Chapter 10

Noise Reduction and Control in Hospital Environment: Design of the NeoNoise Project

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Additional information is available at the end of the chapter

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Abstract

The "NeoNoise Project: Integrated Approach to Minimize Sound Pressure Levels in Neonatal Intensive Care Units" is being conducted by the Research Group on Occupational and Environmental Health of the Research Center on Health and Environment in neonatal intensive care units, since exposure to sound pressure levels in these spaces has been recognized as a factor that influences the quality and well-being of the occupants (workers and others), as well as the recovery of premature infants who are hospitalized. This work reports the rationale and the design of the NeoNoise project as well as the methods used for data collection. A brief review on the results published and available for the scientific community is also made. In general, NeoNoise project intends to make an integration of all relevant factors, with the intention of presenting a guiding document to change the working practices and occupant's behaviors. So far, this study provided data on sound pressure levels by objective and subjective approaches, as well as information about the exposure factors and sensitivity of the occupants to noise.

Keywords: premature infants, study protocol, neonatology, noise effects, noise perception

1. Introduction

Noise is an environmental stressor that is known to have physiological and psychological effects. The body responds to noise in the same way it responds to stress and overtime has potential to impair health. In general, vulnerable groups are underrepresented in study

populations. Although anyone might be adversely affected by noise exposure (environmental or occupational exposure), groups that are particularly vulnerable include neonates, infants, children, those with mental or physical illnesses, and the elderly. In hospital environment, excessive noise is not only annoying, but can also interfere with the proper performance of health care. Evidence shows that hospital noise levels often exceed those recommended by World Health Organization (WHO) [1] and other agencies. In hospitals, patient exposure has been studied more frequently over the years, than professional exposure. However, the particular case of neonatal intensive care units (NICUs) poses a new challenge, due to the "type" of patients involved—ill and/or premature infants. Newborn infants who need intensive medical attention are often admitted into an NICU. These units combine advanced technology and trained healthcare professionals to provide specialized care for ill and/or premature newborns. NICUs may also have intermediate or continuing care areas for babies who are not as sick but do need specialized health care. Noise production in NICU rooms and inside incubators is usually due to alarms produced by life support devices, flow of medical gas, communication among professionals/visitors and during activities of nursing care [2–4]. **Table 1** shows the main causes of noise in NICU.

Source of noise	
Items falling onto the floor	Up to 92 dB(A)
Equipment movement (e.g., bed)	90 dB(A)
Connection of gas supply	88 dB(A)
Door closure	85 dB(A)
Pager	84 dB(A)
Talking	75–85 dB(A)
Ventilator alarm	70–85 dB(A)
Nebulizer	80 dB(A)
Telephone	70–80 dB(A)
Television	79 dB(A)
Oximeter	60–80 dB(A)
Monitor alarm	79 dB(A)
Ventilator	60–78 dB(A)
IV infusion alarm	65–77 dB(A)
Endotracheal aspiration unit	50–75 dB(A)

Table 1. Equipment and behavioral causes of noise in intensive care units [5].

Health professionals are aware about this issue and identified noise as an agent with a negative impact on work performance [6–8]. In fact, it is known that the hospital environment has many occupational health risks due to the variety of clinical and nonclinical tasks performed by

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healthcare workers. The exposures to psychosocial, chemical, physical, mechanical, and biological hazards are common in hospital units and predispose healthcare workers to different types of accidents [9]. However, the work performed in NICU can be particularly psychologically demanding which combined with noise exposure within the NICU can increase the risk of work accidents occurrence, with negative consequences for staff and also for patients. In fact, noise may induce extraauditory effects in professionals including burnout, stress, and fatigue [10]. There is some association between noise and some health outcomes such increases in blood pressure, heart rate, hypertension, and other cardiovascular diseases. Noise exposure can also stimulate the release of epinephrine (adrenaline), increase pain, and alter quality of sleep [11, 12]. Even in newborns these effects are being implicated and associated with noise [13]. Although, it is important to underline that the levels of noise exposures associated with these health effects range widely [14].

