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Does the architectural layout of a NICU affect alarm pressure? A comparative clinical audit of a single-family room and an open bay area NICU using a retrospective study design

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ABSTRACT

Objectives To determine differences in alarm pressure between two otherwise comparable neonatal intensive care units (NICUs) differing in architectural layout—one of a single-family room (SFR) design and the other of an open bay area (OBA) design.

Design Retrospective audit of more than 2000 patient days from each NICU cataloguing the differences in the number and duration of alarms for critical and alerting alarms, as well as the interaction of clinicians with the patient monitor.

Setting Two level 3 NICUs.

Results A total of more than 150 000 critical and 1.2 million alerting alarms were acquired from the two NICUs. The number of audible alarms and the associated noise pollution varied considerably with the OBA NICU generating 44% more alarms per infant per day even though the SFR NICU generated 2.5 as many critical desaturation alarms per infant per day.

Conclusion Differences in the architectural layout of NICUs and the consequent differences in delays, thresholds and distribution systems for alarms are associated with differences in alarm pressure.

INTRODUCTION

The architectural layout and design of a hospital department must address the potentially conflicting needs and aspirations of different stakeholders. In a neonatal intensive care unit (NICU) environment, the usual stakeholders include infants, their families, staff and the hospital administration. Infants require a developmentally supportive environment, one that minimises stressors and facilitates positive stimuli. Families desire privacy and an environment conducive to their active participation in daily caregiving while staff needs are focused on providing adequate care, regulating stress and maintaining a positive work environment.

Strengths and limitations of this study

► There are no studies investigating the relationship between neonatal intensive care unit (NICU) design and associated alarm pressure.
► This comparative clinical audit of patient monitor alarms from a single-family room and open bay area NICU generates benchmarks and may identify opportunities for improving alarm management.
► Since the study is explorative and of an observational study, the non-randomised nature is a limitation.

Over the past two decades, there has been a trend towards the adoption of the single-family room (SFR) NICU, as opposed to the traditional 'open bay-area' (OBA) design.[1 2] Recent evidence has shown an association between the SFR design and improved neurobehavioural and medical outcomes.[3–5] Also, the SFR design offers an opportunity to provide better control over stressors such as light and noise, improve parental and staff satisfaction with care, improve the work environment for nurses and possibly reduce the cost of care without increasing adverse outcomes.[5–14]

Nevertheless, the SFR environment with its reduced patient visibility and increased dependency on patient monitoring creates a challenge for maintaining a safe environment for infants. While former work has shown that safe patient monitoring is feasible in SFR NICUs, differences in the number of alarms generated per patient per unit time (alarm pressure) for NICUs of the SFR and the traditional OBA design remain unexplored.[15] These differences are important to determine because adapting the NICU to the SFR environment can have adverse implications for alarm fatigue—a top patient safety

concern arising due to excessive exposure of clinicians to alarms leading to sensory overload and consequently a delayed or no response to alarms.[16–18] Investigations into how NICU design and associated alarm settings affect alarm pressure can thus lead to opportunities for further improving the NICU environment. While on the one hand, infants in the SFR NICUs may have reduced exposure to noise which enhances physiological stability and reduces alarms; on the other hand, long nurse response times to alarms may, in fact, result in an increased number of alarms.[19 20] Furthermore, reduced patient visibility can also change nursing workflow with implications for the physiological stability of infants, nurse handling of alarms and perceived alarm pressure.

In this study, we explore the differences in the number and duration of alarms for critical and alerting alarms as well as the interaction of clinicians with the patient monitor for two NICUs in the Netherlands. These NICUs have a comparable patient population and care setting with one NICU of an SFR design and the other of an OBA design. The aim of this comparative clinical audit was for benchmarking and sharing the collective operational experiences of two comparable NICUs to identify opportunities for improving alarm management and reducing noise exposure, both at the bedside and at the central posts, for infants and clinicians.

MATERIALS AND METHODS
The NICU environment
The Netherlands has a population of 17 million inhabitants with centralised neonatal intensive care organised in 10 level III centres across the country. The two participating NICUs, Máxima Medical Centre (MMC) Veldhoven and Isala Clinics Zwolle, have a typical annual admission rate of 380 and 330 patients, respectively. The 18-bed MMC NICU, constructed in 2012, is of an SFR design (nine single rooms, five double rooms and one triple room), while the 18-bed Isala NICU, constructed in 2014, has an OBA design (three rooms with six beds each). Figure 1 illustrates the architecture of these units and table 1 compares the characteristics of the units across several dimensions. Excluding the NICU design and the associated differences in alarm handling, the units are mostly similar regarding medical equipment, staffing patterns, the patient population and care practices. Notably, also, the nursing staff in both units has a comparable educational background and professional training since they are all drawn from a small and homogenous, Dutch-speaking population. Furthermore, in both units, the mix of clinicians is similar with neonatologists, fellows (paediatricians in training in neonatology), residents in paediatrics and physician assistants sharing the clinical workload.

