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The characterization of noise levels in a neonatal intensive care unit and the implications for noise management

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Abstract

Background: The effects of noise are particularly harmful for the newborns, and therefore this study assesses and characterizes noise levels in a neonatal intensive care unit (NICU) in a medium-size hospital in the city of Huelva with the aim of optimizing the management and quality of care for newborns.

Methods: The equivalent continuous sound level was recorded as A-weighting curves using Type I sound level meters with levels measured during 100 milliseconds along to 15-day period in the both critical (in and out of incubators), and intermediate care units from a medium-size hospital. These devices were attached to a central beam 80 cm below the ceiling and into one of the incubators.

Results: The maximum noise levels measured for critical (C-in), C(out) and intermediate (I) were: 88.8 dBA, 97.2 dBA and 92.4 dBA, respectively, while for the equivalent noise levels for the total measuring period (15 d) were 57.0 dBA, 63.7 dBA, and 59.7 dBA, respectively. The Fourier frequency analysis has demonstrated several typical periods related to both work activities and family visit, which were: 7 days, 24 h, 12 h, and 3 h.

Conclusions: The statistical analysis revealed a clear correlation between the noise level, the kind of care room, and the time of the day. The results show that the values recommended by international bodies and agencies (AAP, WHO) are surpassed by a large margin, thus making it crucial that certain norms are followed in order to reduce the noise level in the NICU, by means of physical alterations to the layout, and raising awareness of health care personnel and visitors in order to encourage noise prevention in the daily care work and conversation. And finally, has been demonstrated that by applying the t-Student test the mean noise values in both wards are significantly different, which leads us to state that the noise level for the critical wards are higher than in the intermediate care ward.

Background

Recent studies on the quality and risks associated with admission to a medical center have established a relation between the increase in morbidity and mortality, in addition to alterations in the quality of life following discharge from the health center which are usually linked to greater exposure to environmental pathogens, a lowering of the body's defenses and an increase in invasive techniques, among other reasons. Many authors have found a high correlation between noise levels in NICU and adverse effects arising from sleep disorders, underdevelopment of responses to stimuli, deterioration of the nervous system, etc. [1-6]. The noise that occurs in the NICU is linked to the monitoring and follow-up processes of the newborn's state of health, such as alarm systems, electro-medical equipment and incubators, and the general human ambient noise [7].

Several studies have measured the noise levels in NICU, finding very different values depending on the management of the work activities or customs of the place, with equivalent continuous levels in ranges from about 55 up to 83 dBA. These noise levels are high enough to stimulate the newborn's endocrinal and cardiovascular systems, resulting in significant alterations in sleep patterns [8-11]. Bushch-Vishniac et al. [12] determined that the average

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noise level for the John Hopkins Hospital has risen in the last 45 years by around 0.40 dBA a year, mainly due to the increase in audible alarm systems, the installation of air conditioning, control and surveillance systems and electromechanical therapeutics.

In terms of the legal framework, the World Health Organization (WHO) recommends that the newborn inside an incubator should not be exposed to noise levels higher than 35 dBA at night and 40 dBA during the day [13]. As proposed by the US Environmental Protection Agency and supported by the American Academy of Pediatrics (AAP) Committee of Environmental Health, noise levels within the NICU should be kept below 45 dB [14]. More specifically, the AAP recommends that hourly, a NICU's loudness equivalent (LAeq) should be below 50 dBA, the sound level that is exceeded 10% of the time (L10) should be at or below 55 dBA, and the maximum sound (Lmax) should be below 70 dBA [15]. In Spain, the Standards Committee of the Neonatology Society of the Spanish Pediatrics Association recommends a total background noise level in NICU of no more than 55 dBA, and should not exceed 70 dBA [16]. However despite these recommendations, noise levels routinely oscillate between 65 dBA and 85 dBA, normally at low frequency [17].

In this study are correlated the temporal variations of the noise with its causes (Monitoring Systems, work activities, family visits, medical rounds, etc.). Spain is the second noisiest country in the world after Japan [18], according to the World Health Organisation (WHO), so this study is particularly important due to customs and the high noise level in the daily activities of the Spanish people.

