Noise Pollution Control System in the Hospital Environment

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Abstract. Problems related to environmental noise are not a new subject, but they became a major issue to solve because of the increasing, in complexity and intensity, of human activities due to technological advances. Numerous international studies had dealt with the exposure of critical patients to noisy environment such as the Neonatal Intensive Care Units; their results show that there are difficulties in the organization in the developing brain, it can damage the delicate auditory structures and can cause biorhythm disorders, specially in preterm infants. The objective of this paper is to present the development and implementation of a control system that includes technical-management-training aspects to regulate the levels of specific noise sources in the neonatal hospitalization environment. For this purpose, there were applied different tools like: observations, surveys, procedures, an electronic control device and a training program for a Neonatal Service Unit. As a result, all noise sources were identified -some of them are eliminable-; all the service stable staff categories participated voluntarily; environmental noise measurements yielded values between 62.5 and 64.6 dBA and maximum were between 86.1 and 89.7 dBA; it was designed and installed a noise control device and the staff is being trained in noise reduction best practices.

1. Introduction
Noise pollution is a major issue to face and resolve as far as that human activity has increased, due to technological advances, both in complexity and in intensity. This transformation is also reflected on the development of the health care system which has changed from strictly palliative to preventive care, being the last one a fundamental pillar in the patient quality of life with its consequent increase in life expectancy. The personal notes of the British nurse Florence Nightingale -pioneer of modern nursing- marked the beginning on investigations of noise control in the hospital environment with her famous phrase "Unnecessary noise is the most cruel abuse of care which can be inflicted on either the sick or the well" [1]. This phrase becomes, once and again over time, a guide for those who want to deepen the knowledge to improve patient care and emphasize on prevention to avoid new diseases.

In the last 40 years, several papers had reflected the ongoing work of research groups around the world associating the continuous exposure to excessive noise levels –in critical patients as in health workers- with deficiencies in the disease recovery process, diminished quality of life and hindering the normal execution of tasks, affecting attention, communication and learning. These studies had allowed to identify at-risk populations that are more susceptible to suffer hazardous consequences caused by this air polluting agent, such as those who are hospitalized in General Intensive Care Units, Coronary Units or catheterism, newborns with low birth weight and/or pathological preterm infants most of which have not fully developed their hearing. Other papers had analyzed different methods of measuring and registering -both in the environment and inpatient unit-, analysis of national and international regulations, among other aspects [2, 3, 4, 5, 6]. However, up today there is no an unified criteria to lead such investigations [7] and it is possible to state that it is not enough to have a high level technology and a trained staff, it is necessary the presence of an integral healthcare humanized vision, involving direct and indirect responsible actors of patient care, for taking effective control and reduction noise actions.

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Since 2007, in San Miguel de Tucumán-Argentina, the Gabinete de Tecnologías Médicas (GaTeMe) of the Departamento de Bioingeniería of the Facultad de Ciencias Exactas y Tecnología of the Universidad Nacional de Tucumán (DBI-FACET-UNT), the Electromedicine Department of the Sistema Provincial de Salud (SIPROSA) and the Department of Human Resources of the Ministry of Public Health work jointly solving the emerging problems.

The Instituto de Maternidad (IMNSM) is a public institution, in the northwest of Argentina, considered as Reference in its specialty; is one of the ten high complexity hospitals in Tucumán and is classified “Level 3” according to the Organization and Functioning of Neonatology and Neonatal Intensive Care Units (NICU) services guidelines of the National Ministry of Health –R.M. 306/02- and is the last step before to derive, the most complex cases, to Hospital Juan Garrahan in Buenos Aires, Argentina; it has approximately 1250 permanent employees including medical, technical and administrative staff. In 2012, the new Neonatology Service (NS) was inaugurated, it provides healthcare to all newborns (NB) without social insurance or those whose health condition cannot be solved in other provincial health institutions, whether public or private. It has 60 Neonatal Internation Units –incubators and infant warmers- distributed as follows: 25 in Intensive Care, 23 at Intermedia Care, 12 at Growth and Nutritional Recovery, and 3 at Pre-Medical Discharge. This institution attends more than the half of births of the province and this number varies between 11,000 and 13,000 per year, and has one of the highest birth rates in Argentina, with a daily NICU census among 55- 70 patients [8].

The GaTeMe has made several noise levels measurements and their results were published few time ago, they were of 24 h duration and the average value obtained was 63 dBA, consistent with results found in the international literature for different healthcare institutions [9, 10, 11].

