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Review Article

Noise Measurement in NICUs and Incubators with Newborns: A Systematic Literature Review

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This systematic literature review evaluated the methodological quality of studies measuring noise in neonatal intensive care units. A manual and also electronic search in the Medline, Scielo, Lilacs, BDENF, WHOLIS, BDTD, Science Direct, NCBI and Scirus databases resulted in 40 studies that met the criterion "measuring noise in neonatal units and/or incubators". Experts in neonatology and acoustics validated the critical analysis instrument, which obtained a mean = 7.9 (SD=1.3). The inter-observer reliability in 18 articles resulted in an Intra-class correlation coefficient (ICC) of 0.89 (CI 0.75-0.95). The quality indicators were 50% better in those studies that measured noise only in the unit's environment and associated measuring strategies to the physical area. The results showed great methodological variability, which hindered comparability and raised the probability of bias. The conditions required to ensure internal and external validity were observed in few studies.

Descriptors: Noise Measurement; Intensive Care Unit Neonatal; Review Literature as Topic.

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Mensuração de ruído sonoro em unidades neonatais e incubadoras com recém-nascidos: revisão sistemática de literatura

Trata-se de revisão sistemática de literatura para avaliar a qualidade metodológica dos estudos que mediram ruído nas unidades neonatais. Após busca nas bases eletrônicas MEDLINE, SciELO, LILACS, BDENF, WHOLIS, BDTD, ScienceDirect, NCBI e Scirus, e busca manual, foram incluídos 40 estudos que atenderam o critério "mensurar ruído em unidades neonatais e/ou incubadoras". O instrumento de análise crítica foi validado por especialistas em neonatologia e acústica – nota média 7,9 (dp=1,3) – e a confiabilidade interobservador, em 18 artigos, resultou num coeficiente de correlação intraclasse (ICC) de 0,89 (IC95% 0,75-0,95). Os indicadores de qualidade foram 50% melhores para os estudos que mediram somente no ambiente da unidade ao associar as estratégias de mensuração à área física. Os resultados revelaram grande variabilidade metodológica, o que dificulta a comparabilidade e, algumas vezes, representa alta probabilidade de viés. O rigor necessário para garantir a validade interna e externa foi observado em poucos estudos.

Descritores: Medição de Ruído; Unidade de Terapia Intensiva Neonatal; Literatura de Revisão como Assunto.

Mensuración de ruido en unidades neonatales e incubadoras con recién nacidos: revisión sistemática de literatura

Se trata de una revisión sistemática de la literatura para evaluar la calidad metodológica de los estudios que midieron el ruido en las unidades neonatales. Después de buscar en las bases electrónicas Medline, Scielo, Lilacs, BDENF, WHOLIS, BDTD, Science Direct, NCBI y Scirus, y de busca manual, fueron incluidos 40 estudios que atendieron el criterio "mensurar ruido en unidades neonatales y/o incubadoras". El instrumento de análisis crítico fue validezo por especialistas en neonatología y acústica – nota media 7,9 (DE=1,3) – y la confiabilidad inter-observador en 18 artículos resultó en un ICC de 0,89 (IC95% 0,75-0,95). Los indicadores de calidad fueron 50% mejores para los estudios que midieron solamente en el ambiente de la unidad, asociando las estrategias de mensuración al área física. Los resultados revelaron gran variabilidad metodológica, lo que dificulta la comparación y algunas veces representa alta probabilidad de sesgo. El rigor necesario para garantizar la validez interna y externa fue observado en pocos estudios.

Descriptores: Medicíon del Ruido; Unidades de Terapia Intensiva Neonatal; Literatura de Revisíon como Asunto.

Introduction

The use of technology to care for newborns has improved survival though it has also transformed neonatal intensive care units (NICU) into very noisy places[1-2]. Noise in these places can affect newborns, increasing their heart rate and respiratory frequency, dropping their oxygen saturation, diminishing the duration of their sleep state and hindering their ability to stay in a deep sleep state, and also causing alterations in their motor activity[3-4].

