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**DOI**
10.1007/978-3-030-41200-5_31

**Publication date**
2020

**Document Version**
Accepted author manuscript

**Published in**
Advances in Design Engineering - Proceedings of the 29th International Congress, INGEGRAF 2019

**Citation (APA)**
Sanz-Segura, R., Manchado-Perez, E., Ferrer-Duce, M. P., Gonzalez de la Cuesta, D., & Özcan, E. (2020). Design Guidelines for Light and Noise Management in the Neonatal Intensive Care Unit. In F. Cavas-Martínez, P. Morer Camo, F. Sanz-Adan, R. Lostado Lorza, & J. Santamaría Peña (Eds.), *Advances in Design Engineering - Proceedings of the 29th International Congress, INGEGRAF 2019* (pp. 284-293). (Lecture Notes in Mechanical Engineering). Springer Open. https://doi.org/10.1007/978-3-030-41200-5_31

# Design guidelines for light and noise management in the Neonatal Intensive Care Unit

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## Abstract

Neonatal Intensive Care Units (NICU) are environments with a high level of sensory stress. Medical advances and technology have contributed to increase the ratio of survival of premature infants but some devices and practices expose these babies to excessive noise and toxic sensory stimuli for which they are not prepared. This is related to an increase of neonatal morbidities, that are considered as minor sequelae, but that can greatly alter the life of the child and the family. Those responsible for hospital management and caregivers who want to take a step forward, need standards to guarantee the benefit of neonatal health and a proper physical and cognitive development of these babies. Design activity, from a Human-Centered Design approach (HCD), together with Developmental Centered Care (DC) contribute to identify and reduce adverse environmental conditions for newborns and premature infants. The purpose of this paper is to establish a method to provide design recommendations and good practice guidelines from evidence and especially from in-situ observations carried out in neonatal units by a multidisplinary team (i.e., nurses, NICU supervisors and designers). Thus, we identify proposals to reduce stress situations and obtain potential benefits in the development of the hospitalized infant through adaptation of the NICU macroenvironment (i.e. the reduction of light and noise).

**Keywords:** NICU; design guidelines; alarm fatigue; Human-Centered Design.

## 1 Introduction

Medical advances and technology have contributed to increase the ratio of survival of premature infants. This increasing of technological devices nevertheless expose these babies to toxic sensory stimuli for which they are not prepared. This is related to a rise in neonatal morbidities, considered as minor sequelae, but that can greatly alter the life of the child and the family. A premature baby passes directly from the intrauterine environment to an incubator in the neonatal unit. The mother´s womb is a dark and warm environment with soft auditory stimuli where the predominant sound is the voice of the mother; the effect of gravity does not exist and the movement of the baby is limited to his/her own gestures and the mother´s movement. Conversely, a neonatal intensive care unit (NICU) is a cold and noisy environment with inappropriate sound stimuli coming from several sources, many of them artificial. The exposure to excessive noise and light stimuli affects the physiological neonate and the neurobehavioral development of an immature brain [1].

The current actions implemented to reduce these unwanted effects are based on the so-called Developmental Centered Care [2,3]. These evidence-based practices favour the sensorineural and emotional development of newborns and the reduction of stress. Within this approach, the adequacy of the environment (i.e. the reduction of light and noise) is one of the aspects to address as it is directly related to neurobiological development in an ordered chain: touch at 8 weeks, vestibular system at 12 weeks, taste at 16, smell at 22 weeks, hearing at 20 weeks and sight at 30 weeks. Design activity, from a Human-Centered Design approach (HCD) [4], together with Developmental Centered Care (DC) can also help to take a step further and reduce adverse environmental conditions for newborns and premature infants, improving at the same time the wellbeing of the rest of inhabitants in critical care units.

Human Centered Design consist of a nearly anthropological approach that puts the user at the very core of the design process. Its principles are based on obtaining a close empathy with users to better understand their needs. The product itself is thus conceived as a system of services whose functions are devoted to fulfil the user expectations (beyond an artefact constructed of mechanisms and components), providing the better possible user experience. Human Centered Design relates closely to open innovation practices as it aims users to actively participate in the development process of the product, contributing to define design specifications, co-create solutions and evaluate prototypes [4, 5,6,7]. Consequently, our contribution expose the observational study carried out in a NICU in order to provide design recommendations and good practice guidelines obtained from a multidisciplinary collaboration of designers and clinicians (nurses and clinical supervisors) [8]. The objective is to get a better environmental management of the NICU (i.e., light and noise control) to attend in a proper way the needs of its inhabitants (patients, relatives and clinicians).

