5-2018

Noise Levels In The Neonatal Intensive Care Unit: A Systematic Review

Esther Cohn
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NOISE LEVELS IN THE NEONATAL INTENSIVE CARE UNIT:
A SYSTEMATIC REVIEW

by

ESTHER COHN

A capstone research project submitted to the Graduate Faculty in Audiology in partial fulfillment of the requirements for the degree of Doctor of Audiology,
The City University of New York

2018
NOISE LEVELS IN THE NEONATAL INTENSIVE CARE UNIT: A SYSTEMATIC REVIEW

by

ESTHER COHN

This manuscript has been read and accepted by the Graduate Faculty in Audiology in satisfaction of the capstone project requirement for the degree of Au.D.

Carol A. Silverman, Ph.D., M.P.H.

Date ___________________________________________________________________

Faculty Mentor

John P. Preece, Ph.D.

Date ___________________________________________________________________

Executive Officer

THE CITY UNIVERSITY OF NEW YORK
ABSTRACT

NOISE LEVELS IN THE NEONATAL INTENSIVE CARE UNIT:
A SYSTEMATIC REVIEW

by

Esther Cohn

Advisor: Carol A. Silverman, Ph.D., M.P.H.

Objective: The purpose of this systematic review is to investigate noise levels in the Neonatal Intensive Care Unit (NICU) in order to see if they are in compliance with the American Academy of Pediatrics (AAP) proposed standards. This investigation also aims to compare noise levels among various NICU conditions in order to best hospital conditions for noise reduction.

Methods: A comprehensive search of the literature utilizing various peer-reviewed databases through the City University of New York (CUNY) Graduate Center Library was conducted to identify relevant studies on noise levels in the NICUs. Articles that were included in the systematic review were those that assessed noise levels in NICUs. Studies were excluded if the measurements were obtained in order to evaluate intervention strategies or if measurements were taken in unoccupied NICUs.

Results: Thirteen articles met the inclusion criteria for this systematic review. Nearly all of the studies (85%) utilized either a sound level meter (SLM) or dosimeter in order to obtain sound level measurements of the NICU. Noise levels obtained by each study were compared to the AAP standards, which state that the combined background and operational noises in the NICU should not exceed an hourly Leq of 45 dBA or an hourly L10 of 50 dBA. Transient, Lmax sounds should not exceed 65 dBA. In all studies, noise levels were out of compliance for at least
one of the proposed standards. Investigators also found that noise levels were greater in incubators than in the NICU room (3 of 4 or 75%) and were greater in open NICU spaces than closed NICU rooms (3 of 3 studies or 100%). Noise levels were more intense during day shifts than night shifts and noise levels peaked during shift changes and physician rounds (4 of 6 studies or 66.7%). Investigators also noted that noise levels were significantly lower in NICUs that were newer and built with noise attenuation in mind as compared with noise levels in older NICUs (2 of 2 studies or 100%).

**Discussion:** Noise levels in the NICU are overwhelmingly out of compliance with the AAP standards. These elevated noise levels in the NICU have the potential to cause permanent hair cell damage and possible noise-induced hearing loss in NICU babies. Some NICU conditions, however, provide better sound attenuation than others.

**Conclusions:** Elevated noise levels in the NICUs are a problem that must be addressed as they can cause irreversible damage to the auditory system of infants. The building of NICUs should consider sound attenuation characteristics and should make use of sound absorbing materials. The NICU staff should be trained in noise reduction techniques and equipment noise levels and alarm sounds should be reduced as much as possible.

**Key words:** “Neonatal Intensive Care Unit”, “NICU”, “Noise”, “Level”, “Loudness”, “Decibels”, “Newborn”, “Infant”, “Premature”, “Incubator”, “Sensorineural hearing loss”.
ACKNOWLEDGMENTS

I would like to thank my capstone advisor, Dr. Silverman, for all of her feedback and guidance as I researched, wrote, and completed this project. Her dedication and advice were invaluable throughout, and I am deeply grateful. I would also like to acknowledge my professors and supervisors for sharing their knowledge and depth of experience over the last four years; I have learned and gained immeasurably from them both in and out of the classroom.

To my classmates, who have pushed me to grow academically and professionally throughout the program, but above all, have been an amazing group of friends. I look forward to our continuing relationships as colleagues and peers for many years to come.

Finally, I would like to thank my family. To my parents, who have supported me in my education and aspirations since the beginning, with guidance and encouragement through all the years. To my husband Yehuda, for always being by my side and for inspiring me to achieve my goals. Lastly, to my son Simmy, thank you for coming into my life and making my last year of schooling even more exciting—but mostly, thank you for just being you.
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INTRODUCTION

The Neonatal Intensive Care Unit (NICU) is a unit designed specifically for the intensive care of premature and ill newborn infants. The NICU can be an excessively noisy area as it contains loud equipment (e.g., alarms and ventilators) as well as hospital staff. According to the American Academy of Pediatrics (AAP) Guidelines for Perinatal Care (2012), the combined background and operational noises in the NICU should not exceed an hourly Leq of 45 dBA or an hourly L10 of 50 dBA. Transient, Lmax sounds should not exceed 65 dBA.

The Leq is the measured equivalent continuous sound level. This measurement is the constant equivalent of the acoustic pressure changes over a period of time. The L10 is the level of sound that is exceeded 10% of the time during the designated interval. The Lpeak is the highest sound level reached, no matter how brief the duration. The Lmax is the maximum sound level recorded over a small, defined time interval. In most cases, Lpeak exceeds Lmax since the duration of the former can be so brief that the human ear may not fully perceive it (Gray & Philbin, 2000).

According to Gray and Philbin (2000), the A-weighted network for sound pressure measurement in dBA is shaped to estimate the response of the human ear to soft sounds. Slow response time averaging, as opposed to fast or impulse time averaging, is most commonly utilized in NICU noise levels measurements because it yields relatively stable readings when averaging noise levels over one-second intervals. Therefore, slow response time averaging can better evaluate average noise levels over a period of time than fast or impulse time averaging (Gray & Philbin).

Tools used to measure sound levels include sound level meters (SLMs), dosimeters, and a probe tube microphone. A dosimeter is essentially a specialized SLM that averages short interval
time measurements over a longer period of time. Such averaging over longer time periods is helpful when sound levels fluctuate greatly (Gray & Philbin, 2000). A probe tube microphone is used to assess sound pressure level in the ear canal.

Noise exposure at elevated intensity levels over extended periods of time can cause sensorineural hearing loss (Alberti, 1992; Catlin, 1986; Rabinowitz, 2000; Sliwinska-Kowalska & Davis, 2012). Infants in the NICU are at significant risk for noise-induced hearing loss since many are born prematurely and may be exposed to this loud and constant noise while their auditory systems are still developing.

