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Assessment of environmental noise and its effect on neonates in a Neonatal Intensive Care Unit

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A method for analyzing the influence of noise on newborns is proposed. The method consists of defining three different types of time interval (quiet, noisy and nursing) and, for each period, environmental noise levels, heart rate, mean arterial pressure and oxygen saturation is continuously measured. The statistical analysis of the influence of the equivalent noise level, rather than instantaneous noise level, on the behavior of the physiological variables is carried out. Great influence of noise is found by using this method, which is also easily translatable to other intensive care units as actual noise conditions are used in the investigation. Moreover, episodes of Bradycardia, Hypoxia and Hypertension are easily related to simultaneous direct nursing activity or a short but high enough noise event, suggesting that both sustained noisy environment and isolated peak noises lead to the alteration of the physiological variables.

1. Introduction

Noise, understood as being an undesirable sound for the recipient, turns out to be a regular feature of a Neonatal Intensive Care Unit (NICU) [1]. There are universally accepted recommendations for tolerable noise limits in neonatal units [2–4]. Nevertheless, noise levels detected in a number of NICUs often exceed these recommendations [5,6], bringing with them potential risks for the short and long-term development of newborns [7].

Among the numerous secondary effects of excessive noise experienced by premature newborns whilst in hospital [8], there are descriptions of changes in the cardio-respiratory system and of cerebral perfusion [7,9]. Stabilizing the immature infant's cerebral blood flow during the first few days of life has been put forward as one of the strategies to prevent the appearance of intraventricular hemorrhage (10). Moreover, the use of earmuffs in newborns improves sleep efficiency, increase the time of quiet sleep [11,12], reduces the fluctuation in oxygen saturation, stabilizes the behavioral state [13] and may facilitate weight gain [14].

There is little literature studying the response of extremely premature newborns to the habitual noise in a NICU during their first days of life and not using artificial, additional sources of noise. In most cases the patients are exposed to a high level of synthetic noise over short intervals of time (see [7] for a summary of previous research), that has little to do with the real conditions of ambient noise in a NICU. Williams et al. [15] established the variation of heart rate (HR) and mean arterial blood pressure (MABP) according to the level of environmental noise through the analysis of the temporal correlation of these variables measured second by second during a period of 15 min for a collection of eight neonates, obtaining a statistically significant, albeit rather low correlation between noise, HR and MABP. Slevin et al. [16] used another approach that consists of comparing averaged values of physiological variables, including HR, MABP and oxygen saturation (SpO_2), measured under conditions of quietness and the normal NICU environment. Results showed a significant decrease of MABP and a possible increase of HR during the normal period. However, the normal period includes discontinuous noise and infant nursing as well, so that it is not possible to distinguish the real effect of noise on the preterm infants.

In this manuscript, a procedure to evaluate the effect of noise on preterm infants is proposed, defining the periods of quietness, nursing and noisiness that take place during the normal activity of the NICU, and comparing the average, maximum and minimum values of HR, MABP and SpO_2 obtained in several of those periods.

2. Methodology

The proposed methodology consists of the statistical comparison of the average of several physiological variables measured

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Fig. 1. View of the incubator and the location of the outside microphone (top left of the picture).

under three different intervals of quietness, nursing and noisiness. The study protocol was approved by the Hospital Ethics Committee and Informed Consent was obtained from parents before measurements began.

The NICU patients' room contains up to seven incubators with its own equipment. The NICU is an "open doors" unit, with no restriction to parents' access, encouraging them to spend as much time in there as possible. The main noise sources of the NICU room are alarms, the opening and closing of the incubator's drawer and door, loud conversations, equipment ventilators, the sound of mobile phones, using furniture and normal conversations.

The patient studied was a preterm newborn, with a gestational age of 25 weeks and two days, and weighing 600 grams at birth. He is a second twin in a dichorionic-diamniotic pregnancy. The study was performed between the fifth and seventh day after birth. From birth, the patient had presented respiratory distress syndrome (for which he required mechanical ventilation and received two doses of intratracheal surfactant) and a patent ductus arteriosus, which was being treated with ibuprofen. He was treated with antibiotics for clinical suspicion of infection. Because he presented hemodynamic instability, an umbilical arterial access was inserted. The patient was also treated with a continuous infusion of morphine (1.5 mcg/kg/h) and was placed in a Giraffe Incubator® (Ohmeda company), which remained covered with a thick blanket during periods of rest.

Noise was continuously monitored for 56 h in two different locations [17]. The main position is inside the incubator, as close as possible to the infant ear position avoiding any chance of contact between the newborn and the microphone. It is intended in this position to measure the real noise exposure of the patient and thus reflections from the incubator are included as in practice. The secondary location is outside the incubator (Fig. 1), far away from any noise source, in order to avoid the direct field of any source and measure the quantity of environmental noise in the unit. The A-weighted equivalent sound level was measured every second ($L_{eq,A,1s}$) and recorded in a storage unit for post-process. The two sound level meters used in this study are Cesva C310 using Cesva PA13-697 microphones (Type I), and they were calibrated before and after the measurements using in field Cesva CB-5 calibrator.