# 2 Effects of noise and benefits of noise reduction in newborns

## *2.1 Negative effects of noise*

The negative effects of noise detected in this environment stress and alter the state of the newborn, but also of the rest of the inhabitants of the unit (clinicians, family).

-Affectations to the newborn: alterations of the autonomic nervous system (tachycardia, desaturations, apneas...); sleep disruptions; changes in brain activity; an energy expenditure increase; behavioural changes; alterations in the development of speech and language; difficulties in listening to the mother's voice; and hearing loss. Bilateral hearing loss is ten times more frequent in premature babies, being the environmental noise one of the main factors to which they are subjected in critical units [9].

-In the clinician: cardiovascular alterations; increase in stress hormones and blood glucose; increase in muscle tension and in gastrointestinal motility; sleep disturbances; changes in behaviour and mood (fatigue, irritability, anger ...) and alarm desensitization; interference at work (increased cognitive workload affects efficiency and safety and consequently, a more risk of errors) [10].

-In the family: the noise generates anxiety and worry; it produces interferences in the communication with practitioners and their child; difficult family interactions; and the perception of a chaotic and disorganized environment, with emotional implications [11].

## *2.2 Benefits of noise reduction*

The benefits observed in the newborn are:

-an improvement in the control of the autonomic system: reduction of heart rate and blood pressure, as well as the number of apneas.

-reduction of ventilation days, improves digestive tolerance, which reduces the length of hospital stay.

-improves the sleep cycle: lengthens the peaceful sleep.

-avoid increases in intracranial pressure and episodes of hypoxemia.

-normal development of language, attention and perception is favoured.

Regarding health professionals, a better quality of care is observed: paying more attention and reducing errors.

## 3 Effects of light stimulus and benefits of light reduction in newborns

### *3.1 Negative effects of light stimulus increase*

The development of the visual system in a premature should continue without luminous stimulus, mainly in those babies under 30 weeks of gestational age (GA) who do not have defensive capacity for the regulation of the entry of light into the retina (thin eyelids, or inability to constrict pupil). Excess light can affect an adequate sleep pattern. Sleep and mainly the REM phase must be as long as possible for an adequate visual development.

### *3.2 Benefits of light reduction*

AAP (American Academy of Pediatrics) recommends that the luminosity be less than 60 lux, the WHO (World Health Organization) less than 45 lux. In the case of preterm infants less than 30 weeks old, levels greater than 20 lux are not recommended. Nevertheless, there are demanding tasks in which it will be necessary to provide higher levels of light (taking an intravenous catheter, preparation of medication...). In these cases, the high light should not increase the intensity more than 10 % in the rest of children.

The benefits of light reduction to newborns are:

-Improves psychomotor development;

-Increases the stability of the autonomic system and as a consequence lower heart rate, lower blood pressure and apneas;

-Reduces stress and greater weight gain is obtained;

-It favours the reduction of noise and manipulations, therefore, periods of sleep and rest increase;

-More periods of ocular opening, decreasing the motor activity;

-In greater than 32 weeks of GA exposure to light in short periods, establishing a sleep-wake cycle, favours the establishment of the circadian rhythm and increases weight gain.

Likewise, a series of detrimental effects of light reduction have been observed such as a negative influence on the mood and work performance for parents and professionals, so there should be resting areas with light. The scarcity of light hinders proper monitoring and early detection of possible complications arising from the maintenance of venous lines, nasogastric tubes, etc [12].

## 4 Objectives and procedure

The main objective is to raise an environment of light and noise as low as possible to promote the proper neurodevelopment of newborns, especially preterm infants. The procedure is based on a multidisciplinary approach that will include Human Centered Design principles together with the existent Developmental Centered Care basis. Although health education is carried out through awareness-raising routines with individual and global actions, environmental changes should involve a detailed study of medical devices as well as the understanding and interaction of the inhabitants (i.e., nurses) with advanced technology and graphic interfaces [13,14,15]. Human Centered Design offers a systematic, structured methodology of work that might be adapted to different situations and helps to control the process of analysis of problems, generation of ideas and evaluation, making its further implementation easier. Thus, graphical engineering and product design and development might play an important role in successfully designing medical equipment and alarm interfaces compatible with noise and light management.