Health organizations and experts have tried to establish guidelines limiting the levels of noise in NICUs. WHO recommends that noise in hospital facilities should not exceed 30 dB(A)[5]. The American interdisciplinary committee indicates acoustic treatment so that habitual noise does not exceed the recommended parameters: hourly Leq of 45 dB(A), hourly L10 50 dB(A), and Lmax de 65 dB(A)[6]. The Brazilian standard NBR 10152, approved by the Brazilian Technical Standards Association (ABNT)

indicates that levels up to 45 dB(A) are acceptable for nursery wards but do not specify limits for NICUs[7].

Even though knowledge concerning damage caused by early exposure to high levels of noise needs to be improved, stays longer than 48 hours in NICUs are already considered a risk factor for infants' hearing impairment[8-9]. Additionally, changes observed in the development of newborns have encouraged the implementation of new approaches in care delivery that include rebuilding the physical environment of NICUs, especially in relation to the monitoring and control of noise levels. This is an issue to which both Brazilian[10] and international[1,4] nursing professionals have considerably contributed.

Given the potential risks to the patients cared for in NICUs posed by noises, the sound levels of these facilities need to be known. This knowledge is essential in order to implement changes that enable controlling and reducing noises. Given the physical characteristics of these facilities, quantity of equipment and transit of personnel, measuring the level of noise in NICUs is a complex task and a significant challenge. Some authors[11-12] and organizations[13] have studied theoretical concepts of acoustic and methodological issues that meet the specificity of this measurement. Since the 1970s, various researchers have evaluated sound levels in the environment and incubators of NICUs. Identifying how these researchers performed measurements can enable the development of sounder studies. Therefore, this study presents a systematic literature review to evaluate the methodological quality of studies measuring sound levels in the environment and incubators of NICUs.

Method

This systematic literature review was based on a search carried out in electronic databases: Medline, Scielo, Lilacs, BDENF, WHOLIS, BDTD, Science Direct, NCBI and Scirus. Multiple combinations of key words in Portuguese, Spanish and English were used: Noise; Neonatal; Environment; Neonatal Intensive Care Unit; Incubator; Newborns; Measurement; Sound Level; Sound Pressure Level; Metrology; Sound Contamination. No time limit was established. Theses and dissertations were also searched, as were the references cited in the selected papers, from a manual search and consultations with experts.

The retrieved studies were first screened through their titles. Afterwards, the abstracts of the identified studies were read considering the inclusion criterion "measuring noise in neonatal intensive care units and/or incubators", which resulted in a set of studies that were then fully read and only those that actually met the criterion were included in the study. In addition to the studies that did not meet the criterion, literature reviews, research notes, editorial notes and letters to the readers were excluded.

An instrument was developed to evaluate the methodological quality[14] of the studies based on a review of the literature on acoustics, the Brazilian standards and citations of relevant international standards, and on discussions with experts on neonatology, epidemiology, and engineering in acoustics.

The instrument was content-validated by three experts in neonatology and three experts in acoustics through a questionnaire. They evaluated the instrument's items in relation to its applicability, clarity, specificity of instructions, potential bias, redundancy and incompleteness. Each of these concepts was scored according to a numerical Likert scale, in which the higher the score the better the judgment[14]. The following summary measures of the final scores of validation were described: range, median, average and standard deviation.

The instrument's inter-observer reliability was evaluated by three researchers in a random sample of 43% of papers included, with masking. The Intra-class correlation coefficient (ICC) was used with a confidence interval of 95%.

Each item of the instrument was considered as a quality criterion to measure noise in the neonatal environment; the percentage of studies that met each criterion was calculated.

Results

The bibliographic search was carried out between July 2005 and August 2006 and between December 2007 and March 2008. The search process and the number of papers in the phases of retrieval, identification and selection are presented in the Figure 1.