With this in mind, the aim of our study is to identify, assess and make a space-time characterization of the noise levels in the NICU of a typical medium-sized hospital in Spain to find the main correlations with the noise sources, and, as consequence, to establish the right protection measures for noise reduction and elimination.

Methods

The study area is the NICU of the Juan Ramón Jiménez Hospital (HJRJ) in the city of Huelva (southwestern Spain). It is a general public hospital which also has specialist units. The NICU has 31 care units for newborns divided into three levels of medical attention: NICU-C has 9 incubators for newborns in a critical condition. NICU-I is an intermediate intensive care ward with 10 beds and the NICU-M has 12 beds for newborns requiring minimum intensive care.

The continues monitoring was developed for a period of 15 days and each individual noise measurement was made in time of 0.1 s in fast mode, in the NICU-C critical care ward (Figure 1) and the NICU-I intermediate care ward (Figure 2) since newborns in these two units are the most sensitive to noise. A sound level meter was placed in the NICU-C ward 80 cm below the ceiling and 153 cm from the wall. A second meter was placed in the NICU-I ward along the central beam 80 cm below the ceiling and 215 cm from the wall because it is the central point of the NICU, in order to achieve a representative point of the noise. A third meter was placed in the incubator. In line with regulation UNE-EN ISO 1996-1:2005, the equivalent continuous noise level was measured in A weighting and in time intervals of 1 s, and from these individual measurements the different noise index shown in this work were calculated; for example L10, L50, L90, Leq,1 h, etc, depending of the time interval of interest.

Two noise level meters used were the Type I Brüel & Kjäer model 2270 and 2250. The technical characteristics for two meters are: 4.2 HZ broadband linear frequency range with supplied microphone Type 4189, 16.6 – 140 dB A-weighted dynamic range with supplied microphone Type 4189. Outputs: Generator and Headphone. The third was the Rion NL-31, and the technical characteristics are: A weighting: 28-138 dB, C weighting: 33-138 dB, flat: 38-138 dB, Peak sound level: 141 dB, Ranges 100 dB dynamic, frequency 20-12,500 Hz (including microphone).

The sampling period lasted 15 days in order to ensure that the averages were representative and to offset the Hawthorne effect [19] of attention bias in which the study participants alter their behavior when they are aware they are being observed, and avoid interferences that can cause another unexpected variable to influence the study.

The collected data (individual data were for time intervals of 0.1 s) were recorder in the Secure Digital (SD) by Memory Card inside of the level meters and downloaded to PC and were treated and processed in the XLSTAT code developed by Addinsoft and SPSS 13.0.

Results

Figure 3 shows the LAeq,1 h for the 15-day sampling period in the two NICU wards studied. The values for the intermediate care ward are generally lower than those for the critical care ward. The hourly LAeq,1 h minimum and maximum values fluctuate in a small range of about 49 - 52 dBA for the minimum values (3 dBA), and 67 - 72 dBA (5 dBA) for the maximum. The values are constant during the fifteen days. The maximum LAeq, 1 h (about 72 dBA) occurs at around 14:00 on 29/06/2010 (end of visits with medical information to the families), in the NICU-C. The Figure also shows that the equivalent continuous hourly level exceeds 70 dBA in many hours (12 times), in clear breach of WHO recommendations. The LAeq, 1 h in the incubators are, clearly, more lower than out (54dBA - 62dBA). This is because the incubator absorbs something the noise.

An analysis of the LAeq, 1 h in Figure 3 demonstrates that a possible Hawthorne effect is not applicable since the values recorded in the first three days were similar

Figure 1 Location of sound level meter in the NICU critical care ward for newborns.

or slightly higher than those for the following days. In general, the LAeq, 1 h values for the afternoons are significantly higher than those for the mornings due to visiting hours.