Alarm chain
In both units, patient monitoring is carried out using Philips patient monitors (IntelliVue MX 800, Germany). Based on urgency, these patient monitors prioritise patient-related alarms into 'red' and 'yellow' alarms, corresponding to critical and alerting alarms, respectively. In both units, the primary alarm chain comprised the patient monitor, the interbed communication system and central monitors at the nursing stations, where it was possible to get an overview of alarms from all infants. In the SFR NICU, a secondary alarm chain was employed that used a distributed alarming system to send all red alarms to handheld devices carried by nurses, a detailed description of which has been published earlier.[15 21] In the SFR NICU of the MMC, the ventilator (Fabian HFO, Acutronic, Switzerland) was also connected to the patient monitor to ensure that red ventilator alarms, including information on the nature of the alarm, were forwarded to the handheld devices carried by the nurses. Ventilator data for the OBA NICU was unavailable. Regarding alarm sounds, in both the SFR and the OBA NICUs, the red and yellow alarms generated sounds at the patient monitors and the central post.

Both units monitored the three-lead ECG, the respiration rate (using impedance pneumography), oxygen saturation (SpO_2; using disposable sensors), skin temperature and occasionally invasive arterial blood pressure of infants. SpO_2 monitoring was carried out with an averaging setting of 10 s with alarms being generated after a user-adjustable delay if the SpO_2 dropped and remained below a predefined threshold. The heart rate was calculated as the average of the 12 most recent beat-to-beat intervals or the four most recent beat-to-beat intervals if the heart rate was less than 80 bpm.

In both units, the threshold values for generating red alarms corresponding to desaturation, bradycardia and apnoea were 80%, 80 bpm and 20 s, respectively. Bradycardia and apnoea alarms were generated without any delays, while for desaturation alarms, the delay was 10 s and 20 s in the SFR and OBA NICUs, respectively. With regard to the yellow alarms concerning low and high heart rate, the median threshold values in both units were 100 and 200 bpm with alarms generated without delay. In the SFR NICU, the median thresholds concerning low and high SpO_2 were 85% and 95%, with alarms being generated with a delay of 15 s. In the OBA NICU, the corresponding thresholds were 88% and 95% with the delay set to 10 s.