The main structures of the auditory system are formed and anatomically functional by 20 weeks gestational age (GA). The auditory system as a whole is functional at approximately 25 weeks GA. At 25-26 weeks GA, a loud noise will produce physiologic changes in the baby, whether in utero or in the NICU (Graven & Browne, 2008). Thus, most premature infants in the NICU have the ability to hear. Although the fetus physically is able to hear at around 25 weeks GA, the hair cells of the cochlea undergo fine-tuning for frequency discrimination largely between 28 weeks GA and the first few months of life. Acoustic signals of greater intensity cause a decrease in the sensitivity of frequency fine-tuning. Therefore, frequent loud noise exposure during this period of development can cause damage and disruption to the fine-tuning of the cochlea (Graven & Browne), putting developing infants at an increased risk for noise-induced hearing loss. Additionally, according to Lahav and Skoe (2014), overexposure to constant noise while the auditory system is still developing can alter the natural development of the auditory pathways, making them overly sensitive to noise. The neural circuits that develop may focus on noise as a primary sound target rather than as background noise, potentially causing a child, later in life, increased difficulty in understanding speech in background noise.
Because of brain plasticity, however, sufficient exposure to a language-rich environment post NICU stay can positively influence the neural circuits and auditory pathways (Lahav & Skoe).

Another area of concern is the drastic change in sound environment in the NICU as compared with that in the womb. The fetus, in utero, primarily is exposed to low frequency noise (<250 Hz), which is important for hearing maternal heartbeats, digestive noises, and some components of speech (Graven, 2000). Internal and external sounds at frequencies above 250 Hz are largely attenuated by maternal tissue and amniotic fluid. Infants placed in the NICU experience a sudden and drastic change in their acoustic environment (compared with their environment in utero) as the NICU environment is rich with disruptive high-frequency noise including alarms, ringers, ventilators, infusion pumps and staff conversations. The majority of the spectrum of NICU noise ranges from 501 to 3,150 Hz (Lahov, 2015). This high frequency noise exposure could increase risk for noise-induced hearing loss, as the inner and outer hair cells of the ears are still going through the process of fine-tuning in the early postnatal period.

The newborn in the NICU, who is exposed to disruptive high-frequency noise, also has a tremendous lack of exposure to more natural sounds such as speech and language and maternal heartbeats. This is known as the “acoustic gap” between the womb and the NICU environment. The acoustic gap can adversely affect auditory development and later speech and language acquisition (McMahon, Wintermark, & Lahav, 2012). Webb, Heller, Benson and Lahav (2015) compared the size of the auditory cortex in premature babies exposed to regular NICU noise alone with the size of the auditory cortex in those exposed to regular NICU noise as well as to three hours daily of low-pass filtered maternal speech and heartbeat recordings. Measurements of the auditory cortex at one month of age showed significantly larger auditory cortices in the
babies exposed to the maternal recordings (as well as to the regular NICU noise) than in those in the control group exposed only to regular NICU noise.

Another reason that elevated noise levels in the NICU are of such great concern is that many infants in the NICU are treated with ototoxic medications, which, absent noise exposure, can cause sensorineural hearing loss. The synergistic effect between noise exposure in the NICU and ototoxic medications can greatly increase the odds of sensorineural hearing loss in those babies (Li & Steyger, 2009). According to Rees (2007), premature babies who were born before 27 weeks GA and who were exposed to mechanical ventilation noises in the NICU while receiving aminoglycosides for at least seven days had a high probability (68%) of developing hearing loss.

Within the NICU, infants are placed in different levels of care based on their health status. The AAP (2004) proposed recommended definitions for each level of care for hospitals as follows. The proposed definitions classify Level I as “basic” care, designating a well-baby nursery in which infants, born at 35 weeks GA or later, are stable and healthy. A level II NICU is classified as “specialty” care, involving infants born after 32 weeks GA who weigh more than 1500 grams and who are moderately ill. The health problems of these babies are expected to resolve quickly so these babies are not expected to require urgent intensive care. The health problems can include inability to control body temperature or take oral feedings, prematurity, and apnea. A level III NICU is classified as “subspecialty” care, including infants who are extremely high risk and who require continuous life support and urgent and comprehensive care. These infants are born before 32 weeks GA and have extremely low birth weight (1000 grams or less).
Rates of hearing loss in NICU graduates are greater than those found in typical developing babies who did not spend time in the NICU. Williams, Drongelen and Lasky (2007) reported that 2-4% of NICU graduates have bilateral hearing loss, a prevalence that is ten times greater in NICU graduates than in healthy newborns. Similarly, Kent, Clarke, and Bardell (2002) reported that the incidence of hearing loss in NICU graduates is 2-10% whereas the incidence in healthy babies is 1 in 300 (.33%). The cause of such high rates of hearing loss often cannot be identified or narrowed down to just one reason. Many children in the NICU have a predisposition for hearing loss due to prematurity or any other complications for which they are in the NICU. These odds are further increased by ototoxic medications, which increase the risk of hearing loss, and by increased levels of constant noise exposure in the developing ears.

Noise exposure in the NICU not only adversely impacts hearing but also can cause deleterious changes in blood pressure, respiration, oxygenation and heart rate; increases in alertness and crying; and reduce deep sleep (McMahon et al., 2012). Consequently, these changes can lead to adverse alterations of cardiovascular and respiratory systems, which can have long-term developmental effects (McMahon et al.).

With the many possible deleterious effects of elevated noise exposure in the NICU, the purpose of this systematic review is to examine the reported levels of noise in various NICU units and to determine if they fall within the guidelines proposed by the AAP (2012). The findings of this review have implications regarding the potential need for implementation of intervention for hospital staff; quieter machinery where possible in the NICU; and acoustic modifications of the facilities.
METHODS

A systematic review of the literature was performed in order to search articles relevant to this topic. The review of the literature utilized databases available through The CUNY Graduate Center’s library. These databases included CINAHL Complete and PubMed. Various combinations of the following keywords were searched in the article’s title, abstract and text: “Neonatal Intensive Care Unit”, “NICU”, “noise”, “level”, “loudness”.

Moher et al. (2009) described the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analysis) Statement, which was utilized in the processes of determining inclusion in the present systematic review. As shown in Figure 1, the PRISMA Statement includes a four-step flow chart in order to clearly report search results and inclusion and exclusion criteria.

Articles included in the systematic review were those that assessed noise levels in neonatal intensive care units (NICUs). Most of the studies included measurements of another variable for comparison. These comparison measurements included evaluation of noise levels in a well-baby nursery/empty room, inside the NICU incubators, in newer and older NICUs, enclosed and open NICU rooms, daytime and nighttime, types of respiratory support, levels of care and various locations within the same NICU.