Also in Figure 3, we see that 50% of the noise level recorded between 01:00 and 07:00 is less than 53 dBA in NICU-I and under 52 dBA in NICU-C. Noise levels increase early in the morning, reaching a peak when care of the newborns is at its busiest and when shift changes take place between 12:00 and 14:00, with noise levels falling during the night.

Figure 4 was designed to represent the average hourly rates of the percentiles of the equivalent continuous noise level in NICU-I and NICU-C (in and out), in order to establish whether there were peak-time events that could be associated to specific hours of the day. This Figure shows that the background noise level (quantified by L90) varies between 46 dBA and 51 dBA in NICU-C, and between 49 and 52 dBA in NICU-I, which is higher than that recommended by the WHO [13]. Likewise, the L99 (background noise) minimum noise level of about 50 dBA in NICU-I, 46 dBA in NICU-C (out) and 52 dBA in the incubator,

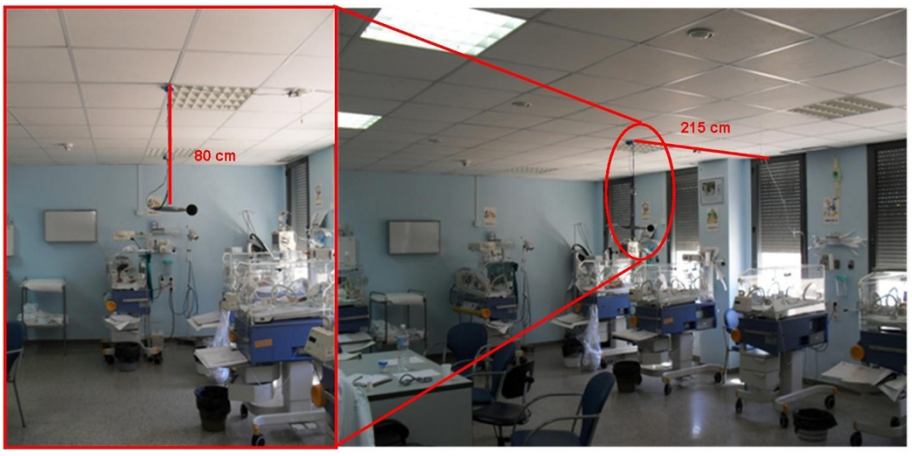

Figure 2 Location of sound level meter in the NICU intermediate care ward for newborns.

