Noise in the NICU: how prevalent is it and is it a problem?

The uterine environment protects the developing fetus from loud and high-frequency sounds, enabling a gradual exposure and learned response to different sounds. For the preterm infant in the neonatal intensive care unit (NICU), this protective environment is lost and replaced by a harsh clinical environment that often exceeds recommended noise levels. There is growing interest in the role of the *ex utero* environment in promoting normal brain development. This article reviews why the preterm infant is more at risk from excessive or sustained noise, what recommendations exist to limit noise, and avenues for future research in this area.

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Key points

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1. Rapid brain growth occurs in the third trimester when, during periods of sleep, the brain develops its neurological foundations for future life.
2. A fetus is protected from exposure to loud, external noise by the mother's body and uterine environment. This protective environment is lost in a preterm infant.
3. Exposure to high sound levels can wake a sleeping infant. Sudden or sustained noise can result in negative physiological responses (eg apnoea, heart rate changes and increased oxygen requirement).
4. Positive sounds, eg the mother's voice, are beneficial and may improve brain development and physiological stability.

"Unnecessary noise, then, is the most cruel absence of care which can be inflicted either on sick or well."[1] The third trimester of pregnancy is a time of rapid brain growth and development where, during periods of sleep, the brain is laying down its neurological foundations for future life. Hearing and responding to sound is essential for speech development, however, for the preterm infant excessive auditory stimulation through exposure to high frequency sounds or those that exceed recommended levels can result in sleep disturbance and altered negative physiological responses for this vulnerable cohort of infants.

The mechanisms of perinatal brain injury in the preterm infant are complex and multi-factorial. There is growing interest in the role of the *ex utero* environment in promoting normal brain development.

Infants in the NICU are vulnerable due to a range of intrinsic and environmental factors. In 2014, the James Lind Alliance brought together patients, carers and clinicians to identify and prioritise research strategies to improve the quality of care and outcome for very preterm infants.[2] The optimisation of the environment, such as light and noise, was listed as a key improvement strategy in the top 10 priorities for preterm birth. However, noise in the NICU remains a significant problem.

The acoustic environment of the NICU should promote neonatal sleep and physiological stability without impeding communication between staff and parents.[3] However, the NICU is a highly complex and noisy environment. Medical technology replaces the functions of the uterus and placenta but provides limited protection to auditory disturbances[4] and exposes infants to sounds that are very different to what they would experience *in utero*. Establishing sleep-wake cycles (SWCs) is essential for neurological and synaptic development[5] and preterm infants have an immature auditory system that can make it difficult for noise to be filtered out and therefore maintain self-regulation.[6] The inability to adjust and learn to 'tune out' excessive or unwanted noise can make preterm infants increasingly vulnerable to the negative effects of noise.

During 2012, there were 726,572 live births of known gestational age in England and Wales of which 52,160 (7.3%) were preterm (<37 weeks' gestation) and 2,474 (<1%) extremely preterm (<27 weeks' gestation).[7] Survival rates have significantly improved for infants born extremely preterm, however there have been no significant improvements in the incidence of conditions such as cerebral palsy, blindness, deafness and attention deficit disorders in this group.[8] Does the harsh environment of the NICU, and differences in noise exposure for the fetus and preterm infant contribute to the health complications for this group?

What is noise?

Noise can be defined as any unwanted sound with variations in intensity (loudness), frequency, timing and duration.[9] Noise can also be subjective; for example what one person perceives as noise another may regard as music. The intensity of sound is measured in decibels (dB), a logarithmic scale where each 10dB increase reflects a tenfold increase in sound intensity.

The frequency of sound is measured in Hertz (Hz). The human ear can hear sounds within the frequency range of 20Hz to 20,000Hz, with increased sensitivity in the 1,000 to 4,000Hz range. The A-weighting slow-response dB scale (dBA) filters sound according to the frequency response of the human ear, enabling sound level meters to monitor and record noise levels to which the ear is most receptive. Noise-induced hearing loss in adults can occur following prolonged exposure (>8 hours) of noise averaged at 85dBA, and exposure time for damage decreases with increasing intensity.[10]

Development of hearing in the fetus

Cochlear development begins at around 10 weeks' gestation and is structurally formed by 15 weeks' gestation with auditory function commencing at around 20 weeks.[11] In the uterus, the fetus is exposed to lower frequency sounds of around 500Hz and protected from higher frequency and loud external noise through absorption of sound by the maternal abdominal wall, uterus and amniotic fluid environment.[12] As the fetus grows and develops, the maternal abdominal wall becomes thinner, providing exposure to a wider range of external sounds.[4] Normal external speech is subject to different levels of attenuation by the intrauterine environment, with higher frequencies receiving greater levels of attenuation.[13] The maternal voice experiences the least attenuation, which may be due to the internal transmission of sound.[14]

