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Assessment and characterization of sound pressure levels in Portuguese neonatal intensive care units

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Abstract

In NICU, systematic exposure to sound pressure levels above the recommended can affect both

neonates and staff. This study aimed to evaluate the sound pressure levels in three Portuguese NICU and the noise perception of staff. The measurements were performed with a sound level meter, considering the location of the main sources of noise and the layout of the units. A questionnaire was applied to assess noise perception of professionals. The staff classified the environment (regarding noise) as “slightly uncomfortable” (41.1%) and 48.4% considered it as “acceptable”. In addition, the majority (55.5%) considered “equipment” as the most annoying source of noise. The results showed that noise levels were excessive in all the evaluated areas of the NICUs, exceeding international guidelines, with the levels ranging between 48.7 dBA to 71.7 dBA. Overall, there is a need for more research in order to verify the effectiveness of some actions and strategies to reduce the impact of noise in NICU.

Keywords: noise; NICU; healthcare staff.

Introduction

The premature infant in the neonatal intensive care unit (NICU) is dependent of highly advanced medical care, which has demonstrated remarkably effective success in treating high risk infant's illness. However, even with an impressive advance of medical technology, the incidence of disability and neurodevelopmental disorders among survivors of NICU remains high and problematic. Indeed, due to the high complexity of procedures and technology used in the NICU, these environment conditions include intense sensorial stimulus such as excessive lighting and noise which are incompatible with well-being of neonates, family and professionals. Mechanical devices, ventilation systems, as well as patients and staff are general sources within hospitals. In the particular case of NICU rooms and inside incubators, noise production is due to alarms produced by life support devices, flow of medical gas, communication among professionals and during activities of nursing care [1-3]. Additionally, ongoing exposure to alarms, noisy incubators and loud jarring sounds occur regularly in the NICU environment, putting premature infants at risk of noise induced hearing loss and other many health problems, such as sleep disorders and failure in cognitive activations [4,5]. NICU infant stress reactions including physiological and behavioral changes have been associated with sound levels in the incubator [6]. In fact, noise has been compared with aminoglycosides as an equal detriment to the developing cochlea. Moreover, it has been documented as a noxious stimulus with deleterious physiological effects in the premature infant. These effects include apnea; bradycardia; and abrupt fluctuations in heart rate, respiratory rate, blood pressure, and oxygen saturation [3,4,7–10]. Sensitivity to excessive noise begins at 6 months gestation and extends through the newborn period 2-3 months after birth [11], with the neonates being more vulnerable to the effects of

noise because of their immaturity. More information regarding auditory and non-auditory health effects of noise has been reported by Basner et al. [5]. Furthermore, noise as a stressor does not only influence negatively the healing process of patients (in this case premature infants) but also puts pressure on the workers which can result in a higher error occurrence [12–14]. In fact, there has been very little research on the influences of acoustic conditions on healthcare staff [15]. It is well stablished that patients are the center of every hospital, but it is known that the hospital environment has many occupational health risks due to the variety of clinical and non-clinical tasks performed by healthcare workers. The exposure to psychosocial, chemical, physical, mechanical and biological hazards are common in hospital units and predispose healthcare workers to different types of accidents [16]. However, the work performed in NICU can be particularly psychologically demanding which combined with environmental factors within the NICU, can increase the risk of work accidents occurrence, with negative consequences for staff and also for patients.

A literature review conducted by Konkani & Oakley [17] showed that several authors studied and characterized acoustic environment of intensive care units in hospitals. The noise amplitude was measured in dB or frequency analysis by some of them, while others applied an approach combining noise measurement with patient or staff questionnaire surveys or interviews. In Portugal, only Nicolau et al. [18] characterized noise levels in NICU. They concluded that noise levels were above the recommended by international guidelines and emphasized the need to train health care staff and include actively health professionals in noise reduction strategies. The current study is integrated in a larger project - *NeoNoise* project, which combine objective and subjective approaches in order to characterize the acoustic environment in Portuguese NICU.

Besides that, this project aims to determine the influence of sound pressure levels in health and well-being of premature infants and health professionals. The main challenge of the project is to develop guidelines to reduce noise levels that take into account the reality of the Portuguese healthcare services [19]. The objective of this study is to quantify noise levels in three NICU and to obtain surveys from healthcare staff in the assessment of real and perceived noise.

