatal Intensive Care Unit (PICU), Neonatal Intensive Care Unit (NICU), Burn Intensive Care Unit (BICU)

2.0 METHODS

This study used a cross-sectional observational design to evaluate the negative impact of noise on ICU nurses, with respect to increased heart rate and stress. Noise was measured continuously for 4 hours on a single shift where sources, places, and activities were recorded to identify the nature of the noise. Further, nurses were followed from 3 different types of ICUs: neonatal intensive care unit (NICU), cardiac intensive care unit (CICU), and pediatric intensive care unit (PICU). Table 2 provides the list of independent and dependent variables.

Table 2. A list of independent and dependent variables used for the study.

Independent Variables	Dependent Variables
Unit (NICU, CICU, PICU)	Noise (continuous, dBA)
Source of Noise (Staff Communication, Communication Devices, In-room Equipment, Patient/Family Communication, Door Open/Closed), and Other)	Heart Rate (continuous, beats/min)
Activity Causing Noise (Patient Interaction, Employee Interactions, Support, and Other)	Percent of time noise is above threshold (75 dBA) (%)
Location of Noise (Axillary Rooms, Gathering Rooms, Outside Patient Room, and Patient Room)	Stress (0—no stress to 100—most possible stress)

2.1. Subjects and Setting

Eighteen registered nurses (RNs) were observed on three ICUs at a single urban pediatric hospital. As seen in Table 3, subjects comprised of 2 males and 16 females. The average age of the nurses was 32.8 years old. There was no exclusion criteria based on demographic data. There was only one exclusion criterion: if the participant did not have a scheduled meeting during the hours of observation, they were not observed.

Table 3. Anthropometric data of the three Intensive Care Units: neonatal intensive care unit (NICU), cardiac intensive care unit (CICU), and pediatric intensive care unit (PICU).

<i>Unit</i>	<i>Gender</i>	<i>Age (yrs)</i>	<i>Experience (yrs)</i>	<i>Weight(kg)</i>	<i>Height(cm)</i>	<i>BMI</i>	<i>Patient Census</i>
P value		0.85	0.9	0.56	0.82	0.79	0.001
NICU Averages	100% F	33.0	6.3	76.3	168.5	26.5	43.7
Std. Dev.	0% M	6.1	4.3	23.0	5.0	7.4	4.6
CICU Averages	100% F	31.8	5.7	66.4	165.1	24.3	17.5
Std. Dev.	0% M	4.5	3.9	7.0	8.8	2.9	4.3
PICU Averages	66.6% F	33.7	5.2	78.0	168.9	25.3	22.2
Std. Dev.	33.3% M	5.9	4.0	24.6	16.7	4.9	3.3
Overall Averages	89% F	32.8	5.7	73.5	167.5	25.4	27.8
Std. Dev.	11% M	5.3	3.9	19.4	10.7	5.2	12.3

These distribution of demographics (age and gender) are very similar to the entire inpatient registered nursing personnel at the pediatric institution, which had a gender distribution of 6.5% male and 93.5% female, as well as an average age of 34.4 years old. As such, the sample appears to be a good representative sample of the entire nursing personnel.

Statistical analyses of the demographics between the units revealed no significance for the majority of the factors, with the exception of patient census—number of inpatients being cared for on a unit per day. The main difference in patient census was for the NICU, which handled significantly more patients per nurse ($p < 0.001$). The NICU was a four pod base space holding up to 6 to 7 infants in each pod at a time. On average there were approximately 24-25 RNs on the unit at a time. The CICU was a twenty-two bed unit. On average there were approximately 13-16 RNs on the unit at a time. The PICU was a 35 bed unit. On average there were approximately 23-24 RNs on the unit at a time. However, the average number of hospital staff could increase on all ICUs for various reasons, such as post-operative patients being brought back to their room during safe-handoff between the operating room (OR) team and intensive care team.

2.2. Apparatus and Tools

The research team used direct measurement apparatuses to collect three categories of data: 1) Noise, 2) Noise Sources and Activities, and 3) Heart Rate. A noise dosimeter (QuestTechnologies, NoisePro Series DL, Wisconsin) was used to measure the noise level (units in decibels). Noise was measured using noise dosimeters with microphones attached to subjects' lapels for a 4 hour period. There were six, 4-hour observation periods (3:30-7:30, 7:30-11:30, 11:30-3:30, 15:30-19:30, 19:30-23:30, and 23:30-3:30), covering a 24 hour spanned of time. To capture variability, the shifts spanned Monday thru Friday to observe all six shifts. The noise levels were measured at 1 minute intervals throughout the observation period.