Hepper and Shahidullah investigated the fetal auditory response to different tone stimuli showing that at 19 weeks' gestation, a fetus can respond to external noise frequencies of 500Hz.[15] To put this into context, 261Hz is middle C on a piano and the frequency of sound doubles with each octave. By 27 weeks' gestation, lower frequencies of 250Hz and 100Hz elicited a response in almost all of the studied fetuses, although there was no response to higher frequencies of 1,000Hz and 3,000Hz, which were first observed at 29 and 31 weeks' gestation, respectively.[15] This fetal response to lower frequencies at earlier gestational ages corresponds with the tuning of the hair cells to specific sound frequencies, which initially starts with lower frequency tuning.[11]

Like other sensory systems, the auditory system needs stimulation to develop normally. Auditory learning is thought to start at around 28 weeks' gestation by repetitive exposure to common sounds such as voice and music during periods of wakefulness or quiet sleep, followed by a period of active or rapid eye movement (REM) sleep.[11] It is during REM sleep that the brain will create long-term synapses in the auditory cortex and brainstem that may become auditory memories.[11]

During the course of a pregnancy, there is a gradual increase in exposure to sounds that are higher in frequency and intensity. For preterm infants in the NICU, the protective uterine environment is lost, with infants being exposed to sudden, louder and higher frequency sounds from equipment and medical alarms. The environment and staff activity in the NICU can potentially alter the development of the auditory system. Exposure to loud background and/or high frequency noise could be harmful, both by direct damage to the auditory system, and by interfering with the infant's SWC.[11] Controlling noxious noise exposure for the preterm infant could therefore protect both auditory and brain development.

Hearing loss in the preterm infant

In the UK, there is a 4-6% prevalence of hearing loss in children at six years of age who were born preterm,[16] which is significantly higher than the background prevalence of hearing loss in healthy term infants.[17] There are a number of complex factors that are associated with hearing loss in preterm infants, including infection, extended mechanical ventilation time, hyperbilirubinaemia and hyponatraemia.[18] Additionally, ototoxic drugs such as aminoglycoside antibiotics or diuretics can cause permanent damage to the cochlear or auditory nerve[19] and there is a suggestion that increased background noise levels may exacerbate this drug-induced hearing loss.[20]

Why is noise and the preterm infant important?

In the uterus, the fetal auditory canal is fluid filled and the fetus hears sounds through bone conduction which, along with the maternal body, filters out higher-frequency sounds.[11] In contrast, for the preterm infant the auditory canal is air filled resulting in little or no attenuation to volume. To compound the problem, preterm infants have immature auditory processing, which can make it difficult for them to habituate and filter out noise to maintain self-regulation.[6] Preterm birth, therefore, potentially alters typical auditory development and learning as these infants are exposed to a wider range of sounds and frequencies, with many sounds occurring suddenly or in a non-rhythmic pattern.

Excessive noise exposure has been associated with longer ventilation times,[6] which impacts on the length of hospitalisation. Sicker, smaller infants are cared for in level 3 NICUs, which typically experience the highest levels of noise.[21,22] Whether it is the excessive noise or the overall health status of the infant that determines longer-term auditory function remains to be resolved.

Exposure to loud, sudden or sustained levels of noise creates excessive auditory stimulation, resulting in sleep disturbance and negative physiological responses including apnoea, changes in heart and respiratory rates, hypoxaemia and increased oxygen requirements.[23]

Sound levels above 55dB have the potential to wake a sleeping term infant,[24] while in preterm infants, sound peaks of 5-15dBA above ambient background levels disrupt sleep patterns.[25] In a small cohort study of eight extremely low birthweight infants (<1kg) with background noise levels of 55-60dBA, preterm infants demonstrated an increase in heart rate in response to sudden noise exposure. Change to mean arterial blood pressure (MABP) was less sensitive and appears to be influenced by birth weight; infants with a higher birth weight (766-910g) experienced a biphasic response with a drop in MABP at around 110 seconds followed by an increase at around 200 seconds after noise exposure. The lower birthweight group (454-694g) also experienced a decrease in MABP but this was delayed until approximately 155 seconds after noise exposure but did not have the subsequent increase seen in higher birthweight infants.[26] In a larger study of 31 infants of >29 weeks' gestation, background noise levels were maintained at 60dB until infants were exposed to a low frequency buzzer of 80dB for three seconds during periods of quiet awake or quiet sleep. The infants were clinically categorised into low- or high-risk for clinical neurological impairment. In response to the low frequency buzzer, all infants experienced an increase in heart rate during quiet sleep, however only those in the high-risk category showed an increased heart rate when they were quietly awake.[27]

