MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

ENVIRONMENTAL SOUND SPECTRAL ANALISYS SUFFERED BY NEONATAL PATIENTS. CASE STUDY: NICU OF HOSPITAL UNIVERSITARIO PUERTA DEL MAR (CÁDIZ)

Rodríguez Montaño, Víctor M.[1]; Beira Jiménez, Juan Luis[1]; Hernández-Molina, Ricardo[1]; Fernández Zacarías, Francisco[1]; Cueto Ancela, José Luis[1]; Bustillo Velázquez-Gaztelu, Pedro Jesús[1].
Laboratorio de Ingeniería Acústica. Universidad de Cádiz.
Av. de la Universidad de Cádiz s/n, CP. 11510 Puerto Real (Cádiz).

Lubián López, Simón[2].
Hospital Universitario Puerta del Mar.
Av. Ana de Viya, 21, CP. 11009 Cádiz.

ABSTRACT
The objective of this work focuses on the frequency analysis of the noise suffered by neonatal patients inside the incubators located in Neonatal Intensive Care Units (NICU). As a rule, noise has been evaluated in relation to the equivalent continuous level per hour ($L_{Aeq,1h}$). Different international organizations, such as the American Academy of Pediatrics, establish a recommended limit for this index of 45 dBA. However, according to the existing literature, the audible range of the neonate is between 400 Hz and 4 kHz, coinciding with the range of human speech intelligibility frequencies. For this, we have carried out a series of acoustic measurements that allow us to evaluate the noise in the NICU of the Hospital Universitario Puerta del Mar in Cádiz, which allows us to show that the indicator used $L_{Aeq,1h}$ must be complemented with a study and frequency analysis to determine acoustic quality and protect to neonates.

Keywords: Frequencies, Noise, Incubator
I-INCE Classification of Subject Number: 61

1. INTRODUCTION

Preterm births are increasingly common in today's society, which poses a serious public health risk, especially those born with less than 1.5 kg of weight. These births are responsible for between 75 and 80% of perinatal mortality and between 40 and 50% of all neurodevelopmental disabilities, including cerebral palsy and long-term mobility [1][2][3].

[1] ricardo.hernandez@uca.es
[2] slubian@yahoo.es

The advanced care provided to premature infants increases the possibilities of survival, although it is evident that there is a certain concern about the over-stimulation which they are subjected, mainly due to external factors, such as light and noise.

Providing an adequate environment in the NICU is essential, since the infants that admitted to the rooms are born prematurely, with low weight and/or with serious health problems. The level of noise in the NICU plays an important role in the communication of health staff, family interactions and child development [4]. According to the American Academy of Pediatrics (AAP), exposure to noise levels 45 dBA can cause cochlear damage or even interrupt the growth and normal development of newborn [5]. This is why the AAP recommends that areas of neonatal care must include sound absorption of continuous background noise and transient sound in any area of patient care does not exceed a $L_{eq,1h}$ of 45 dBA , L_{10} of 50 dBA and $L_{máx}$ should not exceed 65 dBA [6]. We were unable to access the study conducted by the AAP, as well as the test and measurement conditions that were taken into account to determine these maximum levels of L_{Aeq}, L_{10} and $L_{máx}$.

As reported by Knutson [4], the recommendations given by the AAP were not derived from an empirical study, but from an environmental study developed by the US Environmental Protection Agency (EPA). To support the intelligibility of the word between health personnel and patients and to prevent interference with activity or discomfort in the hospital environment, as early as 1974, the EPA recommended that all hospital spaces should be maintained at noise levels below 45 dBA [7]. Since the objective was to protect the public health and the well-being of the patients, a safety margin of 5 dBA was established, so if we add it to the previous 45 dBA, the noise level is 50 dBA, in this case for L_{10} [7]. Although it is true that in principle these limits were not specified as an adequate noise level which the NICUs had to comply with, subsequently, through the recommendations given by the AAP, the Agencia Española de Pediatría (AEP) or the World Health Organization (WHO) have been taken as levels to take into account when designing and redistributing the spaces in the NICUs.

The damage caused by the noise can depends significantly on objective factors such as frequency, intensity, time of exposure and acoustic rest time, as well as subjective factors such as patient susceptibility [8]. The susceptibility of hearing damage can be influenced by causes such as disease or hereditary factors. Thus, preterm infants are more susceptible to effects of ambient noise than those born at term. A lower gestational age, the greater the commitment, since the brain development is nor complete and increases the risk of abnormal brain maturation [9][10].

