Sound Levels in the Neonatal Intensive Care Unit: What Are They?

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A thesis submitted in partial fulfillment of the requirements for the
Master of Science degree in Nursing

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Abstract

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Background

Premature and sick neonates are negatively affected by elevated sound levels in the Neonatal Intensive Care Unit (NICU). The American Academy of Pediatrics (AAP) recommends maximum sound levels of 45 decibels (dB).

Objectives

To measure sound levels in a level III NICU and to observe contributing environmental factors.

Methods

A descriptive quantitative study. Baseline sound levels were measured using a portable sound meter in the NICU and contributing environmental factors were simultaneously observed.

Findings

Mean sound levels were between 61 dB to 65 dB, 90% of the time. Contributing environmental factors: number of people, neonates, alarms, infant acuity, and shift type ($p < 0.05$). Multiple linear regression findings show observational data variables explain 14.5% of the sound levels in the NICU.

Conclusions

Sound levels were consistently high in the NICU and environmental factors contributed significantly to the sound levels. Further studies should evaluate interventions to reduce sound levels in the NICU.

Acknowledgements

As with any journey it begins with the first step. I would compare this master of nursing journey to climbing Mount Everest. It was long, hard, and extremely satisfying. Being a neonatal nurse for more than 25 years, has given me a unique and original perspective on the workings in the Neonatal Intensive Care Unit. It was this realization that I had urgent work to do, that inspired me to start preparations to begin the uphill climb back to graduate work in academia.

I choose to be in the master of nursing not because it is easy, but because it is hard, because the goal will serve to organize and measure the best of my energies and skills, because that challenge is one that I am willing to accept, one I am unwilling to postpone, and one which I intend to climb to the top of my nursing profession.

This journey would not have been possible without the approval of The Ottawa Hospital Research Institute (OHRI). Thank you for approving my proposal and helping me reach the summit. University of Ottawa Research Ethics was instrumental in funding the necessary equipment to carry out this important research, I am grateful for your generosity.

The mark of intelligence is being able to surround yourself with people who know more than you do. For this reason, I find myself in good company, as I have many people to thank who all had a hand in helping me complete this thesis.

First and foremost, I wish to express my deep gratitude to Dr. Denise Harrison for her Sherpa skills, who not only guided me, but often times illuminated the very dark path that I was walking. Your expert knowledge of research has enriched my learning experience. I am grateful for your mentorship. I would like to thank Dr. Janet Squires for her expertise of statistical analysis in providing meaning to the data. You are also a goddess of Knowledge Translation, and I appreciate all you have taught me. Dr. Sarah Lawrence you are a true visionary in the neonatal world. Your commitment to your patients through the promotion

research is inspirational. I cannot thank you enough for all the encouragement and assistance along this journey. Only a seasoned climber knows how to get to the top safely and swiftly. It is an honour to work with you, to collaborate with you, and to advance the care of babies in the neonatal unit with you. You lead by example. I would climb any mountain with you, anytime, anywhere. Janet Brintnell I would like to express my extreme gratitude for your devotion and unyielding support. You are the gatekeeper at base camp, who made me want to be a better nurse, and climb higher. I thank you for your commitment in caring for the babies in the NICU at The Ottawa Hospital.

To my dream team Cate and Tara, it has been an honour and a privilege to be a master nursing student with you. You have both kept me tethered to a lifeline, and saved my life more than once. Without you, this journey would have not been as meaningful. You have taught me the true value of friendship and academic excellence. Your knowledge and skills by far surpass your years. I am eternally grateful to climb this huge mountain with you.

Eric, Brian, Andrew, Vid, and Mark you are my computer Dalai Lamas. Thank you for helping me climb an almost impossible slope. Without you I would have been frostbitten.

Susan Gemmell I sincerely thank you for your shining light and your warmth. I am grateful for you teaching me the value of precise editing. Your skill is extraordinary.

Finally, to Derrick, Jordan, and Morgan Rose, the best family anyone could ever wish for. You are more than I deserve. I thank you for your support, and enthusiasm. Your encouragement helped me take every step forward on this journey to the top of my nursing profession. You remind me every day of how grateful I am to be alive.

It is my sincere wish that every baby be embraced in a delicate cloud of whispering love, as they are admitted to the Neonatal Intensive Care Unit. I wish that every baby could start their journey in this world and climb as high as they dare to dream. I have reached the summit in my academic journey, and I must say the view is spectacular!

Table of Contents

Tables

Figures

List of Abbreviations

AAP	American Academy of Pediatrics
BORN	Better Outcomes Registry Network
CPS	Canadian Pediatric Society
CHEO	Children's Hospital of Eastern Ontario
CIHI	Canadian Institute of Health Information
CIHR	Canadian Institute of Health Research
CSC	Canadian Safety Council
CSS	Canadian Sound Society
dB	Decibel
ELGA	Extremely Low Gestational Age
EPA	United States Environmental Protection Agency
EOIHP	Eastern Ontario Infant Hearing Program
HCP	Health Care Provider
IQR	Interquartile Range
IV	Intravenous
Leq	Equivalent Continuous Sound Level
KT	Knowledge Translation
KTA	Knowledge-to-Action
NICU	Neonatal Intensive Care Unit
NCPAP	Nasal Continuous Positive Airway Pressure
SD	Standard Deviation
TOH	The Ottawa Hospital
USA	United States of America
WHO	World Health Organization

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CHAPTER 1

Introduction

In Canada, about 8% of all babies are born prematurely at less than 37 weeks' gestation (Public Health Agency of Canada, 2013). Based on Canadian population size, prematurity is estimated to cost approximately $587 million nationally per year (Johnston, 2014). Premature infants are admitted to the Neonatal Intensive Care Unit (NICU) for emergency care and for life saving measures, as many are not developed enough to independently sustain their own life outside the intrauterine environment. Advancements in neonatal care now even allow a small percentage of 22-week gestational age infants to survive outside the womb (Moore, Lemyre, Barrowman & Daboval, 2013). While the survival rates for these medically fragile infants have increased due to the advancing technology in the NICU, excessive noise levels in the NICU have not decreased over the past 40 years (Eggertson, 2012; Casavant, Bernier, Andrews, & Bourgoin, 2017). However, treating these preterm neonates requires intense and stressful medical treatments (Zimmerman & Bauersachs, 2012) in an often noisy and brightly lit environment (Cruz, Fernandes, & Oliveira, 2016). As an environment designed to provide medical care to unstable infants, the NICU is equipped with specially trained staff, and advanced medical equipment such as monitoring and alarm systems, as well as cardiorespiratory equipment (Philpott-Robinson, Lane, Korostenski, & Lane, 2017).

This means that infants in the NICU are exposed to excessive sound, potentially 24 hours per day, for the duration of their hospitalization. As noise cannot be totally avoided in the NICU, it is important to examine the baseline sound levels and compare them to the recommendations for this vulnerable preterm population (Smith, Ortmann, & Clark, 2018; Chang, 2006; Darcy, 2008).

Background

The sound level recommendation of the American Academy of Pediatrics (AAP) is 45 dB (AAP, 2007). This noise standard was developed in 1974 by the United States Environmental Protection Agency (EPA). In 1997, the AAP used the EPA standard to create guidelines for sound levels in the NICU, arriving at a recommendation that the environmental noise level should not exceed 45 dB (AAP, 1997). This guideline is accepted by the Canadian Pediatric Society (CPS, 2004) and the World Health Organization (WHO, 1980) as the gold standard of sound level in the NICU. Several research groups have attempted to pressure the AAP to re-evaluate and update the current baseline standard of 45 dB, as this standard is consistently being exceeded, and some claim that it is unattainable (Smith, Ortmann, & Clark, 2018). One study reported that sound levels in the NICU exceeded the AAP recommendation of 45 dB more than 70% of the time (Darcy, 2008). To date, these researchers have not been successful in convincing the AAP to modify its standard sound level recommendation of 45 dB (Smith, et al., 2018).

Numerous studies of sound and noise levels in NICUs have reported that sound levels often exceed 120 dB (Casavant, 2017; Wang, 2014). In a systematic review of 20 studies evaluating noise in the NICU, it was found that many units have implemented sound reduction protocols, including: environmental redesign, reminders, scheduled daily quiet time, education, silencing alarms quickly, staffing ratios, and behaviour modification to reduce sound levels, thus promoting optimal environment for infant development (Casavant et al., 2017; Wang, 2014; Milette, 2010; Byers, 2006; Thear, 2006; Benini,1996; Strauch, 1993).

Sound and noise have been ongoing issues in hospitals for over 160 years. Florence Nightingale (1859) was quoted in her seminal work as saying: “Unnecessary noise, then, is the most cruel absence of care, which can be inflicted on either the sick or well.”

(Nightingale, 1859). In NICU nursing, the concept of developmentally supportive care is defined as the attempt to provide a structured care environment that supports, encourages, and guides the developmental organization of the premature or critically ill neonate (Coughlin, 2009). Research conducted in 1994 by the leading researcher in neonatal developmentally supportive care highlighted that an environment free of excessive noise decreased neonates' oxygen requirements, days on respiratory support, and length of hospital stay, thus improving developmental outcomes (Als, 1994, 2004).

What is Sound and Noise?

Sound is defined as a vibration in the air that has intensity, frequency, and duration (AAP, 1997). Noise is defined as a noxious sound that continues for a prolonged period of time (Casavant, 2017). Noise is an undesirable sound that interferes with communication, voice, or music, and that causes pain or disorder of the ear (Kawada, 2004). The pressure of sound or the intensity of noise is measured in decibels (dB), which uses a logarithmic scale (Rabinowitz, 2000).

Impact of Noise on the Preterm Neonate

Neonates are defined as newborns who are less than one month old. Preterm neonates are defined as infants born before 37 weeks gestation (BORN 2010). According to the Provincial Council for Maternal and Child Health in Ontario (PCMCH), (2013), the definition of a level III NICU is a unit that can care for all high-risk pregnancies, neonates with extreme prematurity (less than 32 weeks gestational age), with a weight of less than 1500 g, or who are critically ill, requiring continuously available personnel and equipment to provide life support for as long as necessary, and has either on-site surgical access services 24/7/365 or timely access (PCMCH, 2013). The Provincial Council for Maternal and Child Health (2013) along with the Better Outcomes Registry Network (BORN) Ontario (2012-

2013) standardized newborn levels of care definitions align closely with those of the Canadian Pediatric Society.

In utero, the fetus is accustomed to the sounds of the mother and is continuously exposed to the interior sensory environment; the rhythmic beating of the mother's heart, the wave-like motion of breathing in and out, the whoosh of blood moving through veins and the muffled sounds of the mother's voice (Moon, 2017). The fetus is exposed to sound levels in utero between 40-60 dB, which are of a low frequency as they are travelling through amniotic fluid to the unborn baby's ear (Hassanein, El Raggal, & Shalaby, 2013). The development of the auditory system begins early in embryonic life, and is a complex multistage process beginning at approximately nine weeks gestation (Schnupp, Nelkin, & King, 2011). From approximately 28 weeks' gestational age, the fetus can hear many sounds from the extrauterine world (Thomas & Uran, 2007). External sounds will be muffled by the mother's abdominal wall and masked by internal organ noises (Schnupp, Nelkin, & King, 2011). There is some evidence that suggests that the human fetus toward the end of pregnancy not only responds to but also can discriminate between different speech sounds (Shahidullah & Hepper, 1994). The transition from muffled quiet sounds inside the mother to life outside in the noisy NICU may be extremely stressful for the preterm neonate. The NICU environment may present an overload of sensory stimuli to the premature neonate, which can potentially alter their physiological responses and lead to behavioural changes (Philpott-Robinson et al., 2017). Excessive noise can negatively impact the physiological state, sleep patterns, growth, and neurodevelopment of neonates in the NICU (Romeu, Cotrina, Perapoch, & Lines, 2016).

For healthy growth and development, preterm neonates must adapt to life outside the uterine environment including: independent breathing, cardiac changes, thermoregulation, commencement of feeding, warding off infection, and maintaining physiological stability (McEwen, 2008). The developing neonate who is exposed to excessive noise during a critical

period may suffer short and long-term adverse effects (Allen, 2012; Cardoso, 2015; Trapanotto, 2004). A study by Wachman & Lahav (2010) reports on the physiological effects of excess noise on neonates in the NICU, stating that sustained noise in the NICU may lead to apnea, hypoxemia, alteration in oxygen saturations, increased oxygen consumption and may contribute to an increase in the calories required for adequate nutrition and growth (Wachman & Lahav, 2010). In addition, the electrical activity of the neonate's central nervous system has been noted to change in response to noise stimulation in the range between 36 dB and 90 dB (Wachman & Lahav, 2010). Excessive noise may also influence the neuroendocrine system and may have an indirect effect on immunity (Wachman & Lahav, 2010). The long-term effects of excessive sound levels may include increased risk of hearing impairment, which is diagnosed in 2% to 10 % of preterm infants versus 0.1 % of the general infant population born at term (Almadhoob, & Ohlsson, 2015). The exposure to sound levels above 45 dB may result in cochlear damage, resulting in hearing deficits in premature neonates (Bremmer, Byers, & Kiehl, 2006). According to some research, in the NICU neonates can be exposed to sound levels potentially as high as 120 dB (Casavant, et al., 2017).

The NICU environment is designed to provide intensive medical care to premature, sick, or unstable neonates. Monitoring equipment present in the NICU generally records vital signs such as heart rate and respiratory rate, blood pressure, oxygen levels and temperature of the infant (Philpott-Robinson, et al., 2017). Alarms will sound in response to changes in these vital signs outside of pre-set parameters, which are considered necessary to alert NICU health care providers (HCPs), and add auditory stimulation to preterm infants (Philpott-Robinson, et al., 2017). The advanced medical equipment such as isolettes, cardiac monitors, respiratory ventilators, alarm systems, as well as conversations between HCPs at the bedside during

multidisciplinary rounds and handovers, all contribute to the excessive sound levels and potentially can be considered noise.

As preterm and sick neonates spend weeks and sometimes months in a NICU, an environment filled with noise, “a culture of quiet” is critical for their growth and development (Casavant et al., 2017). Providing an optimal environment for growth and development may reduce the number of days neonates stay in hospital and may reduce negative long-term outcomes (Disher, 2017). The average length of stay in hospital of a preterm neonate less than 28 weeks gestational age is approximately 83.1 days (Canadian Institute for Health Information, 2005-2006). According to the Finance Department at The Ottawa Hospital (TOH), in 2018, the reported cost for one day in the NICU was approximately $6,900. Based on the average length of stay and the approximate cost per day, the cost of a NICU hospital stay could potentially be as high as $573,390. Therefore, the longer a neonate stays in the hospital the more cost incurred. A related study, examining the cost of implementing noise reduction protocols in the NICU, suggested that the cost is equivalent to $1.22 US per day to reduce 1 dB of sound (Swathi et al., 2014).

There have been many different strategies for reducing sound in the NICU. In a systematic review of 20 studies on the preterm infant’s response to noise, as well as evaluating noise interventions in the NICU, findings showed that many units have implemented sound reduction protocols, including scheduled daily quiet time, to improve infant development (Casavant et al., 2017). In response to the need for decreasing costs of care, while improving neonatal outcomes, there has been an emerging trend to revisit the way NICUs are environmentally designed (Disher et al., 2017).

Disher and colleagues (2017) found that single-room NICUs provided a more controlled, private environment, exposing infants to less noise and light. Infants in this more private environment had increased clinical stability (Disher et al., 2017). The systematic

review by Casavant concluded that staff education was critical to sustaining appropriate sound levels (Casavant et al., 2017). This review suggested that a "Culture of Silence," is warranted throughout each day and night to enhance infant growth and development (Casavant et al., 2017).

A Cochrane systematic review by Almadhoob & Ohlsson (2013), included a single, high-quality study, with 34 preterm infants enrolled in a randomized controlled trial (RCT) testing the effectiveness of reducing sound levels that reached the infants' ears in the NICU. This systematic review, to the best of our knowledge, was the first to evaluate the effects of sound reduction in the NICU and its effect on growth and long-term neurodevelopment outcomes of neonates. The use of earplugs in a NICU was the only noise reducing intervention that they could identify in a single RCT that met their inclusion criteria (Almadhoob & Ohlsson, 2013). Although the results were promising with the ear plug group versus no earplug group in very low birth weight infants showing improved growth at 34 weeks, the study concluded that recommendations for clinical practice could not be made based on the small sample size (n = 34) of this single study (Almadhoob & Ohlsson 2013).

In a study by Schell et al. (2006), researchers who studied the effects of pollution (including noise pollution) on human growth and development noted that noise was a stressor and that growth was reduced by excess noise exposure. Schell and colleagues concluded that birth weights among neonates have been shown to be reduced in relation to increased sound exposure (Schell et al., 2006). The researchers in the Schell study suggest that stress affects growth through the endocrine system. Schell stated that stress from noise activates the hypothalamic-pituitary adrenal axis, and causes growth inhibiting effects through the release action of corticosteroids (Schell et al., 2006). Premature birth or neonatal illness can restrict the infant's development of self-regulation and, as such, puts the infant at risk for adverse neurodevelopment outcomes (Verriotis 2016; Almadhoob & Ohlsson 2013). Pearlman and

colleagues discuss in their research that "constant noise" may act to impact on the developing brain of the neonate, even in the absence of overt hemorrhage or ischemia (Pearlman et al., 2001). There is also research to support that high sound levels affect not only the preterm and sick infants, but also the health of HCPs (Terzi, 2019; Sendelbach & Funk, 2013).

Sources of Sound in the NICU

The advancement of medical technology has led to the development of the modern day NICU, and has improved the survival rates of preterm infants. In 1996, the survival rate was 54% for infants born at 24 weeks' gestation, 82% for 26 weeks' gestation, and 95% for 30 weeks' gestation. The most up-to-date published report by the Canadian Premature Babies Foundation in 2014 reported survival rates that have increased to 59% for 24 weeks' gestation, 87% for 26 weeks' gestation, and 99% for 30 weeks' gestation.

Over the past decade, adverse outcomes, as defined by Canadian Neonatal Network (CNN) and Best Outcomes Resource Network (BORN), for Canadian preterm neonates were significantly reduced to 19.4% as a result of national quality improvement projects (Canadian Neonatal Network, 2017; BORN, 2012). However, although survival rates have continued to increase over the past decade, some researchers report sound levels in the NICU have not decreased with the advancement of medical technology (Casavant et al., 2017). Sound levels in the NICU are a direct result of the health care environment where multiple HCPs come together to provide lifesaving care to critically ill and premature neonates. Casavant reported that the noise is a by-product of this NICU environment. Sound and noise cannot be avoided in the NICU (Smith et al., 2018).

Both the American Academy of Pediatrics (AAP) and the World Health Organization (WHO) set standard sound levels, recommending levels for the NICU of 45 dB, with hourly sound levels not exceeding 50 dB 10% of the time and peaks of noise not exceeding a maximum level of 65 dB at any time (AAP, 2012; WHO 1980). It is significant to note that

sound in NICUs exceeds this recommendation, with sound levels reportedly sometimes exceeding 120 dB (Casavant et al., 2017). In Canada, research by Wang et al. (2013) examined the effects of a targeted noise reduction program in a NICU. The setting focused on a level III NICU in Ontario, Canada. This study examined baseline sound levels, and concluded that the unit consistently exceeded the guidelines, but that a reduction in sound levels was achievable. The authors further concluded that more work is needed to find the optimal NICU design and sound reduction strategy (Wang et al., 2014).

One source of sound in the NICU is the auditory alarms from the monitoring equipment. This critical equipment is responsible for measuring the physical variations and changes in the neonates' vital signs, including heart rate, respiratory rate, oxygen saturation, and blood pressure. Most times, the electronic monitors provide an auditory alarm to alert the HCP to act on behalf of the infant in distress. Although these alarms are necessary, they contribute to the sound levels in the NICU. The monitors ring an alarm outside the pre-set parameters. The setting of the alarm parameters is based on best practice guidelines and policies individualized in each tertiary care NICU.

Conversation between HCPs in the work environment further contributes to increased sound levels. The twice daily shift report, the multidisciplinary rounds performed at each bedside, the teaching of parents, sharing of vital information, and the social interaction, all contribute to the sound levels in the NICU. Another source of sound in the NICU is created by neonatal isolettes. Isolettes are heated, encased beds for premature or sick infants also known as incubators. The isolettes muffle exterior sound due to its construction of double walled Plexiglas. In addition, blankets are often placed over the isolette as a means to further reduce sound for the infant inside. Noise inside the isolette was studied by Zacarias and colleagues (2018), using a comparative study of three models of incubators, all considered to be the least noisy on the market. The three incubators studied differed significantly in noise

insulation from the external environment; continuous sound levels of 53.5 dB to 58 dB were, measured inside the incubator, and external noise was only reduced by 5.2 dB to 10.4 dB (Zacarias et al., 2018). The results of this research concluded that preterm infants in an incubator were exposed to sound levels greater than 45 dB but less than 65 dB, thus exceeding AAP recommendations. They also concluded that with the incubators turned off, if the background sound on the outside does not exceed 45 dB, internal sound will roughly coincide with background sound outside the incubator.

Noise Reduction Strategies in Current Practice

A study by Swathi et al. (2014) examined the adherence of HCPs to behavioural modification of a sound reduction protocol to reduce noise levels. Sound levels were assessed in this study before and after the implementation of sound reduction protocols. The study was conducted in a resource-limited level III NICU of a tertiary care hospital in south India. The NICU census was 36 neonates, and interviews were conducted with 32 staff members including nurses, nurses' aides, and physicians. Firstly, the main strategies used in this study were building awareness momentum, causing awareness percolation, developing a sense of ownership, expansion of caring practices, evolution of adherence, and displaying performance indicators for sound reduction in the NICU (Swathi et al., 2014). The authors found that the main strategies used by the HCPs to ensure adherence to behavioural modification components were identified as core categories for sound reduction protocol. Building awareness and developing a sense of ownership of sound reduction strategies through the expansion of caring practices were key behaviour strategies (Swathi, 2014). Additionally, the authors tried to expand the study's results by developing a theoretical model of a substantive theory to explain how HCPs of a limited resource NICU adapt their practice while maintaining reduced sound levels and supporting a developmentally supportive environment of quiet (Swathi, 2014).