In addition to patient-related alarms, for both units, the patient monitors also stored logs for inoperative (INOP) alarms. These alarms logged situations when the monitor was unable to generate alarms (eg, ECG lead disconnection) or a clinician was interacting with the monitor (eg, silence alarms, pause alarms). Silencing stopped the alarm sounds of a single category of alarm (eg, bradycardia/desaturation) for up to 3 min, after which, the alarm would start resounding if the underlying condition had not resolved. During the silence period, visual indicators of the alarm condition would continue to be displayed. The pause function stopped both the visual and auditory information on the status of alarms of all categories for up to 3 min.
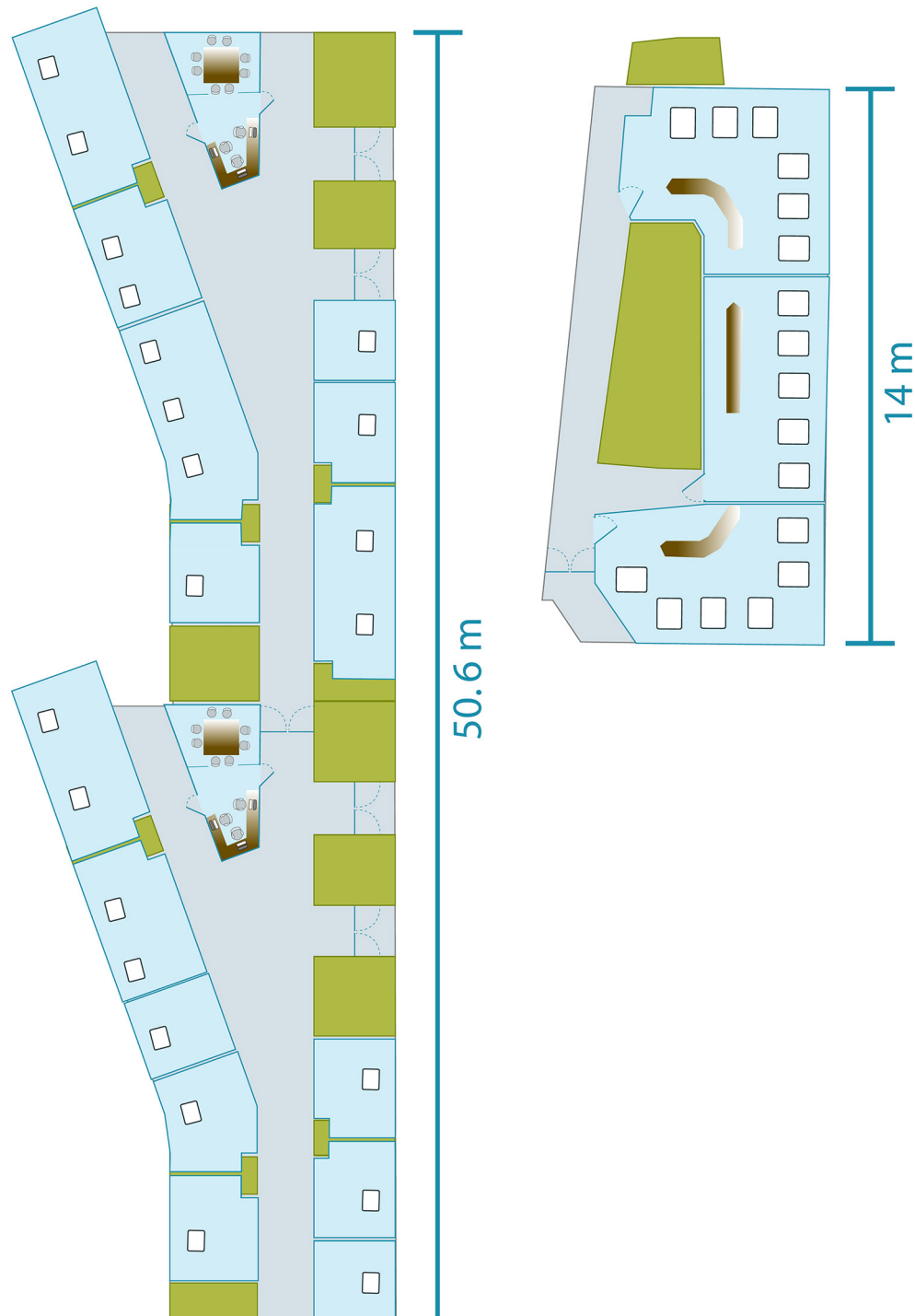
Figure 1 The architectural layout of the single-family room neonatal intensive care unit (NICU) (left) and the open bay area NICU (right). The white spaces indicate the incubator and the blue spaces indicate patient rooms. The green spaces indicate ancillary facilities like the pharmacy and closet space. Grey areas indicate corridors or dead space. Individually, the NICUs are drawn to scale.

Alarm analysis

All alarm data were extracted from the central posts, which maintain a running log of alarms up to 60 days prior. For all types of red, yellow and INOP alarms, the total number of alarms were counted and expressed as the number of alarms generated per patient per day at the unit level. For the ventilator alarms, the alarm pressure was calculated considering only the ventilated days of the study. The duration of each alarm was calculated based on the start and end time of alarms and expressed in median (IQR) duration. The threshold values that were breached when the alarm was generated were also extracted. For the most prevalent red, yellow and INOP alarms, the average number of alarms generated by 100 patients for each consecutive 10 min interval of time was plotted through the course of the day to visualise changes

Table 1 Characteristics of neonatal intensive care units (NICUs) across several dimensions