Between weeks 3 and 6 of gestational age, the auditory system begins to develop, completing, the cochlea and peripheral sensory organs, their normal development between weeks 24 and 25 of gestation [11][12][13]. Although structurally at 28 weeks of gestation, the fetus has auditory perception, it does not mean that auditory development has been completed, since the process of myelination involves the postnatal stage, even up to 3 years of life [12][14].

In the maternal uterus, the fetus begins its auditory experience with low frequency sounds, which are transmitted mainly by bone conduction [15][16]. In this environment, the fetus has a great advantage over the premature infant inside an incubator, since being surrounded by amniotic fluid and tissues of abdomen, the sound that comes them is of less intensity. We could say that these layers act as a bandpass filter where only the frequency components, between 200 and 800 Hz, can reach the ear of the fetus [17].

Although, in the uterus, the fetus is protected against high frequency and high intensity sound, allowing a gradual adjustment of the ciliated cells within the cochlea, the early release of this environment exposes premature infants to sounds by airway over the entire frequency range, when it is likely that its hearing system is accustomed to bone conduction mode [18].

The effects of intense and prolonged noise, mainly of high frequency, on the auditory development of neonates are not known with certainty [19]. It may not be considered very practical, since NICUs are often characterized by unpredictable noise from multiple sources and, therefore, in different frequencies, such as alarms, ventilators, telephones and conversation between health staff and family members [13], ideally for promote healthy auditory development in infants admitted to the NICU, the noise levels of these rooms must be consistent with the intrauterine environment.

In the existing literature, the levels of environmental noise found in the NICU have been reported on numerous occasions, varying between 50 and 90 dBA, far exceeding the limits currently recommended by the AAP, AEP or WHO [9][20][21][22]. Many studies have concluded that exposure to these high noise levels can influence the process of neural organization, reinforcing inappropriate neural pathways and placing the neonates at risk for auditory processing disorders and future learning disabilities [5][23][24]. Although these types of disorders appear in children with normal auditory thresholds, they appear more frequently among children who were born preterm [25].

Kellam y Bhatia [19] indicated that the recommendations set by the AAP do not refer to the frequencies of the sound environment of the NICU. This study was designed to collect descriptive data about the sources that emit high frequency in a NICU by using sound spectral analysis (SSA). The results found by these researchers suggested that there was a bimodal distribution of frequency around 500 Hz, which suggests that human speech contributed to the increase of sound energy in this third octave band. Finally, they concluded that it is necessary to evaluate the noise in frequencies to make the sound spectrum more compatible with the brain development of neonates.

2. METHODS

In this study, several experimental campaigns have been carried out in which noise levels have been measured in the NICU of the Hospital Universitario Puerta del Mar, in Cádiz, and inside of one of its neonatal incubators. These campaigns recorded with a sampling time of one second for periods of more than 24 hours.

Due to sanitary reasons and to avoid the noise generated by the neonate, the measures were taken in incubators not occupied but in operation, which enables us to evaluate the SSA of the sounds produced in the room (alarms, conversations, telephone, furniture drag, etc.) and the ventilator of the incubator.

2.1 Instrumentation and measurement parameters

Several sound meters, such as *Brüel & Kjaer type 2270* and *2250*, as well as the *Brüel & Kjaer* calibrator *type 4231*, have been used for the sound tests. Before and after each test, all the equipment was verified and calibrated. The recorded data were processed using the software *Evaluator type 7820* by *Brüel & Kjaer*.

The sound level meter *B&K 2250* was located inside the incubator in order to study the influence of the room noise inside the incubator. Despite the possible absorption and/or reflections of the noise produced by the walls of the incubator, the interesting thing is to know what the newborn will hear, since it will influence the sound level meter. The microphone was placed at the level of the baby’s head, approximately 10 cm high, placed on the mattress and secured by the use of a small tripod.

In the measurement of the UCIN room, the microphone of the sound level meter *B&K 2270* was located between two incubators (the incubator analyzed and an adjacent incubator occupied), at a distance of approximately 1.50 m from the nearest wall and away from the ceiling.

In all cases, the data were recorded with a sampling time of one second along continuous measurements of at least 24 hours. The main parameters recorded were the continuous equivalent level with A weighting and without weighting (L_{Aeq} and L_{Zeq}). Similarly, the values in linear thirds octave (L_{Zeq}) were recorded for each frequency band (between 12,5 Hz Y 20 kHz), maximum and minimum values with fast time weighting (L_{AFmax} and L_{AFmin}), the temporal weighting values (L_{AIeq}) and peak values with weighting C (L_{Cpeak}).

