www.jpeds.com • THE JOURNAL OF PEDIATRICS

Auditory Exposure in the Neonatal Intensive Care Unit: Room Type and Other Predictors

Roberta Pineda, PhD, OTR/L[1,2], Polly Durant, MSOT[1], Amit Mathur, MD[2], Terrie Inder, MD[3], Michael Wallendorf, PhD[4], and Bradley L. Schlaggar, MD, PhD[2,5,6,7,8]

Objective To quantify early auditory exposures in the neonatal intensive care unit (NICU) and evaluate how these are related to medical and environmental factors. We hypothesized that there would be less auditory exposure in the NICU private room, compared with the open ward.

Study design Preterm infants born at ≤ 28 weeks gestation (33 in the open ward, 25 in private rooms) had auditory exposure quantified at birth, 30 and 34 weeks postmenstrual age (PMA), and term equivalent age using the Language Environmental Acquisition device.

Results Meaningful language ($P < .0001$), the number of adult words ($P < .0001$), and electronic noise ($P < .0001$) increased across PMA. Silence increased ($P = .0007$) and noise decreased ($P < .0001$) across PMA. There was more silence in the private room ($P = .02$) than the open ward, with an average of 1.9 hours more silence in a 16-hour period. There was an interaction between PMA and room type for distant words ($P = .01$) and average decibels ($P = .04$), indicating that changes in auditory exposure across PMA were different for infants in private rooms compared with infants in the open ward. Medical interventions were related to more noise in the environment, although parent presence ($P = .009$) and engagement ($P = .002$) were related to greater language exposure. Average sound levels in the NICU were 58.9 ± 3.6 decibels, with an average peak level of 86.9 ± 1.4 decibels.

Conclusions Understanding the NICU auditory environment paves the way for interventions that reduce high levels of adverse sound and enhance positive forms of auditory exposure, such as language. *(J Pediatr 2017;183:56-66).*

The auditory environment of the preterm infant differs considerably from the environment in-utero. Intense forms of non-natural sounds in the neonatal intensive care unit (NICU), such as ventilatory support, have been reported[1-4] and sound levels in the often chaotic environment may exceed the decibel recommendations of the American Academy of Pediatrics. This is important because the overstimulating environment of the NICU may have adverse effects on the growth and development of preterm infants.[5-7]

To increase family involvement and to decrease the risk of overstimulation, hospitals around the world are converting traditional open ward NICUs to private rooms.[8] Positive benefits of private rooms reported in the scientific literature include a decreased need for medical procedures, decreased stress, improved neurobehavior, and better long-term outcomes.[9-11] Despite these benefits, a prior study also showed that infants hospitalized in the presumably quieter environment of the NICU private room exhibited lower language scores at 2 years of age[12] than infants hospitalized in open ward NICUs. This previous work, however, did not measure auditory exposure.

Although auditory exposure in the NICU is important for the developing preterm infant,[13-17] the appropriate amount or type of auditory exposure has not been defined. The aim of this study was to measure the auditory environment in the NICU and to determine medical, environmental, and sociodemographic factors that predicted the infant's auditory exposure in the NICU. We hypothesized that there would be less auditory exposure in the NICU private room, compared with the open ward. We explored this and other medical and environmental factors that impact the sound environment in the NICU.

Methods

The study was approved by the Washington University Human Research Protection Office, and parents provided informed consent. Language and sound were quantified longitudinally at 4 different time periods across hospitalization: within

CRIB	Clinical Risk Index for Babies	NICU	Neonatal intensive care unit
LENA	Language Environmental Acquisition	PMA	Postmenstrual age

From the [1]Program in Occupational Therapy; [2]Department of Pediatrics, Washington University School of Medicine, St. Louis, MO; [3]Department of Pediatric Newborn Medicine, Brigham and Women's Hospital, Boston, MA; [4]Division of Biostatistics, Washington University, St. Louis, MO; [5]Department of Neurology; [6]Department of Psychiatry; [7]Department of Radiology; and [8]Department of Neuroscience, Washington University School of Medicine, St. Louis, MO

Supported by the National Institute of Health Comprehensive Opportunities for Rehabilitation Research Training (K12 HD055931), the Barnes-Jewish Hospital Foundation, and the Washington University Institute of Clinical and Translational Sciences Clinical and Translational Funding Program (National Institutes of Health/National Center for Advancing Translational Sciences UL1 TR000448), and *Eunice Kennedy Shriver* National Institute of Child Health and Human Development (U54 HD087011) to the Intellectual and Developmental Disabilities Research Center at Washington University. T.I. served as a member of the Editorial Board of *The Journal of Pediatrics* (2007-2015). The other authors declare no conflicts of interest.

http://dx.doi.org10.1016/j.jpeds.2016.12.072

2 weeks of birth, at 30 and 34 weeks postmenstrual age (PMA), and again at term equivalent age (between 37 and 40 weeks PMA).