In order to identify the source of the resulting noise levels, continuous direct observation was carried out by the research staff, writing down the source of the sounds and the approximate time interval of its occurrence. Nursing manipulation of the patient were also collected, since they can cause physiological changes in the neonate and produce a rather high sound level inside the incubator, circumstances that would lead to confusion in the data.

The patient's physiological constants were collected continuously by a Tram 451 M Module® and Solar 8000 M/i Monitor® (GE Medical Systems Information Technologies). The vital signs monitored by the Tram 451 M module which were used for the study were 12-lead ECG analysis, continuous invasive blood pressure and hemoglobin oxygenation (Masimo SpO_2). All information was transferred in real time to the MetaVision® Clinical Information System (*i*MDsoft), from which the data was extracted for the study using Matlab.

2.1. Data analysis

The instantaneous relation between noise levels and physiological time histories, given the great variability of the data, showed in the past a rather weak correlation [15]. In this study, the whole measurement time (56 h) was divided into different classes of intervals according to the following classifications: quiet, noisy and nursing. This procedure yielded several different time intervals *T* for each class.

Table 1
Noisy intervals without nursing.

Noise events	Time	Leq inside	Leq outside	Av HR	Max HR	Min HR	Av MABP	Max MABP	Min MABP	Av SpO_2	Max SpO_2	Min SpO_2
(a), (b), (c)	13:40–14:10	59.5	62.1	150.0	159.3	128	48.7	55.0	42	92.0	96.0	81
(d), (e)	16:50–17:10	60.1	65.7	144.0	149.0	124	49.8	54.3	44	97.5	98.6	94
(d)	1:55–2:05	64.0	65.8	143.7	147.0	139	51.2	62.6	44	96.5	97.0	95
(d), (e)	4:15–4:30	63.4	65.5	133.1	141.6	82	49.5	62.6	38	95.3	96.6	88
(d)	5:50–6:05	63.0	65.2	134.8	141.6	118	49.8	63.3	41	95.6	96.6	92
(d), (f)	8:15–8:30	63.3	65.8	128.1	139.3	77	50.6	61.6	38	91.7	94.0	88
(d), (f), (c)	10:45–11:00	63.6	65.9	147.9	155.6	139	46.5	55.3	33	92.7	94.0	89
(d), (f), (g)	11:05–11:20	63.5	65.9	143.2	150.3	110	49.1	63.3	41	90.3	94.0	84
(d), (e)	11:40–12:10	63.3	65.7	141.2	155.0	94	55.0	67.6	44	93.1	95.3	87
(d), (b), (f), (c)	13:15–13:25	63.1	65.6	148.6	153.6	137	53.0	56.0	43	93.3	94.6	92
(d), (g)	14:25–14:35	63.1	65.6	136.6	143.0	127	48.5	53.6	44	89.6	89.6	88
(d), (f), (e)	16:30–16:50	63.0	65.4	144.4	147.6	125	43.5	48.0	38	91.0	92.6	86
(f), (c)	19:30–19:40	62.9	65.4	158.4	162.6	151	–	–	–	91.3	94.0	87
(d), (e), (c)	9:20–9:35	62.7	65.6	164.9	169.6	156	–	–	–	84.9	97.6	66
(a), (g)	14:50–15:00	62.4	65.3	164.9	167.6	159	–	–	–	86.2	94.3	74
(a), (d), (e)	17:40–18:00	62.4	65.2	149.9	151.6	145	–	–	–	91.4	94.3	81
Average value	(260 min)	62.5	65.2	145.4	152.2	122	49.7	58.7	42	92.2	95.2	85

(a) Normal conversation. (b) Furniture. (c) Opening and closing the drawer of the incubator. (d) Alarms. (e) Opening and closing the portholes of the incubator. (f) Loud conversation. (g) Mobile phone.

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Table 2
Quiet intervals.

