Original Article

# Spectral Analysis of Noise in the Neonatal Intensive Care Unit

**M.D.Livera, B. Priya, A. Ramesh, P.N. Suman Rao, V. Srilakshmi, M. Nagapoornima, A.G. Ramakrishnan[1], M. Dominic and Swarnarekha**

*St John's Medical College Hospital, Bangalore, [1]Medical intelligence and language engineering laboratory, Department of Electrical engineering, Indian Institute of Science, Bangalore, India*

## ABSTRACT

**Objective.** To perform spectral analysis of noise generated by equipments and activities in a level III neonatal intensive care unit (NICU) and measure the real time sequential hourly noise levels over a 15 day period.

**Methods.** Noise generated in the NICU by individual equipments and activities were recorded with a digital spectral sound analyzer to perform spectral analysis over 0.5 – 8 KHz. Sequential hourly noise level measurements in all the rooms of the NICU were done for 15 days using a digital sound pressure level meter . Independent sample t test and one way ANOVA were used to examine the statistical significance of the results. The study has a 90 % power to detect at least 4 dB differences from the recommended maximum of 50 dB with 95 % confidence.

**Results.** The mean noise levels in the ventilator room and stable room were 19.99 dB (A) sound pressure level (SPL) and 11.81 dB (A) SPL higher than the maximum recommended of 50 dB (A) respectively ( $p < 0.001$). The equipments generated 19.11 dB SPL higher than the recommended norms in 1 – 8 KHz spectrum. The activities generated 21.49 dB SPL higher than the recommended norms in 1 – 8 KHz spectrum ( $p< 0.001$).The ventilator and nebulisers produced excess noise of 8.5 dB SPL at the 0.5 KHz spectrum.

**Conclusion.** Noise level in the NICU is unacceptably high .Spectral analysis of equipment and activity noise have shown noise predominantly in the 1 – 8 KHz spectrum. These levels warrant immediate implementation of noise reduction protocols as a standard of care in the NICU. **[Indian J Pediatr 2008; 75 (3) : 217-222]** *E-mail: lavirams@yahoo.com*

***Key words :*** *Noise in neonatal intensive care unit (NICU)*

Noise levels in the neonatal intensive care unit (NICU) above the recommended maximum of 50 dB (A) SPL (SPL - sound pressure level; A – Reference weighting scale for sound) is harmful to the development of the neonates.[1] Noise levels in the range of 60 - 80 dB (A) SPL have been shown to increase the heart rate, respiratory rate and reduce the oxygen saturation of neonates in the NICU.[2] Electrophysiological mapping of the auditory cortex in mice pups exposed to 70 dB (A) white noise for 16 days since birth have shown retardation of neuronal development compared to those reared in standard housing conditions.[3] Reducing the noise levels by 4 dB have demonstrated a reduced requirement for oxygen support and decrease in mean diastolic pressure compared to pre noise reduction values.[4] Though health care personnel in India taking care of newborns in the NICU have been concerned about this, scientifically designed noise reduction protocols are seldom implemented with rigor. At this point of time there is a single study from India which has performed basic decibel level measurements and concluded that sound levels in the NICU range far from safety and at times in the dangerous zone.[5] Considering the fact that injury to the auditory apparatus due to excessive noise is dependent on the intensity at each frequency, there is a need to examine the frequency spectrum of the noise at various frequency bands. The intensity at various frequencies also serves as a guide in selecting the method to be used for noise reduction. Our study has performed spectral analysis of noise generated by individual equipments and activities. Also sequential hourly noise levels over a 15 day period in the NICU were done to assess the real time extent of noise pollution.

