Noise pollution in the NICU

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Background:

Neonatology is a relatively new field in medicine, tracing its roots to 1878 and the invention of the incubator (Dazé Floyd, 2005). Although this device revolutionized care given to these premature babies by keeping them warm, it still did not have much impact on survival rates. Survival rates were so low that from 1896 to 1939, these preterm babies were treated more as artifacts than human lives, used throughout the world as exhibits for thousands to view—the World Exposition in Berlin, Coney Island, etcetera (Dazé Floyd, 2005). Around 1939, survival rates began increasing due to the treatment regimen of separation from mother, attentive care by nurses and wet nurses, prohibited visits by children, and limited visiting time; yet care still open for public viewing in open, multi-patient wards with large windows (Dazé Floyd, 2005).

Although public patient viewing was not the norm for patient care, the use of multi-patient wards was during this time period. In the late 1970s, multi-patient rooms were phased out in favor of private or semi-private rooms (Dazé Floyd, 2005). Yet, neonatal intensive care units (NICUs) remained preserved in the past trends of multi-patient wards due to: the desire to maintain status quo, the spatial needs due the large influx of patients due to infant mortality rates plummeting (dropping 22% 1990-2000), the severe shortage of nurses, and the desire to have the babies monitored constantly to note any physiological changes (Dazé Floyd, 2005; Dureau, 2005).

Technological advances in equipment—including monitors and alarms that did not demand the constant vigilance of caregivers—prompted the first published recommendation for private rooms in the NICU in 1992 (Dazé Floyd, 2005). Even though the first private room NICU was built in 1997, by 2005, there were only 12 facilities with designs for private and semi-private rooms from the hundreds of NICUs nationwide (Dazé Floyd, 2005). As survival rates continued to increase, so did the angst of "intact survival," or survival without disabilities (Dazé Floyd, 2005). Thus, more focus was placed on maximizing the quality of care in the NICU environment. A primary focus of this move was an aim to reduce the level of noise in the NICU.

Sound is defined as a vibration that travels through a given medium and can be measured in decibels (Byers et al., 2006; Lai & Bearer, 2008). Noise, more specifically, is defined as unwanted sound (Byers et al., 2006; Lai & Bearer, 2008). Recognized by the Joint Committee on Infant Hearing as an important environmental factor, noise pollution was investigated (Trapanotto et al., 2004). This organization, founded in 1969, brings together fields such as audiology, pediatrics, and nursing, in the interest of the patients (JCIH). The Committee declared noise as "one of the most polluting physical agents in neonatal intensive care, such that hospitalization in intensive care can be considered in itself a risk factor for preverbal deafness" (Trapanotto et al., 2004). Efforts to minimize noise in the NICU, therefore, conjunctly promote sleep, healthy neonatal physiologic stability, and reduce harmful effects of auditory and neurological development since sound both agitates the mood and complicates the medical condition of the child (Nagorski Johnson, 2003).

Research dating back to the early 1970s has shown sound levels in the NICU to range from 45 to 135 dBA, with a mean generally between 54 and 80 dBA (Chang et al., 2006; Nagorski Johnson, 2003). These levels are astounding giving that workplace standard determines that workers should not spend more than 8 hours at 90 dBA, 4 hours at 95 dBA, 2 hours to 100 dBA, and no continuous exposure to levels over 115 dBA (AAP, 1997). Frequently, noise levels within isolettes exceed 90 dB, the level at which the Occupational Safety and Health Administration (OSHA) requires adults to wear ear protection to defend against hearing loss (Dazé Floyd, 2005). This constant high sound level is partially due to the isolettes themselves, contributing 50 to 80 dB of noise; newer isolette models have capped noise at 50 dB (Lai & Bearer, 2008; Dazé Floyd, 2005). However, the babies themselves cause much of the noise, with accompaniment by staff care providing, staff and family conversations, and additional equipment like respiratory control. In 1974, the American Academy of Pediatrics (AAP) suggested noise in the NICU be below 58 dB; since 1997, the recommendation was lowered to 45 dB after additional research had been conducted (Chang et al., 2006).

Toxicology:

The goal for NICUs is "to provide an environment that promotes sleep, supports neonatal physiologic stability, and reduces potential adverse effects on the auditory development of premature infants (Brandon et al., 2007). Unfortunately, noise disturbs sleep, causes physiologic stress, and leads to complications with hearing and comprehension (Byers et al., 2006).