Events	Time	Leq inside	Leq outside	Average HR	Max HR	Min HR	Average MABP	Max MABP	Min MABP	Average SpO_2	Max SpO_2	Min SpO_2
Silence/Murmurs	14:31–14:43	54.6	56.2	146.7	155	120	50.5	54.7	44	95.3	96.7	92
Silence/Murmurs	22:32–23:01	53.9	60.9	148.3	151	144	47. 7	53.0	42	97.7	98.7	97
Silence/Murmurs	04:43–05:05	52.9	60.4	145.2	147	132	42.0	49.7	37	95.7	97.3	95
Silence/Murmurs	10:25–10:38	53.8	61.3	136.1	148	151	42. 7	43.3	38	94.7	96.0	95
Silence/Murmurs	17:26–17:40	53.6	61.4	145.7	139	139	43.2	45.7	42	97.7	95.7	92
Silence/Murmurs	18:16–18:29	53.4	61.3	141.4	147	150	42.7	43.3	38	94.6	98.0	97
Silence/Murmurs	05:45–05:55	53.2	61	150.8	145	142	–	–	–	95.7	97.3	87
Silence/Murmurs	14:20–14:40	52.6	60.4	142.1	161	162	–	–	–	96.8	97.3	83
Silence/Murmurs	16:05–16:15	53.1	61	156.0	157	151	–	–	–	93.1	96.3	95
Average value	143 min	53.4	60.4	145.0	151.9	140	45.3	49.0	40	96.8	98	92

Table 3
Nursing intervals.

Manipulation events	Time	Leq inside	Leq outside	Average HR	Max HR	Min HR	Average MABP	Max MABP	Min MABP	Average SpO_2	Max SpO_2	Min SpO_2
(a), (b), (c), (d)	12:15–12:40	58.2	62.6	146.4	152.0	134	45.7	57.3	38	90.9	95.0	81
(e), (b)	13–13:20	61.2	61.8	146.1	153.0	105	46.6	56.6	37	89.1	96.3	83
(f), (g) (d), (c)	15:55–16:20	60.6	65.8	133.8	157.6	66	62.9	76.3	46	89.4	99.3	74
(a), (g)	18:10–18:35	62.4	65.7	135.6	156.3	106	62.0	84.0	48	88.9	97.0	78
(e)	18:50–19:05	62.1	65.7	142.5	147.6	111	52.3	56.0	45	96.3	97.0	95
(f), (g), (d), (c)	23:35–00:10	63.5	65.7	137.5	158.3	97	50.8	78.0	37	94.8	96.6	76
(g), (a)	2:25–2:40	63.7	65.7	135.3	142.6	122	44.8	58.0	36	95.6	96.6	91
(f), (d)	5:20–5:35	63.2	65.4	140.3	143.6	130	44.5	52.3	38	94.8	96.0	93
(f), (g), (d), (c)	6:50–7:05	63.4	65.4	131.9	150.3	96	64.8	74.3	43	95.0	99.0	85
(f), (g), (d), (c)	8:55–9:15	63.5	66.0	127.4	148.0	72	68.8	88.6	42	86.6	97.6	51
(e)	10:00–10:15	63.4	65.7	146.2	156.3	140	45.3	55.3	33	92.7	94.0	89
(a), (c), (b)	10:55–11:05	63.5	65.9	143.2	150.3	110	49.1	63.3	41	90.3	94.0	84
(f), (g), (d), (c)	12:10–12:20	63.3	65.7	141.2	155.0	94	55.0	67.6	44	93.1	95.3	87
(b), (c), (d)	12:30–12:45	63.2	65.6	149.5	159.0	138	54.8	65.0	47	93.3	96.3	86
(f), (g), (d), (c)	13:40–13:50	63.1	65.6	139.1	165.3	109	62.5	81.3	44	88.7	92.0	78
(e)	14:00–14:15	63.1	65.6	136.6	143.0	127	48.5	53.6	39	89.6	89.6	88
(a), (b), (d)	14:55–15:05	63.0	65.5	145.7	149.3	126	48.4	53.6	40	89.3	91.3	78
(f), (g), (d), (c).	15:55–16:05	63.1	65.5	134.1	150.3	96	60.3	67.3	51	84.6	94.6	60
(b), (c), (d)	17:05–17:25	63.0	65.4	144.4	147.6	125	43.5	48.0	38	91.0	92.6	86
(f), (g), (d), (c)	18:55–19:10	63.0	65.4	146.0	164.3	87	41.4	50.3	40	86.5	98.6	66
(b), (c), (d)	19:50–20:00	62.9	65.4	158.4	162.6	151	–	–	–	91.3	94.0	87
(e)	8:20–8:30	62.9	65.5	141.6	145.3	134	–	–	–	92.6	98.0	82
(a), (c), (d)	8:50–9:00	62.8	65.6	147.0	147.0	144	–	–	–	95.3	97.3	94
(b), (c)	9:40–9:55	62.7	65.6	164.9	169.6	156	–	–	–	84.9	97.6	66
(f), (g), (d), (c)	10:00–10:10	62.7	65.6	136.4	152.6	91	–	–	–	94.0	99.3	83
(f), (g), (d), (c)	11:30–12:00	62.6	65.5	168.2	169.0	109	–	–	–	84.2	97.6	73
(b), (c)	11:45–12:00	62.6	65.4	160.2	163.0	155	–	–	–	93.1	96.6	82
(c)	12:55–13:05	62.5	65.4	158.0	162.0	151	–	–	–	91.4	95.0	85
(b), (c)	13:55–14:05	62.5	65.4	158.3	161.6	154	–	–	–	91.0	93.3	82
(a)	14:35–14:50	62.4	65.3	164.9	167.6	159	–	–	–	86.2	94.3	74
(f), (g), (d), (c)	15:15–15:25	62.4	65.3	152.7	168.0	90	–	–	–	89.3	98.6	72
(f), (d)	16:45–16:55	62.5	65.3	147.2	158.6	105	–	–	–	83.6	86.0	59
(b), (c)	17:10–17:20	62.4	65.2	149.9	151.6	145	–	–	–	91.4	94.3	81
Average value	505 min	62.5	65.5	145.3	149.8	116	52.75	65.72	39	90.7	95.8	79