**Correspondence and Reprint requests :** A. Ramesh, Associate Professor, Department of Otolaryngology Head and Neck Surgery, St. John's Medical College Hospital, Bangalore-560 034, India Phone : +91 9845236298

**[Received May 25, 2007; Accepted October 31, 2007]**

## MATERIALS AND METHODS

The study was conducted at the neonatal intensive care unit of St John's Medical College hospital, Bangalore from 25th August to 8th September, 2005. This is a tertiary level neonatal health care centre. The average number of neonates in the NICU at a given point of time is 25 (Range 20 -30). The materials that were used during the study were the following: Neonatal mannequin, Digital sound pressure level meter, Digital spectral sound analyzer.

### Spectral analysis of noise generated by individual equipments and activities

The following steps were carried out to perform spectral analysis of noise

- The time chosen to record the noise was 3 A.M on a particular day to reduce ambient noise as it is least noisy in the early hours of the day
- The noise recording was done in an adjoining room of the NICU whose acoustic properties were similar to the NICU.
- A scenario of a neonate being managed in the NICU was simulated by placing a neonatal mannequin on a couch in the room.
- The equipments were placed near the couch as it would be in the NICU.( Approximately at a distance of 1 meter from the mannequin )
- The equipments were switched on individually and the noise generated was recorded and analysed by the digital spectral sound analyser at the level of external auditory meatus (EAM) of the mannequin
- The noise generated by the activities in the NICU was recorded at a distance of 1 meter.

The Medical Intelligence and Language Engineering laboratory at the Indian Institute of Science provided the training to the medical personnel for performing spectral analysis.

### Sequential hourly noise level measurements over a 15-day period

There are 5 rooms in the NICU. The dimensions of the rooms (Length × Breadth × Height in feet ) are as follows ; Ventilator room : 20.6 × 20.6 × 11, Stable room : 20.6 × 20.6 × 11, Isolation room : 14 × 12.9 × 11 , Extreme pre-term room : 13.3 × 20.6 × 11and Pre-term room : 13.3 × 20.6 × 11. All these rooms are separated by glass and aluminum partitions extending from floor to the roof .The maximum number of neonates that can be accommodated in these rooms are as follows. Ventilator room : 6, Stable room : 12 , Isolation room : 4, Extreme pre-term room : 6 and Pre-term room : 6. The hourly noise level measurements were carried out by the following protocol.

- All the duty nurses in the NICU were trained to use the portable digital sound pressure level meter to measure the sound intensity level.
- The sound levels were recorded at the center of each of the rooms by the nursing staff on duty.
- Sequential hourly measurements were performed over a 15 day period (25th August to 8th September, 2005) consisting of 13 working days and 2 holidays.

### Analysis of the noise for selecting the method for reduction

The data derived from spectral analysis of NICU noise was discussed with an expert on active noise control at the Active Noise Control Division of National Aerospace Laboratory, Bangalore. The opinion of the expert on the extent of noise reduction possible at various frequencies was noted.

### Statistical analysis of data

*Internal validity:* The equipments were calibrated using standard sounds at 0.5 – 8 KHz. Noise sampling was done for one minute at the sampling rate of 44,100 samples per second and noise reduction filters embedded in the digital spectral sound analyzer was used to reduce ambient noise from the environment and electronics of the hardware . Noise level measurement from the center of the room is a standard practice and accurately measures the noise in the room.[6]

*External validity:* Geometric mean measurements (dB is a logarithmic scale) along with standard deviation (SD) and range were used to summarize the data as all the data had a symmetric distribution. Noise levels > 50 dB was considered as significant and the mean noise levels measured were compared with this and the statistical significance of the difference was tested using student's t test. The validity of comparing the statistical significance of the difference in sound levels within different frequency groups of the same noise were tested using one way analysis of variance (ANOVA: Tukey and Bonferroni post hoc methods ). The number of neonates in each room of the NICU during the 15 day period of noise measurement was similar to the average occupancy throughout the year. This ensured representative sampling of the target population of neonates in the NICU. p values less than 0.05 was considered statistically significant. The study has a 90 % power to detect at least 4 dB differences from the recommended 50 dB with 95 % confidence. Statistical package for social sciences (SPSS) version 15 was used to perform statistical analysis. Power analysis statistical system (PASS) was used to perform power analysis.