Four of the 20 studies in the Casavant systematic review, from Canada, Brazil, United Kingdom (UK), and the United States of America (USA), also assessed NICU environments to identify areas of increased noise and then implemented noise reduction protocols in the NICU with reduction of sound levels reported in their results. All four of these studies supported the cost-effective impact of staff education and environmental modification on neonatal health (Casavant et al., 2017). The study entitled "Striving for Optimum Noise-Decreasing Strategies in Critical Care," by Disher et al. (2017) outlines potential barriers to reducing noise. This study was a qualitative research project conducted within two units of a 27-year-old tertiary care, level III NICU in Nova Scotia, Canada. The investigators conducted semi-structured interviews with nurses, physicians, allied health professionals, unit support staff, trainees, and parents of preterm or sick neonates. One issue that emerged was sound generated by the need for critical care. Although the interviewed groups identified that alarms needed to be loud for safety reasons in the NICU, it was noted that some staff do not consistently silence alarms quickly. Another issue that emerged from this study was that the staff felt that the sound generated by conversations about critical clinical care was not 'noise,' because it was required for the delivery of care. This highlights that the perception of noise is subjective. According to interviews conducted by Disher, HCPs feel that the sounds generated by conversations are justified. Disher and colleagues identified the barrier, that sound levels were perceived to be positively associated with acuity level of the neonate. Equipment-generated sounds were perceived as being associated with staff talking louder to overcome the ambient sound (Disher, 2017).

A strategy for the reduction of sound levels is of scheduled daily quiet time in the NICU. Quiet time is an established period of time during the day in which there is an active effort to reduce noise, light, and infant handling. The purpose of quiet time is to allow infants an opportunity to rest, heal, and grow. During this time the lights are dimmed, window blinds

are drawn, there is minimal handling, and minimal stimulation and only essential activities are allowed. Parents and visitors are permitted to visit, but are asked to speak in whispered voices. Studies have demonstrated that implementing scheduled daily quiet time in the NICU have a significant impact on reducing sound levels as well as engaging team members in promoting a developmentally supportive culture of quiet (Wang, et al., 2017; Crawley, & Emery, 2006; dos Santos et al., 2015; Laubach, 2014). A Canadian study by Wang et al. (2013) examined the effects of a targeted noise reduction program in a NICU. The study found that the implementation of quiet time from 1330-1500 hours showed a statistically significant decrease in sound levels in their level III NICU with a median difference in noise level in each shift between quiet time and the 90 minutes preceding of 0.12 dB ($p= 0.01$). Although this is a small difference, it is clinically significant because a difference in 3 dB is a doubling of sound levels, therefore this result shows with a scheduled quiet time a lowering of sound level can be achieved. An additional mixed-method study by Laubach and colleagues (2014) evaluated the implementation of quiet time throughout the day at random times to reduce sound levels. The authors concluded that implementation of quiet time guidelines for extended periods was instrumental in achieving sound levels below the national recommended safe sound level. The change in operational practices needs to be reinforced on a continual basis in order to improve sound levels according to Laubach and colleagues. Operational sound practices are both simple and cost-effective practices that the staff have the ability to control and to reduce sound levels in the NICU (Laubach et al., 2014).

Successful sound reduction strategies found in the literature also include positive feedback provided to the staff, with the goal of minimizing sound levels in the infants' environment (Hassanein, El Raggal, & Shalaby, 2013). Ahamed and colleagues (2018) concluded that the biggest breakthrough in sound reduction was achieved when HCPs,

identified as “Noise Monitors,” were assigned for each patient care area, in each room of the NICU. These “Noise Monitors” were staff members responsible for monitoring sound levels and reminding others when sound levels exceeded the acceptable levels (Ahamed, Campbell, Horan, & Rosen, 2018). Wang and colleagues studied noise reduction in the NICU using a sound-activated noise meter (Wang et al., 2014). The stationary, sound-activated noise meter called “SoundEar,” provides direct visual feedback; It was positioned in four different private patient areas in a level III NICU. Sound levels were compared over a two-month period with a stationary noise meter where the machine was activated and delivered direct visual feedback, with a two-month period when a stationary noise meter where the machine did not provide any direct visual feedback. The researchers concluded statistically that the sound meter providing visual feedback was effective in significantly reducing sound levels in the NICU, compared with having the sound meter present but not providing visual feedback during both noisy and quiet periods. The change in noise level in dB at 95% CI was reported as -1.06 (-1.52 to -0.6), $p = 0.001$. The limitations of this study were that sound levels were not measured at the baby’s ear, and that noise meter feedback parameters were set above the recommended 45 dB level.

A systematic review of 12 studies, by Shahheidari and Homer, (2012) examined NICU environmental design, comparing single-family rooms to the open-bay (defined as having multiple neonates cared for in a single room, in an open space, without fixed partitions or walls between them) design. The conclusions were that single-family rooms are quieter environments for preterm infants, and may improve health outcomes compared with open-bay room NICUs (Shahheidari & Homer, 2012). A limitation of this systematic review is that the authors did not conduct quality assessment, meaning most of the studies in the systematic review were conducted in USA, and although their results are generalizable to other developed countries, more research is required to address specific contexts and settings

(Shahheidari & Homer, 2012). The level of evidence in the available studies were not high, as many of the studies were before and after studies, which have the potential for bias (Shahheidari & Homer, 2012). Domanico and colleagues reported a cohort study with positive effects on apnea-prone preterm neonates less than 36 weeks' being cared for in single-family rooms versus neonates in open-bay rooms, which showed a highly significant 57% reduction in total apnea events, which persisted after normalization for differences and correction for conventional mechanical ventilation times (Domanico et al., 2010). More recently, Disher and colleagues reported that single-room NICUs provided a more controlled, private environment which may encourage parental presence and involvement in care and exposes neonates to less noise and light (Disher et al., 2017).

In summary, a variety of strategies for decreasing sound levels in the NICU have been discussed in the literature (Casavant et al., 2017; Disher, 2017; Swathi et al., 2014; Wang et al., 2014; Laubach et al., 2014). Sound reduction strategies, such as promoting a "culture of quiet," through education, reminders, environmental redesign, silencing alarms quickly, consistently scheduled daily quiet hour, and stationary noise meters with real-time visual feedback, are currently in practice in many NICUs globally.

Theoretical Framework

A theoretical framework is the conceptual underpinning of a study, including an overall rationale and conceptual definitions of key concepts (Polit & Beck, 2017). Theoretical frameworks are a collection of interrelated concepts, that can be used to guide research, inform what is measured, and define what statistical relationships are being explored. According to Field and colleagues they define the concept of theoretical frameworks as a scientific way of applying theory to enhance implementation of knowledge creation and action (Field et al., 2014). The Knowledge-to-Action (KTA) framework was developed in Canada by Graham and colleagues (2006), and is the framework used by the Canadian

Institute of Health Research (CIHR, 2012) for the transfer of research findings into practice. It can be broken down into two concepts: knowledge creation and the action cycle (Graham, et al., 2006). The KTA framework was used to inform this thesis. This framework was considered applicable because it is perceived that gaps currently exist between knowledge and action in terms of adhering to recommended maximum sound levels of 45 dB in the NICU across all end users and decision makers including patients, HCPs, managers, and policy makers. The KTA gap is commonly interpreted as knowledge that is not used because there has been a failure to transfer it effectively to the intended audience (Bowen & Graham, 2013). The KTA framework offers a systems perspective, within the model and adaptation of research evidence, taking local context and culture into account (Graham & Tetroe, 2010). This framework integrates the concepts of knowledge creation and action (Graham & Tetroe, 2010). The KTA framework is a conceptual framework that provides an approach to build on the commonalities found in an assessment of planned action theories, and as such is a model for Knowledge Translation (KT) (Straus, Tetroe, & Graham, 2013). KT is defined by the CIHR as a dynamic and iterative process that includes synthesis, dissemination, exchange, and ethically sound application of knowledge to improve the health of Canadians, provide more effective health services and products, and strengthen the health care system (CIHR 2016). The ultimate aim of KT is improved health and health care (Graham & Tetroe, 2007). Knowledge creation includes knowledge inquiry, knowledge synthesis and creation of knowledge tools and/or products. When knowledge moves through each phase of the knowledge creation part of the framework, the resulting knowledge becomes more useful and synthesized for end-users. The action cycle includes the following multiple bi-directional steps: identification of the problem; determine the know/do gap; identify, review select knowledge; adapt knowledge to local context; assess barriers/facilitators to knowledge use; select tailor, implement interventions; monitor knowledge use; evaluate outcomes; sustain

knowledge use (Straus, Tetroe, & Graham, 2013). The primary purpose of KT is to address the gap between what is known from research, knowledge synthesis, and implementation of this knowledge by key stakeholders, with the intention of improving health outcomes (Graham et al., 2006). By applying the KTA framework in this research project, existing sound levels in the NICU were collected as a baseline measurement and compared with the known recommended sound levels of 45 dB, thereby contributing to knowledge creation, the first part of the KTA cycle. This knowledge can then be used in a future study aimed at putting the knowledge into action, informed by the remainder of the action cycle of the KTA framework.

This thesis study was intended to measure baseline levels of sound over different shifts in a level III NICU, and to identify contributing factors in determining how close the unit is to reaching the recommended guidelines of 45 dB. This new knowledge may provide a starting point for the development of future research in planning interventions in the reduction of sound levels while also providing current knowledge for HCPs through the dissemination of the results. Comprehensive baseline sound levels compared with observational data collection had not been studied in the target NICU, thus making this research important in order to fully understand current sound levels. It is hoped that this sound level audit will be a catalyst for discussions around practice, policy, research, and education.

CHAPTER 2

Methods

The purpose of this chapter is to describe the methods used in this thesis to answer the research question including: identification of the research question, specific objectives, study design, setting and participants, measurement tools, assessments and measures, quantitative data analysis, and conflict of interest.

Research Question

What are the sound levels in a Canadian level III NICU, and what are the contributing factors to excessive sound?

Objectives

There were three components that apply to the specific objectives which were firstly to collect sound levels, secondly to compare the sound levels to recommended guidelines of 45 dB, thirdly to collect observational data for identification of the influencing factors contributing to increased noise in the NICU.

Significance of This Study

This study was conducted to ascertain previously unknown baseline sound levels in the level III NICU. Understanding these levels and contributing factors are the first steps of the KTA framework, in terms of knowledge creation. These baseline data will inform future KT studies, which has the potential to improve outcomes of preterm and sick neonates in the NICU, and also has the potential to impact NICUs globally.

Study Design

This study is a descriptive, quantitative, non-experimental design.

Setting and Participants

This observational study was conducted in the level III NICU at The Ottawa Hospital (TOH), General Campus, located in Ottawa, Ontario, Canada. TOH is located in the capital

city of Canada, and provides services to the National Capital Region as well as receiving referrals from a wide catchment area including Quebec and the Far North. TOH serves an urban population and provides tertiary referral perinatal services. It is the primary regional perinatal centre for Eastern Ontario, with an active referral network and high-risk delivery service. As a result, both the patient volume and acuity are high. The unit has a total capacity of 24 infants. The majority of neonates in this NICU are preterm, requiring intensive supportive care.

The study took place in TOH NICU Room A, which is considered to be an open-bay room. An open-bay room is defined as having multiple neonates cared for in a single room, in an open space, without fixed partitions or walls between them, in a confined area, and with multiple HCPs and families present (Disher, 2017; Stevens, 2015; Shahheidari & Homer, 2012). The room is equipped with up to eight beds/isolettes and also a resuscitation overbed for emergency admissions. Room A is divided into two sections by a partial wall (see Appendix A). Most of the neonates cared for in this room are either mechanically ventilated or on nasal continuous positive airway pressure (NCPAP), and are considered the most acute and premature of the neonates in the NICU. The equipment available at each bedside consists of a cardiac monitor that measures heart rate, respiratory rate, blood pressure, and oxygen saturation. This medical equipment is set with predetermined low/high parameters specifically for the preterm neonate and will alarm when readings outside of these pre-set parameters are detected. The equipment allows users to override the pre-set parameters for a period of three minutes to temporary silence alarms. At each bedside there may also be an in-wall suction, in-wall oxygen, a drawer of supplies, an isolette, a ventilator/NCPAP, and intravenous pumps.

There is a central monitoring station in Room A is near the cupboard that stores opioid analgesics. The central monitoring consists of a large computer screen with visual and

auditory display of all of the cardiac and respiratory monitors that are active in the entire unit, and alarms from each. The central monitoring station was installed and tested during the observational data collection period. There is one designated emergency resuscitation overbed, with lifesaving equipment, supplies, and medicines. Resuscitation and stabilization of the majority of vaginally born preterm neonates requiring emergency medical interventions takes place on this overbed, often with a large team of HCPs. X-rays, ultrasounds, and echocardiograms are required frequently in this preterm, critically ill population. Each type of examination requires that a large portable machine be brought into the NICU as well as additional staff to conduct the tests. Eye exams tests are also done at the bedside by specially trained HCPs. An office for the neonatology physicians/residents is located adjacent to NICU Room A, and the door to this room is often open, allowing conversations to contribute to the sound levels. The birthing rooms are adjacent, although separated by a secure fire door that is kept closed most of the time. A blanket warmer is located beside the emergency overbed, and this is accessed by all staff of the unit. This section of Room A also contains a refrigerator used for storage of intravenous medications and injectable drugs, which also may be accessed by all staff of the unit. There are two computer work stations in Room A. There are five sinks with manual paper towel dispensers attached to walls. The parents of infants in the NICU are invited to remain at the bedside 24 hours a day. Nurses are present at the bedside to give nursing care over two 12-hour shifts (0700-1900 and 1900-0700), with nurse patient assignments of 1:1, 1:2, or 1:3, depending on the acuity of the infant.

Infant acuity levels are assigned on a daily basis for all infants in the NICU, on a scale of 1-3. Infant acuity Level 1 is assigned to an infant greater than or equal to 36 weeks and 0 days requiring continuing care. Continuing care is defined as care of an infant requiring oral or nasogastric feedings, occasional enteral feedings, and/or basic monitoring, phototherapy,

management for a limited duration complication such as transient tachypnea of the newborn, antibiotic prophylaxis, hypoglycemia, and feeding difficulties. Infant acuity Level 2 is assigned to an infant greater than or equal to 34 weeks and a birth weight greater than 1800 g with a mild illness expected to resolve quickly. These infants require special care and who are convalescing after intensive care. These infants often require nasal oxygen with oxygen saturation monitoring (acute or convalescing). These infants often require an initiation and maintenance of a peripheral intravenous, and often require gavage feedings. Infant acuity level 3 is assigned to an infant of any gestational age or weight requiring mechanical ventilation support including high frequency and possibly inhaled nitric oxide. Infants in this acuity level are those who often require comprehensive range of subspecialty consultants. When acuity level is above level 3, infants are transferred to speciality children's hospitals for surgical intervention (Provincial Council for Maternal and Child Health Standardized Levels of Care Definitions, updated August, 2013).

There is vinyl linoleum floor and no carpeting in the NICU. The ceiling is made of a solid painted surface with visible air vents, the walls are made of standard construction materials of concrete block. No sound absorbent materials are visibly present. A stationary sound meter, named "SoundEar 2" (Inspiration Healthcare) is currently in operation in the room and is attached to the partial wall separating the two sides of the room. This sound meter provides visual feedback in the form of a lighted image of an ear of different colours, depending on the sound level. The sound meter covers an area of 30 m^2. This device model has no external download capability. The threshold for the sound meter was set at 45 dB: when sound levels are detected above this level, the meter will display a red ear image; when sound levels fall to within 5 dB below the threshold, a yellow ear image lights up; and at sound levels of more than 5 dB below threshold, the meter will display a green ear image.

Assessments and Measures

Data collection consisted of both sound level and observational measurements. These measurements were recorded over 21 different time periods: seven days, seven nights, seven evenings. In order to best reflect the realities of nursing practice, the 21 time periods were divided into the following shifts: seven day shifts from 0600-1400; seven evening shifts from 1400-2300; and seven night shifts from 2300-0600. No identifiable patient or HCP information was collected.

Measurement Tools

Sound levels during the pre-set time periods, observational data collected about the general activity of the NICU, as well as the overall NICU patient census data were collected hourly during the time periods. For sound levels, a portable sound meter, Casella Model CEL242-K, along with the acoustic calibrator Casella CEL-120 were used for data collection. This is a Type 2 noise meter that measures fast and slow sound levels with "A" and "C" frequency weightings. The CEL242-K stores the sound level every second to its internal memory. It also stores a summary of the measurements including start time, date, measurement duration, and maximum sound level. Software to download measurements was purchased from the supplier and measurements were downloaded directly into Excel. Reliability of this sound meter was assured by the calibration done by the company as per the industry standards. In addition, calibration of the portable sound meter prior to and post data collection was carried out twice daily.

The Biomedical Engineering department at The Ottawa Hospital was consulted to assess and approve the new sound meter for use in the NICU, and support the functioning of equipment and downloading of data. Measures to ensure infection control guidelines were met, by cleaning the meter and calibrating instrument with disinfecting solution prior to and post data collection.

For each time period of the study, the sound meter was positioned in exactly the same location, in Room A in the NICU, midway between both sides of the partial wall, in an unobstructed location. The sound meter was attached to a tripod for 360-degree sound recording on a portable stand with wheels to facilitate ease of movement in the case of an emergency.

To ensure consistency in data collection, a research protocol for set-up procedures was developed. All the steps in the protocol were followed each shift and were documented in the field notes. Details about date, day of data collection, pre/post calibration, low/high parameters, sound level run number, battery level, when batteries were changed, were collected in field notes for each shift. The set-up research protocol consisted of: disinfecting all equipment with alcohol based cleanser, powering up, acoustic calibration check and documentation of parameters, insertion of microphone, switching the calibrator "on," pressing the "level," button to select 114 dB, setting the meter to the correct range of low and high limits, waiting 3 seconds for the output to settle, removing the calibrator from the microphone and switching the calibrator "off," attaching the sound meter to the tripod, pressing "on" to begin recording sound levels, placing the tripod in same location on portable cart with wheels, setting a stop watch for 60 seconds count down for observational data collection each top of hour. At the end of each 8-hour time recording period, the acoustical calibration was rechecked by: inserting microphone into calibrator, pressing "on," to switch calibrator to on, pressing "level" to select 114 dB, setting meter to correct range of low- and high-level parameters, waiting 3 seconds for output to settle, recording calibration parameter in field notes, removing the calibrator from the microphone and switching "off," disinfecting all equipment with alcohol based cleanser and placing the sound meter and calibrator in protective case for transport.

At the beginning of each hour, the hourly data collection commenced, using the clock on a smart phone to ensure the accuracy of the hourly periods. A sole researcher was present for each period of data collection and remained with the sound meter the entire time, except for biologic breaks, when a staff member was asked to watch the sound meter. At no period in time was the sound meter unattended. Sound measurements continued for the entire shifts of data collection and did not stop until the end of the shift. A second calibration of the noise meter occurred at the end of the shift to ensure consistency of data, and recorded in field notes. For observational research to be meaningful, scientific observation must be consistent with the specific objectives of the study; there must be a standardized and systematic plan for the observation and recording of the data; all observations must be checked and controlled; and the observations must be related to scientific concepts and theories (Lobiondo-Wood & Haber, 2013). The observational method used in this research was no concealment without intervention. The researcher is neither concealed nor intervening. The researcher made no attempt to change participants' behaviour at any time during data collection period. HCPs in the NICU were informed by email that sound and observational data would be collected on specific dates and periods of time. Observational data were simultaneously collected each shift, along with sound measurements. Details were collected about the infants' acuity level, number of neonates in the room, the number of people, the number of alarms, the number of IV pumps, the number of suctioning events, the number of emergency events, and any extra events.

During the data collection period, the researcher did not engage people except to greet them when spoken to. The researcher did not initiate conversations nor contribute to the sound in any manner during data collection. If people spoke to the researcher, a whisper voice volume was used to answer the question and a conversation happened away from the sound meter in another room, while keeping the noise meter within eyesight. In order to

reduce sound in the vicinity of data collection, the researcher set up and calibrated the equipment prior to turning on the sound meter at the beginning of each hour.

An observational data collection tool (Appendix B) was used to collect NICU unit information hourly. Observational data collection was performed by the researcher recording events on a clipboard while sitting on a portable chair. The numbers of HCPs and parents present in the room were recorded separately on the data collection sheet, but later were combined in a final category of total people. Multidisciplinary rounds, consisting of an attending neonatologist, a neonatal fellow, several pediatric residents, elective medical students, registered nurses, nurse clinical leader, pharmacist, nutritionist, and respiratory therapist, was conducted at each neonates' bedside during the data collection period each morning. The neonates' parents were invited to attend these rounds as well. Nurses contributed verbally to multidisciplinary rounds as well as at shift handover at the end of each shift from the bedside. Parents were identified by wristbands provided by the hospital for identification. Observational data were also collected during key times that occurred over the duration of the 8-hour sound measurement periods: on multidisciplinary rounds, during admissions, and during emergency procedures. The level of neonate acuity was recorded (see "Setting and Participants," above, for a description of the neonate acuity levels). The number of ventilators or NCPAP machines in use at the time of measurement was counted and recorded on the observational data collection sheet. The number of monitor alarms, number of suctioning events, and number of emergency events at the time of measurement was counted every hour on the hour for 60 seconds using a smart phone stopwatch to ensure accuracy, and was recorded on the observational data collection sheet. Emergency events are defined as any event that occurred unexpectedly, was urgent or critical in nature, that required the assistance of at least one other HCP, and deviated from normal neonatal care. No

individual patient data were collected. Sound data were downloaded using Microsoft Excel Version 16.16.13. (Microsoft Corporation, 2018).