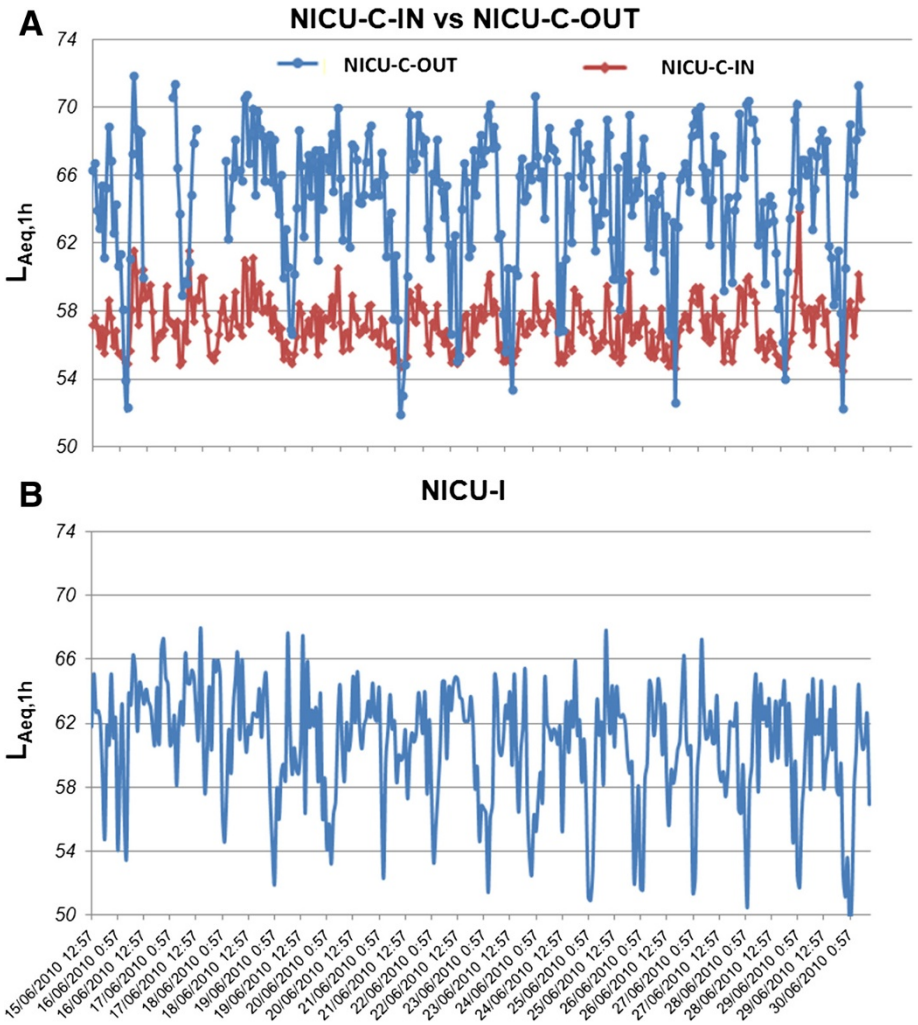

Figure 3 Comparative equivalent continuous noise levels – 1 hour integration ($L_{Aeq,\ 1h}$). A: in the NICUC IN vs NICU C OUT and **B:** NICU-I at HJRJ.

was to be expected due to sounds coming from outside the hospital, such as passing traffic in the surrounding area. The noise inside the incubator is higher and constant due to electromechanical equipment.

The L10 levels (peak noises) are similar in both wards, between 55 dBA and 65 dBA in NICU-C and 53-67 dBA in NICU-I. Inside the incubator the L10 is around 54-57 dBA. This acoustic rate remains stable during the day (8:00 to 22:00) with oscillations below 5 dBA, and the minimum recorded at around 05:00 when activity in these wards is at its lowest. Also noteworthy is that noise levels reach a maximum when care activity is at its busiest, between 08:00 and 15:00, which demonstrates that the wards are noisiest when nursing and monitoring are at their most intense.

We also observe that acoustic levels in NICU-C are generally more uniform than in NICU-I. In the incubator is more uniform without large swings. In relation with the climate noise, L10-L90, in NICU-C (in) the Figure 4 shows a constant range between 2 and 4 dBA, reflecting a constant climate noise with maximum to 7:00, 11:00, 13:00 and 14:00 with values around 4 dBA. On the other hand, the values of NICU-C (Out) show a wider range between 9-16 dBA, with maximum in the visits hours 13:00-14:00 h and 19:00 h, as we shall see in Figure 5. In relation to the NICU-I, we can observe that the range of climate noise is wider than in NICU-C (out), with values between 4-16 dBA, being highest in the shift changes. Lastly, we can observer that in all cases the minimum values were obtained during the night period (0:00-6:00 h).

Figure 5 presents the hourly integrated values of the equivalent continuous noise level for the 15-day period. There are certain similarities. Higher levels of noise happens with the staff sift changes (8:00, 15:00 and 22:00 hours). In the night there is a lower noise level due to lower activity in the care. The highest levels are in the feedings times.