Establishing SWCs is essential for neurological and synaptic development,[25] and the emergence of REM and non-REM sleep is essential for creating long-term memories and enabling the brain to learn and adapt to stimuli.[28] For preterm infants, the development of SWC is accelerated with postnatal age when compared to gestational age alone[29,30] suggesting that external sensory inputs such as noise, light, touch and medication could affect brain development.

Repeated interruption to sleep leads to fatigue and increased calorie requirements for the preterm infant.[31] Kuhn studied the arousal state of 26 infants born between 26-31 weeks' gestation.[25] Noise levels were recorded inside the infant's incubator; the average hourly exposure to sound peaks above background levels of at least one second in duration were 78% for 5-10dBA, 17% 10-15dBA and 5% exceeding 15dBA. Infants transitioning from sleep state to wakefulness in response to sound peaks occurred, on average, 4.2% at 5-10dBA and 5.5% 10-15dBA. The transition from sleep to crying or fussing elicited a greater response of 29.7% and 34.1% at 5-10dBA and 10-15dBA, respectively.[25] Kuhn estimated that on average, infants are disturbed by noise 18 times a day and calculated that over a nine-week hospital stay, this could equate to 1,134 disturbances to sleep solely due to noise.[25] It is well documented that for the adult, interruptions or deprivation in sleep caused by noise can have significant health consequences. For the preterm infant, interruptions in sleep may have far wider implications, as the third trimester is a time of rapid brain growth, development and synaptic formations. There is limited data on the disruption of SWCs to brain function beyond behavioural responses for this vulnerable group.

Recommendations for NICU noise levels, exposure and effects

The acoustic environment of the NICU is determined by the equipment (in particular alarms, **FIGURE 1**), unit design, staff and family presence. The acoustic environment should promote neonatal sleep and physiological stability and it is recommended that, in the areas where infants are cared for, average hourly noise levels (Leq) should not exceed 45dBA. Maximum noise levels (Lmax), regardless of duration or source, should not exceed 65dBA.[3] These levels are of an equivalent intensity to a quiet library and normal conversation, respectively. Several studies demonstrate that noise levels within the NICU far exceed these recommendations; in some instances average noise levels were reported above 60dB[32-36] with Lmax exceeding 78dB.[35,37]

While there are no specific recommendations for sound frequency exposure, dB levels should be monitored, reported and recommended with the A-weighted scale to reflect human hearing. Two studies to date have measured frequency in the NICU, finding that lower frequency sounds dominate with peaks observed at 500Hz, corresponding with normal speech.[32,38] It was also found that peaks occur at higher frequencies up to 3,150Hz from devices such as alarms from ventilators and infusion pumps, however the effects on the preterm infant of this exposure remain unknown.[32,38]

Many NICUs are designed to reduce the risk of infection transmission with hard, smooth surfaces that are easily cleaned but tend to reverberate and increase sounds in a unit. Structural changes or the addition of acoustically absorbent material on walls that are above clinical activity areas can reduce noise reverberation and levels away from sound sources.[3] These structural changes may alter and reduce sound levels within the neonatal nursery but are individual approaches to noise attenuation more appropriate?

FIGURE 1 A nurse turning off an alarm near an infant's incubator.

Can incubators help control noise exposure?

The infant in an open cot has no protection from noise generated from equipment, alarms, telephones or conversations. Incubators offer some attenuation against direct external noise exposure with ventilator and infusion pump alarms, registering as 55-75dBA in the open environment compared to 51-57dBA inside incubators.[6] External material covers over the plastic lid may also improve noise attenuation, with average background noise levels ranging from 70-80dBA in an uncovered incubator, dropping to 51-74dBA when the cover was in place.[39]

However, the protection against external noise that incubators offer is at the expense of increased reverberation of sound from within. The internal smooth plastic window is poor at absorbing but good at reflecting sounds, which increase overall levels inside the incubator. The provision of adequate bedding material inside the incubator can absorb some sound and may reduce the incidence of sound reverberation.[40] Activities that occur inside incubators expose infants to greater noise levels than those experiencing the same procedure in an open cot. For example, it has been reported that open endotracheal suction increased by 8dBA to 58dBA when performed inside an incubator.[6]