Quantitative Data Analysis

Sound data were exported from the sound meter using the proprietary software (Noisemeter Casella CEL242-K) into Excel spreadsheets. Sound levels were recorded every second as A-weighted equivalent sound measurements (dBA). Equivalent continuous sound level measurement (Leq) was used for analysis. Leq or equivalent continuous sound levels are used because sound levels often fluctuate over a wide range of time. Leq describes sound levels that vary over time, resulting in a single decibel value which considers the total sound energy over the time period of interest. Therefore, for the purpose of analysis, the dB sound measurement that was downloaded was used for evaluation and to compare to the guidelines of the AAP.

Sound level results were compared with the 45 dB maximum recommended by the AAP. The average sound levels were the dependent variable in the study and this was correlated linearly to the NICU observational data collection. Depending on the distribution of the data, mean differences and standard deviations (SDs) of sound levels, or medians and IQRs at different time periods were compared. Run charts were created to visually show the sound measurements plotted over time, related to the significant observational data collected. The run chart test was a test for non-random variation of consecutive data points that occurred either above or below the median with a $p < 0.001$; 95% confidence interval.

The IBM SPSS Statistics 26 (IBM, 2019) software program was used for the analysis of the sound level data. To address the factors contributing to the sound levels in the NICU, descriptive statistics were calculated for each group of days, evenings, and night shifts. In each group the mean, median, SD, interquartile range (IQR), and range, were compared.

Multiple linear regression was used to analyze events contributing to sound levels. Multiple regression is a statistical procedure for understanding the relationship of two or more independent variables (Polit, 2010). In multiple linear regression certain assumptions must be met: the dependent variable must be an interval or ratio; multivariate normality must be demonstrated (each variable and all linear combinations are assumed to be normally distributed); linearity must exist such that there is a straight line relationship between pairs of variables; there must be homoscedasticity where variability in scores for one variable are similar at all values to another variable; and finally, there must be independence of errors, where errors of prediction are assumed to be independent of each other (Polit, 2010). Multivariate linear analysis is statistically powerful because it shows the strength of the relationship. Betas were used as the standardized coefficient indicating the weight of the predictor variable expressed as a standardized z score in the regression equation.

There are two hypotheses to consider: the Null Hypothesis is that there is no relationship between the sound levels in the NICU and the number of neonates, the number of people, the number of alarms, infant acuity level, and shift type when considered together as a group of variables. The research hypothesis is that there is a relationship between the sound levels in the NICU and the number of neonates, the number of people, the number of alarms, infant acuity level, and shift type, when considered together as a group of variables. The data were examined for influencing factors contributing to sound levels in the NICU (number of neonates, number of people, number of alarms, acuity level, and shift type). The regression equation proposed was therefore: $Y= b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4 + b_5 X_5$. To explain this formula: where "Y" equals the predicted value for the dependent variable (sound levels); "b_0" equals the intercept; "X_1 to X_5" equals the values for the independent variables (number of neonates, number of people, number of alarms, acuity level, and shift

type); "b_1 to b_5" equals the regression coefficients for the independent variables listed above (Polit, 2010).

Independent Variables

For variable **b_1 (the number of infants):** The Null Hypothesis is that there is no relationship between the sound levels in the NICU and the number of infants, when controlling for b_2 (number of people), b_3 (number of alarms), b_4 (infant acuity), and b_5 (shift type) taken together. The Alternate Hypothesis is that there is a relationship between the sound levels in the NICU and the number of infants when controlling for b_2 (number of people), b_3 (number of alarms), b_4 (infant acuity), and b_5 (shift type), taken together.

For variable **b_2 (the number of people):** The Null Hypothesis is that there is no relationship between the sound levels in the NICU and the number of people, when controlling for b_1(number of infants), b_3 (number of alarms), b_4 (infant acuity), b_5 (shift type). The Alternate Hypothesis is that there is a relationship between the sound levels in the NICU and the number of people when controlling for b_1 (number of infants), b_3 (number of alarms), b_4 (infant acuity), and b_5 (shift type), taken together.

For variable **b_3 (the number of alarms):** The Null Hypothesis is that there is no relationship between the sound levels in the NICU and the number of alarms, when controlling for b_1 (number of infants), b_2 (number of people), b_4 (infant acuity), and b_5 (shift type). The Alternate Hypothesis is that there is a relationship between the sound levels in the NICU and the number of alarms when controlling for b_1 (number of infants), b_2 (number of people), b_4 (infant acuity), and b_5 (shift type), taken together.

For variable **b_4 (the infant acuity):** The Null Hypothesis is that there is no relationship between the sound levels in the NICU and the infant acuity level, when controlling for b_1 (number of infants), b_2 (number of people), b_3 (number of alarms), and b_5 (shift type). The Alternate Hypothesis is that there is a relationship between the sound levels

in the NICU and the acuity level when controlling for b_1 (number of infants), b_2 (number of people), b_3 (number of alarms), and b_5 (shift type), taken together.

For variable **b_5 (the shift type):** The Null Hypothesis is that there is no relationship between the sound levels in the NICU and the shift type, when controlling for b_1 (number of infants), b_2 (number of people), b_3 (number of alarms), b_4 (infant acuity). The Alternate Hypothesis is that there is a relationship between the sound levels in the NICU and the shift type when controlling for b_1 (number of infants), b_2 (number of people), b_3 (number of alarms), and b_4 (infant acuity), taken together.

Each variable was recoded into a dichotomous variable to contrast factors in one category with the other variables (see Table 1). The details of the multiple linear regression matrix and how it relates to the β and the p-values of each of the independent variables (see Table 4). With the independent variables in this study, there were more than two categories within each independent variable. Categories were created to represent newly coded variables to represent the original coded variable, where the number of the original categories minus one represents the new category (Polit, 2010). The recoded variables were created for all the above listed independent variables to contrast the factors in one category with that of the dependent variable of sound levels. The rationale recoded variables must be dichotomous variables is because linear regression will treat the categories as ordered continuous if you do not. The multiple linear regression model treats all data as a mean unless you break down the data.

For the variable **X_1 (the number of people):** the recode used for number of people, "0" was used to code for no person; and "1" was used to code for one person or more. The rationale for this is in order to interpret the results, putting X_1 (number of people) into two levels, the categorical variable may be directly entered as a predictor or predicted value in multiple linear regression model. The regression weight is either added or subtracted to the

predicted value of Y (dependent variable) depending upon whether it is positive or negative. For the variable **X_2 (the number of neonates):** the recode used for number of neonates, "0" was used to code for no neonates; and "1" was used to code for one neonate or more. For the variable **X_3 (infant acuity):** the recode used for number of alarms, "0" was used to code for no infant acuity; and "1" was used to code for 1 infant acuity or more. For the variable **X_4 (the number of alarms):** the recode used for number of alarms, "0" was used to code for no alarms; and "1" was used to code for one alarm or more. For the variable **X_5 (the shift type):** the recode used for shift type, "0" was used for day shift (0700-1900); and "1" was used for night shift (1900-0700). Table 1 was created to identify the new variables used in comparison of the indicator variable with the explanatory variable and summarize each with descriptive statistics. The values will be reported in results (see Table 4).

Table 1.
Recoding of Sound Levels: Dependent Variable and Independent Variables

Indicator Variable					**Explanatory Variable**
X_1 Number of People	**X_2 Number of Neonates**	**X_3 Infant Acuity**	**X_4 Number of alarms**	**X_5 Shift Type**	
1	**0**	**0**	**0**	**0**	**Number of People**
0	**1**	**0**	**0**	**0**	**Number of Neonates**
0	**0**	**1**	**0**	**0**	**Infant Acuity**
0	**0**	**0**	**1**	**0**	**Number of Alarms**
0	**0**	**0**	**0**	**1**	**Shift Type**

Note: Drafted as a correlation table. Each variable was recoded into dichotomous variable.

Ethics

A research ethics boards (REB) application was submitted to The Ottawa Hospital Research Ethics Board (TOH-REB), and approval was received on February 2, 2019 (see Appendix C). Research ethics was then submitted to University of Ottawa Research Ethics Board, and approval was received on March 4, 2019 (see Appendix D).

Conflict of Interest

It must be noted that the principal investigator and MScN candidate is a Registered Nurse employed in the NICU at TOH, thus bias may be present due to a possible conflict of interest for the principal investigator who is an employee of the hospital NICU in which the research is being conducted.

CHAPTER 3

Results

Sound Level Results

Data collection began on March 31, 2019 and ended on May 8, 2019. A total of 21 shifts where sound measurements were collected and monitored every second (seven-day shifts, seven- evening shifts, and seven-night shifts) resulting in 604,800 measurements of sound collected and recorded for analysis. Data were analyzed for only five of the day shifts, because the noise meter CEL 242-K was initially calibrated too high (factory pre-set low and high parameters were 60 and 130 dB respectively) by the manufacturing company. This resulted in numerous empty cells in the output of sound levels, when sound levels were lower than the 60dB low parameter. Therefore, day one and two sound level data were excluded from analysis. For the remaining 19 shifts the low and high parameters were set at 30 and 100 dB respectively. Sound level data are reported (see Table 2) as descriptive statistics based on shift type (days, evenings, and nights).

The highest mean sound levels and SD (mean [SD]) were recorded during one day shift at 59.5 dB (SD 2.82). Night shift mean sound levels were 57.1 dB (SD 3.71). Evening shift recorded the lowest means at 51.0 dB (SD 2.71). Differences in sound levels across shift types were statistically significant ($p < 0.001$). The range of sound levels varied from day to day and from weekday to weekend (sees Table 2). The range of lowest minimum sound levels were 47.1 dB on Sunday of evening shift to the highest maximum at 83.5 dB on Thursday day shift. Weekend sound levels were loudest on night shift with a maximum sound level of 81.6 dB recorded, whereas the lowest sound level recorded on the weekend was obtained on the evening shift at 47.1 dB. There was a statistically and clinically significant pattern of sound elevation during the day shift as compared with the night shift (mean 59.5 dB versus 52.3 dB; 95% confidence interval (CI) = 0.126 to 0.314 dB; $p < 0.001$). The mean

maximum sound level ranges reached were 83.5 dB for day shift, 83.0 dB for evening shift, and 80.9 dB for night shift (see Table 2). For all periods, the mean sound levels were above the AAP recommendation of 45 dB.

Sound level data were initially assessed to ensure that they met the assumptions of normal distribution as noted in method section. It was ascertained that the sound level data were normally distributed, thus means and standard deviations (SDs) for the data are reported (see Table 2). To explain what the normal distribution is when comparing the relationship between each X_1 to X_5 (independent variable: number of neonates, number of people, number of alarms, infant acuity, shift type), and Y (dependent variable: sound levels), we observe that the distribution is linear over the range of values studied. The distribution of (dependent variable: sound levels) have equal variances (or SDs) at each value of each independent value X; that is the standard deviation of Y is the same, no matter what the value of X. Sound level data were determined to be ratio level of measurement variable because it is measured in decibels and has a meaningful zero. A ratio level of measurement is a classification that describes the nature of information within the values assigned to variables, for example magnitude or amount. The skewness index was zero for a symmetric distribution. The index of kurtosis is zero, it can be described that this distribution is trending toward Mesokurtic, which denotes shapes neither pointy nor flat. These requirements were all met for normal distribution.

Figure 1 illustrates the differing mean sound levels between shift type (day, evening, night) and how they compare to the AAP-recommended guideline of 45 dB. The difference between the highest and lowest mean sound levels of the shift was only 2.6 dB (see Figure 1). Although this is a small difference, it is clinically significant because a difference in 3 dB is a doubling of sound levels.

Table 2.
Descriptive Statistics of Sound Levels

Day† Shift	**Day of the Week**	**Mean (SD) (dB)**	**Minimum Sound (dB)**	**Maximum Sound(dB)**
3	Tuesday	58.3 (2.64)	50.6	71.4
4	Wednesday	57.6 (2.37)	49.4	77.2
5	Thursday	59.5 (2.82)	49.8	83.5
6	Friday	58.6 (2.42)	50.2	78.6
7	Saturday	56.9 (2.34)	50.9	81.6
Total	5 shifts	290.9 (12.2)	250.9	392.3
Average		58.2 (2.4)	50.2	78.5
Evening Shift	**Day of the Week**	**Mean (SD) (dB)**	**Minimum Sound (dB)**	**Maximum Sound(dB)**
1	Sunday	56.6 (3.53)	47.1	76.1
2	Monday	54.1 (2.65)	48.2	83.0
3	Tuesday	53.7 (2.32)	49.0	81.1
4	Wednesday	55.5 (2.34)	47.6	78.9
5	Thursday	51.0 (2.71)	47.8	76.2
6	Friday	51.6 (2.25)	48.3	81.3
7	Saturday	52.7 (3.67)	48.9	77.1
Total	7 shifts	375.4 (19.5)	336.9	553.7
Average		53.6 (2.8)	48.1	79.1
Night Shift	**Day of the Week**	**Mean (SD) (dB)**	**Minimum Sound (dB)**	**Maximum Sound(dB)**
1	Sunday	54.9 (2.64)	51.8	80.9
2	Monday	57.1 (3.71)	48.9	75.3
3	Tuesday	53.8 (3.18)	47.8	76.3
4	Wednesday	52.8 (3.44)	49.2	78.6
5	Thursday	52.3 (3.19)	47.9	73.0
6	Friday	55.7 (2.95)	53.2	75.6
7	Saturday	55.0 (3.11)	51.4	80.6
Total	7 shifts	381.5 (22.2)	350.2	540.3
Average		54.5 (3.1)	50.0	77.1

Table 2: Descriptive statistics of sound level based on shift, day of the week, and reported in mean dB. The timing of the different shifts is reported by the 24-hour clock (Day shift 0600-1400; Evening shift 1400-2300; Night shift 2300-0600).
† Day shift 1-2 excluded due to missing data. Total data analysis therefore reported for 19 shifts.

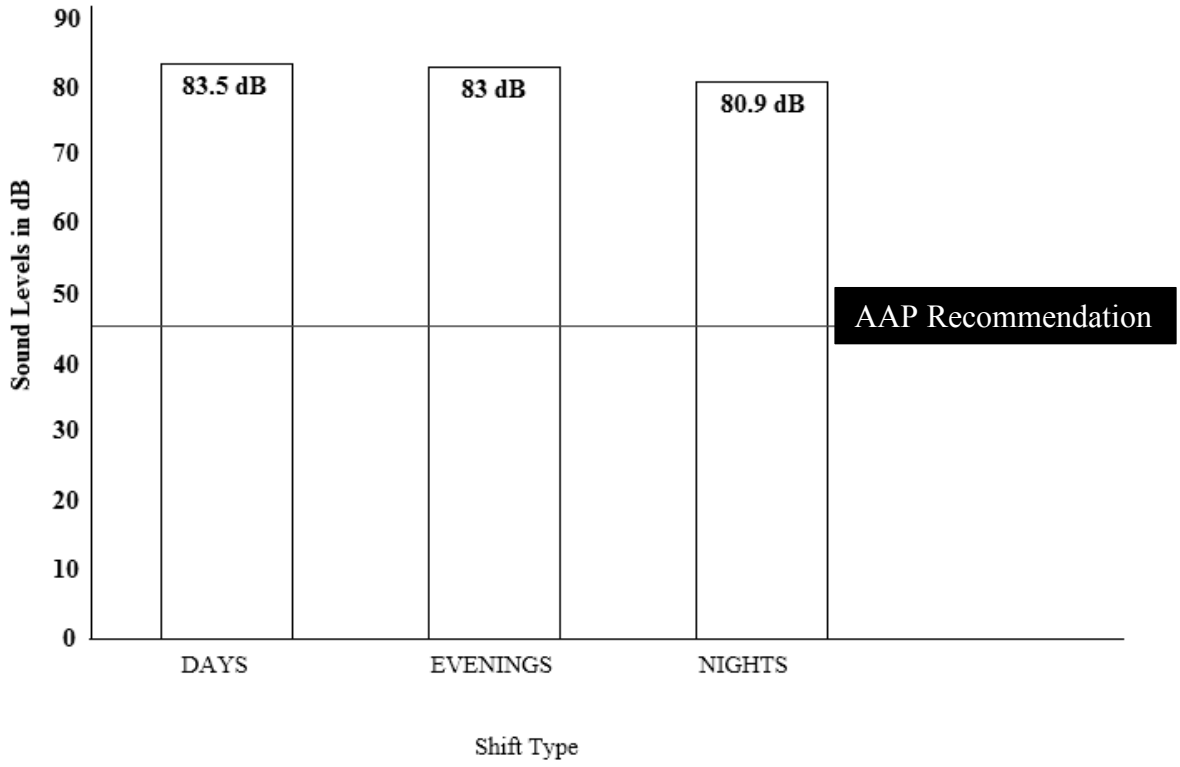

Figure 1. Maximum sound levels based on shift reported as means.
Note: Black horizontal line in middle of graph depicts AAP-recommended sound level of 45dB.

Figure 2 shows the distribution of sound level measurements in dB including the medians and IQRs during three randomly chosen shifts one from each (days, evenings, and nights). Medians and IQRs were used to illustrate these data because, even though the data from this sound level audit are normally distributed, box-plots (which are traditionally used for data that are not normally distributed) are valuable in showing the distribution of the data. Figure 2 visually represents all the data points collected for all 19 shifts, as illustrated by the numeric values. This illustrates the similarity of the data for each of the three different shifts in relation to the mean sound levels, similar variability with very few outliers and that much of the sound level data is in the higher quartile range. The numerals indicate the number of times the same dB level was recorded by the sound meter (see Figure 2).

Ninety per cent of the time, sound levels were between 61 dB to 65 dB. In order to further highlight the discrepancy between actual sound levels and the AAP guideline of 45 dB, figures were created to depict *all* sound data for each of the shifts: days, evenings, and nights (see Figures 3, 4, 5 respectively).

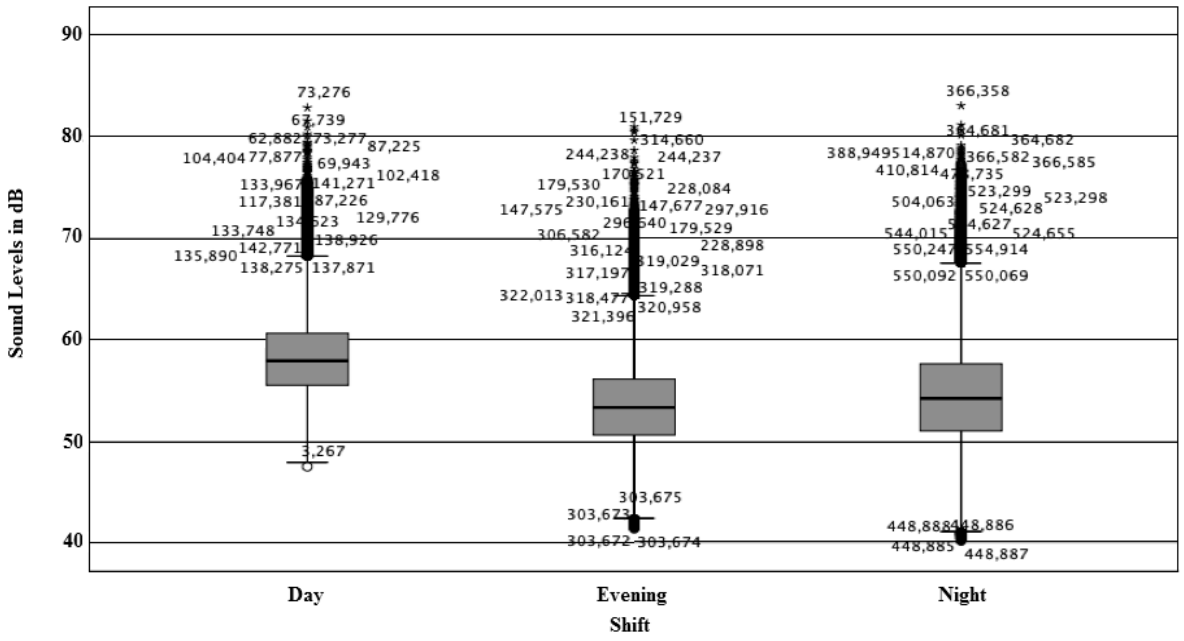

Figure 2. Box-plots of sounds levels in dB.
Box-plots showing the distribution of sound level measurements during the three shifts (days, evenings, nights). Data reported as medians and Inter Quartile Range (IQR).
The top of the rectangle shows the third quartile (Q3), the horizontal line near the middle shows the median, the bottom line shows the first quartile (Q1). The vertical line extending from the top of the rectangle shows the maximum value within 1.5 *IQR and the vertical line from the bottom indicates the minimum value within 1.5 *IQR. The numerals indicate the number of times the same dB level was recorded by the noise meter.