(a) Diaper change. (b) Repositioning the mattress. (c) Placing the mask. (d) Change of position. (e) Feeding. (f) Aspiration. (g) Cure of injuries.

For each interval, values were obtained for an A weighted equivalent sound level $L_{eq,A,T}$ inside and outside the incubator. Quiet intervals were defined as those with an absence of noise and activity of any kind so that only background noise is measured. Noisy intervals were defined initially as those in which the average noise level inside the incubator was 4 dB (following Slevin et al. [16] above the average value of the interior noise of the quiet intervals, without coinciding with nursing activity on the newborn. However, a differential of +6 dB gives more clear influence of noise on physiological variables and all the analysis is carried out considering the latter differential. Finally, nursing intervals are defined by the existence of nursing care on the patient without considering the noise level reached inside the incubator. Note that the baby is not taken out of the cut during the nursing so the interior noise will arise.

For the same intervals, the maximum, minimum and averaged values of the following physiological variables were also obtained: HR measured in beats per minute (bpm); MABP, measured in millimeters of mercury (mmHg) and SpO_2 measured in percentage of oxygen in blood. The maximum and minimum physiological variables were calculated from an average size 3 filter on the data vector. This filter averaged each three consecutive data points, following steps of one data point so that another vector of the same size as the vector or raw data is obtained. The higher number was

Table 4
Activities in the NICU's room, occurrence in noisy intervals and its approximate environmental noise level inside the cot.

Activity	Leq (dBA)	Number of noisy events
Opening and closing the portholes of the incubator	65–70	6/16 (37.5%)
Murmurs	30	
Normal conversation	45–50	3/16 (18.75%)
Loud conversation	60–70	5/16 (31.25%)
Opening and closing the drawer of the incubator	75–80	5/16 (31.25%)
Fixation of the syringe	70–75	
Moving the furniture	55	2/16 (12.5%)
Ventilator of the equipment	60	
Sound of the mobile phone	75–80	2/16 (12.5%)
Alarms	65–80	12/16 (75%)
Background noise (no NICU working)	42–45	
Background noise (NICU working)	50–55	

selected for the maximum and the lower number for the minimum.

Once all the data was arranged by time intervals, it was possible to conduct a statistical analysis in order to find out if the behavior of physiological variables depends on the quantities of noise. Concretely, two types of hypothesis tests, also called significance tests, were carried out: Wilcoxon and Student *t*-test for related samples. The statistical hypothesis for this study is an affirmation about whether noise affects the physiological variables of the neonates. Therefore, the hypothesis could be:

- Null (H_o): assuming that the physiological variables are random and there are no differences between noisy and quiet moments.
- Alternate (H_a): assuming that physiological variables are different with and without noise and that noise is statistically significant.

Before performing any test, a determinate order must be followed to obtain a more significant and valid result. The first step is to check whether the population distribution is normal, which means finding out if the physiological variables follow a normal distribution, by using the Kolmogorov–Smirnov test. For this statistical analysis only intervals longer than 10 min are used so that the majority of the measurement time was not used since the conditions did not suit the definition of the intervals (short noises, short manipulations of the baby or environmental noise under the trigger value of 6 dB above quiet periods) and thus ensuring the clear predominance of noise, nursing or quietness in each of the selected intervals.

A second analysis was also carried out and focused in linking the occurrence of clinical episodes such as bradycardia

Table 5
Noisy versus quiet intervals.

Physiological variable	Value	Normality?	Test	*P* value	Is the noise statistically significant?
HR	Average	Yes	T-Student	0.0405	Yes
			Wilcoxon	0.037	
	Maximal	Yes	T-Student	0.372	No
			Wilcoxon	0.4595	
	Minimal	Yes	T-Student	0.006	Yes
			Wilcoxon	0.0075	
MABP	Average	Yes	T-Student	0.005	Yes
			Wilcoxon	0.014	
	Maximal	Yes	T-Student	0.015	Yes
			Wilcoxon	0.014	
	Minimal	Yes	T-Student	0.0215	Yes
			Wilcoxon	0.0315	
SpO_2	Average	Yes	T-Student	0.047	Yes
			Wilcoxon	0.057	
	Maximal	Yes	T-Student	0.109	No
			Wilcoxon	0.131	
	Minimal	Yes	T-Student	0.025	Yes
			Wilcoxon	0.037	

Table 6
Nursing versus quiet intervals.