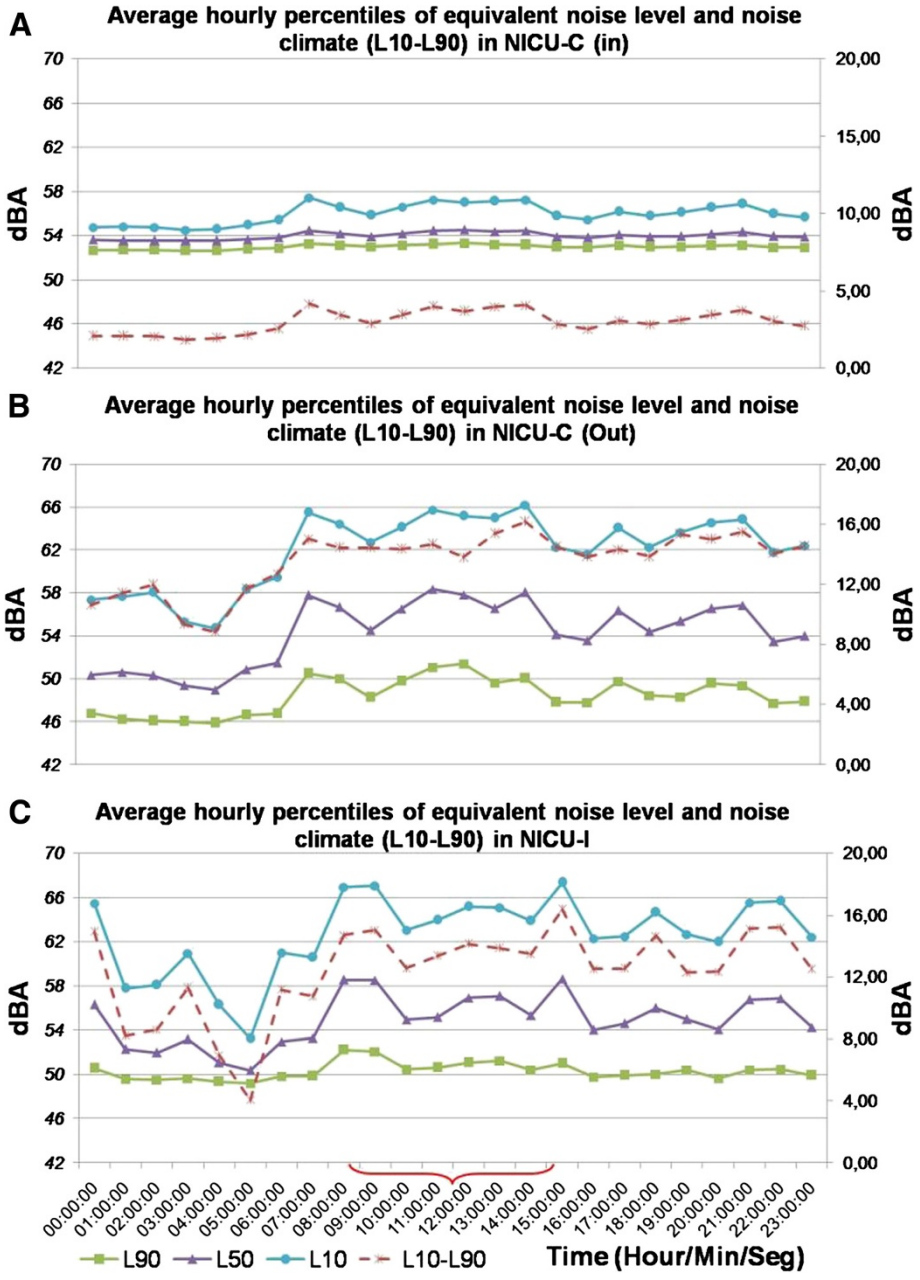

Figure 4 Average hourly percentiles of equivalent noise level and noise climate given by L10-L90. **A)** in NICU-C (in), **B)** NICU-C (out) and **C)** NICU-I.

Obviously there are more instances of intervention, monitoring and follow-up of newborns in the NICU-C ward where the most critical care takes place, with a consequently greater noise level throughout the day. The NICU-C-out ward recorded LAeq,1 h of 69 dBA at 08:00, which is when the biggest number of health care personnel starts work. Hence, the high noise level is directly attributed to talking by the staff, again verified by the second peak which occurs at 15:00 when the majority leaves work. This Figure also shows the close relation between the activities of the health care personnel in the NICU and the noise level in each ward.