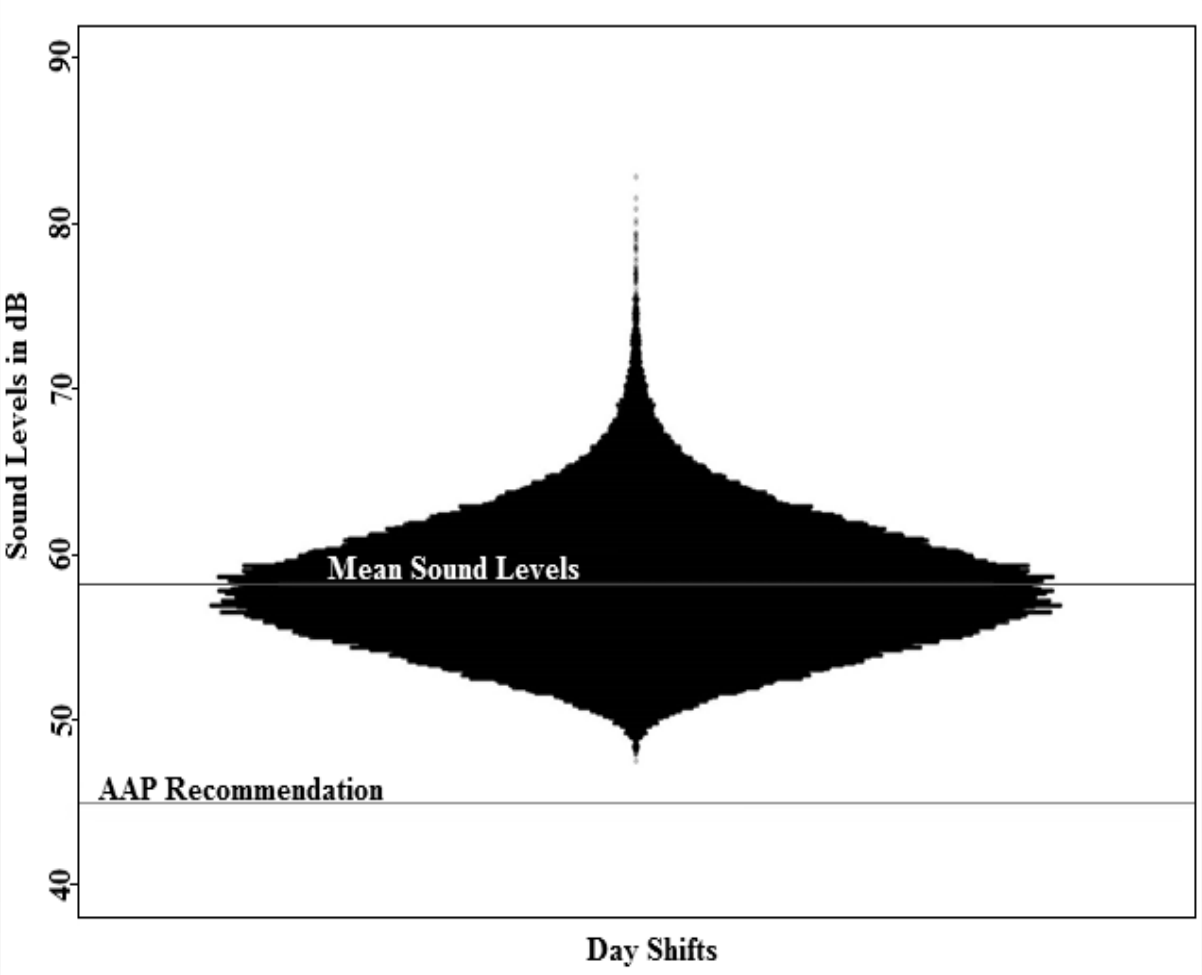

Figure 3. Scatter plot for day shift.
All day shift data, with every data point of sound collection plotted. Mean sound levels were below 60 dB.

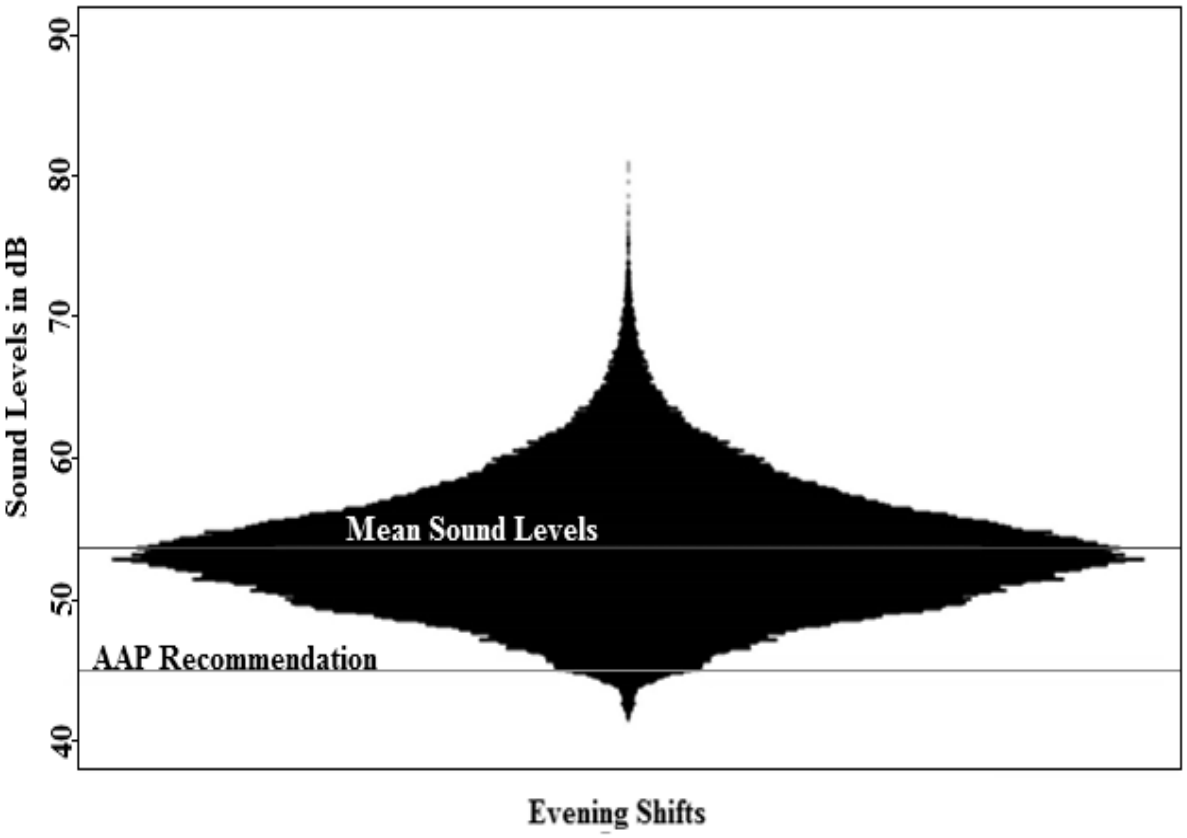

Figure 4. Scatter plot for evening shift.
All evening shift data, with every data point of sound collection plotted. The mean sound levels were below 51 dB.

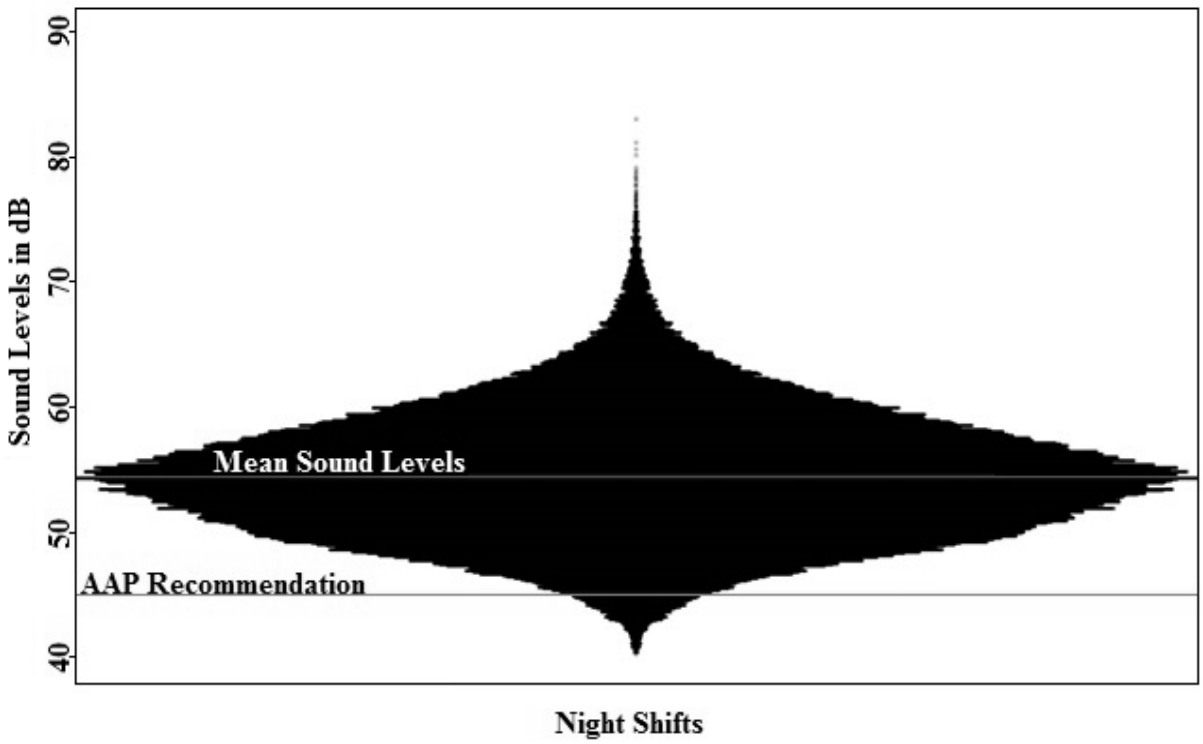

Figure 5. Scatter plot for night shift.
All night shift data with every data point of sound collection plotted. The mean sound levels were below 57.1 dB.

Observational Data Results

Observational data were collected alongside sound level meter measurements, with 19 shifts of data collection analyzed. Observational data collected included: total number of people, total number of alarm events, total number of IV pumps, total number of ventilators, total number of NCPAPs, total number of emergency events, and total number of suctioning events. It was observed that there were many people, including HCPs, parents, and visitors walking through the NICU every shift. HCP voices were observed to be at a conversational volume of speech, with a recorded sound measurement of 67.2 dB during the shift. The conversational volume was verified, when the volume of conversations appeared to be excessive and a measurement was noted and recorded. It was observed that monitor alarms were often not being silenced quickly, and they were frequently alarming for greater than three minutes. Alarm fatigue is defined as desensitization to alarm sounds, resulting in HCPs not responding to alarms quickly (Sendelbach & Funk, 2013). It was observed that some HCPs commented to each other that the SoundEar noise meter reminder device was illuminated red frequently each shift due to conversations and alarms. There were repetitive sounds that were occurring during data collection that were verified by noting and recording the sound level. Examples of repetitive sounds recorded were measurement readings of 73 dB for ventilator alarms, 60.2 dB for cardiac monitor alarms and 75 dB from the central monitor alarms. Other examples are as follows: sound level generated by the blanket warmer was 57.3 dB; sound measurement of the blanket warmer door being opened and closed on one occasion was recorded at 72.2 dB, and sound level recorded from the milk warmer was 66.7 dB. The sound level recorded from the portable X-ray was 66.9 dB being wheeled into the NICU. On each shift objects were frequently dropped. For example, a portable thermometer, a clipboard, a glucose scan machine, creating sound levels of approximately 80.5 dB. The dropped object is described in the field notes as unidentified because the researcher heard the

dropped item and was not able visualize the actual object from the recording position. The lowest sound level measurement recorded during this study was 49 dB recorded in an empty NICU room, with no people, and no equipment. This sound level was recorded during the Friday evening shift, when the census was four neonates and uncharacteristically low. The room was emptied on one side of the partial wall to allow for polishing of the floor and the application of floor wax, so as not to impact the neonates with the harsh smell of floor chemicals. The guidelines were exceeded even in an empty NICU room.

Number of Neonates

The number of neonates in the room varied throughout the 8-hour shifts due to the unpredictable nature of admissions to the NICU and the various reasons neonates may have to be moved in or out of the room. For example, neonates could be moved due to an admission or discharge of another infant. During the observational data collection period, the total number of neonates in the room ranged from four to nine. With respect to the neonates themselves, the number and acuity varied significantly over the study period. For example, on Friday of Evening Shift, there were nine neonates and the total infant acuity was 6, whereas on Sunday of Day Shift there were eight neonates but the total infant acuity was 22. The varying number of neonates in the room at any time can be explained by nursing assignments (balancing the number of neonates and neonatal acuity). For example, if a nurse assignment has a high neonate acuity level and a new admission arrives to the NICU, the nursing assignment may change and the neonate may be moved in order to accommodate the new admission. Therefore, a neonate may be moved to a different room under the care of a different nurse. This movement of neonates and all their equipment from one room to another is an additional source of elevated sound levels. For example, it was observed that it takes on average two nurses and one respiratory therapist to move a ventilated neonate from one room to another and generated sound levels of 76.3 dB.

Number of People

The entire NICU was staffed with 13 nurses on days and 13 nurses on nights during the data collection period. It was also noted that there was an assigned resuscitation nurse who did not have a patient assignment, but went to emergency deliveries. For the purpose of data analysis, the total number of people were combined and included all: neonates, HCPs, parents, and visitors present in the room. The number of people in the room was continuously fluctuating throughout each shift. The total number recorded was a mean of the number recorded at each of the hourly measurements. Parents, visitors, and HCPs were freely moving in and out of the room, especially as the room is a thoroughfare to the labour and delivery rooms, to the medication fridge, to the narcotic cupboard, and to the physician and residents' room. The largest number ever of people in the room at a given time was recorded during the day shift. For instance, the number of people in the room was highest on Saturday of Day Shift, with a count of 34 versus the lowest number recorded on Thursday of Evening Shift when there were seven people in the room. The mean number of people in the room during the study ranged from 9.0 to 23.3.

On Saturday of Day Shift there was a neonatal death. At this event there were up to 15 family members and four HCPs present at the infant's bedside. A religious ceremony to baptize the infant and give the final rites by a priest occurred on this shift. This extra event substantially increased the total number of people in the room and resulted in an observed increase in sound levels to 68 dB on this shift.

The neonatal transport team came to the NICU on three separate occasions during the period of data collection to transport a medically unstable infant out of TOH NICU to the Children's Hospital of Eastern Ontario (CHEO) NICU for surgical care. The neonatal transport team consisted of two CHEO HCPs and a large portable transport isolette containing a cardiac monitor, oxygen, defibrillator, and other equipment. The sound meter

recorded 76.3 dB of sound during the transport team attendance in the NICU; this was attributed to not only the increased total number of people, but also to conversations and report at the bedside. In this study, HCP conversations recorded at the bedside had a sound level of 67.2 dB above the background noise.

Neonate Acuity

As stated in the Methods (Setting and Participants), the measurement of neonate acuity comprises three categories from Level 1 to 3. Over the course of sound data collection, the overall total neonate acuity fluctuated daily, based on the assignment of neonates being admitted for prematurity, being acutely ill, or being moved to other rooms to make space for new admissions. It was observed that the higher the neonate's acuity, the more HCPs were present, meaning more conversations at the bedside, and more equipment at the bedside including ventilators and multiple intravenous pumps, thus generating higher sound levels. When neonate acuity was assigned as above 3, the transport team was notified and arrived to transport the infant to the adjacent hospital for needed surgical intervention.

Total Alarm Events

Total alarm events were compiled for each of the day, evening, and night shifts. There was never a time throughout the data collection period where the alarm count during any hour was zero. When counting the number of alarms per 8-hour shift, it was noted that some shifts were significantly noisier with more alarms than other shifts. A total of 2,595 alarm events were recorded over the seven-day shifts, 1,471 over evening shifts, and 1,412 over night shifts. This highlights the high number of alarm events, especially during day shifts. Figure 6 illustrates the number of alarm events for the total period in each of the three shift types. For example, the highest alarm counts were on Friday of Day Shift there were 882 alarm events counted versus the lowest alarm counts on Monday of Night Shift when there were 163 alarm events. There were fewer alarm events counted during the weekends than on weekdays (see

Figure 6). Comparing the weekend shifts with weekday shifts, the observed alarm count was 1,494 for Saturday and Sunday, versus 2,027 for Thursday and Friday. During an individual random shift (Friday of Day Shift used as an example), the alarm count was each beep of an alarm counted, which ranged from approximately 5 to 106 alarm events in the 60 seconds of measurement each hour. The lowest alarm count was on Tuesday of Day Shift with a count of 159, and the highest alarm count was on Friday of Day Shift with an alarm count of 882. Both the highest and the lowest alarm counts occurred on day shifts. Mondays had the smallest number of alarm events counted at 674 in total, and Fridays had the highest number of alarm events counted at 1,319 in total, which is almost a doubling of alarm event counts (see Figure 6). The alarms ringing during the day shifts represented 47% of the total alarm events recorded versus evening shift with 27% of the total alarm events recorded, and night shift representing 26% of the total alarm events recorded. Alarms rang for many reasons in the NICU, including a ventilator malfunction on Friday of Day Shift that is explained further below, and the variability in infant acuity with higher acuity requiring more equipment and less stable neonates, equating to more alarm events.

Total IV Pumps

There was a wide range in the number of intravenous (IV) pumps in the NICU counted during data collection. Their numbers ranged from 3 on Thursday of Night Shift to 22 on Wednesday of Day Shift. This is a significant contributor to the sound generated in the room during data collection, as each IV pump alarms intermittently for various reasons such as occlusion, empty, and end of infusion. It was observed that for higher acuity neonates requiring continuous nursing care and intervention, more IV pumps were needed to provide medications. It was observed that on Wednesday of Day Shift, a single neonate with an acuity level of 3 required seven IV pumps. The sound level recorded by a single IV pump alarming was 84.2 dB.

Total Ventilators

Modern day ventilators are used to provide respiratory and oxygen support to preterm and sick neonates in the level III NICU. Assisted ventilation is usually a temporary measure for supporting pulmonary function until the neonate can breathe on their own. Ventilators are equipped with a variety of alarms for low oxygen pressure, inadequate oxygen volume delivery, and disconnections. These alarms are functional when the ventilator is turned on and plugged in. There are many possible reasons for ventilator malfunction alarms including disconnection from the power supply, empty batteries, poor battery backup, or failure of the electrical components. A ventilator malfunction occurs when the machine is not functioning properly. As a result, the machine continuously alarms. During this study in the NICU, one ventilator malfunction caused alarms to ring continually for approximately 20 minutes. As a result of the ventilator malfunction, the Biomedical Engineering department of the hospital was contacted and two biomedical engineers arrived to repair the ventilator and attempt to silence the alarm. It was decided to replace the ventilator with another model of ventilator, and two respiratory therapists were called to assist in the transfer of the infant to the new ventilator machine. This incident provides an example of unanticipated and unpredictable events that arise in a NICU setting due to the nature of the population and the equipment. This one ventilator malfunction represented 34% of the total alarm events counted over the entire week of day shifts. During the observational data collection period, there was a range in the number of ventilators being used. On the Monday of Day Shift, seven separate neonates were being continuously ventilated. It was observed that no ventilators were in use during any of the seven evening shifts where data were collected. This is a highly unusual observation.

Total CPAP

The number of continuous positive airway pressure (CPAP) machines used during the observational data collection period ranged from 0 to 5 per shift. It was observed that these minimally invasive respiratory machines alarm frequently when pressure is lost at the nose or mouth of the neonate, contributing to the high sound levels generated. The sound generated by the CPAP machines when alarming was found to be 69.2 dB.

Total Emergency Events

The number of emergency events that were observed during data collection period ranged from 0 to 4 per shift. These events included procedures such as X-rays, ultrasounds, echocardiograms, insertion of peripherally inserted central catheters, intubation, or neonate self-extubation. Although some of these procedures are not emergencies by definition, they are included in this category for the purpose of data collection.

Portable X-rays occurred daily in the NICU, ranging from 0 to 2 each shift. When a neonate requires an X-ray, a phone call is placed to request the procedure. An X-ray technician brings a large portable X-ray machine into the unit to the neonate's bedside. The machine is on wheels, but is awkward to manoeuvre and generates high sound levels. Maneuvering the neonate and equipment for the X-ray often requires 2 or 3 HCP at the bedside.

Neonatal ultrasounds and echocardiograms occurred four times each shift on day shift, but did not occur on evenings or night shifts during the study. The ultrasound or echocardiogram portable equipment is brought to the neonate's bedside for approximately 15 to 20 minutes. The ultrasound or echocardiogram procedures do not themselves generate high sound levels at the bedside, but the movement of the large portable machines and the additional personnel creates increased sound levels.

Total Suctioning Events

Neonates in the NICU undergo nasopharyngeal and endotracheal suctioning in order to clear the airway of secretions and obstructions. Inline suctioning can also be performed, and is done by way of the endotracheal tube through a closed suctioning system. Inline suctioning is less invasive for the neonate, and also generates lower sound levels compared with more traditional suctioning. The sound generated by traditional nasopharyngeal suctioning was 68 dB. During this study, it was observed that most neonates were suctioned endotracheally by the inline method. Inline suctioning occurred from 0 to 13 times per shift. There were four shifts where no suctioning events occurred.

Extra Events

Construction occurred on two separate occasions during data collection (Thursday and Friday of Day Shift). The duration of the construction ranged from three to five hours on each of these two shifts. Equipment such as the use and unfolding of ladders contributed to the maximum sound measurement recorded for construction of 74 dB. The construction was an unexpected and important factor in the low infant count on these two-day shifts, as neonates were moved to accommodate for computer installation and maintenance workers. Although construction is not a regular occurrence in the NICU, regular maintenance is common, including changing light bulbs and repairing mechanical equipment, all of which generate high levels of sound and noise. Computer technicians were present in the room setting up a central computer monitoring system on two additional day shifts (Wednesday and Thursday of Day Shift) of data collection. The computer technicians contributed to the total number of people and conversations present in the room, resulting in high sound levels during their work, recorded at 71.2 dB.

The closure of the blanket warmer door was recorded as an extra event in observational data collection. The blanket warmer was accessed by most HCPs. All staff

were responsible for how the blanket warmer door was opened or closed. It was observed that the blanket warmer door was opened and slammed closed on multiple occasions, with an observed random recorded sound level up to 72.2 dB. By way of comparison, a vacuum cleaner generates sound levels of approximately 70 dB. While these extra sound levels occurred frequently each shift, the peak sound level occurred briefly and not for a prolonged period of time.

Announcements are broadcast over the overhead hospital sound system at any time during the 24 hours per day. These announcements occurred multiple times on every shift and were recorded as extra events along with their sound levels in dB. Emergency codes were announced throughout the hospital, and in the NICU. Announcements were transmitted from overhead speakers. The overhead hospital announcements resulted in recorded sound levels of up to 76.4 dB.