Materials and Methods

This study was carried out in the NICU of three hospitals (A, B and C) located in the north region of Portugal. The study included a walkthrough inspection, measurements for the assessment of the sound pressure levels and assessment of health care professional's noise perceptions. The authorization to perform the study was given by three hospitals, after favorable statement by their Ethics Committee or approval by their respective administration boards, including NICU responsible.

Walkthrough survey

A walkthrough inspection was made to characterize the built environment and indoor spaces of the three NICU under study. A checklist for this purpose was used. Detailed information regarding the building environment such as traffic and rural/urban surroundings and other external noise sources, construction characteristics, among others, was gathered. Identification of all relevant information such as area, finishing materials, and conditions concerning floor, walls, ceiling, windows and ground as well as equipment installed and health care activities routines was made. The existing equipment were common to the three NICU, namely: cardiopulmonary monitors, blood pressure monitors, ventilators (attached to an endotracheal tube or to continuous positive airway pressure (C-PAP) tubes), oximeters, Bili lights, among others. It was possible to

verify that NICU had some preventive measures to reduce noise levels, mainly maintenance programs of the equipment.

NICU - A

The clinical area of the unit consists of two rooms (A1—Intensive Care and A2—Special Care), without total separation between infrastructures. Room A1 includes the integrated set of physical, technical, and human expertise, where premature infants in critical condition with failure of vital bodily functions are assisted by advanced life support for 24 h/d. Room A2 also includes the same resources but not intended for neonates requiring mechanical ventilation. Both preparation of parenteral nutrition and medication are located in a common area of the two rooms, but the entrance is accessed through room A. The NICU (rooms A and B) has capacity to provide care for 19 patients with a total of 14 incubators and 5 nurseries. The existing physical infrastructure separating the compartments consists of plywood with glazed surface on top. The floor is concrete with vinyl covering and walls are half covered with vinyl and half plasterboard panels coated with washable paint.

NICU - B

This unit consists of two rooms (B1 and B2), without physical separation between infrastructures. The floor is concrete with vinyl covering and walls and ceiling are in plasterboard panels coated with washable paint. Each room provide care for approximately 3 and 6 newborns, respectively. Both the preparation of the parenteral nutrition and medication are in room B2 and, as a result, it has the greatest amount of staff activity. This NICU has capacity to provide care for 9 patients.

NICU - C

In hospital C, the NICU consists of 3 areas. The areas C1 and C2, which are divided by a glass wall with a corridor that allows communication between the two. The floor is concrete with vinyl covering and walls and ceiling are in plasterboard coated with washable paint. C1 and C2 are equipped with 5 incubators and 5 nurseries as well as a workstation, which supports both areas. The C3 area is an open space with 6 incubators and 3 nurseries. It has a workstation devoted to the preparation of medication and parenteral nutrition. This NICU has capacity to provide care for 19 patients.

Noise Measurements

The measurements were carried out continuously over 24 hours, during seven days in each measurement place (work station, traffic zone, inside incubator (except NICU B)). The measurement protocol was based on the orientations of previous studies [20]. In this context, a preliminary survey was performed in order to identify noise sources. Measurements were performed using a sound level meter class 1 (01 dB®, model Solo-Premium) at least 1 m away from the walls/equipment at a height between 1 m and 1.65 m and inside incubators. The measurements of peak sound pressure level ($L_{p,\ Cpeak}$) were made using the C filter and the A-weighted equivalent sound pressure level (L_{Aeq}) were obtained using the A filter (frequency weighting filter that simulates human hearing). Slow response time averaging (1 second) was also used considering it's the most appropriate response for the majority of the applications in hospitals and provide stable readings [21]. To ensure accurate measurement, recording was preceded by calibration of the sound level meter [22] with an acoustic calibrator class 1 (RION®, model NC-74). Reference values given by WHO [23] and other organizations, were used in the analysis and interpretation of results. After the field measurements, the data were

transferred and processed in the dBTRAIT software, version 5.4.

