

## Targeted Noise Reduction Observational Study for Reducing Noise in a Neonatal Intensive Care Unit

Sanjay CHAWLA<sup>1</sup>, M WAIHY<sup>1</sup>, D KAMAT<sup>1</sup>, S SHANKARAN<sup>1</sup>, B PANAITESCU<sup>1</sup>, B WANG<sup>1</sup> and G NATARAJAN<sup>1</sup>, Paul BARACH<sup>1,2,2</sup>.

<sup>1</sup> Division of Neonatology, Department of Pediatrics, Children's Hospital of Michigan, Pediatrics, Children's Hospital of Michigan, Detroit, MI, USA.

<sup>2</sup> Jefferson College of Population Health, Philadelphia, PA; <sup>3</sup> Department of Health Law & Science, Sigmund Freud University, Vienna, Austria.

### ABSTRACT

**BACKGROUND:** Sleep is critical to patient recovery in the hospital, hospitalization is not restful, and inpatient sleep deprivation has been linked to poor outcomes. Excessive noise in neonatal intensive care units (NICUs) can interfere with infants' growth, development and healing. Sound levels in many NICUs exceed the recommended levels by the World Health Organization.

**METHODS:** We implemented a unit-based nursing empowerment approach focused on noise reduction strategy in an urban, tertiary academic medical center NICU that included baseline noise measurements. We conducted a survey involving staff and visitors regarding their opinions and perceptions of noise levels in the NICU. Ongoing feedback to staff after each measurement cycle was provided to improve awareness, engagement and adherence with noise reduction strategies. After widespread discussion with active clinician involvement, consensus building and iterative testing, changes were implemented including: lowering of equipment alarm sounds, designated 'quiet times' and implementing a customized education program for staff.

**INTERVENTIONS:** A multi-phase noise reduction quality improvement (QI) intervention to reduce ambient sound levels in a patient care room in our NICUs by 3 dB (20%) over 18 months. **RESULTS:** The noise in the NICU was reduced by 3 dB from baseline. Mean (s.d.) baseline, phase 2, 3 and 4 noise levels in the two NICUs were: LAeq: 57.0 (0.84), 56.8 (1.6), 55.3 (1.9) and 54.5 (2.6) dB, respectively (P < 0.01). Adherence with the planned process measure of 'quiet times' was >90%.

**CONCLUSIONS:** We implementing a multi-pronged QI initiative resulted in significant noise level reduction in two multi-pod NICUs. It is feasible to reduce noise levels if QI interventions are coupled with active engagement of the clinical staff and following continuous process of improvement methods, measurements and protocols.

**Keywords:** Noise reduction, quality improvement, intensive care unit

<sup>1</sup> Corresponding Author Email: Pbarach@gmail.com

## 1. INTRODUCTION

Premature neonates admitted to the neonatal intensive care unit (NICU) are at risk for long-term neurodevelopmental impairments.<sup>1</sup> Unfavorable NICU environmental factors, including exposure to excessive noise may have adverse effects on the growth and neurodevelopment of neonates.<sup>2–4</sup> Noise in NICUs may be associated with physiologic changes such as apnea, bradycardia, increased blood pressure, decreased perfusion and lower oxygen saturation levels.<sup>5,6</sup> In animal studies, the developing fetal cochlea has been shown to be damaged by intense low-frequency sounds, even with noise exposures as short as 16 h.<sup>7</sup> Sound levels 470 dBA can interfere with the sleep of term infants.<sup>8</sup> Premature infants may have a lower threshold for noise-induced arousal than term infants.<sup>9</sup> In adults, sleep quality in critically ill patients is poor,<sup>10</sup> and noise-related wakefulness has been described as a major stressor.<sup>11</sup> Noise attenuation within recommended levels in the NICU may also improve physiologic stability for vital signs, growth, neurosensory maturation, parent–infant interaction, and speech and language development.<sup>12,13</sup>

The World Health Organization suggests that the A-weighted energy equivalent sound pressures (LAeq) in patient rooms should not exceed 35 dB during the day, and the A-weighted maximum sound pressure level, with fast time constant (LAm<sub>ax</sub>), should not exceed 40 dB at night.<sup>14</sup> The fetus in utero is partially protected from high-frequency noise 4500 to 1000 Hz, which gets attenuated by 20 to 50 dB.<sup>15,16</sup> The recommended safe sound levels in the NICU are: hourly Leq (equivalent continuous sound level) of 45 dB(A); hourly L10 (sound level exceeded 10% of time) of 50 dB(A); and 1 s duration maximum dB level (L<sub>max</sub>) of 65 dB (A).<sup>17</sup> Most NICUs in the United States have sound levels higher than those recommended levels.<sup>13</sup> Sound levels are often excessive inside incubators as well.<sup>5,18</sup>