Table 3 summarizes observational factors that were captured for each of the three shift types (days, evenings, and nights). Figure 6 was created to show the alarm counts based on shift (days, evenings, nights) that were counted and recorded hourly during the observational data collection. Run charts were created in order to understand sound levels in the NICU and how they fluctuate by time of shift, compared with the AAP recommendation of 45 dB. The run charts illustrate the sound levels in dB plotted each hour over the length of the 8-hour period of time. These run charts with the median line presented visually show the sound level data for a random shift (day, evening, and night). It can be observed that the sound levels not only fluctuate, but also where the sound level falls in relation to the AAP recommendation. The run charts further emphasize the discrepancy between the AAP-recommended sound level of 45 dB and the actual sound levels in the NICU. It can be observed that certain daily events (e.g., multidisciplinary bedside shift rounds denoted by the symbol of a star) affect the sound levels routinely at certain times. (see Figures 7, 8, 9).

Table 3.
Summary of Observational Data

Shift Day† 06-1400	Mean number people	Mean number Alarm Events	Mean number of IV pumps	Mean number of Ventilators	Mean number CPAP	Mean number of Emergency Events	Mean number of Suctioning Events
3	23.3	14.5	16.2	6.0	0.8	0	0.2
4	15.4	17.6	21.1	5.0	0	0.3	0.8
5	16.6	17.4	17.0	4.0	0	0.3	0.9
6	17.7	42	16.0	4.0	2.0	0.3	0.6
7	20.3	23.9	17.0	4.0	2.0	0.4	0.3
Total	93.3	115.4	87.3	23.0	4.8	1.3	2.8
Grand Mean	18.7	23.1	17.5	4.6	1.0	0.3	0.6

Shift Evening 14-2300	Mean number people	Mean number Alarm Events	Mean number of IV pumps	Mean number of Ventilators††	Mean number CPAP	Mean number of Emergency Events	Mean number of Suctioning Events
1	12.8	16.0	4.0	0.0	4.0	0.0	0.1
2	17.3	20.3	6.1	0.0	2.7	0.2	0.1
3	11.4	20.6	5.0	0.0	2.0	0.0	0.2
4	9.6	19.0	3.0	0.0	1.0	0.0	0.0
5	9.0	17.3	3.0	0.0	2.0	0.0	0.1
6	13.6	18.3	8.1	0.0	2.4	0.3	0.2
7	14.8	17.5	5.0	0.0	3.0	0.0	0.0
Total	88.5	129	34.2	0.0	17.1	0.5	0.7
Grand Mean	12.6	18.4	4.9	0.0	2.4	0.1	0.1

Shift Night 23-0600	Mean number people	Mean number Alarm Events	Mean number of IV pumps	Mean number of Ventilators	Mean number CPAP	Mean number of Emergency Events	Mean number of Suctioning Events
1	13.3	22.2	10.1	4.0	1.0	0.1	0.5
2	10.7	18.1	12.0	5.0	1.0	0.0	0.7
3	12.6	26.7	7.0	4.0	1.0	0.0	1.0
4	13.9	25.1	10.1	3.0	3.7	0.1	0.7
5	13.7	23.8	3.0	0.0	4.0	0.1	0.0
6	11.9	22.6	4.0	4.0	2.0	0.0	0.5
7	10.4	17.5	6.0	0.0	3.0	0.2	0.2
Total	86.5	156	52.2	20.0	15.7	0.5	3.6
Grand Mean	12.4	22.3	7.5	2.9	2.2	0.1	0.5

Table 3 Summary of observational data collection for each shift. Data calculated and presented as means.† Days 1-2 of day shift excluded due to missing data.
†† There were no ventilators in use during the entire evening shift data collection period, which is highly unusual.

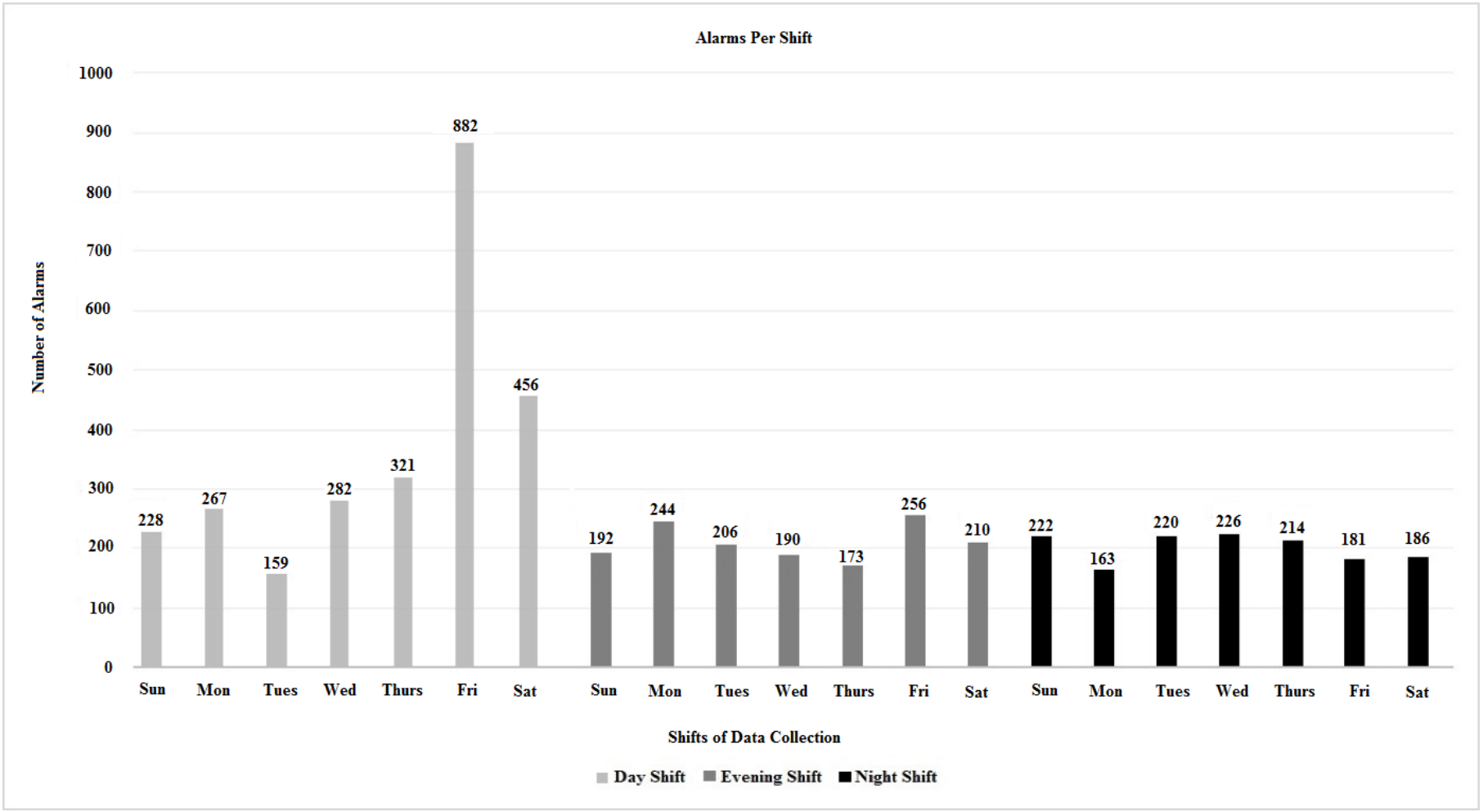

Figure 6. Number of alarms based on shift.
Alarms counted hourly each shift during observational data collection.

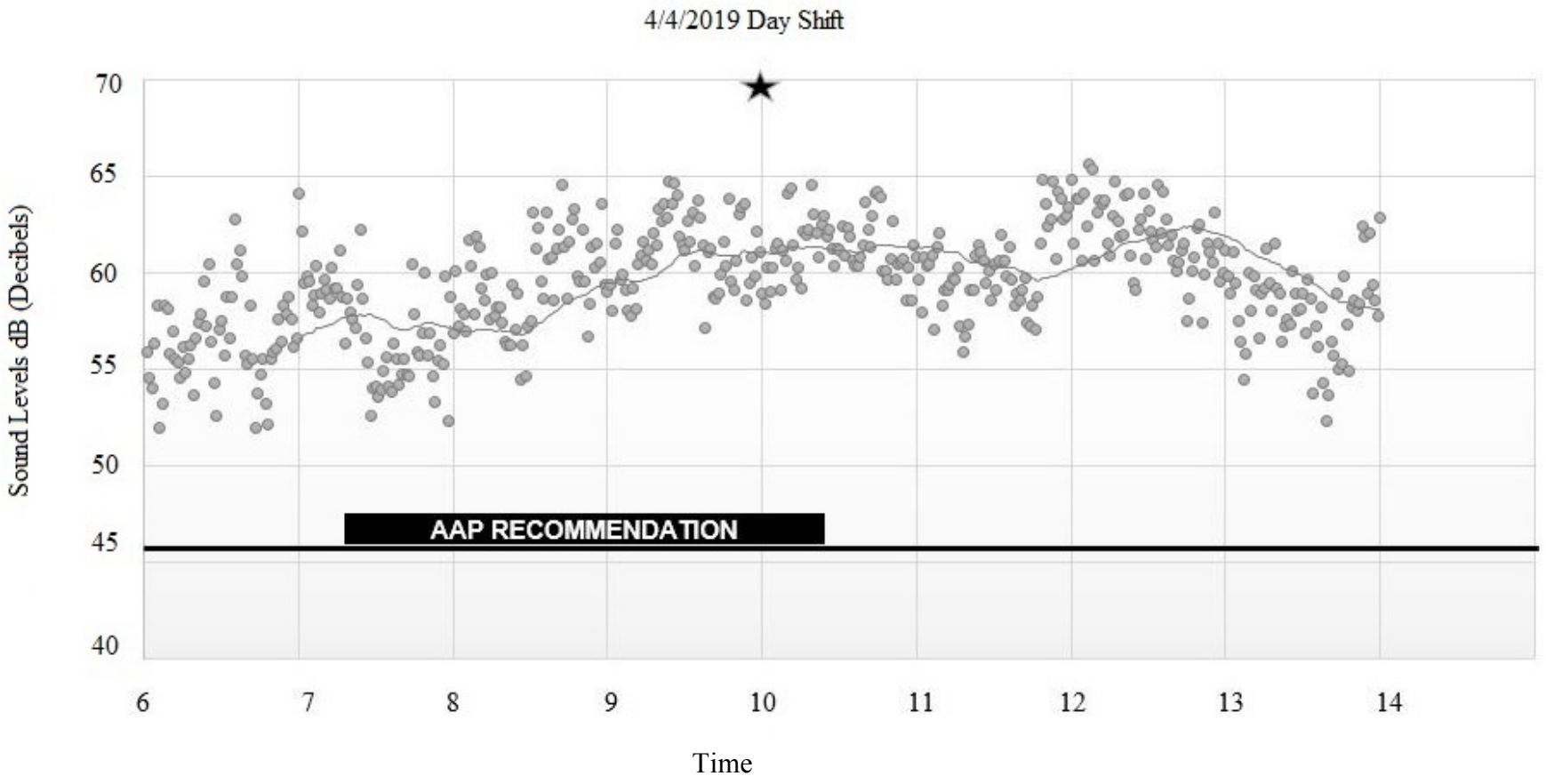

Figure 7. Run chart for random day shift.
Sound level data for random 8-hour day shift. The dots represent the mean sound levels. The black vertical bold line is the AAP recommendation of 45 dB sound levels. Median line is grey running through the data. The star represents sound levels in dB during multidisciplinary shift rounds.

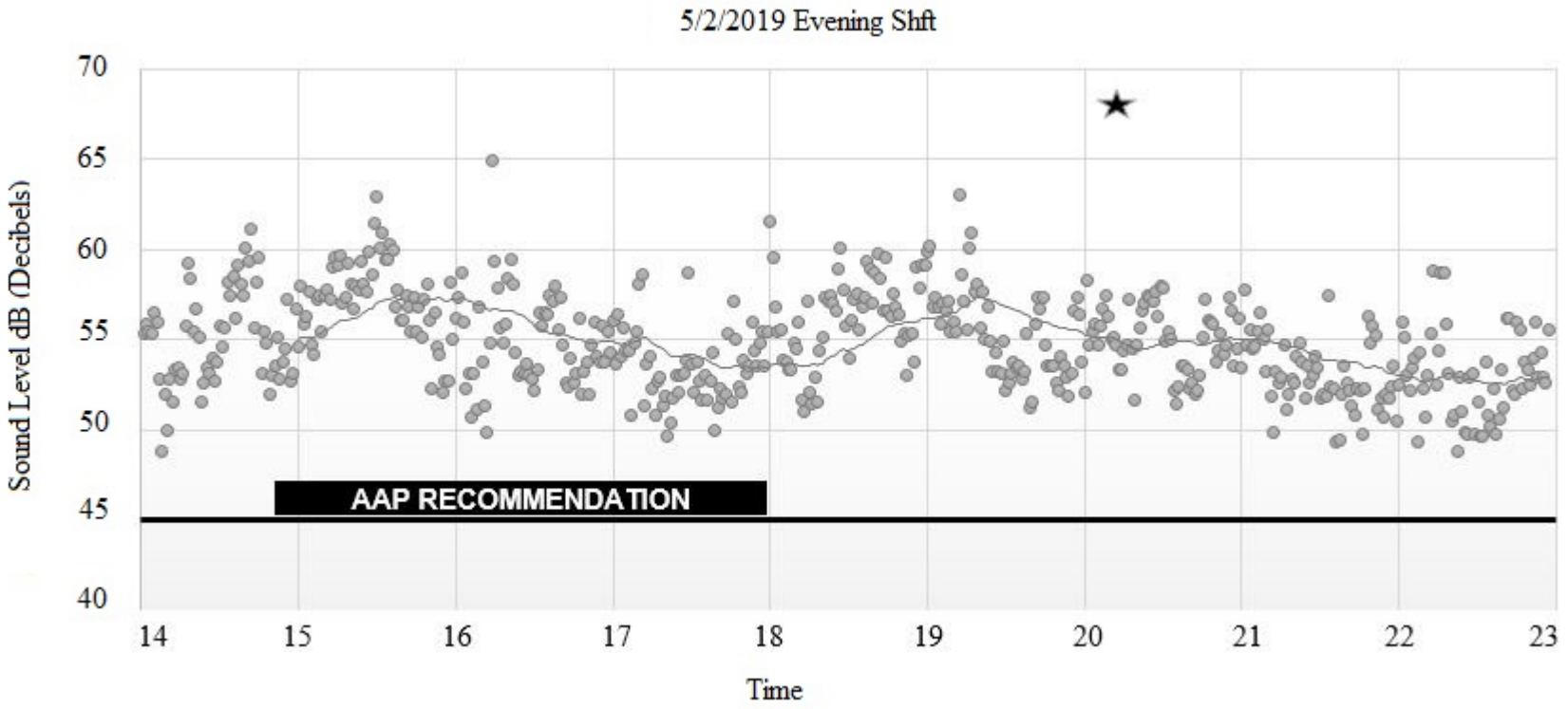

Figure 8. Run chart for random evening shift.
Sound level data for random 8-hour evening shift. The dots represent the mean sound levels. The black vertical bold line is the AAP recommendation of 45 dB sound levels. Median line is grey running through the data. The star represents sound levels in dB during multidisciplinary shift rounds.

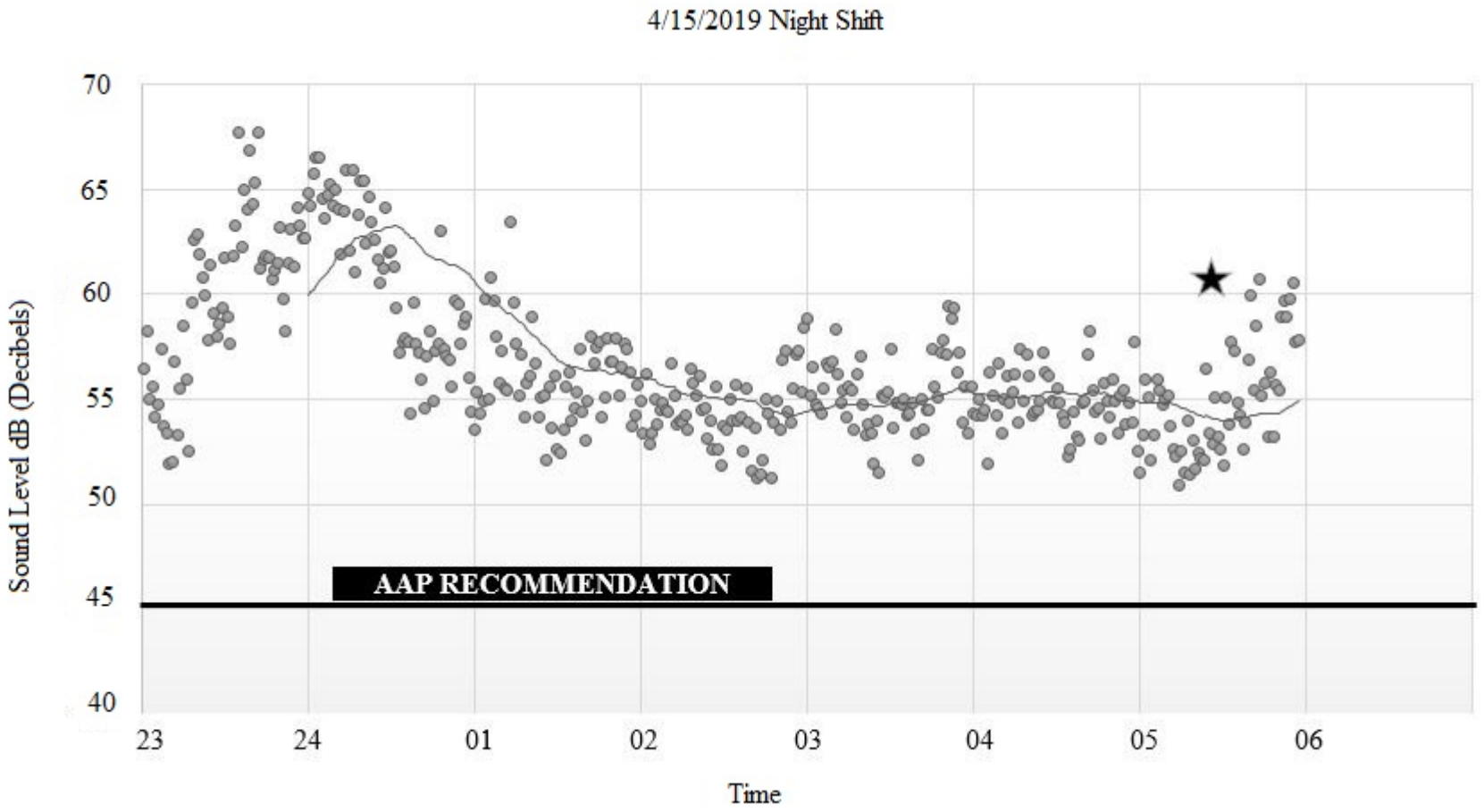

Figure 9. Run chart for random night shift.
Sound level data for random 8-hour night shift. The dots represent the mean sound levels. The black vertical bold line is the AAP recommendation of 45 dB sound levels. Median line is grey running through the data. The star represents sound levels in dB during multidisciplinary shift rounds.

Statistical Analysis

The combination of variables to predict sound levels from number of neonates, number of people, number of alarms, acuity level, and shift type was statistically significant, F *(*16445.629), $p < 0.001$. The beta (β) is used to make direct comparisons. For example, the beta is in terms of the units of the independent variable, while beta is standardized meaning in standard deviation units. That is why it can be used to compare independent variables of different units of measure. Table 4 was created to explain sound levels in the NICU. This is done to make direct comparisons using the beta values which tells how much each independent variable change. Note that all the variables significantly predict sound levels in the NICU when all five variables are included.

There was a statistically significant positive correlation between elevated sound levels and number of people, $r (48) = .35$, $p < 0.001$. This positive correlation means that as the number of people increased in the room, so did the sound levels. Simultaneous multiple linear regression was conducted to investigate the best prediction of sound levels in the NICU. The means and SDs of sound levels can be found in Table 2. For the purpose of this study and as previously explained, all assumptions of multiple linear regression were met (Polit, 2010). In multiple linear regression certain assumptions must be met: the dependent variable must be an interval or ratio (sound levels are interval); multivariate normality must be demonstrated (each variable and all linear combinations are assumed to be normally distributed); linearity must exist such that there is a straight line relationship between pairs of variables; there must be homoscedasticity where variability in scores for one variable are similar at all values to another variable; and finally, there must be independence of errors, where errors of prediction are assumed to be independent of each other (Polit, 2010). Among the 604,800 sound measurements collected, a multiple linear regression model was developed where sound levels "Y" (dependent variable) predicts the X_1 number of people; X_2 number of

neonates; X_3 neonate acuity; X_4 number of alarms; and X_5 shift type (independent variables). The "b" values were the regression coefficients for the independent variables. Where: $Y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4 + b_5 X_5$. $Y = 53.273 + .253 X_1 - .102 X_2 + .155 X_3 + .006 X_4 - .691 X_5$. If X_2 and X_3 and X_4 and X_5 are held constant or controlled for, then the sound levels increase by 0.253. (0.253 is the coefficient for X_1 number of people). If X_1 and X_3 and X_4 and X_5 are held constant or controlled for, then the sound levels decrease by -0.102. (-0.102 is the coefficient for X_2 number of neonates). If X_1 and X_2 and X_4 and X_5 are held constant or controlled for, then the sound levels increase by 0.155. (0.155 is the coefficient for X_3 infant acuity). If X_1 and X_2 and X_3 and X_5 are held constant or controlled for, then the sound levels increase by 0.006. (0.006 is the coefficient for X_4 number of alarms). If X_1 and X_2 and X_3 and X_4 are held constant or controlled for, then the sound levels decrease by -0.691. (-0.691 is the coefficient for X_5 shift type).