The final version of the instrument used to evaluate the articles is composed of five modules: Module I – study identification; Module II – characterization of neonatal environments; Module III – measurement methodology; Module IV – measurement of the interior of incubators with newborns; Module V – study design. The final scores of content validation varied from 6.3 to 9.9, median 7.6 and average 7.9 (SD=1.3). The

averages of the evaluations by module varied from 7.6 (SD=1.2) to 8.1 (SD=1.6) and were close to the median scores. Module II obtained the highest average concept (8.1) followed by modules III with 7.9, IV with 7.8, and V with 7.6. The average score obtained by each question in the questionnaire for validation displayed greater variability: between 6.0 and 9.6. Among the experts' significant contributions, the following are highlighted: the inclusion of an item on the calibration of instruments and the removal of some items related to architecture.

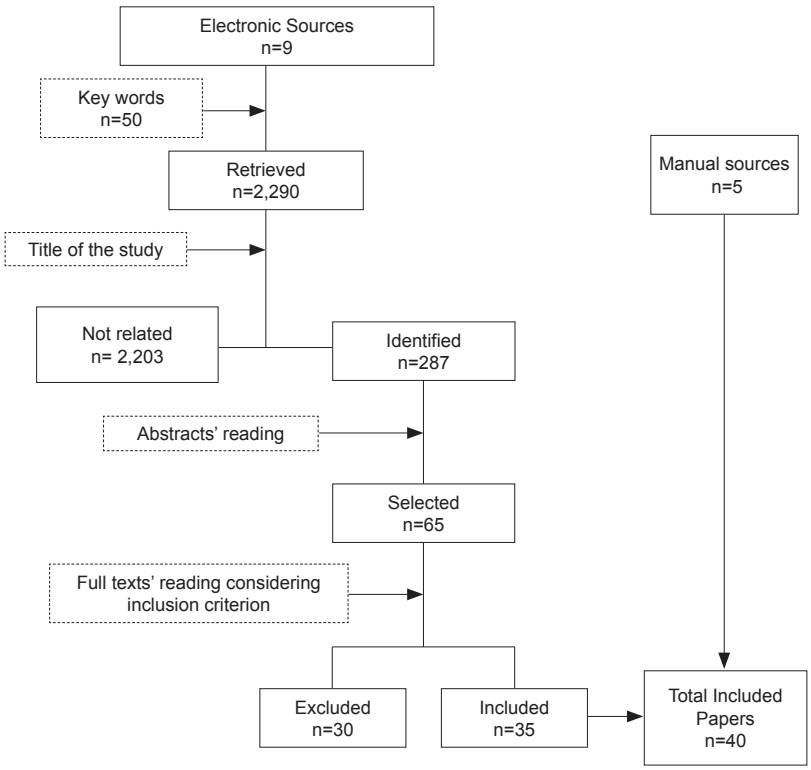

Figure 1 – Process of bibliographic search and number of retrieved papers

The evaluation of inter-observer reliability in 18 papers resulted in a global ICC of 0.89 (CI = 0.75-0.95). For Module II it was 0.28 (-0.58 – 0.71), for Module III 0.89 (0.76 – 0.96), for Module IV it was 0.65 (0.22 – 0.86), and for Module IV 0.83 (0.63 – 0.93).

The 40 studies included in the review were divided into Group A with 24 studies[15-38] that measured noise only in the NICU and Group B with 16 studies[39-54] that measured noise both in the NICU environment and in the incubators. The percentages of adherence to quality criteria evaluated by the instrument are presented in Table 1.

Table 1 – Percentage of studies that met the quality of critical analysis criteria: Group A (n=24) measured noise in the neonatal environment and Group B (n=16) measured noise both in the neonatal environment and inside incubators with newborns

Quality criteria by module	A %	B %
Module II – Characterization of neonatal environment		
II.1. Reported level of noise in the external area	13	6
II.2. Reported the measurements of the physical area/floorplan	88	38
II.3. Related the measurement strategies to the physical area	83	44
II.4. Reported the presence/absence of acoustic treatment	33	33
II.5. Reported the quantity of beds	67	44
II.6. Reported the number of occupied beds	25	6
II.7. Considered the equipments in use	58	56

(continue...)