Studies were excluded if the measurements were obtained in order to evaluate intervention strategies or if measurements were taken in unoccupied NICUs. Exclusion criteria also included articles that were not in English or were unavailable in full length. Studies were also excluded on the basis of quality where studies did not provide adequate information to interpret results.

The original search within listed databases using listed key terms led to the browsing of 319 articles. Twenty-two studies that were duplicates then were excluded. Two-hundred-and-
nine article titles were deemed unrelated to the topic of this systematic review. Twelve studies written in a language other than English were excluded and fourteen studies were excluded after review of the abstracts revealed that the content was unrelated to the topic of this systematic review. Twenty articles were excluded since the focus of those studies were intervention methods for NICU noise. Nine studies were excluded since they involved noise measures only in empty/unoccupied NICUs. Twelve studies could not be obtained via The CUNY Graduate Center Library and eight studies were excluded on the basis of poor quality of research. Following this complete review, thirteen studies were found to have met the inclusion criteria for this systematic review.
RESULTS

Figure 1 shows a PRISMA flowchart for the literature search and retrieval process for the systematic review of noise levels in the NICU. As can be seen from this figure, the database search yielded 319 studies.

Study Characteristics

The study characteristics are summarized in Table 1. All abbreviations used and their definitions are listed in Table 2.

As shown in Table 1, instruments used to measure sound levels included sound level meters (SLMs), dosimeters, and probe microphones. Of the 13 studies, 7 (53.8%) used only an SLM, 3 (23%) used only a dosimeter, 1 (7.7%) used both an SLM and dosimeter, 1 (7.7%) utilized a probe tube microphone, and 1 (7.7%) failed to specify the instrument used.

Nearly all studies (12 of 13 or 92 %) involved noise measurements with A-weighted networks (unit of sound pressure level is dBA). Of these 13 studies, 9 (69.2%) utilized slow response time averaging whereas 3 (23.1%) of the studies did not specify response time averaging type. And 1 of the 13 studies (7.7%) (Surethiran et al., 2013), which involved obtaining probe microphone measures at the entrance of and inside the infant’s external auditory meatus, reported measurements in dB SPL units.

The site of noise measurements varied across the studies, and 4 of the 13 studies (30.8%) assessed measurements at more than one location. Of the 13 studies, 5 (38.5%) conducted noise measurements at the midpoint of the room, and 4 (30.5%) conducted measurements at bedside. Additionally, 6 of the 13 studies (46.2%) assessed noise levels inside the incubator. In 1 of the 13 studies, (7.7%) as noted by Matook, Sullivan, Salisbury, Miller and Lester(2010), SLM
Figure 1. PRISMA flow chart for retrieval and inclusion process for systematic review, based on Moher et al.(2009).
measurements were performed from within a box in the room but the location of the box within the room was unreported.

The length of time and frequency of noise measurements also varied greatly between studies. Of the 13 studies, investigators in 12 studies (92.3%) reported the time and frequency of measurements. Of those 12 studies, investigators in 2 studies (16.7%) performed noise measures over a 24 hours period; investigators in 4 studies (33.3%) performed measurements over 4 to 7 day period; and investigators in 4 studies (33.3%) performed measurements over a 3 to 4 week period. One investigator (8.33%) completed measurements one day per month over a 6-month period (Byers, Waugh & Lowman 2006). Lastly, Surenthiran et al. (2013) performed two in-ear measurements (one inside the external auditory meatus and one right outside) for each participant.
### Table 1

*Study Characteristics*

<table>
<thead>
<tr>
<th>Authors</th>
<th>Instrument</th>
<th>Decibel Frequency Weighting</th>
<th>NICU/Hospital Level/Environment</th>
<th>Within Study Comparison</th>
<th>Incubator Measures</th>
<th>Location of Measurements</th>
<th>Length of Time/Frequency of Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anagnostakis et al (1980)</td>
<td>SLM</td>
<td>dBA</td>
<td>Normal nursery vs NICU vs incubator</td>
<td>Yes</td>
<td>1) Midpoint of normal nursery and NICU; 2) Incubator</td>
<td>1) Open room measures: 4 days, every 2 hours (48 measures total) 2) Incubator measures: 10-20 measures at various locations within incubator</td>
<td></td>
</tr>
<tr>
<td>Chen et al (2009)</td>
<td>SLM</td>
<td>dBA (slow)</td>
<td>Enclosed NICU and open NICU</td>
<td>No</td>
<td>Near bedside</td>
<td>Continuous measurements over a 24-hour period</td>
<td></td>
</tr>
<tr>
<td>Kent et al (2002)</td>
<td>SLM</td>
<td>dBA (slow)</td>
<td>1) Phase 1: standard NICU vs acute care NICU; 2) Phase 2: NICU vs incubator</td>
<td>Phase 1: No; Phase 2: Yes</td>
<td>1) Phase 1: a) Acute care NICU room (high levels of activity) b) Standard care NICU room (less activity); 2) Phase 2: a) 2 standard care NICU rooms, perimeter of room b) Incubator</td>
<td>1) Phase 1: 12-hour day shifts, over a 6-day period; 2) Phase 2: 24-hour recording shifts, over a 4 day period</td>
<td></td>
</tr>
<tr>
<td>Parra et al (2017)</td>
<td>Dosimeter</td>
<td>dBA</td>
<td>Empty room vs NICU vs incubator</td>
<td>Yes</td>
<td>1) Control measurement: midpoint of empty room; 2) Midpoint of each</td>
<td>1-sec intervals over a 24-hour period</td>
<td></td>
</tr>
</tbody>
</table>