Feature	SFR NICU	OBA NICU
NICU design		
Level of NICU	III	III
No. of beds	15 rooms, 18 beds	3 rooms, 18 beds
Design	Private room	Open bay area (OBA)
Geometry	Rectangular, long corridors	Three central stations overlooking connected rooms
Equipment and alarms		
Patient monitor	Philips MX800	Philips MX800
ECG sensor	3M Red Dot or Ambu BlueSensor (for infants <1500 g)	3M Red Dot 2282E (for preterm infants) or 2269T (for term infants)
SpO$_2$ sensor	LNOP NeoPt-L or LNOP Neo, Masimo SET	M1132A, M1133A and M1134A, Philips
Temperature sensor	21091A, Philips	21078A, Philips
Ventilator	Fabian HFO	Fabian HFO
Alarm distribution	Central monitors, interbed communication and handheld devices	Central monitors and interbed communication
Ventilator connected to patient monitor	Yes	No
Silencing of red alarms possible from	Bedside monitor only	Bedside monitor and the central post
Silencing of yellow alarms possible from	Bedside monitor and the central post.	Bedside monitor and the central post
Pausing of red and yellow alarms possible from	Bedside monitor only	Bedside monitor only
Nursing care		
Typical nurse–patient ratio	1:2	1:2
Daily feeding frequency	12	24 until 1000 g, 12 until 1500 g and 8 after that
Time of nursing care	Need-based, but only prior to enteral feeding at even hours of the day.	Need-based, no fixed time

SFR, single-family room.

in alarm pressure and interaction of clinicians with the patient monitor. All data were analysed using Matlab R2015b (MathWorks, Massachusetts, USA).

Patient demographics

In totality, 2126 patient days (from 158 patients between 3 August 2016 and 30 December 2016) and 2035 patient days (from 170 patients between 26 June 2016 and 30 November 2016) were analysed from the NICUs at MMC and Isala, respectively. There were no exclusion criteria. This convenience sample of approximately 150 calendar days was chosen based on the expected frequency of occurrence of alarms from a previous audit.[21] As is standard practice, this retrospective analysis of anonymised data, aimed at quality improvement, did not require ethical approval. The patient metadata and clinical characteristics of the infants enrolled in the study are shown in table 2. Statistical analysis of differences in patient metadata and clinical characteristics were carried out using the χ^2 goodness of fit test (or Fisher's exact test where appropriate). A p value ≤0.05 was considered statistically significant. Effect size as measured by proportion

difference was carried out for statistically significant variables.

Patient and public involvement

All data were retrospectively acquired without involvement of any patients. There was no public involvement.

RESULTS

More than 150 000 red alarms and nearly 1.2 million yellow alarms from patient monitors were analysed from 4161 patient days. The SFR NICU and the OBA NICU generated, on average, 42.4 and 23.4 red alarms per infant per day, respectively. For both units, the desaturation, bradycardia and apnoea alarms were the most common (table 3). While the number and duration of bradycardia alarms were similar for both units, the SFR NICU produced 2.5 times as many desaturation alarms per infant per day, but of shorter duration.

For yellow alarms, the SFR NICU and the OBA NICU generated, on average, 174.4 and 289.6 alarms per infant per day, respectively. The most prevalent alarms were

Table 2 Patient metadata and clinical characteristics of the infants enrolled in the study

Characteristic	SFR NICU	OBA NICU	P values
Duration of study (days)	149	158	–
Patient days	2126	2035	–
No. of infants	158	170	–
Male (%)	53	54	0.73
Infants with gestational age <32 weeks	96 (60.8%)*	116 (68.2%)	0.16
Infants with gestational age <28 weeks	35 (22.2%)	40 (23.5%)	0.77
Infants with birth weight <1500 g	76 (48.1%)	86 (50.6%)	0.65
Infants with birth weight <1000 g	34 (21.5%)	41 (24.1%)	0.57
No. of ventilated days (invasive, SIMV or SIPPV or HFO)	399 (18.8%)	473 (23.2%)	0.0004
Surfactant administration	38	54	0.12
No. of infants with sepsis (positive blood culture)	22 (14.8%)	20 (12.7%)	0.59
No. of infants with NEC, stage ≥II (X-ray confirmation)	1 (0.70%)	1 (0.60%)	0.95
No. of infants with IVH, grade ≥III	11 (7.4%)	18 (11.4%)	0.24
No. of infants treated for PDA (ibuprofen or indomethacin)	5 (3.4%)	6 (3.8%)	0.85

*All percentages are based on the number of infants or patient days for the corresponding NICU.
HFO, high-frequency oscillation; IVH, intraventricular hemorrhage; NEC, necrotizing enterocolitis; NICU, neonatal intensive care unit; OBA, open bay area; PDA, patent ductus arteriosus; SFR, single-family room; SIMV, synchronised intermittent mandatory ventilation; SIPPV, synchronised intermittent positive pressure ventilation.

the low and high SpO_2 and heart rate alarms (table 3). The OBA NICU had 37.4% and 91.1% more low and high SpO_2 alarms per infant per day, compared with the SFR NICU.