Equipment alarms from monitors, infusion pumps and ventilators, as well as voices of staff members, consultants and families contribute to the noise in the patient care rooms. Noise levels also have important implications for hospital staff, including staff wellbeing and satisfaction, work efficiency, burnout rates and medical errors.<sup>19,20</sup> A recent simulation of 20 anesthesia residents under noise (Leq 76.5 dB) and quiet (Leq 72 dB) conditions found that excessive noise levels may increase stress, as indicated by perceived levels of fatigue and task load.<sup>21</sup>

Complaints from our medical and nursing staff that our NICU was ‘too noisy and disruptive for work’ prompted this quality improvement (QI) program. The aims of our QI program were (a) to measure the sound levels in a patient care room in the NICU and compare them to the recommended levels, (b) determine the perceptions of staff and families about noise and its sources in the NICU and (c) reduce ambient sound levels in patient care rooms, as measured by Leq(A) by 3 dB (20%) over 18 months. A period of 18 months was chosen to allow adequate time for stability of multiple interventions in each phase lasting 3 to 4 months.

## 2. METHODS

### Design and study population

We studied two academic NICUs, one at the Children’s Hospital of Michigan (CHM) and the other at Hutzel Women’s Hospital (HWH), both part of the Detroit Medical Center (DMC) and Wayne State University in Detroit, Michigan—between April 2012 and December 2013. The NICUs at CHM (a 40-bed

level-IV unit) and HWH (a 25-bed level-III unit) have admission rates between 850 and 1000 admissions each year. Typically, four to six patients are cared for in one room, with one to three patients on mechanical ventilation. We also use high-frequency ventilators in both units. Each room is 24 Å~ 36 feet in size. At the time of data collection, neither NICU had acoustic ceiling tiles. All patients are monitored continuously by cardiorespiratory and a pulse oximeter monitor. Both NICUs are pediatric and neonatal–perinatal medicine training programs staffed with four to six pediatric residents and one to two fellows rotating through neonatology, in addition to the residents and fellows on each consulting service. Both NICUs allow up to two family members to visit at the bedside at any time.

To prevent any possible changes in the staff behavior, we took the following measures: (a) the noisemeter was concealed in a nondescript box and placed in the room for a longer period of time than the actual data collection; (b) staff were not told when the data were being collected; and (c) the noisemeter (model CR162C Optimus Red Integrating Sound Level Meter; Cirrus Research, Hunmanby, North Yorkshire, UK) was placed in the middle along a wall at least 3 feet away from the closest incubator and with no sound barriers between the recorder and the neonate. The study was approved by the Wayne State University Institutional Review Board.

**Measurement of noise levels.** Noise was measured in both NICUs every 2 seconds, 24 hours a day for 5 consecutive days. This process was performed at baseline and at the end of each phase to determine changes related to the planned stepwise interventions. The noisemeter can record and store noise data continuously for at least 7 days. The noisemeter was calibrated before each recording according to the company’s recommendations. Noise data were uploaded to the first author’s (SC) computer using the Noise Tools software (Hunmanby, North Yorkshire, UK). Data are reported by hourly averages: Leq refers to the average hourly dB level, L10 refers to the average hourly dB level exceeded 10% of the time and Lmax refers to the maximum dB level reached at any point within the hour. These measures were then compared to the recommended noise levels.

### **Phases of QI interventions**

**Data collection and interventions with each phase.** During phase 1 (baseline) of the study, baseline noise levels were obtained in each unit. An anonymous survey of all NICU staff (for example, physicians, nurses and respiratory therapists) and family visitors solicited opinions about perceived noise levels on a 5-point Likert scale, consisting of ‘unacceptably high,’ ‘high,’ ‘acceptable,’ ‘quiet,’ and ‘very quiet.’ We also asked them to identify the largest source of noise and to suggest how noise could be reduced. The survey questions were developed based on previously published literature for reduction of excessive sound in NICU.<sup>22</sup> The survey questions were pilot-tested on NICU clinicians and refined accordingly. From the surveys and a review of the literature, we identified staff education, ‘quiet times,’ and equipment alarms as key potential interventions to reduce excessive noise.