- **Anagnostakis et al (1980)**: SLM, dBA, Normal nursery vs NICU vs incubator, Yes, 1) Midpoint of normal nursery and NICU; 2) Incubator
- **Chen et al (2009)**: SLM, dBA (slow), Enclosed NICU and open NICU, No, Near bedside
- **Kent et al (2002)**: SLM, dBA (slow), 1) Phase 1: standard NICU vs acute care NICU; 2) Phase 2: NICU vs incubator, Phase 1: No; Phase 2: Yes, 1) Phase 1: a) Acute care NICU room (high levels of activity) b) Standard care NICU room (less activity); 2) Phase 2: a) 2 standard care NICU rooms, perimeter of room b) Incubator
- **Parra et al (2017)**: Dosimeter, dBA, 9 single rooms and 4 double rooms in new hospital with new equipment, Empty room vs NICU vs incubator, Yes, 1) Control measurement: midpoint of empty room; 2) Midpoint of each, 1-sec intervals over a 24-hour period
<table>
<thead>
<tr>
<th>Authors</th>
<th>Instrument</th>
<th>Decibel Frequency Weighting</th>
<th>NICU/Hospital Level/Environment</th>
<th>Within Study Comparison</th>
<th>Incubator Measures</th>
<th>Location of Measurements</th>
<th>Length of Time/ Frequency of Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matook et al (2010)</td>
<td>SLM</td>
<td>dBA (slow)</td>
<td>Level III, five-bay NICU with an average of 50 infants (10-12 per bay)</td>
<td>4 quadrant comparison</td>
<td>No</td>
<td>SLM placed inside wooden box, microphone snaked through a hole at top of box</td>
<td>NICU; 3) Occupied Incubator 1) 20 12-hour day shifts; 2) 20 12-hour night shifts</td>
</tr>
<tr>
<td>Williams, et al (2007)</td>
<td>dBA (slow) for all measures except dB SPL measures for Lpeak</td>
<td>Isolation rooms; level II rooms; level III rooms</td>
<td>Room levels within newer vs older constructed NICUs</td>
<td>No</td>
<td>Bedside</td>
<td>7 days, 5-sec intervals, total of 120,960 5-second samples per placement</td>
<td></td>
</tr>
<tr>
<td>Ramm et al (2017)</td>
<td>Dosimeter</td>
<td>dBA</td>
<td>2 Level VI rooms</td>
<td>Open NICU vs enclosed NICU pod</td>
<td>No</td>
<td>Bedside in high traffic area</td>
<td>Every 60 secs for 4 continuous weeks</td>
</tr>
<tr>
<td>Domanico et al (2011)</td>
<td>SLM</td>
<td>dBA (slow)</td>
<td>Level III NICU</td>
<td>Open NICU vs SFR</td>
<td>Yes</td>
<td>Incubator in open Bay NICU and SFR</td>
<td>1) Peak activity periods (i.e. shift changes and visitation); 2) Quiet periods</td>
</tr>
<tr>
<td>Robertson et al (1998b)</td>
<td>1. SLM for noise distribution survey and central site measures; 2. Dosimeter for quadrant area measures</td>
<td>dBA (slow)</td>
<td>12 bed unit</td>
<td>Bedside vs quadrant area vs NICU room</td>
<td>No</td>
<td>1) Noise distribution survey at bedside; 2) Quadrant area measures at midpoint of each quadrant; 3) Central site measures at midpoint of room</td>
<td>1) Noise distribution survey during physician rounds; 2) Quadrant area measures during 3-week period (48 hours of data); 3) Central site measures during 3-week period (48 hours of data)</td>
</tr>
<tr>
<td>Byers et al</td>
<td>SLM</td>
<td>dBA (slow)</td>
<td>Renovated</td>
<td>NICU vs</td>
<td>Yes</td>
<td>Bedside, near the 1 day per month</td>
<td>NICU room</td>
</tr>
<tr>
<td>Authors (2006)</td>
<td>Instrument</td>
<td>Decibel Frequency Weighting</td>
<td>NICU/Hospital Level/Environment</td>
<td>Within Study Comparison</td>
<td>Incubator Measures</td>
<td>Location of Measurements</td>
<td>Length of Time/ Frequency of Measures</td>
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<tr>
<td>Developmental NICU and standard (control room) NICU</td>
<td>Probe microphone</td>
<td>dB SPL</td>
<td>Opening of EAM vs inside EAM; No respiratory support vs conventional ventilation vs CPAP</td>
<td>Yes</td>
<td>Incubator, in/next to each baby's ear</td>
<td>1) 1 measure at the opening of the EAM; 2) 1 measure inside the EAM</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dosimeter</td>
<td>dBA (slow)</td>
<td>12 bed unit</td>
<td>Quadrant location; time of day</td>
<td>No</td>
<td>Midpoint of each quadrant</td>
<td>1-minute intervals within 48-hour periods, over 4 weeks (total of 48 hours of weekday data)</td>
</tr>
<tr>
<td></td>
<td>SLM</td>
<td>dBA (slow)</td>
<td>2 open bay level II NICU nurseries pods, each pod containing 10-12 bed spaces</td>
<td>No</td>
<td>Midpoint of 2 NICUs</td>
<td>24-hour measures for 5 weekdays (120 hours total)</td>
<td></td>
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<tr>
<td>Abbreviation</td>
<td>Definition</td>
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<tr>
<td>NICU</td>
<td>Neonatal intensive care unit</td>
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<tr>
<td>AAP</td>
<td>American Academy of Pediatrics</td>
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<tr>
<td>Leq</td>
<td>Equivalent continuous sound level</td>
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<tr>
<td>L10</td>
<td>Sound level measured 10% of time interval</td>
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<tr>
<td>Lmax</td>
<td>Maximum sound level during interval</td>
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<tr>
<td>Lpeak</td>
<td>Peak instantaneous sound level</td>
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<tr>
<td>SLM</td>
<td>Sound level meter</td>
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<td>dBA</td>
<td>A-weighted decibels</td>
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<tr>
<td>SFR</td>
<td>Single family room</td>
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<tr>
<td>EAM</td>
<td>External auditory meatus</td>
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<tr>
<td>CPAP</td>
<td>Continuous positive airway pressure</td>
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<tr>
<td>SD</td>
<td>Standard deviation</td>
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</table>
Statistical Analysis

Table 3 shows the methods of statistical analysis, results and statistical significance of the findings for the studies. Wherever applicable, the Leq, L10, Lmin, Lmax and Lpeak findings are shown. For studies in which the investigators did not record Leq, L10, Lmin, Lmax, or Lpeak, relevant information regarding the analysis of sound level measurements were specified.

Of the 13 studies, 6 (46.2%) involved noise level measurements in NICU incubators. Of these 6 studies, 2 (33.3%) involved within incubator measurements only, so these measurements were not compared with any outside incubator measurements (Domanico, Davis, Coleman & Davis, 2011; Surenthiran et al., 2003). In the remaining 4 of the 6 studies (66.7%), incubator noise level measurements were compared with noise measurements outside of the incubators; of these 4 studies, the results in 3 (75%) revealed that noise levels in the incubators were significantly greater than those in the NICU room (Anagnostakis, Petmezakis, Messaritakis & Matsaniotis, 1980; Kent et al., 2002; Parra, Suremain, Audeoud, Ego & Debillon, 2017). In contrast, Byers et al. (2006) found that the newer incubators (purchased in or after 1999) provided approximately 4 dB of noise reduction in comparison with noise levels associated with radiant warmers and older incubators (purchased between 1990 and 1994).