The final model had an adjusted R^2 of 0.145. The R^2 value accounts for the variance in sound levels explained by the model. According to Polit (2010) this is considered a small effect because it was slightly more than 0.10. The findings from the multiple linear regression analysis taken together are that the observational data collected explained 14.5% (adjusted R^2 of 0.145) of the sound levels in the NICU. Therefore, 85.5% of the sound levels come from factors not observed in this research. The model of analysis shows a statistically significant result ($p < 0.001$). The five variables (number of people, number of neonates, infant acuity, number of alarms, and shift type) were statistically significant predictors of the sound levels in the NICU. This means that these variables do have a relationship to the sound levels in the NICU, thus we accept the Alternate Hypothesis that there is a relationship between the sound levels in the NICU and the number of infants, the number of people, the number of alarms, infant acuity level, and the shift type.

Table 4.
Multiple Linear Regression

Variable	b	β	SE	R^2	p-value
Intercept	53.273	-	0.043	-	-
Number of People	0.253	0.350	0.001	0.360	< 0.001
Number of Neonates	-0.102	-0.049	0.005	0.094	< 0.001
Infant Acuity	0.155	0.057	0.006	0.150	< 0.001
Number of Alarms	0.006	0.038	0.000	0.147	< 0.001
Shift Type	–0.691	–0.120	0.009	0.145	< 0.001

Table 4. Summary of Simultaneous Multiple Linear Regression of the sound levels on the five variables (number of people, number of neonates, infant acuity, number of alarms, shift type). Dependent variable is noise. Intercept is a mathematical constant with no clinical interpretation. 95% Confidence Intervals for the coefficients. Overall $R^2 = 0.145$, adjusted $R^2 = 0.145$, $F = 16445.629$, (N = 19). P-value: all five variables are statistically significant predictors of the response variable.

CHAPTER 4

Discussion

Integrated Discussion of Sound Levels in Relation to Observational Data

This chapter provides an integrated discussion of the findings from this study of sound levels and factors associated with high sound levels in the NICU with that of other published studies of sound levels in NICUs around the world. Based on the findings, there are three main points of discussion: i) the identification of baseline sound levels in a level III NICU; ii) a comparison of current sound levels in the NICU with the AAP sound level recommendation of 45 dB; and iii) a consideration of environmental factors that contribute to increased sound levels. Finally, the findings are discussed in terms of their implications for nursing practice, education, and research.

Summary of Thesis Findings

Literature Review

A literature review was undertaken to identify factors associated with sound reduction strategies. Results of the literature review revealed sound reduction strategies for promoting a quiet NICU including: environmental redesign; reminders; scheduled daily quiet time; education; silencing of alarms quickly; and staffing ratios. Many of these strategies are currently in practice in many NICUs (Casavant, 2017; Laubach, 2014; Wang, 2013).

Objectives of Study

The first objective of this study was to collect sound levels in a level III NICU, and then compare the sound levels with the AAP-recommended guidelines of 45 dB. As described in the analysis of the results, the mean sound levels were consistently higher than the recommendation. The maximum mean sound levels for day shift were highest at 85.8 dB. The mean sound levels for evening shift were 83 dB and for night shift were 80.9 dB. The mean sound level in each shift indicates that sound levels in this NICU are almost double the

AAP recommendation of 45 dB. Sounds levels were consistently above the guidelines for all data collected. In fact, 90% of the time, sound levels were louder than 60 dB. It was noted that although the mean sound levels were above the recommended 45 dB over all three periods measured (days, evenings, nights), days were only 2.3 dB louder than nights. Putting this into context, a difference of 3 dB is an actual difference in 50% of sound. To explain further, an increase of 3 dB doubles the sound intensity, but a 10-dB increase is required before a sound is perceived to be twice as loud. Therefore, a small increase in decibels represents a large increase in intensity of sound. For example, 10 dB is 10 times more intense than 1dB, while 20 dB is 100 times more intense than 1 dB.

The final objective of this study was to collect observational data in order to identify factors contributing to increased sound levels in the NICU. Observational data were collected by the sole researcher (KM) simultaneously with sound measurements by the sound meter. There was no control over the census or the infant acuity at the time of data collection. During the data collection period, the HCPs continued to perform their tasks and work with little or no interaction with the researcher. The NICU is a dynamic environment that inherently experiences constant change in census, neonate acuity, and number of HCPs, families, and visitors present in the unit. The nurses working at the bedside mostly work days and nights in 12-hour shifts, and the unit was staffed with the same number of nurses at the bedside on day and night shift.

The contributing factors observed during this study which added to the elevated sound levels in the NICU were multifactorial including the level of conversational voice, the dropping of objects, the alarms that rang and were not silenced in a timely manner, the high numbers of people present in the NICU during multidisciplinary rounds, the open-bay room design, and the lack of daily scheduled quiet time. The observational data collected during

this study identified many factors contributing to the sound levels in the NICU, but there are likely many other contributing factors not identified in this research.

Comparison of Findings with Other Published Literature

A review of published literature on sound levels in the NICU confirms the widespread presence of elevated sound levels. In the current study, the sound levels were found to be consistently above the AAP recommendations for all periods of time (days, evenings, and nights). This finding is supported by evidence from other studies (Casavant, 2017;Disher, 2017; Laubach, 2014; Wang, 2013; Milette, 2010; Darcy, 2008; Byers, 2006;Thear, 2006). For example, a systematic review of 20 studies by Casavant and colleagues (2017), reported that NICU sound levels often exceeded 120 dB. In the present study, day shift sound levels were registering a maximum of 83.5 dB, followed by the evening shift with a maximum highest mean level of 83.0 dB, versus night shift at 80.9 dB maximum. The trend of higher sound levels of day-to-night shift is not consistent across the research. For example, a study by Darcy (2008) reported mean night shift sound levels of 60.6 dB, higher than the mean day shift sound levels of 59.1 dB. Similar to this study, Disher and colleagues (2017), reported that the range of sound levels in their NICU ranged from 55 dB to 82 dB, which exceeded the recommended standards at nearly every point in time. In order to explore factors associated with high sound levels, Disher conducted focus groups with HCPs (nurses, physicians, allied health professionals, support staff, students) and parents in the NICU. Their findings highlighted that HCPs' conversation was the key factor attributed to higher sound levels (Disher 2017). In the current study for this thesis, high sound levels of day-to-night shift was observed to be consistently high due to bedside conversations on all shifts and more activity, more conversations, and numbers of people present at the bedside during the day.

Laubach (2014), reported in their study that the baseline sound level in an open-bay NICU was approximately 58 dB, well above the AAP-recommended 45 dB guideline. The

authors noted that there was no specifically designated one-hour "quiet time" period, but rather that all the time was quiet time in practice. As part of the Laubach study, some newly renovated single-family rooms were included as part of the sound level data collection. Results support the hypothesis that accommodating neonates in single-family rooms in the NICU, as opposed to open-bay rooms, has tremendous benefits in terms of reducing NICU sound levels, and as a result improving the neurodevelopmental growth of preterm neonates. Sound abatement features used in the renovated rooms included specialized ceiling tile and flooring. The authors reported that the average sound level in the single-family rooms was 46.3 dB, compared with the baseline of 58 dB for the open-bay design rooms. Further, the decentralization of the nurses' station reduced socialization and conversations (Laubach, 2014). In TOH NICU, there are no single-family rooms, other than one isolation room which was not in use during the data collection period. In the Laubach study the SoundEar noise meter was installed in single-family rooms to provide continuous monitoring of sound levels. The authors also reinforced verbal reminders to maintain recommended sound levels within the NICU. During data collection for this thesis, it was observed that some HCPs commented to each other that the SoundEar noise warning device was illuminated red, however conversation appeared to continue at a normal level, and was not observed to be altered to a lower level of voice as a result of the visual warning. This observation could be due to alarm fatigue causing staff to be over sensitized to seeing the SoundEar noise warning device being illuminated red. In the current study for this thesis, the Sound Ear 2 is the model present in the NICU, and simply provides a colour change indicating high noise levels and does not provide an actual decibel sound level for HCPs to see in actual time. The different models of SoundEar noise meters provide different information.

Wang and colleagues (2013) conducted a study in a newly renovated level III NICU, where the environmental design is decentralized with single-family rooms. Their noise

reduction strategy consisted of physical, clinical, and educational components. Firstly, they worked with the physical plant and information services to find ways to decrease peak noise levels from a structural hospital perspective. Secondly, they instituted daily quiet time, and posted signage around their NICU reminding HCPs and visitors to monitor their noise. They installed the SoundEar 2 sound monitoring device in all their rooms. They developed strategy regarding behaviours that support noise reduction such as: conducting conversations away from the bedside, talking softly, keeping rounds away from the bedside, coordination of infant care schedules around sleep states. Finally, they developed an educational intervention for their HCPs, on the principals of a quiet NICU environment, and provided literature to all family and visitors about the need for quiet periods. They reported a lowest daily mean sound level of 47.5 dB in their NICU post-intervention. Their average baseline noise level was 49 dB, which also exceeds the AAP-recommended guideline of 45 dB. Their lower than average baseline sound levels, compared with the current study and other published studies, could be a direct result of this newly redesigned environment, or of the planned educational strategies directed at both HCPs as well as families and visitors. Wang concluded that although sound levels were higher than recommended, reductions could be made based on optimal NICU design and noise reduction strategies. The Wang study suggested that educational programs can be effective at reducing sound levels along with reminders such as the SoundEar 2 sound monitoring device. To compare the noise reduction policy in the Wang study to the TOH NICU in this current thesis study where there is no noise reduction policy, there are differences with regards to education for noise reduction, scheduled daily quiet time, and ongoing regular Developmental Care Committee meetings.

Thear and colleagues (2006) reported that the mean sound level in their NICU was approximately 63 dB. In attempting to reduce these high sound levels, the authors' strategy for sound reduction involved engaging the HCPs working in the NICU both pre-intervention

and post-intervention in the evaluation of sound levels. The study concluded that by limiting loud conversations at the bedside and instituting three scheduled quiet times per day, NICU sound levels decreased. By contrast, in this current study, HCP conversations were observed to be at normal conversation volume and it was noted that few people lowered their voice in the NICU. It was observed and not measured that HCPs appeared to continue with their duties and tasks and did not alter their conversational voice volume, which was at a medium volume most times, but at a loud volume periodically when multiple people were talking simultaneously. Thear and colleagues (2006) through their strategy of awareness engaged HCPs in education and evaluating their conversational sound levels. Ongoing education has also been reported in other studies (Ahamed, 2018; Casavant, 2017; Altimier 2015; Laubach, 2014; Hassanein, 2013; Wang, 2013; Konkani & Oakley, 2012; Milette, 2010) in order to promote lower noise levels.

Strategies for Sound Reduction

The practice of intentionally reducing sound levels in the NICU was not observed during the data collection period in this current study. The author made no attempts to reduce noise during the data collection periods, in spite of the fact that this unit had made previous attempts to reduce noise. In November 2016, a quality improvement initiative at TOH to reduce night time noise between the hours of 2100 to 0700, to ensure a quiet, healing environment for all patients was implemented throughout the entire hospital (TOH, 2016). The data for this thesis study was collected in an open-bay design room with up to nine neonates being cared for simultaneously, and where scheduled daily quiet time does not occur. Many NICUs have implemented quiet time with good results of lower sound levels (Casavant, 2017; Dos Santos, 2015; Laubach, 2014; Wang, 2013; Crawley & Emery, 2006). Strategies implemented in other interventional studies that will be discussed in detail below include: environmental redesign; reminders; scheduled daily quiet time; education; silencing

alarms quickly; staffing ratios, and modification of HCP's behaviour including altering communication such as conducting conversations and multidisciplinary shift report away from the bedside, or reducing the tone of voice when speaking near preterm neonates (Laubach, 2014; Wang, 2013; Thear, 2006).

Environmental Redesign

Strategies for sound reduction includes environmental redesign. However, TOH NICU is an open-bay design with up to nine babies being cared for in one room. In addition, construction was occurring at the time of data collection at TOH NICU. Although construction is not a regular occurrence in the NICU, regular maintenance is common, including changing lightbulbs, repair and adjustment of mechanical equipment, and cleaning activities, all of which generate sound and noise. When conducting this research, it was noted that maintenance workers were present daily in the NICU. They spoke in full conversational volume voices to HCPs and each other. In addition, equipment such as ladders, carts, and chairs, were observed being dragged across the floor and contributed to a sound measurement recorded for a maximum of 74 dB. It appeared that no attempt was made to buffer the sound created by maintenance.

The physical environment of the NICU can contribute to high sound levels. For example, an open-bay unit, with multiple neonates cared for by multiple HCPs in a single room is noisier than a unit with single-family rooms with one infant and family per room (Shahheidari & Homer, 2012). In the research conducted for this study, it was observed that the number of neonates in the room ranged from 4 to 9. Up to 34 people were observed to be present in the room. Disher and colleagues (2017) studied the outcomes of neonates cared for in single NICU rooms compared with open-bay NICUs. Their research concluded that single-room NICUs may provide a controlled, more private environment which encourages parent presence and involvement in care, and exposes neonates to less noise and light (Disher,

2017). For example, redesigning the modern NICU environment into that of a single-family room design (Disher, 2017) provides a quieter environment in comparison to the antiquated open-bay room with multiple neonates and multiple people all contributing to elevated sound levels. Stevens and colleagues (2015) reported that single-family NICU rooms were linked to a reduction in length of stay in the NICU. One explanation for this could be that the single-room NICU design provides increased parental involvement increasing developmental care of the neonate, and thus potentially decreasing length of stay in hospital (Stevens, 2015).

Laubach and colleagues (2014), suggested operational and structural changes were also required in order to provide a supportive neuroprotective environment for sleep and growth of preterm neonates (Laubach, 2014). Although Laubach reports the beneficial improvements brought on by renovation for environmental redesign, and the use of sound abatement materials with high ratings of sound absorption, such as flooring and ceiling tiles designed to reduce noise (Laubach, 2014). Environmental modifications to reduce sound in the NICU were illustrated by Ahamed and colleagues. These included lowering alarm sound intensity, the use of inline suctioning, and requiring cell phones and beepers to be turned to vibrate at infant bedsides (Ahamed, 2018).

From an environmental redesign perspective, more NICUs are moving toward single-family rooms in an attempt to provide a quieter NICU environment. The concept of restructuring of the physical layout of the NICU is an expensive financial and long-term commitment for improving sound levels, which could potentially explain why environmental redesign is undertaken cautiously and slowly. However, in the here and now, there are small changes that can be made in the NICU to improve sound levels. It should be acknowledged that, from an environmental perspective, implementing and sustaining a quiet environment in the study NICU is challenging, given the open-bay layout of the unit (see Appendix A) and the unpredictability of the population.

Reminders

Strategies for sound reduction include reminders. Reminders can be defined as a visual or auditory cue that causes someone to remember something. Reminders can help to reduce sound levels in the NICU by modifying the behaviour of HCPs. Reminders have been documented in the research as a strategy for sound reduction in the NICU with positive results (Plummer, 2018; Wang, 2013; Laubach, 2014; Cheung, 2012). A systematic review of 35 studies by Cheung (2012), reports on reminders as a strategy for improving HCP behaviour. Reminders can take many forms from simple paper Post-it reminders, to "Quiet Please" signs, to complex computerized reminders including the SoundEar (2 or 3) noise meter reminders. Cheung highlights that reminders can be effective in changing HCPs behaviour and improving processes of care, positive in changing behaviour, but also cost-effective and simple to initiate (Cheung, 2012). Reminders have been shown to be effective in the lowering of sound levels in the NICU (Laubach, et al., 2014). Sound-activated noise meters are electronic reminder tools used by many hospitals to alert HCPs that sound levels are increasing. As previously explained in the Methods chapter of this thesis, these are stationary electronic devices attached to walls in high noise areas that provide visual reminders in the form of images of ears of different colours, depending on the sound levels. As previously explained, when the noise level exceeds 45 dB, the meter displays a red ear image; when sound levels are less than 5 dB below threshold, a yellow ear image appears; and when the noise level is more than 5 dB below threshold, the meter displays a green ear image. In one study, Plummer and colleagues (2018) determined that a sound-activated noise meter could lead to a sustained reduction in sound levels in a critical care unit. The study demonstrated that the introduction of a SoundEar visual noise warning device was an isolated intervention that passively affected the volume and quality of speech of HCPs (Plummer, 2018). The median sound levels recorded by Plummer 2018, were reduced from 57.4 dB to

53.5 dB following the introduction of a visual sound meter. Although sound levels were still well above the recommended 45 dB, a reduction in sound level did occur. As previously explained and to put this into context, a difference of 3 dB represents an actual difference of 50% in terms of sound. This change becomes relevant when evaluating small changes in dB, but are related to large changes in sound intensity. The authors reported that sound-activated visual noise display meters were an effective way to reduce sound levels that would appear to be driven by behavioural change (Plummer, 2018).

Wang and colleagues studied noise reduction in the NICU using the SoundEar 2 sound-activated noise meter, which provided a visual reminder as discussed (Wang, 2014). Using this electronic sound meter device, Wang and colleagues compared sound levels obtained over a two-month period using a stationary noise meter without a visual signal, with sound levels obtained when the noise meter visually displayed the data. The researchers concluded that the sound meter that provided visual sound levels were more effective in reducing sound levels in patient care areas of the NICU, compared with having a sound meter present but not providing visual feedback during noisier and quieter periods (Wang, 2014).

In the present study the visual reminder of the SoundEar 2 displaying a coloured reminder of excessive sound was present, yet sound levels observed to remain high over the whole study period. While collecting observational data for this research it was observed that many HCPs verbally acknowledged that the SoundEar 2 was illuminated with a red ear, meaning that it exceeded the guidelines. It was observed to be illuminated almost exclusively red for the entire period of data collection, but HCPs did not appear to alter their behaviour or volume of conversation as a result. Therefore, in this case, the visual reminder of the illuminated SoundEar2 alone was insufficient to change HCP behaviour as opposed to the Wang study where it was present as a visual reminder. Anecdotally, many HCPs verbalized during the data collection for this study, that no matter how quietly they talk, the noise of the

mechanical and electronic alarms keep the SoundEar 2 in the red range, so there is no point in whispering as it will not improve the sound levels. The objective of decreasing noise in the NICU, including communicating in a whisper sound level voice, is to encourage developmentally supportive care providing preterm and sick neonates a NICU environment that supports their growth and development into healthy babies (Altimier & Phillips, 2016). It can be argued that tone of voice matters, especially when there are multiple people in the room surrounding the neonates, each independent conversation level of voice increasing the overall level of voice collectively. The argument of futility can be applied to the increased sound levels in the NICU. A HCP's outlook on increased sound levels may greatly modify one's attitude toward sound reduction strategies. Attitudes matter as a means of altering and engaging behaviour. The Wang (2014) study highlighted awareness and ongoing education as a strategy to reduce sound levels. At the present time, many HCP's have developed behaviours that contribute to increased sound levels, such as talking in full conservational level of voice. HCP's view their work environment as part of their personal space and not that of the sensitive environment of the developing preterm neonate. As educated HCPs we need to lead by example to show our HCP colleagues and NICU families in the room that reducing sound levels by talking quietly in a whisper level of voice serves the purpose of providing appropriate supportive neurodevelopmental care. This small behavioural change of lowering the conversational level of voice, could potentially cause a lowering of the sound levels at the neonates' bedside. Changing the behaviour is the key to practice change in the overall environment.

Laubach and colleagues (2014) reported in their study that HCPs required reminders to maintain recommended sound levels. In the Laubach study, the reminders that were used to decreased sound levels included visual reminders such as signage or seeing the sound meter in the unit. In our study, the SoundEar 2 did not seem to result in a change in

behaviour. Perhaps the SoundEar 3, which displays a visual dB output of the current sound level, would potentially be a more effective alternative. The direct dB sound level could provide HCPs with immediate direct feedback of the actual sound levels in addition to simply, the colour of the SoundEar, which reflects any level above 45 dB and thus would not visually differentiate the additional sound added by conversation.

In summary, reminders may be effective in reducing sound levels in the NICU (Plummer, 2018; Laubach, 2014; Wang, 2013; Cheung, 2012). The practice of reminding HCP's needs to be ongoing in order to improve the quality of sound in the NICU. As part of a multifaceted strategy for sound reduction, reminders can potentially play a part in the optimization of the NICU environment. However, reviewing the research show that the improvements are small, highlighting that reminders on their own have limited effectiveness (Wang, 2013).

Scheduled Daily Quiet Time

Strategies for sound reduction includes the practice of scheduled daily quiet time. A quiet hour intervention involves an established period daily where an active effort is made to decrease handling of neonates, noise, and to promote rest and quiet. Often lights are dimmed, doors, where possible, are shut, and elective procedures and investigations are minimized. The concept of quiet time was first introduced in the 1990s (Strauch, 1993). A study by Laubach, (2014) reported quiet time as a sound reduction strategy in their NICU. They described their quiet time guidelines as dimmed lights, sound levels kept to a minimum, and conversations encouraged in whisper tones. In addition, parents were encouraged to visit before quiet time commenced, signs were posted at all door entrances and HCPs were alerted of quiet time. They reported that staff members can also serve an important role prior to quiet time implementation by identifying perceived noise characteristics to target during quiet time (Laubach, 2014).

In the systematic review by Casavant (2017) it was found that quiet time had a significant impact on decreasing sound levels and reeducation was critical in improving HCP attitudes toward promoting quiet time (Wang, 2013; dos Santos, 2015; Laubach, 2014). The Casavant study concluded that due to the limited amount of research describing the effects of implementing noise reduction strategies, additional studies are required focusing on the implementation of quiet hours in order to enhance the knowledge base (Casavant, 2017).

In a study by Crawley & Emery (2016), they examined nursing staff attitudes toward daily quiet time before and after an implementation of a practice of initiating a program consisting of two separate daily scheduled quiet times in their NICU. Although there have been numerous strategies discussed in the research to improve neonates' neurodevelopment in the NICU, nursing staff attitudes are not well known (Crawley & Emery, 2016). The study found that HCPs were compliant and welcomed the implementation of quiet time (Crawley & Emery, 2016). Although Crawley & Emery's research makes no recommendations for clinical practice directly, it offers an opportunity for staff to examine their own personal beliefs toward scheduled daily quiet time (Crawley & Emery, 2016).