In comparison to other controls of pollutants present in the environment, the environmental noise control is not treated as a priority; perhaps because most of its effects become evident in the long term and are not often noticed by those who suffer them until they have turned severe and irreversible. Currently, the information about dose-response relationship in human beings is not homogeneous and it can be found endless criteria around de globe, however there are no doubts about the harmful effects of noise. Therefore, some actions are needed to limit and monitor the noise exposure based on an appropriate scientific assessment, particularly the dose response relationship because it is the basis in an evaluation process and risk management [12].

Finally it should be noted that a critical patient, such as premature or pathological newborn (NB), exposed to a hostile acoustic environment such as NICU, hinders the organization of the developing brain. In case of being under excessive, continuous and high-pitched noise levels, it could show up some injury in the sensitive hearing structures with a high risk of hearing loss and biorhythms disorders.

The purpose of this paper is to present the development and implementation of a system, which addresses technological, management, and training aspects in order to monitor and control the noise pollution levels focused to neonatal hospitalization.

2. Materials y Methods

The different stages for the developing of the noise control system are detailed below. They could be applied in any health institution, whether public or private, when a noise reduction policy is desired.

2.1. Adaptation period

In this stage, the working group that is external to NS, should become familiar with the daily tasks of the service staff, working in partnership to generate a collaborative working environment. It must be avoided any change in habits or behavior of the staff, as well as the characteristics and dynamics of its functioning. The IMNSM is a Maternity with Family Centered Policy (MFC) and this is the reason why it has the following features: unlimited access for parents during the 24 hours, prearranged visit schedule for grandparents and siblings, residence for mothers and a multidisciplinary team formed by 4 professionals under “Newborn Individualized Developmental Care and Assessment Program” training (NIDCAP) -in order to apply the Family-centred developmentally supportive care (FDSC)-. NIDCAP is a FDSC reference method and nowadays this team is the only group on Argentinian Northwest enrolled in this
training that focuses into the observation, characterization of the physical space and adequate care of patients, trying to improve the interaction between family -that takes care of the NB- and staff [13]. Once the IMNSM Research and Teaching Committee approved the project and previous to any action in the NICU, a series of interviews were performed, to key actors of the project -Medical Director of NS, NIDCAP team, Technical Director-. This allowed to detect needs in order to develop tools to enable a prompt recognition, properly based, to decide the actions to be taken. There were developed and implemented both, a survey to the NS staff -performed by applying a set of techniques designed to gather data about selected issues in a systematically way- and in vivo-in situ observations to register any event that disturb the NICU environment [14].

It was designed a descriptive cross-sectional study; the population was composed by the SN staff located at the IMNSM’s 3rd floor that, fully or partially, develops their tasks at these facilities, inasmuch as their activities create the micro and macro environment of the service. The survey design was leaded by GaTeMe, was reviewed, approved and authorized by the NIDCAP team, the Head of SN and the IMNSM Research and Teaching Committee. The participation was voluntary, including “closed-ended questions” -the subject must choose one or more answers from a pre-set list- and “open-ended questions” -subject can respond freely using their own words-. The application methodology was self-administered -no interviewer is required -, saving resources and allowing the simultaneous filling of several questionnaires at each turn. This also reduced the bias that would produce the interviewer presence, because the instrument was filled at his absence -on a separated physical space- providing privacy, anonymity and giving time to consider his answer to the interviewee. The survey was divided into 5 sections -Employee information, tasks performed, noise sources, noise level knowledge, suggestions and personal opinion- [15]. The second tool -“observation”- was the systematic, valid and reliable record of behavior or overt conduct [16]. Two ways of implementation can be chosen:

- Participatory observation: where the observer interacts with the subjects observed
- Non-participatory observation: where the observer does not interact with the subject observed.

Non-participatory observations were chosen at two different moments: initial reconnaissance observations and during environmental noise measurements. The most significant issues noted were the work rate, staff attitudes, tasks performed, handling ability of Medical Technology (MT), number of people present at NICU, among others, in order to correlate or identify particular variables or noise sources that could not be detected or stated by staff in the survey.