Figure 1. *Sound level meters position in the NICU.*

3. RESULTS

3.1 Neonatal Intensive Care Unit

In the two measurements made in the NICU, the noise levels were much higher than the recommendations made by the different international entities (AAP, AEP, WHO), reaching levels between 46.6 dBA and 90.3 dBA, with an average energy $L_{Aeq(24\ h)}$ of 60.0 dBA in the first campaign and 63 dBA in the second campaign. The peak levels L_{Cpeak} were 108.0 dBC and 109.1 dBC respectively.

If a spectral analysis of the sound is performed over 24 hours, it can be verified, as reflected in figures 2 and 3, that the highest levels of noise match the frequency range of the audible range of human speech, that is, the sound source that produces the highest level of sound pressure is the conversations that occur in the room.

Although both times the sound level meters is located at the same point in the NICU, in the first measurement campaign (figure 2) we find lower values than in the second (figure 3).

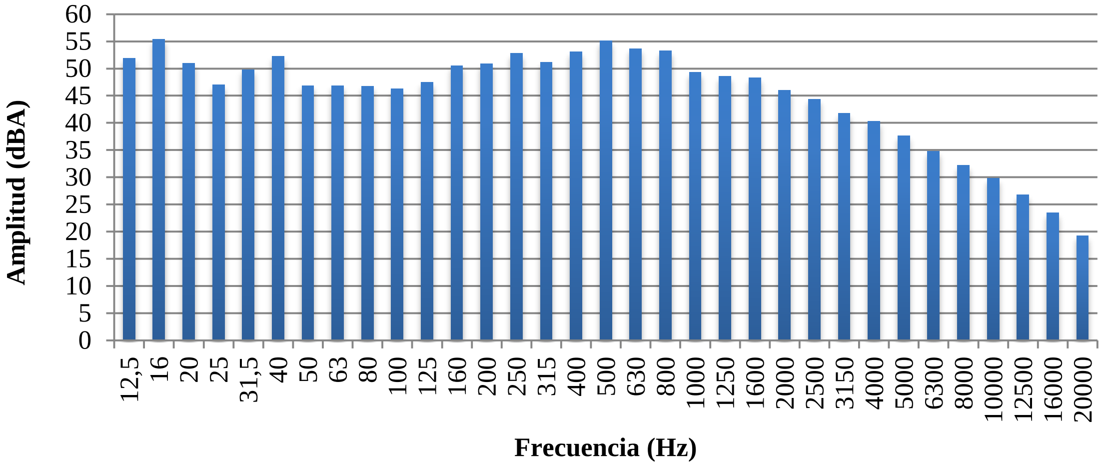

Figure 2. *Frequency spectrum of noise levels in the NICU noise levels, in the 1st measurements campaign.*

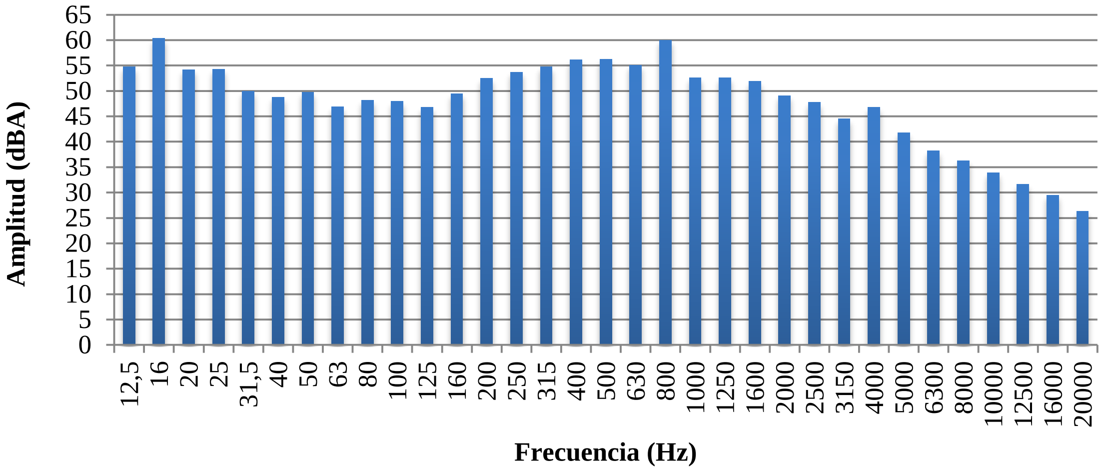

Figure 3. *Frequency spectrum of noise levels in the NICU noise levels, in the 2nd measurements campaign.*