To this end, all the inhabitants of the neonatal intensive care unit (clinicians, babies, families and caregivers) have been taken as the focus of our observational study, paying special attention to premature babies under 32 weeks and/or under 1500 grams due to the risks involved in being subjected to an excessively noisy and luminous environment. As a first step to noise control and management, measurements were made during the month of March 2019 in a public hospital, using a sonometer model KOBAN KS1351 with a measurement range between 35 and 130 dB. Table 1 shows the true peak sound pressure levels generated by different sources in a NICU. Newborns are exposed to noises that exceed 88 dBA during their stay in the neonatal unit. The sources of noise that contribute the most to this aggressive environment are the staff voices and the alarms from medical devices such as respirators, monitors, pumps and other life support devices. The American Academy of Pediatrics (AAP) recommends that background noise level in neonatal units should be less than 45 dBA with transient sound to 65-70 dBA; The World Health Organisation (WHO) recommends levels below 30-35 dBA [16, 17]. Once the design guidelines and recommendations have been implemented, the new results and (noise and light) measurements will be compared with the results compiled in Table 1.

**Table 1.** Frequent sources of noise and measured number of decibels.

| *Sources* | *Sound pressure level in dBC (in the incubator)* | *Sound pressure level in dBC (out of the incubator)* |
|---|---|---|
| Close door of small incubator | 89 | 84 |
| Close drawer | - | 76 |
| CPAP / respirator | 78 | 65 |
| Incubator motor | 70 | 50 |
| Sensor medics | 76 | 76 |
| Place analytical tubes | 72 | - |
| Hit with a finger | 88 | 84 |
| | | |
| Pulse oximeter alarms | 81 | 86 |
| Infusion pump alarm | 70 | 78 |
| Respiratory machine alarm | 76 | 82 |
| Monitor alarms | | 85 |
| CPAP alarms | | 82 |
| Close the door | - | 85 |
| Move chair | - | 80 |

## *4.1 A Developmental Centered Care and Human-Centered Design multidisciplinary approach*

The proposed procedure for obtaining a series of design guidelines for noise and light reduction in NICUs is shown in Table 2. The contribution consists in the development of some tasks to be carried out separately by clinicians from a Developmental Centered Care approach and designers with a Human Centered Design focus; and some complementary activities to be carried out by a multidisciplinary team comprising participants from both disciplines.

**Table 2.** Tasks to be developed separately, and by a multidisciplinary team.

| *Phase* | *Clinicians* | *Designers* | *Multidisciplinary team* |
|---|---|---|---|
| *Initial research* | Previous investigation:<br>-Analysis of the general context in NICU.<br>-Gathering of existing literature on the relevance of the environment in possible sequelae on neonates.<br>-Support of scientific data on the influence of sensory stimulation on neonates in sleep and wakefulness.<br>-Support of scientific data on the development of the auditory and visual system of the newborn. | Previous investigation:<br>-Study of alarms in diverse critical environments, but especially in hospital settings (more general, not just NICU).<br>-Centre in the different perspective of the clinicians, babies and relatives.<br>-Support of scientific information from other analogous areas. | Focus the investigation on:<br>- Influence of the alarms in a NICU unit on the presence of environmental noise and its impact on the development of the newborn.<br>- Approach from a broad context that starts from the study of alarms in general critical contexts, then sanitary, then NICU. |
| *Specific research* | Empirical observation:<br>-Description of noise and light sources in NICU.<br>-Measurement of environmental noise and light.<br>-Observation of the effects of noise and light in newborns, personnel and family. | Focus the study on alarms in healthcare environments:<br>-Description of types of alarms.<br>-Multimodal perspective (sound alarms vs other types of alarm).<br>-Perspective psychology of perception and communication theory. | Detailed description of the NICU ecosystem in relation to the presence of noise originating from alarms and its influence on newborns, staff and family members.<br>Detailed reference of the theoretical and scientific framework that contextualizes the empirical observations. |
| *Analysis* | General comparison of the characteristics of intrauterine vs external environment. | Categorization of the types of sounds present in the external environment, produced by machines and equipment (Causal / Intentional). | Comparison of the sonorous characteristics of the intrauterine versus external environment, describing the latter in a more systematic, extended and detailed way respecting to machines and devices. |