In phase 2 of the study, a quiet-time taskforce was developed, which consisted of nurse and physician champions—one nurse educator, one nurse practitioner, and two or three registered nurses at each NICU. The taskforce helped educate staff and reminded them of the goal to reduce noise levels. We used the Plan, Do, Study, Act (PDSA) improvement methodology at each phase with subsequent iterative improvements.<sup>23</sup> Noise data were analyzed once a week throughout the study, regularly given as feedback

to the staff, and were used in planning the next study phase.

In phase 3, the study personnel educated small groups of staff on the adverse effects of noise, and on the importance of noise shielding and revising the workflow to reduce noise and improve patient outcomes. Staff also received the initial survey results, and the baseline and phase 2 noise levels. The intervention required staff and visitors to speak softly in the patient care area, and required staff to respond to equipment alarms as quickly as possible. As exposure to human sound is important for neonates, we promote 'kangaroo care' philosophy and staff and family members talking/singing to their infants at all times.

Phase 3 introduced the concept of the 'quiet times' program in addition to continuing the education and feedback to staff. Each shift on each unit was asked to select three, 60-to-90 min periods throughout the day. The 'quiet time' requirements were to dim the lights, keep conversations to a minimum, use a soft, 'library voice' and respond quickly to equipment alarms. All staff were also requested to put their pagers on vibrate during these periods. In addition to 'quiet times,' the sound volume of equipment alarms throughout the entire unit (pulse oximeters and cardiorespiratory monitors) was reduced from near-maximum to about 50 to 60% sound levels. Nursing staff and physicians' input was sought before determining the lowest and safe audible volumes for each alarm. Daily feedback was given to the NICU staff members on the noise levels in the unit during this phase of the study by posting a graph of the noise level in the hallway of the NICU and through daily discussion in clinical rounds. In addition, we used a color-coded system (green/red) to provide feedback on the sound level for the previous day.

During phase 4 of the study, the pediatric residents rotating through the NICU were trained on the recommended and current noise levels in the NICUs. The physicians in training were encouraged to help nursing staff respond promptly (within 10 s) to alarms. We also extended the duration of 'quiet times' up to 2 h. In addition, we also used a SoundEar Noise Warning Sign from Noisemeter (Hunmanby, North Yorkshire, UK). This ear-shaped sign glows green when the sound level is within the desired range, turns yellow when the sound level is within 5 dB of a maximum limit and turns red if the noise reaches the maximum limit. At the end of phase 4, the sound levels were recorded for another 5 days. The time interval from baseline to phase 4 was 14 months.

The primary outcome measure was  $Leq(A)$  level in each study phase. The process measures included adherence to 'quiet times' collected in real time by 'champions' in phase 4 and, the proportion of nursing staff receiving education on recommended noise levels, and the adverse effects of excessive noise. The balancing measures collected were staff reports of complaints about either (1) 'quiet times' interfering with workflow or efficiency, or (2) 'lower equipment alarm volumes' affecting patient care.

Noise levels measured at the end of phase 4 were compared to baseline levels. A difference of 3 dB was considered to be clinically important.

### **Statistical methods**

Noise levels were combined for both units and were reported by shift: (morning, 0700 AM to 1500 PM; evening, 1500 PM to 2300 PM; and night, 2300 PM to 7 AM) for each of the four phases of the study. Changes in sound levels across the four time phases for each shift were examined by analysis of variance using Tukey's honestly significant difference tests to control for multiple comparisons, for the whole sample and stratified by morning/evening/night shifts. The median noise levels for each phase were

compared with Friedman’s test, with F-values 43 implying a statistical significance level at 0.05 level. All data were analyzed with the SPSS software program, version 21.0 (SPSS, Chicago, IL, USA).

## RESULTS

### Survey responses

Of 190 staff members, 106 completed the validated survey (survey response rate of 56%), as did 61 of 100 (61% response rate) family members approached about doing so. Most staff members judged the noise to be either unacceptably high or high, whereas 71% family members judged it to be either quiet or acceptable. Family members and staff both felt the equipment was the greatest source of excessive noise.

Staff members responded in the survey that staff education (52%), using single patient rooms (21.9%) and ‘quiet times’ (17.8%) would be the most important interventions to reduce noise levels. Accordingly, we focused on education and implementation of ‘quiet times’ as key drivers (Figure 1).