Investigators of two studies examined the difference in noise levels between newer, renovated NICUs and older NICUs. The results of these studies indicated significantly lower noise levels in the newer renovated NICU as compared with the levels in the older NICU (Byers et al., 2006; Williams et al., 2007). Williams et al. noted that the older NICU, which opened in 1989, had vinyl floors, sheetrock walls, and acoustic tiling in the ceiling. The newer NICU, opened in 1999 with noise control as a high priority in its construction, was carpeted and kept separate from all storage closets, workstations, and hallways. Byers et al. reported that the
renovated ("developmental") NICU had sound absorbing flooring, wall panels and ceiling tiles, privacy curtains, open visitation, and staff who received special training that included sound level management. Conversely, the non-renovated, older NICU ("control") had vinyl floors with no sound absorbing materials in floors, walls or ceilings, restricted visiting hours, and no staff training for sound level management.

The investigators in 2 of the 13 studies (15.4%) analyzed the difference in noise levels between different levels of care in the NICU (Kent et al., 2002; Williams et al., 2007). The findings of both studies revealed greater noise levels in the setting with the more intensive level of care for at least one study variable, as compared with settings involving a less intensive level of care. Kent et al. reported significantly greater noise levels in the acute care NICU as compared with those in the standard care NICU. Similarly, Williams et al. found significantly greater noise levels in the Level III NICU than in the Level II NICU in the newer NICU (opened in 1999). They reported, however, that in the older NICU (opened in 1989), noise levels were significantly greater for Level II care as compared with those for Level III care. Williams et al. suggested that this finding may have resulted from the lack of sound absorbing materials and smaller room sizes, which likely exacerbated peak sounds creating a more intense, mean sound level.

Investigators compared noise levels in enclosed versus open NICU rooms in 3 of the 13 (23.1%) studies (Chen et al., 2009; Domanico et al., 2011; Ramm, Mannix, Parry & Gaffney, 2017). They all found significantly greater noise levels in the open NICU spaces than in the closed NICU rooms. Ramm et al., however, only reported this difference for the measured quiet shift (1-2 am) and morning rounds, whereas they found no difference between room types for "nurse handovers" or isolated peak levels.
Investigators in 6 of the 13 (46.2%) studies analyzed differences in noise levels between night and day shifts. In the majority of these studies (4 of 6 or 66.7%), noise level measurements were significantly greater during the day shifts than during the night shifts (Matook et al., 2010; Ramm et al., 2017; Robertson, Cooper-Peel & Vos, 1998; Williams et al., 2007). In these studies, noise levels during shift changes and/or physician rounds were significantly increased as compared with those during all other times of day or night. Conversely, Lahav (2015) and Robertson, Kohn, Vos, and Cooper-Peel (1998) found no significant difference in noise levels between nighttime and daytime or between shift changes/physician rounds. Nonetheless, Robertson et al. (1998b) did report that Saturdays were significantly nosier than all other days of the week, probably because of increases in visitation on Saturdays as compared with other days of the week. Lahav noted significantly greater levels of exposure to frequencies in the human speech range (501-3150 Hz) during daytime than during nighttime hours. Statistical analysis for comparison of noise levels in different hospital conditions are displayed in Figure 2.

![Noise Level Comparisons for Hospital Conditions](image)

**Figure 2.** Percentage of studies that found increased noise levels in the above compared hospital conditions
Additionally, Table 3 also shows the results of comparison of study findings with the AAP NICU noise levels standards. These regulations state that in any NICU, the Leq should be less than 45 dBA, the L10 should be less than 50 dBA, and the Lmax should be less than 65 dBA. If the results did not exceed these limits, then the noise measures were listed in the table as in compliance with the standards (so “Yes” would be listed in Table 3); if the results exceeded these limits, then the noise measures were listed in the table as not in compliance with the standards (so “No” would be listed in Table 3).

Investigators of 12 of the 13 (92.3%) studies assessed Leq. Of these 12 studies, 100% reported that the Leq was not in compliance with AAP standards for at least one condition; 2 of the 12 (16.7%) found Leq compliance with the AAP standards for one condition. Parra et al. (2017) found Leq to be in compliance with the AAP standards for the “empty room” condition but found it to be out of compliance for the “open room NICU” and “Incubator” conditions. Surenthiran et al. (2003), who assessed ventilator conditions in the incubator by measuring sound pressure level in the external auditory meatus, found that although Leq at 1000 Hz was in AAP compliance for the “no respiratory support” and “conventional ventilation” conditions, it was out of compliance for the “CPAP” condition. Since measurements were recorded in dB SPL, a direct comparison of results with the AAP standards, which utilize A-weighted decibels, could not be made. At 1000 Hz, however, dB SPL is comparable to dBA; since Surenthiran et al. recorded measurements per frequency (200-8000 Hz), noise level measurements at 1000 Hz could be examined to determine compliance with AAP standards. In one other study (Lahav, 2015), noise levels also were reported. Thus, investigators of 2 of 13 (15.4%) studies assessed noise levels by frequency. Lahav assessed noise levels by frequency in two open NICU rooms by night and day.
In order to quantify high frequency noise exposure as well as exposure to frequencies that envelope the human speech range (501-3150 Hz).

In 5 of the 13 (38.5%) studies, L10 levels were assessed and were found to be out of compliance with AAP standards. In 7 of the 13 (53.8%) studies, Lmax levels were determined. In 5 of these 7 studies (71.4%), Lmax levels were out of compliance with AAP standards; in the other 2 studies (28.6%), Lmax levels were in AAP compliance. Robertson et al. (1998b), found Lmax to be in compliance for quadrant area and midpoint NICU room measures in a 12-bed NICU room. Byers et al. (2006) reported Lmax within compliance for standard and developmental NICUs, as well as for radiant warmers and newer and older NICU incubators.

Results of the comparisons between NICU noise levels and AAP standards are displayed in Figure 3.