**Table 1. Spectral analysis of noise generated by the equipments used in the Neonatal ICU***

| Equipment | Sound pressure level (dB SPL) across the spectrum of frequencies | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.5 KHz | 1 KHz | 2 KHz | 3 KHz | 4 KHz | 5 KHz | 6 KHz | 8 KHz |
| Ventilators without alarm | 54 | 59 | 65 | 67 | 70 | 71 | 72 | 75 |
| Ventilators with alarm | 59 | 67 | 73 | 73 | 77 | 78 | 81 | 83 |
| Monitors without alarm | 24 | 52 | 58 | 61 | 65 | 66 | 66 | 69 |
| Monitors with alarm | 32 | 63 | 68 | 71 | 72 | 75 | 76 | 77 |
| Radiant warmer with alarm | 24 | 51 | 59 | 61 | 65 | 64 | 67 | 68 |
| Phototherapy unit | 37 | 60 | 65 | 68 | 69 | 71 | 72 | 72 |
| Infusion pumps with alarm | 32 | 61 | 68 | 70 | 71 | 74 | 75 | 77 |
| Nebuliser | 56 | 57 | 62 | 59 | 62 | 65 | 69 | 65 |
| Incubator without alarm | 32 | 62 | 68 | 69 | 73 | 75 | 76 | 79 |
| Incubator with alarm | 38 | 68 | 73 | 83 | 73 | 77 | 82 | 83 |

* Ambient noise in the room : 40 dB SPL (A)

## RESULTS

### Spectral analysis of noise generated by individual equipments

Table 1 shows the spectral analysis of noise generated by individual equipments. Figure 1 represents the distribution pattern of these measurements. The mean noise levels at 1 – 8 KHz is 19.11 dB higher than the recommended maximum level of 50 dB ( $p < 0.001$ ) .The mean levels at 0.5 KHz is well within the recommended level except for the noise generated by the ventilators and nebulisers which is higher than recommended levels by 8.5 dB.

The mean noise level at 0.5 KHz is 38 dB SPL (SD = 12.97; Range: 24 – 59) and at frequencies 1 – 8 KHz is 69.11 dB SPL (SD = 7.15 ; Range: 51 – 83).The mean intensity at 0.5 KHz was lower than that at 1 – 8 KHz by 31.11 dB . This difference was highly significant with F value by ANOVA for significance of the difference between groups being 9.53 (df= 9.8) and $p < 0.001$.Ventilators and incubators with alarms generated the maximum noise of 83 dB SPL at 8 KHz .

### Spectral analysis of noise generated by individual activities

Table 2 shows the spectral analysis of noise generated by individual activities. Figure 1 represents the distribution pattern of these measurements. The mean noise level at 0.5 KHz is 33.38 dB SPL ( SD : 1.94 ; Range 32 – 38 ).The mean noise levels at 1 – 8 KHz is 71.49 dB SPL ( SD : 5.62 ; Range : 60 – 88 ) . All the activity generated noise at 0.5 KHz is well within the maximum recommended level whereas the noise at 1 – 8 KHz is 21.49 dB above the maximum recommended level. This finding was highly significant with $p < 0.001$. The F value by ANOVA for within groups significance was 11.60 (df=102) with $p < 0.001$ which is highly significant .The maximum noise is generated by vacuum cleaners and dropping of trays at 88 dB and 82 dB SPL respectively.