Physiological variable	Value	Normality?	Test	*P* value	Is the manipulation statistically significant?
HR	Average	Yes	T-Student	0.076	No
			Wilcoxon	0.1665	
	Maximal	Yes	T-Student	0.243	No
			Wilcoxon	0.254	
	Minimal	Yes	T-Student	0.0095	Yes
			Wilcoxon	0.0065	
MABP	Average	Yes	T-Student	0.030	Yes
			Wilcoxon	0.0215	
	Maximal	No	Wilcoxon	0.009	Yes
	Minimal	Yes	T-Student	0.0925	No
			Wilcoxon	0.075	
SpO_2	Average	Yes	T-Student	0.0585	No
			Wilcoxon	0.0845	
	Maximal	No	Wilcoxon	0.287	No
	Minimal	Yes	T-Student	0.018	Yes
			Wilcoxon	0.0185	

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Table 7
Nursing versus noisy intervals.

Physiological variable	Value	Normality?	Test	*P* value	Is noise statistically significant?
HR	Average	No	Wilcoxon	0.163	No
	Maximal	No	Wilcoxon	0.007	Yes
	Minimal	No	Wilcoxon	0.0175	Yes
MABP	Average	Yes	T-Student	0.274	No
			Wilcoxon	0.407	
	Maximal	No	Wilcoxon	0.0205	Yes
	Minimal	Yes	T-Student	0.3795	No
			Wilcoxon	0.3915	
SpO_2	Average	No	Wilcoxon	0.2345	No
	Maximal	Yes	T-Student	0.1195	No
			Wilcoxon	0.1025	
	Minimal	Yes	T-Student	0.172	No
			Wilcoxon	0.2545	

Table 8
Noisy (>58 dB) versus quiet intervals.

Physiological variable	Value	Normality?	Test	P value	Is noise statistically significant?
HR	Average	Yes	T-Student	0.15	No
			Wilcoxon	0.245	
	Maximal	Yes	T-Student	0.075	No
			Wilcoxon	0.0661	
	Minimal	Yes	T-Student	0.02	Yes
			Wilcoxon	0.0055	
MABP	Average	Yes	T-Student	0.0855	No
			Wilcoxon	0.06	
	Maximal	Yes	T-Student	0.0315	Yes
			Wilcoxon	0.025	
	Minimal	Yes	T-Student	0.405	No
SpO_2			Wilcoxon	0.355	
	Average	Yes	T-Student	0.049	Yes
			Wilcoxon	0.056	
	Maximal	Yes	T-Student	0.009	Yes
			Wilcoxon	0.0085	
	Minimal	Yes	T-Student	0.003	Yes
			Wilcoxon	0.0025	

(HR < 120 bpm [18]), hypoxemia (SpO_2 < 88% [19]) and hypertension (MABP > 49 mmHg [10]) to noise events. In this analysis, all the events suffered by the baby during the complete monitoring time were identified and after that, the cause of such a response was pursued and linked to one of the defined intervals.

3. Results and discussion

Only one patient was available for the investigation, but was representative of his gestational age. This limitation was overcome by taking a long time measurement which gives a reasonable amount of data to establish significant statistical results to support the proposed method of analysis. The actual data set for the statistical analysis is composed by 16 noisy intervals, 9 quiet intervals and 33 nursing intervals. All of the intervals last between 10 and 35 min and the total interval time of each class are 260, 143 and 505 min respectively. The result of each interval and also the averaged results of the measured variables for each class interval are shown in Tables 1–3. The averaged L_{Aeq} values for the grouped quiet intervals inside the incubator is almost 10 dBA below the same parameter for noise or nursing intervals, thus demonstrating a clear difference between quiet and other intervals. However, and surely by chance, the averaged L_{Aeq} for grouped noisy and nursing intervals present the same value of 62.5 dBA. In general terms, the noise levels found in the present study are quite similar to other results published in the literature regarding noise levels in NICUs [1,5,6], therefore the methodology and results could be extrapolated to other NICU rooms or even general proposed Intensive Care Unit [20] in order to seek for the effect of noise on physiological variables. Table 4 seems to indicate that the main source of noise is from the alarms, since they appear in the 75% of the noisy intervals considered with a noise level of up to 80 dB(A) but also the own noise sources of the NICU gives also quite high noise levels [17]. It must be noted that some common actions such as opening and closing the incubator or its drawer also produce instantaneous loud noise levels.