![Figure 3. Percentage of studies that found NICU noise levels to be within compliance and out of compliance for AAP standards for at least one condition](image-url)
<table>
<thead>
<tr>
<th>Authors (year)</th>
<th>Results</th>
<th>Method of Statistical Analysis</th>
<th>Statistical Significance</th>
<th>Compliance with American Academy of Pediatrics NICU Standards (Leq &lt; 45 dBA; L10&lt; 50 dBA; Lmax &lt; 65 dBA)</th>
</tr>
</thead>
</table>
| Anagnostakis et al (1980) | Mean Noise levels (SD): *Normal Nursery Open Room* 44 dB (1.6)  
*NICU Open Room* 51 dB (2.0)  
*Incubator in NICU*:  
Midpoint of mattress 53 dB (0.9)  
Sides of mattress 55 dB (1.0)  
Each time nurse opened incubator sleeves 63 dB (0.8)  
Under the hood, when ordinary oxygen supply (51/min) was given 70 dB (1.8)  
Under the hood, when supplemental oxygen was given through humidifier 75 dB (1.5)  
Respirator/ventilator in operation 65 dB (1.7)  
Air compressor in operations 67 dB (1.8)  
During baby's cry 75 dB (85) | N/A | No (Leq) | |
| Chen et al (2009)     | *Closed room mean noise measurements (SD):*  
Leq: 48.9 dB (1.63)  
L10: 51.1 dB (2.64)  
LMax 65.3 dB (4.41) | Independent *t*-test | Intensity of open room noise measurements are significantly greater than closed room noise measurements for Leq***, L10*** and LMax*** | No (Leq, L10, Lmax) (for both conditions) |
<table>
<thead>
<tr>
<th>Authors (year)</th>
<th>Results</th>
<th>Method of Statistical Analysis</th>
<th>Statistical Significance</th>
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</thead>
<tbody>
<tr>
<td>Kent et al (2002)</td>
<td>Open room mean noise measurements (SD): Leq: 53.4 dB (1.64) L10: 56.1 dB (2.01) Lmax: 70.1 dB (3.56)</td>
<td>ANOVA Tukey's HSD</td>
<td>Phase A: Main effects for position (acute care vs. standard NICU vs. AAP recommended room SPL) were significant for Leq***, L10***, Lmax*** Differences between rooms for Lpeak NS Post hoc analysis for differences in position via Tukey's HSD: Acute care noise levels significantly greater than standard care noise levels, and both rooms noise levels significantly greater than AAP standards for Leq and L10; Differences in noise between rooms for Lmax NS, but both were greater than AAP standards. Phase B:</td>
</tr>
</tbody>
</table>

Compliance with American Academy of Pediatrics NICU Standards (Leq < 45 dBA; L10 < 50 dBA; Lmax < 65 dBA)
<table>
<thead>
<tr>
<th>Authors (year)</th>
<th>Results</th>
<th>Method of Statistical Analysis</th>
<th>Statistical Significance</th>
<th>Compliance with American Academy of Pediatrics NICU Standards (Leq &lt; 45 dBA; L10&lt; 50 dBA; Lmax &lt; 65 dBA)</th>
</tr>
</thead>
</table>
*Open room medians (IQR)*: Leq- 59.5 dB (56.5,62)  
L10- 61.8 dB (59.2,63.4)  
Lmax- 85.2 dB (79.7,92.2)  
*Incubator medians (IQR)*: Leq- 65.8 dB (65.4-68.5) | Wilcoxon signed-rank test  
Student's t-test | Wilcoxon signed-rank test: open room medians vs incubator medians  
Incubator noise significantly greater than open room noise for Leq***, L10*** and Lmax*** | No (Leq***, L10***, Lmax***)  
(for open room and incubator)  
Yes (Leq; Empty room) |
|                | Lmax: 78 dB  
Lpeak: 100 dB | **ANOVA:**  
Main effects for position (ambient room noise vs incubator vs. AAP recommended room SPL) were significant for Leq*** and L10***  
Noise differences between locations for Lpeak NS  
**Post hoc analysis for differences in position via Tukey’s HSD:** Incubator noise levels significantly greater than ambient room noise levels, and both significantly greater than AAP standards for Leq and L10  
Differences between ambient room noise and incubator for Lmax NS, but both were greater than AAP standards. | |
<table>
<thead>
<tr>
<th>Authors (year)</th>
<th>Results</th>
<th>Method of Statistical Analysis</th>
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<th>Compliance with American Academy of Pediatrics NICU Standards (Leq &lt; 45 dBA; L10&lt; 50 dBA; Lmax &lt; 65 dBA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matook et al (2010)</td>
<td>Overall mean (range) of SLM readings for all 480 hours of recordings: Leq: 85.15 dB (49.5,89.5) Lpeak: 134.45 dB (66.4,138.9) Lmax: 100.81 dB (50.2,105.2)</td>
<td>Friedman ANOVA Wilcoxon signed-rank test</td>
<td>1) ANOVA: Decibel levels differed significantly by bay for Leq, Lmax and Lpeak***; Wilcoxon: Mean Leq of the middle bay was significantly greater than all four other bay areas***; 2) No statistical difference found between mean Leq decibels levels by quadrants (p=.765). Lpeak and Lmax levels were significantly higher for the back two quadrants as compared to the front two quadrants***; 3) Mean day shift levels were significantly higher than mean nightshift levels for Leq, Lmax and Lpeak***; 4) Weekday levels significantly higher than weekend levels****; 5) Noise levels during shift changes significantly higher than all other times for Leq, Lmax and Lpeak***;</td>
<td>No (Leq, Lmax) (for all locations/times ) No recommended standard for Lpeak</td>
</tr>
<tr>
<td>Williams et al NICU A (Older) Estimated Median Leq:</td>
<td>ANOVA</td>
<td>Mean Leqs were greater in NICU A</td>
<td>No (Leq,</td>
<td></td>
</tr>
<tr>
<td>Authors (year)</td>
<td>Results</td>
<td>Method of Statistical Analysis</td>
<td>Statistical Significance</td>
<td>Compliance with American Academy of Pediatrics NICU Standards (Leq &lt; 45 dBA; L10&lt; 50 dBA; Lmax &lt; 65 dBA)</td>
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</table>
| (2007)        | Isolation: 63 dB  
Level II: 64 dB  
Level III: 61 dB  
NICU B (Newer) Estimated Median Leq:  
Isolation: 61 dB  
Level II: 57 dB  
Level III: 58 dB | than NICU B across all room types***;  
Level II room was the most noisy room type in NICU A and the least noisy room type in NICU B***;  
Noise levels were similar for level III and isolation rooms across hospitals;  
The highest peak sound levels occurred significantly more often in NICU A across all room types as compared to NICU B***;  
Noise measurements were greater during the day shifts (7am-7pm) as compared to night shifts (7pm-7am) across all locations;  
Peaks in noise occurred during shift changes at 7am and 7pm in NICUs A and B. | | Lmax, L10)  
(Across all conditions) |
| Ramm et al (2017) | **Overall Mean (range) dB across four week period:**  
Open NICU 49.0 dB (26.3,74.5)  
NICU Pod 47.3 dB (26.5,75.9)  
**Mean dB for 1:00-2:00 am (quiet time):**  
Open NICU 49.1 dB | Chi Squared  
X² test for significance and direction of relationship between time of day and level of noise within each area | No (Leq for NICU and Pod)  
L10 and Lmax not assessed. |
### Authors (year)

<table>
<thead>
<tr>
<th>Results</th>
<th>Method of Statistical Analysis</th>
<th>Statistical Significance</th>
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<tbody>
<tr>
<td>NICU Pod 44.5 dB</td>
<td></td>
<td>greater than Pod noise levels for the quiet shift** and the morning rounds**</td>
</tr>
<tr>
<td>Mean dB for morning ward rounds: Open NICU 52.4 dB NICU Pod 48.8 dB</td>
<td></td>
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<tr>
<td>Mean dB during nursing handover: Open NICU 53.1 dB NICU Pod 51.0 dB</td>
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<td></td>
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<tr>
<td>Isolated peak dB levels: Open NICU 74.5 dB NICU Pod 75.9 dB</td>
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</table>