The auditory system develops in utero in weeks 22 to 24 with the development of cochlear function, peripheral sensory end organs, and first hearing capacities (Brandon et al., 2007; Lai & Bearer, 2008; Krueger et al., 2005). Blink-startle responses to vibroacoustic stimulation begin at 24 to 25 weeks and are consistent after 28 weeks illustrating a fetus's ability to detect and process sounds (AAP, 1997). The womb provides fetuses with rhythmic, familiar acoustical signals over a range of low frequencies which developing ears can tolerate (Brandon et al., 2007; Dazé Floyd, 2005). The fetus hears the mother's voice as a unique, clear sound against the background uterine sounds; this maternal voice recognition in utero is essential to train the baby to pay attention to the mother's speech after birth and is strongly influential in developing the baby's own future speech patterns (Brandon et al., 2007). Furthermore, the uterine environment serves as a protection against other low-, mid-, and high frequency, unwanted sounds other than the mother's voice and the uterine environment itself (Brandon et al., 2007). At weeks 27 to 29 the child hears a 40 dB threshold of sound, decreasing to roughly the adult threshold level of 13.5 dB at 42 weeks, illustrating the essential auditory development occurring postnatal (AAP, 1997). Premature babies may spend this time—crucial for outer ear, middle ear, and cochlear development—in the NICU, lacking the protection of the uterus for this development occurring in the last trimester (Lai & Bearer, 2008; Krueger et al., 2005). These NICU babies are exposed to sounds that move through the air rather than through the liquid environment of the uterus (Brandon et al., 2007). Not only is the medium more harsh and unnatural, so are the sounds themselves—constant, piercing, and arrhythmic (Brandon et al., 2007; Chang et al., 2006).

One study by Trapanotto et al. (2004) measured the levels of the corrugator supercilii muscle, a muscle employed in the expression of suffering, specifically the downward and inward depression of the forehead to create a frown. The corrugator supercilii muscle contraction, or the "startled" reflex response, is initiated by the brainstem in response to a sudden, intense stimulus (Trapanotto et al., 2004). Trapanotto et al. proposed that the intense noise levels were sufficient to cause muscles of the upper face and middle ear to contract in defense to reduce the level of noise perceived, as has been seen through similar by electromyographic (EMG) studies on adults exposed to various sound intensities. Typical sound-associated care practices in the NICU were simulated: opening a small and large sterile bag (up to 85 dB), instrumental monitoring and treatment like alarms and ventilation (up to 73 dB), faulty behavioral guidelines such as falling equipment (up to 90 dB), radio, or loud talking. The results showed the loudest noise, the falling stool, elicited the highest level of muscle contraction (Trapanotto et al., 2004). Furthermore, behavioral evaluation indicated the babies closed their eyes, breathed irregularly, and moved their arms, legs, and head excessively (Trapanotto et al., 2004). What's more astounding is this research was conducted on full term babies, with a mean gestation of 39 weeks, a healthy weight, and an uncomplicated delivery (Trapanotto et al., 2004). It may be assumed that babies with less developed auditory and neurologic systems may experience more harmful effects due to noise pollution.

Other research studies have indicated that noise of 80 dBA and above is associated with apnea (suspension of breathing), bradycardia (slowing of the heart), fluctuations in heart rate, increased intracranial pressure, increased blood glucose, increased serum cholesterol, increased muscle tension, decreased transcutaneous oxygen tension, auditory disorders, altered immune function, disturbed sleep patterns, behavioral problems (excessive crying and agitation), and changed blood pressure, respiratory rate, oxygen saturation, and perfusion levels (Brandon et al., 2007; Byers et al., 2006; Chang et al., 2006; Lai & Bearer, 2008; Krueger et al., 2005; Trapanotto et al., 2004).

Environmental risk assessment:

The logarithmic decibel scale is used to measure sound. The scale functions such that a small increase in numeric measurements, such as a 4 dBA increase, can equate to a doubling of loudness (Byers et al., 2006). Generally, sound measurements use an A-weighted, slow response measurement system (dBA) to best exemplify how people hear sound, de-emphasizing high and low frequencies that humans don't usually hear and instead emphasizing those frequencies to which the human ear responds (Table 1) (Byers et al., 2006).