During the same observation period, identification of specific noise sources were tracked by research team members utilizing a noise log (Appendix A), on a personal digital assistant (PDA). The categories used on the noise log are summarized in Table 4. Each subject had a data collector observing them and logging sources of noise at 5 minute intervals using the noise log. The log was investigator-developed to track key activities, sources of noise, and relevant notes. The log used a list of sources of noise from each unit and consolidated them into main categories to create one standard log.

The final direct measurement recorded was heart rate, measured using a heart rate monitor (CamNTEch, Actiheart, Cambridgeshire). The heart rate monitor was positioned across the chest of the subjects during the entire observation period. Heart rate readings were recorded every 15 seconds.

The final outcome measure was the self-report of stress at the beginning (pre), middle—2 hours into the study period (mid) and end (post) of the observation period. The stress assessment was based on the Specific Rating of Events Scale¹⁸ that was designed for the U.S. Army

Research Laboratory stress program. Subjects rate how stressed they are right now on a scale of 0 (not at all stressful) to 100 (most stress possible).

Table 4. Categories of location, source, and activity from investigator developed Noise Log.

Location	Activity	Source
Auxiliary Rooms: Utility Rooms, Equipment Room, Kitchen/Nutrition Room, Medication Room, Pyxis Area Gathering Rooms: Break Room, Conference Room Outside Patient Room: Work Station, Front Desk, Hallway, Office Patient Room: Pt. Room 1, Pt. Room 2, Pt. Room, Other, Pod	Patient Interaction: Assessments/Interview, Rounds, Pt./Parent Education Employee Interactions: Employee Discussion, Change Shifts Support: Procedures, Stocking Supplies, Medicine Administration Other: Other	Staff Communication: Staff conversations Communication Devices: Pager/Cell Phone, Overhead Pager In-Room Equipment: IV Pumps, Monitors, Vacuum Tube System, TV Patient/Family Communication: Patient crying/yelling, Family Conversations Other: Other, Environmental Services Door: Door Open/Closed

2.3. Procedures

Subjects were recruited by email as well as in person during staff and shared governance council meetings. Verbal agreement to participate in the study indicated consent a waiver was approved by the hospital's Institutional Review Board (IRB). Individuals who agreed to participate were randomly selected for observation and were scheduled at least 3 days prior to the observation time. Individuals were removed from the selection pool after observation, unless all other scheduled staff declined to participate or had already participated in the study. Two

subjects were re-observed at two different times due to the lack of other working staff being scheduled during the day of observation for their unit. The 4-hour observation blocks were carried out during the day, evening and night shift during weekdays (Monday thru Friday). Observations were not conducted on weekends due to scheduling conflicts. On average, data for 5 to 6 subjects were collected per week.

Prior to each data collection period, all devices were calibrated and nurses were asked for their demographics: birthdate, height, weight, years of experience; and caffeine intake (in cups) during the past 24-hour period. At this time, subjects were informed that they may discontinue participation in the study at any time without penalty. They were also asked to self-report their stress at the start of the observation period.

Next, the subject was fitted with the noise dosimeter and a heart-rate monitor. The microphone for the noise dosimeter was attached along the left anterior shirt collar. To obtain heart rate baselines, subjects were asked to sit, walk, run, and sit again while wearing the heart rate within these first 10 minutes.

A study team member then followed the worker for the 4-hour observation time block documenting noise exposures at five minute intervals on the noise log using a PDA. Each data collector carried a personal noise meter to identify when noise levels exceed thresholds, called “excessive SPLs” (e.g. noise exceeding 75 dBA) to identify noise sources in between the five-minute intervals. A threshold of 75 dBA was used, as the National Institute on Deafness and Other Communication Disorders (NIDCD) reported that sounds less than 75 dBA are unlikely to cause physiological damage¹⁹.

Data collectors were recruited and hired from area academic institutions to carry out observations on units. They were trained on sampling sources of noise using pre-recorded video.

