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PROGRAMA DOUTORAL EM SEGURANÇA
E SAÚDE OCUPACIONAIS

Sound Pressure Levels in Portuguese Neonatal Intensive Care Units

Thesis submitted to the Faculty of Engineering in fulfillment of the requirements
for the degree of Doctor of Philosophy in Occupational Safety and Health

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ESCOLA
SUPERIOR
DE SAÚDE



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* just after I completed my thesis, my daughter was born healthy at 19/07/2019 with 50,5 cm and 3,745 Kg

MUITO OBRIGADO
A TODOS

ABSTRACT

Exposure to sound pressure levels in neonatal intensive care units has been recognized as a factor which influences the quality and well-being of the occupants (workers and others), as well as the recovery of premature infants who are hospitalized. Prematurity and low birth weight of newborns lead to the need of a special care in neonatal units, and their permanence in these places can be extended for a long period. Evidence indicates that exposure to high levels of noise adversely affects human health, and these effects are dependent upon various factors. In hospitals, there are many sources of noise, and high levels exert an impact on patients and staff, increasing both recovery time and stress, respectively.

This study aimed to make an integration of all relevant factors, with the intention to contribute to change the working practices and occupant's behaviors. This thesis provides 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. With this in mind several studies were performed, such a systematic review to examine the studies related to noise in NICUs to understand the sources and effects of noise, as well as some strategies to reduce noise exposure.

Since the Portuguese reality regarding noise levels in NICU wasn't very explored yet, a study aiming to evaluate and characterize the sound pressure levels in three Portuguese NICUs and the noise perceptions of staff, was performed. Additionally, a study with the purpose to assess the newborns exposure to noise during several health care activities of two NICU, was conducted. After those studies concerning the characterization of environmental conditions of NICU, more two studies were carried out to test two noise reduction strategies. One of them a study aiming to develop, implement, and evaluate the effectiveness of a training program on noise reduction in NICU, was performed. The other one, pretended to evaluate the sound pressure levels and to assess noise perception of professionals in a NICU before and after structural modifications and layout redesign. Finally, some good practices guidelines were summarized in order to promote a healthier environment and to prevent noise production.

All the mentioned studies involved walkthrough inspections, noise measurements and questionnaire surveys. For that, two sound level meters were used as well as the respective acoustic calibrators and specific software's. Also, a questionnaire was applied for this purpose. Data was managed in specific statistics software's.

It was found that the noise levels to which the newborns and staff are exposed in NICU, often exceeds the recommended levels for these spaces. But it should be recognized that is very difficult accomplish the proposed levels. However, slightly improvements were found in terms of noise reduction, but unfortunately, the pattern was similar to other studies. Evidence also shows several adverse health effects for newborns and health care staff perceptions of noise.

Staff working in NICU environments need more education to understand the effects of noise on the preterm infant's physiological stability. With this education, they will be more aware of the need to change their actions and behavior to reduce noise, which can benefit their patients, and parents, as well as themselves. Even recognizing that a training program is important to change behaviors, this need to be considered in a broader context to effectively control noise in the NICU. Some initial resistance to the implementation of some recommendations is expected, but evidence shows that in general, with training, health care staff recognize the need of changes. Also, the enrolment of hospital top management is fundamental.

KEYWORDS: NOISE EXPOSURE; NICU; HEALTHCARE WORKERS; PREMATURE NEWBORNS; NOISE REDUCTION STRATEGIES.

RESUMO

A exposição a níveis de pressão sonora nas unidades de cuidados intensivos neonatais (UCIN) tem sido reconhecida como um fator de interferência no bem-estar dos ocupantes (trabalhadores e outros), assim como, na recuperação dos pacientes. A prematuridade e o baixo peso dos recém-nascidos levam à necessidade de um cuidado especial nas unidades neonatais, e a sua permanência nesses locais pode ser prolongada por um longo período. Evidências científicas indicam que a exposição a níveis de ruído significativos afeta negativamente a saúde humana. Nos hospitais, existem variadas fontes de ruído, e os níveis existentes exercem um impacto tanto sobre os pacientes, aumentando o tempo de recuperação e afetando o desenvolvimento dos recém-nascidos, como sobre os profissionais de saúde, através do desenvolvimento de efeitos essencialmente não-auditivos, como o stress e outras alterações fisiológicas.

Este trabalho tem como objetivo fazer uma integração de todos os fatores relevantes, com a intenção de contribuir para mudar as práticas de trabalho e os comportamentos dos ocupantes. Os objetivos específicos são: caracterizar os níveis de pressão sonora em diferentes locais da UCIN; determinar a sua influência na saúde e bem-estar de prematuros e profissionais de saúde, identificando a percepção destes sobre condições de trabalho, conforto e principais fontes de ruído e desenvolver um guia de boas práticas objetivando controlar e prevenir a produção de ruído.

Esta tese fornece dados sobre níveis de pressão sonora através de abordagens objetivas e subjetivas, bem como informações sobre os fatores de exposição e sensibilidade dos ocupantes ao ruído. Neste sentido, vários estudos foram realizados, nomeadamente: uma revisão sistemática sobre o tema, dois estudos sobre caracterização e avaliação dos níveis de ruído em UCINs e dois estudos versando sobre o impacto de estratégias de redução de ruído.

A revisão sistemática objetivou determinar os estudos relacionados ao ruído em UCINs para entender as fontes e os efeitos do ruído, bem como algumas estratégias para reduzir a exposição e produção de ruído.

Uma vez que praticamente não existiam dados sobre a realidade portuguesa em relação aos níveis de ruído em UCIN, foi realizado um estudo com o objetivo de avaliar e caracterizar os níveis de pressão sonora em três UCINs portuguesas e a percepção dos profissionais de saúde sobre condições de trabalho, conforto e principais fontes de ruído. Além disso, foi realizado um estudo com o objetivo de avaliar a exposição dos recém-nascidos ao ruído durante atividades rotineiras de cuidados de saúde de duas UCIN. Após esses estudos sobre a caracterização das condições ambientais da UCIN, foram realizados mais dois estudos para testar duas estratégias de redução de ruído. Um deles, com o objetivo de desenvolver, implementar e avaliar a efetividade de um programa de formação sobre redução de ruído em UCIN. O outro, com o propósito de avaliar os níveis de pressão sonora e avaliar a percepção de ruído de profissionais de uma UCIN antes e após modificações estruturais e *redesign* do *layout*. Finalmente, algumas boas práticas foram elencadas para promover um ambiente mais saudável e prevenir a produção de ruído nestes espaços.

Todos os estudos mencionados envolveram visitas às instalações, medições de ruído e aplicação de questionários. Assim, foram utilizados dois sonómetros, bem como os respetivos calibradores acústicos e softwares específicos. Também foi aplicado um questionário para esse propósito. Os dados foram geridos em softwares estatísticos específicos.

Constatou-se que os níveis de ruído aos quais os recém-nascidos e os profissionais estão expostos na UCIN, frequentemente excedem os níveis recomendados para esses espaços. Contudo, deve-se reconhecer que é muito difícil cumprir com os níveis recomendados. Ainda assim, ligeiras melhorias foram encontradas em termos de redução de ruído, tendo os resultados sido similares a outros estudos.

Os profissionais de saúde que trabalham em ambientes de UCIN necessitam de mais informação para entenderem os efeitos do ruído na estabilidade fisiológica do bebé prematuro. Com informação e sensibilização, eles serão mais conscientes da necessidade de alterarem as suas ações e comportamentos para reduzir o ruído, para benefício dos bebés e pais, assim como deles mesmos. Mesmo reconhecendo

que um programa de formação e sensibilização é uma estratégia importante para mudar comportamentos, é necessário que seja considerada num contexto mais amplo para controlar efetivamente o ruído na UCIN. Espera-se alguma resistência inicial à implementação de algumas recomendações, mas as evidências mostram que, em geral, com informação e formação, os profissionais de saúde reconhecem a necessidade de mudanças. É fundamental o envolvimento da gestão de topo dos hospitais neste processo de mudança.

PALAVRAS-CHAVE: EXPOSIÇÃO AO RUÍDO; UCIN; PROFISSIONAIS DE SAÚDE; RECÉM-NASCIDOS PREMATUROS; ESTRATÉGIAS DE REDUÇÃO DE RUÍDO.

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LIST OF ABBREVIATIONS

AAP – American Academy of Pediatrics
ACSS – Administração Central do Sistema de Saúde, IP
C-PAP – Continuous Positive Airway Pressure
dB – Decibel
dB(A) – Decibel A-weighted
dB(C) – Decibel C-weighted
EWA – Ergonomic Workplace Analysis
ICU – Intensive Care Unit
IV - Intravenous
HR – Heart Rate
Hz – Hertz
L₁₀ – A-weighted Sound Level 10% of the Time
L_{Aeq} – A-weighted, Equivalent Sound Level
L_{eq} – Equivalent Sound Level
L_{max} – A-weighted, Maximum, Sound Level
L_{Cpeak} – C-weighted, Peak, Sound Level
NICU – Neonatal Intensive Care Unit
O₂ – Oxygen
RCT – Randomized Control Trial
SAP – Sound Absorbent Panel
TP – Training Program
WHO – World Health Organization

LIST OF PUBLICATIONS

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Publications in Scientific Meetings with complete paper

Carvalhais, C., Silva, M. V., Silva, J., Xavier, A. & Santos, J. (2018). Noise in neonatal intensive care units: a short review. In Taroudakis, M. (Eds.), *Proceedings of Euronoise 2018* (pp.545-550). Crete, Greece: EAA – HELINA. ISSN: 2226-5147.

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CHAPTER 1: Introduction, Objectives and Theme Overview

1.1 General 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 and/or occupational exposures), groups that are particularly vulnerable include newborns, 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 (NICU), 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 a NICU. These units combine advanced technology and trained health care 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.

Table 1 - Equipment and behavioral causes of noise in intensive care units [5, 6].

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	~ 57 - 85 dB(A)
Ventilator alarm	70 - 85 dB(A)
Nebulizer	80 dB(A)
Telephone	70 - 80 dB(A)

Source of noise	
Television	79 dB(A)
Oximeter	60 - 80 dB(A)
Monitor Alarm	~ 65 - 79 dB(A)
Ventilator	60 - 78 dB(A)
IV infusion alarm	65 - 77 dB(A)
Endotracheal aspiration unit	50 - 75 dB(A)

Health professionals are aware about this issue and identified noise as an agent with a negative impact on work performance [7–9]. In fact, 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 [10]. 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 for patients. In fact, noise may induce extra-auditory effects in professionals including burnout, stress and fatigue [11]. 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 [12,13]. Even in newborns these effects are being implicated and associated with noise [14]. Although, it is important to underline that the levels of noise exposures associated with these health effects range widely [15]. Figure 1, presents a general noise reaction scheme which can be used for hypothesis testing in noise epidemiology considering the cause-effect [16].

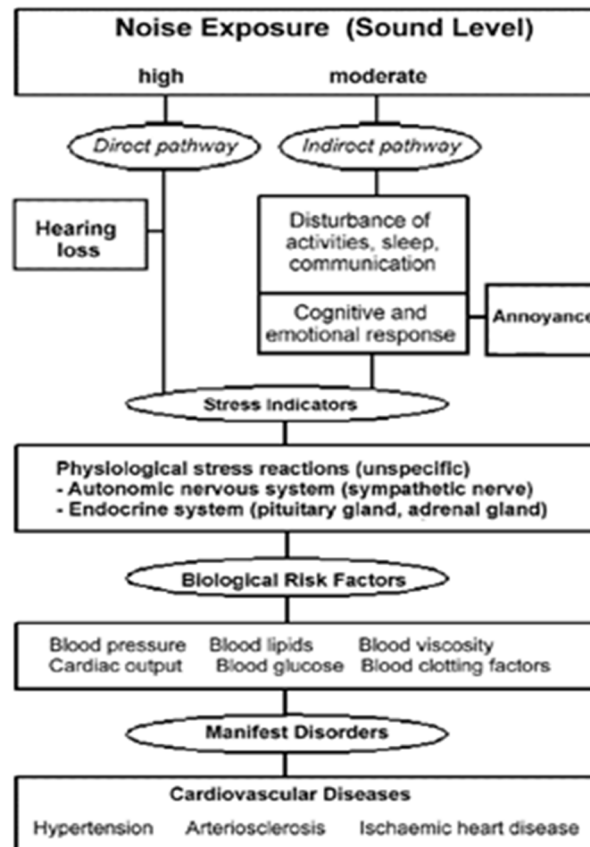


Figure 1 – Noise reaction scheme [16].

1.2 Rationale and aim of the study

A literature review conducted by Konkani & Oakley [17] 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. [18] surveyed patients to identify the noisiest time of the day - patients were also asked to list the noises that they felt were annoying. Connor & Ortiz [19] conducted a survey where patients rated the noise level before and after a staff education program. However, to our knowledge in Portugal, after 2000 only one study was performed in intensive care units, namely in NICU. Nicolau et al. [14] characterized noise levels in six NICU of Lisbon region, revealing that noise levels were above the recommended by international guidelines. They emphasized the need to train health care staff and include actively health professionals, in noise reduction strategies. Just recently another two Portuguese studies revealed that the majority

of professionals considers neonatology units noisy and uncomfortable in performing functions and believes that noise has adverse effects [20] and that sound levels were higher than those recommended by various international organizations (American Academy of Pediatrics; World Health Organization; US Environmental Protection Agency) in the various indicators [6]. Portuguese legislation regarding occupational noise is mainly devoted to activities liable to present noise exposure. Only in those cases the employer shall evaluate and if needed, to measure the levels of noise that workers are exposed to. So, in cases like hospitals and another (not industrial) activities, with relatively low noise levels in the legislation perspective, it is very difficult to perform and address recommendations to reduce noise levels, so international guidelines such WHO plays a very important role.

Due to the lack of data in Portugal, including lack of studies measuring the effectiveness of noise reduction strategies, this study 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 study 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 study the relationship between the previous factors; (5) to establish good practices for these environments, in order to control noise production and improve well-being, comfort and satisfaction levels of professionals and patients.

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1.4 Noise in neonatal intensive care units: a short review

Summary

Prematurity and low birth weight of newborns lead to the need of a special care in neonatal units, and their permanence in these places can be extended for a long period. Indoor environmental conditions, such noise levels above the recommended, may induce some risks, not only for the newborns development, but also for health care staff. This literature review aims to examine the studies related to noise in neonatal intensive care units to understand the sources and effects of noise, as well as some strategies to reduce noise exposure. The search strategy included an electronic search in databases (ISI Web of Knowledge and PubMed) of scientific articles published in English/Portuguese between 2010-2017. Studies providing data on noise levels found in the neonatal units, the effects on health of newborns and staff and the measures to minimize these effects were included. The exclusion criteria were as follows: duplicate printings; non-English/Portuguese language; editorials, letters, patents, errata, meeting abstracts and conference papers. Twenty-two articles were considered for full analysis. It is important to note that some potentially relevant studies were rejected due to language criteria. It was found that noise levels to which the newborns and staff are exposed in NICU, often exceeds the recommended levels for these spaces. Evidence also shows several adverse health effects for newborns and health care staff perceptions of noise. There is no consensus regarding the best intervention to reduce noise levels.

1.4.1 Introduction

There is a growing concern about the fact that environmental conditions affect the well-being of patients, family members, and staff in hospitals. Perhaps nowhere in the healthcare environment is more important than in neonatal intensive care units (NICU), where fragile infants fight for survival. The fragility of newborns, the increasing implementation of high-risk procedures and the low tolerance to medication errors are some of the concerns of health care professionals working in NICU [1]. However, indoor environmental conditions may also induce some risks to the newborns development. Since infants in the NICU are constantly surrounded by high sound pressures levels, the acoustic environment of NICU and the potential auditory and non-auditory impact of excessive levels have been important topics of research for the past 20 years [2]. There are recommendations and guidelines stating that a pressure level above 45 dB(A) can be harmful to the infant's ears and can affect their growth and development [2]. In fact, the World Health Organization (WHO) goes even further and recommend that the average background noise in hospitals should not exceed 35 dB L_{Aeq} for areas where patients are treated or observed [3].

The aim of the study was to examine the studies related to hospital noise in neonatal intensive care units (NICUs) to understand the sources and effects of noise and to describe best practices and strategies to reduce noise levels.

1.4.2 Methods

Bibliographic search

The identification and selection of studies to be included in the review was carried out through an extensive literature search using the PubMed and Web of Science databases. The search also included checking for related articles in the reference list of the located articles and other relevant literature. Only articles written in English and published in the period from 2010 to the year 2017, were included. The last search date was August 8, 2017.

The search strategy developed comprised two terms that were intersected using the Boolean term "AND". Some of the searched terms were: „noise“, „NICU“,

„workplace“, „premature infants“, „newborns“, „incubator“, „training“, or „noise reduction“.

Selection criteria

All searches were focused on in title or abstract. After importing all results into Mendeley, the articles were screened with respect to title, abstract and keywords. The exclusion criteria were as follows: duplicate printings; non-English/Portuguese language; editorials, letters, patents, errata, meeting abstracts, and conference papers. Only peer-review articles reporting quantitative and/or qualitative assessment of sound pressure levels in NICU, focused on effects of noise on newborns and health care staff in NICU written in English/Portuguese, were included. Two reviewers evaluated the eligibility of all articles, and disagreements were resolved by consulting a third reviewer.

1.4.3 Results

The search strategy yielded a total of 104 citations before duplicates removal. After checking the duplicates, 92 papers were considered for screening. A total of 38 papers were deemed potentially relevant based on abstract. After application of the eligibility criteria while considering the full text, another 16 papers were excluded. A total of 22 studies were considered for the final analysis. Figure 2 displays the flowchart of the search strategy. The included studies refer to the noise levels in the NICU, the effects of noise on the health of both newborn and workers and measures to minimize it.