As proposed by the US Environmental Protection Agency and supported by the American Academy of Pediatrics (AAP) Committee of Environmental Health, noise levels within the NICU should be kept below 45 dB (AAP, 1997). More specifically, the AAP recommends that hourly, a NICU's loudness equivalent (Leq) should be below 50 dBA, the sound level that is exceeded 10% of the time (L10) should be at or below 55 dBA, and the maximum sound (Lmax) should be below 70 dBA (Table 1) (Byers et al., 2006).

Since neonatology is such a critical field involving a lot of medical attention, it integrates many different facets of care including pediatric and nurse specialists as well as the care provided by family. What level NICU care the patients are under can influence NICU noise levels. Level III NICUs, providing the greatest level of support for the sickest infants, have sound levels significantly higher than those of Level II (Brandon et al., 2007; Antonucci et al., 2009). Noise sources in the NICU can be structurally predetermined by the layout, design, and specific functionality of the area: heating, air-conditioning, and ventilation systems, plumbing lines, door mechanisms, overhead paging systems, location of staff desks, travel paths (Brandon et al., 2007). Furthermore, the equipment used to sustaining these children's lives and keep them healthy can generate noise: incubators, ventilators, oxygen saturation monitors, alarms, automatic paper-towel dispensers (Brandon et al., 2007). Care giving routines involving talking, something as absent minded as setting a plastic bottle on the top of an incubator, abruptly closing an isolette porthole, use of room doors (110 dB up to every 2.2 minutes), opening packaging, writing or tapping on incubators, dropping equipment, or leaving water to bubble in ventilator tubing can add from 62 to well over 100 dB to the neonate's environment (Table 2 and 3) (Brandon et al., 2007; Dazé Floyd, 2005; Byers et al., 2006; Lai & Bearer, 2008).

Patients in incubators typically receive 5 to 18 dB less sound pollution than do children in open bed warming units due to sources like alarms, talking, and equipment that are buffered by the incubator (Chang et al., 2006; Brandon et al., 2007; Byers et al., 2006; Nagorski Johnson, 2003). Research by Lasky & Williams (2009) showed in one NICU, noise levels increased 0.22 dB per week due to the transition from an isolette to a bed and due to the various respiratory support the patients were on. Ventilators and CPAP generate more noise, roughly 5 dB more, than nasal cannula or room air (Laksy and Williams, 2009). Although both the incubator and mechanical ventilation systems both produce significantly more noise than do beds and room air or nasal cannula, there are less noise variability levels associated with the two former units of care (Lasky & Williams, 2009). This may be due to the barrier the isolette provides against the environment or due to a reduction of talking when the condition is serious, requiring an isolette or a respiratory support.

Sound levels should be frequently and randomly taken in the NICU, especially after any change is made to the environment so that the effect of the noise levels is known (Brandon et al., 2007). When measuring, hospitals should pay careful attention to all sound levels, Leq, L10, and Lmax (Table 1).

Impact:

Effects of noise pollution on NICU patients are both short- and long-term (Brandon et al., 2007). Noise pollution has an observed dose-response relationship on NICU health such that repeated and extended exposure leads to more pronounced morbidity and mortality events (Trapanotto et al., 2004). However, the relationship is also dependent on age and severity of patient's medical condition (Trapanotto et al., 2004). Thus, the long-term effects depend not only on the amount of sound but when in the child's development they receive the noise stimulation (Brandon et al., 2007). Many of the toxicological effects that the neonates experience in reaction to noise, as listed above, disrupt the child's energy consumption, leading to physiological instability and problems with growth and development (Chang et al., 2006).