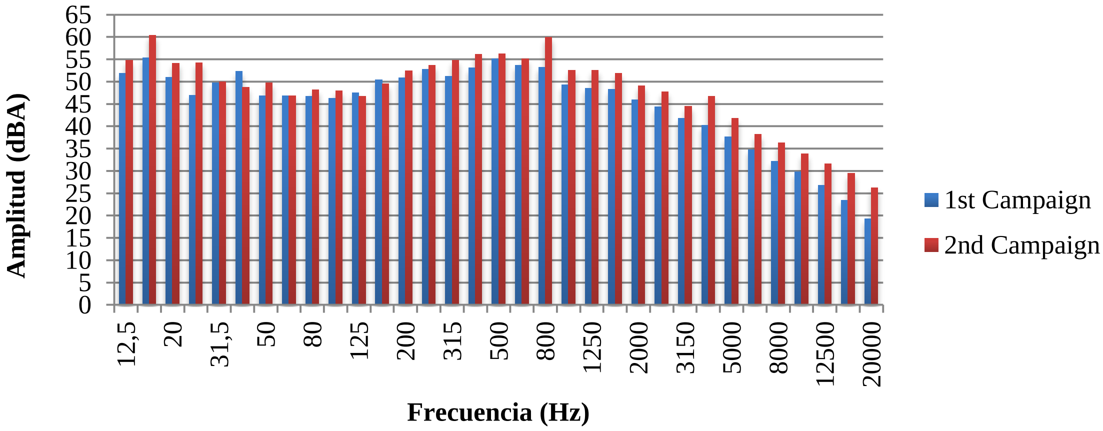

Figure 4. *Comparison of the sound spectrum recorded in the two measurements campaign in the NICU.*

As can be seen in figure 4, noise levels exceed 45 dBA marked as a recommended limit in low, medium and high frequency, decreasing from 3.15 kHz. The spectrum morphology, in both cases, is very similar, showing that the higher the frequency, the smaller the amplitude of the recorded sound.

3.2 Inside the neonatal incubator

On this occasion both measurement campaigns were carried out at different points in the NICU and in different incubator models. In the first case, the incubator analyzed was the *Ohmeda Medical Giraffe OmniBed* (*Giraffe*) located at one end of the room and away from the workbench and monitoring of health staff.

In this test, the sound pressure levels range from 44.2 dBA to 84.2 dBA, with $L_{Aeq\ (24\ h)}$ being 50.4 dBA. L_{Cpeak} were found around 108.3 dBC. In reference to the spectral analysis of sound (figure 5), the highest levels are in low frequency, falling below 45 dBA from 250 Hz.

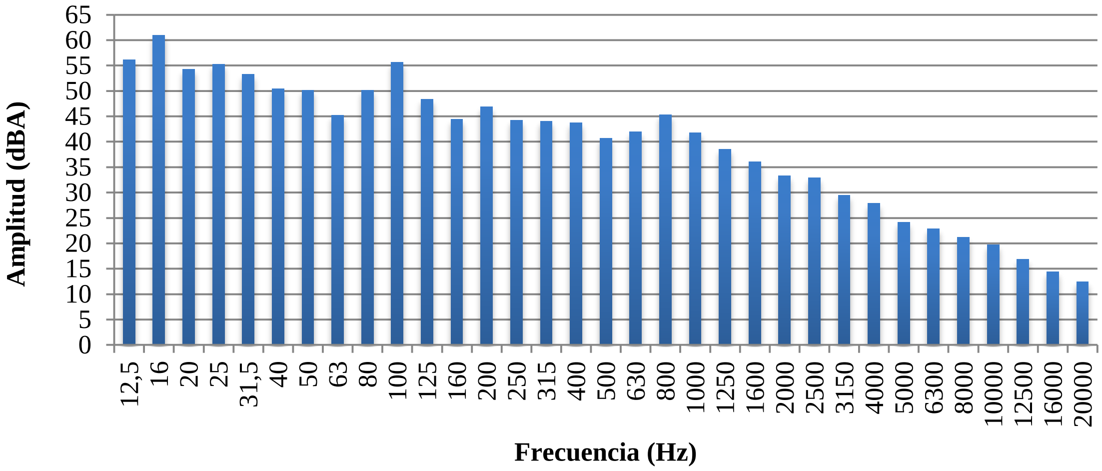

Figure 5. *Frequency spectrum of noise levels inside the Giraffe incubator, in the 1st measurements campaign.*