### Compliance with American Academy of Pediatrics NICU Standards (Leq < 45 dBA; L10 < 50 dBA; Lmax < 65 dBA)

<table>
<thead>
<tr>
<th>Authors et al (2011)</th>
<th>Leqs per location (quiet time Leq; busy/active time Leq in dBA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open bay: Closest to entry/nursing station: 50 dB; 55 dB Furthest from entry/nursing station: 55 dB; 50 dB SFR (single family room): Closest to entry/nursing station: 35 dB; 35dB Furthest from entry/nursing station: 35 dB; 35 dB</td>
<td></td>
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<tr>
<td>Leqs centered at 2kHz, midrange human voice (quiet time Leq; busy/active time Leq)</td>
<td></td>
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<tr>
<td>Open bay:</td>
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</table>

** Open bay room: No (Leq) SFR: Yes (Leq)
<table>
<thead>
<tr>
<th>Authors (year)</th>
<th>Results</th>
<th>Method of Statistical Analysis</th>
<th>Statistical Significance</th>
<th>Compliance with American Academy of Pediatrics NICU Standards (Leq &lt; 45 dBA; L10 &lt; 50 dBA; Lmax &lt; 65 dBA)</th>
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<tbody>
<tr>
<td>Robertson et al (1998b)</td>
<td>Data from noise distribution survey discarded since the noise level reading never stabilized and researchers were required to estimate measurements. Therefore these results were rendered unreliable. Mean hourly Leq for Quadrant area and central location ranged from 58.1-59 dB. Mean Lmax for quadrant and central locations ranged from 64.3 dB - 65.2 dB</td>
<td>ANOVA</td>
<td>Differences in Leq between quadrant position*** and day of the week*** were found to be significant where quadrants 3 and 4 were significantly noisier than quadrants 1 and 2 and Saturday was the noisiest day of the week; Difference between day shift (7am-7pm) and night shift (7pm-7am) NS; Differences between nursing shift changes/physician rounds and other times of day NS</td>
<td>No (Leq) Yes (LMax)</td>
</tr>
</tbody>
</table>
| Byers et al (2006) | *Control room mean dBA(SD)*  
Lmin 57.4 dB(6.5)  
Leq 60.0 dB (7.3) | Independent sample t-tests | Noise levels were significantly lower in the developmental room as compared with the control room for | No (Leq and L10 for all conditions) |
<table>
<thead>
<tr>
<th>Authors (year)</th>
<th>Results</th>
<th>Method of Statistical Analysis</th>
<th>Statistical Significance</th>
<th>Compliance with American Academy of Pediatrics NICU Standards (Leq &lt; 45 dBA; L10&lt; 50 dBA; Lmax &lt; 65 dBA)</th>
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<tr>
<td></td>
<td>L10  61.1 dB (7.8) Lmax- 62.8 dB (8.5) <em>Developmental NICU mean dBA (SD)</em> Lmin- 53.0 dB (5.2) Leq- 54.9 dB (4.1) L10- 55.9 dB (4.1) Lmax- 57.0 dB (6.5) Radiant Warmer Estimated mean dBA: Lmin- 52 dB Leq- 56 dB L10- 58.5 dB Lmax- 61 dB Newer Incubators Estimated Mean dBA: Lmin- 55 dB Leq- 56 dB L10- 56.1 dB Lmax- 58 dB Older Incubators Estimated Mean dBA: Lmin- 57.5 dB Leq- 60 dB L10- 61dB Lmax- 61 dB</td>
<td>all noise level measurements***</td>
<td>Yes (Lmax for all conditions)</td>
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Surenthiran et al (2003) Mean intensity at 1000Hz in dB SPL *No respiratory support: Independent sample t* Comparison of mean in-the- ear noise intensities between groups No recommended
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<tr>
<th>Authors (year)</th>
<th>Results</th>
<th>Method of Statistical Analysis</th>
<th>Statistical Significance</th>
<th>Compliance with American Academy of Pediatrics NICU Standards (Leq &lt; 45 dBA; L10&lt; 50 dBA; Lmax &lt; 65 dBA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robertson et</td>
<td>100% of Lpeak measurements exceeded</td>
<td>ANOVA</td>
<td>Period A: (physician rounds)</td>
<td>No</td>
</tr>
<tr>
<td>In ear: 41.7 dB</td>
<td>tests without respiratory support vs. those with conventional ventilation across all frequencies assessed (.2-8kHz) NS (p&gt;.05); Comparison of mean in-the-ear noise intensities between groups revealed significantly louder levels in the CPAP group as compared to the conventional ventilation group for 0.5-8kHz* (difference NS at 0.2 kHz p=.05); Comparison of mean in the ear noise intensities between groups revealed significantly louder levels in the CPAP group as compared to the without respiratory support group for 0.5-8kHz* (difference NS at 0.2kHz p=.05); For all groups NS difference between measurements taken just outside the ear canal and those taken within the EAM across all measured frequencies (0.2-8kHz) (p&gt;.05)</td>
<td>standards for dB SPL; dB SPL comparable to dBA only at 1000 Hz; Yes (Leq at 1kHz for no respiratory support and conventional ventilation) ; No (Leq at 1kHz for CPAP)</td>
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<td>Out of ear: 39.6 dB</td>
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<td>Conventional ventilation:</td>
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<td>In ear: 39.5 dB</td>
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<td>Out of ear: 39.2 dB</td>
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<td>CPAP:</td>
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<tr>
<td>In ear: 55.1 dB</td>
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<tr>
<td>Out of ear: 51.9 dB</td>
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<tr>
<td>Authors (year)</td>
<td>Results</td>
<td>Method of Statistical Analysis</td>
<td>Statistical Significance</td>
<td>Compliance with American Academy of Pediatrics NICU Standards (Leq &lt; 45 dBA; L10&lt; 50 dBA; Lmax &lt; 65 dBA)</td>
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<tr>
<td>al (1998a)</td>
<td>70 dB</td>
<td></td>
<td></td>
<td>recommended standard for Lpeak</td>
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<tr>
<td></td>
<td>31.3% of Lpeak measurements exceeded 90 dB</td>
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<td></td>
<td>2.1% of Lpeak measurements exceeded 100 dB</td>
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<td></td>
<td>Period B: (afternoon; does not correspond to any scheduled activity)</td>
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<tr>
<td></td>
<td>Period C: (evening; does not correspond to any scheduled activity)</td>
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<tr>
<td></td>
<td>Relations between Lpeak measurements, time of day, quadrant location and day of week were significant***</td>
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<tr>
<td></td>
<td>Lpeak &gt; 90 dB is increased 5% during period A, this corresponds to 16% of overall measurements that exceed 90 dB;</td>
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<td></td>
<td>Period B represents increase of 1.9% &gt;90 dB;</td>
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<td></td>
<td>Period C represents increase of 3.8% &gt;90dB</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Lahav (2015)</th>
<th>Mean Leqs in dBA:</th>
<th>t-test</th>
<th>The difference between nighttime and daytime Leqs NS (p&lt;.056)</th>
<th>No (Leq)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Daytime: 60.1 dB</td>
<td></td>
<td>Significantly greater exposure to sound frequencies in the human speech range (501-3150 Hz) during the daytime as compared with the nighttime*</td>
<td></td>
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<tr>
<td></td>
<td>Nighttime: 58.7 dB</td>
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<td></td>
<td>Frequency spectrum analysis revealed the infants were exposed to:</td>
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<td></td>
<td>20-500 Hz: 100% of the time</td>
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<tr>
<td></td>
<td>501-3150 Hz (human speech range): 55%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Authors (year)</td>
<td>Results</td>
<td>Method of Statistical Analysis</td>
<td>Statistical Significance</td>
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<td>of the time 3151-6300 Hz: 1.6% of the time 6301-16000 Hz:&lt; 1% of the time</td>
<td>Compliance with American Academy of Pediatrics NICU Standards (Leq &lt; 45 dBA; L10&lt; 50 dBA; Lmax &lt; 65 dBA)</td>
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</tbody>
</table>
DISCUSSION