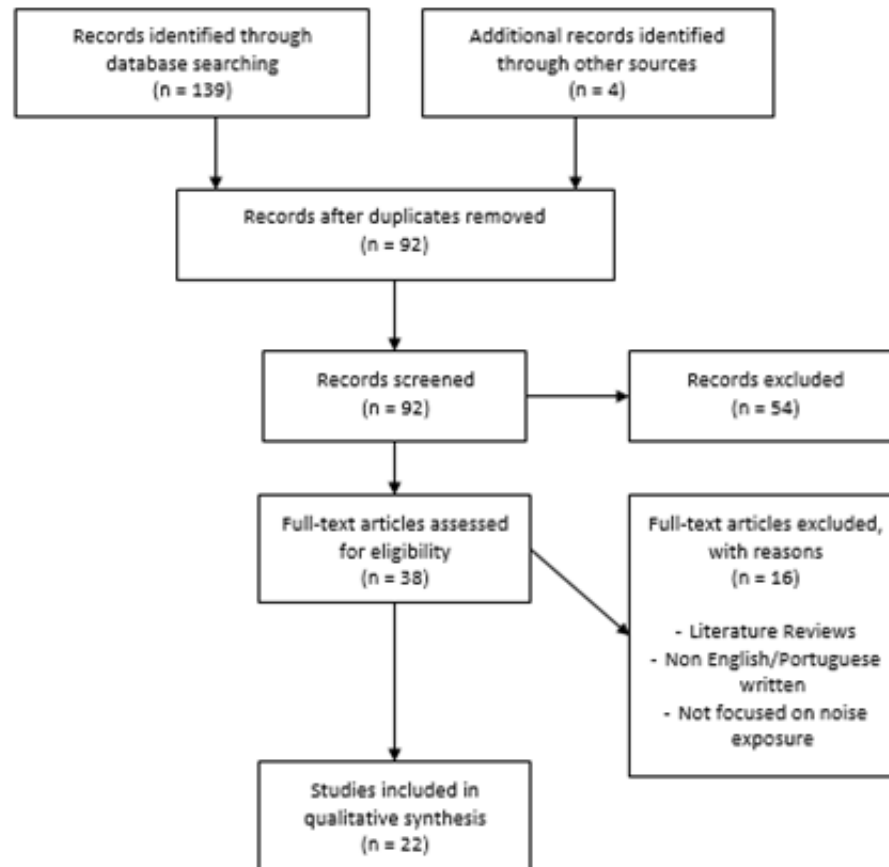


Figure 2 - Flow diagram of the articles screening process.

1.4.4 Discussion

Noise levels in NICU

NICU are highly technically advanced, with enhanced ability to provide medical and nursing care. The uterus is not a quiet place, it has a rich soundscape with sounds coming mainly from the mother's heart and blood vessels, who may even help the neurological development of babies and improve their understanding of rhythm and melody [4]. However, in NICU environment there is an excessive level of noise [5]. The NICU ambient noise is higher than in most homes or offices, and with newborns in contact with disturbing noises of short duration and at irregular intervals, it could cause increasing environmental stress [6]. Ideally, in order to promote a healthy hearing development, noise levels in the NICU should be identical in half intrauterine environment [7]. Unfortunately that does not occur, due

to the noise produced by the operation of multiple devices combined with the conversations between professionals and the unexpected noise from procedures of this place [1,8,9]. Evidence shows that noise often exceed the recommended 45 dB(A) [1,8,10–15]. Infant incubators are often used in NICU for care of newborns. They are made to keep a child protected and designed with transparent sections to enable correct viewing, sensors and devices to monitor the vital status of the infant, and environmental controls for temperature, humidity, additional gas, among others. They are mainly used on newborns with less than 37 weeks of gestation. These tools, along with the full range of services that NICU provide, have greatly increased the survival of many premature babies and low birth weight [4]. However, many studies found high levels of noise within the incubators, which result in numerous adverse effects for health [11,16]. These adverse health effects can have lasting consequences that compromise the quality of life of children who have gone through these treatment units [4]. The noise in incubators is generated by equipment such as IV (intravenous) infusion pumps, fans, warning sounds and heating machines. As this environment is closed, these sounds reverberate against the hard dome wall, amplifying the noise that reaches the neonate. In general, 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 [8]. In fact, Carvalhais et al [1] performed a study, characterizing noise levels *per* health care activity. The tasks under study included administering medications, monitoring vital signs, providing hygiene and supplying vital nutrients to newborns. The noise levels ranged between 46.6 dB(A) to 74.6 dB(A). Some published data revealed that in the NICU, low frequency noise is more frequent than high frequency noise, with some exceptions due to loud midfrequencies alarms [8,9,17].

Effects of noise on newborns

The uterine environment provides high low-frequency sounds, with the maternal voice to stand out in the background sounds [19]. On the other hand, the premature infant spends most of his early months in the incubator, exposed to continuous and unpredictable noise [5]. The sensory nervous system of the newborn is able to capture the environmental stimuli and process them through the central nervous

system. However, the organization of the central nervous system is immature so that the autonomous, motor and sensory functions are easily saturated [19].

The sound (especially when it is sudden and high) produces an alarm reaction characterized by excitation of subcortical systems (particularly the amygdala), autonomic nervous system, somatic reflexes and hormonal regulation system (catecholamine corticosteroids secretion), that may also have consequences for the respiratory system [20]. Although these changes are rare, the exposure to noise can result in apnea and bradycardia, increasing the risks of hypoxic episodes and so impacting the recovery and survival of the vulnerable preterm infant. Shimizu and Matuso [21] stated that noise exposure increases the risk of attention deficit disorder, and may result in tachycardia, bradycardia, increased intracranial pressure, and hypoxia. There is evidence that can cause sleep disorders and interfere with circadian rhythms [16].

Cardoso et al [22] conducted a study where were performed several noise measurements levels in a neonatal unit. They used a sample of 61 newborns that weight between 1000 and 2500g. In this study the environmental noise measurement occurred in two different moments: the usual situation in the NICU, that is, at the time of highest noise caused by a higher flow of people, use of equipment for clinical control, shift changes, medical visits, health care procedures; and during the “nap time”, where the health care staff decrease their activities, try not to talk, the parameters of devices with alarms are decreased, and the movement of people is also diminished. The study variables were the heart rate (HR) and oxygen (O₂) saturation. The HR ranged from 137.74 beats *per* minute to 142.59 when the newborn infants were exposed to noise. Unlike the first variable, the oxygen saturation decreases with the noise, going from 95.58 to 94.96%. For the variable HR, a variation between 110 and 160 beats per minute can be notice, which is an important change considering the reference standard for newborns, even for underweight newborns, is a mean of 120 beats *per* minute. Another variable, O₂ saturation, which represents the percentage of inspired oxygen that reaches the more distant cells in the body, also shows a very significant variation, between 91 and 98%, considering that the normal level is 100%. There is evidence of deleterious effects of high levels of sound pressure occurring in newborns, for example, higher O₂ consumption and increase HR, which result in higher energy consumption [22]. The cardiac response to acoustic stimulation depends on the

behavioral state, exposure history to sound based condition of the central nervous system, prenatal and perinatal events and age of the child after birth. Hearing loss is diagnosed in 2% to 10% of premature infants against 0.1% of the general pediatric population [6]. Despite that, evidence about non-auditory effects of exposure to environmental noise on public health is growing [23]. Recent studies indicate that excessive exposure of newborns to noise can result in various psychological disorders that may have long-term effects on the nervous system.

Noise and healthcare staff

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 extra-auditory effects in professionals including burnout, stress, and fatigue [24]. 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 [7,25]. In general, evidence shows that technology together with the high number of health professionals within the NICU creates a busy and noisy environment [26]. High noise levels are associated with an increased rate of errors and accidents, leading to decreased performance among employees [6,8,27]. A study conducted by Morrison et al [28] studied the correlation between noise and nursing stress using a questionnaire and measuring salivary amylase and heart rate. This study concluded that noise is potentially a significant contributor to higher heart rates, and tachycardia among nurses, as well as nurses' stress and annoyance. Reported stress due to noise was closely correlated with predictors of burnout in these nurses. In NICU the heart rate of nurses' goes from 67 to 184 beats *per* minute [14]. A study conducted by Ryherd et al. [29], used a questionnaire to parse nurses' perception of noisy environments, and revealed that 91% of nurses felt that noise could negatively affect them in their routine work environment. It was also found that 66% of nurses felt irritation and fatigue, 43% had concentration problems, and 40% experienced tension headaches as an effect of noisy work environment. So it is possible to say that nurses considered noise a disturbing

agent with an associated negative impact [9]. Santos et al [8] performed a questionnaire survey to assess noise perceptions of health professionals in NICUs. Among the staff, 41.1% classified the environment (regarding noise) as “slightly uncomfortable”; 48.4% considered it as “acceptable.” The majority (55.5%) considered “equipment” the most annoying source of noise. The study also comprised noise measurements, and results showed that noise levels were excessive in all the evaluated areas of the NICUs, exceeding international guidelines, with levels ranging between 48.7 dB(A) to 71.7 dB(A). In fact, Basner et al [23] stated that noise levels in hospitals are now typically more than L_{Aeq} 15–20 dB higher than those recommended. Similar data were found in the majority of the studies.

Noise reduction strategies

Unfortunately, there are few studies developing methods, which are effective to reduce noise in NICU [4]. Safe noise levels are essential for personal communication, family interactions, healthy child development and safe work environment, so it is important for practitioners to understand the current recommendations for the sound levels of these units [30]. The results suggest that neonatal nurses have lack of expertise in noise prevention area, and that they would benefit by becoming involved in an educational program based on prevention of sound stimulation [19]. Other measures that units can put into practice is easily gently close the doors of children's incubators – fix and move the pressure bottle of mechanical ventilator to outside the infant incubator. Several studies indicate that a major strategy to reduce noise is to change the behavior of health professionals [10,11,32–34]. Brown [30] indicates several noise minimization measures to educate the multidisciplinary team and parents/visitors about the potential consequences of high noise levels and strategies for noise reduction, such: reduce conversation at the bedside and move and speak quietly; reduce alarm volumes; respond quickly to telephones, alarms, beeps, crying babies, and other disturbances; avoid putting things on top of incubators; close incubator portholes and drawers quietly; reduce telephone ringer volume; remove radios from the NICU; regularly remove water from ventilator and continuous positive airway pressure (C-PAP) tubing; cover incubators with thick blankets or

cover to absorb sound; implement a quiet hour protocol; limit the use of the air conditioning system; reduce the volume of beeps or use the vibrating mode; minimize movement of personnel thorough and around NICU; avoid tapping and banging on incubators; avoid leaning on incubators to write; open packaging away from incubators, among others. A well-structured training program also seems to be a low cost measure to start the noise reduction process in the hospital [11]. Altuncu et al [32], conducted a study where they measure the noise levels inside the incubator with and without sound absorbent panel (SAP). They prove that SAP reduce noise levels in infant's incubator and is an efficient measure to adopt. Other strategies are noise reduction guidelines, architectural changes, renovation and/or preventive maintenance of equipments, including parameters to the acquisition of equipments containing audible alarms [11]. In fact, several studies have shown that the "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 [35,36].

1.4.5 Conclusions

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), a group that is particularly vulnerable is the premature infants/newborns group. In hospital environment, excessive noise is not only annoying, but can also interfere with the proper performance of health care staff. Evidence shows that hospital noise levels often exceed those recommended by WHO and other agencies.

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CHAPTER 2: Methodological Aspects and Thesis Structure

2.1. Thesis Organization

The thesis is divided into seven chapters. The content of each chapter is given below.

Chapter 1 includes a general introduction, which describes, relevance and motivation for this work. It also presents the main objectives of the thesis. An overview and the state-of-the-art through a brief review are also included in this chapter.

Chapter 2 presents the thesis organization and general methodological considerations.

Chapter 3 presents a manuscript that assessed and characterized three NICUs. Noise measurements and a questionnaire survey were performed. Additionally, differences between NICUs noise levels and other variables considering the sample of workers were analyzed.

Chapter 4 presents a manuscript regarding the sound pressure levels which newborns are exposed during healthcare routine procedures. Two NICU were included in this study.

Chapter 5 provides a manuscript regarding the impact of a training program (TP) as a strategy for noise reduction in NICU. This study was performed in one NICU and noise measurements were performed before and after the TP.

Chapter 6 comprises a manuscript that investigated the effect of structural modifications and layout redesign in a NICU, on noise reduction. Noise measurements and a questionnaire survey was made, before and after the intervention.

Finally, **Chapter 7** presents the overall discussion of the results, the main findings and good practices regarding noise reduction in NICU. Also, underlines future perspectives for research indicating possible lines of work to complement and further development of the studies undertaken during this thesis.

The structure of the manuscripts was maintained according to the journal guidelines in which they were submitted, including the reference style. For the unpublished parts of this thesis the style was uniformed to Vancouver. Tables and figures were numbered consecutively throughout the thesis.

2.2. Methodological aspects

This study was conducted in three NICU located in hospitals of the North of Portugal involving some tasks/activities which were performed simultaneously in order to complete the study. It was designed to be carried out in two different phases. The study protocol as well as the concluded sub-stages/studies are presented in Figure 3.

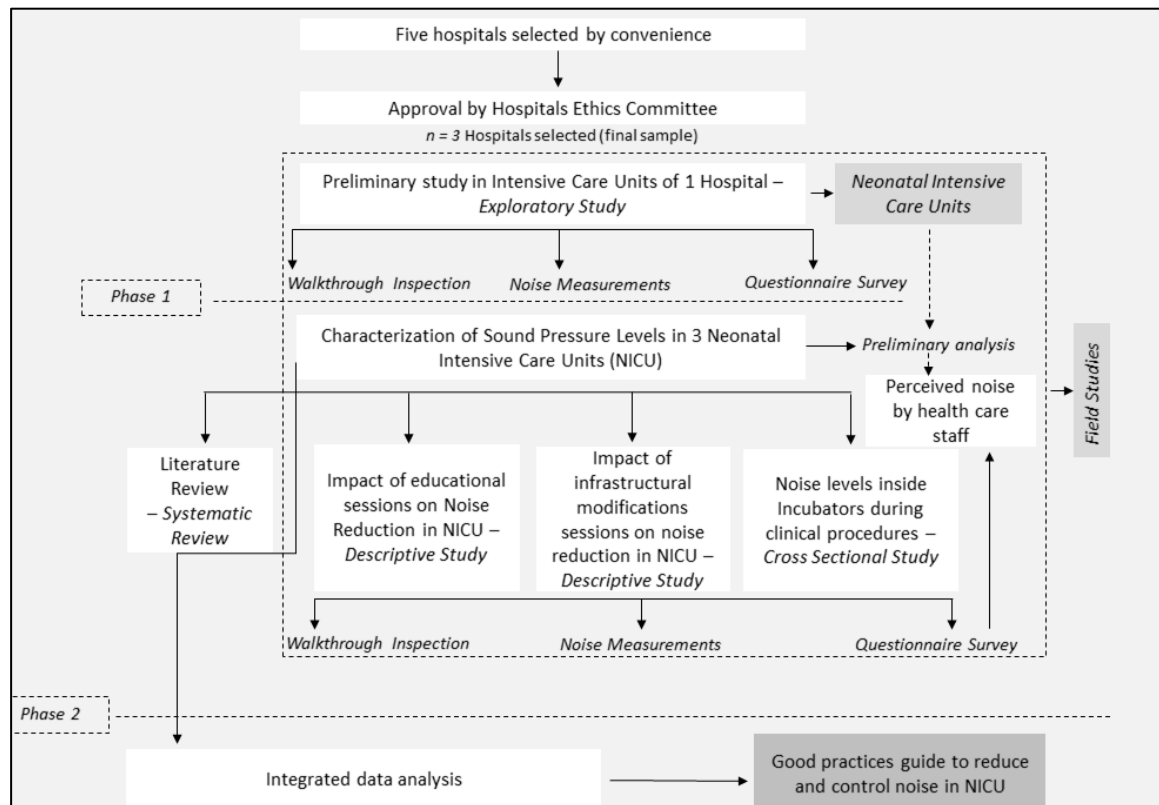


Figure 3 – Study protocol.

2.2.1. Selection of the NICU and Ethical Issues

Five hospitals were contacted, and authorization to perform the study was given by three hospitals, after favorable statement by their Ethics Committee and/or approval by their respective administration boards. The study was carried out according to the Helsinki Declaration. Figure 4 shows the location of these three hospitals.



Figure 4 - Spatial distribution of the 3 hospitals involved in the study (A and B in Porto and C in Vila Real, Portugal).

2.1.1 Field Investigations in NICU

As shown in Figure 3, field investigations were transversal to most of the sub-stages of the study. They included walkthrough inspections and assessment of sound pressure levels in the different spaces of the selected NICU. Additionally, health care staff answered a self-reporting questionnaire. Some general considerations about methodological procedures are made below.

Walkthrough Inspections

Walkthrough inspections were made, in order to characterize the built environment and indoor spaces of the three NICU 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 health care units (Portaria 615/2010 from 3rd August 2010), which have specific criteria for the design, conception and equipment that should exist in NICU. Also, Decree-Law 243/86 from 20th August 1986 and Portaria 987/93 from 6th October 1993, regarding minimal requirements for working conditions (applicable to hospitals), were also 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 routines was made. Partial information about the characteristics of NICU is presented in Table 2. Detailed information is given in Chapters 3, 4, 5 and 6.

Table 2 - General characteristics of the three NICU.

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.

*When necessary, one more incubator can be installed.

Noise Measurements

The measurements were mostly carried out continuously over 24 hours, during seven days in each measurement place (workstation, traffic zone, inside incubator). Inside the incubator, short measurements (5 to 10 min.) were also made. More information is given in Chapters 3, 4, 5 and 6.