These activities are periodical which is verified by a temporal series analysis of the noise, which yielded the periods of greatest significance: 7 days, 24 hours, 12 hours and 3 hours. The first of these periods relates to the weekend effect in which work activity decreases markedly towards the end of this seven-day period. The 3-hour period is also noteworthy as the newborns are fed every three hours. In the NICU-C, the relation between feeding times and noise

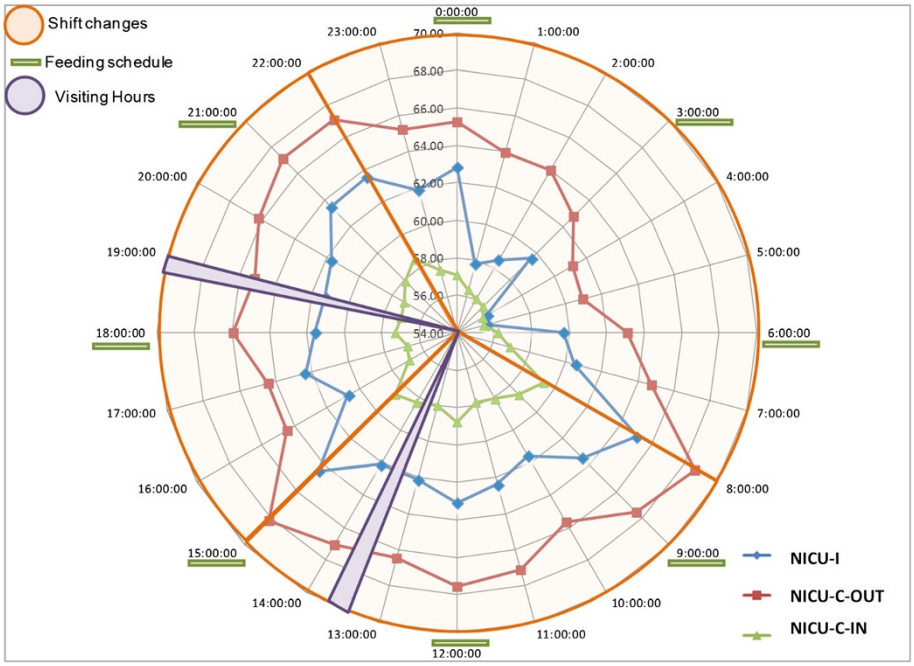

Figure 5 LAeq,1 h register (24 h) in the NICU at HJRJ. Circle graph.

levels is weak since most newborns are fed by nasogastric drip. In terms of visiting times at 13:30 and 18:45, there is a rise in the average hourly noise level in the NICU-C while the average noise level in the NICU-I remains stable or falls.

The normality of the distribution of LAeq,10 min data was tested with the result that the noise in each ward did not distribute normally, as was to be expected since there are considerable internal correlations in the noise measured for each hour of the day (see Figure 6). By contrast, if we apply a normality test to LAeq, 10 min at a specific hour of the day for the 15 days of the sampling we find that these data have a high degree of normality. It does not have the normal distribution that would be obtained for the mean value and standard deviation measured experimentally (N = 326 values, μ = average = 64.65 dBA, Sx = Standard Deviation = 3.98 dBA, U = Standard Uncertainty of the Average = 0.22 dBA). It can be demonstrated that by applying the t-Student test the mean noise values in both wards are significantly different, as obtained from their intervals at 95% confidence (μC = 64.6 ± 0.4 dBA; μI = 60.6 ± 0.4 dBA), which leads us to state that the noise level in the critical care ward for newborns is 4.0 dBA higher than in the intermediate care ward.

By contrast, if we take a specific hourly period such as 00:00-01:00 in NICU-I, the resulting data set (N = 6 · 15 = 90 data) still has a normal distribution with 95% confidence. Likewise, if we apply the Shapiro-Wilk test we get W = 0.838 (p-value = 0.159), so the null hypothesis is acceptable at a significance level of 5% (alpha = 0.05) since the p-value obtained (0.159) is greater than the alpha considered (0.05). This result confirms our hypothesis that the noise level has a normal distribution if the sampling period is restricted to 1 hour, which is less than the shortest of the characteristic periods of the data series (3 hours or the newborns' feeding time).