Fifty-eight consecutive preterm infants born at ≤28 weeks gestation were recruited from August 2012 to October 2014. Exclusion criteria were failed hearing screening, multiple birth, and congenital anomalies. The study site was the 75-bed level IV NICU at St. Louis Children's Hospital (St. Louis, Missouri) that has 38 traditional open ward beds and 37 private rooms. As part of routine care, infants were assigned to a bed space in either the open ward or in a private room upon admission, based on bed availability and staffing, and remained in the assigned room type for their entire hospitalization. Private rooms had an average area of 168 square feet and were enclosed by 3 walls, with a sliding glass door for the fourth wall. The open ward was composed of 4 large rooms (ranging from 802 to 1375 square feet) with 8-14 beds per room. The nurse to infant ratio varied, based on staffing and medical complexity, but typically was 1 nurse for every 2 infants, and was similar whether an infant was in the open ward or private room. As part of the standard of care, parents were welcome in the NICU 24 hours a day Mothers were encouraged to engage in the care of their infant and to put their infants skin-to-skin when visiting. Loungers were available at the bedside in both open ward and private rooms. Volunteers were available to hold infants whose parents were unable to visit, but this was implemented inconsistently during the study time period, and volunteers typically held older infants as they approached term age.

Study Procedures

The Language Environmental Acquisition (LENA) (LENA Research Foundation, Boulder, Colorado) device is a digital language processor that captures environmental sound for up to 16 hours. The LENA has been used in previous research on infants in the NICU at 32 weeks PMA and 36 weeks PMA, justifying it as an appropriate method of capturing noise and language in the NICU.[14] Before the study started, 2 methods of recording were evaluated. The quantification of sound was similar when the LENA was hanging in the infant's bed (within a pouch that was cut out from the vest) and when the infant wore it in a vest (the recommended method). As it would be less invasive for the infant, for this study, the LENA was hung on the infant's crib or inside the incubator within 2 feet of the infant's ear. A sign at the bedside indicated the LENA was in use during the recordings (as required by the institutional review board). LENA recordings commenced before 10 a.m. each morning and automatically ended 16 hours later. Data from the digital language processor was downloaded into the LENA Pro software, which generates an estimate of the amount of time spent with meaningful words, distant words, electronic sounds, noise, and silence. Each outcome variable was recorded as the amount of time it was the predominant auditory stimulus in the room over a 16-hour period. In addition, the LENA software defined the number of adult words heard during each recording as well as the highest and average decibel levels in the infant's auditory environment. The LENA quantified sound at 4 different time points: within 2 weeks of birth, at 30 and 34 weeks PMA, and at term-equivalent age (37-40 weeks PMA). When an infant was born at 28 weeks gestation, the birth recording was often the same as the 30 weeks PMA recording. The infant's PMA on the day of each recording was recorded.

Environmental factors during the sound recordings were documented. These included room type (open ward or private room), the census in the NICU and in the infant's room (for open wards), bed type (incubator or open crib), parental presence or absence, the number of times a parent held the infant, the number of pumps (defined as any device that delivered fluids via nasogastric or intravenous line and produced sounds upon completion or interruption), and the type of respiratory support (room air, oxygen via nasal cannula, continuous positive airway pressure, mechanical ventilation, or high-frequency oscillatory ventilation).

Infants were placed in an incubator on admission and were transitioned to a crib when they were able to maintain temperature (at approximately 1800 g). Maternal factors were collected from the medical record at the time of the infant's birth, including age, marital status, education level (dichotomized as college education or no college education), the number of prenatal visits, delivery type, and prenatal illicit drug exposure (from toxicology reports at delivery). Social factors were collected, including the infant's sex and race (dichotomized as African American or non-African American). Medical factors were collected from the medical record. These included estimated gestational age at birth, birth weight, head circumference at birth, Apgar scores at 1 and 5 minutes, use of prenatal or postnatal steroids, days on total parenteral nutrition, total days of breast milk feedings, breast milk at discharge, presence of moderate to severe brain injury (defined as having either a grade III-IV intraventricular hemorrhage, cystic periventricular leukomalacia, or cerebellar hemorrhage as determined by cranial ultrasound scan and/or magnetic resonance imaging), presence of patent ductus arteriosus (treated with indomethacin or surgical ligation), necrotizing enterocolitis (all stages), retinopathy of prematurity requiring surgical intervention, score on the Clinical Risk Index for Babies (CRIB),[18] length of stay, days, and types of respiratory equipment (high-frequency oscillation, mechanical ventilation, continuous positive airway pressure, high humidity, nasal cannula), total oxygen hours (including time on any of the aforementioned), and oxygen requirement at 36 weeks PMA.

Statistical Analyses

For variables of meaningful words, distant words, electronic sounds, noise, and adult word count, a log transformation of the sound measurements were used to stabilize the variance. We tested for room type, PMA, and room type by PMA interaction using a mixed random effects repeated measures ANOVA model (with infant within room type as the random effect). When the room type by PMA interaction was significant ($P < .05$), the effect of PMA, stratified by the room type, was explored. When the interaction was not significant, we investigated the relationships of PMA and sound as well as the