Inter-rater agreement was assessed during these sessions. If an agreement of 95% or greater was not obtained, retraining was conducted until that level was reached.

At the end of the data collection period, the waist belt, dosimeters and heart-rate monitor were removed. Subjects were reimbursed with cafeteria vouchers valued at \$5 in gift certificates.

2.4 Data Analyses

Data for the noise log were entered into an Excel spreadsheet. Noise logs were stored in a locked cabinet in the unit liaison's or key personnel's office space, until one research member recorded them into an excel spreadsheet. Dosimeter and heart-rate monitor data were downloaded by the study team and saved to the protected storage location on the day of data collection.

All of the files (noise, heart rate, and log) were combined into one larger database for subsequent data and statistical analyses. In order to combine the files, data sampling had to be coordinated by converting all data into 5 minute intervals. The log data had the least frequent sampling rate of once every 5 minutes so all other sampling was converted to this rate. Noise was sampled at 1 every minute which then was converted to a 5 minute average, Heart rate data were collected at 15 second intervals so that 20 data points were averaged to get the 5 minute sample rate. All data values were visually inspected for malfunction (e.g. signal dropped).

2.5 Statistical Analyses

Descriptive statistics were computed to determine the mean and standard deviations for the different effects (e.g. unit, source, activity, location). A repeated measures analysis of variance (ANOVA) with a within-subjects design was utilized to determine if noise and heart

rate were impact by the independent variables (unit, source, activity, and location). Significant effects from the ANOVA were compared with the Tukey honest difference test. A Kruskal-Wallis Test was utilized to determine whether any differences resulted for the stress indices across the pre-, mid-, and post-assessments. Correlations between noise and heart rate were computed overall as well as blocked on the different independent variables relationship.

3.0 RESULTS

3.1 Average Noise Levels for Nurses in ICUs

From the 18 observations completed on the ICUs, an overall mean noise level of 77.57 dBA was calculated. Subjects were exposed to minimum SPLs of 50.32 dBA and maximum SPLs of 101.18 dBA. These results are displayed in Table 3.1. When sorted by unit (Table 3.2), the NICU recorded a greater mean of 80.08 dBA as compared to the CICU and PICU which recorded means of 79.07 dBA and 73.68 dBA.

Table 3.1: Average Noise levels for each subject (average of the 5 minute interval noise)

Subject	Mean	Std Dev	Minimum	Maximum
1	78.81	7.38	61.68	95.26
2	78.49	5.29	66.70	93.54
3	80.34	3.98	68.86	88.06
4	81.67	3.61	74.18	97.12
5	80.16	5.45	69.70	93.10
6	80.72	7.20	65.76	101.18
7	78.93	4.51	68.22	89.34
8	77.27	3.67	68.78	85.32
9	80.79	5.25	72.98	90.24
10	81.63	4.10	72.82	89.96
11	78.84	5.13	68.56	88.42
12	77.35	4.25	69.82	92.56
13	71.72	5.06	60.22	84.92
14	73.94	3.49	67.52	82.38
15	79.11	7.23	65.80	91.40
16	87.61	3.64	79.36	94.76
17	65.93	8.19	51.38	86.68
18	63.38	6.95	50.32	78.56
Overall	77.57	7.84	50.32	101.18

Table 3.2: Average Noise levels for ICU Unit (average of the 5 minute interval noise)

Unit	Mean	Std Dev	Minimum	Maximum
NICU	80.08	5.74	61.68	101.18
CICU	79.07	4.75	68.22	92.56
PICU	73.68	10.13	50.32	94.76

As seen in Figure 3.1 (different alpha characters indicate significant difference from here on, example: A=AB, A<B), average noise varied as a function of location with gathering rooms (rooms where nurses gather such as break and conference rooms) having the highest SPLs ($p<0.05$). Several rooms averaged above the 75 dBA level: gathering rooms, outside of the patient's room, and patient's rooms. No significance was found for activity or source with respect to noise levels. However, all SPLs for these variables exceeded 75 dBA.

Figure 3.1: Average Noise Level as a Function of Location of Noise Source ($p<0.05$) (Different Alpha characters indicate significant difference)

3.2: Frequency of Noise Recordings for Nurses in ICUs

By breaking down the distribution of noise as a function of location, it was possible to distinguish, which areas nurses had the most noise exposure. Figure 3.2 illustrates the distribution of noise by location group and specific location. When using location group, it was

seen that 63% of noise measurements occurred in the patient's room while the least amount (6%) of noise recordings occurred in gathering rooms. When looking at specific location, it's noteworthy that 13% of noise occurred at nurses workstations, which is one of the areas in the broader outside patient room classification.