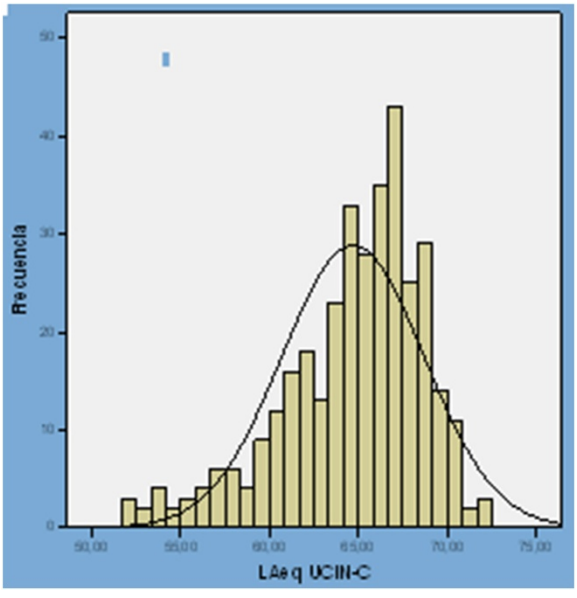

Figure 6 Experimental frequency distribution of the LAeq, 10 min.

Discussion

The results are consistent with those of other authors [20-28] in which the hours with the highest levels of noise are between 08:00 and 15:00, when care activity around the newborn in NICU is at its busiest. In terms of the maximum, minimum and average noise levels recorded, the studies in NICU that we have analysed present a wide range of values oscillating between 36-80 dBA [21-25]. The results of our study show that the noise levels in NICU at HJRJ fall within a similar range. However, our study recorded maximum values that exceeded those of other researchers, at 80 dBA in LAeq,10 min averages. The equivalent sound level in other studies has a broader range (between 40 and 90 dBA) than the one recorded in our study (between 48.8 and 72.2 dBA), and with an integrated hourly average of LAeq,24 h noise of 64.5 dBA, which easily surpasses international standards and recommendations for newborns in NICU [13,14]: LAeq,1 h = 45 dBA, L10 (hourly) = 50 dBA and Lmáx = 65 dBA, which is a considerable problem that remains unresolved [29,30].

The behavior of the hourly noise level in our study is consistent with that of Mackenzie [31], who established that the level of noise increased as the working day progressed and decreased in the afternoon. This is in accordance with Argote et al. [24] and Brandán et al. [22] who stated that noise levels rise at those times when the ward is cleaned in the mornings, and when relatives visit in the afternoons. Another characteristic that influences noise level relates to the health care work performed by personnel in shifts, with the night shift (22:00 – 08:00) showing the lowest levels and the morning and afternoon shifts registering the highest values, which is in line with various other studies [20-26].

Our study agrees with other authors [32-34] that noise levels exceed advisable. This may be due to a high number of patients, poor sound insulation, among other factors.

Conclusions

This study has demonstrated the high levels of noise pollution that newborns and health professionals are exposed to in NICU. Noise varies according to the shift, with levels at their highest during the morning and falling substantially at night. The critical care unit endures the highest noise levels. Measures to reduce these high noise levels in NICU include sound insulation (design, walls, closed doors with silent locking), drawing up an preventative maintenance equipment programme, placing the newborn as far as possible from machines, which could also be removed from the ward (fridges, computers, medical case history trolleys, etc). It would be advisable to raise awareness among personnel of the noise they make during work, and achieve a gradual decrease in the noise emanating from alarms to acceptable levels. Also needed is a reduction in conversational noise among personnel and visitors to the wards, which could be achieved by hanging the appropriate warning signs in these areas. In addition, it would be needed to develop a guideline for noise mitigation, and educational preparation of the staff and patient's visitors with the implementation of protocols and to assess the progress.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

The overall implementation of this study including design, experiments and data analysis were done by JPB, MG, MH and AMV and manuscript was drafted by JCF and JPB. All authors have made extensive contribution into this study and critically reviewed the article. All authors read and approved the final manuscript.

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