Table 1 – (continuation)

Quality criteria by module	A %	B %
Module III – Measurement methodology		
III.1. Reported the unit of reference	100	100
III.2. Described the measuring equipment	100	100
III.3. Reported the use of standards	29	13
III.4. Reported the time of noise acquisition	100	63
III.5. Reported the use of frequency – weighting filter (A, B or C)	88	88
III.6. Reported form of acquisition (intermittent or continuous)	79	69
III.7. Reported the time scale used	63	56
III.8. Informed the microphone placement	75	63
III.9. Reported the number of recorded sound events	29	31
III.10. Described the position of the equipment in relation to the sources	13	0
III.11. Leq Measurement	71	44
a. Lmin	8	13
b. Lpeak	25	13
c. Lmax	38	19
III.12. Associated Leq measurement to sources	46	31
a. Associated Leq measurement to different periods	54	13
b. Associated Leq measurement to different events	33	0
III.13. Associated Lpeak values with sources	25	13
III.14. Discriminated the sources of noise	75	75
III.15. Used a field diary to identify sources	33	44
III.16. Associated noise peaks to sources	46	38
Module IV - Measurement in incubators with newborns		
IV.1. Informed where the microphone was placed inside the incubator	-	81
IV.2. Described the life support devices in use	-	69
IV.3. Described exposure to environmental noise in the unit	-	69
IV.4. Associated noise peaks with periods in which the incubator was being handled	-	31
Module V – Study design		
V.1. Performed reliability analysis	13	25
V.2. Reported equipment calibration	67	56
V.3. Masked the real time of measurement	17	13
V.4. Recorded the specialty of the professional handling the equipment	13	13
V.5. Reported training interventions	29	13
V.6. Used representative sample of different periods	42	31
V.7. Used representative sample of different types of noises	46	31
V.8. Reported the average number of people in the unit	25	19

Group A[15-38]
Group B[39-54]

Discussion

The instrument that evaluated the studies included in the review displayed satisfactory face validity[14] (79%). It was also reliable in relation to inter-observer variability according to ICC values, except in Module II, in which difficulties characterizing the neonatal environment were found.

The evaluated quality criteria were most completely verified in the studies that measured noise only in the NICU (Group A) compared to those that also measured noise in incubators (Group B). Such a fact demonstrates the complexity of this task that requires specific and detailed projects.

Characterization of the neonatal environments

Because of the way sound waves propagate, measuring the area's physical dimensions and carefully evaluating the architecture of the places where noise will be measured are steps that enable appropriate planning of the measurement strategies[13]. Most of the studies in Group A[15-34] were more rigorous in relation to these aspects than those in Group B[39-42].

The number of beds occupied at the time of measurement is another aspect that needs to be considered because the circumstances that interfere in the level of noise such as level of activity, number of individuals in the unit, number of life support devices in

use, are directly proportional to the occupancy rate[12]. This information was observed in only 25% of the studies in Group A[28-29,31-34] and in 6% of the studies in Group B[43].

Life support devices in use are one of the main sources of noise in an NICU[12]. A total of 57% of the studies considered the presence of such devices in the measurement strategies. The studies that addressed this issue in more detail were those whose objective was related to the identification of sources[19,24,28-30,33-34,35-36], associated with the adoption of interventions to reduce environmental noise[20,23,41,44].

Only recently did the use of material capable to absorb sound emerge and become consolidated[6,12]. Easily cleaned flooring and covering were already in use due to the need to prevent and control infections, but result in a high level of reflection of sound waves[12]. Such a situation may explain why acoustic treatment is only reported in 33% of the studies in both groups[23-25,27,31,41,44-45] conducted from 2000 on in units that carried out structural changes to reduce noise levels.

NBR 10.151[13] establishes that the measurement of noise levels should also take into account the external area of the place that contains the sources. Few studies (10%) report the level of noise in the external area near the neonatal environment; the number of such studies is higher in Group A[15,20,33] than in Group B[40].

