NICU Noise: 50 Years of Worry, and We're Finally Getting Somewhere!

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A low profile, right-sized, easy to firmly apply and easy to remove, skin-friendly noise muffling device, engineered to provide significant acoustic protection against the majority of loud transient noises encountered by neonatal patients — whether the transient high frequency loud noises premature neonates typically experience in the NICU, or the broader frequency loud noises generated during infant transport or MR imaging — would represent a highly useful addition to current neonatal patient care.[1,2] Such a device — quite simply "earmuffs that actually work" — could be a key part of a *data-driven*, holistic approach to reducing stressful infant noise exposure within the modern healthcare environment. To understand why, we first need to know a little history — and then review the modern data on NICU noise exposure.

In 1970, Richard Nixon founded the Environmental Protection Agency, the EPA. In 1974, two EPA researchers working on indoor office safety walked out alone into the middle of a rural tomato field in California's Central Valley on a still summer night and measured just how quiet it was.

It was very quiet. So quiet that two people could conduct a conversation with 100% comprehension standing ten feet apart without raising their voices. Ideal acoustics, in fact, for indoor office work.[3] The average sound level in that otherwise deserted tomato field measured 45 dBA.

Meanwhile, also during the 1970's, neonatal intensive care units (NICU's) began proliferating throughout the United States — and more and more extremely premature newborns began surviving to hospital discharge. These new NICU's were noisy. Vital Sign monitors alarmed frequently, as did first generation transcutaneous oxygen saturation monitors of various designs. Doctors were shouting verbal orders, the portable X-ray machines made noise, the incubators made noise, the ventilators made noise — sometimes LOTS of noise — and they too had their own alarms. The telephones never stopped ringing.

It soon became obvious — most US NICU's were *too* noisy. NICU nurses could see that their patients weren't getting enough sleep. Not only that, quite a few NICU 'graduates' had permanent hearing disabilities. Some of that hearing loss might be due to excess noise exposure. After all, exposure to excess oxygen had helped cause an epidemic of blindness from Retinopathy of Prematurity, during the 1960's.

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In 1997, the American Academy of Pediatrics decided that it needed to establish an acoustic standard for NICU's.[4] At that time, good data on hearing impairment and long-term occupational exposure to factory noise was widely available, but little was known directly relevant to this novel environment — the NICU. Or to the response to noise of NICU patients — particularly premature infants.

Using the data that did exist, the Academy's focus was on preventing noise-related hearing loss. Noise-related sleep disturbance was recognized, but not directly addressed. Neither was vital sign instability — now commonly considered evidence of patient stress.

In the end, the Academy published a Position Paper that concluded that the best way to prevent even the slightest chance of NICU noise causing patient hearing loss was to adopt as a recommended Guideline for NICU Acoustics the EPA's 1974 recommended noise level for an ideally quiet business office. The 'tomato field' standard: an average sound level of 45dBA.

NICU's in the United States have struggled to achieve this degree of quiet ever since.

Indeed, the AAP standard for acceptable NICU noise level is nearly unattainable — and now is known to be irrelevant. Caregivers can state this with confidence because, since the 1970's, our understanding of normal fetal and newborn noise exposure, as well as the acoustic characteristics of NICU noise — has grown markedly. In addition, the clinical implications of NICU noise with respect to sleep and stress have now been reported in detail.

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A brief summary of more modern findings related to fetal and NICU Noise Exposure and the Effects of Noise Exposure upon NICU patients follows:

1) The normal fetal acoustic environment has been well measured,[5] as has the fetal and neonatal response to external noise. The gravid uterus is not quiet at all. In fact, it is much louder, on average than 45 dBA. Most of the sound that the fetus is exposed consists of low-frequency noise from maternal blood circulation, as well as bowel activity. The fetus also hears her mother's voice very well whenever she is talking—but the maternal uterus and anterior abdominal wall effectively filter out all but the loudest external noises, particularly noises of high frequency.

2) A gross motor response of the fetus and the neonate to loud external noises is almost always present by 32 weeks of gestation[6] and may frequently be observed at earlier gestational ages. Typical fetal and neonatal 'non-auditory' responses to loud external noise besides body movements include tachycardia, apnea, and arousal.[7] Collectively, these responses to loud noises are considered to be strong evidence of increased patient stress.