2. Rationale and aim of the project

A literature review conducted by Konkani and Oakley [15] showed that several authors studied and characterized acoustic environment of intensive care units in hospitals. Studies measuring noise amplitude in dB or frequency analysis or through an approach combining noise measurements and patient or staff questionnaire surveys or interviews are quite usual in this domain. Dube et al. [16] surveyed patients to identify the noisiest time of the day, and were also asked to list the noises that they felt were annoying. Connor and Ortiz [17] conducted a survey where patients rated the noise level before and after a staff education program. However, to our knowledge in Portugal, until 2010 only one study was performed in intensive care units, namely in NICU. Nicolau et al. [13] characterized noise levels in six NICUs of Lisbon region, revealing that noise levels were above the recommended by international guidelines. They emphasized the need to train healthcare staff and include actively health professionals in noise reduction strategies. Due to the lack of data in Portugal, including lack of studies measuring the effectiveness of noise reduction strategies, the Research Group on Occupational and Environmental Health of the Research Center on Health and Environment (SOA/CISA), designed the "NeoNoise Project: Integrated Approach to Minimize Sound Pressure Levels in Neonatal Intensive Care Units." NeoNoise project intends to be a contribution to understand the role of educational, environmental, and infrastructural factors on noise reduction and health promotion in neonatal intensive care units considering two major risk groups: premature infants and staff. The specific goals of the project are (1) to characterize sound pressure levels in different locations of NICU; (2) to determine the influence of these levels on health and well-being of premature infants and health professionals (3) to identify staff perceptions regarding working conditions, comfort, and main noise sources in NICU; (4) to develop and implement a quiet time protocol in NICU; (5) to study the relationship between the previous factors; (6) to create a good practices guide for these environments, in order to control noise production and improve well-being, comfort and satisfaction levels of professionals and patients; and finally (7) to suggest recommendations for health authorities, the scientific community and general public.

The main goal of this work is to present and discuss the study design and protocol of the NeoNoise project, by reviewing its rationale and outlining methods that might be implemented by other researchers in this field.

3. Materials and methods

This project started in 2011 and is being conducted in three NICUs located in hospitals of the North of Portugal involving some tasks/activities that were or will be performed simultaneously in order to complete the study. NeoNoise was designed to be carried out in two different phases. The study protocol and the concluded and ongoing substages/studies (underlined in red) are presented in **Figure 1**.