2.2. Inspection and Environmental Noise (EN) Measurements
The GaTeMe developed noise measurements procedures and reports for Neonatal Services according to ISO 17025 / IRAM 301 guidelines. These documents state the steps to perform EN measurements at NS, recommending its use in NICU services because they attend the most complex and unstable patients. The procedures are based on the standards IRAM 4113-1 & 2 / ISO-1996 1 & 2, IRAM 4074-1 & 2 / IEC 61672-1 & 2, IRAM 4220-1 &2 / IEC 60601-1 & 2-19 and the American Academy of Pediatrics Recommendations (AAP) [17]. There were performed a series of A frequency weighted sound pressure level (SPL) measurements, sampled every second for 24 hours, on days detailed below: March 26 (Day 1: Start at 11:00 h), March 27 (Day 2: Start at 21:00) and March 30 (Day 3 : Start at 13:00 h) of 2014. Measurement periods were selected in order to record during the weekend, visiting schedule -grandparents and siblings- and Medical interconsultation -regular activity among internal medicine specialists-. The instruments were placed without disrupting the staff work, the microphone was located at 1.20 m above the floor based on the patient location and evaluating the most critically inpatient unit -as closely as possible to the incubator to get data of the nearby environment under working conditions-. The AWIC tool -web application for the clinical engineering area- provided the information about the NS equipment [18]. The available MT manuals were evaluated to study their operating principles, modes of using and configuration of basic parameters, in order to find repetitive errors or problems in their operation that turn them into noise sources, for the developing of both, control and noise reduction.
The infrastructure facilities inspection found that the NS covers an area of 820 m² and is made up of external brick walls and double-glazed glass panels on the north side—bordering Mate de Luna avenue—which is basically an air sealed camera enclosed between two layers of glass of 3 + 3 mm each one. This build, sets and guarantees a volume of dry air between the layers, and this air chamber reduce heat transfer between indoor and outdoor while reducing the entry of solar radiant energy and noise transfer. The new structure, built during remodeling inside the floor, was executed by using masonry partitions with iron structures, plasterboard ceilings without any insulation or sound absorption components on the upper dome formed by such plates and the original ceiling. Internal divisions were solved applying dry construction method using shock and impact resistant, waterproof, and fireproof materials.

2.3. Environmental Noise Warning Device

Among the solutions that can be proposed to mitigate this problem, some are administrative and others lead to design and develop specific supporting technologies. Worldwide, there are control-monitoring level devices for noise pollution for those environments where there is a need to warn or indicate when a preset safety noise limit has been reached—values defined by legislation or international recommendations-. Today, there are no devices—made in Argentina—with this features, therefore, health care institutions must contact sales providers or import these devices. Therefore, health institutions face high international prices and difficulties to import, which discourages incorporating this technology. In search of a solution, the academic field have designed and developed a device called "Electronic Ear", whose purpose is to monitor the noise level and activate a warning visible light signal. The values referred below as safe and dangerous are configurable, allowing a gradual adjustment, always aiming to get to the lowest levels possible.

For this application the chosen limits are:

1. If the measured value < Safe value, the visible light signal is GREEN
2. If the safe value < Measured value < Dangerous value, the visible light signal is YELLOW
3. If the measured value > Dangerous value, the visible light signal is RED

This device can be used in critical services as well as in any other environment in which, after making an EN assessment, monitoring results indicate that there is one of the following situations:

1. The use of Personal Protective Equipment (PPE) its required
2. No PPE needed, but there are high noise levels during working hours, or pregnant women during their gestational period exposed to high noise levels.
3. Health institutions with patients on treatment and / or recovery where low noise levels are needed to guarantee their evolution and improving the care quality.

It should be noted that this device is a facilitator for the implementation of a “culture of silence”, with all the benefits that this implies. Figure 1 shows a simplified block diagram of the “Electronic Ear Vincent 1.0”.

![Figure 1: “Electronic Ear” simplified block diagram](image-url)
The 1st block captures the sound signal via an omnidirectional electret microphone, with flat frequency response in the range of audible frequencies and a sensitivity of 18 mV output for a signal of 1 Pa at 1 kHz. The acoustic signal, transduced into an electrical signal, is amplified by a ultra-low noise operational amplifier and conditioned by filter cascades that consist of a band pass filter to remove low frequency components above 16 KHz (because they are not of interest for the actual purposes), a notch filter to eliminate 50 Hz noise, and finally an "A-weighted" response active filter. The frequency weightings are defined in the standards to which a noise measurement instrument is designed, in this case the filter transfer function is defined in the standard IEC 61672-1 by the following equation [19]. This standard also specifies the performance and tolerances for the frequency weighting curves to be used.

\[ A(f) = 20 \cdot \log_{10} \left( \frac{f_4^2 \cdot f_4}{(f^2 + f_1^2)(f^2 + f_2^2)^{1/2}(f^2 + f_3^2)^{1/2}(f^2 + f_4^2)} \right) - A_{1000} \]

In this equation the constants \( f_1 \) and \( f_4 \) are calculated from the solution of two biquadratic equations (See section 5.4.9 of the Standard) while \( f_2 \) and \( f_3 \) constants represent poles that are obtained from linear equations (See section 5.4.10 of the Standard). The \( A_{1000} \) normalized constant, expressed in decibels, represents the power gain needed to provide a 0 dB frequency weightings at 1 kHz and its value defined in the IEC is -2.000 dB, while \( f_1 = 20.60 \text{ [Hz]}, f_2 = 107.7 \text{ [Hz]}, f_3 = 737.9 \text{ [Hz]} \) and \( f_4 = 12194 \text{ [Hz]} \). With this values, the active signal processing network filter -to adapt the system response to the human ear- was synthesized applying the Butterworth approximations and was implemented by using ultra-low noise operational components.