The results of Tables 1–3 show differences in the mean values for most of the indicator variables studied under different conditions, finding a noticeable short term decrease of HR and SpO_2 and also short term increases of MABP, results that are generally consistent with previous published research [7,21–25]. It is worth to note that, under noisy environment, Min. HR shows a 20 units decrease and thus being very close to the limit of bradycardia, that Min. SpO_2 reduces its value below the limit of hypoxemia and that the Max. MABP reaches values clearly above the hypertension and hence a great significance of the variations should be expected.

Statistical analysis should confirm whether or not physiological variables are affected by noise, looking for a different statistical distribution of these variables under low and high noise conditions, provided that there is no other change in environmental variables that could influence the results. The results are summarized in

Table 9
Clinical events detected under nursing. Initial value means the value at the beginning of the clinical event. Event value means the most critical value reached. Time interval reflects the time at where the initial and event values are picked up.

Event	Day	Time interval	Initial value	Event value	% Variation
Hypertension (mmHg)	15	12:34–12:38	41	59	43.90
	15	13:11–13:15	39	63	61.53
	15	15:57–16:20	46	80	73.91
	15	18:10–18:35	47	87	85.10
	15	18:51–19:05	45	59	31.11
	15	23:35–00:10	46	85	84.78
	16	05:29–05:33	38	54	42.10
	16	06:51–07:05	43	76	76.74
	16	08:59–09:15	42	93	121.4
	16	10:50–11:00	44	58	31.81
	16	12:10–12:15	45	62	37.77
	16	12:30–12:45	44	67	52.27
	16	13:40–13:50	44	83	88.63
	16	14:58–15:02	40	59	47.50
	16	15:56–16:05	45	74	64.44
	15	15:58–16:20	50	80	60.00
	15	23:41–23:55	47	85	80.85
	16	06:50–07:10	43	76	76.75
	16	08:59–09:16	49	93	89.80
	16	13:45–13:51	48	83	72.92
	16	16:04–16:07	56	68	21.43
	15	16:10–16:17	148	66	55.40
	15	18:23–18:28	131	106	19.08
	15	19:03–19:05	143	111	65.38
Bradycardia (bmp)	15	23:41–23:46	158	97	38.61
	16	06:51–06:57	136	96	29.41
	16	09:00–09:04	143	72	49.65
	16	09:09–09:11	141	81	42.55
	16	13:44–13:47	171	109	36.26
	16	16:03–16:06	141	96	31.91
	17	15:24–15:26	172	90	47.67
	15	16:07–16:17	86	74	13.95
	16	09:01–09:04	90	51	43.33
Hypoxemia (%)	16	13:43–13:46	90	78	13.33
	16	16:03–16:10	88	60	31.82
	17	15:22–15:28	90	66	26.67
	17	16:43–16:57	89	67	24.72

Table 10
Clinical events detected under noisy conditions. Initial value means the value at the beginning of the clinical event. Event value means the most critical value reached. Time interval reflects the time at where the initial and event values are picked up.

Success	Day	Time interval	Initial value	Event value	% Variation
Hypertension (mmHg)	15	13:47–13:58	45	57	26.66
	15	16:53–17:00	44	59	34.09
	16	02:01–02:05	47	75	59.57
	16	04:18–04:26	38	66	73.68
	16	05:57–06:04	44	69	56.81
	16	08:16–08:20	39	59	51.28
	16	08:25–08:30	39	67	71.79
	16	10:55–11:00	44	58	31.81
	16	11:15–11:18	45	67	48.88
	16	11:44–11:48	44	70	59.09
	16	11:51–12:10	45	77	71.11
	16	13:15–13:25	43	61	41.86
	16	02:02–02:04	47	75	59.57
	16	05:57–06:01	44	69	56.82
	16	11:14–11:18	45	67	48.89
	16	11:43–11:47	44	70	59.09
	16	04:17–04:21	134	82	38.81
Bradycardia (bmp)	16	08:24–08:29	138	77	44.20
	16	11:14–11:16	148	110	25.68
	16	11:43–11:45	145	94	35.17
Hypoxemia (%)	17	09:29–09:38	96	66	31.25

Tables 5–7. In general terms, all the variables are found to follow Normal distribution, thus both the T-Student and Wilcoxon tests are carried out, obtaining very similar results for both tests in most cases.

Table 5 shows that statistically significant differences are found (significance level p is set for lower values than 0.05) between all the quantities measured due to the presence of noise when compared to those of quiet moments, except for the max. HR and the

Table 11
Clinical events under quiet moments. Time interval reflects the time at where the initial and event values are picked up.