The measurement protocol was based on the orientations of previous studies [1-3] since we cannot classify this type of noise as occupational or environmental noise. The “community noise” (also called environmental noise (WHO perspective), residential noise or domestic noise) is defined as noise emitted from all sources except noise at the industrial workplace. Main sources of community noise include road, rail and air traffic, industries, construction and public work, and the neighborhood [4]. The main indoor noise sources are ventilation systems, office machines, home appliances and neighbors [4]. So, specific environments such hospitals (including ward and treatment rooms), schools and preschools (including rooms for sleeping and outdoor playgrounds), dwellings (including bedrooms and outdoor living areas), are within the scope of community noise. Guideline values for community noise are proposed for each environment by WHO

[4] but, there are no specific guidelines available to perform measurements in this kind of spaces. In this sense, scientific evidence was essential to design the measurement protocol. It is a good practice when making measurements to hold the sound level meter away from your body (since it shields the microphone from noises behind) and other surfaces to reduce the effect of echoes [3]. Thus, measurements were performed at least 1 m away from the walls/equipment at a height between 1 m and 1.65 m (whenever possible, above 1.5m) and inside incubators. This agrees with the protocol measurement adopted by Nicolau et al [1]. Measurements were performed using two sound level meters' class 1 mounted on a tripod: the 01 dB®, model Solo-Premium and the Brüel & Kjær, model 2250 (Figure 5). The measurements of peak sound pressure level (L_{Cpeak}) were made using the C filter, since peak noises can lead to the alteration of physiological response of the newborn [5] and the A-weighted equivalent sound pressure level (L_{Aeq}) 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 [6]. Slow response time averaging (1 second) was also used because is the most appropriate response for most of the applications in hospitals and provide stable readings [3]. To ensure accurate measurement, recording was preceded by verification of the sound level meters [7] with the respective acoustic calibrators class 1: RION®, model NC-74 and Brüel & Kjær, model 4231. All the equipment was calibrated in an accredited calibration laboratory, by the Portuguese Institute for Accreditation.

Other acoustical parameters were gathered but mostly the L_{Aeq} was used to compare with the existing guidelines since it is the acoustical parameter used by WHO [4] for areas where patients are treated or observed. The L_{Aeq} (corresponds to L_{eq} A-weighted) is the measured equivalent continuous sound level. This measurement is the constant equivalent of the acoustic pressure changes over a period of time. The L_{10} is the level of sound that is exceeded 10% of the time during the designated interval. The L_{peak} is the highest sound level reached, no matter how brief the duration. The L_{max} is the maximum sound level recorded over a small,

defined time interval. In most cases, L_{peak} exceeds L_{max} since the duration of the former can be so brief that the human ear may not fully perceive it [3].



Figure 5 – Sound level meters used in the study (images captured from <https://www.locadif.fr/> and from <https://www.bksv.com/en/products/sound-and-vibration-meters/sound-level-meters-and-vibration-meters/2250-series/Type-2250-S>)

In the analysis and interpretation of results reference values given by WHO [4], for community noise, were used. Table 3 shows reference levels for hospitals. WHO proposes that the average background noise in hospitals should not exceed 35 dB L_{Aeq} for areas where patients are treated or observed and other organizations such as the United States Environmental Protection Agency (45 dB(A) daytime / 35 dB(A) night) [8] and the American Academy of Pediatrics (AAP), through the Committee on Environmental Health (45 dB(A)) [9]. Also according to the AAP, but through the guidelines for perinatal care which were developed by the Committee on Fetus and Newborn and the American College of Obstetricians and Gynecologists' Committee on Obstetric Practice, it must be ensured that continuous background sound and transient sound in any bed space or patient care area does not exceed an hourly equivalent continuous sound level (L_{Aeq}) of 45 dB and an hourly L_{10} of 50

dB, both A-weighted slow response. Transient sounds or $L_{\max}$, should not exceed 65 dB, A-weighted slow response. In addition, staff work areas, staff lounge areas, and family areas, the combination of continuous background and operational sound should not exceed an hourly L_{eq} of 50 dB and an hourly L_{10} of 55 dB, both A-weighted slow response. The transient sounds should not exceed 70 dB, A-weighted slow response in these areas [10].

Recently, in Portugal, the Central Administration of Health System (ACSS – Administração Central do Sistema de Saúde) published a technical recommendation for Neonatology Units which analyze and characterize a unit of neonatology in terms of integration in the hospital building, relations with other services and general organization. In terms of acoustical conditions, they recommend sound pressure levels below 40 dB(A) [11].

Table 3 - Recommended noise levels in hospitals (patient areas).

Organization	Recommended values
United States Environmental Protection Agency [8]	45 dB(A) daytime 35 dB(A) night
World Health Organization [4]	For areas where patients are treated or observed - 35 dB(A) L_{Aeq} For wardrooms in hospitals - 30 dB(A) L_{Aeq} with a corresponding L_{Amax} (maximum A-weighted sound pressure level) of 40 dB(A)
7 th Guidelines for Perinatal Care – American Academy of Pediatrics [10]	45 dB(A) L_{Aeq} , 50 dB(A) L_{10} and 65 dB(A) L_{max} .
Committee on Environmental Health – American Academy of Pediatrics [9]	45 dB(A)
Technical recommendations for neonatology units - Central Administration of Health System (Portugal) [11]	40 dB(A)* (womb-like level)

*This recommendation is based on the Health Building Note 09-03 NHS [12], a document which promotes guidance for the design of hospital neonatal units in UK, including special care, family spaces and specialist clinical rooms.

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. For the questionnaire developed a pre-test was made in order to ensure that the questions were correctly understandable. It was applied in a small sample ($n=11$) that reflected the target population (healthcare staff). Since it was composed by independent indicators of noise perception, no further validation process was required. It was intended to be a short questionnaire to ensure a quick fulfillment. It was divided into three main sections containing 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 scale consisted in personal judgments made about noise in the NICU environment and was expressed in a continuous two-pole scale, composed by 4-points (clearly acceptable, acceptable, unacceptable, clearly unacceptable). The question regarding comfort consisted in a 5-point one-pole scale, with a point of origin indicating the absence of the effect (comfortable), and 4 degrees of increasing intensity of the effect (slightly uncomfortable, uncomfortable, very uncomfortable, extremely uncomfortable). A unipolar scale question type indicates a respondent to think of the presence or absence of a quality or effect. The remaining were closed questions, allowing the selection of the most appropriate answer. Regarding the noisiest shift the options were: morning, afternoon, and night shifts. Concerning the main sources of noise, the options were: team conversation, equipment, visitors, and healthcare procedures. Additionally, an open answer was possible in this question, where the participants had the opportunity to add other noise sources.

There was no contact between the researchers and the participants. The questionnaire was delivered and received (in a closed envelope) by a nurse, responsible for the NICU. The questionnaire fulfillment was completely anonymous and confidential, to avoid potential bias of the results of the survey because of fear of repercussions if they complain. This questionnaire was used in different stages of this thesis (Appendix 1).

2.1.2 Literature review

This task consisted in a short systematic review, conducted in selected databases, to summarize studies characterizing noise levels in hospital NICUs, in this decade (since the year 2010), to gather more relevant and recent information. Some of the keywords used, were: „noise“, „NICU“, „workplace“, „premature infants“, „newborns“, „training“, or „noise reduction“. It was an important study, in order to determine gaps in knowledge and to define the purpose and concept of this study, more accurately.

2.1.3 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. 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. 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 Chapter 5.

The tasks regarding the effectiveness of environmental or infrastructural modifications were conducted in one NICU. As referred before, this field investigation involved a walkthrough inspection using a checklist and measurements for the assessment of the sound pressure levels. Some infrastructural modifications were performed in the selected NICU for this study (C). Noise measurements were already made before and after these modifications.

2.1.4 Good Practices to Reduce noise in NICU

Based on acquired knowledge obtained from the studies developed, good practices to control noise production and guarantee a quiet environment were established. One of them is the quiet time protocol. Quiet times are designated hours where activity and conversation are 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 be defined considering 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. Good practices guide 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. Chapter 7 provides more information regarding good practices in NICU to reduce noise levels.

2.1.5 Data management and analysis

Data gathered during the study was managed and analyzed through IBM SPSS™ (Statistical Package for the Social Sciences) 20th and 25th versions and MS Excel® 2013 and 2016 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 (for the measurements made with 01 dB®, model Solo-Premium sound pressure meter). After the field measurements made with Brüel & Kjær, model 2250 sound pressure meter, the data were transferred and processed in the measurement partner suite - BZ 5503 software from Brüel & Kjær. Databases were developed specifically for the study in order to record the large amount of data. 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 L_{Aeq} and L_{Cpeak}

values. Normality, parametric and non-parametric tests of hypothesis were also used as appropriate. All tests considered a 95% confidence interval.

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CHAPTER 3: Assessment and characterization of sound pressure levels in Portuguese neonatal intensive care units

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 dB(A) to 71.7 dB(A). 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.

3.1 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 established 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.

3.2 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.

3.2.1 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.

3.2.2 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.

3.2.3 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.

3.2.4 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.

3.2.5 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_{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.

3.2.6 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 4.

Table 4 - 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)
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)

3.2.7 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.

3.3 Results

The noise levels obtained in the six rooms of the assessed NICU's are shown in Table 5, as well as the frequencies spectrum in octave bands.

Table 5 - Values of mean L_{Aeq} (dB(A)) ($p=0.103$) and L_{Cpeak} (dB(C)) ($p=0.237$).

NICU	Room	Area	Frequencies (Hz)									
			L _{Aeq} Mean (min-max)	L _{Cpeak}	63	125	250	500	1000	2000	4000	8000
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

In NICU A, L_{Aeq} (dB(A)) values ranged between 58.1 (A2 – Traffic Zone) to 71.7 dB(A) (A1 – Work Station). In NICU B, L_{Aeq} ranged between 59.3 (B1) to 59.7 dB(A) (B2). In NICU C, L_{Aeq} ranged between 53.3 (C2) to 57.8 dB(A) (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_{Cpeak} (dB(C)) value was found in the “Work Station” area of Room A1 (143.3 dB(C)). Data showed that no significant differences were found between L_{Cpeak} (dB(C)) 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 4.

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 6.

Table 6 - 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)					

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.

3.4 Discussion

As shown in Table 5, 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 dB(A) daytime / 35 dB(A) night) [24] and the American Academy of Paediatrics (45 dB(A)) [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 5). 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 5 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 6). 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 5). 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].

3.5 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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**CHAPTER 4: Newborns safety at neonatal
intensive care units: are they exposed to
excessive noise during routine health care
procedures?**

Abstract

Neonatal intensive care unit (NICU) noise may be stressful to preterm infants. This research evaluated the newborns exposure to noise during several health care activities of two NICU. The measurements of the equivalent continuous A-weighted sound pressure level and peak sound pressure level were carried were performed with a sound level meter, as close as possible of the newborn. The results showed that sound pressure levels were excessive in all the evaluated tasks, exceeding international guidelines. The levels ranged between 46.6 dB(A) to 74.6 dB(A). There is a need for more research in order to verify the effectiveness of specific strategies to reduce the impact of noise in NICU.

Keywords:

Noise; NICU; Newborns.

4.1 Introduction

The fragility of newborns, the increasing implementation of high-risk procedures and the low tolerance to medication errors are some of the concerns of health care professionals working in neonatal intensive care units (NICU). However, indoor environmental conditions may also induce some risks to the newborns development. Since infants in the NICU are constantly surrounded by high sound pressures levels, the acoustic environment of NICU and the potential auditory and non-auditory impact of excessive levels have been important topics of research for the past 20 years¹. There are recommendations and guidelines stating that a pressure level above 45 dB(A) can be harmful to the infant's ears and can affect their growth and development¹. In fact, WHO goes even further and recommend that the average background noise in hospitals should not exceed 35 dB L_{Aeq} for areas where patients are treated or observed². Previous observations identified that some of the greatest noise in the NICU comes from staff conversation (often related to rounding), equipment's, visitors and healthcare procedures³. It is undeniable that the greatest continuous sound load in NICU comes from respiratory equipment, gas flow, monitor alarms, among others⁴. On the other

hand, the noise exposure of premature infants in incubators is determined by the noise situation in the neonatological care unit and by the acoustical properties of the incubator. However, nursing manipulation of the patient can also cause a rather high sound level inside the incubator and produce physiological changes in the neonate⁵. Wachman and Lahav⁶ considered that there is a gap in knowledge regarding the determination of types of noise and sounds that are least harmful to premature infants. Indeed, there is lack of studies assessing the noise production of specific health care procedures⁷, in contrast with studies monitoring background noise levels and identification of different equipment as noise source. The main purpose of this work is to verify if newborns are exposed to excessive noise levels during daily health care activities.

4.2 Materials and Methods

This study was conducted in the NICU of two hospitals (A and B) located in north region of Portugal. The clinical area of the NICU A, is divided in two areas and has capacity to provide care for 19 patients with a total of 14 incubators. The NICU B consists of three areas, equipped with a total of 9 incubators and 8 nurseries. The study included short measurements (5 up to 10 min.) for the assessment of the sound pressure levels (peak sound pressure level (L_{Cpeak}) and A-weighted equivalent sound pressure level (L_{Aeq})). Three short measurements were made *per* set of tasks. The tasks under study included administering medications, monitoring vital signs, providing hygiene and supplying vital nutrients to newborns. Measurements were performed using a sound level meter class 1 (01 dB®, model Solo-Premium) which was calibrated with an acoustic calibrator class 1 (RION®, model NC-74). The main position was inside the incubator, as close as possible to the infant ear avoiding any chance of contact between the newborn and the microphone. The data were processed in the dBTRAIT software, and the analysis involved descriptive and inferential statistics. The 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 was used for statistical analysis.

4.3 Results

The average noise levels obtained during the 6 health care tasks of the assessed NICUs are shown in Figure 6.

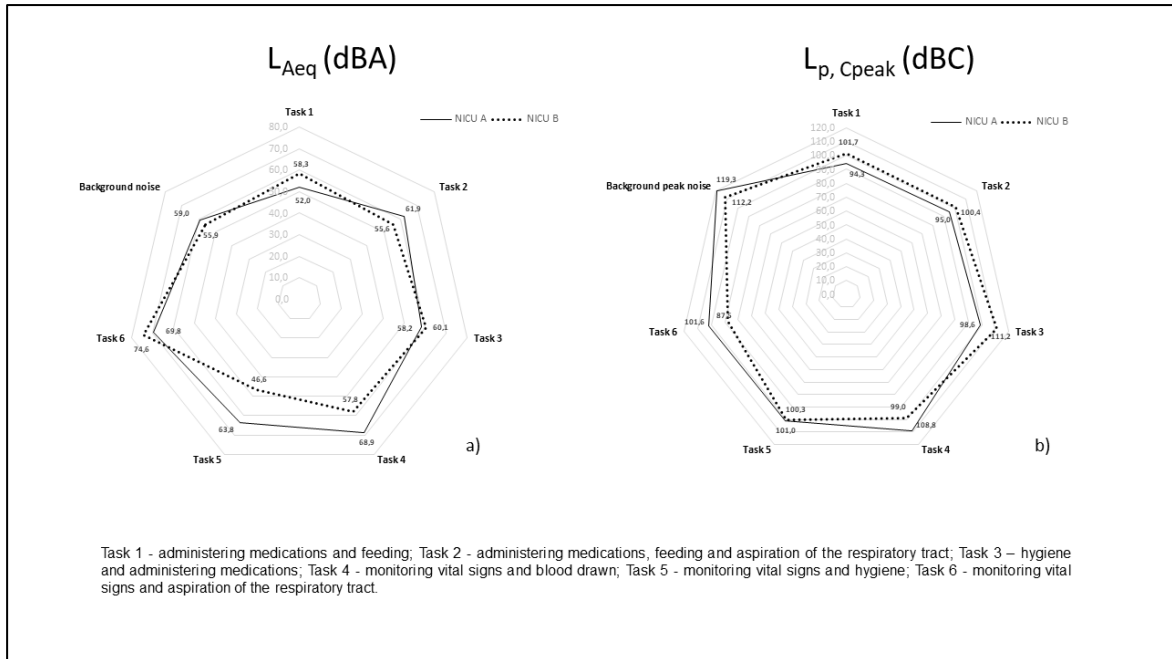


Figure 6 - Average values of L_{Aeq} (a) and L_{Cpeak} (b) during health care tasks.

In NICU A, L_{Aeq} (dB(A)) values ranged between 52.0 ± 1.2 and 69.8 ± 5.4 dB(A), being the highest value obtained in Task 4. Regarding NICU B, values ranged between 46.6 ± 4.3 and 74.6 ± 6.8 dB(A). In this case, Task 6 had the highest average noise level. No significant differences were found between tasks ($P = 0.063$) and NICU ($P = 0.052$). The highest L_{Cpeak} (dB(C)) value was found during the Task 3 of NICU B (111.2 dB(C)). The lowest L_{Cpeak} value, was found during Task 6. Regarding NICU A, L_{Cpeak} (dB(C)) values ranged between 94.3 ± 3.5 and 108.8 ± 7.2 dB(A) (Task 4). In general, NICU B had highest peak levels. Nevertheless, no significant differences were found between tasks ($P = 0.120$) and NICU ($P = 0.077$).

4.4 Discussion

The identification of the source of the resulting noise levels involved continuous direct observation by the research team, identifying the source of the sounds and the approximate time interval of its occurrence. It was found that certain manipulations to the incubator, such as closing the doors improperly cause significant increase to sound levels within the incubator or produce a noise peak. Other factors such, baby crying, placing material on the incubator or closing the portholes, could influence the noise production near the newborn and the obtained levels. In all the tasks, the noise levels were above the recommended. Data analysis revealed that once the incubator is turned on and manipulations are performed to provide appropriate care, sound levels increase. As Farrehi et al⁸ stated that “hospital noise is a multifactorial problem and that a single solution is unlikely”. In this sense, educational, environmental and infrastructural measures should be fully analyzed and considered (combined or isolated) to minimize the impact of noisy environments on occupants. In this case, periodic awareness/training sessions should be considered as a first measure to minimize noisy events originated by health care staff.

4.5 References

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**CHAPTER 5: Is there sufficient training of
healthcare staff on noise reduction in
neonatal intensive care units? A Pilot study
from NeoNoise Project**

Abstract

Evidence indicates that exposure to high levels of noise adversely affects human health, and these effects are dependent upon various factors. In hospitals, there are many sources of noise, and high levels exert an impact on patients and staff, increasing both recovery time and stress, respectively. The goal of this pilot study was to develop, implement and evaluate the effectiveness of a training program (TP) on noise reduction in a Neonatal Intensive Care Units (NICU) by comparing the noise levels before and after the implementation of the program. A total of 79 health professionals participated in the study. The measurements of sound pressure levels took into account the layout of the unit and location of the main sources of noise. General results indicated that L_{Aeq} levels before implementation of the training program were often excessive, ranging from 48.7 ± 2.94 dB(A) to 71.7 ± 4.74 dB(A), exceeding international guidelines. Similarly following implementation of the training program noise levels remained unchanged (54.5 ± 0.49 dB(A) to 63.9 ± 4.37 dB(A)), despite a decrease in some locations. There was no significant difference before and after the implementation of TP. However, a significant difference was found for L_{Cpeak} , before and after training staff, suggesting greater care by healthcare professionals performing their tasks. Even recognizing that a TP is quite important to change behaviors, this needs to be considered in a broader context to effectively control noise in the NICU.