The weighted signal is amplified to obtain easily manageable electrical values and is squared to obtain its effective value. In this stage, the weighted noise value could be read but the instant noise variations are so fast and therefore the operator will face serious difficulties to register it. In order to measure sound pressure levels of fluctuating sounds, it can be selected one of these two methods:

- Peak values: Is the fastest analysis method that takes as reference the peak levels of the audio signal; it is not the same as the Maximum Sound Level -referred to as the Lpeak or sometimes Lpk-. There is no time-constant applied and the signal has not passed through an RMS circuit or calculator. This is the true Peak of the sound pressure wave.
- Root Mean Square (RMS) Values: Takes as reference the average value of the audio signal -shows the range where most of the energy is concentrated-, not only the peaks at particular instants.

As the physiological response of the human ear can be equated to measure RMS value of fluctuating sounds -for example, if a person hears a thunder of few seconds and in that time heard a thunder higher in intensity than the first, the subject perception will be such that the increase in volume is similar to the RMS value of both sounds and not as a maximum or peak value (PEAK) like in electrical analysis- it was used a logarithmic output True RMS-to-DC Converter chip.
The A weighted output signal and two adjustable DC voltage values -representing the thresholds defined as safe and dangerous- are driven to the PIC16F628A microcontroller Inputs in a comparator mode that in addition it was programmed to change between 3 externally configurable comparison times -1, 2 or 3 seconds- according to the staff desire. This module controls the visible warning signal made of high intensity RGB LED strips. All the parts and components were mounted in a molded cabinet of 2mm thick steel sheets welded to avoid the entry of dust and/or contaminants. It consists of a rear cover; a frame and a divider that serves as a support for the frontal acrylic on which has been recorded an image -ear shape- in order to facilitate the warning interpretation (see Figure 2).

![Figure 2: 3D graphic representation of the Noise Control Electronic Dispositive](image)

2.4. Capacitation

This is an effective mechanism to motivate the employees, particularly for those workers that believe that they have not reach their maximum capacity yet. PAHO has a pedagogical line, work-study methodology centered, designed to give a “in-service training” to health care staff because they consider that is not enough to offer training programs to institutions -taught courses and conferences at work environments often lack commitment to effective work processes-. Based on these guidelines, the training process began forming a workgroup and performing meetings with the participation of the IMNSM Directors Board and NIDCAP team as a space to discuss-analyze-propose-authorize the applicable possible solutions, which are currently in development, for the implementation and support of the IMNSM NIDCAP program.

The designed training program based on the NFI guidelines and the previously performed team tasks includes themes like “Introduction and theoretical concepts of FDSC”, “Professional role in the FDSC”, “Synactive Theory of Infant Development”, “Benefits of FDSC”, “Macroenvironment-Microenvironment and family”, “Light as an environment pollutant: Harmful effects, measurement units, typical NICU values”, “Noise as an environmental pollutant: Harmful effects, measurement units, typical NICU values”, “Interventions to improve the care quality”, “NICU noise and light intensity: situational diagnosis”, “Recommendations and strategies to minimize noise: Parents and staff”, “Family role as a natural caregiver”, “The importance of teamwork to implement the FDSC”.

3. Results

The period of adaptation allowed a deep knowledge of the actual operation of the NS, allowing to identify
critical points and to detect the main high noise pollution levels generators. The NS mainly perform a
permanently overloaded healthcare work, where the days of highest demand correspond to the beginning
of each week, especially after of a 72 h long weekend, and along the year the workload rate shows a
pronounced increase due seasonal diseases. In this context, MT is an important noise source either in
normal or wrong operation or due to insufficient knowledge, wrong configuration of alarms and control
parameters.
Modern noise measurement instruments acquire, store and analyze the data (data logging) simplifying the
field tasks, becoming in other instrument of the NS equipment set. However, in this case, it was necessary
the presence of an operator to register the noise events that, applying his expert judgment, were
representative during the identification of noise sources process. It was extremely important the
interchange and contact with staff previously to any installation, operation and record of the noise
measurement equipment to facilitate the understanding of the objective and to generate a cooperative
environment avoiding the alterations in the staff behavior and customs –as an example, stating that it does
not register voice or conversations-. Therefore the non-participatory observations allowed to categorize the
noise sources according to their frequency of occurrence as shown below:

![Figure 3: Causes and Noise sources identified at the observations according to their frequency of occurrence](image)

All the data acquired were analyzed searching for time zones with an increase or decrease trend and
correlate them with the operation of the NS. The results of this analysis are in table 1; it shows the quantity
of time in which the 70 dBA and 80 dBA were exceeded -extremely high EN values for NS-. It can be
noted that the greatest density values that exceeded 80 dBA are located on the 3rd Day which corresponds
to Sunday-Monday measuring period, and the mayor noise pollution time slot was Monday from 7:00 to
12:00 am. This is correlated with the visits of specialists and external interconsulting physicians, diagnosis
and NB monitoring procedures, exceeding the values registered during visiting of siblings and grandparents.

| SPL (dBA) | T>70 (dBA) | T>80 (dBA) |
|----------|------------|------------|
| Dia 1    | 62.94      | 20'15''    | 1'14''     |
| Dia 2    | 62.53      | 23'35''    | 0'09''     |
| Dia 3    | 64.60      | 72'01''    | 8'45''     |
For the patient macroenvironment analysis, were performed both the data acquiring and the NIDCAP observations techniques. It can be noted that during some regular maneuvers carried out on newborn, there is a tendency to a heart rate increase, significant changes in oxygen saturation and respiratory rate; as can be seen in the following graphs.

For the survey, there was the voluntary participation of 121 of the 195 employees of the service (62.05%) and all occupations were represented. The analysis of their answers determined that the respondents perceive a change in the noise level during day hours (60.48%) highlighting morning shifts and particularly on Mondays during the performing of different medical procedures. This allowed to change the preconception that visits are the cause of the largest noise pollution compared to other sources, and this was an important tip for the capacitation design to staff and subsequent implementation of the MFC policy.

Figure 4: Results obtained at the NIDCAP observation. a) Noise levels inside and outside the Infant Incubator; b) Changes in oxygen saturation percentage and light levels inside the Infant Incubator; c) Changes in heart and respiratory rate before and during a nursing procedure.
At present, the training has been completed by 80% of staff and at first it was led to medical specialties, nursing and kinesiology chiefs. Currently is being elaborated a differential training, led to the non-health care staff to whom this problematic and solutions must be presented from a different perspective.

For the installation of the "Electronic Ear" it has being developed a three stages measurement procedure: prior to installation, during installation and tracking operation over time at control intervals –today in application-. The last two stages are sources of further comments and improvement proposals as a continuous feedback process for the multidisciplinary teamwork.

4. Conclusion

The data analysis shows that the equivalent SPL values are higher than those recommended by the AAP and other international recommendations, but similar to those reported by health care institutions all over de world; it also shows similar values compared to those obtained in previous evaluations –since 2009-. This work performs an evaluation about the role of social component in the environmental noise levels, relationship between the levels of light and noise pollution, and the effects that those agents can generate on human behavior with its subsequent impact on neonatal macro environment.

The noise sources identification process was systematized, allowing their standardization and its potential replication in any service or health care institutions. The methodology adopted allowed a quick familiarization of the service to any external actor or in case of external audit to evaluate the acoustic situation. Regarding the noise sources observed, it could be conclude that some of them are potentially minimized or eliminable, principally with the cooperation of professionals and family –as an example, less loudness of alarms-. This is the reason to bring the training process first to all chiefs of service and specialties. Each hierarchical actor of the different medical specialties, has begun the in-service training for workers with the objective "small changes in behavior will deeply improve the hospitalization conditions". However, there are other sources that depend on the architectural design of the NICU and may not be possible to easily modify -e.g. sound of falling water for hands hygiene-, limiting the implementation of some actions. The main way to mitigate noise pollution is raising awareness via a continuous training programs that include topics like Family-centered developmentally supportive care –also referred as FDSC-, Newborn Individualized Developmental Care and Assessment Program -known as NIDCAP- and effects of the Environmental Noise (EN) on newborns (NB), all this accompanied by Best Practices Policies Design with axes on training both staff and family. Through this project the mitigation of environmental noise was tackled from data analysis instead of subjective analysis plus the designing of specific technology to suit the requirements of the institution support staff. It is vital to create a collaborative working environment, strengthening the feeling of safety, trust and confidence from parents to health care staff, turning them as an example of behavior to imitate.

The set of tools described can be adapted and replicated in any services in health care institutions, with the hope of contribute in improving the operation of critical care services, providing quality care and the best possible working environment for health care staff, family and patients.

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