The breakdown of the distribution of noise recordings as function of activity (shown in Figure 3.3), indicates that most noise recordings were taken during support activities (procedures, stocking supplies, and medicine administration) and during employee interactions (employee discussion and shift change). When breaking these down into specific activities, it was seen that 29% of these recordings were taken during employee discussion and that 20% were taken during procedures, with the least percentage occurring during patient rounds and stocking supplies.

Figure 3.4 shows the breakdown of the distribution of noise recordings as a function of source. It is clearly seen that staff communication outweighed all other sources of noise by 51% of recordings being over threshold for both the location group and specific source. While other specific sources were below 12%.

3.3: Frequency of Noise Levels Exceeding 75 dBA Thresholds as Identified by handheld dosimeter

A threshold of 75 dBA was used to indicate excessive SPLs in the ICUs. Figure 3.5 shows all subjects spent a substantial amount of time during observation over threshold. Also visible is the large amount of variability between subjects in different units in terms of time spent over threshold; with one subject spending 96.3% of the recorded time over the threshold, while another spending just 11.3% of the recorded time over threshold. Figure 3.6, shows that

noise levels in two of the ICU units (NICU and CICU) were above threshold (75dBA) over 70% of the time. Although the

a)

b)

Figure 3.2. Breakdown of the distribution of noise recordings as a function of location: a) location group and b) specific location.

a)

b)

Figure 3.3. Breakdown of the distribution of noise recordings as a function of Activity: a) activity group and b) specific activity.

a)

b)

Figure 3.4. Breakdown of the distribution of noise recordings as a function of Source: a) source group and b) specific source.

PICU had the least amount of time spent over threshold, recordings still show nearly half of observations were spent over threshold at 44.3%.

Figure 3.7 provides the breakdown of the distribution of hand-held noise recordings above threshold (75dBA) as function of location (by location group and by specific location). While noise recorded in patients' rooms were over threshold 51% of the time, recordings in gathering rooms were over threshold 29% of the time. The gathering room's location group consisted of the break and conference room, which suggests no patient care was taking place while excessive SPLs were generated.

Figure 3.5. Breakdown of the distribution of hand-held noise recordings above threshold (75 dBA) for each subject.

Figure 3.6. Percentage of hand-held noise recordings above threshold (75dBA) for each unit.

Figure 3.8 provides the distribution of hand-held noise recordings above a threshold of 75 dBA as a function of activities completed by nurses (by activity group and by specific activity). When looking at activity group, support activities and employee interactions show similar results of 34% and 33%. However when sorted by specific activity, a standout of 29% of staff conversations were spent over threshold. Procedures, other and medical administration recordings showed a significant percent over the threshold at 20%, 19%, and 13%, respectively.

Again, Figure 3.9 provides a summary of the hand-held noise readings that exceeded the 75dBA threshold as a function of source group and the specific source. When looking at the breakdown of specific sources, staff conversations (51%), other (12%), monitors (10%), family conversations (6%), and patient crying/screaming (6%) accounted for the most time spent over threshold. All other specific sources recorded 4% or less over threshold.

a)

b)

Figure 3.7. Breakdown of the distribution of hand-held noise recordings above threshold (75dBA) for units as function of location a) location group and b) specific location.

a)

b)

Figure 3.8. Breakdown of the distribution of noise recordings above threshold (75dBA) as a function of activities completed by the nurses: a) activity group and b) specific activity.

a)

b)

Figure 3.9. Breakdown of the distribution of hand-held noise recordings above threshold (75dBA) for units as a function of source: a) source group and b) specific source.

3.4: *Frequency of 5-minute intervals of Noise Exceeding 75 dBA Thresholds as Identified by personal dosimeter*

As seen in Figure 3.10, the noise levels for the 5-minute intervals were frequently above the 75 dBA threshold levels for most of the nurses. In the worst case, one subject recorded 100% of their observation over threshold, while another subject recorded less than 10% of an observation above the threshold.