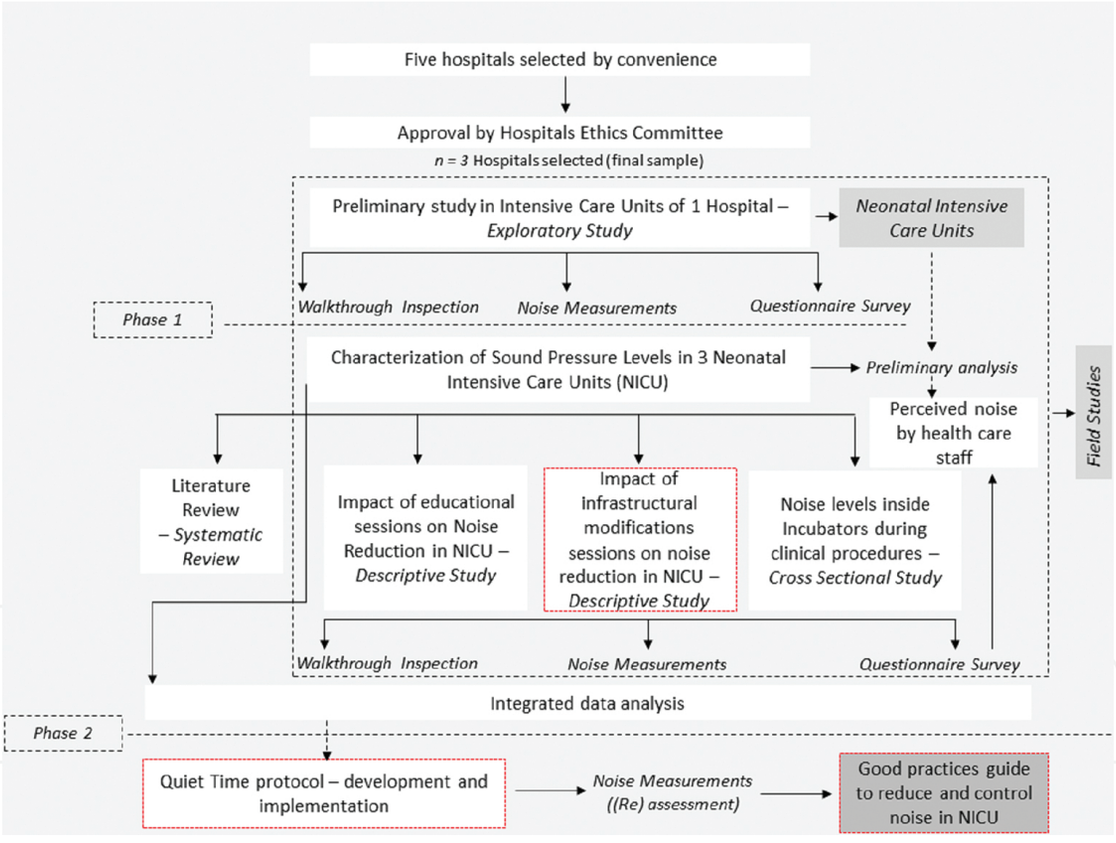

Figure 1. NeoNoise protocol.

3.1. Selection of the NICU and ethical issues

The north region of Portugal has six public hospitals with differentiated perinatal support. Five hospitals were contacted, and authorization to perform the study was given by three hospitals, after favorable statement by their Ethics Committee and approval by their respec-

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tive administration boards. The study was carried out according to the Helsinki Declaration. **Figure 2** shows the location of these three hospitals.

Figure 2. Spatial distribution of the three hospitals involved in the study (A and B in Porto and C in Vila Real, Portugal).

3.2. Field investigations in the NICU

As shown in **Figure 1**, field investigations were transversal to the most of the substages of the project. They included walkthrough inspections and assessment of sound pressure levels in the different spaces of the selected NICU. Additionally, healthcare staff answered a self-reporting questionnaire. In order to perform the ongoing tasks, some general considerations about methodological procedures are made below.

3.2.1. Walkthrough inspections

Walkthrough inspections were made by two trained researchers, in order to characterize the built environment and indoor spaces of the three NICUs under study. A checklist for this purpose was used. It should be noted, that since in Portugal there is no legislation related to NICU design for public institutions, the checklist was based on legal requirements applicable to private healthcare units, which have specific criteria for the design, conception, and equipment that should exist in NICU. 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 healthcare routines was made. Partial information about the characteristics of NICU is presented in **Table 2**. Detailed information is given in [3, 18, 19].

NICU	General characterization
A	14 incubators, 5 nurseries, 2 workstations, 4 sinks, 1 isolation room, 1 waste storage room, 1 storage room, 1 meeting room.
B	6 (or 7)* incubators, 3 nurseries, 1 workstations, 5 sinks, 2 isolation room, 1 storage room, 1 meeting room.
C	11 incubators, 8 nurseries, 2 workstations, 4 sinks, 1 milk preparation room, 1 WC, 1 storage room, 1 meeting room.

Note. *When necessary, one more incubator can be installed.

Table 2. General characteristics of the three NICUs.

3.2.2. Noise measurements

The measurements were mostly carried out continuously over 24 hours, during seven days in each measurement place (work station, traffic zone, inside incubator). Inside the incubator, short measurements (5–10 min.) were also made. The measurement protocol was based on the orientations of previous studies [20]. In this sense, 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). The measurements of peak sound pressure level (Lp, Cpeak) were made using the C filter and the A-weighted equivalent sound pressure level (LAeq) were obtained using the A filter, which is a frequency weighting filter that simulates human hearing. "C-weighting" curve was used, providing a flat frequency response with slight attenuation for high and low frequencies. It is usual to measure the peak noise levels in hospitals environment in order to define improvements to the acoustical environment [21]. Slow response time averaging (1 s) was also used because it is the most appropriate response for the majority of the applications in hospitals and provides stable readings [22]. To ensure accurate measurement, recording was preceded by calibration of the sound level meter [23] with an acoustic calibrator class 1 (RION®, model NC-74). In the analysis and interpretation of results reference values given by WHO [1], were used. **Table 3** shows reference levels for hospitals, given by WHO and other organizations. After the field measurements, the data were transferred and processed in the dBTRAIT software, version 5.4.