Measurement method

All the studies described the measurement equipment and the most frequently used were Sound Pressure Level (SPL) measurers as recommended by NBR 10.151[13]. More recent studies[23,27,31,33,37,44] also used computer systems with programs to acquire and process noise, which allows more time to capture the noise and more flexibility in analyzing it. The analysis of different sound frequencies motivated the use of octave bands[46-48].

All the analyzed studies measured in dB, complying with standards and recommendations found in the specific literature[11,13]. However, the standards used were reported only in a few studies in both Groups, A[20,22-24,29,33-34] and B[45-46]. It is important to note that these recommendations are usually generic and may not cover the specific complexity of measuring sound in neonatal environments due to the diversity of the units' physical characteristics, sources, and type of care required. One example is the recommendation[13] to perform measurements in at least three different positions with a distance of at least 0.5m between them and a minimum distance of 1 meter between the microphone and any type of surface such as a ceiling, floor or furniture whenever possible to avoid interference and reflections. Even though 75% of the studies in Group A reported the placement of the microphone, these did not provide the details.

The absence of description of the type of frequency-weighting filter and the type of time scale used hinder comparison of results and this inadequacy leads to measurement bias. A large proportion (88%) of studies reported the type of frequency-weighting filter. Filter type A, most recommended for measurements in environments with newborns[11], was the most used. Filter types C or L[11] are the most recommended to measure intense noise of short duration. Of the eight studies that aimed to measure noise with these characteristics, three used filter type C[19,25,34] and two type L[27,49]. A little more than half of the studies in the Groups A[16-17,21-25,27-28,30-34,36] and B[40-42,44,46,49-51] recorded the type of time scale used. A slow timescale is the most recommended to evaluate noise in the NICU, but certain situations, such as measurement of noise peaks, require the use of a fast or impulse time scale[11].

The Leq measure, strongly recommended, was used in 71% of the studies in Group A[16,20-21,23-25,27,29-34,36-38] and in 44% of Group B[41-42,44,46,49-51]. It is important to note that this type of measurement was more frequently observed from the 1990s on, perhaps due to the technological development of measurement equipment and the availability of PCs and software.

Identifying sources of impulsive noise is an essential aspect in the decision concerning what interventions to reduce noise will be required. This type of source was discriminated in 75% of the studies in both groups. In Group A the following were identified: life support device alarms[17,22,24,27-30,32,34-35]; conversation[19,21-22,24-25,28,30,32,34,37]; handling of cupboards, drawers, bins and doors[24,26-27,30,32]; falling objects[24,30]; moving furniture and equipment[17,22,30]; telephones[28,30]; use of sinks[27], and transit of professionals[17]. In Group B, in addition to the equipment alarms[40-42,44,48,51-52] and conversation[41,43-44,49-51], team activities near the incubators were also observed[41,50-51], opening and closing hatches[49-50], voluntary and involuntary contact with the dome[50], and the handling of doors and drawers[49]. The most frequently used strategy to identify these sources was recording, in specific instruments, the points when impulsive noises were emitted and their respective sources with later association to the measured noise levels[17,24,28,30,32-34,37,40-41,43-44,49-50,52].

Another important aspect consists of associating measured noise levels with the days of the week and periods of the day due to oscillations in the care routine of the NICU. Frequent events that occur randomly such as case discussions, urgent situations and admissions should also be considered. This association was predominantly observed in Group A, between measured levels and days of the week or periods of the day[16,19-21,23-24,27,30,32-34,37-38] and between measured levels and different events[16,19-21,24,32-34,37-38]. Only two studies[50-51] in Group B associated the measured levels with the days of the week or periods of the day.

The main difficulty faced in this review was assessing the time of acquisition of sound and evaluating its representativeness, clearly and concretely reported in only one study[27]. The variability related to the different periods of the day, days of the week and work shifts need to be taken into account[19] as well as the frequency of the different events that are part of the care routine of an NICU.

Specific aspects of measurement inside incubators with newborns

Given the reduced area, the placement of a microphone in an incubator is an issue even more critical than in the environment and there is no specific regulation available. Most of the studies in Group B[39,41-42,44-46,49-50,52-54] reported the microphone was placed near to one of the newborn's ears, not exactly describing the position. To avoid interference of any vibration produced in the incubator, we suggest keeping the microphone suspended without contact with any surface[11,47].