Overall, the OBA NICU generated 44% more patient monitor alarms per day. The distribution of red and yellow alarms through the course of the day, for all patient monitor alarms and their most prevalent subtypes, for both NICUs, is shown in figure 2. The number of red monitor alarms is higher in the SFR NICU while the number of yellow alarms is higher in the OBA NICU. The low SpO_2 and desaturation alarms exhibit periodicity in their occurrence, as has been reported earlier.[21 22]

For the SFR NICU, logs of the ventilator alarms were available since ventilators were connected to patient monitors. Nearly 15 000 red and 202 000 yellow ventilator alarms were analysed. Appendix A shows that the ventilator alarms also exhibit a clear 2-hourly periodicity for both the red and yellow alarms. For the SFR NICU, while the patient monitor generates 42.4 and 174.4 red and yellow alarms per infant per day, the ventilator further adds 15 red and 206.5 yellow alarms, respectively. For red ventilator alarms, the most common alarms were the alarms corresponding to the disconnection of the ventilator circuit (55.5%), problems with the endotracheal tube (27.25%) and high peak inspiratory pressure (15.4%). For the yellow alarms, the most common alarms corresponded to low inspiratory pressure (72.4%), insufficient volume delivery (7.3%), low minute volume (4.6%) and low positive end-expiratory pressure (4.2%).

With regard to the interaction of clinicians with the patient monitor, nurses pause alarms (all categories of alarms get paused) more often in the SFR NICU while

nurses in the OBA NICU silence alarms much more often. For the alarms that were silenced, the alarm condition persisted beyond 3 min for nearly one-third of the alarms in the OBA NICU as opposed to 11% in the SFR NICU, leading to resounding of alarms (table 3).

Notably, patient characteristics between the two units were comparable (p value >0.05) with the exception of ventilated days (p value <0.01). However the effect size, as measured by proportion difference, for ventilated days is small with the OBA NICU having a 4.5% higher risk of ventilation.

DISCUSSION
The number of audible patient monitor alarms (red+yellow+technical INOP) is high for NICUs of both the SFR and the OBA design, as has been reported earlier.[15 16 21–25] However, the number of alarms and the associated noise pollution vary considerably with the OBA NICU generating 44% more alarms per patient per day. Multiple studies in different NICUs have shown a periodic increase in alarms through the course of the day, and this periodicity can be observed for both NICUs included in this study.[15 21 22] This periodic increase in alarms has been found to be associated with both nursing care events as well as the delivery of enteral feeds.[26] The SFR NICU of this study had a 2-hourly frequency of enteral feeding, and this is reflected in a 2-hourly increase in alarms. The peaks in alarm pressure for the OBA NICU are less clear since the frequency of enteral feeding was dependent on the weight of infants with a frequency of once every 1–3 hours (see table 1). The periodic increase in the interaction of clinicians with the patient monitor

Table 3 Characteristics of the red (desaturation, bradycardia and apnoea), yellow (low and high SpO$_2$ and heart rate) and INOP alarms for the SFR and OBA NICUs of MMC and Isala

Alarm type	NICU design (delay*)	Mean no. daily of alarms/infant	% of total alarms	Median (IQR) duration of alarm (s)	Mean daily duration of alarm/infant (min)
Desaturation	SFR (10 s)	31.76	75.14†	10(4–23)	10.65
	OBA (20 s)	13.22	56.47	17(7–41)	7.59
Bradycardia	SFR (0 s)	7.27	17.20	5 (3–12)	1.05
	OBA (0 s)	7.14	30.49	5 (3–12)	1.07
Apnoea	SFR (0 s)	0.92	2.18	9 (5–19)	0.24
	OBA (0 s)	1.19	5.09	9 (4–16)	0.29
SpO$_2$ low	SFR (15 s)	88.98	51.03	14 (6–30)	38.70
	OBA (10 s)	122.25	42.22	14(6–31)	55.33
SpO$_2$ high	SFR (15 s)	53.08	30.43	26(10–64)	47.70
	OBA (10 s)	101.46	35.04	12(5–32)	55.72
Heart rate low	SFR (0 s)	15.04	8.62	5 (3–8)	1.59
	OBA (0 s)	13.27	4.58	5 (3–8)	1.41
Heart rate high	SFR (0 s)	11.82	6.77	8 (4–20)	3.42
	OBA (0 s)	17.13	5.91	8 (4–20)	5.04
Silence	SFR	17.49	–	–	–
	OBA	59.42	–	–	–
Pause	SFR	9.3	–	–	–
	OBA	3.35	–	–	–
Technical alarms	SFR (0 s)	4	–	–	–
	OBA (0 s)	3.88	–	–	–
Resounding of alarms	SFR	1.67	–	–	–
	OBA	22	–	–	–

*Delay corresponds to the delay before generating the alarm once the threshold is breached.
†Percentages correspond to contribution of alarms from the same category (red/yellow).
INOP, inoperative; MMC, Máxima Medical Centre; NICU, neonatal intensive care unit; OBA, open bay area; SFR, single-family room.