Health Care Staff Perceptions

The analysis of noise perception of health care staff in their workplaces involved the application of a questionnaire, in order to characterize working conditions, comfort and the main noise sources. The developed questionnaire already tested in previous studies of this project, was divided into three main sections containing a total of 11 questions: (1) demographic information (sex, age, profession, years of work in NICU, shift); (2) judgment of personal acceptability of noise and comfort; and (3) judgment of the noisiest shift and main sources of noise in the NICU. The personal acceptability statement and the tolerance scale consisted of judgements made about the local noise environment. Furthermore, there was no contact between the researchers and the participants in the study (volunteers), during the fulfilment of the questionnaires, since they were delivered by a nurse (responsible for the NICU) and placed inside an envelope after its fulfilment, in a completely anonymous process. At the end of the shift, they were collected by the responsible nurse who sent it to the researchers. Of the total of 95 questionnaires, 90.5% were answered by women. The mean age of the sample was 40.4 years (min. 24.0; max. 61.0), and regarding the years working at NICU, the mean was 10.1 years (min. 0.5; max. 35.0). Detailed information regarding the health care staff who participated in the questionnaire survey is given by Table 1.

Statistical Analysis

The processing and data analysis involved descriptive and inferential statistics. The normality Kolmogorov Smirnov test, Student’s t-test for independent samples and ANOVA one way were applied. The software IBM SPSS (Statistical Package for the Social Sciences) 20th version and

MS Excel 2013 were used for the analysis.

Results

The noise levels obtained in the six rooms of the assessed NICU's are shown in Table 2, as well as the frequencies spectrum in octave bands.

In NICU A, L_{Aeq} (dBA) values ranged between 58.1 (A2 – Traffic Zone) to 71.7 dBA (A1 – Work Station). In NICU B, L_{Aeq} ranged between 59.3 (B1) to 59.7 dBA (B2). In NICU C, L_{Aeq} ranged between 53.3 (C2) to 57.8 dBA (C1). No significant differences (P=0.103) were found between the three NICU. NICU C had the lowest noise levels and NICU A, the higher ones. The highest $L_{p,\ Cpeak}$ (dBC) value was found in the "Work Station" area of Room A1 (143.3 dBC). Data showed that no significant differences were found between $L_{p,\ Cpeak}$ (dBC) values (p=0.237). Except in room A1 – Work Station and A1/C2 - Inside Incubator, 500 Hz was the frequency which had higher levels in the areas under study. The demographic characteristics of the sample of health care staff who participated in this study are presented in Table 1.

Of the total of 95 questionnaires, 36.8% were received from NICU A, 38.9% from NICU B and 24.2% from NICU C. The majority of the questionnaires (90.5%) were answered by women. Additionally, more than a half of the sample was composed by nurses (54.7%), followed by operational assistants (25.3%) and physicians (18.9%). Also, the majority of the staff have worked in NICU between 5 to 20 years (49.5%), and the mean age of the sample was 40.4 years. At the time of the questionnaire survey, workers who participated in the study were mainly from the morning shift (55.8%). The responses of the relevant questions of the questionnaire are shown in Table 3.

Regarding the acceptability of the working environment, 3.2% of the participants rated noise as

"Clearly Acceptable" on their workplace, 48.4% as "Acceptable", 40.0% as "Unacceptable" and 8.4% as "Clearly Unacceptable". Statistical differences between professional groups and NICUs, were found. Concerning the main sources of noise, 55.8% of staff reported "equipment", including telephones and the signals and sounds from medical devices, as the most annoying noise sources in NICU. The "Team conversation" was rated by 27.4% of professionals, "visits" by 9.5% and “healthcare procedures” by 7.4%. No statistical differences between shifts, professional groups, years working at NICU and NICU´s, were observed. With reference to the perception of comfort in relation to the work environment, 9.5% of health professionals considered the work environment as "Comfortable", 41.1% “Slightly uncomfortable”, 30.5% "Uncomfortable", 13.7% “Very uncomfortable” and 5.3% “Extremely uncomfortable”. Statistical differences between NICUs and years working in these environments, were found. Finally, health staff reported the most annoying shift regarding noise: 62.1% of respondents considered the morning shift as the most uncomfortable, followed by night shift rated by 33.7% of the participants. Statistical differences between NICUs, were found.

Discussion

As shown in Table 2, noise levels in the three NICU were higher than the recommended by WHO, which proposes that the average background noise in hospitals should not exceed 35 dB L_{Aeq} for areas where patients are treated or observed [23], and by other organizations such the United States Environmental Protection Agency (45 dBA daytime / 35 dBA night) [24] and the American Academy of Paediatrics (45 dBA) [25]. Considering that concentration, precise communication and fast decisions are necessary in hospitals, the acoustical environment has to be considered an enormous strain for the staff and a potential risk [12]. Generally, NICU A had