### Noise levels

Noise levels were markedly higher than recommended at baseline and remained higher than recommended for all shifts at the end of phase 4 (Table 1). We found a statistically significant reduction in noise levels in the two NICUs in the two phases of the study, from phase 1 (baseline) to phase 4 ( $P = 0.004$ ). The baseline, phase 2, phase 3 and phase 4 sound levels (mean  $\pm$  s.d.) in two NICUs were: LAeq:  $57.5 \pm 1.4$ ,  $56.8 \pm 1.6$ ,  $55.3 \pm 1.9$  and  $54.5 \pm 2.6$  dB, respectively ( $P < 0.01$ ) (Table 1). The ‘key drivers’ implemented in each phase are presented in Figure 2. As sound intensity is presented as a logarithmic unit, the reduction in sound LAeq from baseline (LAeq 57.5 dB to phase IV LAeq 54.5 dB) was about 19%. The change during morning shift of 1.4 dB, while not statistically significant, may have clinical significance. In phase 4, multiple audits revealed that the compliance rates with the implementation of ‘quiet times’ as a process measure were over 95%. We conducted an anonymous, voluntary survey that was completed by 50 staff members of the two units. In response to ‘quiet times’ and other changes implemented for reduction of noise, 10 (20%) staff members reported an improvement in work satisfaction, while 40 (80%) reported no change; 9 (18%) reported an improvement in work efficiency, while 41 (82%) reported no change.

Shift	Phase 1	Phase 2	Phase 3	Phase 4	P-value
Morning (7 AM–1500 PM) $L_{eq}$	57.7	58.4	57.1	56.3	0.11
Morning (7 AM–1500 PM) $L_{10}$	59.5	60.5	58.6	58.2	0.19
Morning (7 AM–1500 PM) $L_{max}$	82.3	85	83.7	83.2	0.11
Evening (1500 PM–2300 PM) $L_{eq}$	57.5	57.1	55.1	54.2	0.01
Evening (1500 PM–2300 PM) $L_{10}$	59	58.8	56.7	55.6	0.02
Evening (1500 PM–2300 PM) $L_{max}$	83	82.5	80.7	79.9	0.001
Night (2300 PM–7 AM) $L_{eq}$	55.7	55.0	53.6	52.8	0.07
Night (2300 PM–7 AM) $L_{10}$	56.7	56.2	55.2	54.0	0.35
Night (2300 PM–7 AM) $L_{max}$	80.9	81.0	78.8	78.4	0.006
Overall $L_{eq}$	57.0	56.8	55.3	54.5	0.01
Overall $L_{10}$	58.9	58.5	56.8	55.9	0.05
Overall $L_{max}$	83.1	82.8	81.1	80.6	0.02

Abbreviations:  $L_{10}$ , sound level exceeded 10% of time;  $L_{eq}$ , average hourly dB level;  $L_{max}$ , maximum dB level; NICU, neonatal intensive care unit. <sup>a</sup>Each measurement represents average A-weighted energy equivalent sound pressure levels for the time period (morning/evening/night/overall (24 h)).

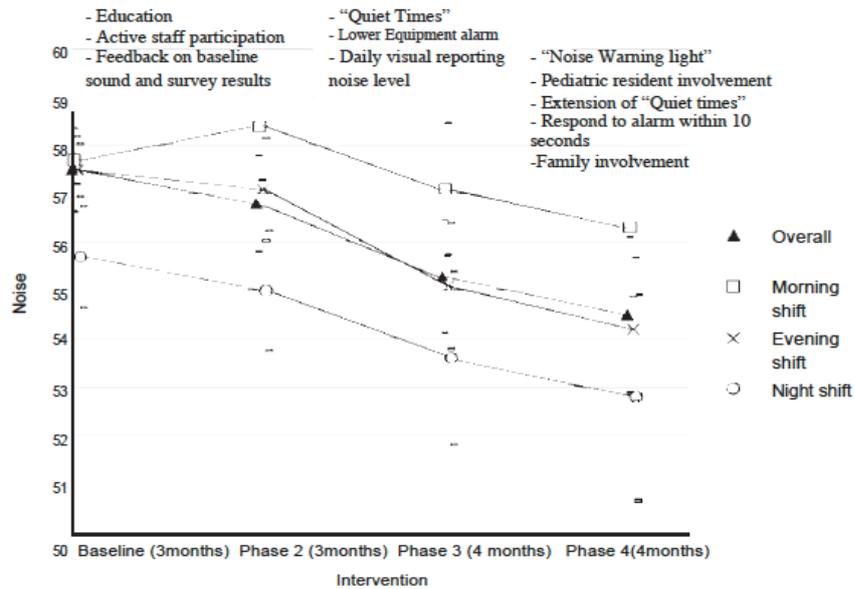


Figure 1. Sound levels in the NICU over four phases with 'key drivers' in each phase. NICU, neonatal intensive care unit.