5.1 Introduction

Evidence indicates that human exposure to high levels of noise produces physiological and psychological disorders, and that these effects are dependent upon various factors (Guthrie et al. 2014). Noise in neonatal intensive care units (NICU) is recognized as an agent with negative implications on health and well-being of premature infants (Nicolau et al. 2005) and health professionals. Philbin and Gray (2002) documented that sound pressure levels in intensive care units ranged between 55 to 75 A-weighted decibels (dB(A)). These results are higher than the limit recommended by the World Health Organization (WHO), which recommends that the

average background noise in hospitals should not exceed 35 dB L_{Aeq} for areas where patients are treated or observed. For wardrooms in hospitals the guideline values indoors are 30 dB(A) L_{Aeq} (A-weighted equivalent sound pressure level) with a corresponding L_{Amax} (maximum A-weighted sound pressure level) of 40 dB(A) (Berglund et al. 1999). These levels are influenced by the equipment (including alarms, monitors, ventilators, infusion pumps, nebulizers) and by health professionals/visitors behavior (with tasks and conversation) (Short et al. 2011), as shown in Table 7 (Pugh and Griffiths 2007).

Table 7 - Equipment and behavioral causes of noise in intensive care units. Adapted from Pugh and Griffiths (2007)

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)

In general high-intensity noise levels may induce physiological instabilities in newborns, such as apnea, bradycardia and abrupt fluctuations in heart rate, respiratory rate, blood pressure and oxygen saturation (Philbin and Klaas 2000; Wachman and Lahav 2011). Complex exposures to multiple chemical and physical agents, such noise, have the potential to produce several different sorts of interaction with regard to health outcomes (Fechter 2004; Guthrie et al. 2014). Actually, noise

acting in synergy with ototoxic drugs may increase the risk of sensorineural hearing loss in premature infants (AAP 1997; Surenthiran et al. 2003). Other long-term negative effects include language difficulties and altered brain development (Brown 2009), abnormal auditory development as well as suggestion of a link between excessive noise and attention deficit hyperactivity disorder (Bremmer et al. 2003). Health professionals are concerned about this issue and identified noise as a barrier to work performance (Gurses and Carayon 2009; Sampaio Neto et al. 2010). In fact, noise may induce extra-auditory effects in professionals including burnout, stress and fatigue, which results in errors (Mahmood et al. 2011).

In Portugal there has been a considerable increase in preterm births, which in 2004 increased from 6.7% to 8.8% in 2009 (Machado et al. 2011). 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. Environmental modifications might effectively decrease noise levels (Philbin and Gray 2002; Philbin and Klaas 2000; Ramesh et al. 2009); however, the process of caring for hospitalized patients, require frequent and ongoing interpersonal discussions. Minimizing patient exposure to interpersonal communications between healthcare staff requires a behavioral change. A well-structured training program seems to be a low-cost measure to begin noise reduction process in a hospital environment (Tsunemi et al. 2012).

The aims of this study were to (1) assess the levels of noise by measuring the equivalent sound pressure levels in zones located in NICU of a Portuguese hospital and (2) examine the influence of implementation of a training program (TP) for staff on noise reduction.

5.2 Materials and Methods

5.2.1 Clinical Settings

All measurements were performed in a NICU of a hospital located in Porto, Portugal, between July 2011 (first phase – measurements taken prior to implementation of TP) and July 2012 (second phase – measurements obtained 6 months after the implementation of TP). The clinical/technical area of the unit consists

of two rooms (A – Intensive Care and B – Special Care), without total separation between infrastructures. Room A includes the integrated set of physical, technical and human expertise, where newborns in critical condition with failure of vital bodily functions are assisted by advanced life support for 24 hr/day. Room B also includes an integrated set of physical, technical and human expertise, intended to provide care for infants with failure of an organ or system, but not intended for neonates requiring mechanical ventilation. The existing physical infrastructure separating the compartments consists of plywood with glazed surface on top. The floor is concrete with vinyl covering, walls are made of painted plasterboard with three glass windows and the roof is concrete. NICU (rooms A and B) has capacity to provide care for approximately 19 patients with a total of 14 incubators and 5 nurseries. 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, and consequently underwent greatest amount of staff/traffic activity.

5.2.2 Noise Measurements

Noise level measurements were performed using a sound level meter class 1 (01 dB®, model Solo-Premium). In accordance with Robertson et al. (1998), a preliminary survey was performed in order to identify noise sources. In both rooms (A and B) measurements were made continuously over 24 hours in two areas: work stations and traffic zones (at least 1m away from the walls at a height between 1m and 1.65m). In room A noise was also determined inside an incubator. The measurements of peak sound pressure level (L_{Cpeak}) were made using the C filter and the A-weighted equivalent sound pressure level (L_{Aeq}) were obtained using the A filter, which is a frequency weighting filter that simulates human hearing. Slow response time averaging (1 sec) was also used because is the most appropriate response for the majority of the applications in hospitals and provide stable readings, according to Philbin and Gray (2002). To ensure accurate measurement, recording was preceded by calibration of the sound level meter (Kent et al. 2002), with an acoustic calibrator

class 1 (RION®, model NC-74). In analysis and interpretation of results reference values given by WHO were used (Berglund et al. 1999).

5.2.3 Training Program (TP)

The TP was performed through a lecture of approximately 60 min and conducted by the investigators. In order 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. The lecture included the results of the sound pressure levels obtained in the first phase and comparing these to the recommended values suggested by WHO and other regulatory agencies. The negative impact of noise on health, both for neonates and professionals, was also discussed and some actions that needed to be implemented to ensure noise reduction were undertaken. Regarding these actions, the health professionals were led to discuss and reflect on current practice, framing the problem. The health professionals were encouraged to develop an action plan to address specific noise issues, in order to be involved in the process and obtain their commitment for future implementation of noise reduction protocols. Without their commitment, the transfer of knowledge may not be effective in changing practices and behavior.

5.2.4 Statistical Analysis

The processing and data analysis involved descriptive statistics, with analysis of L_{Aeq} and L_{Cpeak} values. All tests considered a 95% confidence interval. The normality Shapiro-Wilk test and the Student's t test for paired samples were applied. The software IBM SPSS™ (Statistical Package for the Social Sciences) 20th version and MS Excel® 2013 were used for the analysis.

5.3 Results

The training content and the staff perception regarding the main sources of noise in the NICU and suggestions to decrease noise in these environments are presented in Table 8.

Table 8 - Training content and feedback from healthcare staff.

Training content	Healthcare staff feedback	
	<i>Main factors that contribute to the noise level on unit</i>	<i>Suggestions to help decrease the noise level</i>
– General concepts of noise; – The impact of noise exposure in a hospital setting; – National legislation and international standards regarding noise exposure in hospitals; – Main health effects of noise exposure of neonates and health professionals; – Presentation and discussion of results for the study developed in the NICU; – Recommendations to reduce noise in neonatal units.	– Traffic in the room; – Visitors behavior; – Equipment / alarms; – Team conversation; – Some healthcare procedures.	– Limit number of visitors; – Keep voices down; – Improve the technology regarding the implementation of a centralized control of all the alarms of NICU in workstation area; – More quiet at change of shift; – Substitute metallic materials (drug transport cars for eg.) by others made of washable plastic; – Perform some tasks more carefully to avoid noise production.

In general, the healthcare staff identified equipment, visitors, healthcare procedures, traffic inside the rooms and team conversation as the main sources of

noise in the NICU. The results obtained in the two rooms of NICU before and after implementation of TP are shown in Table 9.

Table 9 - Values of mean L_{Aeq} (dB(A)) and L_{Cpeak} (dB(C)), before and after implementation of the training program.

Room	Area	L_{Aeq} (dB(A)) –		L_{Aeq} (dB(A)) -	
		Before	L_{Cpeak} (dB(C)) –	After	L_{Cpeak} (dB(C)) -
		Mean $\pm$ SD (Min-Max)	Before	Mean $\pm$ SD (Min-Max)	After
A	Work Station	71.7 $\pm$ 4.74 (47.8-114.6)	143.3	58.8 $\pm$ 2.72 (47.6-76.4)	102.8
	Traffic Zone	60.4 $\pm$ 5.32 (43.6-91.5)	115.8	59.5 $\pm$ 1.95 (53.0-75.0)	101.5
	Inside Incubator	48.7 $\pm$ 2.94 (42.2-68.1)	104.1	54.5 $\pm$ 0.49 (53.3-65.7)	92.8
B	Work Station	59.9 $\pm$ 6.01 (39.5-85.8)	106.3	60.3 $\pm$ 3.09 (46.4-79.2)	99.7
	Traffic Zone	58.1 $\pm$ 3.07 (43.8-82.0)	113.2	63.9 $\pm$ 4.37 (47.0-82.2)	98.9

SD – Standard Deviation; $p = 0.917$ L_{Aeq} (dB(A)); $p = 0.043$ L_{Cpeak} (dB(C)).

Before implementation of TP, L_{Aeq} (dB(A)) values ranged between 60.4 to 71.7 dB(A) in Room A and between 58.1 to 59.9 dB(A) in Room B. Inside the incubator, L_{Aeq} was 48.7 dB(A). After implementation of TP, L_{Aeq} values in Room A areas ranged between 58.8 to 59.5 dB(A) and in Room B, ranged between 60.3 to 63.9 dB(A). The L_{Aeq} values inside the incubator increased to 54.5 dB(A). The results demonstrated no significant differences between L_{Aeq} values before and after TP implementation, although some relevant work practices concerning the impact of noise were adjusted.

The highest L_{Cpeak} (dB(C)) value was found in the “Work Station” area of Room A before TP implementation (143.3 dB(C)). Data showed that significant differences were found between L_{Cpeak} (dB(C)) values before and after TP.

Table 10 shows the frequencies spectrum in octave bands among the areas under study.

Table 10 - Spectral analysis of noise generated in rooms A and B, before and after the implementation of the TP.

	Room	Area	Frequencies (Hz)							
			63	125	250	500	1000	2000	4000	8000
			dB							
Before TP	A	Work Station	78.3	75.3	71.6	68.8	65.9	63.1	59.8	56.2
		Traffic Zone	52.9	50.7	56.0	56.7	52.6	52.9	50.7	48.6
		Inside Incubator	61.8	61.8	58.2	47.2	49.9	46.2	39.1	31.3
	B	Work Station	54.5	53.1	55.1	56.7	54.6	53.2	52.6	46.0
		Traffic Zone	53.8	49.4	57.6	59.1	59.1	57.8	54.8	48.4
After TP	A	Work Station	52.7	55.7	54.8	55.5	53.3	51.4	50.6	45.1
		Traffic Zone	48.3	50.8	53.2	56.5	53.1	55.8	51.0	44.9
		Inside Incubator	55.1	53.9	48.0	46.8	44.5	37.7	36.9	27.2
	B	Work Station	53.9	49.6	54.2	58.7	54.6	52.4	48.3	40.8
		Traffic Zone	51.2	47.3	51.4	53.7	50.9	50.5	52.2	47.6

The 500 Hz was the frequency which had higher levels in the majority of the areas before and after the implementation of TP (Room A (“Traffic Zone” – 56.7 dB(A) and 56.5 dB(A)); Room B (“Work Station” – 56.7 dB(A) and 58.7 dB(A); “Traffic Zone” – 59.1 dB(A) and 53.7 dB(A))).

5.4 Discussion

During TP sessions, noise was identified by professionals as a disturbing agent and exerted a negative impact (Table 8), is in agreement with data presented by Gurses and Carayon (2009) and by Santos et al. (2014) who demonstrated that health professionals perceived “equipment’s” as one of the most annoying noise sources followed by "team conversation" and “visits”.

The “Work Station” of Room A had a decrease on L_{Aeq} and L_{Cpeak} values, 71.7 to 58.8 dB(A) and 143.3 to 102.8 dB(C), respectively (Table 9). It was apparent by professionals, that greater care was being undertaken in carrying out their tasks regarding noise production. 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 L_{Aeq} 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 more attention needs to be taken. Regarding the values inside the incubator, despite the elevation of L_{Aeq} values after the TP (48.7 dB(A) to 54.4 dB(A)), the levels obtained exceeded the recommended threshold. In general, the results obtained (Table 9) may be attributed to the number of newborns that were in NICU before (14 without specific care needs) and after TP (10, which two were helped by an oximeter and ventilator, that may produce 60-78 and 60-80 dB(A) respectively (Pugh and Griffiths 2007)). Similar data were reported by Tsunemi et al. (2012).

Data analysis revealed that low frequencies tend to have more influence on noise produced in the NICU than higher frequencies (Table 10). These results are in agreement with Gray and Philbin (2000), who stated that noise in nurseries is dominated by low frequencies, with some exceptions due to loud mid-frequencies alarms. Kellam and Bhatia (2008) suggested that human speech contribute to the spike in sound energy at 500 Hz.

Despite adherence by healthcare staff to TP, there was no significant reduction of noise after TP implementation. These results suggest that it is necessary to consider several factors that may ensure the effectiveness of TP. It seems that TP impact was lost over time, but diminution of L_{Cpeak} values may indicate that health professionals undertake their activities more carefully. In fact, the effectiveness of training healthcare professionals presents some contradictory findings in literature (Oliveira et al. 2013). Several studies showed that the implementation of TP in this area contributed to reduction of sound average levels, although by itself does not yield the recommended threshold levels and its impact tended to decrease over time (Philbin and Klaas 2000). It is suggested that a TP incorporated into a more comprehensive quiet protocol, involving low cost environmental (or others) modifications, seems to ensure decrease of noise levels (Ramesh et al. 2009) affecting positively patient well-being and improvement of satisfaction levels (Connor and Ortiz 2009). Other studies also reported some resistance from health professionals to noise reduction programs, being a factor that needs to be considered in future programs (Taylor-Ford et al.

2008). Connor and Ortiz (2009), noted in their study that staff also believed that noise affected the physiologic, psychologic, and overall health of patients. In this study, the impact of staff education was measured by patient-satisfaction scores surveys. In surveys after staff education, improvement was expressed in fewer poor ratings and an increase in good to very good ratings (Connor and Ortiz 2009).

5.5 Conclusions

Noise is a common problem in NICU and exerts significant adverse implications for health and well-being of patients and staff. Results showed that after 6 months of TP implementation, there was no significant noise reduction in the NICU and inside the incubator. However, L_{Cpeak} data are an indication that in conjunction with other factors, a TP may be an excellent action to reduce noise levels. While recognizing the importance of TP in order to promote changes in the team's attitudes, it needs to be recognized that the effects are not long lasting. The training sessions needs to be repeated more often, and physicians, nursing staff, supervisors, senior leadership, staff from related departments and family members/visitors need to attend. Noise in all the rooms of a NICU might be reduced considerably by incorporating affordable behavioral and environmental modifications, and by renovation and/or preventive maintenance of equipment. Training the staff in order to implement quiet work behaviors is essential and needs to be seen as a first step to implement a quiet time protocol in neonatal intensive units.

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CHAPTER 6: The impact of structural changes on noise levels in a neonatal intensive care unit

Abstract

Background: The design of neonatal intensive care units (NICU) influences both patient safety and clinical outcomes as well as the acoustic conditions. In NICU exposure to sound pressure levels above the recommended can affect both neonates and healthcare staff.

Objective: This study aimed to evaluate the sound pressure levels and to assess noise perception of professionals in a NICU before and after structural modifications and layout redesign.

Methods: The measurements were performed with a sound level meter. A questionnaire was applied to staff before and after the intervention. The opinion of healthcare staff regarding noise in NICU was better after the intervention, when compared with the responses previously given.

Findings: The results showed that noise levels were excessive in the NICU (before and after), exceeding the international recommendations, with the levels ranging between 46.6 dB(A) to 57.8 dB(A) before and 52.0 dBA to 54.0 dB(A) after intervention. 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; layout; design; healthcare; sound.

6.1 Introduction

Neonatal Intensive Care Units (NICU) are very important in maintaining the health and wellbeing of infant patients in a hospital. Neonatal units are focused specifically on the health of newborns and the care for medically unstable or critically ill newborns requiring health care, surgical procedures, continual respiratory support, among other interventions. The spaces which support the newborns include delivery rooms, nurseries, and other spaces where high-risk infants are monitored and given both intensive and intermediate care.

The design of neonatal intensive care units influences both patient safety and clinical outcomes. Design contributes to the type and quality of care given for all people

involved in neonatal spaces, including newborns, parents, other family members, friends and hospital workers and must address their different needs (Joshi et al., 2018). The intensity of a neonatal unit can be overwhelming for a premature infant that has not fully developed yet. Indeed, acoustical quality of the NICU plays a very important role since it is a basic design principle such as layout or family and visitor comfort. In fact, the NICU is often characterised by loud, unpredictable noise from extraneous sources such as alarms, ventilators, phones and staff conversation to which preterm infants are especially vulnerable (Santos, Carvalhais, Xavier, & Silva, 2018; Wachman & Lahav, 2011).

Nowadays, there are mainly two distinct architectural designs NICUs the open-bay and the single-family room designs (Szymczak & Shellhaas, 2014). The open-bay design facilitated communication between staff, collegiality, and interprofessional collaboration among members of the neonatal team. Over the last decades, the implementation of single-family room designs is increasing due to the enhanced transmission of sound and light in open-bay designs (Meredith, Jnah, & Newberry, 2017). Evidence also shows and improved and safer environment as well as positive health outcomes in single-family rooms (Lester et al., 2014; Ramm, Mannix, Parry, & Gaffney, 2017; Szymczak & Shellhaas, 2014). In fact, regarding noise levels, single-family rooms are much preferred to open-bay or alternative layouts. Increased noise can exacerbate stress levels on all parties, but single-family rooms aid in noise reduction through structural means. Families can also exercise greater control over the environment of their child, minimizing stimuli that may adversely affect him or her, and promoting sleep. Finally, single-family rooms provide a quiet atmosphere for private conversations among families, as well as nurses and physicians, encouraging communication and parental involvement (Stevens et. al, 2010). In Portugal, the most adopted NICU design is the open-bay model. Single-occupancy rooms exist, but in general they are available to newborns who present a disease that requires some isolation, such as a suspected airborne infection.