NICU patients are exposed to a harsh hospital environment during a time of rapid growth of their immature brain (Brandon et al., 2007). The neurologic systems of these children are not able "to process and filter noxious stimuli and to maintain self-regulation" (Byers et al., 2006). Excessive sound levels, presumably defined as any levels above recommendations, can lead to permanent cochlear damage, hearing delay, speech delay, and a weakening of the cerebral vasculature walls leading to intracranial bleeding (Krueger et al., 2005). These hearing and speech delays may lead to attention difficulties like Attention Deficit Disorder (Brandon et al., 2007). In general, neonates have a harder time maintaining attention to a given signal than full-term infants (Brandon et al., 2007). The early exposure to constant background noise causes an inability to hear a given frequency and to discriminate sound patterns later in life, skills essential to understand speech (Dazé Floyd, 2005). Most commonly, these patients lose the ability to hear the frequencies that they've been constantly exposed to (Trapanotto et a., 2004). This high incidence of hearing loss can be measured several ways. One is by examining the increased risk of sensorineural hearing loss. Depending on gestational age and severity of medical condition, neonates experience a 4 to 13% incidence rate for sensorineural hearing loss as compared to the 2% loss found in all newborns (Lai & Bearer, 2008). Combining the risk of developing a sensorineural hearing loss with the risk of developing a mixed hearing loss, there is a tenfold greater risk for NICU babies versus those who did not spend time in the NICU (Antonucci et al., 2009).

Furthermore, care of neonates affects society as a whole. It is estimated that care for very-low-birth-weight infants totals one third of all US healthcare costs (Dazé Floyd, 2005). Those expenses fail to even account for costs to maintenance such as energy, housekeeping, facility operational costs, and staffing (Dazé Floyd, 2005). Healthcare economists attest that 60% to 70% of NICU costs were due to daily room charges, indicating that shorter stays would lead to less health care spending (Dazé Floyd, 2005). Thus, emphasis should be placed on increasing the effectiveness of the time spent in the hospital, maximizing effective treatments, minimizing complications due to iatrogenic factors, like hospital induced infection or noise pollution. This requires creating the best environment in which patients can develop healthy and quickly and complications are minimized. By improving noise management practices, NICUs could see a decrease in over 50% of their costs and an increase in their effectiveness.

Resolutions:

As research by Lasky & Williams (2009) stated "it is unlikely that any NICU newborns consistently experience AAP-recommended noise levels." Hospitals should place emphasis on providing medical justice by giving their most helpless patients the highest level of care, as recommended by research specialists in the field. To address noise pollution, there have been many suggestions and trials of noise reducing techniques found in literature.

NICU noise reform should ideally begin when constructing, renovating, or modifying a NICU. Hospitals administration should consult AAP, EPA, and other environmental health specialists when building a NICU, hosting environmental renovations, or changing equipment (Brandon et al., 2007; Lai & Bearer, 2008). When constructing a NICU, a location should be chosen away from areas with high vehicular, helicopter, and service vehicle traffic (Lai & Bearer, 2008). Within the unit itself, common staff work areas and major traffic paths should be far removed from the patients to limit noise (Lai & Bearer, 2008). It is also ideal that rooms be private or semiprivate to decrease the amount of noise generated by baby fussing, families talking, and equipment like incubators, monitors, ventilators, and telephones be minimized. Private rooms maximize the possibility that all such fixed equipment like sinks, storage areas, and heating or cooling systems can face away the head of the bed, as much removed as possible (Lai & Bearer, 2008). Literature suggests that fixed equipment such as drawers, doors, and bins be both padded and plastic instead of metal to minimize sound resonation (Lai & Bearer, 2008). Another reason for private rooms besides minimizing noise is personalize care. During this early development, NICU patients vary drastically from one to another, due to the differences in gestational age and differences in their length of stay, staying between a few days upwards to a year (Dazé Floyd, 2005). Thus, this range of ages yields a range of needs, a dilemma best tackled by providing care in private and semiprivate rooms, creating an independent environment meeting each patient's needs (Dazé Floyd, 2005). This emphasis on the NICU environment is a key aspect of a relatively new method of NICU care—developmental care (Byers et al., 2006). Byers et al., (2006) conducted a study comparing the sound levels in a room that had received developmental care modifications and a room that had not. Although developmental care works best in a new or renovated NICU with private or semiprivate rooms, it can be implemented as simple room modifications. In the study, both rooms had infants in incubators, on ventilators, similar in physical design, floor plan, square foot per infant, equipment, staffing ratio, heating, ventilation, air-conditioning, and used quilts to cover incubators (Byers et al., 2006). The renovated room however had sound-absorbing flooring, wall panels, ceiling tiles, privacy curtains, and was staffed by those who received a developmental care course to emphasize the importance of managing the environment (Byers et al., 2006). While the control room had none of these renovations, it did have restricted visiting while the developmental room had no such restrictions (Byers et al., 2006). The study found a 4 to 6 dBA or roughly a one-quarter reduction of sound in the renovated room (Byers et al., 2006). Still the Leq of 50 dBA was not met by either NICU room, but the Lmax restriction of 70 dBA was met by both room and the L10 restriction of 55 dBA was met only by the developmental room (Byers et al., 2006). Lastly, changing the equipment itself, by adding acoustical foam inside incubators or by insulating incubators with double plexiglass, can also reduce noise levels perceived by the patients (Antonucci et al., 2009; Brandon et al., 2007). Construction and renovation reformations to NICU noise pollution are extensive and expensive. Although they are effective, they require a lot of time for development and funding.