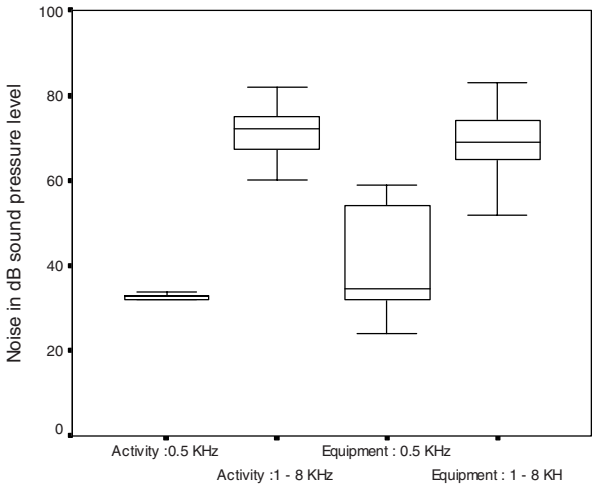


**Fig. 1.** Box plots of equipment and activity noise levels at 0.5 KHz and 1 - 8 KHz.

### Sequential hourly noise level measurements over a 15 day period

Table 3 shows the hourly noise level measurements over a 15 day period (13 working days and 2 holidays) in the NICU. The noise in the ventilator room and stable room were 19.99 dB and 11.81 dB above the maximum recommended respectively whereas the isolation , pre-term rooms and extreme pre-term were 6.95 and 7.12 dB and 4.56 dB above the maximum recommended respectively. All these findings were highly significant with $p < 0.001$.

## DISCUSSION

### Sequential hourly noise level measurements in the NICU

In this study the noise level measurements have shown a mean level of 69.99 dB (A) SPL and 61.81 dB (A) SPL in the ventilator and stable room respectively. This finding was highly significant statistically. These values are much

**Table 2. Spectral Analysis of Noise Generated by Activities in Neonatal ICU**

| Activity | Sound pressure level (dB SPL) across the spectrum of frequencies | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.5 KHz | 1 KHz | 2 KHz | 3 KHz | 4 KHz | 5 KHz | 6 KHz | 8 KHz |
| Vacuum cleaning | 38 | 62 | 69 | 72 | 79 | 76 | 76 | 88 |
| Handling of trays | 33 | 61 | 67 | 69 | 71 | 74 | 75 | 79 |
| Dropping of katori | 32 | 61 | 67 | 70 | 72 | 74 | 75 | 79 |
| Tap running | 32 | 60 | 67 | 70 | 72 | 75 | 75 | 79 |
| Pushing of trolley | 33 | 62 | 67 | 69 | 74 | 74 | 76 | 78 |
| Phone ringing | 33 | 63 | 65 | 71 | 72 | 73 | 73 | 78 |
| Chair moving | 33 | 62 | 67 | 69 | 72 | 74 | 76 | 78 |
| Rounds | 32 | 62 | 67 | 70 | 72 | 74 | 75 | 77 |
| Mother talking | 33 | 60 | 65 | 68 | 72 | 74 | 75 | 77 |
| Hand dryer | 34 | 61 | 66 | 69 | 72 | 73 | 75 | 77 |
| Baby crying | 32 | 60 | 68 | 71 | 70 | 74 | 75 | 76 |
| Calling aloud | 32 | 62 | 67 | 69 | 70 | 74 | 74 | 75 |
| Dropping trays | 37 | 67 | 72 | 76 | 77 | 79 | 80 | 82 |

**Table 3. Sequential hourly noise level measurement in various rooms of the neonatal intensive care unit over a 15 day period**

| Room | Mean noise levels ( dB SPL )* | Range ( dB SPL )* | 95 % confidence with p value ** |
|---|---|---|---|
| Ventilator Room | 69.99 | 61.15 – 72.48 | 66.93 – 70.99 (p< 0.001) |
| Stable Room | 61.81 | 57.22 – 66.02 | 59.57 – 62.87 (p< 0.001) |
| Isolation Room | 56.95 | 54.07 – 58.77 | 55.77 – 57.38 (p< 0.001) |
| Extreme pre-term Room | 54.56 | 52.22 – 57.79 | 53.62 – 56.66 (p< 0.001) |
| Pre-term room | 57.12 | 53.62 – 59.52 | 52.22 – 58.87 (p< 0.001) |

*( dB SPL : Decibel sound pressure level )
**p values were calculated to examine for significance of these intervals above the maximum recommended of 50 dB

above the maximum recommended 50 dB (A). Noise levels ranging from 61 – 80 dB SPL in level III NICUs have been reported by other studies.[7,8,9] Our study has reaffirmed this fact in a typical level III NICU in India. In the ventilator room the equipments may be the major contributor to noise levels. The stable room lies between the lounge and the isolation and this could have contributed to increased activity and hence more noise. A limitation of these measurements was that there was no blinding, that is the caregivers were aware when the noise levels were being measured. So there is a possibility that the noise levels could have been higher.