(figure 2) indicates an attempt to suppress alarm-related noise during these periods.

The higher incidence of red alarms in the SFR NICU is primarily due to more desaturation alarms, likely due to a shorter delay (10 s as opposed to 20 s in the OBA NICU) in generating the desaturation alarm once the threshold value (80% in both units) is breached.[25] Irrespective of the averaging setting employed, longer delays allow the oxygen saturation levels to recover, resulting in fewer alarms of a longer duration, which is unsurprising since they arise due to desaturation events that did not resolve spontaneously within the set delay period.[25]

In a previous study carried out in the SFR NICU of MMC, we identified that the median nurse response times to red desaturation alarms was quite long at 56 s.[19] Since extended desaturation events are associated with adverse outcomes, there is a natural tendency for SFR NICUs to err on the side of caution and opt for shorter delays.[27] However, for the OBA NICUs with direct visual oversight and potentially shorter distances and nurse response times, slightly longer delays in generating the alarm, on average, help in reducing the mean daily duration for

which the alarms sound and reduce noise in the typically noisier OBA environment.[28–30] The choice of delay gets further challenged since a study has shown that in infants born small for gestational age, a high incidence of even short hypoxaemic events (20 s) within 3 days of birth is associated with higher mortality at 90 days of life.[31] Therefore, we should contemplate dynamically adjusting not just alarm thresholds but also alarm delays, based on the vulnerability profile of infants, with shorter delays in place for the most vulnerable infants. In summary, there exists a delicate tradeoff between the choice of alarm delays and the risk of alarm fatigue.[32] Quantifying alarm pressure as described in this study is an important step in assessing the risk of alarm fatigue. It also serves as a baseline measure that can be used to contrast changes in alarm settings such as delays that may affect alarm pressure.