Organization	Recommended values
United States Environmental Protection Agency [24]	45 dBA daytime 35 dBA night
World Health Organization [1]	For areas where patients are treated or observed—35 dB LAeq For wardrooms in hospitals—30 dBA LAeq with a corresponding LAmax (maximum A-weighted sound pressure level) of 40 dBA
Committee on Environmental Health—American Academy of Pediatrics [25]	45 dBA

Table 3. Recommended noise levels in hospitals.

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3.2.3. Questionnaire survey

The analysis of staff noise perception in their workplaces involved the application of a questionnaire, in order to characterize working conditions, comfort, and the main noise sources. The questionnaire developed and 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. There were no contacts between the researchers and the participants. The questionnaire was delivered and received by a nurse, responsible for the NICU. The questionnaire fulfillment was completely anonymous and confidential. This questionnaire was (and will be) used in different studies of the project. Information regarding noise perception by professionals during the completed stages is given by [18]. Other results and respective data analysis regarding questionnaire survey are being considered for another publication.

3.3. Literature review

This task consisted in a short systematic review, conducted in selected databases and based on PRISMA statement [26], to summarize studies characterizing noise levels in hospital NICUs, in the last 15 years (since the year 2000), to gather more relevant and recent information. Some of the keywords used were NICU, noise and hospital, noise, among others. It was an important study, in order to determine gaps in knowledge and to define the purpose and concept of the NeoNoise project, more accurately.

3.4. Behavioral and structural modifications in NICU

The activities regarding behavioral changes were already performed. In this phase of the project measurements were made before and after a training program (TP) in one NICU. TP was conducted by three researchers. The TP was performed through a lecture of approximately 60 min and conducted by the investigators. To ensure that all the staff of the NICU under study such as physicians, nursing staff, and auxiliary staff attended the lecture (n = 79), 14 training sessions were given [2, 6]. The lecture included (1) general concepts of noise; (2) the results of the sound pressure levels obtained in the first phase and the comparison of these to the recommended values suggested by WHO and other regulatory agencies; (3) the negative impact of noise on health, both for neonates and professionals; and (4) some actions that needed to be implemented to ensure noise reduction were undertaken [6]. Regarding these actions, health professionals had a significant role in the development of an action plan to address specific noise issues. Detailed information is given in [6].

The tasks regarding the effectiveness of environmental or infrastructural modifications will be conducted in one NICU. As referred before, this field investigation will involve a walkthrough inspection by two trained researchers using a checklist and measurements for the assessment of the sound pressure levels. Some infrastructural modifications are being performed in the selected NICU for this study (B). Noise measurements were already made before and will be carried out after these modifications.

3.5. Quiet time protocol (QTP)

Based on acquired knowledge obtained in all the studies developed within the scope of NeoNoise project, it will be developed a quiet time protocol involving not only frequent and ongoing training sessions of healthcare staff, but also other good practices to control noise production and guarantee a quiet environment. Quiet times are designated hours where activity and conversation is minimized to allow patients to rest. Some authors referred the most effective model is to have a period in the afternoon and a period during the night, when quiet hours are observed. However the structure of the quiet times must to be defined taking into account shift changes, among other specific activities of the NICU. Quiet hours could be observed in many ways (when possible), such: conduct conversations in workstations and other areas in a hushed manner; encourage visitors to participate and also to take breaks to let patients rest; restrict phone conversations to designated areas of the NICU; minimize or eliminate clinical interventions (e.g., blood draws, etc.) during these hours, etc. The effectiveness of QTP will be tested in three NICUs, through noise measurements and questionnaire survey.

3.6. Good practices guide

Based on previous phases of NeoNoise project and taking into account the reality of the Portuguese healthcare services, a manual will be developed and published. This will help health professionals in the adoption of efficient strategies to reduce the production of noise not only in NICU but also, in other intensive care units.