3) Most modern NICU's are quieter than those of past decades—with average dBA measurements in the 50's—quieter except when there are transient vital signs or ventilator function-related monitor alarms, or patient care interventions that involve the manipulation of respiratory tubing, infant feeding and cleaning, or the opening/closing of an incubator.[8] These transient noises are associated with acute vital signs instability among NICU patients.

A Single Family Room NICU patient room.

4) The relatively quiet background noise level state of most modern NICU's has been achieved through various measures, including the wider adoption of Single Family Room (SFR) as opposed to open bay NICU design. In addition, numerous common-sense behavioral interventions directed at quieting caretakers and ancillary personnel have been widely implemented, and NICU patient monitoring equipment itself has improved, yielding fewer false-positive alarms.

Of note, SFR architecture has not been a panacea. The problem of transient loud noises that disrupt patient sleep and induce stress persists, even in SFR environments. There also is preliminary evidence to suggest that some SFR's may be *too quiet*, and delay speech acquisition.[9] This negative outcome would be expected if adequate exposure to the human voice is not provided to the maturing neonatal patient cared for in a SFR environment.

5) An added complexity in the area of infant noise exposure during healthcare is the loud noise exposure that many neonatal patients encounter during both in-hospital and inter-hospital transport, and also during MR imaging.[10] The loud noises experienced by infants during both ambulance and helicopter transport, as well as during MR imaging, tend to be more spread across the frequency spectrum than the primarily high frequency noises most common in the NICU.[11]

Newborn Interfacility Transport - typical equipment

6) Evidence to support the hypothesis that exposure to background NICU noise levels above 45dB constitutes a significant or direct contributing cause of later hearing impairment in NICU patients is lacking. In contrast, exposure to loud noise transients is known to cause physiological instabilities in neonates including changes in cardiac activity, increases in respiratory rate, apneas, bradycardias and hypoxic episodes.[12,13] Noise induces a pain-like stress response in neonates.[14] Further, exposure to loud noises disrupts sleep.[15] Since the amount of sleep *and* sleep–wake patterns may significantly affect neurodevelopment and long-term behavioral and cognitive outcomes,[16,17,18] sleep disruption during care should be avoided.

In addition, infant MR imaging currently often is constrained in both image quality and study duration by motion-related artifact. Most neonatal patients undergoing prolonged MR imaging either are sedated, or great lengths are taken to muffle their exposure to procedural noise, which has been observed to have an arousing, non-auditory effect—even on recently fed and swaddled infants.

7) Finally, evidence that adequate early exposure to human voices is essential for proper infant speech development now is overwhelming.[19,20]

Considering the above, a modern, holistic and *data-driven* approach to the problem of noise exposure among hospitalized neonates would primarily consist of an effort to reduce the frequency and intensity of patient exposures to arousing, stressful, loud transient noises—both low and high

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frequency — while concurrently maintaining a reasonably quiet NICU. Ensuring adequate patient exposure to normal speech also would be necessary. A combination of 1) intelligent NICU design, 2) appropriate patient care-provider behavior, as well as 3) situation-specific on-patient interventions to physically muffle patient exposure to transient loud noises — would constitute the three mainstays of such a rational solution.

Types of neonatal ear muffs in current use.

Unfortunately, many hearing protection devices currently in use for neonates have significant limitations. Moldable ear canal plugs of various compositions represent an effective noise-muffling intervention, but rarely are employed due to fears of ear canal skin irritation and/or difficult plug removal. Adhesive foam ear coverings provide at most 7dB of noise protection, are not well-suited to the frequent application-removal-inspection-reapplication cycles characteristic of best-practice NICU care, detach easily in humid patient-care environments, and are not recommended for use during MR imaging. Adult-style semi-spherical ear muffs shrunk to term infant size can provide quite good acoustic muffling, but are bulky and difficult to secure snugly. They also are untested and unavailable in sizes suitable for the premature neonatal population. Of note, an improved design for MR and NICU safe neonatal ear muffs, appropriate for both premature and term infants, recently has become available.

After some 50 years of justifiable concern and confusion, clinicians finally have both the data and the tools to minimize the adverse effects of excessive noise exposure upon medically fragile newborns.

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