Another means of change with similar levels of affectivity but decreased costs, does not require making changes to the unit's actual structure but rather a modification of the knowledge, attitudes, behaviors, and performance of all those who comprise the NICU environment (Brandon et al., 2007). Considering this and the fact that human-related behaviors such as care given and conversations held are the major source of NICU noise, educational programs for NICU staff, ancillary services, and parents patient's families would be an effective method to initiation a change, by initiating awareness (Brandon et al., 2007; Chang et al., 2006; Nagorski Johnson, 2003). Studies have shown that decreasing conversation alone had the greatest effect in NICU noise reduction (Dazé Floyd, 2005). NICUs can experience about a 5 dB reduction in noise with an effective staff educational and behavior modification model, as cited in Krueger et al. (2005). Krueger et al. illustrated that the loudest times in the NICU occurred during the morning shift change (from 6 to 8 AM) and during the morning rounds (from 10AM to 12PM). Furthermore, the loudest areas overall in the NICU were located across from the staff computer area, the NICU entrance, and the sink, places common for gathering (Krueger et al., 2005). Protocols suggested to minimize the effects of this essential communication between staff members included staff briefing occurring outside the unit (Krueger et al., 2005). Other suggestion may be having physical constant reminders, like posters, and explanatory pamphlets for families would remind staff and family to keep their noise levels down as well as key in any visitors as to important restrictions in the NICU, such as maintaining a low volume. Besides the physical reminders, a system of peer monitoring or random sound monitoring can be employed (Nagorski Johnson, 2003). A study by Chang et al. (2006) tested the efficacy of using noise-sensor light alarm to keep down noise levels in the NICU. The alarm was set to light up when noise levels reached 65 dBA (Chang et al., 2006). The presence of the alarm increased the amount of sound levels (Leq) below 58 dBA by 28% for incubators and 4% for open beds (Chang et al., 2006). Furthermore, the amount of sudden peak noise (SPNs) instances decreased by 63% for incubators and 70% for open beds (Chang et al., 2006). Another care behavior modification that has already been tested is the quite hour protocol. By restricting all noise during the lost hour of each of the three shifts within a day, researchers demonstrated a significant mean noise level decrease and a positive effect on sleep state (Nagorski Johnson, 2003). Other suggestions include spacing out care activities to eliminate noise overlap (Nagorski Johnson, 2003). Regardless of what protocol is enacted, Nagorski Johnson (2003) suggested to go through these five steps: 1.) Assess the NICU, 2.) Develop a protocol, 3.) Prepare the staff, 4.) Implement the protocol, 5.) Evaluate the progress.

There are simpler initiatives to reduce noise pollution but may possibly prove to be less effective interventions. A few strategies include applying additional protection to the patient directly by covering incubators with a blanket or putting hats or ear muffs on the child to stifle noise (Nagorski Johnson, 2003; Trapanotto et al., 2004; AAP 1997). Another idea would be to restrict staff, family, and visitors to either wear quite shoes or surgical shoe covers to muffle the sound of their shoes (AAP, 1997). Forbidding phone usage within the unit, both room phones and cell phones, and putting a designated area outside of the unit would be another way to decrease the conversation and noise within the unit (Krueger et al., 2005). Suggestions like removing loudspeaker announcement systems would if fact decrease sound, but would also I fear jeopardize safety if there were a fire, bomb, kidnapping, etcetera (Krueger et al., 2005). Similarly, ideas such as having alarms use only lights not sounds or be directly connected to a nurse paging system or something more radical like conducting rounds outside room may also have unwarranted safety consequences, like not seeing the light, not feeling the page, or missing an important physiological change by not directly observing the patient.