3.7. Data management and analysis

Data gathered during the project is being managed and analyzed through IBM SPSS™ (Statistical Package for the Social Sciences) 20th version and MS Excel® 2013 software's. Data obtained by measurements were transferred and processed in the dBTRAIT software version 5.4 and exported to MS Excel® 2013 for further analysis. Databases were developed specifically for the study by the research team in order to record the large amount of data. Data input was the responsibility of two researchers of the project. An exploratory analysis of the variables of interest was carried out using classic descriptive statistics to calculate frequencies, means, medians, and associated dispersion measures with analysis of LAeq and Lp, Cpeak values. Normality, parametric and nonparametric tests of hypothesis were also used as appropriate. All tests considered a 95% confidence interval.

3.8. Dissemination

As previously mentioned, some studies within the scope of NeoNoise project were published or submitted for publication in international peer reviewed journals and presented at international scientific conferences. The results were communicated to the NICU responsibles to better understand noise production and its sources and to contribute for the development of preventive measures, through technical reports and short information sessions. Additionally, a final conference/seminar will be organized to disseminate results to the general public.

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4. Results and discussion

NeoNoise is the first Portuguese study addressing the effect of noise on premature infants and healthcare staff through objective measurements of sound pressure levels and subjective analysis by questionnaire surveys, and testing the effectiveness of different noise reduction strategies in the NICU. Data collection was carried out successfully (except for the stages that are not completed yet). Data analysis is still ongoing, but preliminary results were already presented at scientific meetings and published or accepted for publication. Formal recommendations to national authorities and public education materials will be made available in written documents.

In the exploratory study shown in **Figure 1**, Santos and Miguel [19] combined objective measurements of noise and a questionnaire survey in order to characterize noise levels in eight intensive care units (ICU) of a hospital, located in Porto, Portugal. The study also involved the application of the Ergonomic Workplace Analysis (EWA) methodology adapted by Miguel et al. [27] for the determination of risk level and intervention prioritization. The values of LAeq dBA obtained in the ICUs ranged from 50.0 to 65.0 dBA in the center of the units and between 57.8 and 67.1 dBA at the bedside of the patients. These values are above those recommended by WHO. Similar results were obtained by several authors in the same type of units [4, 8, 28, 29]. It is important to note that during the measurements, different operational equipment, including alarms, monitors, ventilators, infusion pumps, and nebulizers were operating. The conversation between the health professionals team at ICU was also identified as a possible source of noise that interfered the results. Comparing the results, it was found that the morning LAeq dBA values were higher than the afternoon ones, which may be related to the fact that during this period, medical examinations and hygiene of patients were more frequent. All ICUs had noise levels above the recommended and NICU was considered for further studies due to the patients involved: premature infants, who are not able to complain about noise. In fact, in Portugal there has been a considerable increase in preterm births, which in 2004 increased from 6.7 to 8.8% in 2009 [30]. Thus, it is essential to promote a quiet environment to reduce the impact of noise levels on health and well-being of premature infants and health professionals. In this sense, Santos et al. [3] documented some preliminary results on noise levels and responses given by healthcare staff of a NICU. It was found that during the week, the mean values of LAeq dBA obtained in the evaluated rooms ranged from 48.3 to 82.5 dBA. The results demonstrated that Monday LAeq dBA values were higher than the others days of the week, ranging between 52.0 and 86.0 dBA. Furthermore, sound pressure levels were significantly higher on weekdays than on weekend days ($p < 0.05$). In general, mean values of LAeq were lower in night shift; such was already reported for other authors [31, 32]. Night period is characterized by fewer visitors and health professionals and low lighting, which might reduce conversation. Significant differences have been found between the morning and night shift ($p < 0.05$) and between the afternoon and night shift ($p < 0.05$). On the other side, no significant differences has been found between the morning and afternoon shift ($p = 0.369$). Questionnaire survey showed that patient care activities and conversation between staff and visitors were identified as an important source of noise. This study concluded that noise levels were above the

recommended and that routine activity of healthcare professionals has been identified as a potential source of noise. It was emphasized that training the staff in order to implement quiet work behaviors is essential, but changing physical elements of a space can result in great noise reduction. Following those conclusions, Carvalhais et al. [6] conducted a pilot study regarding the effectiveness of a training program on noise reduction in an NICU. The results showed that after six months of TP implementation, there was no significant noise reduction in the NICU rooms and inside the incubator. The "Work Station" of Room A had a decrease on LAeq and Lp, Cpeak values, 71.7–58.8 dBA and 143.3–102.8 dBC, respectively. However, in the "Traffic Zone" of Room B, the noise level increase almost 6 dB after the TP, probably attributed to the presence of visitors and other staff (from ancillary departments that did not participated in the TP) and might be the source of this rise. The LAeq values obtained in the "Work Station" and "Traffic Zone" before and after the implementation of TP exceed the recommended values given by WHO for day and night periods, indicating