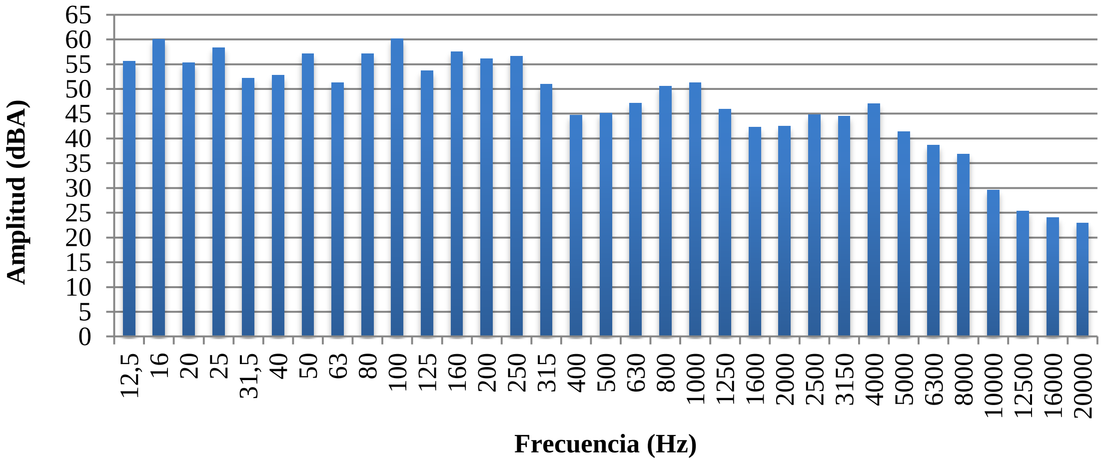

Figure 6. *Frequency spectrum of noise levels inside the OCP 3000 incubator, in the 2nd measurements campaign.*

The second measurement campaign was carried out inside an *Ohmeda Medical Ohio Care Plus 3000* (*OCP 3000*) incubator, located in the middle of the room and close to the workbench and monitoring of health staff.

As can be seen in figure 6, as in the previous case, the highest levels occur at low frequency, although this time the 45 dBA marked as the recommended limit is exceeded in the entire frequency band below 1600 Hz.

In both campaigns there is a peak in the frequency band of 100 Hz, which can be due to the reflection of the harmonic associated with the network frequency (50 Hz).

4. DISCUSSION

4.1 Neonatal Intensive Care Unit

The objective of this work focuses on the frequency analysis of the noise that occurs in the NICU and inside a neonatal incubator, with the intention of checking the noise levels that premature infants support and if they are consistent with the auditory development of this.

The sound environment is formed by atypical sounds coming from conversations, telephones, ventilators and alarms [13]. Each alarm produces one or several different tones, most of them in high frequency, emitting unpredictably depending on the state of the neonate (low, medium or high priority) [13]. These sound sources raise the noise levels reaching up to 90 dBA, according to the test carried out, a level well above the limits recommended by the AAP for a healthy hearing development of the newborn.

Does this level really affect the newborns that are inside the incubators? If we compare the frequency spectrum of the room with those inside the incubator (figure 7), it is verified that the levels, in the whole sound spectrum, are very similar. Fernández Zacarías [26] indicated in his article the behavior of the materials that make up the dome of the incubators, coinciding with this study.

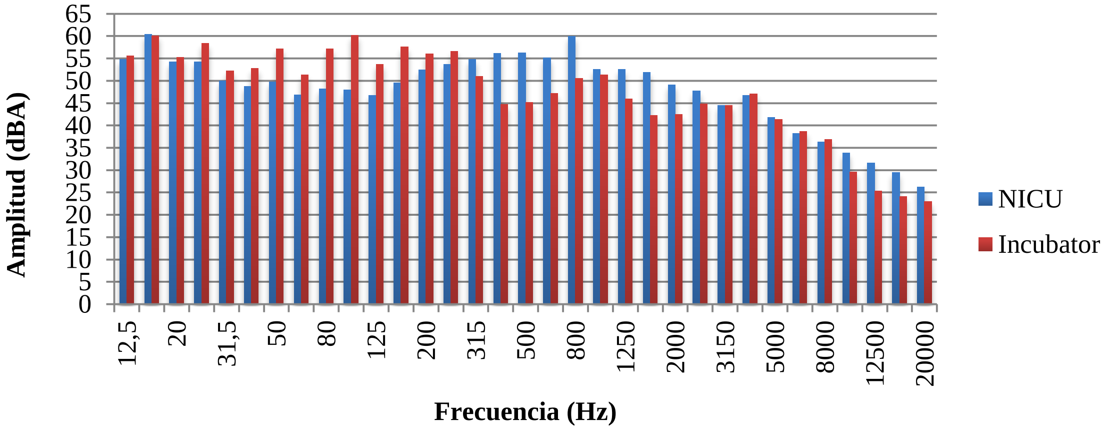

Figure 7. *Comparison of the sound spectrum recorded in the NICU and inside the incubator.*