NICU layout changes and structural modifications have shown to be effective in reducing noise levels produced by staff, equipment or building generated sound. The latter, promoted by the number of beds, ventilation system, location of workstation, etc.

(Philbin & Gray, 2002). However, data comparing noise levels before and after a structural intervention is sparse and the confirmation of the influence of physical changes on noise reduction is needed (Santos et al., 2018).

The aim of this study is to examine the influence of a structural intervention and layout change in a NICU by measuring the equivalent sound pressure levels before and after the intervention and by collecting indicators of noise perception of the healthcare staff. The NICU under study was transferred to another building of the hospital which suffered several structural reorganizations to improve the clinical response.

6.2 Materials and Methods

This study was carried out in a NICU located in the north region of Portugal and was conducted in two main phases: before and after a structural/layout change intervention. Both phases (pre and post-intervention) included a walkthrough inspection to characterize the built environment and indoor spaces of the NICU, measurements of the sound pressure levels and assessment of health care professional's noise perceptions. The study was conducted after institutional authorization. All ethical and confidential issues were addressed, and staff were informed about the study. Since this study only gathered environmental data no approval was needed by institutional board on human subjects' protection.

6.2.1 NICU Pre-Intervention

Before structural and layout intervention the NICU (A1) consisted of two main areas as shown in Figure 7 (a). There were other support areas, such mother's room, nurses room, etc., which were not included in this study. The areas A1.1 (nursery room) and A1.2 (incubators room), were divided by a glass wall with a corridor that allows communication between the two. The area of the spaces was 27,47 m² (295,7 ft²) (A1) and 27,83 m² (299,6 ft²) (A2). The floor was concrete with vinyl covering and walls and ceiling were in plasterboard coated with washable paint. A1 and A2 were equipped with 5 incubators and 6 nurseries as well as a workstation, which supports both areas.

6.2.2 NICU Post-Intervention

In this phase, the NICU (A2) was designed as an Open-bay model (Figure 7 (b)). The NICU was transferred to another building of the hospital which suffered several structural reorganizations to improve the clinical response. The materials used were consistent with the ones used before intervention and the main difference pre and post-intervention was an increase of the space area and the inexistence of a glass wall separating the rooms. Additionally, the ventilation system was designed considering the sound attenuation in the space. The floor was concrete with vinyl covering and walls and ceiling were in plasterboard coated with washable paint. The area (A2.1) was an open space with 116,30 m² (1252 ft²), 6 incubators and 7 nurseries improving the maximum capacity up to 13 bed spaces, spread along a rectangular configuration. It had a workstation devoted to the preparation of medication and parenteral nutrition. During the measurements five newborns were admitted in the NICU (three in incubators and two in nurseries).

The equipment installed was the same in both phases, 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.

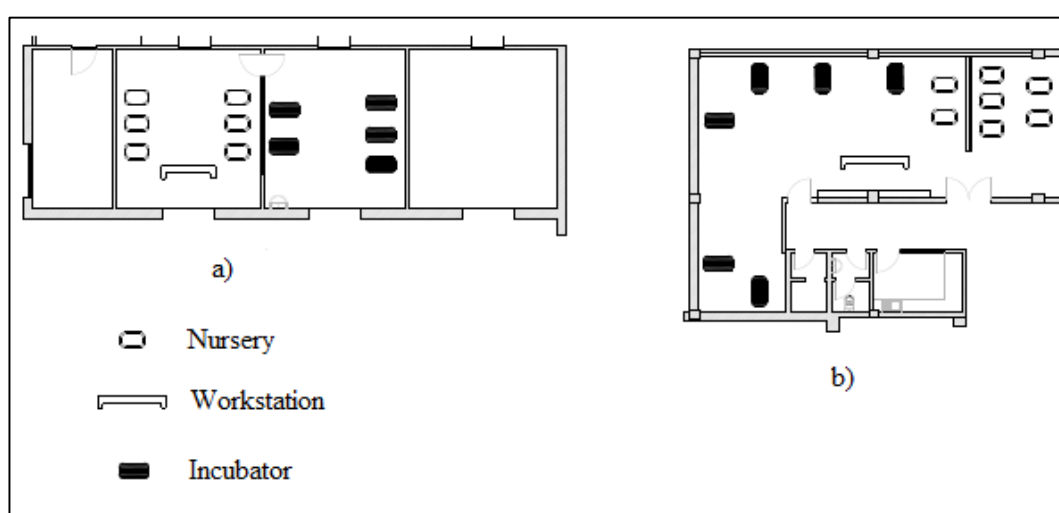


Figure 7 - Layout of NICU before (a) and after (b) the intervention.

6.2.3 Noise measurements

Pre-intervention noise level measurements were performed using a sound level meter class 1 (01 dB®, model Solo-Premium). Post-intervention noise level measurements were performed using a sound-level meter class 1 (Brüel & Kjær, models 2250). In accordance with Robertson et al. (1998), a preliminary survey was performed in order to identify noise sources. In both phases, measurements were made continuously over 24 hours at least 1m away from the walls at a height between 1m and 1.65m. Noise was also determined inside an incubator. The measurements of peak sound pressure level (L_{Cpeak}) were made using the C filter, since peak noises can lead to the alteration of physiological response from the newborn (Romeu, Cotrina, Perapoch, & Linés, 2016) and can affect patients experiencing long restorative periods, with noise interruption (Wiese, Wang, & Ronsse, 2009). The A-weighted equivalent sound pressure level (L_{Aeq}) was obtained using the A filter, which is a frequency weighting filter that simulates human hearing. Slow response time averaging (1 sec) was also used as it is the most appropriate response for the majority of the applications in hospitals and provide stable readings (Philbin & Gray, 2002). To ensure accurate measurement, recording was preceded by verification of the sound level meters (Kent, Tan, Clarke, & Bardell, 2002), with the respective acoustic calibrators class 1 (RION®, model NC-74 and Brüel & Kjær, model 4231). The analysis and interpretation of results reference values given by WHO were used (Berglund, Thomas, & Dietrich, 1999). Spectral analysis of sound frequency was performed, since protocols for measuring NICU noise should also include a spectral analysis of the sound frequency (Lahav, 2015).

6.2.4 Health Care Staff Perceptions

The NICU has three fixed shifts (morning: 8:00 am-3:00 pm; afternoon: 3:00 pm-10:00 pm; night: 10:00 pm-8:00 am). The team is composed by nurses, operational assistants and physicians. 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 (Carvalhais, Santos, Vieira da Silva, & Xavier, 2015; Santos et al.,

2018), 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 survey participants during the time that they were being filled out. The survey was distributed and collected by a nurse to maintain anonymity. At the end of the shift, they were collected by the responsible nurse who sent it to the researchers.

6.2.5 Statistical Analysis

The processing and data analysis involved descriptive statistics, with analysis of L_{Aeq} and L_{Cpeak} values. All tests considered a 95% confidence interval. The normality Shapiro-Wilk test, the Student's t test for paired samples and the Student's t test for independent samples, were applied. The software IBM SPSS™ (Statistical Package for the Social Sciences) 25th version and MS Excel® 2019 were used for the analysis.

6.3 Results

The noise levels obtained in the NICU before (A1) and after (A2) the intervention are shown in Table 11, as well as the frequencies spectrum in octave bands.

Table 11 - Values of mean L_{Aeq} (dB(A)) ($p=0.800$) and L_{Cpeak} (dB(C)) ($p=0.313$).

NICU	Room	Area	Frequencies (Hz)									
			L _{Aeq}	L _{Cpeak}	63	125	250	500	1000	2000	4000	8000
			Mean ± SD									
			(min-max)									
dB												
A1 Pre-intervention	A1.1	Work Station	53.3 ± 2.74 (46.2-79.1)	112.2	48.8	42.4	45.3	50.1	47.1	47.8	41.8	40.4
	A1.2	Work Station	57.8 ± 1.32 (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 ± 0.23 (41.2-63.4)	104.6	56.1	50.0	52.0	41.1	39.2	34.2	32.1	30.3

NICU	Room	Area	Frequencies (Hz)									
			L _{Aeq}	L _{Cpeak}	63	125	250	500	1000	2000	4000	8000
			Mean ± SD									
			(min-max)									
dB												
A2 Post- Intervention	A2.1	Work Station	54.0 ± 2.01 (40.7-69.4)	106.9	23.7	32.6	41.1	49.9	46.9	47.6	44.0	34.2
		Inside Incubator	52.0 ± 0.36 (50.7-53.3)	67.4	37.7	41.5	41.8	46.2	48.6	40.0	33.9	26.8

SD – Standard Deviation

In NICU pre-intervention L_{Aeq} (dB(A)) mean values were 53.3 (room A1.1) and 57.8 dBA (room A1.2). Post-intervention L_{Aeq} (dB(A)) mean value was 54.0 dBA (room A2.1). No significant differences ($p=.800$) were found between the two phases – pre and post structural intervention in the NICU. The highest L_{Cpeak} (dB(C)) value was found in the “Work Station” area of Room A1.1 (112.2 dB(C)). Data showed that no significant differences were found between L_{Cpeak} (dB(C)) values ($p=.313$). Except in room A2.1 – 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 before and after structural intervention in this study are presented in Table 12.

Table 12 - Characteristics of the healthcare staff before and after the intervention.

	Before N (%)	After N (%)	
		Completed	Final
N	23	20**	15* (drop out n=8)
SEX			
Male	0	5 (25.0)	0
Female	23 (100)	15 (75.0)	15 (100)
AGE IN YEARS			
18-39	6 (26.1)	4 (20.0)	4 (26.7)
40-59	15 (65.2)	16 (80.0)	11 (73.3)
≥ 60	0	0	0
Missings	2 (8.7)	0	0
PROFESSIONAL GROUP			
Operational Assistants	8 (34.8)	4 (20.0)	4 (26.7)
Nurses	13 (56.5)	12 (60.0)	9 (60.0)

	Before N (%)	After N (%)	
		Completed	Final
Physicians	1 (4.3)	4 (20.0)	2 (13.3)
Missings	0	0	0
YEARS AT NICU			
<5	6 (26.1)	4 (20.0)	3 (20.0)
5-20	11 (47.8)	10 (50.0)	8 (53.3)
>20	4 (17.4)	5 (25.0)	3 (20.0)
Missings	2 (8.7)	1 (5.0)	1 (6.7)
SHIFT			
Morning	12 (52.2)	10 (50.0)	7 (46.7)
Afternoon	6 (26.1)	3 (15.0)	3 (20.0)
Night	5 (21.7)	2 (10.0)	1 (6.7)
Missings	0	5 (25.0)	4 (26.7)

Notes: *15 participants fulfilled the questionnaire before and after the intervention (drop out after intervention n=8 (34.8%)).

**Those participants only responded after the intervention and were not included for T-test for paired samples analysis.

The number of valid questionnaires included in the study is N=43 (23 pre-intervention and 20 post-intervention). However, only 15 participants responded before and after the intervention, so further analysis was made considering those participants. More than a half of the sample was composed by nurses, followed by operational assistants and physicians. Also, most of the staff have worked in NICU between 5 to 20 years. At the time of the questionnaire survey, workers who participated in the study were mainly from the morning shift. The responses of the relevant questions of the questionnaire are shown in Figures 8, 9, 10 and 11.

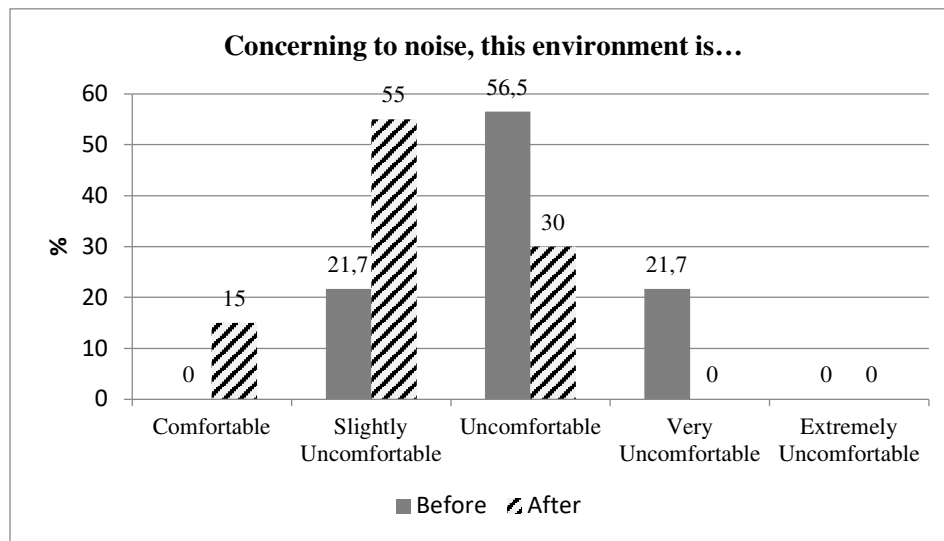


Figure 8 - Workers responses regarding acceptability ($p<.001$).

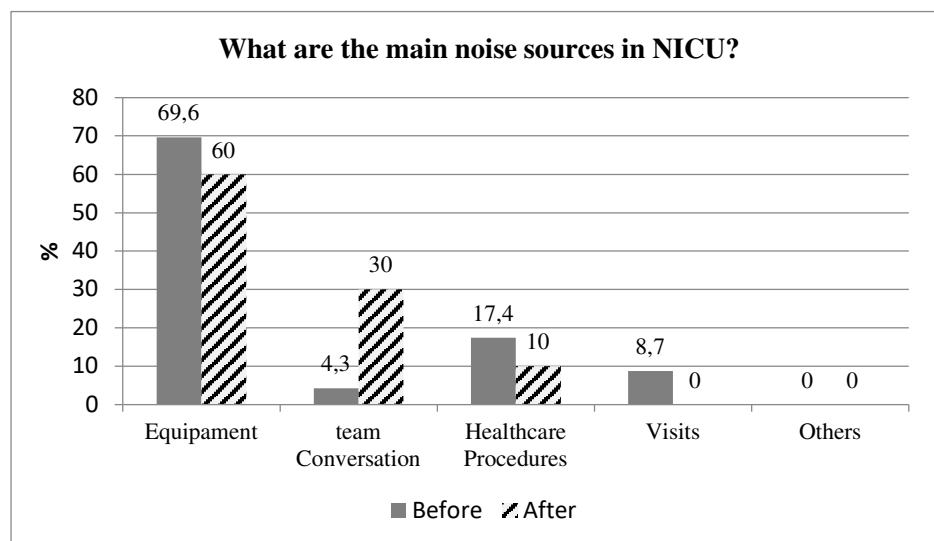


Figure 9 - Workers responses regarding noise sources in NICU ($p=.537$).

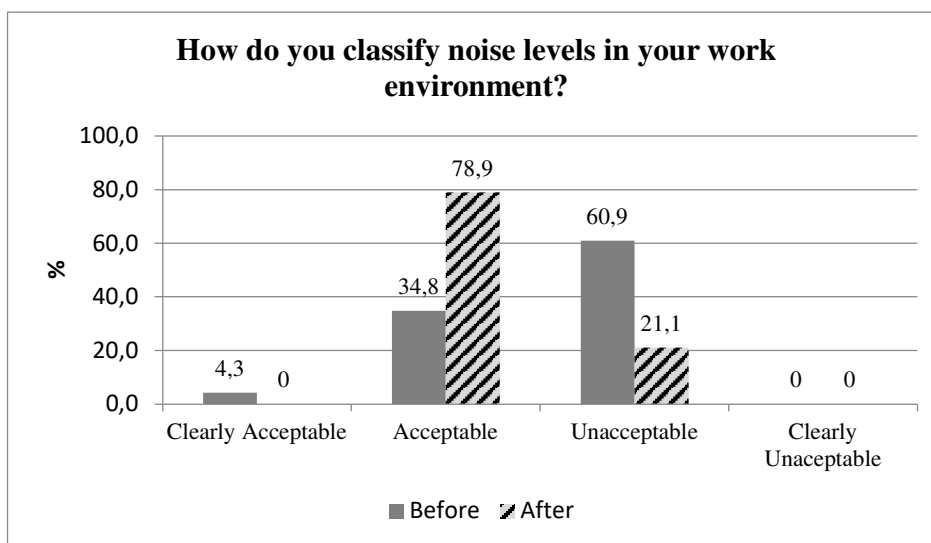


Figure 10 - Workers perceptions of comfort of the work environment ($p=.005$).

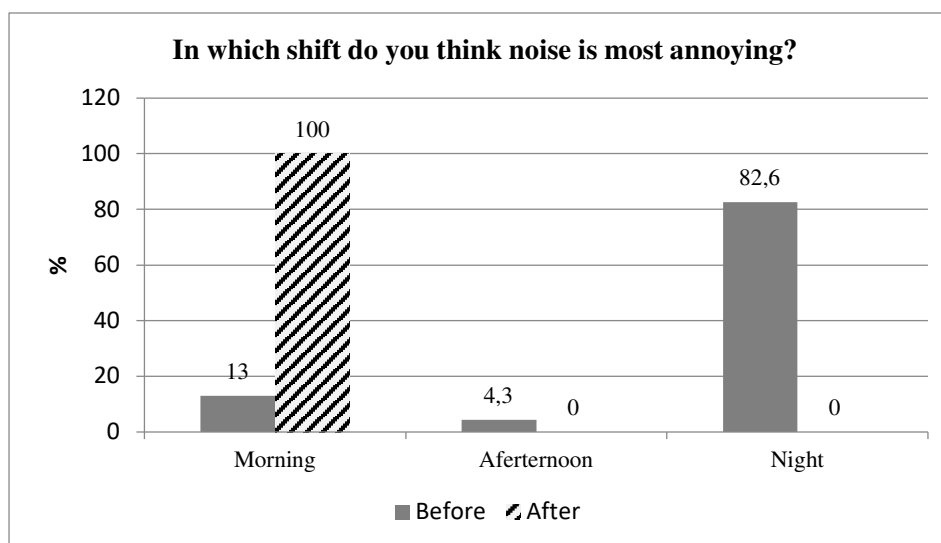


Figure 11 - Workers perceptions regarding the noisiest shift ($p<.001$).