The practice of quiet time was implemented at TOH NICU where this research was conducted in 2014, and the policy was updated in 2016 (TOH, 2016), however the practice had drifted over 12 months prior to the data collection period, and communication with senior leadership revealed that quiet time had not been in practice in the NICU for a period of greater than 12 months (senior leadership, personal communication, June 10, 2019). Despite this, at the hospital where this study was conducted, reducing noise is a documented organizational priority and there are published statements indicating that quiet time occurs in the NICU (TOH, 2019; TOH 2015). The explanation given for the loss of the practice of quiet time in the NICU, was that high infant acuity made it too challenging to consistently enforce this sound reduction measure (senior leadership, personal communication, June 10,

2019). The reasons for this are multifaceted, and, as stated above, include increasing acuity with the resuscitation and survival of an increasingly extremely low gestational age (ELGA) population of neonates, the current lack of an active Developmental Care Committee, inadequate resources for education, and the fact that previous signage concerning quiet time has disappeared and has not been replaced. All are factors contributing to the lack of observable scheduled daily quiet time. In effect, quiet time practices have become nonexistent (senior management, personal communication, June 10, 2019). This highlights the challenges that can be encountered when attempting to implement best practice in the care of preterm neonates, in this case to reduce high sound levels currently recorded in the NICU and promote a supportive neurodevelopment for the neonate. There has been a significant increase in patient acuity over the past three years at the hospital where the study took place (BORN, 2010). This increased acuity was also a barrier identified by senior management and staff to sustaining a scheduled daily quiet time (senior leadership, personal communication, June 10, 2019).

In summary, there is evidence in the research literature to support daily scheduled quiet time as a sound reduction strategy. The practice of quiet time is a practical and cost-effective means of reducing sound levels in the NICU (Casavant, 2017; dos Santos et al., 2015; Laubach, 2014; Wang, 2013; Crawley, & Emery, 2006, Strauch, 1993). The current lack of quiet time in the study NICU highlights the challenges in consistently implementing and sustaining best practices.

Education

Strategies for sound reduction includes the education of HCPs. Education through workshops and information sessions has been used in several studies as a strategy to reduce sound levels in the NICU (Ahamed, 2018; Casavant, 2017; Altimier, 2015; Laubach, 2014; Hassanein, 2013; Wang, 2013; Konkani & Oakley, 2012; Milette, 2010). For example,

Milette and colleagues (2010) created a noise awareness educational program consisting of one-hour education sessions. Sound levels post education session were found to be lower, suggesting that staff education is key to modifying HCP behaviour. Wang and colleagues (2013), showed that four months after implementation of their noise reduction policy which included educational strategies, sound levels were effectively lowered in their NICU. In 2013, Wang and colleagues examined the effects of a targeted noise reduction educational strategy in their NICU. Although baseline sound levels in the study consistently exceeded the AAP guideline, the authors reported that reductions in sound levels are achievable through educational programs and adjusting monitor alarm settings. A noise reduction policy was developed, informed by best practice guidelines, existing evidence, and tailored strategies such as daily scheduled quiet time, coordination of infant care schedules to consider sleep states, and manipulation of the neonates' environment to reduce the amount of noise exposure. A result of the study supported, professional opportunities for continuing education on the benefits of quiet time, which were provided to HCPs, family, and visitors (Wang, 2013). For example, all new HCPs received education during orientation on the principles of a quiet NICU environment. They also provided professional opportunities about the environmental effects of noise to all HCPs. Finally, literature created by Wang and colleagues, was created and provided to all family and visitors regarding the benefits of a quiet environment for premature neonates (Wang et al., 2013). Laubach and colleagues (2014) developed an educational module for HCPs on the effects on the neonate and outcomes associated with excessive noise in the NICU. The educational module consisted of firstly, providing information on existing sound levels in their open-bay NICU, compared with the recommended guidelines. Secondly, the authors shared the sound levels associated with common day-to-day operational care practices. Lastly, the authors surveyed HCPs and shared the results. The result was that the authors created an environment in their NICU

which promoted buy-in and ownership by HCPs to facilitate practice change (Laubach et al., 2014). It is not known if these strategies were effective in the long term, or if change was sustained over time. There is a lack of literature about the lasting impact on educational strategies.

When discussing contributing factors to sound levels, it is valuable to examine the impact of HCPs behaviour in the NICU. Communication between HCPs in the work environment contributes to increased sound levels. Throughout the observational portion of this study, HCPs communication were the most important contributing factor to increased sound levels through twice daily shift report, multidisciplinary rounds performed at each bedside, parent teaching, sharing of vital information, and social interaction in the NICU. It is noteworthy that during data collection, three HCPs asked what data were being collected for the research, and these questions were asked of the researcher at a conversational voice volume. These questions were asked despite information being shared prior to commencement of the study via an email to all NICU HCPs. It appeared that HCPs continued their conversational voice volume at the neonates' bedsides despite being sent the information, and seeing the researcher (KM) in the room collecting sound levels and observational data. It appeared they were not altering their tone of voice or behaviour, related to the sound level audit.

Silencing Alarms Quickly

Strategies for sound reduction includes silencing alarms quickly. Most of the monitoring equipment in the NICU have alarms that alert HCPs when machines malfunction, and when infant vital signs fall outside of the pre-set parameters. There is also a "pause alarm" feature that can be pushed to silence an alarm for three minutes. Despite the multiple and frequent alarms, they are necessary to notify the HCPs to urgently act on behalf of the infant in their care. These alarms add to the sound levels in the NICU. Atia and colleagues

(2019), published a pilot RCT of an intervention aimed at reducing sound levels during skin-to-skin care. The intervention included reducing alarm volume levels from monitoring equipment. Atia and colleagues reported that the majority of HCPs considered that the interventions to reduce NICU sound levels during skin-to-skin care were acceptable and did not interfere with their care delivery. Altimier and colleagues (2015) examined the effects of addressing alarming monitors quickly. They recommended strategies based on developmental care principals for reducing sound levels in the NICU through an evidence-based total change management program designed to optimize the NICU environment and caregiving practices. The effect of their comprehensive developmental care training program was shown to be beneficial based on the neuroprotective care measures through the incorporation of evidence-based literature, and standardized clinical practices for all staff. The seven neuroprotective core measures are: healing environment (including the measurement of noise levels in dB), partnering with families, positioning and handling, safeguarding sleep, minimizing stress and pain, protecting skin, and optimizing nutrition (Altimier, 2015).

In this current study, it was observed that few staff consistently silenced alarms quickly or used the "pause alarm" feature. The researcher (KM) observed very few HCPs actively silencing monitor alarms in less than three minutes. This practice of allowing monitor alarms to ring unnecessarily contributes to the increased sound levels in the room. When considering this behaviour there are two issues to address: firstly, the behaviour of HCPs in not silencing the alarms, and secondly, the reason for the alarms themselves. Most of the monitoring equipment was observed to alarm when infant vital signs fell outside of the pre-set parameters. Despite the multiple and frequent alarms, the alarms were not silenced in a quick manner of less than three minutes. There were times during this study when the alarming of monitor alarms was continuous despite the cardiopulmonary monitor having a three-minute "pause alarm" feature. Working in the NICU is a highly stressful job and alarm

fatigue is high among HCP (Sendelbach & Funk, 2013). Providing a quiet sound environment is not only important for optimization of the environment for the preterm and sick neonates in the NICU, but also ultimately supports the quality of HCP's personal health. Similar to not decreasing the level of conversational voice, by not quickly and actively silencing alarming monitors, the HCP's behaviour can be viewed as a failure to provide developmentally supportive care to the preterm neonates. However, silencing alarms quickly can be extremely challenging for the HCPs. As noted during observational data collection, if care was being provided to a specific infant in one part of the room, and another infant's cardiac monitor was alarming, it was impossible for the HCP caring for both neonates to silence the alarm quickly. The monitor alarms would ring continuously until the HCP could finish their task and go to the alarming monitor to silence the alarm. This challenge would only increase with increasing acuity. This may also relate to being understaffed. As highlighted in the literature, hospital NICUs are understaffed by 31% to 68% when compared with recommended safe staffing guidelines (Rogowski et al., 2013).

The work performed by HCPs in the NICU can be both physically and psychologically demanding, especially with shifts that have high alarm counts. Another contributor to elevated sound levels can be alarm fatigue. Alarm fatigue is defined as desensitization to alarm sounds, resulting in HCPs not responding to alarms quickly (Sendelbach & Funk, 2013). Sendelbach & Funk (2013) reported alarm fatigue in staff members working in an environment where they were exposed to high numbers of alarms, which contributed to sensory overload. However, Sendelbach & Funk, also noted that rigorous clinical trials are necessary to determine if reducing alarm burden will compromise patient safety (Sendelbach & Funk, 2013). Rogowski et al. (2013), identified adequate staffing as an important factor in managing patient alarms. They also reported on quality improvement projects that have employed strategies to reduce sound levels such as daily

changes of cardiac electrodes with proper skin preparation so that the electrodes do not lift off of the neonates' skin, HCP-targeted education, and customization of alarm parameters. NICUs have an abundance of monitoring equipment with alarms that ring frequently. During the study data collection periods, large numbers of alarms occurred on all shifts studied, with one shift (day shift #6) recording over 800 alarms. This number of alarms is shockingly high, especially as in many cases there were multiple alarms ringing simultaneously, which often continued to alarm for extended periods (an extended period is defined as a time that exceeds 5 minutes). There were very few times in a shift when a monitor alarm was not ringing. Therefore, alarm fatigue may be considered to be contributing to the elevated sound levels. As discussed, alarm fatigue can also be partly attributed to workloads and staffing.

The number of alarms in this current study, may be partially attributed to the age of ventilators/monitors used in the NICU. The age of the ventilators in this NICU was reported by the hospital Biomedical Engineering department to be between one and seven years old, depending upon the model. This is relevant because it speaks to the factors of aging equipment, lack of resources, and the standards of sound, depending upon the model. If the ventilator equipment is outdated and contributes to the alarm count for the shift, then it is a contributing factor to the alarm fatigue experienced by HCPs. During the study period a ventilator had to be borrowed from another hospital to meet the physical demands of the premature neonates present in the NICU at the time. In other words, the requirements of the neonates present in the NICU at the time were greater than the available lifesaving equipment. By contrast, there was also a time period during the week of evening shift data collection where there were no ventilators in use in the room where data collection took place. It must be noted that this is an unusual occurrence. In summary, the NICU is a high alarm environment and HCPs can potentially suffer from alarm fatigue. Reduction in the number of excessive alarms requires appropriate staff-to-infant ratios, so that HCPs can

respond to alarms more quickly. There are strategies to reduce the number of alarms in intensive care settings, which may in turn help to prevent alarm fatigue among HCPs. Effective strategies reported include adequate staffing, education, and the customization of alarms (Sendelbach & Funk, 2013; Kahn, 1998).

Staffing Ratios

The staff-to-infant ratio has been shown to affect increased sound levels in the NICU. A retrospective study done by Rogowski and colleagues (2013) reported that in the USA, substantial understaffing in NICUs is prevalent, despite national staffing ratio guidelines. The national guidelines specify a range of nurse-to-patient ratios across infant acuity levels. For example, neonates with the lowest acuity levels have a recommended nurse-to-patient ratio of 1:3. In contrast, the highest acuity neonates have recommended ratios of 1:1 (one nurse per patient) (AAP, 2007), yet understaffing occurs 31% to 68% of the time (Rogowski et al., 2013). Even though this research by Rogowski and colleagues was conducted in the USA, it is relevant to the Canadian context, where researchers have noted that there is also long-standing understaffing of nurses in Canadian NICUs (Drebit et al., 2010; Oulton, 2006). This research supports the notion that high staffing ratios can be a factor in increased sound levels in the NICU, and explains why that may lead to difficulty silencing alarms in a timely manner. Although staff-to-infant ratio was not specifically measured in this current study, it was observed as another factor that impacted the sound levels as reported by Rogowski (2013) and colleagues. They reported widespread and substantial NICU nurse understaffing, relative to the national guidelines. Their results documented one-third of NICU infants were understaffed, and the greatest variation of 68%, was for the most complex critical care unit (Rogowski, et al., 2013). Rogowski and colleagues reported that to meet the minimum staffing guidelines on average would require an additional 0.11 of nursing staff per infant overall, and 0.34 of nursing staff per high acuity infant (Rogowski, 2013). While the

Rogowski study is related to nurse staffing and infection rates, the practice of appropriate staffing ratios to neonates can also apply to neonates of high acuity in a level III NICU. Understaffing and high acuity of the neonates are an impediment to sound level reduction (Almadhoob & Ohlsson, 2013). Standardized definitions for neonatal acuity levels of care were developed by the Provincial Council for Maternal and Child Health (February 2008) and are aligned with the Ontario Medical Association policy on Maternal and Newborn Care in Ontario. Acuity-based staffing guidelines for neonatal nursing were last updated in 2013 by the Provincial Council for Maternal and Child Health. It is not known how well the guidelines are followed or how guideline adherence relates to infant outcomes (Rogowski, et al., 2013).

When collecting observational data for this thesis for example, it was observed that for a HCP-to-infant ratio of 1:1, the reaction time is almost immediate to silence any monitor or ventilator alarms for the infant being cared for. If the HCP-to-infant ratio is 1:2, the HCP will be inevitably be slower to respond, as there will be events occurring with one infant while the demands of the second infant may occur simultaneously. If an HCP has a 1:3 ratio assignment, then it stands to reason that attention to silencing alarms in a timely manner is difficult to achieve when the HCP's focus may be elsewhere.

Behaviour Modification

Strategies for sound reduction includes behaviour modification. Behaviour modification can be defined as changing HCP's behaviour using motivational techniques, either consequences or rewards, by changing the environment and offering incentives. Kahn and colleagues (1998) highlight a behaviour modification strategy to reduce sound levels focusing on HCPs. In this study, the researchers suggested that conversations be held away from the bedside because conversations accounted for 49% of sound levels (Khan, 1998). This behaviour modification resulted in a 20% decrease in noise (Khan, 1998). At TOH

NICU, it is the current standard of care for nursing and medical handover to be conducted at the patient bedside, including multidisciplinary rounds. This is in contrast to Kahn and colleagues' recommendations to conduct conversations away from the bedside. In a more recent study by Wang and colleagues (2013), the noise reduction policy implemented in their NICU also included recommendations that conversations and multidisciplinary rounds take place away from the bedside (Wang, 2013).

In addition to staff conversation affecting the sick and preterm neonates, the high sound levels produced by conversation can also affect the staff. A recent study published by Terzi and colleagues (2019), reported that high sound levels of 71 dB in the NICU affected nurses' job satisfaction and anxiety levels. The study suggested that increased quality of patient care could be achieved by providing healthy working conditions including lower sound levels for nurses working in speciality units such as NICUs (Terzi, 2019). In addition to generally high sound levels, this study noted that HCP conversation sound levels were recorded at 67.2 dB, which is well above the recommendations of 45 dB. Staff anxiety and job satisfaction become relevant when staff retention is an issue in particular NICUs (Terzi, 2019).

In summary, the strategies to decrease sound levels in the NICU include environmental redesign, reminders, scheduled daily quiet time, education, silencing alarms quickly, staffing ratios, and behaviour modification (Atia, 2019; Disher, 2017; Altimier, 2015; Almadhoob & Ohlsson, 2013; Sendelbach & Funk, 2013; Wang, 2013; Bremmer, 2003; Khan, 1998). These strategies have all been shown to lead to a reduction of excessively high sound levels.

Additional Factors Contributing to Sound Levels

Patient factors may also contribute to elevated sound levels in the NICU. The preterm neonates themselves contribute to the sound level. Preterm and sick neonates cry, which often

sets off the monitor alarms indicating their vital signs are outside the range of the pre-set parameters. In this study it was observed that as the number of neonates and HCPs in the NICU increased, the sound levels appeared to increase. It was also observed that the sicker a baby was, (in other words, the higher the acuity) the more sound generated at the bedside, due to more HCP conversations, more lifesaving interventions, more alarms from cardiopulmonary instability, more IV pumps, and more medications requiring a second nurse to verify dosage.

In this thesis, it was demonstrated that a positive relationship between mean sound level and infant acuity exists, such that for each one-point increase in infant acuity there was an increase in sound level of 0.15 dB. This relationship can be summarized by saying the sicker the infant, the louder the NICU. No other studies that report on infant acuity and the relationship to increased sound levels have been found to date. However, sound levels have been found to be higher in level III NICUs compared with level II NICUs, implying that increased noise is associated with increased acuity and level of care with the associated technologies that are utilized in the complex NICU environment (Levy, 2003).

Hearing Loss in Preterm Neonates

Periods of increased sound can adversely affect sick neonates. In this current study, the mean sound levels were 83.5 dB for day shifts. This level of sound is above the recommendations and potentially puts preterm neonates being cared for in this NICU at greater risk for hearing loss (Almadhoob, & Ohlsson, 2015). The long-term effects of excessive sound levels include increased risk of hearing impairment, which is diagnosed in 2% to 10 % of preterm neonates versus 0.1% of the general term population (Almadhoob & Ohlsson, 2015). The exposure to sound levels above 45 dB may result in cochlear damage, resulting in hearing deficits in premature neonates (Etzel, Balk, Bearer, & Miller 1997).

The physiological effects on the undeveloped preterm neonate can potentially contribute to hearing issues. A study done by Williams (2009) reported that noisy events resulted in significant changes in vital signs for preterm neonates, especially when compared with full-term neonates. Events of acute distress in response to increased sound levels were also reported by Darcy and colleagues (2008), and they suggest that this can lead to life-threatening situations, such as sudden and severe decrease in oxygen saturation, as well as apneic and bradycardic events. A study done by White-Traut (2009), reported that preterm neonates were more vulnerable to sound and took longer to habituate. The definition of habituate is to become accustomed or used to the sounds and noise. A study by Wachman and Lahav (2010) reports on the physiological effects of excess noise on neonates in the NICU, stating that sustained noise in the NICU may cause apnea, hypoxemia, alteration in oxygen saturation, and increased oxygen consumption, and may contribute to an increase in the calories required for adequate nutrition and growth. Wachman and Lahav also report that electrical activity of the neonate's central nervous system changes in response to noise stimulation in the range from 36 dB to 90 dB. (Wachman & Lahav, 2010). Excessive noise may also influence the neuroendocrine system and may have an indirect effect on immunity (Wachman & Lahav, 2010).

The Canadian Pediatric Society (CPS) in 2011 released a position statement indicating that universal newborn hearing screening is essential and that delayed diagnosis of hearing deficits leads to significant harm for children and their families. However, when universal newborn hearing screening, diagnosis, and intervention occur early, it translates to improved language outcomes (Patel & Feldman, CPS, 2011). In the NICU where this study was conducted, hearing screening was previously conducted in the hospital but in 2019, was switched to the outpatient setting (Province of Ontario). This change of practice potentially takes the focus of hearing issues away from the NICU and places hearing screening issues

into the community. If being a neonate in the NICU is a contributing factor for hearing loss, then hospitals which do not screen for hearing have potentially transferred accountability of hearing issues to the community. It is unclear how many parents will have their infants hearing tested in the community after discharge from the NICU, and how many parents may view hearing testing as an option and choose to opt out. It is unknown the compliance rate of hearing tests now that testing is not done in the NICU and has moved to the community. The purpose of hearing screening is to identify neonates with permanent hearing loss, support language development, and monitor children at risk for hearing loss (EOIHP, 2019). In Ontario, Canada, it is recommended that all infants under 2 months of age should be tested. According to the Eastern Ontario Infant Hearing Program it is reported that 4 out of 1,000 infants have hearing loss at birth or before age five (EOIHP, 2019).

Knowledge Translation

It is beneficial to be able to identify the relationships between elevated sound levels and the variables that contribute to them. In the study NICU, key factors contributing to elevated sound levels included: conversations (including multidisciplinary rounds) carried on at the bedside with full volume conversational voice, alarms ringing for prolonged periods, and the lack of a daily scheduled quiet time practice. Understanding the relationships between high sound levels and contributing factors can lead to the next step of identifying what can be done to potentially reduce the impact of elevated sound levels. In addition, examining practices, policies, and interventions employed in other NICUs, in other hospitals, and in other countries, can help us gain an understanding of what can be done at our local level. Not all NICUs have the same infant population, acuity level, capacity, or environmental layout. Some NICUs serve a very different population of neonates than the NICU where this study was conducted. However, the end goal of sound reduction is universal for all NICUs and can also be applied to other parts of the very complex hospital

environment. In order for this research to be used by others, there has to be practical applications.

In the book *Diffusion of Innovation* (Rogers, 2003), author Everett Rogers explains that the way an innovation is communicated over time among members of a social system is part of the solution leading to change and sustainability. Rogers explains that the members of an organization are involved in the innovation process (Rogers, 2003, pp.429). This thesis explores the sound levels in the NICU and characterizes some contributing factors to those levels. At this point, if: i) sound levels are elevated in the NICU; ii) elevated sound levels negatively impact the preterm neonates; and iii) nurses are responsible for advocating to protect their patients from adverse outcomes, then why are the sound levels in the NICU still higher than the AAP recommendation? This problem of noise has continued for many years with some hospitals taking note and creating strategies for optimizing sound levels, such as environmental redesign to single-family rooms, the implementation of daily scheduled quiet time, silencing alarms, reminders, and education (Disher, 2016).

Presseau et al. (2019) discuss how implementation of interventions to change behaviour of HCP's require detailed specification of the behaviours targeted for change to ensure alignment between the intervention components and measured outcomes (Presseau, et al., 2019). For future research, detailed descriptions of behaviours and their changes will become critical in order to clarify behaviours of stakeholders across multiple levels of the health care system (Presseau, et al., 2019).