### Relevance of active and passive noise reduction technology in the NICU

The spectral analysis of equipments has shown that the ventilators and nebulisers produce unacceptable noise levels in the ≤ 0.5 KHz spectrum. Similar observations have been made for frequencies below 250 Hz in equipments using compressors and motors.[10] At frequencies ≤0.5 KHz passive methods using acoustic treatment is not efficacious as the wavelength is longer. Antinoise ( $180^0$ opposite phase and same amplitude as ambient noise) against this low frequency noise could be employed to reduce the noise levels by incorporating this technology into equipments having high speed motors and compressors. The limitation of implementing active methods is the high cost of installation of about 1 lakh Indian rupees per equipment. Till date these technologies have been used to reduce noise in the cockpits of aircrafts.

The spectral analysis of equipments and activities has shown a high level of noise in the high frequency region. Noise induced inner ear injury is maximum around 4 KHz. A mean of 20.25 dB level above the recommended by equipments and activities at high frequencies is a matter of concern. Passive methods such as behavioral modification could reduce this noise.[11,12]This calls for implementation of rigorous noise control protocols in the NICU.[13] A noise reduction protocol has been implemented in our NICU and we intend to publish the results as a sequel to this publication.

### A model noise control protocol for level III NICU in India

Based on the findings of this study and recommended specifications for NICU design [13] we propose a model noise control protocol for a typical NICU. We have put forth guidelines that could be adapted in a particular set up as per the space and budgetary limitations.

An NICU noise control protocol should consist of 3 main activities namely a) noise monitoring activities b) noise reduction activities c) hearing screening of exposed neonates.

***Noise monitoring activities:*** A portable digital sound pressure level meter is an essential tool required for monitoring noise. The approximate cost is 20,000 Indian rupees. Everyday at 10 o'clock in the morning the noise levels in each of the rooms in the NICU should be measured at the center of the room. If the noise levels exceed 50 dB (A) SPL then noise reduction methods must be employed. The A weighted scale focuses on noise in the spectrum of 1-5 KHz. So if there is more than 20 dB difference between A and C weighted scale then the possibility of higher level noise in the spectrum less than 1 KHz and more than 5 KHz should be considered and spectral analysis is recommended.

***Noise reduction activities:*** Noise in the NICU is generated by equipments , activities in the NICU and noise transmitted into the NICU from outside by airborne and structure borne conduction. So noise reduction is implemented for each of these components.

- Activity modification: This is the most difficult method as human activity is not easy to control. A daily meeting of the staff and review of the existing noise levels and its harmful effects on the infants could be used to sensitize the personnel for activity modification. The family members of the infant should also be included in these sessions so as to make them aware of the harmful effects of noise and the need to be less noisy. The two main behaviors that need to be modified are handling of metallic objects carefully and talking in whispers. The discussions at the bedside may be avoided and conducted in a separate room outside.
- Equipment noise reduction: High frequency noise generated by equipments can be measured using the sound pressure level meter. The alarm volume should be adjusted till the noise is 50 dB SPL. The motors and compressors of ventilators and nebulisers produce noise mainly at ranges below 0.5 KHz. Active noise control would be required to reduce this noise. This technology is expensive so if resources permit it should be employed. Visual alarms are ideal to reduce noise but it requires one person to be constantly looking at the monitors which is labor intensive and may not be practical.
- Control of noise reverberations within the NICU: Any noise generated in the NICU gets reflected and re-reflected till it losses its energy which is called reverberation. This phenomenon adds to the already existing noise levels. Acoustic tiles on the roof and veneer flooring reduce reverberations. Acoustic foam is not ideal for NICU as it accumulates dust and is difficult to clean frequently.
- Control of air borne and structure borne noise transmitted into the NICU from outside : All activities which can be avoided inside the NICU like telephone ringing and transport of linen must be done in an area separated from the NICU by double wall aluminum partition or a corridor. Windows must have fixed frame double glass fittings. The noise from activities above the roof is limited by false ceilings. Centralized or split air conditioning is preferred and the terminal end of the duct must be lined with acoustic foam.