As presented in Figure 8, pre-intervention perception regarding the acceptability of the working environment, 4.3% 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". In the post-intervention phase, 78.9% classified the working

environment as "Acceptable" and 21.1% as "Unacceptable". These results show an improvement on the acceptance of healthcare staff regarding noise after changing NICU. Concerning the main sources of noise presented in Figure 9, in pre-intervention phase, 69.6% 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 4.3% of professionals, "healthcare procedures" by 17.4% and 8.7% for "visits". Post-intervention, participants found, once again, equipment as the most annoying source of noise (60.0%), but also recognized "Team conversation" (30.0%) and "healthcare procedures" (10.0%) as sources with potential to increase annoyance in NICU. Figure 10 refers to the perception of comfort in relation to the work environment. Pre-intervention results showed that 41.1% of health professionals considered the work environment as "Slightly uncomfortable", 21.7% "Uncomfortable", 56.5% "Very uncomfortable" and 21.7% "Extremely uncomfortable". After the intervention in NICU, 15.0% felt that NICU was "Comfortable", 55.0% "Slightly uncomfortable" and 30.0% "Uncomfortable". The results suggest that after the alterations made in the NICU, the healthcare staff perceived the working environment as more comfortable than before. Finally, health staff reported about the most annoying pre-intervention shift (Figure 11). 82.6% of respondents considered the morning shift as the most uncomfortable, followed by night shift rated by 13.0% of the participants. In contrast, the post-intervention survey, showed that all participants (100%) found that the morning shift as the noisiest. Statistical differences ($p < .05$) between the two groups of workers (pre and post-intervention), were found for all the relevant questions, except for the question regarding the main sources of noise ($p > .05$).

6.4 Discussion

After structural intervention and layout changes which were performed in the NICU, L_{Aeq} sound levels and L_{Cpeak} slightly decreased, in contrast with other studies (Krueger, Schue, & Parker, 2007; Philbin & Gray, 2002). Noise levels pre and post-intervention 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 (Berglund et al., 1999), and by other organizations such the

United States Environmental Protection Agency (45 dB(A) daytime / 35 dB(A) night) (U. S. Environmental Protection Agency, 1974) and the American Academy of Paediatrics (45 dB(A)) (American Academy of Pediatrics: Committee on Environmental Health, 1997). Results inside incubators showed the same pattern, maybe due to the healthcare procedures/activities during measurements. Other studies found noise levels significantly above the recommended during routine clinical procedures (Carvalhais, Silva, Xavier, & Santos, 2017; Parra, de Suremain, Berne Audeoud, Ego, & Debillon, 2017). Data analysis revealed that low frequencies tend to have more influence on noise produced in the NICU than higher frequencies, both pre and post-intervention. These results are in agreement with the work reported by Gray & Philbin (2000), who stated that low frequencies are predominant in sound pressure levels in nurseries. Nonetheless, the presence and impact of high frequency noise in NICU is real and the exposure of a normally developing newborn by high frequency noise, may potentially result in abnormal auditory development (Lahav, 2015).

In the work developed by Kellam & Bhatia (2008) it is suggested that human speech contributes to increased sound levels at 500 Hz. In fact, this was the frequency with the highest level in the majority of measurement places. There is some evidence showing a reduction in sound pressure levels predominantly above 400 Hz during the night. During this time there is a tendency to decrease conversation and alarm sounds (Carvalhais et al., 2015; Livera et al., 2008; Santos et al., 2018), suggesting that staff activity and conversation are noise sources with impact in noise production. The questionnaire survey revealed that most staff considered equipment and conversation between the team as the main sources of noise, especially after the intervention in the NICU. Despite that, one observes a tendency to perceive NICU environment as more comfortable and the noise levels more acceptable after the structural modification. Morning shift was considered the noisiest after intervention, as stated by other authors (Santos et al., 2018).

Philbin (2004) acknowledged that every NICU has its own design and location, and that sound measurement can never be the ideal, but stressed that sound can be minimized when reconstructing an NICU. The homogeneity of results pre and post- intervention can be explained by the fact that the structural interventions were minor, despite the

fact that NICU was placed in another building of the hospital, and basically the building materials and furnishings were identical, as well as the healthcare procedures and most of the healthcare staff. The most significant change was the layout of the NICU and the area increase. Carvalhais, da Silva, Xavier, & Santos (2019) considered a good practice to include sound control and noise as important factors when purchasing new equipment or making infrastructural modifications at a NICU. As Krueger et al. (2007) stated, the fact that the study occurred in one NICU is a limitation, but the opportunity to compare sound levels before and after a structural intervention is unique. Another limitation is the fact that the structural modifications aimed firstly to the reorganization and improvement of the clinical response of many units and not only the NICU. This means that some other structural measures to reduce noise levels were not implemented such as the use of materials with an improved sound absorption rate or the option for other NICU design, as opposite to the chosen open-bay model. Indeed, there is evidence that smaller rooms with less incubators/nurseries or even single-family rooms promotes a quieter environment (Domanico, Davis, Coleman, & Davis, 2011; Kol, Aydin, & Dursun, 2015; Ramm et al., 2017), despite the fact that noise levels still exceed the recommended ranges in the majority of the cases. In our study, NICU had two smaller rooms equipped with five incubators and six nurseries, respectively, and now it has one room with thirteen incubators/nurseries. Data showed no significant differences between noise levels based on layout design. In this case, our results in both assessment phases, are in agreement with the findings of Basner et al. (2014), that noise levels in hospitals are typically more than L_{Aeq} 15–20 dB higher than those recommended. Also, Smith, Ortmann, & Clark (2018) recognized the inability of NICUs to comply with current noise level ranges, and propose changes in NICU noise level recommendations. Indeed, the noise reduction strategies implemented or tested in the last years hasn't resulted in the impact needed, even though some improvements (e.g. noise levels decrease) have been observed (Ahamed, Campbell, Horan, & Rosen, 2017; Carvalhais et al., 2015).

6.5 Conclusions

This study aimed to confirm the influence of physical/structural changes within NICU space on noise reduction. Our results showed that no significant differences on noise levels occurred before and after those changes. These results must be framed considering the type of intervention made, since, when structural intervention or layout rearrangement are performed with noise attenuation in mind, significant attenuation is expected. The studied NICU (pre and post-intervention) presented higher sound pressure levels than recommended by international organizations. However, the perceived environment of the NICU by healthcare staff, improved after the structural modifications. A combined approach to reduce noise in those spaces must be addressed. Continuous education aiming at a cultural change of the staff should be a priority, keeping in mind the newborns health and recovery.

Implications for practice: Noise is a common problem in NICU environments and exerts significant adverse implications for health and well-being of patients and staff. In this study, results showed that noise levels were above international recommendations, before and after a structural intervention. Hospital management should consider noise as an important factor when purchasing new equipment or making infrastructural modifications in a NICU environment. Staff working in NICU need continuing education and awareness about the effects of noise on the preterm infant's health and to understand how to avoid noise production.

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CHAPTER 7: General Discussion, Main Findings, Recommendations and Future Research

7.1 General Discussion

This thesis is the first Portuguese study addressing the issue of noise exposure 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 NICUs. Data collection was carried out successfully in all the stages designed for the study. Data analysis was performed, and results were already presented at scientific meetings and published or accepted for publication.

In the exploratory study shown in Figure 2, Santos & Miguel [1] 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. [2] for the determination of risk level and intervention prioritization. The values of L_{Aeq} dB(A) obtained in the ICUs ranged from 50.0 dB(A) and 65.0 dB(A) in the center of the units and between 57.8 dB(A) to 67.1 dB(A) 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 [3–6]. 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 which interfered the results. Comparing the results, it was found that the morning L_{Aeq} dB(A) 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 [7]. 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. [8]

documented some preliminary results on noise levels and responses given by health care staff of a NICU. It was found that during the week, the mean values of L_{Aeq} dB(A) obtained in the evaluated rooms ranged from 48.3 dB(A) and 82.5 dB(A). The results demonstrated that Monday L_{Aeq} dB(A) values were higher than the other days of the week, ranging between 52.0 and 86.0 dB(A). Furthermore, sound pressure levels were significantly higher on weekdays than on weekend days ($p<0.05$). In general, mean values of L_{Aeq} were lower in night shift; such was already reported for other authors [9,10]. 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 hand, no significant differences have 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 [8]. This study concluded that noise levels were above the recommended and that routine activities 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 [8]. Following those conclusions, Carvalhais et al. [11] (Chapter 5) conducted a pilot study regarding the effectiveness of a training program on noise reduction in a 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 L_{Aeq} and L_{Cpeak} values, 71.7 to 58.8 dB(A) and 143.3 to 102.8 dB(C), 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 L_{Aeq} 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 more attention needs to be taken. A spectral analysis was also made, revealing that 500 Hz was the frequency which had higher levels in the areas under study. In this study health care 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.

Since infrastructural modifications might effectively decrease noise levels, a study testing the effectiveness of those modifications was conducted in one NICU (Chapter 6). In this study noise measurements before and after structural interventions, were made. Also, healthcare staff reported their feelings regarding noise in the NICU environment, before and after the modifications. The opinion of healthcare staff regarding noise in NICU was better after the intervention, when compared with the responses given before. The results showed that noise levels were excessive in the NICU (before and after), exceeding the international recommendations, with the levels ranging between 46.6 dB(A) to 57.8.7 dB(A) before and 52.0 dB(A) to 54.0 dB(A) after intervention.

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 with a larger sample, was performed in order to characterize health staff perceptions regarding noise in NICU [12,13]. A total of 95 professionals from three NICU, participated in this study (Chapter 3). 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%). In general, noise levels in the three NICU are 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. In fact, noise levels were also higher than 40 dB(A), which is the only reference value for this type of hospital areas in Portugal [37]. Also, short noise measurements during clinical procedures/tasks, showed that certain actions, such as closing the doors improperly cause significant increase to sound levels within the incubator or produce a noise peak (Chapter 4). Other factors such, baby crying, placing material on the incubator or closing the portholes, could influence the noise production near the newborn and the obtained levels.

Even though some of noise reduction strategies showed some improvements, still the sound pressure levels were above the recommended. 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 [17].

Some limitations of the study were 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. Some activities such control measurements in an empty room to establish the background noise of the unit, were not performed since there was no availability of empty rooms during the measurement's periods. Logistical issues during measurements due to the NICU configuration and lack of space, were also a limitation. The type of data collected was also limited to the approval by the ethics committees'/directive boards of the studied hospitals. For example, no contact with visitors and no availability to access clinical data from newborns, were possible.

7.2 Good practices to reduce noise in the neonatal intensive care unit

Abstract: Indoor environmental conditions in neonatal intensive care units, such noise levels above the recommended, may induce some risks, not only for preterm infants' development, but also for health care staff. The aim of this work is to summarize some good practices that can be followed by health care staff in a daily basis, which are intended to promote noise reduction in neonatal intensive care units. It is expected some initial resistance to the implementation of some recommendations, but evidence shows that in general, with training, health care staff should recognize the need of changes.

Keywords: Noise Reduction, NICU, Recommendations.

7.2.1 Introduction

In neonatal intensive care units (NICU), the objective is to keep even the most fragile preterm infant alive until they have developed to a level of medical stability. The NICU is often designed as one large room or “Open-Bay” where staff can monitor multiple infants all in one space. This type of NICU configuration is the most common in Portugal. In fact, an open room environment led to unpredictable sounds that contrasts with the protective environment of a mother’s womb [18]. Sound is one of the most pervasive stimuli in the NICU and is perceived differently through the tissues of the womb. For the preterm infant, this is a time when auditory development is taking place and sleep can be affected by constant startles. Noise may also cause physiological stress, which can impact cognitive development and increase length of stay [19]. Several studies performed in NICU, have consistently noted that the recommended noise levels have been violated at day and night periods [11,12, 20–23]. A recent study conducted in Portugal, shows that noise levels were excessive in all the evaluated areas of the NICUs (noise levels ranging between 48.7 dB(A) to 71.7 dB(A)), exceeding international guidelines which proposes that the average background noise in hospitals should not exceed 35 dB L_{Aeq} for areas where patients are treated or observed (WHO), 45 dB(A) daytime / 35 dB(A) night (United States Environmental Protection Agency) and 45 dB(A) (American Academy of Pediatrics) [24]. The aim for controlling noise levels in the NICU is to preserve a large portion of each hour for infant sleep. Noise levels found in hospitals frequently disturb sleep states and disrupt stable behavioural states in healthy term and preterm infants [9]. Loud sound levels also affect health care staff. Elevated sound levels interfere with adult communication and performance of complex tasks [11]. They also increase fatigue, irritability and work-related stress [25]. Constant exposure, to sound pressure levels greater than 80 dB, will damage health care workers hearing, but those values are not a threat in hospital environment, when comparing with an industrial setting, due to reduced time exposure. In hospital context, safe noise levels are essential for personal communication, family interactions and healthy child development, so it is important for practitioners to understand the current recommendations for the sound levels of these units [26].

7.2.2 Purpose

The purpose of this work is to present recommendations for healthcare staff, to reduce noise in NICU, in order to promote an environment that enables the neonate the opportunity to develop and grow to their fullest potential, as well as the health care staff perform their work safely. The recommendations to reduce noise imply the adoption of acceptable noise levels/standards and encouragement and commitment of allied health professionals to work within those levels and decrease extraneous noise. All staff, parents, and visitors must be aware of the effect of noise on premature and ill neonates, to guarantee the achievement of any implemented actions to reduce noise.

7.2.3 A brief overview of strategies to reduce noise in NICU

Carvalhais et al [27] in their short review, summarized some studies regarding noise in NICU. They found that neonatal nurses have lack of expertise in noise prevention area, and that they would benefit by becoming involved in an educational program based on prevention of sound stimulation [28]. Indeed, evidence shows that a major strategy to reduce noise is to change the behavior of health professionals [20,29,30]. Brown [26] summarizes noise minimization measures to educate the health care team and parents/visitors about the potential consequences of high noise levels and measures for noise reduction, such: reduce conversation at the bedside and move and speak quietly; reduce alarm volumes; respond quickly to telephones, alarms, beeps, crying babies, and other disturbances; avoid putting things on top of incubators; close incubator portholes and drawers quietly; reduce telephone ringer volume; remove radios from the NICU; regularly remove water from ventilator and C-PAP tubing; cover incubators with thick blankets or cover to absorb sound; implement a quiet hour protocol; limit the use of the air conditioning system; reduce the volume of beeps or use the vibrating mode; minimize movement of personnel thorough and around NICU; avoid tapping and banging on incubators; avoid leaning on incubators to write; open packaging away from incubators, among others. A well-structured training program also seems to be a low cost measure to start the noise reduction process in the hospital [20]. Staff members can do a lot to change the environment

for their patients. For instance, by keeping conversations at a very low level, they discourage loud noises such as laughing, and by being careful not to place equipment (even small items such as pens) on top of incubators. They should be very gentle when opening and closing portholes in the incubators and institute routine quiet periods. Altuncu et al [31], conducted a study where they measure the noise levels inside the incubator with and without sound absorbent panel (SAP). They prove that SAP reduce noise levels in infant's incubator and is an efficient measure to adopt. Other strategies are noise reduction guidelines, architectural changes, renovation and/or preventive maintenance of equipment, including parameters to the acquisition of equipment containing audible alarms [20]. In fact, several studies have shown that the "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 [32,33]. Obviously, recently built NICU reap the benefits of improved sound insulation and design. For instance, nowadays, monitor alarms can easily be transmitted visually, eliminating one of the most reported causes for noise production in NICU [12,13]. Also, shift change discussions should be moved away from the bedside, and devices such as portable x-ray machines should be located as far from the baby as possible. The implementation of a Quiet Period or Quiet Hour (QH) in the NICU (reduced light, noise, staff activity and infant handling), has been reported as a good tool with beneficial effects, namely the improvement in some physiological parameters [34,35]. Many hospital units have their QH in the afternoon, between about 4 and 5 pm, but it varies among units. QH allows healthcare staff to provide these three important elements of good newborn care: More quiet - Providers will try to keep the unit as quiet as possible, and there will be less talking, lower voices, and minimal noise from machines and alarms. Softer light - Lights will be dimmed and shades and curtains will be drawn. Less disruption - Providers will avoid doing procedures and, when possible, fit them in before or after QH. A daily QH reduces newborn stress levels, which helps maintain a healthy blood pressure, heart rate, breathing, oxygen levels, and other important processes [34]. Also, allows for more and better (deeper) sleep, which helps all newborns grow and helps sick babies heal faster. Finally, it will protect preterm infants fragile hearing and promotes healthy brain

and sensory development. Despite the obvious role of the health care staff in the implementation of this a QH protocol, the visitors have an important role too. First, they must learn when QH happens. Secondly, they must plan their comings and goings around QH (trying to be in NICU 15 minutes before QH starts and stay until the hour is over. When fewer people are moving around, the NICU will be calmer during this time). Then, the visitors need to consider the following: spend the hour resting quietly with the newborn, keep conversation to a minimum and turn of the TV and the phone's ringer. However, there are some barriers to the implementation of this protocol, such as: the resistance of health professionals, the limitation of health procedures during this time and the lack of communication regarding the implementation of this protocol to other health professionals from other hospital services.