4.2 Inside the neonatal incubator

Measurements taken in the first campaign provide noise levels within the *Giraffe* incubator. These measurements indicate that the sound pressure levels exceed the current recommendation of 45 dBA, but if its sound spectrum is observed (figure 5), these levels are lower than those recommend from 160 Hz and are exceeded at low frequencies.

However, in the second campaign of measurements taken in the *OCP 3000* incubator, the sound spectrum (figure 6) indicates that the recommended level exceeds the entire frequency band below 1600 Hz.

This situation raises doubts about whether the *OCP 3000* incubator really produces a higher noise level compared to the *Giraffe* incubator. Well, we could say yes, the previous studies [26][27] already made a comparison between these two models and could verify this question. Although studies indicated the difference between the noise kevels thy issued, the difference was not as wide as that obtained on this occasion.

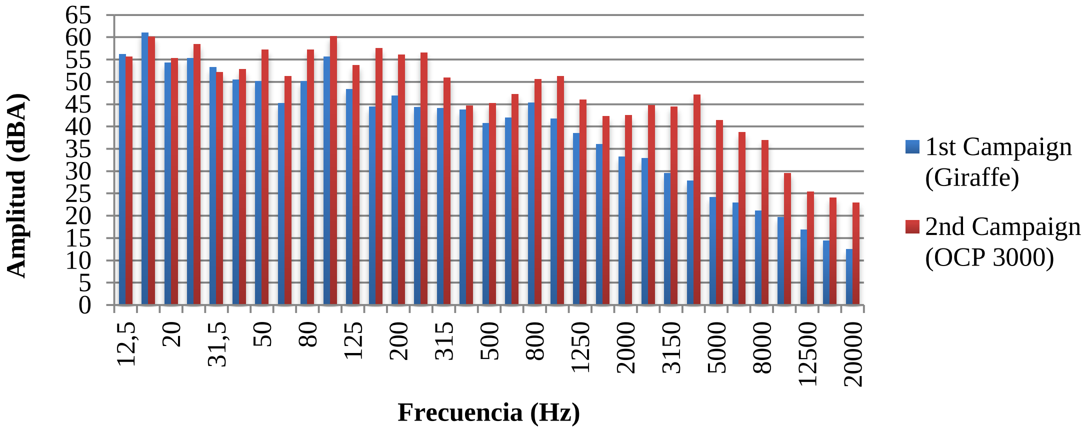

Figure 8. *Comparison of the sound spectrum recorded in the two measurements campaign inside the incubator.*

The question is resolved due to the location of the incubator in each of the measurement campaigns. In the first case, the *Giraffe* incubator was at one end of the room, away from the work table and the monitoring of health personnel, while in the second case, the *OCP 3000* incubator was in the center of the room and close to this work space. Clearly, this is the main cause of the noise levels being much higher within the *OCP 3000* incubator. The noise level that occurs in these workspaces is much higher than at any other point in the NICU.

It is important to remember that intrauterine structures significantly reduce sound frequencies above 500 Hz. For example, Gerhardt and Abrams [28], through animal experiments, showed that a signal of 72 dB at 500 Hz is reduced by 24 dB, while at higher frequencies this reduction is greater, that is, 38 dB at 1000 Hz and 48 dB at 2-4 kHz.

Up to week 27 of gestational age, the fetus listens to lower frequencies (below 500 Hz) and probably cannot detects frequencies above 500 Hz until week 29, due to the filtering of maternal tissues [28]. As of the third trimester, the range of hearing sensitivity of the fetus varies from 500 Hz to 1 kHz, while that of neonates to terms is between 400 Hz and 4 kHz [29].