*Hearing screening:* All the neonates in the NICU should be screened for hearing impairment before discharge from the hospital or latest at the first follow up visit to the hospital.

## CONCLUSIONS

The mean noise levels in all the rooms of a typical neonatal intensive care unit are unacceptably higher than the maximum recommended level of 50 dB (A) SPL ($p < 0.001$). Noise levels in the 1 – 8 KHz spectrum is predominantly higher than lower frequencies. These levels warrant immediate implementation of noise reduction protocols.

## ACKNOWLEDGEMENTS

The authors acknowledge Dr Narasimhan, Deputy Director , Division of active noise control, National Aerospace Laboratory for the expert opinion on relevance of this technology for NICU , Christoffel Blinden Mission for the grant-in-aid for the purchase of sound pressure level meter, Dr M.N.Munjal , Head of Mechanical engineering, Indian Institute of Science, Bangalore for his opinion regarding noise control measures , Dr Ravi C.Nayar, Head of the department of E.N.T and the management of St John's National Academy of Health Sciences for support of this effort.

## REFERENCES

1. White RD. Recommended standards for newborn ICU design. *J Perinatology* 2003; 23(Suppl 1 ) : 5-21.
2. Johnson AN. Neonatal response to control of noise inside the incubator. *Pediatric Nurs* 2001; 27 : 600-605.
3. Chang EF, Machael MM. Environment noise retards auditory cortical development. *Science* 2003; 300 : 498-502.
4. Slevin M, Farrington N, Duffy G, Daly L, Murphy JF . Altering the NICU and measuring infant's responses. *Acta Pediatr* 2000; 89 : 577-581.
5. Vivek G, Soodan KS, Girish G, Vishal S, Nair MNG. Evaluation of sound pressure level in NICU. *J Neonatogy* 2005; 19 : 155-159.

6. Robertson A, Kohn J, Vos P, Cooper-Peel C. Establishing a noise measurement protocol for neonatal intensive care units. *J Perinatology* 1998; 18 : 126-130.
7. Guimaraes H, Oliveira AM, Spratley J, Mateus M, d'orey C, Coelho JL, Souto A, Santos NT. The noise in neonatal intensive care units. *Arch Pediatr* 1996; 3 : 1065-1068.
8. Benini F, Magnavita V, Lago P, Arsian E, Pisan P. Evaluation of noise in the neonatal intensive care unit. *Am J Perinatology* 1996, 13 : 37-41.
9. Nzama NP, Nolte AG, Dorfling CS. Noise in a neonatal unit: Guidelines for the reduction or prevention of noise. *Curationis* 1995; 18 : 16-21.
10. Robertson A, Cooper-Peel, Vos P. Sound transmission into incubators in the neonatal intensive care unit. *J Perinatology* 1999; 19 : 494-497.
11. Jonckheer P, Robert M, Aubry JC, De Brouwer C. Noise in neonatology: The impact of hospital staff. *Presse Med* 2004; 33: 1421-1424.
12. Chang YJ, Lin CH, Lin LH. Noise and related events in a neonatal intensive care unit. *Acta Paediatr Taiwan* 2001; 42: 212-217.
13. M Kathleen Philbin RN. Planning the acoustic environment of a neonatal intensive care unit. *Clinics in Perinatology* 2004; 31: 331-352.