The results from the 5-minute intervals were slightly different than the individual events identified by hand held dosimeter (recorded by researcher). In Figure 3.11, the patient's room accounted for 70% of the noise recordings for the 5-minute intervals that were above threshold, followed by outside the room at 20%, while both gathering rooms and auxiliary rooms were at 5%.

Figure 3.12 illustrates activities completed by nurses and the percent of recordings over the 75 dBA threshold for 5 minute intervals. Of these activities, 37% of support activities, 32% of employee discussion, and 16% of patient interactions were regularly over threshold. The other category was over threshold 15% of the time. When breaking down activities by specific activity, it can be seen that employee discussion (28%), procedures (22%), medical administration (14%), and assessment of patients (10%) were the most common activities with regular recordings over threshold.

When determining the percent of noise sources above threshold for 5-minute intervals, it was seen that over half of staff communication recordings were spent above threshold when defined by source group and specific source (Figure 3.13). Source group recordings for in-room equipment were above threshold 21% of the time, while patient/family communication, others, doors open/closed, and communication devices being over threshold 15% or less. When

defining specific sources, only staff communications, monitors, and the 'other' category recorded percentages 10% or greater for recordings above threshold.

Figure 3.10. Breakdown of the distribution of 5-minute interval noise recordings above threshold (75 dBA) for each subject.

a)

b)

Figure 3.11. Breakdown of the distribution of 5-minute intervals of noise recordings above threshold (75dBA) as a function of location: a) location group and b) specific location.

a)

b)

Figure 3.12. Breakdown of the distribution of 5-minute intervals of noise recordings above threshold (75dBA) as a function of Activities of the nurses: a) activity group and b) specific activity.

a)

b)

Figure 3.13. Breakdown of the distribution of 5-minute intervals of noise recordings above threshold (75dBA) as a function of Source: a) source group and b) specific source.

3.5: Average Heart Rate for Nurses in ICUs

Table 3.3 summarizes heart rate averages at the unit level as well as the overall average. On average, the heart rate was 80.3 bpm. The NICU recorded the highest heart rate average (91.79 bpm), while recording the maximum heart rate of 123.95 bpm.

Table 3.3. Average Heart Rate as a Function of Unit.

Unit	Mean	Std Dev	Minimum	Maximum
NICU	91.79	12.99	65.90	123.95
CICU	77.19	12.58	52.10	101.15
PICU	71.92	13.98	40.20	99.70
Overall	80.30	13.18	52.73	108.27

Gathering rooms, outside of the patients' rooms, and patients' rooms were found to significantly ($p < 0.0001$) impact the average heart rate of nurses (see Figure 3.14). All activities, including patient interactions, employee interactions, support activities, and other were found to significantly ($p < 0.0001$) affect average heart rate of nurses (Figure 3.15). Average heart rates of nurses were significantly ($p < 0.009$) affected by sources with averages about 80 bpm for all sources (Figure 3.16).

Figure 3.14: Average Heart Rate as a Function of Location of Noise Source ($p < 0.05$) (Different Alpha characters indicate significant difference)

Figure 3.15: Average Heart Rate as a Function of Activity being Performed by Nurse ($p < 0.05$) (Different Alpha characters indicate significant difference)

Figure 3.16: Average Heart Rate as a Function of Source of the Noise ($p < 0.05$) (Different Alpha characters indicate significant difference)

3.6: Correlation between Noise Level and Heart Rate

Table 3.4 summarizes the correlations between noise level and heart rate as a function of unit, location, activity, and source. A correlation for the data revealed noise and heart rate were significantly affected at the 0.05 level by NICU and PICU; location in the gathering rooms, outside the patient's room, and the patient's room; all measured activities; and by sources such as staff communication, in-room equipment, and patient/family communication.

Table 3.4: Correlation between Noise Level and Heart Rate as a Function of Unit, Location, Activity, and Source.

Overall	0.264
UNIT LEVEL	
Unit 1	0.170
Unit 2	-0.070
Unit 3	0.134
LOCATION	
Auxiliary rooms	0.163
Gathering Rooms	0.304
Outside room	0.214
Patient room	0.289
Other	0.342
ACTIVITY	
Patient Interactions	0.555
Employee Interactions	0.252
Support Activities	0.143
Other	0.216
SOURCE	
Staff Communication	0.234
Communication Devices	-0.242
In Room Equipment	0.273
Patient/Family Communication	0.451
Doors Open/Closing	-0.051
Other	0.176

*Correlations found significant at the 0.05 level are in bold

3.7: Average Stress Levels for Nurses in ICUs pre-, mid-, and post-observation period.