Hepper y Shahidullah [30] explored the ability of human fetus responses to external auditory stimuli by using pure tones (100 Hz, 250 Hz, 500 Hz, 1000 Hz and 3000 Hz). The recording of the fetal movements by ultrasound, revealed the sensitivity of the fetus of 19 weeks of gestation, to external sounds in the low frequency range below 500 Hz, later, at the age of 27 weeks of gestation, most of the fetuses responded to sounds below 500 Hz but none of them responded to sounds of 1000 Hz and 3000 Hz. The response to sounds above 1000 Hz was not observed until 33 weeks of gestation. In all the frequency bands presented, a significant decrease in the applied intensity was observed to provoke a response in fetuses of higher gestational age, supposedly due to the maturation of the auditory system and probably to the thinning of the intrauterine walls in the third trimester of pregnancy [18]. The fetal auditory system is characterized by an increase in spectral sensitivity, both at low and high frequencies, with a decrease in the hearing threshold [31].

With the above, it is worth asking whether the levels of noise, found inside the incubators, affect the neonates. The answer to this question could be affirmative, since through the bibliographic study carried out, it has been found that the sound frequencies measured in the incubator are within the audible range of the neonates.

5. CONCLUSIONS

Considering the existing bibliography, the audible range of the neonate is between 400 Hz and 4 kHz, coinciding with the range of intelligibility frequencies of human speech. After the acoustic measurements made in the NICU of the Hospital Universitario Puerta del Mar, in Cádiz, it was possible to evaluate the noise levels both in the room and inside the incubators, which shows that the indicator uses $L_{Aeq,1h}$ must be completed with a study and a frequency analysis to determine the acoustic quality and hearing protection of newborns.

The NICU is full of sounds that occupy the whole spectrum of frequencies and affect the noise levels measured within the incubators, mainly in low and medium frequencies, being attenuated in greater proportion in high frequency due to the walls that compose them.

According to the results obtained in the acoustic campaigns, the location of the incubator in the room can directly affect the environmental acoustic quality perceived by the neonate inside the incubator, for which a characterization study of the NICU is necessary. Once the room has been characterized, there must be reserved areas within it to locate certain neonates according to gestational age. It has been found that the sound frequencies measured inside the incubator are within the audible range of the neonates, so this environment requires modifications to make the sound spectrum more compatible with the hearing of neonates, which points to the correct auditory development of these.

5. ACKNOWLEDGEMENTS

We want to thank the health staff of the NICU of the Hospital Universitario Puerta del Mar for their help in carrying out this study.

6. REFERENCES

[1] C. V. Ananth and A. M. Vintzileos, "Epidemiology of preterm birth and its clinical subtypes," *J. Matern. Neonatal Med.*, vol. 19, no. 12, pp. 773–782, 2006.

[2] A. Ovalle *et al.*, "Factores asociados con el parto prematuro entre 22 y 34 semanas en un hospital público de Santiago," *Rev. Med. Chil.*, vol. 140, no. 1, pp. 19–29, 2012.

[3] R. L. Goldenberg, J. F. Culhane, J. D. Iams, and R. Romero, "Epidemiology and causes of preterm birth," *Lancet*, vol. 371, no. 9606, pp. 75–84, 2008.

[4] A. J. Knutson, "Acceptable noise levels for neonates in the neonatal intensive care unit," *Indep. Stud. Capstones*, p. Program in Audiology and Communication Sciences, W, 2012.

[5] American Academy of Pediatrics. Committee on Environmental Health, "Noise: A Hazard for the Fetus and Newborn," *Pediatrics*, vol. 100, no. 4, pp. 724–727,

1997.

[6] A. D. M. Jackson, “Guidelines for Perinatal Care,” *Am. Acad. Pediatr.*, 1986.

[7] U. S. E. P. Agency, *Information on levels of environmental noise requisite to protect public health and welfare with an adequate margin of safety*. 1974.

[8] T. Morata and U. Santos, “Efeitos do ruído na audição. In: Santos, UDP. Ruído: Riscos e Prevenção. São Paulo, Hucitec,” pp. 43–54, 1996.

[9] L. da Silva Reis Santana *et al.*, “Measurement of acoustic noise levels in a Neonatal Intensive Care Unit,” *REME Rev. Min. Enferm.*, vol. 19, no. 2, pp. 27–31, 2015.

[10] R. Tamez and M. Silva, “Impacto do ambiente da UTI Neonatal no desenvolvimento neuromotor,” *Enferm. na UTI neonatal Assist. ao recém-nascido alto risco. Rio Janeiro Guanabara Koogan*, pp. 147–154, 1999.