The purpose of this systemic review of the literature was to investigate noise levels in the NICUs and to compare them with the standards recommended by the AAP (2012). Additionally, the effects of various NICU conditions on noise levels were explored.

In most studies that assessed noise levels in a NICU incubator, noise levels were elevated as compared with those outside of the incubator (Anagnostakis et al., 1980; Byers et al., 2006; Kent et al., 2002). Elevated sound levels may be associated with hospital staff and/or visitors tapping on the incubators or putting down clipboards, as well as the baby’s own cries or equipment noise including ventilators, alarms, etc. (Altuncu et al., 2009). In general, noise levels in the incubator often are increased as compared with those outside due to the small enclosed space, which increases sound pressure levels. Nevertheless, Byers et al. (2006) found that newer incubators (purchased after 1999) provided approximately 4 dB of attenuation as compared with noise levels associated with older incubators and radiant warmers. The findings of this systematic review suggest that newer incubators appear to have more protective qualities. Further research is needed to substantiate this finding.

Similarly, Byers et al. (2006) and Williams et al. (2007) found that newer hospitals with NICUs that were built with sound attenuation in mind were associated with decreased noise levels as compared with noise levels in older NICUs. The NICU layout also had a significant effect on noise exposure for open versus enclosed NICU rooms. All of the studies that compared these two conditions found significantly greater noise levels in the open NICU spaces than in the closed NICU rooms (Chen et al., 2009; Domanico et al., 2011; Ramm et al., 2017).

In the majority of studies involving analysis of noise levels by time of day, noise levels were increased during day shifts as compared with those during night shifts, and noise levels
peaked during physician rounds and shift changes (Matook et al., 2010; Ramm et al., 2017; Robertson et al., 1998a; Williams et al., 2007). These findings indicate that increased noise levels are at least partially caused by hospital staff. Therefore, hospital staff should be trained regarding noise standards and methods for minimizing noise levels throughout all hours of the day.

Overall, the majority of studies found that noise levels were not in compliance with AAP (2012) recommended standards, thereby exposing the NICU infants to potentially harmful levels of sound. Elevated noise levels in the NICU are a problem that faces most NICUs. They can have very harmful, lifelong effects on the babies who spend time there. The findings of this systematic review of the literature have shown that although noise levels in most NICUs are not in compliance with the AAP standards, a number of hospital conditions can be modified and staff awareness training can be implemented to effect reduced NICU noise levels. According to Livera et al. (2008), modifications to staff activity in the NICU should include proper training, speaking quietly, and not tapping or banging on incubators and ensuring that incubator doors are closed gently. Additionally, all alarm volumes should be decreased as they are often unnecessarily loud and visual or tactile alarms should be utilized. Lastly, phones should be silenced in the NICU and phone calls should be taken outside the NICU. McMahon et al. (2012) suggested increased use of private rooms in place of open bay areas.

Future research should continue to explore the effects of noise exposure on infants in the NICU and the relations between ototoxic medications and noise induced hearing loss in NICU babies. The use of newer incubators in reducing noise level exposure as well as the efficacy of staff trainings in noise reduction in the NICUs also should continue to be investigated.
CONCLUSIONS

In this systematic review, the findings of research on noise levels in the NICU were examined. The results also were evaluated with reference to the AAP standards (2012). Noise levels for various NICU conditions within each study were also evaluated and compared with one another in order to help determine ideal NICU setup and environment.

The findings of the reviewed literature revealed that all of the NICUs assessed had noise levels exceeding at least one of the AAP standards (2012) and nearly all of studies failed to meet any of the AAP noise level standards. The failure of NICUs to meet noise level standards must be recognized. The issue is of great importance since increased noise levels can lead to noise induced hearing loss, especially in premature and newborn ill infants whose auditory systems are still developing and may be taking ototoxic medications. Ototoxic medications, which can cause hearing loss independently, have synergistic effects in terms of the risk and severity of noise-induced hearing loss when combined with elevated noise exposure.

Although AAP noise levels standards overwhelmingly were not met in the NICU, there were NICU conditions that had specific effects on the intensity of noise exposure. The majority of investigators who assessed incubator noise levels found that noise levels were increased inside the incubators. In all of the studies that compared noise levels in open versus closed NICU spaces, noise levels were higher in the former than in the latter spaces. When noise levels in hospitals with NICUs that were newer and designed with noise attenuation in mind were compared those in older NICUs, the findings revealed significant attenuation in those newer NICU settings. Lastly, when noise levels were evaluated by time of day, study findings showed that noise levels were greater during the daytime and on weekends than at other times and were especially high during physician rounds and shift changes.
The findings of this systematic review show that loudness levels in NICUs are a serious problem impacting the hearing sensitivity of newborns that must be addressed. Additionally, comparison of various NICU conditions revealed that certain NICU conditions are more favorable than other NICU conditions in reducing noise levels. Therefore, these conditions should be considered and evaluated in all NICU settings in order to reduce noise levels and to provide the best care possible by reducing the risk of irreversible noise-induced hearing loss in NICU graduates.
REFERENCES