| | | | |
|---|---|---|---|
| *Needs identification* | Identification of opportunity: Improvement of care (Description of requirements). | Identification of opportunity: Improvement of care (Description of requirements). | Identification of intervention points and opportunities for improvement. |
| *Ideation* | List of proposals for NOISE reduction and adaptation of the LIGHT. | Adaptation of the model Event / Alarm / Reaction. This relates and allows positioning:<br><br>-The event to be measured by the machine or installation.<br><br>-The type of alarm used to provide staff with a type of information and trigger their response.<br><br>-The type of response, its risk of success / error, its promptness. | Mapping of the particular NICU case on the model of the Event / Alarm / Reaction of:<br><br>1. Situation previous to the list of proposals of the clinical team.<br><br>2. Situation expected after implementation of proposals. |
| *Proposal prototyping* | Drafting of a decalogue / compliance / protocol of action. | Validation of the adapted-to-case Event / Alarm / Reaction model. | Review of the decalogue.<br><br>Drafting of conclusions.<br><br>Justification of the adequacy of the measures proposed in the decalogue.<br><br>Implementation and evaluation of the obtained results. |

## 5 Design guidelines for noise and light reduction

As a result of the multidisciplinary iteration, the proposals listed below were considered as the most relevant design recommendations for noise and light reduction (see Table 3 and Table 4). Work is currently under progress and the benefits are still to be evaluated to obtain quantitative data after a reasonable implementation time. Data compiled in Table 1 will be used as a reference to stablish comparison and rank future achievements.

**Table 3.** Measures for noise reduction.

| *Measures for noise reduction* |
|---|
| Staff sensitization: a brochure will be delivered to the parents and staff. |
| Avoid talking loud, and when close to incubators speak in whispers. |
| Avoid the accumulation of medical personnel: talk in restricted areas or offices. Avoid accumulation in the NICU entrance and especially in changes of guard. |
| Reduce slamming doors in main entrance, vending machines and lockers. |
| Switch or mute mobile phones. |
| When intermittent withdrawals of CPAP or high flow are made, withdraw them from inside the incubator and turn them off, closing the flow. |
| When the BiPAP Infant flow is withdrawn intermittently, remove it from the incubator and place an adhesive in the areas of the cannulas to avoid the alarm jumping due to low flow. |
| Control the alarm of the minute volume of the respirator. |
| Control periodically the accumulation of water in the breather pipes and remove it. |
| Careful opening and closing of incubator. |
| Do not touch the incubator with fingers or place objects on it or write on them. |
| Reduce alarms volume, transform into light alarms if possible and respond asap. |
| Telephone: reduce the volume and move it away from the incubator areas. |
| Install and maintain a sound level meter or decibel meter. |

**Table 4.** Measures for light reduction.

| *Measures for light reduction* |
|---|
| Light in the unit to be tenuous, being almost obscure where the most premature newborns are. To the extent possible, use individual and controlled intensity light bulbs for each child, covering the eyes to avoid direct light to the eyes. |
| Light sleep-wake transition: keep dark environment in the night hours and dim light during the day. When the children are manipulated, try to perform when they are awake or wake them up in a soft and progressive way, not abruptly. |
| Provide use of covers in younger children on incubators. |
| Close monitoring of children who carry nasogastric tube or via, controlling it every hour through the use of flashlights. |
| Use natural light whenever possible. Blinds will be kept low both in the NICU and in neonates, closing them completely when direct light comes in. |

## 6 Conclusions

Available knowledge from product design expertise of aspects related to the identification of user needs can be greatly appreciated in areas closely related to human experience, such as healthcare [14,18]. In addition to this, design activity contributes significantly to the improvement of the proposals arising from professionals from other fields of expertise. Multidisciplinary team working and co-creation provide a capacity for problem-solving, consistent with open innovation strategies. Besides, a multidisciplinary approach takes advantage of the human centred design approach, the knowledge of technology implied in the development of advanced devices (such as those present in NICUs) and the possibilities of the state-of-the-art graphic interface design, in collaboration with the expertise contributed by the clinicians. All in an organized and objective focused manner. Future measurements of noise and light are still to be taken in order to quantify the obtained benefits, and compared to those compiled in Table 1. Also further observation must be carried out at different moments of activity (i.e. day vs night, or week day vs weekends, or while different nurse teams are at work).

The multidisciplinary iteration can provide very useful results, although sometimes team working can be difficult due to the different technical formation, knowledge and professional culture of the participants. Thus, a future line of investigation is to provide tools and a general framework to ease the incorporation of design procedures to the ambit of healthcare.

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