## DISCUSSION

Our continuous multipronged QI study was able to achieve a successful reduction in ambient noise levels in two multipod tertiary care NICUs. We demonstrated that mean LAeq levels were significantly lower after the QI intervention compared to before with a reduction of up to 3 dB. To better estimate the impact of differences in sound pressure levels, it is important to appreciate that a dB is a logarithmic unit.

Our phased intervention program included staff training and feedback, process mapping, reduction in equipment alarm levels, active staff involvement with behavior modification, implementation of designated 'quiet times' and the use of visual 'noise warning lights.' The 'key drivers' for attenuation of noise in our NICUs were implemented after discussions and agreement with staff members and based on their detailed feedback from conversations and the survey results.

This study also compared the perceptions of family members and hospital staff about the sound levels in NICUs. Interestingly, most family members considered sound levels in the NICU to be acceptable, whereas most hospital staff considered the sound levels in the NICU to be too high.

Other studies of ICU noise levels have found that the WHO recommendations of 40 dB could not be achieved in intensive care units with an open ward system, but could be achieved in single family room NICU design.<sup>24,25</sup> A recent study by Wang et al. noted high baseline noise in the NICU.<sup>26</sup> They noted reduction in noise levels by noise reduction policy, education, audits and feedback mechanisms. Our findings are in line with these studies. A reduction of 1.4 dB during morning shift, although not significant statistically, may be clinically significant. The lack of marked noise reductions in morning shifts may be related to bedside rounds and the number of providers present in the NICU during this shift. A recent study by Lahav noted that during daytime, infants were exposed to 20% more sound as compared to during the night time within the speech frequency for human speech ( $P = 0.018$ ).<sup>27</sup> High background noise may lead to the Lombard effect, and contribute to louder speech; in our study, family and providers were likely to talk louder in the room given higher ambient noise levels.<sup>28</sup>

We currently promote multidisciplinary, family-centered rounds at the bedside of neonates with the

active involvement of caregivers and family members. Strategies to reduce noise related to physician rounds would need to consider the effects on family satisfaction, family and staff in discussions, and trainees' education. Random audits of noise levels with feedback to clinicians may help. Meticulous attention to keeping incubator portholes closed during morning rounds and other periods of excessive noise should reduce noise exposure to the infants to some degree.

Extremely low-birth-weight infants are exposed to high noise levels averaging 56.4 dB(A) during NICU stay.<sup>29</sup> Average sound levels in our NICUs far exceeded the recommended levels for NICUs, consistent with previous studies.<sup>5,18</sup> Our results are consistent with the current, limited literature indicating that ambient noise can be reduced with interventions, such as staff education and behavioral and environmental changes.<sup>22,26</sup>

No staffing or structural changes to walls and ceiling materials have been made in the NICU since this QI initiative was begun. A recent audit showed that the compliance with the implementation of 'quiet times' remained at 95%, suggesting sustained process gains. Reducing noise in the NICU may improve the physiologic stability and outcomes of neonates.<sup>30,31</sup> Other strategies to reduce neonates' exposure to excessive noise include reconstructing the NICU to reduce ambient noise.<sup>32</sup> Protecting premature neonates with ear muffs or ear plugs can improve their physiologic stability and facilitate weight gain.<sup>33,34</sup> Hospital staff is also constantly exposed to excessive noise in NICUs. Reducing the noise might improve staff and family members' satisfaction and work efficiency.<sup>19,20</sup>

### **Limitations of the study**

Our study has several limitations. We measured ambient noise levels in the room and not at the ear level of infants in the incubator. However, we demonstrated that differences in sound transmission over the 3 feet between our measuring device and the infants were negligible without interceding sound barriers. Sound exposure for each individual neonate may vary and depend on several factors, including the level of monitors, placement in an open crib or an incubator. Although we investigated a theoretically more noise-friendly sound environment, the clinical impact of these results remains hypothetical, given the lack of patient outcome data. Neonates in an incubator are not entirely protected from NICU sounds, and may be completely exposed when the incubator doors are opened or when they receive skin-to-skin care by family members.

### **CONCLUSIONS**

We demonstrated that NICUs are very noisy places, with a constant level of noise equivalent to a restaurant. Despite reducing noise levels considerably, we were not successful in lowering noise levels to comply with the recommended WHO levels, especially during the morning shift. Other interventions, such as redesigning the NICU to a single room model, the use of sound-absorbing surface materials, and innovative alarm management programs may help. In addition, the role of ear muffs or ear plugs to provide protection to individual neonate from excessive noise should be explored.

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