Incubators control heat and humidity for the preterm infant, but, by design are sources of noise generation. Objects striking the plastic walls can create short, intermittent, loud sounds. Placing objects such as bottles on the top of the plastic window can create sounds that exceed 110dBA,[23] while the careless closing of incubator porthole doors and tapping on the window produces noise levels in the region of 80dBA and 70dBA, respectively.[6,41]

Individual hearing protection

If noise levels cannot be reduced further, is the provision of individual hearing protection for neonates in the NICU an acceptable solution?

Duran et al studied the effects of wearing earmuffs in 20 preterm infants.[42] This type of hearing protection reduces noise exposure by 7-12dBA. In this crossover comparative study, the preterm infants were observed for two days with the earmuffs in place and then acted as a control group being observed for two days without individual hearing protection. The presence of the hearing protection resulted in no difference in physiological changes between the two groups. However, behavioural states were more consistent, with longer time periods in quiet sleep for infants wearing the earmuffs compared to the control group, who were observed to be more frequently awake or crying.

Unfortunately, the adhesive that keeps smaller hearing protection devices in place has the potential to cause damage to delicate preterm skin. The tight seal around the ear can also cause damage to developing ear structure if maintained in place for long periods of time and therefore is only recommended for short-term use, eg during magnetic resonance imaging.[43]

Sound and voice recognition are essential for language development. In the uterus, the fetus is exposed to maternal voice and heart beat in a protective environment enabling the development of auditory learning. Webb et al replicated uterine sounds to preterm infants to determine whether this exposure would promote brain development as if the baby was not born preterm. This study suggests that there is benefit in replicating uterine sounds for preterm infants, minimising the negative effects of auditory stimulation from the NICU environment.[44] Loud peaks of sound were attenuated thereby reducing the negative impact of the additional volume with both the control and experimental group being exposed to approximately 60dBA in the NICU environment. While this is a small study with recommendations for future research in this area, it is unlikely that reducing the input of maternal voice is beneficial.

Minimising sensory inputs and creating an environment that is very quiet with long periods of silence can result in delayed language and cognitive development, inhibiting and delaying brain maturation and development.[22,45] Creating an individualised environment with a Newborn Individualised Developmental Care and Assessment Program (NIDCAP)-approach may be more effective than trying to remove all negative sounds. Low-risk preterm infants who received individually based NIDCAP orientated care showed significant improvements in neurodevelopmental outcomes, including self-regulation and posture at two weeks of age.[46] The challenge for modern NICUs is not only to minimise noxious noise but to promote and individualise positive sounds such as the maternal voice.

Effects of noise on staff

Noise levels in the neonatal and hospital environment should not impede recovery of the infant, but in addition should ideally not increase stress levels or negatively affect work performance of staff.[3] Sudden, excessive or prolonged noise is not only detrimental to the patient but can also impact healthcare workers.[47] Noise can have the direct effect of increased stress, burnout and poor concentration, and negatively influences work and performance.[48]

Nursing staff in a level 3 NICU perceived noise levels to be quieter at night, although measured levels demonstrated no significant change between day and night levels.[36] In one study in a paediatric intensive care unit, nurses displayed increases in heart rate when exposed to a 10dB increase in noise levels above background levels. Interestingly the increase in heart rate was less marked with increasing nursing experience[47] suggesting a possible habituation to the environment over time. Repeated exposure to certain sounds can create a state of habituation, which can be of concern if clinical staff silence or 'tune out' to the sound of a critical alarm.[47]

Conclusion

In the NICU, it is essential that infants are provided with optimal care and environmental conditions to reduce infant mortality and morbidity. Preterm infants are devoid of the protective uterine environment and often have little or no protection from sounds that originate in the NICU from essential medical equipment. This is at a time of rapid brain growth and development.

Infants in the NICU are frequently exposed to sounds above recommended standards that can create excessive auditory stimulation resulting in sleep disturbance and negative physiological responses, with

FIGURE 2 A 'SoundEar' measures noise levels in the neonatal unit and can alert staff to high background noise.

changes in heart rate, oxygenation levels and respiratory rates. Reducing sound levels throughout the whole NICU benefits not only infants but also staff and visitors. The provision of an individually designed noise reduction strategy such as the use of a noise measurement device (**FIGURE 2**) or careful closing of incubator porthole doors, can eliminate sudden peaks in noise levels experienced by the preterm infant. Exposure to positive sounds such as the maternal voice is beneficial and may improve brain development and stability in an otherwise hostile environment.