Success	Day	Time interval	Initial value	Event value	% Variation
Hypertension (mmHg)	15	14:31–14:35	46	60	30.43
	15	22:35–22:38	43	57	32.55
	16	04:47–04:50	48	51	6.250
	16	10:26–10:27	38	52	36.84

max. SpO2, confirming the general behavior observed when comparing the mean results of Table 1.The same procedure of comparison is applied to the population of physiological values obtained under manipulation and the values corresponding to quiet intervals (Table 6). In general, different statistical behavior is found, although not in all of the variables: max. and averaged HR, min. MABP, averaged SpO2 and max. SpO2 seem not to be affected by nursing, which suggests different effect of noise and nursing on

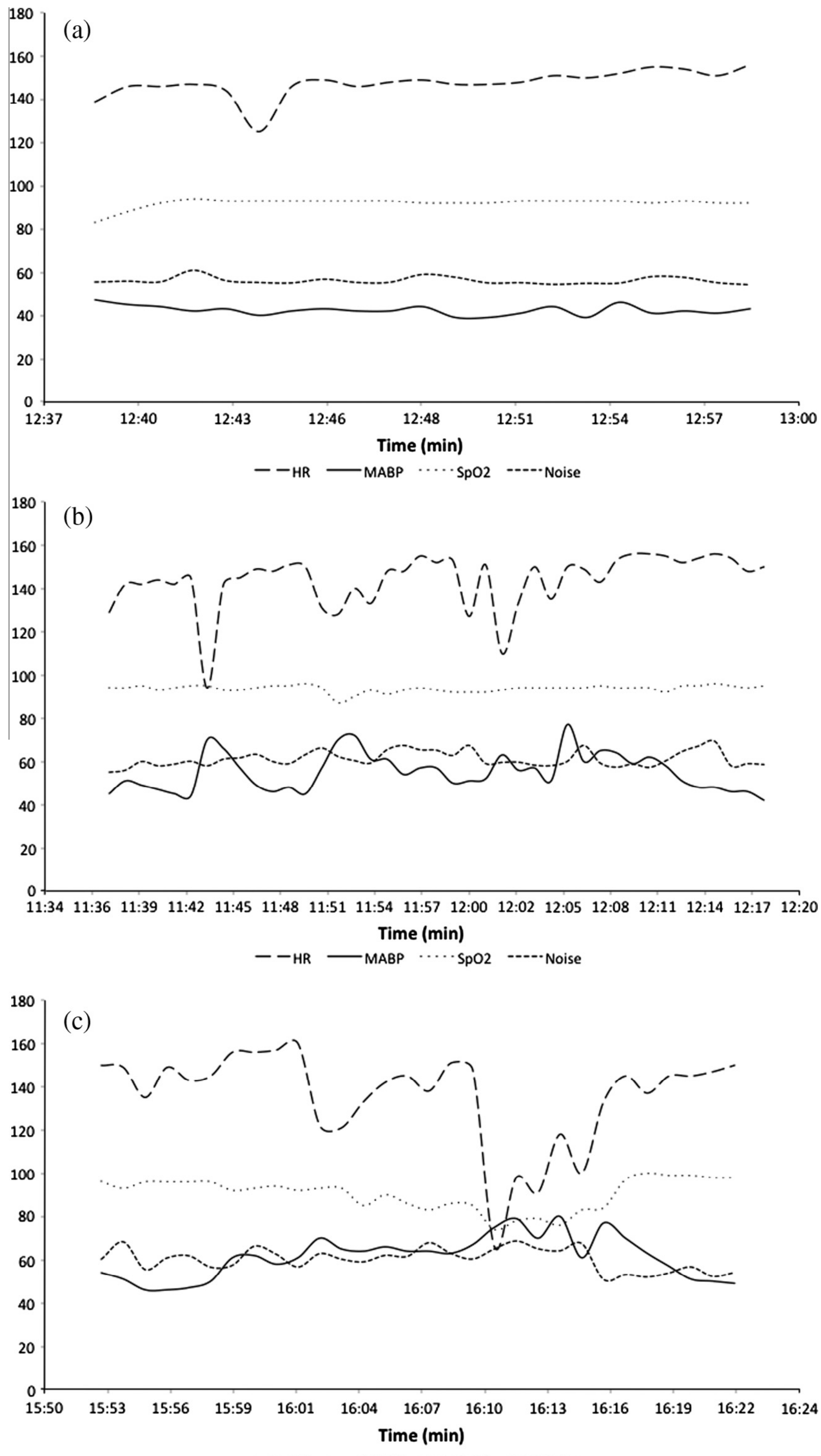

Fig. 2. (a) Interval of a quiet moment. (b) Interval of a noisy moment without nursing. (c) Interval of a moment with nursing.