[11] H. P. Parmelee and M. D. Sigman, “Perinatal brain development and behavior,” *Mussen PH, ed. Handb. child Psychol. vol II, 2nd ed. New York John Wiley sons*, pp. 95–156, 1983.

[12] A. Nieto Sanjuanero, “Evaluación de los niveles de ruido en una Unidad de Cuidados Intensivos Neonatales,” 2012.

[13] R. Hernandez Molina *et al.*, “Análisis del ambiente sonoro en una Unidad de Cuidados Intensivos de Neonatología,” *XI Congr. Iberoam. Acústica; X Congr. Ibérico Acúsica; 49º Congr. Español Acústica -TECNIACUSTICA’18-*, 2018.

[14] P. E. Klass, R. Needlman, and B. Zuckerman, “The developing brain and early learning,” *Arch. Dis. Child.*, vol. 88, pp. 651–654, 2003.

[15] D. Querleu, X. Renard, F. Versyp, L. Paris-Delrue, and G. Crèpin, “Fetal hearing,” *Eur. J. Obstet. Gynecol. Reprod. Biol.*, vol. 29, pp. 191–212, 1988.

[16] J. P. Lecanuet and B. Schaal, “Fetal sensory competencies,” *Eur. J. Obstet. Gynecol. Reprod. Biol.*, vol. 68, no. 1–2, pp. 1–23, 1996.

[17] F. Z. Abdollahi, M. Joulaie, A. Darouie, and T. Ahmadi, “Auditory Development in Infants,” *Glob. J. Otolaryngol.*, vol. 10, pp. 5–7, 2017.

[18] A. Lahav, “Questionable sound exposure outside of the womb: frequency analysis of environmental noise in the neonatal intensive care unit,” *Acta Paediatr.*, vol. 104, no. 1, pp. e14–e19, 2015.

[19] B. Kellam and J. Bhatia, “Sound spectral analysis in the Intensive Care Nursery: Measuring high-frequency s ound,” *J. Pediatr. Nurs.*, vol. 23, no. 4, pp. 317–323, 2008.

[20] K. Persson Waye, “A caring sound environment in hospitals?,” *Care Sound*, pp. 11–26, 2013.

[21] A. C. Donis Paz, “Contaminación acústica en la Unidad de Neonatología del Hospital Roosevelt,” 2013.

[22] A. P. Garrido Galindo, Y. Camargo Caicedo, and A. M. Vélez-Pereira, “Nivel continuo equivalente de ruido en la unidad de cuidado intensivo neonatal asociado al síndrome de burnout,” *Enferm Intensiva*, vol. 26, no. 3, pp. 92–100, 2015.

[23] R. C. White-Traut *et al.*, “Maturation of the cardiac response to sound in high-risk preterm infants,” *Newborn Infant Nurs. Rev.*, vol. 9, no. 4, pp. 193–199, 2009.

[24] J. Neille, K. George, and K. Khoza-Shangase, “A study investigating sound sources and noise levels in neonatal intensive care units,” *SAJCH South African J. Child Heal.*, vol. 8, no. 1, pp. 6–10, 2014.

[25] D. Kurtzberg, D. R. Stapells, and I. F. Wallance, “Event-related potential assesment of auditory system integrity: implications for language development,”

Early identificationof infants with Dev. Disabil., 1988.
[26] F. Fernández Zacarías, J. L. Beira Jiménez, P. J. Bustillo Velázquez-Gaztelu, R. Hernández Molina, and S. Lubián López, "Noise level in neonatal incubators: A comparative study of three models," *Int. J. Pediatr. Otorhinolaryngol.*, vol. 107, no. July 2017, pp. 150–154, 2018.
[27] V. M. Rodríguez Montaño, "Análisis del acondicionamiento acústico del habitáculo de una incubadora neonatal: propuestas de mejora," 2018.
[28] K. Gerhardt and R. Abrams, "Fetal exposures to sound and vibroacoustic stimulation," *J. Perinatol.*, vol. 20, pp. 20–29, 2000.
[29] G. B. Avery, M. A. Fletcher, and M. G. MacDonald, *Neonatología : fisiopatología y manejo del recién nacido*. Médica Panamericana, 2001.
[30] S. B. Hepper PG, "Development of fetal hearing," *Arch Dis Child*, pp. 81–87, 1994.
[31] R. N. Aslin, D. B. Pisoni, and P. W. Jusczyk, "Auditory development and speech perception in infancy," *Mussen PH, ed. Handb. child Psychol. vol II, 2nd ed. New York John Wiley sons*, vol. 573, 1983.