Improving the acoustic neonatal environment is a key improvement strategy for parents, carers and clinicians. More research is needed into the effects of noxious and positive noise on auditory and brain development in these vulnerable infants to reduce morbidity and continue to work towards optimising neonatal care.

References

1. **Nightingale F.** *Notes on Nursing*. London: Harrison; 1860. p47.
2. **James Lind Alliance.** *Preterm Birth Top 10*. [Online] Available from: www.jla.nihr.ac.uk/top-tens/preterm-birth-top-10 [Accessed 16 March 2016].
3. **White R.D., Smith J.A., Shepley M.M.** Recommended standards for newborn ICU design. *J Perinatol* 2013;33:S2-S16.
4. **Als H.** Toward a synactive theory of development: promise for the assessment and support of infant individuality. *Infant Med Health J* 1982;3:229-43.
5. **Strauch C., Brandt S., Edwards-Beckett J.** Implementation of a quiet hour: effect on noise levels and infant sleep states. *Neonatal Netw* 1993;12:31-35.
6. **Byers J.F., Waugh W.R., Lowman L.B.** Sound level

exposure of high-risk infants in different environment conditions. *Neonatal Netw* 2006;25:25-32.
7. **Office for National Statistics.** *Gestation-specific Infant Mortality, 2012.* [Online] Available from: http://webarchive.nationalarchives.gov.uk/20160105160709/http://www.ons.gov.uk/ons/dcp171778_379562.pdf [Accessed 16 August 2016].
8. **Costello K.L., Hennessy E.M., Haider S. et al.** Short term outcomes after extreme preterm birth in England: comparison of two birth cohorts in 1995 and 2006 (the EPICure studies). *Br Med J* 2012;345.
9. **Gray L.** Properties of sound. *J Perinatol* 2000;20:S6-S11.
10. **Health and Safety Executive.** *Current Practice in Health Surveillance for Noise*, 2013. [Online] Available from: www.hse.gov.uk/research/rrpdf/rr966.pdf [Accessed 16 August 2016].
11. **Graven S.N.** Auditory development in the fetus and infant. *Newborn Infant Nurs Rev* 2008;8:187-93.
12. **Gerhadt K.J., Abrams R.M.** Fetal exposures to sound and vibroacoustic stimulation. *J Perinatol* 2000;20:S20-29.
13. **Querle D., Renard X., Versyp F.** Fetal hearing. *Eur J Obstet Gynecol Reprod Biol* 1988;28:191-212.
14. **Richards D.S., Gerhadt K.J., Abrams R.M.** Sound levels in the human uterus. *Obstet Gynecol* 1992;80:186-90.
15. **Hepper P.G., Shahidullah B.S.** Development of fetal hearing. *Arch Dis Child* 1994;71:F81-87.
16. **EPICure Study Group.** EPICure: facts and figures: why preterm labour should be treated. *BJOG* 2006;113:10-12.
17. **Vohr B.** Overview: Infants and children with hearing loss – part I. *Ment Retard Dev Disabil Res Rev* 2003;9:62-64.
18. **Bergman I., Hirsch R.P., Fria T.J. et al.** Cause of hearing loss in the high-risk premature infant. *J Pediatr* 1985;106:95-101.
19. **Joint Formulary Committee.** *British National Formulary* [69]. London: BMJ Group and Pharmaceutical Press; 2015.
20. **Blackburn S.** Environmental impact of the NICU on developmental care. *J Pediatr Nurs* 13:279-89.
21. **Levy G.D., Woolston D.J., Browne J.V.** Mean noise amounts in level II Vs level III neonatal intensive care units. *Neonatal Netw* 2003;22:33-38.
22. **Stromswold K. Sheffield E.** *Neonatal Intensive Care Unit Noise and Language Development.* Rutgers University Centre for Cognitive Science Technical Report 2004.
23. **Bremmer P., Byers J.F., Kiehl E.** Noise and the premature infant: physiological effects and practice implications. *J Obstet Gynecol Neonatal Nurs* 2003;32:447-54.
24. **Kenner C., McGrath J.** *Developmental Care of Newborns.* St Louis: Elsevier; 2004.
25. **Kuhn P., Zores C., Langlet C.** Moderate acoustic changes can disrupt the sleep of very preterm infants in their incubators. *Acta Paediatr* 2013;102:949-54.