7.2.4 Good practices guidelines proposal for health care staff to reduce noise

Some of the following measures were based on Lubbe et al [22] study. Those guidelines should be included and incorporated in the usual tasks/activities of the staff in NICU, in order to promote a healthier environment for the infants hospitalized. Indeed, some easy measures that can be implemented are:

- Move conversations away the bedside, and use a quiet voice;
- Consider implementing a “QH” on each shift;
- No loud voices/laughing in patient care areas;
- Do not allow incubator doors to snap/click shut;
- Do not tap with fingers, write, or place equipment on top of incubator;
- Cover incubator tops and cribs when indirect lighting is not available to shield individual beds from light;
- Communication devices placed on vibrate mode for patient care areas;
- Wear quiet soled shoes in patient care areas;
- Face alarms away from infants and lower the volume as much as is safe;
- Respond quickly to alarms;

- Minimize respiratory equipment noise by turning off unused baggers and suction and draining water in ventilator circuits;
- Pad storage drawers and doors;
- Use plastic trash cans without lids;
- Conduct “loud” or “noisy” care giving related activities away from the bedside whenever possible; and finally,
- Consider sound control and noise as important factors when purchasing new equipment or making infrastructural modifications at NICU.

7.2.5 Conclusions

Collaboration and awareness among all hospital staff and visitors are vital to the success of the proposed recommendations or any new practice introduced. The nursing staff will surely find challenging the accomplishment of the proposed practices. They must modify their workflow to comply with the proposed measures. In general, healthcare staff recognize the problem under noise production in NICU, and this fact will surely help to embrace those guidelines.

7.3 Final Remarks and Future Research

This was the first Portuguese study characterizing sound pressure levels in neonatal intensive care units and the main strength of this work was the combination of strategies to reduce noise levels that were 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 was to contribute and to promote healthier environments both for infants and health care professionals in hospitals. With that in mind, some particularly important outcomes of this thesis will be to contribute to educate health care staff and to make recommendations to reduce and control noise production in those environments. For that, a technical manual will be developed and made available for healthcare

professionals containing specific actions considering the Portuguese reality. Additionally, health promotion programs should be the mainstream of all interventions and should integrate as much as possible, staff, patients and visitors, not only to promote change in behavior but also a change in (safety) culture. Top management should also be aware and be involved in this paradigm changing process.

Several investigation questions were brought to light in this thesis, requiring further supporting evidence and scientific clarification. The following matters should be addressed in future research related to noise in neonatal intensive care units:

- Large well designed, conducted and reported randomized control trials (RCT) studying different aspects of noise reduction are needed, as a noise reduction to below the recommended levels has not been achieved in most neonatal intensive care units;
- Long-term studies relating physiological responses of newborns and sound pressure levels were already performed, but there is lack of evidence;
- RCT relating the sound pressure levels in incubators that reaches the individual infant by using earmuffs or earplugs;
- Studies involving all the stakeholders: Assess annoyance, sleep disturbance, stress, or any detrimental health effects on healthcare staff, infants, and visitors.

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APPENDICES

APPENDIX 1 - Questionnaire

Questionário ao Trabalhador

Projeto NeoNoise

1. Género: M ☐ F ☐

2. Idade: Menos de 25 ☐ 25-29 ☐ 30-34 ☐ 35-39 ☐ 40-44 ☐ 45-49 ☐ 50-54 ☐ 55-60 ☐ Mais de 60 ☐

3. Categoria Profissional: _____ 4. Serviço: _____

5. Experiência Profissional: _____ anos _____ meses 6. Tempo de Serviço (neste serviço): _____

7. Horário de Trabalho (turno a que está afeto neste momento): _____

8. Como classifica o ruído no seu ambiente de trabalho? (selecione a opção com que mais se identifica)

Claramente Aceitável	Aceitável	Inaceitável	Claramente Inaceitável
☐	☐	☐	☐

9. Na sua opinião, qual é o turno que considera mais ruidoso?

Turno da manhã	Turno da tarde	Turno da noite
☐	☐	☐

10. Qual ou quais a(s) fonte(s) de ruído que mais o incomoda(m)?

Equipamentos	Procedimentos durante o tratamento ao doente	Conversa entre a equipa	Visitas	Outros
☐	☐	☐	☐	☐ Qual (ais)? _____

11. Em relação ao ruído, acha que este ambiente é...

Confortável	Ligeiramente desconfortável	Desconfortável	Muito desconfortável	Extremamente desconfortável
☐	☐	☐	☐	☐

Muito obrigado pela colaboração.

APPENDIX 2 – Published articles in peer-review journals



Is There Sufficient Training of Health Care Staff on Noise Reduction in Neonatal Intensive Care Units? a Pilot Study From Neonoise Project

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IS THERE SUFFICIENT TRAINING OF HEALTH CARE STAFF ON NOISE REDUCTION IN NEONATAL INTENSIVE CARE UNITS? A PILOT STUDY FROM NeoNoise PROJECT

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Evidence indicates that exposure to high levels of noise adversely affects human health, and these effects are dependent upon various factors. In hospitals, there are many sources of noise, and high levels exert an impact on patients and staff, increasing both recovery time and stress, respectively. The goal of this pilot study was to develop, implement, and evaluate the effectiveness of a training program (TP) on noise reduction in a neonatal intensive care unit (NICU) by comparing the noise levels before and after the implementation of the program. In total, 79 health professionals participated in the study. The measurements of sound pressure levels took into account the layout of the unit and locations of the main sources of noise. General results indicated that L_{Aeq} levels before implementation of the training program were often excessive, ranging from 48.7 ± 2.94 dBA to 71.7 ± 4.74 dBA, exceeding international guidelines. Similarly, following implementation of the training program, noise levels remained unchanged (54.5 ± 0.49 dBA to 63.9 ± 4.37 dBA), despite a decrease in some locations. There was no significant difference before and after the implementation of TP. However, a significant difference was found for $L_{p,Cpeak}$ before and after training staff, suggesting greater care by health care professionals performing their tasks. Even recognizing that a TP is quite important to change behaviors, this needs to be considered in a broader context to effectively control noise in the NICU.

Evidence indicates that human exposure to high levels of noise produces physiological and psychological disorders, and that these effects are dependent upon various factors (Guthrie et al., 2014). Noise in neonatal intensive care units (NICUs) is recognized as an agent with negative implications on health and well-being of premature infants (Nicolau et al., 2005) and health professionals. Philbin and Gray (2002) documented that sound pressure levels in intensive care units ranged between 55 to 75 A-weighted decibels (dBA). These results are higher than the limit recommended by the World Health Organization (WHO), which recommends that the average background noise in hospitals should not exceed 35 dB L_{Aeq} for areas where patients are treated

or observed. For wardrooms in hospitals the guideline values indoors are 30 dBA L_{Aeq} (A-weighted equivalent sound pressure level) with a corresponding L_{Amax} (maximum A-weighted sound pressure level) of 40 dBA (Berglund et al., 1999). These levels are influenced by the equipment (including alarms, monitors, ventilators, infusion pumps, nebulizers) and by health professionals'/visitors' behavior (with tasks and conversation) (Short et al., 2011), as shown in Table 1 (Pugh and Griffiths, 2007).

In general, high-intensity noise levels may induce physiological instabilities in newborns, such as apnea, bradycardia, and abrupt fluctuations in heart rate, respiratory rate, blood pressure, and oxygen saturation (Philbin and Klaas, 2000; Wachman and Lahav, 2011). Complex

TABLE 1. Equipment and Behavioral Causes of Noise in Intensive Care Units

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)

Note. Adapted from Pugh and Griffiths (2007).

exposures to multiple chemical and physical agents, such as noise, have the potential to produce several different sorts of interaction with regard to health outcomes (Fechter, 2004; Guthrie et al., 2014). Actually, noise acting in synergy with ototoxic drugs may increase the risk of sensorineural hearing loss in premature infants (American Academy of Pediatrics [AAP], 1997; Surenthiran et al., 2003). Other long-term negative effects include language difficulties and altered brain development (Brown, 2009), abnormal auditory development, and suggestion of a link between excessive noise and attention deficit hyperactivity disorder (Bremmer et al., 2003). Health professionals are concerned about this issue and identified noise as a barrier to work performance (Gurses and Carayon, 2009; Sampaio Neto et al., 2010). In fact, noise may induce extra-auditory effects in professionals, including burnout, stress, and fatigue, which results in errors (Mahmood et al., 2011).

In Portugal there has been a considerable increase in preterm births, which in 2004 increased from 6.7% to 8.8% in 2009 (Machado et al., 2011). 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. Environmental modifications might

effectively decrease noise levels (Philbin and Gray, 2002; Philbin and Klaas, 2000; Ramesh et al., 2009); however, the process of caring for hospitalized patients requires frequent and ongoing interpersonal discussions. Minimizing patient exposure to interpersonal communications between health care staff members requires a behavioral change. A well-structured training program seems to be a low-cost measure to begin noise reduction process in a hospital environment (Tsunemi et al., 2012).

The aims of this study were to (1) assess the levels of noise by measuring the equivalent sound pressure levels in zones located in NICU of a Portuguese hospital and (2) examine the influence of implementation of a training program (TP) for staff on noise reduction.

MATERIALS AND METHODS

Clinical Settings

All measurements were performed in a NICU of a hospital located in Porto, Portugal, between July 2011 (first phase—measurements taken prior to implementation of TP) and July 2012 (second phase—measurements obtained 6 months after the implementation of TP). The clinical/technical area of the unit consists of two rooms (A—Intensive Care and B—Special Care), without total separation between infrastructures. Room A includes the integrated set of physical, technical, and human expertise, where newborns in critical condition with failure of vital bodily functions are assisted by advanced life support for 24 h/d. Room B also includes an integrated set of physical, technical and human expertise, intended to provide care for infants with failure of an organ or system, but not intended for neonates requiring mechanical ventilation. The existing physical infrastructure separating the compartments consists of plywood with glazed surface on top. The floor is concrete with vinyl covering, walls are made of painted plasterboard with three glass windows, and the roof is concrete. The NICU (rooms A and B) has capacity to provide care for approximately 19 patients with a total

of 14 incubators and 5 nurseries. 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, and consequently underwent greatest amount of staff/traffic activity.

Noise Measurements

Noise level measurements were performed using a sound level meter class 1 (01 dB, model Solo-Premium). In accordance with Robertson et al. (1998), a preliminary survey was performed in order to identify noise sources. In both rooms (A and B) measurements were made continuously over 24 h in 2 areas: work stations and traffic zones (at least 1 m away from the walls at a height between 1 m and 1.65 m). In room A, noise was also determined inside an incubator. The measurements of peak sound pressure level ($L_{p, Cpeak}$) were made using the C filter, and those of the A-weighted equivalent sound pressure level (L_{Aeq}) were obtained using the A filter, which is a frequency-weighting filter that simulates human hearing. 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, according to Philbin and Gray (2002). To ensure accurate measurement, recording was preceded by calibration of the sound level meter (Kent et al., 2002), with an acoustic calibrator class 1 (RION, model NC-74). In analysis and interpretation of results, reference values given by WHO were used (Berglund et al., 1999).

Training Program (TP)

The TP was performed through a lecture of approximately 60 min and conducted by the investigators. In order to ensure that all the staff members of the NICU under study, such as physicians, nursing staff, and auxiliary staff, attended the lecture ($n = 79$), 14 training sessions were given. The lecture included the results of the sound pressure levels obtained in the first phase and comparing these to the recommended values suggested by WHO and

other regulatory agencies. The negative impact of noise on health, for both neonates and professionals, was also discussed and some actions that needed to be implemented to ensure noise reduction were undertaken. Regarding these actions, the health professionals were led to discuss and reflect on current practice, framing the problem. The health professionals were encouraged to develop an action plan to address specific noise issues, in order to be involved in the process and obtain their commitment for future implementation of noise reduction protocols. Without their commitment, the transfer of knowledge might not be effective in changing practices and behavior.

Statistical Analysis

The processing and data analysis involved descriptive statistics, with analysis of L_{Aeq} and $L_{p, Cpeak}$ values. All tests considered a 95% confidence interval. The normality Shapiro–Wilk test and Student's *t*-test for paired samples 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 training content and the staff perception regarding the main sources of noise in the NICU and suggestions to decrease noise in these environments are presented in Table 2. In general, the health care staff identified equipment, visitors, healthcare procedures, traffic inside the rooms, and team conversation as the main sources of noise in the NICU.

The results obtained in the two rooms of NICU before and after implementation of TP are shown in Table 3. Before implementation of TP, L_{Aeq} (dBA) values ranged between 60.4 and 71.7 dBA in room A and between 58.1 and 59.9 dBA in room B. Inside the incubator, L_{Aeq} was 48.7 dBA. After implementation of TP, L_{Aeq} values in room A areas ranged between 58.8 and 59.5 dBA and in room B ranged between 60.3 and 63.9 dBA. The L_{Aeq} values

TABLE 2. Training Content and Feedback From Health Care Staff

Training content	Healthcare staff feedback	
	Main factors that contribute to the noise level on unit	Suggestions to help decrease the noise level
1. General concepts of noise	1. Traffic in the room	1. Limit number of visitors
2. The impact of noise exposure in a hospital setting	2. Visitors behaviour	2. Keep voices down
3. National legislation and international standards regarding noise exposure in hospitals	3. Equipment/alarms	3. Improve the technology regarding the implementation of a centralized control of all the alarms of NICU in workstation area
4. Main health effects of noise exposure of neonates and health professionals	4. Team conversation	4. More quiet at change of shift
5. Presentation and discussion of results for the study developed in the NICU	5. Some health care procedures	5. Substitute for metallic materials (e.g., drug transport cars for) with others made of washable plastic
6. Recommendations to reduce noise in neonatal units		6. Perform some tasks more carefully to avoid noise production

TABLE 3. Values of Mean L_{Aeq} (dBA) and $L_{p,Cpeak}$ (dBC), Before and After Implementation of the Training Program

Room	Area	L_{Aeq} (dBA)—before, mean $\pm$ SD (min–max)	$L_{p,Cpeak}$ (dBC)—before	L_{Aeq} (dBA)—after, mean $\pm$ SD (min–max)	$L_{p,Cpeak}$ (dBC)—after
A	Work station	71.7 $\pm$ 4.74 (47.8–114.6)	143.3	58.8 $\pm$ 2.72 (47.6–76.4)	102.8
	Traffic zone	60.4 $\pm$ 5.32 (43.6–91.5)	115.8	59.5 $\pm$ 1.95 (53.0–75.0)	101.5
	Inside incubator	48.7 $\pm$ 2.94 (42.2–68.1)	104.1	54.5 $\pm$ 0.49 (53.3–65.7)	92.8
B	Work station	59.9 $\pm$ 6.01 (39.5–85.8)	106.3	60.3 $\pm$ 3.09 (46.4–79.2)	99.7
	Traffic zone	58.1 $\pm$ 3.07 (43.8–82.0)	113.2	63.9 $\pm$ 4.37 (47.0–82.2)	98.9

Note. SD, standard deviation; $p = .917$ L_{Aeq} (dBA); $p = .043$ $L_{p,Cpeak}$ (dBC).

inside the incubator increased to 54.5 dBA. The results demonstrated no significant differences between L_{Aeq} values before and after TP implementation, although some relevant work practices concerning the impact of noise were adjusted.

The highest $L_{p,Cpeak}$ (dBC) value was found in the “work station” area of room A before TP implementation (143.3 dBC). Data showed that significant differences were found between $L_{p,Cpeak}$ (dBC) values before and after TP. Table 4 shows the frequencies spectrum in octave bands among the areas under study. The 500 Hz was the frequency that had higher levels in the majority of the areas before and after the implementation of TP (room A: “traffic zone”—56.7 dBA and 56.5 dBA; room B: “work station”—56.7 dBA and 58.7 dBA; “traffic zone”—59.1 dBA and 53.7 dBA).

DISCUSSION

During TP sessions, noise was identified by professionals as a disturbing agent and exerted a negative impact (Table 2), which is in agreement with data presented by Gurses and Carayon (2009) and by Santos et al. (2014), who demonstrated that health professionals perceived “equipment” as one of the most annoying noise sources, followed by “team conversation” and “visits.”

The “work station” of room A had a decrease on L_{Aeq} and $L_{p,Cpeak}$ values, 71.7 to 58.8 dBA and 143.3 to 102.8 dBC, respectively (Table 3). It was apparent that greater care was being undertaken by professionals in carrying out their tasks regarding noise production. 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) who might be the source of this rise. The L_{Aeq} 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 more attention needs to be taken. Regarding the values inside the incubator, despite the elevation of L_{Aeq} values after the TP (48.7 dBA to 54.4 dBA), the levels obtained exceeded the recommended threshold. In general, the results obtained (Table 3) may be attributed to the number of newborns that were in NICU before (14 without specific care needs) and after TP (10, of whom 2 were helped by an oximeter and ventilator, which may produce 60–78 and 60–80 dBA, respectively [Pugh and Griffiths, 2007]). Similar data were reported by Tsunemi et al. (2012).

Data analysis revealed that low frequencies tend to have more influence on noise produced in the NICU than higher frequencies (Table 4). These results are in agreement with Gray and Philbin (2000), who stated that noise in nurseries is dominated by low frequencies, with some exceptions due to loud midfrequencies alarms. Kellam and Bhatia (2008) suggested that human speech contributes to the spike in sound energy at 500 Hz.

Despite adherence by health care staff members to TP, there was no significant reduction of noise after TP implementation. These results suggest that it is necessary to consider

several factors that may ensure the effectiveness of TP. It seems that TP impact was lost over time, but diminution of $L_{p,Cpeak}$ values may indicate that health professionals undertake their activities more carefully. In fact, the effectiveness of training health care professionals presents some contradictory findings in the literature (Oliveira et al., 2013). Several studies showed that the implementation of TP in this area contributed to reduction of sound average levels, although by itself this does not yield the recommended threshold levels and its impact tended to decrease over time (Philbin and Klaas, 2000). It is suggested that a TP incorporated into a more comprehensive quiet protocol, involving low-cost environmental (or other) modifications, seems to ensure decrease of noise levels (Ramesh et al., 2009), positively affecting patient well-being and improvement of satisfaction levels (Connor and Ortiz, 2009). Other studies also reported some resistance from health professionals to noise reduction programs, a factor that needs to be considered in future programs (Taylor-Ford et al., 2008). Connor and Ortiz (2009) noted in their study that staff members also believed that noise affected the physiologic, psychologic, and overall health of patients. In this study, the impact of staff education was measured by patient satisfaction scores surveys. In surveys after staff education, improvement was expressed in fewer poor ratings and an increase in good to very good ratings (Connor and Ortiz, 2009).