While it was hypothesized that noise was going to adversely impact stress, the readings were highly variable and resulted in no differences between pre-, mid-, and post-observation (Table 3.5). There also was no difference between the units with respect to stress or timing of stress observation.

Table 3.5. Pre, mid, and post stress rating by unit (not significant at $p > 0.05$).

Unit	Pre Stress	Mid Stress	Post Stress
NICU Averages	29.00	35.00	31.00
CICU Averages	31.67	28.33	22.50
PICU Averages	15.83	21.67	16.67
Overall Averages	25.29	27.94	22.94

4.0 DISCUSSION

The results of the study provide an interesting perspective of the noise levels that nurses were exposed to in ICUs. Direct observation of noise levels from dosimeters on the nurses found SPLs on all three units (NICU, PICU, and CICU) ranging from 50.32 dBA to 101.18 dBA, with an overall average of 77.57 dBA. These values are well above the EPA recommended hospital SPLs limits of 45 dBA during the day and 35 dBA during the night or the WHO recommended 8-hour time-weighted average values that are not to exceed 30 dBA with peaks not exceeding 40 dBA^{1,2}. Thus, it is clear the results suggest a definite noise problem exists in the studied ICUs. When breaking down units individually, the NICU generated the highest mean at 80 dBA with the CICU being very similar at 79 dBA. The PICU had significantly lower noise at about 74 dBA. A few factors may contribute to this difference. First, patient census may have been a major contributor as the NICU had the largest average patient census (44 patients), which was more than double the either the CICU or PICU (approximately 20 patients). Other factors that may contribute to the higher noise levels in NICU are types of equipment and alarms, layout of the pods, and additional communication requirements.

To better understand the unacceptably high SPLs, the study team broke down noise levels as a function of location, activity, and source. When determining the significance of each variable based on average noise level, only location showed significant influence where gathering rooms such as conference and break rooms had the greatest noise levels. Further, the different noise levels for locations, activities, and sources were not significant but had average values that exceed 75 dBA, indicating significant noise levels and a real noise problem still exists.

A slightly different picture of the noise was found when looking at the distribution of the noise samples—counts of events when looking at the location, activities, and sources of the noise. When looking at the distribution of noise as a function of location, noise levels were most often recorded in patients' rooms, including pods. The high frequency of noise events in the patient rooms was not surprising as the nurses would spend most of their time in the patient rooms. On the contrary, where high noise levels were recorded, gathering rooms (29% of the recordings), the frequency was the lowest (6% of the recordings). Thus, the combination of elevated averages (average above 75 dBA) and highest frequency of events would indicate that the patient room was a primary source of excessive noise for the nurses.

When looking at nursing activities, employee communication was the primary source of noise (more than 50% of readings) and excessive noise (above 75 dBA) with discussions contributing to most of these interactions. While nursing communication is vital in the ICUs, it was also a primary source and a priority for interventions. One such intervention might be a better on-person communication system with a microphone and ear piece that would allow the nurses to communicate directly with other nurses at a lower volume. Training of nurses in soft tones, or installing sound dampening materials within the unit may also be viable interventions.

Another major source of noise (both frequency and above threshold) was in-room equipment, such as IV pumps, monitors, vacuum tubes, and televisions. While it was not surprising that this equipment were major sources, it was surprising that in-room equipment was not the primary source of the excessive noise. Alarms and operating noise for a given piece of equipment may not be excessive but when they are combined, the levels build on each other. For example, TV noise levels can be driven up by parents or patients turning up the volume above

the noise of the other equipment. Better designs for equipment that target noise abatement will likely be the best way to control this type of noise.