In summary, for future research, education has the potential to facilitate the reduction of sound levels in the NICU through behaviour modification. The elevated sound level in the NICU is a complicated and complex problem. There is no general consensus in the literature or single independent intervention that can solve the issue. Initiatives including customized learning, the provision of educational opportunities for new staff at orientation, the sharing of

baseline information, the creation of literature for families and visitors, and surveys to promote ownership and buy-in from HCPs have all been demonstrated to be effective (Ahamed, 2018; Casavant, 2017; Altimier 2015; Laubach, 2014; Hassanein, 2013; Wang, 2013; Konkani & Oakley, 2012; Milette, 2010). Certainly, educational interventions are a strategy for knowledge implementation, but it must be kept in mind that the audience for KTA is larger than just HCPs who are the usual targets for continuing medical, nursing, and professional development in the NICU. Strategies for KTA vary according to the targeted audience and all levels of HCPs, families, visitors, and staff must be part of the significant collaboration when developing strategies for practice change. Designing implementation interventions to change behaviour of HCP's and other professionals in the health care system requires detailed specification of the behaviours targeted for change (Presseau, et al., 2019). We can therefore build on current research of the baseline sound level data and contributing factors to the sound levels, to move forward to action, thus engaging the KTA cycle, with the end goal of reducing sound levels in the NICU and optimizing infant outcomes.

Implications for Current Practice

Nurses are frontline HCPs and as such have a professional responsibility to maintain a high standard of professional practice through patient advocacy (CNO, 2012). The College of Nurses of Ontario highlights a professional standard of accountability that includes advocacy by nurses for their patients as a key indicator (CNO, 2012). Nurses are governed by a self-regulating body, and have a responsibility to provide the highest quality of nursing care to their clients through the guiding principles of standards of practice.

Nurses can also demonstrate a high professional standard through the dissemination of knowledge by sharing research findings to other HCPs in the local setting of the NICU and through the communication of evidence-based practice. Nurses are in a unique position as a profession to lead by example through the modelling of effective behaviours in promoting a

quiet environment in the NICU. For example, there is some empirical evidence to support whisper conversations at the bedside and daily scheduled quiet time (Casavant, 2017; dos Santos et al., 2015; Laubach, 2014; Wang, 2013; Crawley, & Emery, 2006, Strauch, 1993). Therefore, by considering sound level management in the NICU as an essential component of each nurses' professional role in caring for their preterm neonatal patients, and by providing an environment of quiet to enhance growth and neurodevelopment of this vulnerable population, nurses can become role models for other HCPs through leading by example.

The most important gap to report is the gap between the evidence and current practice in the NICU. For example, the evidence tells us that sound levels are higher than the recommendation, but the practice is that HCPs still contribute to excessive sound levels. This was observed in practices such as not silencing monitor alarms quickly, participation in conversational level discussions at the bedside and during multidisciplinary rounds, slamming blanket warmer doors, and dropping items on the floor.

This research examined the current baseline sound levels in a tertiary care open-bay room, level III NICU in Ottawa, Canada. A finding of this research showed elevated sound levels, consistently high above the recommended level of 45 dB. As previously mentioned, several research groups have attempted to pressure the AAP to re-evaluate and update the current baseline standard of 45 dB, as this standard is consistently being exceeded, and some claim that it is unattainable (Smith et al., 2018). One study reported that sound levels in the NICU exceeded the AAP recommendation of 45 dB more than 70% of the time (Darcy, 2008). In our NICU, sound levels exceeded the recommended 45 dB sound level, 100% of the time. It is implied through this thesis that the 45 dB may be too low of a standard, and that the recommendation for sound level needs to be revised to an attainable level. Previous studies by Wang (2013) and colleagues reported 49 dB as an average noise level in an empty room. To date, researchers have not been successful in convincing the AAP to modify its

standard sound level recommendation of 45 dB (Smith, et al., 2018). Research shows that levels above 45 dB are known to adversely affect preterm neonatal outcomes (Philpott-Robinson 2017). Which demonstrates an impossible situation. A number of suggestions for changing clinical practice can be recommended in order to reduce sound levels in the NICU. These include reducing or removing conversations from the bedside (including multidisciplinary rounds); ensuring voice levels are in a whisper or lower register at the bedside; silencing alarming monitors quickly; reinstating daily scheduled quiet times, and reinstating/creating a Developmental Care Committee to focus on aspects of developmental care of the preterm infant. The Developmental Care Committee could facilitate the provision of evidence-based care to the premature population, and also could educate fellow colleagues. Reminders to reduce sound levels could be directed at HCPs and others in the NICU when the sound levels are elevated through the use of the SoundEar 3 and/or newly created signage.

Implications for Future Research

An immediate way forward for this research begins by disseminating the baseline sound level results back to the HCPs in the NICU of the current study. It is clear from past research that knowledge creation, distillation, and dissemination are not enough to ensure behaviour change. Effective implementation is critical. Ongoing education is essential. The next step could be to provide HCPs with feedback and knowledge about current practices in the context of sound levels in the NICU. Following this, a barrier and facilitator assessment of HCP's perceptions of elevated sound levels could potentially be conducted to plan interventions to reduce sound levels. This would give HCPs ownership of the problem and begin the development of possible solutions to reduce sound levels. Authors of a Cochrane systematic review concluded that interventions tailored to prospectively identified barriers are more likely to improve professional practice than other interventions (Baker 2010). Using

the KTA framework by Graham and Tetroe (2010) to select, tailor, and implement interventions could provide the needed structure to reach the goal of reducing sound levels in the NICU.

Future research means translating the knowledge into action. Now that we are aware that sound levels in this NICU are above the recommendation of the AAP, action must be taken. The KTA is a process where knowledge creation is part of tailoring knowledge to the know/do gap which requires action by the potential users of the knowledge (Graham & Tetroe, 2010). Within the KTA framework the next steps are: i) adapting knowledge to the local context; ii) assessing the barriers and facilitators to the knowledge use; iii) selecting, tailoring, and implementing interventions; iv) monitoring knowledge use; v) evaluating outcomes; and vi) sustaining knowledge use (Graham, 2012).

Further research, focused on effective sustainable ways to reduce sound levels in this and other NICU settings, including different parts of the NICU including inside the isolette is warranted. Research could include an evaluation of the long-term effect of different noise reduction protocols on the growth and development of preterm neonates. Potential future research could also include an integrated KTA research approach that would operationalize the know/do cycle, for example, engaging individual HCPs to take ownership of the management of sound levels in the NICU, through a barrier and facilitator assessment, thus continuing the KTA cycle of knowledge creation (Graham, 2012). The effect of education in reducing noise levels were reported in a study by Incekar, and colleagues (2019). Their results showed that noise levels were significantly lower 6 weeks after the education program compared with before the program ($p < 0.01$). They suggested that the education was effective in terms of reducing noise levels in the environment, and positively affecting the behaviours of the HCP. It can be concluded that the sustainability of educational programs

must be targeted, individualized, and ongoing in order to sustain a "culture of quiet" in the NICU.

The sound levels collected in this study can potentially relate back to the local context of the NICU, assisting the synthesis of the evidence collected, and is part of the dissemination of the results that must be shared with the HCP's. The development of high-quality guidelines for noise reduction will be valuable tools for providing quality care in the NICU. However, although sound reduction guidelines are necessary, they are not enough to ensure that practice is evidence-based. Guidelines must be adapted to daily practice in the individual NICU in order to reduce the gap between guideline recommendation and delivering care to the preterm population. The elevated sound level in the NICU is a complicated and complex problem. There is no general consensus in the literature or single independent intervention that can solve the issue. An opportunity for the reduction of sound levels through interventions exist for future research studies in the NICU.

The quality improvement initiative by Ahamed and colleagues created a change in culture in their NICU, by including collaboration between designated noise champions, HCPs, and families. The role of noise monitor or "champion of change" is also discussed by Rogers (2003). The presence of a champion can increase the success of an innovation. Therefore, the designation of a staff member as a "noise champion," can potentially reduce the sound levels in the NICU.

Strengths and Limitations

A key strength of this study was the fact that baseline sound data collection and observational data collection occurred simultaneously. Data collection was carried out by a sole researcher familiar with the environment, in the same way each shift, thus ensuring reliability of measurements. The purpose of the data collection was to establish a baseline sound level measurement and to identify key factors that influence sound levels in the NICU.

These goals were met. The portable sound meter measured sound continuously, and recorded over 8-hour periods for the period of a week during each of three shifts: days (0600-1400), evenings (1500-2200), and nights (2300-0500) in order to capture variations in sound levels. Sound measurements were taken during three different weeks, over a total of 19 different time periods. The strength of this method is that large amounts of data (both sound level and observational data) were collected, which were comprehensive and detailed. The present study compares to other studies as it confirms that sound levels in the NICU are above the AAP recommendation of 45 dB, and highlights key factors that contributed to the elevated sound levels.

This is potentially the first study to conduct a multivariate linear regression analysis of sound levels in the NICU and observational factors that contribute to those sound levels, such as number of people in the room, number of neonates in the room, number of alarms, infant acuity, and shift type. The findings of this study provide a baseline for knowledge inquiry for HCPs in the NICU. This study provides needed information to further knowledge inquiry to the identified problem of sound levels in the NICU, which will ultimately improve premature infant outcomes.

Despite the strengths of the study, there were also some limitations. Limitations include the large number of variables present in the NICU environment that were not observed or evaluated, and which potentially alter the context of the sound levels. It would be challenging to record all the variables that contribute to sound levels while collecting observational data. For example, with large numbers of people entering and exiting the room simultaneously, it was challenging to count. In addition, the extremely frequent monitor alarms were challenging to count. Alarms rang almost constantly, and there were often multiple alarms ringing simultaneously. The stopwatch proved to be a valuable resource in aiding the attempt to count the number of people and number of alarms accurately.

Another potential limitation to this study was the fact that the researcher was visible to others on the unit while data were being collected. It was anticipated that this could potentially alter behaviour of study participants related to the Hawthorne effect. The Hawthorne effect is defined as behavioural change of research participants due to an awareness of being observed (Wickstrom & Bendix, 2000). Chiesa and Hobbs argue that without specifying the dimension of the Hawthorne effect and contextual information, researchers forfeit the opportunity to defend their research findings from bias (Chiesa & Hobbs, 2008). Over the course of the study, only three people asked what data were being collected and what exactly was being recorded and documented. It appeared that HCPs were speaking most times, in a medium level of conversational volume at the bedside, and the amount of casual conversations continued as normally would, regardless of research being conducted on sound levels in an unconcealed manner. Oftentimes HCPs were observed talking to each other from different rooms. As a result, the Hawthorne effect was not felt to be a factor evident during the collection of observational data in this study.

One drawback to the use of unconcealed observational research can be reactivity. Reactivity is defined as the participants' responses to being studied (Lobiondo-Wood & Haber, 2013). Reactivity calls into question the possibility of the Hawthorne effect (or observer effect), a type of reactivity in which individuals modify their behaviour as a result of their awareness of being observed. However, as stated, this did not seem to occur in this study as HCP's carried on with a normal volume of conversation and were not observed modifying their level of voice neither higher nor lower.

In addition to the normal sound levels in the NICU, the construction activity was itself a limitation, as this generated unusual noise that contributed to the increased recorded sound levels. During the period of data collection, some neonates had to be moved to other rooms in the unit in order to allow for wires to be pulled through the ceiling for the installation of a

new computer system in the hospital. The construction activity may have contributed to the sound levels as well as altering the infant census and the normal activity of the room where data were being collected. In terms of relative acuity levels, the room where data collection occurred usually contained the sickest and the most premature neonates in the NICU (highest acuity). However, averaged over the 19 days of data collection, it is considered that the data collected is a fair representation of the overall level of acuity in the NICU, in spite of the changes that occurred due to construction, conversations, and other activities.

Conclusion

This Master of Science in Nursing thesis has explored the actual sound levels of a tertiary care Canadian level III NICU over the course of 21 days of data collection with 19 different shifts analyzed. Findings reinforce that sound levels are consistently higher than the AAP recommendations of 45 dB. The results identify important factors that contribute to overall sound levels, and which have important implications for HCPs who care for premature neonates in the NICU. Environmental factors contribute to high sound levels which can adversely affect preterm and sick neonates' growth and neurodevelopment. Factors contributing to elevated sound levels in the NICU include the number of people in the room, the number of neonates in the room, the number of alarms present, the infant acuity, and the shift type (day, evening, or night). Therefore, further studies should evaluate interventions to reduce sound levels in the NICU. Short-term solutions for the reduction of sound levels include behavioural strategies such as: silencing monitor alarms, using whisper quiet conversations at the bedside during care and during multidisciplinary rounds, and daily scheduled quiet time. Long-term solutions include environmental redesign to single-family rooms and the use of sound absorption materials in the unit environment. Optimal environmental layout of the NICU will potentially contribute to lower sound levels in the future.

Nurses must provide best practice and a high standard of care to the preterm neonate population as mandated by the College of Nurses of Ontario (2012). It is through the promotion of a quiet environment, with a reduction in unnecessary sound levels, that the preterm neonate's growth and neurodevelopment can be best improved. These research findings serve as a baseline for future KT research. It is hoped that this sound level audit will be a catalyst for discussions around practice, policy, research, and education. What we can do today is share the results of this baseline sound audit with the HCPs working in the NICU at

the hospital where the data were collected, in order to bring awareness to the deleterious effects of sound on the preterm neonate's growth and neurodevelopment.

In conclusion, this thesis research highlights that HCPs have more work to do in order to reduce sound levels in the NICU. We would be well advised to continue the example of Florence Nightingale, employing direct strategies that are within our capabilities and based on current research. Through the KTA cycle, it is imperative to understand how to advance current knowledge to create new knowledge when applying the current baseline sound levels in the NICU. The strength of KTA lies in the systems perspective, and falls within the social constructivist paradigm which promotes social interaction and adaptation of current research evidence, taking local context and culture into account (Graham & Tetroe, 2010). All HCPs have the opportunity to make change, and we must support and empower each other in the goal of providing high-quality care to our most vulnerable population, preterm neonates, by ensuring optimal sound levels, and promoting a culture of quiet in the NICU. Essentially, understanding current sound levels in the NICU can help establish the developmental care principals surrounding the care of preterm neonates, which could potentially provide a sound reduction. The application of the baseline sound level data has started the cycle of KTA by identifying the problem of consistently high sound levels. This research study can contribute to the body of knowledge for nursing and other HCP's as a foundation to build on research in future studies. The KTA framework was designed to be used by a broad range of audiences working in diverse contexts (Graham & Tetroe, 2010); this has a direct application to this study which can be used to guide the HCPs in provision of developmentally supportive care to the preterm neonatal population by reducing sound levels in the NICU.

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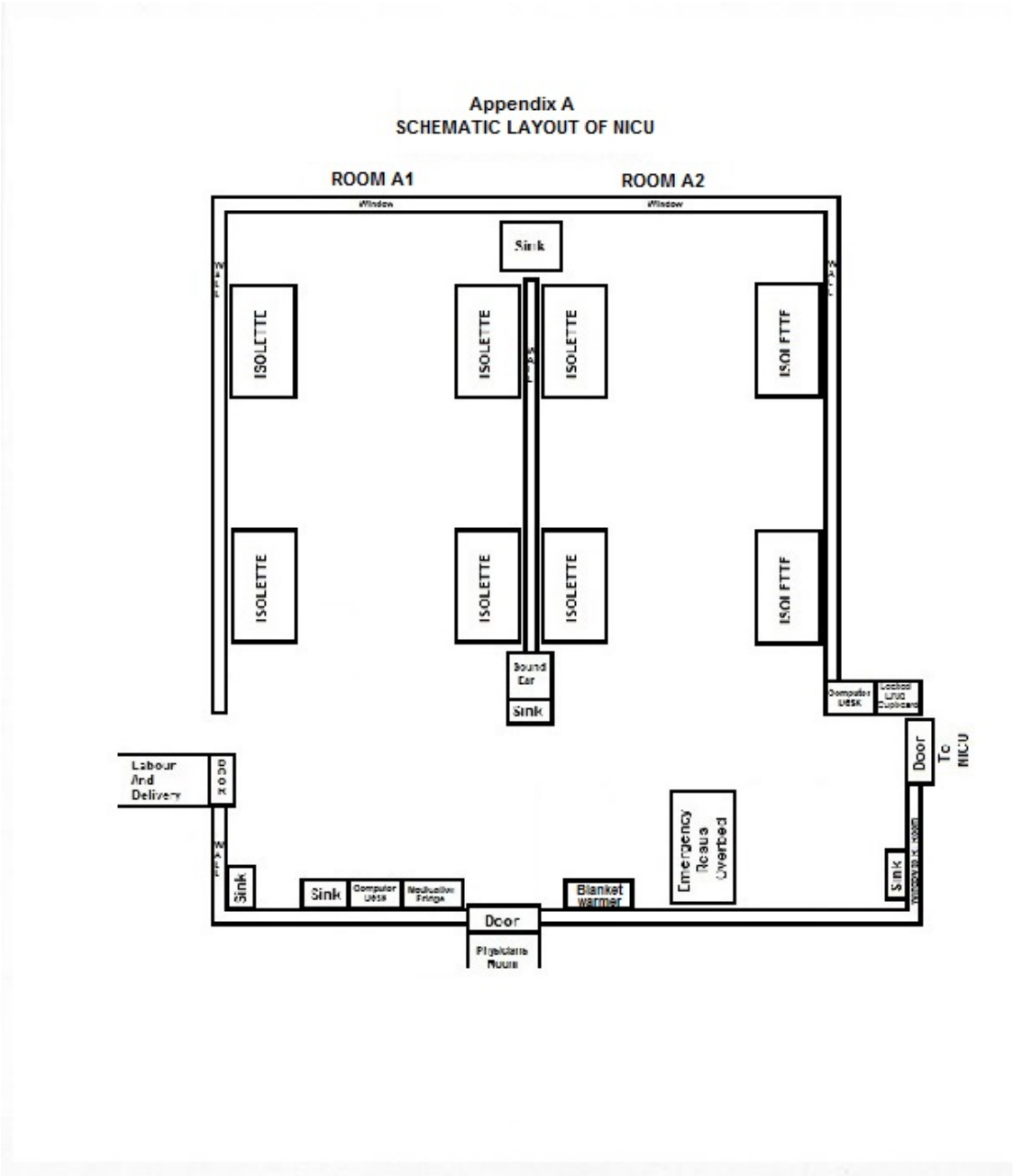
Appendices

Appendix A Schematic Layout of NICU



Appendix B Observational Data Collection

Acuity of Neonate	# of HCP	# of Neonates	# of Parents	# of Visitors	# of IV/per baby	# of Suctioning Events	# of Vents	# of NCPAP	# of alarms	# of Emergency Events

Appendix C Research Ethics Approval Letter – OHRI

The Ottawa Hospital RESEARCH INSTITUTE | L'Hôpital d'Ottawa INSTITUT DE RECHERCHE

February 07, 2019

Ms. Kelli Mayhew

Re: OHRI Institutional Approval for Ottawa Health Science Network Research Ethics Board (OHSN-REB) Submission

20190068-01H;

Sound Levels in the Neonatal Intensive Care Unit: What are they?

Dear Ms. Kelli Mayhew,

This letter serves as **Ottawa Hospital Research Institute (OHRI)** Institutional Approval for the above-referenced study. Please maintain this documentation in your investigator study file.

Based on the information you provided about this study through the Clinical Research Registration Form, you have satisfied the requirements for institutional (OHRI) approval. This includes initial research ethics approval by OHSN-REB, appropriate departmental/service area notifications and execution (fully signed versions) of all agreement(s) required to begin the study locally. Please note there may be additional agreement(s) pending execution that are required to send funds, samples, or data to external sites, but are not required for you to begin your study locally.

Changes and/or additions to your study that may require additional agreement(s) or revisions to existing agreement(s) must be communicated to the OHRI Contracts Office. This should be undertaken simultaneously with any related OHSN-REB amendment submission.

Changes and/or additions to your study that affect various hospital/institution departments (e.g., pharmacy, Department of Medical Imaging, EORLA, EEG, etc.) must be communicated to the relevant departments.

As mentioned in the 'Response' tab of the Ethics application, you have 3 months from the date of initial OHSN-REB approval to submit French documents including the translation certificate to OHSN-REB through the Translated Documents section of the ethics application (if applicable).

Should you have any questions, please contact REBadministration@ohri.ca or 613-798-5555 extension 16719.

Director, Clinical Research Administration
Ottawa Hospital Research Institute | Institut de recherche de l'Hôpital d'Ottawa

Civic Campus, Box 675, 725 Parkdale Avenue, Ottawa, Ontario, K1Y 4E9
613-798-5555 extension 16719 Fax : 613-761-4311 http://www.ohri.ca/ohsn-reb

Appendix D Research Ethics Approval Letter – University of Ottawa

04/03/2019

Université d'Ottawa
Bureau d'éthique et d'intégrité de la recherche

University of Ottawa
Office of Research Ethics and Integrity

Lettre d'approbation administrative I Letter of administrative approval

Numéro de dossier / Ethics File Number	H-02-19-2759
Titre du projet / Project Title	Sound Levels in the Neonatal Intensive Care Unit: What Are They?
Type de projet / Project Type	Thèse de maîtrise / Master's thesis
CÉR primaire / Primary REB	Réseau de science de la santé d'Ottawa (RSSO) / Ottawa Health Science Network (OHSN)
Statut du projet / Project Status	Approuvé / Approved
Date d'approbation (jj/mm/aaaa) / Approval Date (dd/mm/yyyy)	04/03/2019
Date d'expiration (jj/mm/aaaa) / Expiry Date (dd/mm/yyyy)	07/02/2020

Équipe de recherche / Research Team

Chercheur / Researcher	Affiliation	Role
Kelli MAYHEW	École des sciences infirmières / School of Nursing	Chercheur Principal / Principal Investigator
Denise HARRISON	École des sciences infirmières / School of Nursing	Superviseur / Supervisor
Sarah LAWRENCE	CHEO/TOHGC	Co-chercheur / Co-investigator
Janet Elaine SQUIRES	École des sciences infirmières / School of Nursing	Co-superviseur / Co-supervisor

Conditions spéciales ou commentaires / Special conditions or comments:

OHSN REB # 20190068-01H

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