Two third of the studies[39,41-42,44-45,47,49,52-54] considered the situations that directly interfere in the noise levels captured inside the incubators – life support devices used by the newborn and exposure to noise of the unit through the incubator's main door and hatches. However, only few of them[40-41,49-50,54] described the association between the handling of the incubator and occurrence of noise peaks in its interior. Situations such as opening and closing the hatches or the intensive care door, moving the mattress tray, or putting objects on the dome may produce noise that varies from 78 to 93 dB[10].

All and any exposure to continuous noise of low frequency such as the incubator's motor, medium frequency (human voice), high frequency (alarms of equipment, telephones) and also noise originating from the handling of incubators, should be considered during the measurement of their interior because these represent potential risks to the newborns' health[2].

Study design

Methodological rigor, necessary to ensure internal and external validity and also the reliability of the obtained results, was not observed in most of the studies. The calibration of equipment, a mandatory procedure before performing measurements[7,11,13], was reported in 67% of the studies in Group A and in 56% of Group B.

The number of people present in the unit during the measurement was recorded in few studies[24,27,31-34,44,50-51]. This is an important determinant of noise levels[30,32,44] given the activities performed by people[30,43], specifically conversation[25,30,32,34,43-44].

A concern in masking the real point when the measurement was taken was not observed in most of the studies. It may lead to biased results since the behavior of individuals in general may change during observation.

Information concerning training/sensitization of people before measurement was found mainly in studies the objective of which was to evaluate the levels of noise before and after interventions aimed to modify the behavior of the team[17,23,26,29,37,43-44].

Verifying how noise was sampled and the representativeness of these samples was another difficulty faced. An important obstacle consists of establishing a concept of sample representativeness since noise levels oscillate according to the dynamic functioning of the NICU. One possibility would be to consider the events that can be prevented. A total of 37% of the analyzed studies described a sample considered representative by the instrument[16-17,19,23-24,27,30,32-33,36,40-41,44,50-51]. The sample design was not identified in the remaining; if it existed, it was not described. Even if there was no intention to intervene, an important aspect for the quality of the study design is the clear description of the sample design. In terms of sample size, the increase in the sample representativeness is directly proportional to a longer time of acquisition of sound and a lower time of integration of noise.

Potential sources of measurement variability are many and diverse and could be the object of reliability analysis. Analysis of the reliability of field records to identify sources of noise and related events is observed in some studies[24,30,32,41,49]. The researchers were previously trained and the observation results were concomitantly compared to evaluate reproducibility.

Final considerations

This review showed evidence of great variability in relation to the methods employed to measure noise

levels in the NICU environment and in the incubators, highlighting inconsistencies in sample size and representativeness, configurations of measurement devices, places where noise was captured and evaluation of circumstances that contribute to the present levels. The study also revealed that advancements and significant improvements occurred over time due to the availability of improved technologies for measuring noise and to facilitate the work of researchers in this field.

Due to the vulnerability of the patients cared for in these units, controlling the level of environmental noise should be a practice adopted in every NICU. Since each unit has its own physical and functioning characteristics, the measurement of noise, even while a complex task, needs to be performed in each unit. Additionally, further research is needed to establish the noise levels that do not pose risks to newborns, especially preterm infants. The first step to conduct these investigations is to acquire accurate knowledge concerning the levels of noise present in the unit environment and inside incubators. The recommendations noted in this study's discussion can support new studies to measure noise levels with the highest quality possible in relation to the current stage of knowledge in the field.

The publication of Brazilian studies in the field is still incipient, since most of the studies were performed in other countries. However, six of the seven Brazilian studies analyzed were developed with the direct participation of researcher nurses. This fact shows that Brazilian Nursing is in consonance with the new approaches of neonatal care, is concerned to adapt the environment of NICUs for newborns, particularly in relation to noise levels. This study can be an important reference source for the development of such a task.

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