the higher noise levels (mainly in A1). Since it is the large unit, it has a considerably larger multidisciplinary staff, more traffic from ancillary support and visitors, and more equipment in use, which contribute to the overall noise levels than do smaller units. Other studies comparing single-room NICU with open-unit NICU (similar to NICU A, B and C) revealed higher noise levels mostly in open-units [26,27]. Basner et al. [5] stated that noise levels in hospitals are now typically more than L_{Aeq} 15–20 dB higher than those recommended which is in agreement with the majority of the obtained results (Table 2). As a matter of fact, similar data were found in other studies [2,18,28]. Accordingly, hospital noise might be an increasing threat to patient rehabilitation and staff performance. Even though the noise levels reported in Table 2 were not high enough to be considered as a danger for hearing, these average levels might be strong enough to induce physiological stress responses as well as disorders regarding communication and work performance [12]. The questionnaire survey showed the same pattern: the majority of the staff classified NICU environment regarding noise as "Slightly Uncomfortable" and "Uncomfortable", despite the statistical significant differences between the responses of the staff of the three NICU (Table 3). In general, noise was identified by healthcare professionals as an agent with a negative impact on the environment. Indeed, other studies in hospital context found similar data [1,29,30]. However, in a study conducted in an emergency department, 53% of the sample (only constituted by nurses) felt their cognitive function was never or rarely affected by noise [31]. The morning shift was perceived as the most annoying, followed by night shift. This can be explained by the concentration of staff activity during the morning (medical routines, clinical interventions, visits, among others). During the night, noise levels are expected to decrease in order to encourage natural sleeping. Several studies showed a noise reduction during

the night shift about 2 dB [2] up to 5 dB [32] when compared with the morning shift. There were statistical differences of the perceived comfort and noisiest shift between NICU, maybe due to the influence of specific organizational factors of the NICUs. There were also significant statistical differences of the perceived comfort considering the years working at NICU. This may due to the fact that 35.8% of the respondents work at NICU less than 5 years and 59% were more experienced working at NICU environment.

Data analysis revealed that low frequencies tended to have more influence on noise produced in the NICU than higher frequencies (Table 2). These results are in agreement with Gray & Philbin [21], who stated that noise in nurseries is dominated by low frequencies, with some exceptions due to loud mid-frequencies alarms. Livera et al. [33] analyzed the noise generated by the equipment's used in the NICU, across the spectrum of frequencies, and concluded that those (incubators, ventilators, infusion pumps, radiators, etc.) equipped with alarm, produce higher sound pressure levels at higher frequencies. Kellam & Bhatia [34] suggested that human speech contribute to the spike in sound energy at 500 Hz. In addition, results described by Carvalhais et al. [1] showed the same pattern. In fact, evidence shows a reduction in sound pressure levels predominantly above 400 Hz during the night, where there is a tendency to decrease conversation and alarm sounds [1,33].

Conclusions

The studied NICUs presented higher sound pressure levels than recommended by international organizations. Thus, routine activities of healthcare professionals have been identified as a potential source of noise. The need to elevate the level of speech to overcome the noisy environment in the NICU, thereby increasing the negative impacts on staff, newborns, and their

families, is another concern. High noise levels are associated with an increased rate of errors and accidents, leading to a performance decrease among staff. Several actions could be taken in order to minimize exposure to noise in NICU. Almadhoob & Ohlsson [14], stated that by minimizing the sound levels that reach the neonate, the resulting stress on the cardiovascular, respiratory, neurological and endocrine systems can be diminished, thereby promoting growth and reducing adverse neonatal outcomes, as well as, improving staff performance and parental satisfaction. For instance, it can be achieved by lowering the sound levels in an entire unit, treating the infant in a section of a NICU or in a 'private' room, and lastly with incubators in which the sound levels are controlled. In fact, several studies showed that "private room" or single-room NICU environment has been the most effective way to address sound issues, especially when used in conjunction with a cultural change among the staff [26,27]. Lastly, regardless of the adjustment period of the operational management in NICU to deal with the new design [35], these single-room NICU also seems to improve staff satisfaction regarding physical environment and working conditions [36]. In addition, the confirmation of the influence of other physical changes of the space on noise reduction, is also needed. An action plan, including a quiet time protocol could be seen as a first step to improve a quiet environment, especially when structural modifications are not economically viable or predicted. However, more research is needed in order to verify which daily healthcare activities have more impact in noise production inside incubators. After that it will be easier to address specific actions when performing those activities.

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Table 1: Characteristics of the surveyed healthcare staff (N=95).