When analyzing and breaking down the distribution of the 5-minute interval above threshold data, patterns were identified that were very similar to the hand-held recordings. In general, while the trends were similar, there were many more instances of noise exceeding the 75 dBA levels for the 5-minute interval averages, indicating that the hand-held measures underestimated the threshold noise. Both methods were able to identify the trouble areas, sources, and activities in a similar manner, just having different frequencies of noise threshold counts. The ICU unit appeared to have little impact on the number of thresholds exceeded where all three accounted for between 23% and 39% with the NICU and CICU having the most thresholds exceeded (about 75% of readings observed were above threshold, see Figure 3.6). In all, the primary activities that exceed the thresholds were: employee discussions, procedures, and medical administration. As stated above, the locations that had the greatest number of excessive threshold values was the patient room, with the primary sources being staff conversations and in-room equipment. Doors closing and opening were not as prevalent for a source of excessive noise (less than 5%), which was contrary to what was expected. Now that the locations, activities, and sources have been identified, more targeted assessments can further isolate the source of the high noise levels.

While there were certainly activities, locations and sources that contribute to the noise levels that exceeded thresholds, one of the more interesting noise results was the high variability amongst the nurses where the number of observation exceeding the thresholds ranged from <10% to 100% . Even within a single unit, the noise levels varied between nurses, potentially indicating “hot spots” around the unit. This variability also indicated that the activities and

locations may play a major role in the exposure as different nurses likely completed different activities at different locations.

The heart rate findings indicated that ICU nurses had an average of >75 bpm which is well above the targeted heart rate of (60 bpm). While these readings were not recorded at resting, the values do indicate some level of demand and stress on the body. An elevated heart rate was particularly evident for the NICU where average values were closed to 92 bpm. While significant differences were not as prevalent as for noise levels, several interesting differences existed. First, the patient rooms had the highest heart rates (about 85 bpm) with the auxiliary rooms having the second highest levels (about 84 bpm). Second, the activity with the greatest heart rates on average was patient interactions. Third, communication with patient or family, doors opening/closing, and in room equipment appeared to be potentially linked to elevated heart rate. As a whole, these activities, sources, and locations may be linked to both elevated noise levels as well as heart rate.

To further investigate this relationship, correlations between noise level and heart rate as a whole and as a function of unit, location, activity, and source were analyzed. There are well-established classifications for correlations: mild (<0.39), moderate (0.40 to 0.69), and strong (>0.70). Based on these criteria, there was a mild correlation (0.264) between heart rate and noise when considering the overall data. One reason for the lower overall correlation was the low or negative correlations between heart rate and noise for 7 out of 18 nurses observed. Basically, there was 1/3 of the sample who have limited or no correlation between noise and heart rate. There were two factors, both of which relate to patient-nurse interaction, that had a moderate correlation between noise and heart rate. First, the highest correlation was found for patient interaction ($r=0.555$) with the second highest for the activity of communicating with patient or

family ($r=0.451$). The moderate correlation between heart rate and noise for these factors could have resulted from increase stress when interacting with patients, higher noise levels elevate heart, and other factors relating to patient-nurse interaction could result in elevated heart rate. Bottom line, a relationship appeared to be present between noise and heart rate when the nurse was actively involved with the patient.

Although none of the correlations were moderate to strong, there were several conditions where a significant “mild” correlation was found. For two of the ICUs, NICU and PICU, the correlation was around 0.15 with the other unit, CICU having no correlation (-0.07). This raises an interesting question about what makes the CICU so different from the other two ICUs with respect to the relationship between heart rate and noise. Several factors could influence this relationship: patient census, design of unit, and individual characteristics (e.g. genetics, stress tolerance, body weight, etc). Several other areas had mild correlations: gathering rooms and outside patient rooms which may be related to the interaction of the tasks and environment for these areas. Overall, noise appeared to slightly influence the heart rate and more likely would be an interactive affect with environment, stress levels, and individual characteristics.

With many of the readings of noise exceeding the EPA recommendations and WHO guidelines as well as the higher 75 dBA threshold used in the current study, some type of intervention in the form of equipment or behavioral modifications needs to be implemented. Solutions should aim to eliminate or reduce noise. Solutions may include: 1) modifications to equipment such as reducing the noise generated from monitors, IV pumps, feeding pumps, and vacuum tubes; 2) changes to visiting hours and/or number of visitors allowed aside patients’ bed, 3) re-design of nurses’ communication devices where alarms are replaced with vibration or visual cues and 4) redesign of the rooms to use noise absorbent materials and layouts. One of the

most important factors in controlling the noise levels might be ensuring that the nursing staff is aware of the sources of noise and how noise could be reduced or eliminated. Modifications in behavior will be the first line of action in controlling noise and the ill effects that result from noise.