26. **Williams A.L., Sanderson M., Lai D. et al.** Intensive care noise and mean arterial blood pressure in extremely low-birth-weight neonates. *Am J Perinatol* 2009;26:323-29.
27. **Schulam C.A.** Effects of auditory stimulation on heart rate in premature infants as a function of level of arousal, probability of CNS damage, and conceptional age. *Dev Psychobiol* 1969;2:172-83.
28. **Graven S.N., Browne J.V.** Sleep and brain development: the critical role of sleep in fetal and early neonatal brain development. *Newborn Infant Nurs Rev* 2008;8:173-79.
29. **Natalucci G., Hagmann C., Bernet V. et al.** Impact of perinatal factors on continuous early monitoring of brain electrocortical activity in very preterm newborns by amplitude-integrated EEG. *Pediatr Res* 2014;75:774-80.
30. **Sisman J., Campbell D.E., Brion L.P.** Amplitude-integrated EEG in preterm infants: maturation of background pattern and amplitude voltage with postmenstrual age and gestational age. *J Perinatol* 2005;25:391-96.
31. **Almadhoob A., Ohlsson A.** Sound reduction management in the neonatal intensive care unit for preterm or very low birth weight infants. *Cochrane Database Syst Rev* 2015;30:CD010333.
32. **Lahav A.** Questionable sound exposure outside of the womb: frequency analysis of environmental noise in the neonatal intensive care unit. *Acta Paediatr* 2015;104:e14-e19.
33. **Fruedenthal M., van Stuijvenberg M., van Goudoever J.B.** A quiet NICU for improved infants' health, development and well-being: a systems approach to reducing noise and auditory alarms. *Cogn Tech Work* 2013;15:329-45.
34. **Kent W., Tan A., Clarke M., Bardell T.** Excessive noise levels in the neonatal ICU: potential effects on auditory system development. *J Otolaryngol* 2002;31:355-60.
35. **Krueger C., Schue S., Parker L.** Neonatal intensive care unit sound levels before and after structural reconstruction. *MCN Am J Matern Child Nurs* 2007;32:358-62.
36. **Darcy A.E., Hancock L.E., Ware E.J.** A descriptive study of noise in the neonatal intensive care unit. *Adv Neonatal Care* 2008;8:S16-26.
37. **Philbin M.K., Gray L.** Changing levels of quiet in an intensive care nursery. *J Perinatol* 2002;22:455-60.
38. **Kellam B., Bhatia J.** Sound spectral analysis in the intensive care nursery: measuring high-frequency sound. *J Pediatr Nurs* 2008;23:317-23.
39. **Saunders A.N.** Incubator noise: a method to decrease decibels. *Pediatr Nurs* 1995;21:265-68.
40. **Johnson A.N.** Neonatal response to control of noise inside the incubator. *Pediatr Nurs* 2001;27:600-05.
41. **Thomas K.A., Uran A.** How the NICU environment sounds to a preterm infant: update. *MCN Am J Matern Child Nurs* 2007;32:250-53.
42. **Duran R., Ciftdemir N.A., Ozbek U.V. et al.** The effects of noise reduction by earmuffs on the physiologic and behavioural responses in very low birth weight preterm infants. *Int J Pediatr Otorhinolargyngol* 2012;76:1490-93.
43. **Philbin M.K.** The influence of auditory experience on the behavior of preterm newborns. *J Perinatol* 2000;20:S77-87.
44. **Webb A.R., Heller H.T., Benson C.B., Lahav A.** Mother's voice and heartbeat sounds elicit auditory plasticity in the human brain before full gestation. *PNAS* 2015;112.10:3152-57.
45. **Pineda R.G., Neil J., Dierker D. et al.** Alterations in brain structure and neurodevelopmental outcome in preterm infants hospitalized in different neonatal intensive care unit environments. *J Pediatr* 2014;164:52-60.
46. **Als H., Duffy F.H., McAnulty G.B. et al.** Early experience alters brain function and structure. *Pediatrics* 2004;113:846-57.
47. **Morrison W.E., Haas E.C., Shaffner D.H. et al.** Noise, stress, and annoyance in a pediatric intensive care unit. *Crit Care Med* 2003;31:113-19.
48. **Messingher G., Ryherd E., Ackerman J.** Hospital noise and staff performance. *J Acoust Soc Am* 2012;132:2031.