All noise abatement will require time and team effort and will never achieve full efficacy (Krueger et al., 2005). Some NICU sounds are unavoidable, such as infant produced noise, capable of raising the environmental noise level 20 dBA, approximately tripling the baseline sound level (Byers et al., 2006).

Research needs:

Although there is a lot of information on this topic and a more extensive literature review would have covered more material, I found a lot of holes in the research I conducted. There was a lot of research stating the physiological responses to NICU noise pollution, but I found no research indicating why these changes were thought to be associated with noise pollution rather than with another NICU dilemma. My findings were supported when I read in Trapanotto et al. (2004), stating that “the limited amount of research performed on the physiological response to noise in the pediatric setting has focused exclusively on the reactivity of autonomous nervous system.” Another frontier that should be studied is the long-term effects of NICU noise pollution. Discovering if noise pollution of NICU patients is associated with hypertension, as it is in the general adult population, would make an even stronger argument for why to support NICU noise reduction programs, a way to preventively reduce the incidence of heart disease in this country (Lai & Bearer, 2008). By gathering more long-term effects of NICU noise pollution, there would be more research to build a strong cost-effective analysis. With the current deficit we are in as a nation and the high percentage of healthcare cost spent in the NICU, a cost-effective analysis would be a solid manner to capture popular attention and support and enact change. The Nagorski Johnson (2003) article also raised the question of the long-term effects of sound monitoring. The article stated there is a potential “Hawthorne effect” in that when staff is aware they are being monitored, they decrease their noise by limiting conversations and activities, thus not displaying the real sound environment (Nagorski Johnson, 2003). Thus, looking at long-term effects of constant sound monitoring or discrete random monitoring would be an interesting phenomenon to study. Chang et al (2006) discounts the effectiveness of educational program suggesting a monitoring program instead. However, pairing the two may lead to a more effective intervention and an interesting topic for further research. Lastly, randomized, controlled trials of clinical efficacy of noise reduction efforts are essential (Lasky & Williams, 2009). As indicated in the resolutions section of this paper, there are many ways to reduce level but not all of which have data associated with them and possibly none of which compares the cost-effectiveness between two interventions. Thus, although has come a long way since its beginning in 1878, it still has a lot of area for future direction.

Appendix

Table 1. Sound level measures and their definitions (Byers et al., 2006).

Measure	Definition
A-weighted slow response	Sound measurement system that best approximates human perception of sound (A-weighting de-emphasizes high and low sound frequencies and emphasizes frequencies between 1 kilohertz [kHz] and 6.3 kHz, in an effort to simulate the relative response of the human ear.)
dBA	Sound level in A-weighted decibels, which is closest to the human perception of sound
L10	Sound level that is exceeded 10 percent of the time during the data collection period
Leq	Loudness equivalent sound level during the data collection period
Lmax	Maximum sound level during the data collection period
Lmin	Minimum sound level during the data collection period

Table 2. Common NICU noise sources (Brandon et al., 2007)

Noise Source	Decibel (dB) Level
Pump alarms	60–78
Finger tapping on the incubator	70–95
Pulse oximeter alarm	86
Bubbling water in respiratory tubing	62–87
Loud voices	>100

Table 3. Common noise levels (AAP, 1997).

Quality	Peak Intensity, dBA	Example[2]	Inside Incubator[41]	Effect
Just audible	10	Heartbeat		
Very quiet	20–30	Whisper		<35 dBA desired for sleep
Quiet	40	Average home		
	50	Light traffic	Background	<50 dBA desired for work
Moderately loud	60	Normal conversation	Motor on and off	
	70	Vacuum cleaner	Bubbling in ventilator tubing	Annoyance
Loud	80	Heavy traffic Telephone ringing	Tapping incubator with fingers	
	90	Pneumatic drill	Closing the metal cabinet doors under the incubator	Hearing loss with persistent exposure
Very loud	100	Power mower	Closing solid plastic porthole	
Uncomfortably loud	120	Boom box in car[44]	Dropping the head of the mattress	Pain and distress
	140	Jet plane 30 m overhead		

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