The incidence of yellow alarms is higher for the OBA NICU, primarily because of more low and high SpO$_2$ alarms. The higher incidence of low SpO$_2$ alarms is largely due to a narrower alarm limit (88%–95%; median values of alarm thresholds), evidence of which can also be found elsewhere.[22] Furthermore, in comparison with the
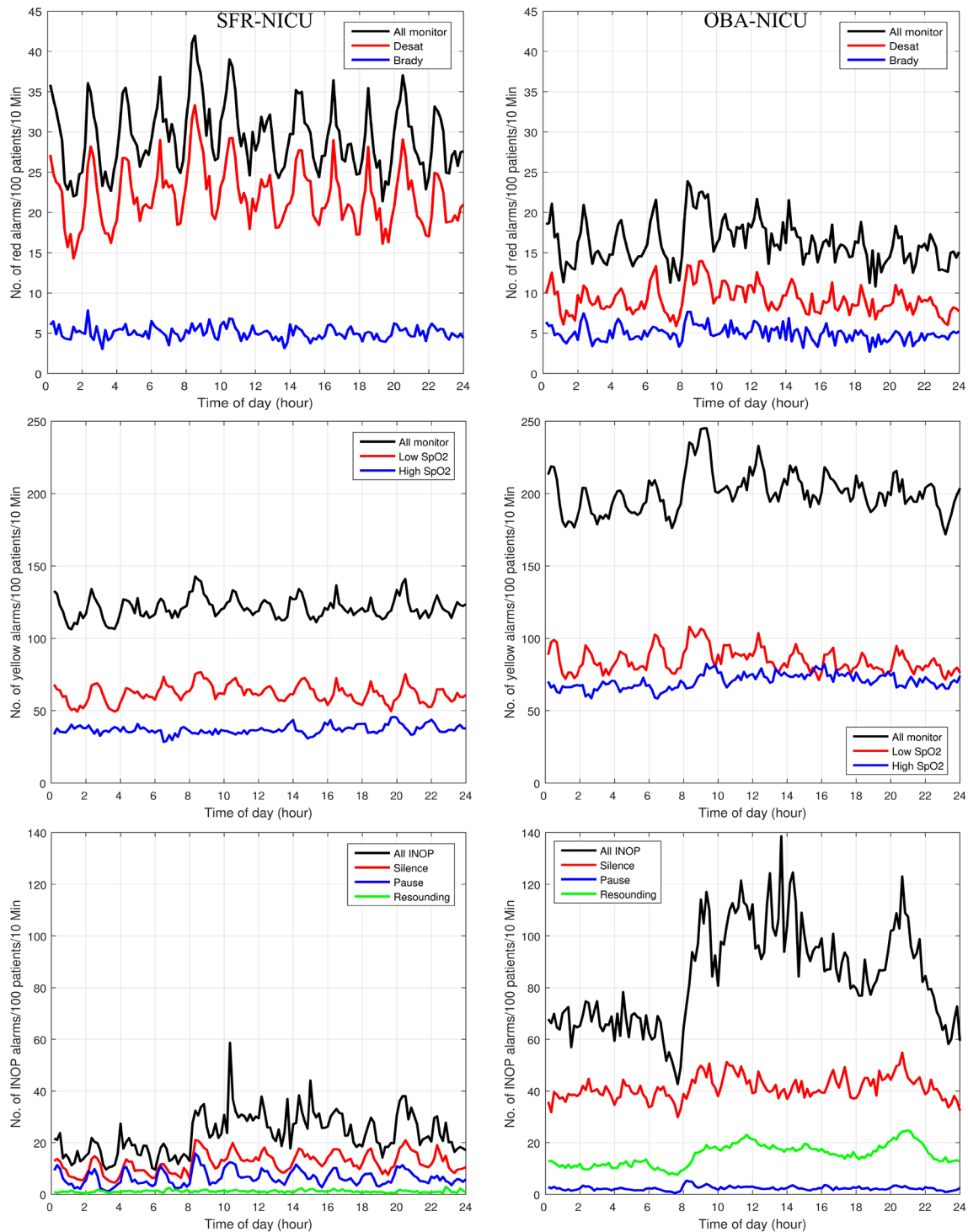
Figure 2 The average number of logs corresponding to red (top), yellow (middle) and inoperative (INOP) (bottom) alarms measured during the study period plotted through the 24 hours of the day in the single-family room neonatal intensive care unit (SFR NICU) (left column) and the open bay area (OBA) NICU (right column). The alarm rate is shown for 100 patients per 10 min. Note that the resolution of the y-axis varies for each row of subplots.

SFR NICU, the delay for yellow alarms is shorter (10 s as opposed to 15 s in the SFR NICU), which leads to more alarms. The considerably larger number of high SpO_2 alarms is difficult to explain but important to consider since hyperoxaemia is associated with an increased risk of retinopathy of prematurity. It should be noted that alarms for high SpO_2 are off when infants are breathing room air, so all alarms corresponding to high SpO_2 originate solely from infants on intermittent supplemental oxygen. While the greater number of high SpO_2 alarms in the OBA NICU might partly be due to the shorter delay in generating the alarm, it might also be due to rebound hyperoxaemia as a result of nurses increasing supplemental oxygen to combat a large number of low

SpO_2 alarms.[33] This rationale is further supported by the finding that for 37.5% of high SpO_2 alarms, thresholds were set to higher than 95%, while in the SFR NICU, only 16% of high SpO_2 alarms had a threshold higher than 95% (data not shown but calculated from the alarm logs of these units).

Regarding ventilator alarm management, as has been pointed out by the ECRI Institute and research groups, multiple challenges exist.[34–36] In particular, the ECRI Institute highlights that collecting and analysing ventilator data can be challenging, and limited research exists on ventilator alarms.[19 24 37] To the best of our knowledge, this study is the largest audit of ventilator alarms, and we show that the daily alarm pressure (average) because of ventilators, in fact, exceeds that due to patient monitors alone. It should be noted that although on average ventilator alarm pressure is high, it is also dependent on the mode of ventilation. The periodic increases in ventilator alarms (online supplementary file), similar to the pattern observed in patient monitor alarms, might be in response to nursing care (eg, endotracheal suctioning) and enteral feeding.[26] Opportunities to reduce ventilator-related alarms have been suggested elsewhere.[37]