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the neonate. The comparison of the statistical distribution of the variables under noise events and under nursing should clarify if noise and nursing have the same effect on the patient. Table 7 summarizes the results of such a comparison and several differences arise, demonstrating that noise and manipulation have a different effect on the patient. Concretely, the variables most affected by noise, which are min. HR and max. MABP, do not distribute statistically in the same way as under manipulation. It can thus be concluded that, in general terms, the effect of noise on a neonate is not equivalent to the effect of manipulation, although it shows a rather similar response. Finally, Table 8 is equivalent to Table 5 but considering noise intervals as those with an $L_{Aeq,T} > 58$ dB, i.e. with a differential of +4 dB respect to quiet intervals as did Slevin et al. [16]. Results show different behavior of the physiological variables for noise intervals (+4 dB) and quiet intervals, but differences are lesser that using the differential of +6 dB, suggesting some correlation between the intensity of the noise and the intensity of the effect on the newborn.

Fig. 2 shows some time history examples of $L_{Aeq,1min}$, HR, MABP and SpO_2 for quiet, noisy and nursing intervals. It is clear that the physiological variables are altered by exposure to noise since they do not remain stable as they otherwise do in quiet moments. Concretely, the HR follows an irregular behavior that resembles the biphasic heart rate response found in previous research [15] showing, in the present case, an initial quite dramatic decrease in HR followed by a small HR acceleration. The alteration is even greater when the patient is nursed, as can be seen in Fig. 2(c), confirming the greater numerical variation found in the averaged values of minimal HR and maximal MABP under nursing.

An account of all the events of Bradycardia, Hypoxemia and Hypertension was carried out for the complete monitoring time (not only the intervals considered in the statistical analysis). In all cases was found some direct nursing activity or a noise event simultaneous to the clinical event. To carry out the analysis the classification of quiet, nursing and noisy intervals is still maintained with the difference that there is no limiting time for defining the period, as what it is pursued is the MAX value and not the averaged response. Thus, the noisy interval is now a period of (any) time that fulfills the condition of $L_{Aeq,T} > 60$ dB. Tables 9–11 collected all the clinical events according the interval in which they happened.

It is worth noting that there are no events of Hypoxemia and Bradycardia during the quiet intervals. However, 6 and 1 episodes of Hypoxemia, and 10 and 4 of Bradycardia are registered respectively under nursing and in a noisy environment. These figures cannot be directly compared since the total time for each kind of interval is different. If time is taken into account, Bradycardia takes place at rates of 0.02 and 0.015 events/min for nursing and a noisy environment, and Hypoxemia at rates of 0.012 and 0.004 events/minute respectively. Those results suggest a greater occurrence of events during nursing intervals. If these rates are applied to the total time under quiet conditions (143 min), the results would show 3 clinical events of Bradycardia and 1 case of Hypoxemia, thus it seems clear that the absence of events in a quiet environment is significant, especially in this particular case of a sick and extremely premature newborn.

The average MABP for the patient is 45.3 mmHg and the standard deviation is 3 mmHg, so that the limit proposed [10] suits this study well. Under this condition, 21 Hypertension events were counted under nursing (0.064 events/min), 16 under noisy conditions (0.078 events/min) and only four for quiet moments (0.038 events/minute). Note also that from the four events registered during quiet moments, two of them give a maximum value which is very close to the individual limit of 45.3 + 6 bmp, so the ratio of Hypertension occurrence is clearly higher for nursing and noisy intervals than for quiet intervals. Moreover, the ratio of variation of the MABP for the clinical events under noisy environment is in most cases close or above the 50% of increase.

4. Conclusions

A procedure to detect the effect of environmental noise on newborns was proposed and tested on one patient with a gestational age of 25 weeks and two days, and weighing 600 g at birth. The procedure consisted of statistically comparing the averaged values of noise inside and outside the incubator, HR, MABP and SpO_2 taken for a time intervals lasting 10 min at least. Three different intervals of clear predominance of quietness, nursing and noisiness were defined after direct observation of the patient. A noisy interval is defined when the averaged noise level is 6 dB above the background noise. Results show that noise altered most of the physiological variables considered (only the maximal HR and the maximal SpO_2 are not statistically affected by noise) and had an effect on the newborn rather similar to that of nursing, something not strange as nursing activity in itself gives a noisy environment.

As a complementary strategy, the identification of clinical episodes such as Bradycardia, Hypoxia and Hypertension is carried out for all the monitored time. In all cases some direct nursing activity or a noise peak is found to take place simultaneously. From these results, it seems that noise infers in different ways on the newborn. On one side, sustained (averaged) noisy environment lead to consistent alteration of the (averaged) physiological variables. On the other side, isolated short noises can punctually alter the physiological variables, although its effect is not as consistent as using averaged data. Hence regulation of noise in NICU should consider both types of noise inside the cot and limit the averaged sound level as well as the, for example, maximum noise level.

The followed procedure is based on the actual noise conditions that can be found in any NICU and relies on averaging the results rather than finding instantaneous event-correlation, although the latter effect must be also be taken into account.

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