TABLE 4. Spectral Analysis of Noise (dB) Generated in Rooms A and B, Before and After the Implementation of the TP

	Room	Area	Frequencies (Hz)							
			63	125	250	500	1000	2000	4000	8000
Before TP	A	Work station	78.3	75.3	71.6	68.8	65.9	63.1	59.8	56.2
		Traffic zone	52.9	50.7	56.0	56.7	52.6	52.9	50.7	48.6
		Inside incubator	61.8	61.8	58.2	47.2	49.9	46.2	39.1	31.3
	B	Work station	54.5	53.1	55.1	56.7	54.6	53.2	52.6	46.0
		Traffic zone	53.8	49.4	57.6	59.1	59.1	57.8	54.8	48.4
		Inside incubator	55.1	53.9	48.0	46.8	44.5	37.7	36.9	27.2
After TP	A	Work station	52.7	55.7	54.8	55.5	53.3	51.4	50.6	45.1
		Traffic zone	48.3	50.8	53.2	56.5	53.1	55.8	51.0	44.9
		Inside incubator	55.1	53.9	48.0	46.8	44.5	37.7	36.9	27.2
	B	Work station	53.9	49.6	54.2	58.7	54.6	52.4	48.3	40.8
		Traffic zone	51.2	47.3	51.4	53.7	50.9	50.5	52.2	47.6
		Inside incubator	55.1	53.9	48.0	46.8	44.5	37.7	36.9	27.2

CONCLUSIONS

Noise is a common problem in NICU, and exerts significant adverse implications for health and well-being of patients and staff. Results showed that after 6 months of TP implementation, there was no significant noise reduction in the NICU and inside the incubator. However, $L_{p,Cpeak}$ data are an indication that in conjunction with other factors, a TP may be an excellent action to reduce noise levels. While recognizing the importance of TP in order to promote changes in the team's attitudes, it needs to be recognized that the effects are not long lasting. The training sessions need to be repeated more often, and physicians, nursing staff, supervisors, senior leadership, staff from related departments, and family members/visitors need to attend. Noise in all the rooms of a NICU might be reduced considerably by incorporating affordable behavioral and environmental modifications, and by renovation and/or preventive maintenance of equipment. Training the staff in order to implement quiet work behaviors is essential and needs to be seen as a first step to implement a quiet time protocol in neonatal intensive units.

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Newborns Safety at Neonatal Intensive Care Units: Are they Exposed to Excessive Noise during Routine Health Care Procedures?

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Abstract

Neonatal Intensive Care Unit (NICU) noise may be stressful to preterm infants. This research evaluated the newborns exposure to noise during several health care activities of two NICU. The measurements of the equivalent continuous A-weighted sound pressure level and peak sound pressure level were carried were performed with a sound level meter, as close as possible of the newborn. The results showed that sound pressure levels were excessive in all the evaluated tasks, exceeding international guidelines. The levels ranged between 46.6 dBA to 74.6 dBA. There is a need for more research in order to verify the effectiveness of specific strategies to reduce the impact of noise in NICU.

Keywords: Noise; NICU; Newborns; Infants

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Introduction

The fragility of newborns, the increasing implementation of high-risk procedures and the low tolerance to medication errors are some of the concerns of health care professionals working in neonatal intensive care units (NICU). However, indoor environmental conditions may also induce some risks to the newborns development. Since infants in the NICU are constantly surrounded by high sound pressures levels, the acoustic environment of NICU and the potential auditory and non-auditory impact of excessive levels have been important topics of research for the past 20 years [1]. There are recommendations and guidelines stating that a pressure level above 45 dBA can be harmful to the infant's ears and can affect their growth and development. In fact, WHO goes even further and recommend that the average background noise in hospitals should not exceed 35 dB L_{Aeq} for areas where patients are treated or observed [2]. Previous observations identified that some of the greatest noise in the NICU comes from staff conversation (often related to rounding), equipment's, visitors and healthcare procedures [3]. It is undeniable that the greatest continuous sound load in NICU comes from respiratory equipment, gas flow, monitor alarms, among others [4]. On the other hand, the noise exposure of premature infants in incubators is determined by the noise situation in the neonatological care unit and by the acoustical properties of the incubator. However, nursing manipulation of the patient can also cause a rather high sound level inside the incubator and produce physiological changes in the neonate [5].

Wachman et al. [6] considered that there is a gap in knowledge regarding the determination of types of noise and sounds that are least harmful to premature infants. Indeed, there is lack of studies assessing the noise production of specific health care procedures [7], in contrast with studies monitoring background noise levels and identification of different equipment as noise source. The main purpose of this work is to verify if newborns are exposed to excessive noise levels during daily health care activities.

Materials and Methods

This study was conducted in the NICU of two hospitals (A and B) located in north region of Portugal. The clinical area of the NICU A, is divided in two areas and has capacity to provide care for



Figure 1 Average values of L_{Aeq} (a) and $L_{p, Cpeak}$ (b) during health care tasks.

Task 1 - administering medications and feeding; Task 2 - administering medications, feeding and aspiration of the respiratory tract; Task 3 - hygiene and administering medications; Task 4 - monitoring vital signs and blood drawn; Task 5 - monitoring vital signs and hygiene; Task 6 - monitoring vital signs and aspiration of the respiratory tract.

19 patients with a total of 14 incubators. The NICU B consists of three areas, equipped with a total of 9 incubators and 8 nurseries. The study included short measurements (5 up to 10 min.) for the assessment of the sound pressure levels (peak sound pressure level ($L_{p, Cpeak}$) and A-weighted equivalent sound pressure level (L_{Aeq}). Three short measurements were made *per* set of tasks. The tasks under study included administering medications, monitoring vital signs, providing hygiene and supplying vital nutrients to newborns. Measurements were performed using a sound level meter class 1 (01 dB®, model Solo-Premium) which was calibrated with an acoustic calibrator class 1 (RION®, model NC-74). The main position was inside the incubator, as close as possible to the infant ear avoiding any chance of contact between the newborn and the microphone. The data were processed in the dBTRAIT software, and the analysis involved descriptive and inferential statistics. The 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 was used for statistical analysis.

Results

The average noise levels obtained during the 6 health care tasks of the assessed NICUs are shown in **Figure 1**. (Task 1 - administering medications and feeding; Task 2 - administering medications, feeding and aspiration of the respiratory tract; Task 3 - hygiene and administering medications; Task 4 - monitoring vital signs and blood drawn; Task 5 - monitoring vital signs and hygiene; Task 6 - monitoring vital signs and aspiration of the respiratory tract). In NICU A, L_{Aeq} (dBA) values ranged between 52.0 ± 1.2 and 69.8 ± 5.4 dBA, being the highest value obtained in Task 4. Regarding NICU B, values ranged between 46.6 ± 4.3 and 74.6 ± 6.8 dBA. In this case, Task 4 had the highest average noise level. No significant differences were found between tasks ($P=0.063$) and NICU ($P=0.052$). The highest $L_{p, Cpeak}$ (dBC) value was found during the Task 3 of NICU B (111.2 dBC). The lowest $L_{p, Cpeak}$ value, was found during Task 6. Regarding NICU A, $L_{p, Cpeak}$ (dBC) values ranged

between 94.3 ± 3.5 and 108.8 ± 7.2 dBA (Task 4). In general, NICU B had highest peak levels. Nevertheless, no significant differences were found between tasks ($P=0.120$) and NICU ($P=0.077$).

Discussion

The identification of the source of the resulting noise levels involved continuous direct observation by the research team, identifying the source of the sounds and the approximate time interval of its occurrence. It was found that certain manipulations to the incubator, such as closing the doors improperly cause significant increase to sound levels within the incubator or produce a noise peak. Other factors such, baby crying, placing material on the incubator or closing the portholes, could influence the noise production near the newborn and the obtained levels. In all the tasks, the noise levels were above the recommended. Data analysis revealed that once the incubator is turned on and manipulations are performed to provide appropriate care, sound levels increase. As Farrehi et al. [8] stated that "hospital noise is a multifactorial problem and that a single solution is unlikely". In this sense, educational, environmental and infrastructural measures should be fully analyzed and considered (combined or isolated) to minimize the impact of noisy environments on occupants. In this case, periodic awareness/training sessions should be considered as a first measure to minimize noisy events originated by health care staff.

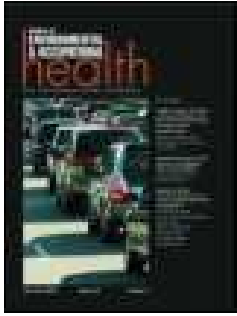
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Assessment and characterization of sound pressure levels in Portuguese neonatal intensive care units

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ABSTRACT

In the NICU, systematic exposure to sound-pressure above the recommended level can affect both neonates and staff. This study aimed to evaluate the sound pressure levels in three Portuguese NICUs and the noise perceptions 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 perceptions of professionals. Among the staff, 41.1% classified the environment (regarding noise) as “slightly uncomfortable”; 48.4% considered it as “acceptable.” The majority (55.5%) considered “equipment” 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 levels ranging between 48.7 dBA to 71.7 dBA. Overall, there is a need for more research to verify the effectiveness of some actions and strategies to reduce the effect of noise in the NICU.

ARTICLE HISTORY

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KEYWORDS

Health care staff; NICU; noise

The premature infant in the neonatal intensive care unit (NICU) is dependent on highly advanced medical care, which has demonstrated remarkably effective success in treating high-risk infant 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 environmental conditions include intense sensorial stimuli such as excessive lighting and noise, which are incompatible with well-being of neonates, family, and professionals. Mechanical devices, ventilation systems, patients, and staff are general sources within hospitals. In the 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 activities of nursing care.^{1–3} In addition, ongoing exposure to alarms, noisy incubators, and loud jarring sounds occurs 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 nonauditory health effects of noise has been reported by Basner et al.⁵ Furthermore, noise as a stressor not only influences negatively the healing process of patients (in this case premature infants) but also puts pressure on 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 health care staff.¹⁵ It is well established 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 nonclinical tasks performed by health care workers. Exposure to psychosocial, chemical, physical, mechanical, and biological hazards is common in hospital units and predisposes

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health care workers to different types of accidents.¹⁶ However, the work performed in the NICU can be particularly psychologically demanding, which, combined with environmental factors within the NICU, can increase the risk of work accidents, with negative consequences for staff and patients.

A literature review conducted by Konkani and Oakley¹⁷ showed that several authors studied and characterized the acoustic environments of intensive care units in hospitals. The noise amplitude was measured in decibels (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 al¹⁸ have characterized noise levels in the NICU. They concluded that noise levels were above that recommended by international guidelines and emphasized the need to train health care staff and actively include health professionals in noise-reduction strategies. The current study is integrated into a larger project, the NeoNoise Project, which combines objective and subjective approaches to characterize the acoustic environment in Portuguese NICUs. In addition, this project aims to determine the influence of sound pressure levels on the 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 consider the reality of the Portuguese health care services.¹⁹ The objective of this study was to quantify noise levels in 3 NICUs and to obtain surveys from health care staff on their assessment of real and perceived noise.

Methods

This study was carried out in the NICUs of 3 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 professionals' noise perceptions. The authorization to perform the study was given by 3 hospitals after favorable statements by their ethics committees or approval by their respective administration boards, including the NICU responsible.

Walkthrough survey

A walkthrough inspection was made to characterize the built environment and indoor spaces of the 3 NICUs 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 activity routines, was made. The existing equipment in the 3 units was common to NICUs: 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 the NICUs had some preventive measures to reduce noise levels, mainly maintenance programs for 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. The preparation of both parenteral nutrition and medication is located in a common area of the two rooms, but the entrance is accessed through room A1. The NICU (rooms A1 and A2) 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 a 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 them. The floor is concrete with vinyl covering, and walls and ceiling are in plasterboard panels coated with washable paint. Each room provides care for approximately 3 and 6 newborns, respectively. The preparation of both parenteral nutrition and medication is 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 are divided by a glass wall with a corridor that allows communication between them. 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 7 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 A preliminary survey was performed 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 , C_{peak}) were made using the C filter, and the A-weighted equivalent sound pressure levels (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 is the most appropriate response for the majority of the applications in hospitals and provides stable readings.²¹ To ensure accurate measurement, recording was preceded by calibration of the sound-level meter²² with an acoustic calibrator class 1 (RION, model NC-74). Reference values given by WHO²³ 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.

Perceptions of health care staff

The analysis of noise perceptions of health care staff in their workplaces involved the application of a questionnaire to characterize working conditions, comfort, and the main noise sources. The developed questionnaire, already tested in previous studies of this project, was divided into 3 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 fulfillment of the questionnaires since they were delivered by a nurse (responsible for the NICU) and placed inside an envelope after

fulfillment in a completely anonymous process. At the end of the shift, the envelope was 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 (minimum 24.0; maximum 61.0); the mean years working at NICU was 10.1 (minimum 0.5; maximum 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 6 rooms of the assessed NICUs are shown in Table 2, as well as the frequency spectrum in octave bands.

In NICU A, L_{Aeq} (dBA) values ranged between 58.1 (A2: traffic zone) and 71.7 dBA (A1: work station). In NICU B, L_{Aeq} ranged between 59.3 (B1) and 59.7 dBA (B2). In NICU C, L_{Aeq} ranged between 53.3 (C2) and 57.8 dBA (C1). No significant differences ($p = .103$)

Table 1. Characteristics of the surveyed health care staff ($N = 95$).

	NICU A	NICU B	NICU C	Total	
N	35	37	23	95	
%	36.8	38.9	24.2	100	
					N %
Sex					
Male	6	3	0	9	9.5
Female	29	34	23	86	90.5
Age (years)					
18–39	21	18	6	45	47.4
40–59	13	18	15	46	48.4
≥ 60	1	1	0	2	2.1
Missing	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
Missing	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
Missing	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) ($p = .103$) and $L_{p, Cpeak}$ (dB) ($p = .237$).

			Frequency (Hz)										
NICU	Room	Area	L _{Aeq}		L _{p, Cpeak}	63	125	250	500	1000	2000	4000	8000
			Mean	min–max									
Decibels													
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

were found between the 3 NICUs. NICU C had the lowest noise levels and NICU A had the highest. 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 ($p = .237$). Except in rooms A1: work station and A1/C2: inside incubator, 500 Hz was the frequency that 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. More than a half of the sample was composed of nurses (54.7%), followed by operational assistants (25.3%), and physicians (18.9%). The majority of the staff had worked in the NICU between 5 and 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 to the relevant questions on the questionnaire are shown in Table 3.

Regarding the acceptability of the working environment, 3.2% of the participants rated noise as “Clearly Acceptable” in 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 the NICU. The “Team conversation” was rated most annoying by 27.4% of professionals, “visits” by 9.5%, and “health care procedures” by 7.4%. No statistical differences between shifts, professional groups, years working at NICU, and NICUs were observed. Regarding the

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 (%)	<i>p</i>			
						Shift	Years at NICU	Professional groups	NICUs
1. How do you classify noise levels in your work environment?	Clearly acceptable	0	2	1	3.2	.903	.471	.849	<. .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	.310	.854	.859	.160
	Team conversation	13	12	1	27.4				
	Visits	3	4	2	9.5				
	Health care procedures	1	2	4	7.4				
3. Concerning noise, this environment is ...	Comfortable	2	7	0	9.5	.855	.027	.425	<. .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 do you think the noise is most annoying?	Morning	30	26	3	62.1	.052	.321	.425	<. .001
	Afternoon	1	2	1	4.2				
	Night	4	9	19	33.7				

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.

Comment

As shown in Table 2, noise levels in the 3 NICUs were higher than those 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 as the United States Environmental Protection Agency (45 dBA daytime / 35 dBA night)²⁴ and the American Academy of Pediatrics (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 Overall, NICU A had the highest 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 than do smaller units, all of which contribute to the overall noise levels. Other studies comparing single-room NICUs with open-unit NICUs (similar to NICUs A, B, and C) revealed higher noise levels mostly in open units.^{26,27} Basner et al⁵ 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). 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 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 the NICU environment regarding noise as “Slightly Uncomfortable” and “Uncomfortable,” despite the statistically significant differences between the responses of the staff of the 3 NICUs (Table 3). In general, noise was identified by health care professionals as an agent with a negative effect on the environment.

Indeed, other studies in hospitals have found similar data.^{1,29,30} However, in a study conducted in an emergency department, 53% of the sample (composed only of nurses) felt their cognitive function was never or rarely affected by noise.³¹ The morning shift was perceived as the most annoying, followed by the 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 of about 2 dB² up to 5 dB³² when compared with the morning shift. There were statistical differences between NICUs in the perceived comfort and noisiest shift, maybe due to the influence of specific organizational factors of the NICUs. There were also significant statistical differences in the perceived comfort relative to the years working at the NICU. This may be because 35.8% of the respondents had worked at the NICU less than 5 years and 59% were more experienced working in a 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 agree with those of Gray and Philbin,²¹ who stated that noise in nurseries is dominated by low frequencies, with some exceptions due to loud midfrequency alarms. Livera et al³³ analyzed the noise generated by the equipment used in the NICU, across the spectrum of frequencies, and concluded that those equipped with alarms (incubators, ventilators, infusion pumps, radiators, etc.) produce higher sound pressure levels at higher frequencies. Kellam and Bhatia³⁴ suggested that human speech contributes to the spike in sound energy at 500 Hz. In addition, results described by Carvalhais et al¹ 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 health care 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 effects 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 to minimize exposure to noise in the NICU. Almadhoob and Ohlsson¹⁴ 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. This can be achieved, for example, by lowering the sound levels in an entire unit or treating the infant in a section of a NICU or in a “private” room or with incubators in which the sound levels are controlled. In fact, several studies have shown that the “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} Last, regardless of the adjustment period of the operational management in the NICU to deal with the new design,³⁵ these single-room NICUs also seem to improve staff satisfaction regarding physical environment and working conditions.³⁶ Confirmation of the influence of other physical changes on noise reduction is also needed. An action plan, including a quiet-time protocol, could be seen as a first step to create a quiet environment, especially when structural modifications are not economically viable or predicted. However, more research is needed to verify which daily health care activities have more effect in noise production inside incubators. After that it will be easier to address specific actions when performing those activities.

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