	NICU A	*NICU B*	*NICU C*	*N* (%)
N (%)	35 (36.8)	37 (38.9)	23 (24.2)	95 (100)
SEX				
Male	6	3	0	9 (9.5)
Female	29	34	23	86 (90.5)
AGE IN YEARS				
18-39	21	18	6	45 (47.4)
40-59	13	18	15	46 (48.4)
≥ 60	1	1	0	2 (2.1)
Missings	0	0	2	2 (2.1)
PROFESSIONAL GROUP				
Operational Assistants	6	10	8	24 (25.3)
Nurses	21	18	13	52 (54.7)
Physicians	8	9	1	18 (18.9)
Missings	0	1	0	1 (1.1)
YEARS AT NICU				
<5	10	18	6	34 (35,8)
5-20	20	16	11	47 (49.5)
>20	3	2	4	9 (9.5)

	NICU A	*NICU B*	*NICU C*	*N* (%)
Missings	2	1	2	5 (5.3)
SHIFT				
Morning	20	21	12	53 (55.8)
Afternoon	9	9	6	24 (25.3)
Night	6	7	5	18 (18.9)

Table 2: Values of mean L_{Aeq} (dB) (p=0.103) and $L_{p,\ Cpeak}$ (dB) (p=0.237).

NICU	Room	Area	L_{Aeq} Mean (min-max)	$L_{p,\ Cpeak}$	Frequencies (Hz) 63	125	250	500	1000	2000	4000	8000
					dB							
A	A1	Work Station	71.7 (47.8-114.6)	143.3	78.3	75.3	71.6	68.8	65.9	63.1	59.8	56.2
		Traffic Zone	60.4 (43.6-91.5)	115.8	52.9	50.7	56.0	56.7	52.6	52.9	50.7	48.6
		Inside Incubator	48.7 (42.2-68.1)	104.1	61.8	61.8	58.2	47.2	49.9	46.2	39.1	31.3
	A2	Work Station	59.9 (39.5-85.8)	106.3	54.5	53.1	55.1	56.7	54.6	53.2	52.6	46.0
		Traffic Zone	58.1 (43.8-82.0)	113.2	53.8	49.4	57.6	59.1	59.1	57.8	54.8	48.4
B	B1	Work Station	59.7 (50.0-73.6)	107.5	55.9	55.0	57.5	58.9	57.2	54.9	52.6	49.6
	B2	Work Station	59.3 (50.2-71.5)	108.9	57.1	51.6	56.1	58.3	56.1	54.0	51.5	44.7

C	C1	Work Station	53.3 (46.2-79.1)	112,2	48.8	42.4	45.3	50.1	47.1	47.8	41.8	40.4
	C2	Work Station	57.8 (42.6-77.4)	109,2	50.8	49.5	48.3	55.1	53.2	51.1	44.8	42.3
		Inside Incubator	46.6 (41.2-63.4)	104.6	56.1	50.0	52.0	41.1	39.2	34.2	32.1	30.3

Table 3: Judgment of personal acceptability of noise, comfort, noisiest shift and main sources of noise in NICU, reported by health care staff (N=95).

Question/Statement	Answer	NICU A (n)	NICU B (n)	NICU C (n)	Total (%)	P			
						Shift	*Years at NICU*	*Professional Groups*	*NICU's*
1- How do you classify noise levels in your work environment?	Clearly acceptable	0	2	1	(3.2)	0.903	0.471	0.849	< 0.001
	Acceptable	12	26	8	(48.4)				
	Unacceptable	15	9	14	(40.0)				
	Clearly unacceptable	8	0	0	(8.4)				
2 - What are the main noise sources in NICU?	Equipment	18	19	16	(55.8)	0.310	0.854	0.859	0.160
	Team conversation	13	12	1	(27.4)				

	Visits	3	4	2	(9.5)				
	Healthcare procedures	1	2	4	(7.4)				
3 - Concerning to noise, this environment is…	Comfortable	2	7	0	(9.5)	0.855	0.027	0.425	< 0.001
	Slightly uncomfortable	10	24	5	(41.1)				
	Uncomfortable	13	3	13	(30.5)				
	Very uncomfortable	5	3	5	(13.7)				
	Extremely uncomfortable	5	0	0	(5.3)				
4 - In which shift you think the noise is most annoying?	Morning	30	26	3	(62.1)	0.052	0.321	0.425	< 0.001
	Afternoon	1	2	1	(4.2)				

Night	4	9	19	(33.7)