	***N* (%)**	**Mean (min-max)**
N	95 (100)	
Sex		–
Male	9 (9.5)	
Female	86 (90.5)	
Age in years		40.4 (24–61)
18–39	45 (47.4)	
40–59	(48.4)	
>60	2 (2.1)	
missings	2 (2.1)	
Professional group		–
Operational assistants	24 (25.3)	
Nurses	52 (54.7)	
Physicians	17 (17.9)	
missings	2 (2.1)	
Years at NICU		10.1 (0.5–35)
<5	34 (35,8)	
5–20	47 (49.5)	
>20	9 (9.5)	
missings	5 (5.3)	
Shift		---
Morning	53 (55.8)	
Afternoon	24 (25.3)	
Night	18 (18.9)	

Table 4. Demographic characteristics of the sample (n = 95) [18].

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more attention needs to be taken. A spectral analysis was also made. In this study healthcare professionals (n = 79) were asked to identify the main sources of noise. Visitors, equipment, healthcare procedures, and conversation among others, were generally the most referred sources.

The workers perception in those environments is very important in the definition, development, and implementation of an intervention to reduce noise levels and to ensure that changes take place. In this sense, a questionnaire survey was performed in order to characterize health staff perceptions regarding noise in NICU [18]. A total of 95 professionals from three NICUs participated in this study. **Table 4** shows the characteristics of the sample.

The majority of the respondents (55.8%) found "equipment" (including telephones and the signals and sounds from medical devices) as the most annoying noise sources and the NICU environment regarding noise as "slightly uncomfortable" (41.1%). Since environmental modifications might effectively decrease noise levels [32–34], a study testing the effectiveness of those modifications is proposed in this project, as shown in **Figure 1**.

The data gathered until now is still under analysis, but **Table 5** shows the average noise levels by NICU (the noise levels inside incubators were not considered in this analysis).

NICU	LAeq (dB) Mean (min-max)
A	59.0 (48.3–82.5)
B	52.4 (38.9–71.3)
C	55.8 (42.8–72.8)

Table 5. Average noise levels by NICU.

The noise levels in the three NICUs are higher than that recommended by WHO, which proposes that the average background noise in hospitals should not exceed 35 dB LAeq for areas where patients are treated or observed (**Table 3**). As concentration, precise communication and fast decisions are necessary in the hospital in general, the acoustical environment has to be considered an enormous strain for the staff and a potential risk [35].

5. Conclusion

The main strength of NeoNoise is the combination of strategies to reduce noise levels that are being tested. Furthermore, the different types of studies and approaches, combining questionnaire surveys, educational interventions, and objective measurements provided the collection of a large variety of data, focusing on multiple aspects of staff perception and behavior, as well as factors related to the direct environment of the premature infants. The main concern in NeoNoise was to contribute and to promote healthier environments both for infants and healthcare professionals in hospitals. With that in mind, some particularly

important outcomes of this project will be to contribute to educate healthcare staff and to make recommendations to reduce and control noise production in those environments. Health promotion programs should be the mainstream of all interventions and should integrate as much as possible, staff, patients, and visitors. Some limitations of the study are related to the challenge of working in an environment such a NICU, where the tasks and activities performed, are continuously changing due to the evolution of the infants health state.

This work outlines the study design and methods that might be followed by future researchers conducting field studies regarding noise reduction in healthcare facilities. The preliminary findings are relevant to characterize noise exposure of premature infants and staff in NICU. So far, preliminary data analysis revealed that noise levels in the three NICU demonstrated to be higher than recommended. The next step in ongoing analysis is to develop and implement a quiet time protocol, assess its effectiveness and to produce a good practices guide to reduce noise production in a daily basis, improving work conditions as well.

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