While these results are preliminary and somewhat inconclusive with respect to the link between noise and heart rate, there are several limitations that need to be discussed to put these results into context. The greatest limitation of the study came from looking at heart rate as the only outcome variable. Heart rate is impacted by several factors; thus, it is hard to suggest a causal relationship exists that is completely isolated to noise. This might explain why mild correlations were found between noise and heart rate. Other health outcomes such as stress biomarkers, joint loading due to changes in muscle coactivation that has been found to accompany stress²⁰; and hearing loss may provide further evidence of the detrimental impact of excessive noise levels in the ICUs.

Another potential limitation of this study was too few subjects. Having a larger sample size could have provided a more conclusive relationship between noise and heart rate. Although the sample population was representative of hospital demographics, as predominately female, it did not allow measurement of difference in gender. Factors such as gender, age, race/ethnicity could influence the impact of noise on outcomes such as stress and heart rate.

Further, sampling biases could have been present since not all nurses in the three units were observed. Observing nurses for only a 4-hour period, instead of their entire shift may have caused an abbreviated exposure assessment. Additionally, the observations were limited to the weekdays. Since nursing tasks are highly sequenced and repetitive, sampling for a short period and not entire shift could have a potential for bias, causing an underlying reason for the subject

variability. Overall, the 4-hour period could have some bias but sampling strategy should minimize these concerns. The sampling strategy also focused on the unit level, which will minimize the individual bias that could have resulted.

To better understand the impact of noise on heart rate, future research should take into account subjects' race, diet, stress, family history, physical activity, tobacco/alcohol use, and medical history when trying to link increased noise to increased heart rate. A comprehensive study needs to build on the current results by including long-term measurement of noise, multiple health outcomes for both nurses and patients, and multiple measurements of noise and outcomes (e.g. prospective study). Such a study will lead to better understanding of the link of noise to adverse health effects by identifying specific sources.

5.0 CONCLUSIONS

The current study provides a snapshot of the noise exposure for ICU nurses. Several important results were found. First, in general, ICUs have significant amount of noise with almost 70% of the readings being above the 75 dBA level. The NICU and CICU were found to have the highest levels of noise exposure (on average about 80 dBA). The threshold of 75 dBA was also found to be routinely exceeded for these two ICUs (75% of the 5-minute intervals). The NICU also had the highest levels of heart rate. Other factors that impacted noise levels were located in the patient room, communicating with the patient, family members, and other nursing staff, and to a lesser extent doors opening and closing. The correlation results indicated a mild relationship between noise and heart rate with slightly higher correlations when nurses were communicating with the patient or parent. In all, the noise levels and the potential adverse health effects point to a need for implementation of effective interventions in the form of engineering controls or at the very least, administration controls—limiting exposures and requiring low level talking. On the practical side, the results provide insight into target areas for the controls such as conversations and in-room equipment. Finally, the results provided a stepping stone for future research to investigate better the sources of noise and the link of noise to other health outcomes.

Note Concerning Institutional Review Board (IRB)

It was determined, by the IRB, that this study did not meet the regulatory criteria for research involving human subjects, which indicated ongoing IRB oversight was not required.

Study ID: 2011-3269

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Appendix A: Investigator Developed Noise Log

FILL IN THE HOUR	:00	:05	:10	:15	:20	:25	:30	:35	:40	:45	:50	:55	Notes
Location													
Patient room													
Unit													
Pod													
Off unit													
Work station													
Medication Room													
Front desk													
Conference room													
Office													
Break room													
Pyxis Area													
Equipment alcoves/rooms(Linen Cart)													
Dirty Utility room													
Clean Utility room													
Kitchenette/Nutrition Room													
Doors													
Call Lights													
Other:													
Activities													
Assessments/interview													
Change of shift													
Participant holding pt.													
Admissions/Discharges													
Procedure													
Rounds													
MRT													
Code													
Environmental													
Medication Administration													
Parent/Pt. education													
Stocking Supplies													
Meal Tray Delivery													
Other:													
Noise Sources													
Patient crying/yelling													
Call lights													

Monitors													
IV Pumps													
Feeding Pumps													
Nurse Servers													
Pager/cell phone													
Staff conversations													
Family conversations													
Doors													
Overhead paging													
Icemakers													
Other:													