In the OBA NICU, the exposure of infants to alarm sounds is likely higher since both the number of daily alarms (red+yellow+technical INOP) is higher and the mean daily duration for which alarms sound is longer (table 3). Furthermore, in an OBA environment, there is greater exposure to alarm sounds originating from other infants. Noise due to alarms, as experienced by the nurses, is also likely higher in the OBA NICU since nurses are exposed to both red and yellow alarms originating from all infants. In the SFR NICU, nurses receive red alarms on handheld devices and therefore spend less time at the central post and likely experience fewer alarm sounds. In the OBA NICU, nurses silence alarms more often than in the SFR NICU, probably because they spend more time at the central post as opposed to nurses in the SFR NICU who have handheld devices and are safe in the knowledge that all red alarms will be transmitted to them. In both units, pausing alarms was possible only at the patient monitors (bedside). Nurses in the SFR NICU paused alarms more often than nurses in the OBA NICU. This behaviour might be because nurses in the SFR setting do not have visual oversight of the infants in their charge and might tend to respond to alarms by visiting the bedside more frequently and thereby creating more opportunities to pause alarms.

In this study, we compared alarm pressure between two NICUs, one of an SFR design and the other of an OBA design. In other aspects, both units are comparable since they use similar monitoring equipment and have similar patient populations and alarm handling protocols – with a nurse response expected to red alarms while yellow alarms serve as alerts. However, the non-randomised nature of the study is an unavoidable limitation despite the fact that the units are comparable with regard to the case mix as measured by patient data including gestational age, birth weight and mortality (acquired from the Dutch perinatal registry, data not shown). Furthermore, differences in nurse characteristics of the two units can also affect alarm pressure, but these differences are expected to be minimal since all nurses are drawn from a small and homogenous Dutch-speaking population with a comparable educational and professional background. Nevertheless, certain local factors, such as the immediate availability of other clinical personnel such as residents, can affect the delivery of care and thereby the alarm pressure. The results of the audit of patient monitoring alarms of the two NICUs show that considerable differences in alarm pressure exist, and these are at least partly attributable to the delays set in generating alarms. The choice of alarm thresholds and delays and thereby the exposure of infants and nurses to alarm sounds are in turn related to the architectural layout of the NICUs. In the two NICU designs studied, the burden of alarms and exposure to alarm sounds experienced by infants and nurses is higher in the OBA NICU. Additionally, there might also be a relationship between excessive exposure to alarm sounds and the changing of upper alarm limits for SpO_2 alarms, potentially leading to SpO2 levels not staying within guideline recommendations.[38] In particular, this has clinical implications associated with the distribution of oxygen saturation in preterm infants, especially if the target range for SpO_2 is narrow.[39] While alarm fatigue and the consequent increase in the risk of missed alarms is detrimental to clinical outcomes in all settings, within the NICU context, the associated noise is particularly disruptive to the short-term stability of the cardiac and respiratory systems as well as the sleep cycles of infants. Alarm-related noise is also stressful to staff and negatively affects the work environment.[40–42]

Recently, the OBA NICU of this study has introduced a portable and non-audible alarm system to reduce noise in the unit with alarms sounding only at the central post. Implementing such a system reduces noise pollution in the NICU, originally a key advantage of the SFR design. Because of architectural layout and typically shorter distances from the central post to the bedside, OBA NICUs are better positioned to implement longer delays for generating alarms. Based on the results of this study, we can identify that in the OBA NICU, implementing longer delays, for example, 20 s for yellow SpO_2 alarms, will reduce the corresponding alarms by more than 50%, leading to lower noise exposure for nurses at the central post. Furthermore, in the OBA NICU of this study, by introducing even an 8 s delay for yellow alarms corresponding to low and high heart rate, 75% and 50% of these alarms can be eliminated (table 3).

About the SFR NICU in the study, sounding yellow alarms at the bedside where no clinician is present for the vast majority of the day does not serve to draw the attention of the caregiver to the clinical status of the infant. These alarms, however, contribute to more than 80% of the noxious noise experienced by the infant. In comparison with the new alarm system of the OBA NICU, the

potential benefits of the SFR design, at least with regard to lower exposure to noxious sounds, may not be fully realised unless close attention is paid to the choices for communicating alarms to the caregivers.

To conclude, for the design of new NICUs and the remodelling of older units, in addition to the various aspects such as the nurse–patient ratios that are typically considered, attention should also be paid to how the architectural layout and the consequent choices for alarm settings and alarm distribution affect alarm pressure and by association alarm fatigue.[43–45] If non-audible alarm systems can be implemented, the opportunity to implement longer delays in the OBA NICUs, at least for yellow alarms, can lead to reduced alarm pressure in comparison with SFR NICUs.

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