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The Physiological Effects of an Adjusted Alarm Architecture on a Neonatal Intensive Care Unit

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ABSTRACT

Aim: The effects of using handheld devices in combination with filtering and delaying alarms were investigated. Effects on the number of alarms, patient safety, and nurses' experience were evaluated.

Methods: Alarm and physiological trend data were collected over two periods of three months for a control ($n = 54$) and intervention ($n = 47$) group. During the intervention period, an adapted alarm architecture, filtering and delaying alarms, was implemented, and the number of alarms, critical cardiorespiratory events, and episodes of decreased oxygen saturation and heart rate were compared to the contemporary alarm architecture. Nurses filled out a survey on their experiences.

Results: The adapted alarm architecture reduced the number of alarms by 84%. This reduction did not result in significant differences in the number of critical events. Additionally, the duration and depth of the patient's episodes of mildly decreased oxygen saturation and heart rate were unaffected. Nurses reported that they continue to receive too many alarms and occasionally miss alarms.

Conclusion: Alarms can be filtered and delayed, reducing the number of alarms and preventing alarm fatigue. Patient safety is not at risk since the number of critical events and the decreases in oxygen saturation and heart rate do not differ significantly between the groups.

1 | Introduction

Monitoring vital patient parameters is the backbone of intensive care medicine. In addition, various devices such as ventilators and infusion pumps notify nurses when action is warranted. This results in a multitude of alarms for the intensive care nurse, leading to desensitisation to these alerts, also known as alarm fatigue. As a result, nurses tend to ignore or delay responding to these safety alerts, thereby compromising safety [1–4]. The risk of alarm fatigue can be reduced by limiting the alarms to those that actually require action. This reduces the alarm pressure on caregivers and contributes to ensuring patient safety [3].

Another factor contributing to the alarm burden is the patients' environment and how the alarms are sent to the nursing staff. In an open bay unit, monitor and device alarms are generated at the bedside of each patient, and alarms are usually also displayed on a central workstation. In order to receive alarms, a nurse must

Summary

- Implementing an adapted alarm architecture has led to a large reduction in the number of alarms through filtering and using delays.
- The number of alarms was reduced without compromising patient safety in terms of critical cardiorespiratory events and episodes of decreased oxygen saturation and heart rate.
- Future studies should focus on implementation in single-patient rooms to overcome the fact that nurses still hear and see the original alarms.

maintain constant visual and audible contact with the patient. This not only limits the nurses' physical workflow, but with more than 150 alarms per patient per day [5], it also leads to exposure to many more alarms that are aimed at colleague nurses.

Neonatal intensive care units (NICU) are currently shifting from open bay units to single-patient rooms. This minimises the sound levels for the patient, in addition to other advantages like patient and family privacy and infection prevention [6–8]. However, this means that nurses cannot always be in the same room as the patients they are taking care of, requiring the use of another form of alarm transmission. For this purpose, handheld devices are often used.

The transition to single-patient rooms changes the caregivers' workflow in many ways. The loss of direct sight and sound necessitates trust in the handheld devices to adequately transmit the alarms that were previously directly registered by the nurse. And alarms need to be escalated when the primary nurse does not respond. Importantly, this technical interface may enable the modification of alarm delivery, for example, by filtering less urgent alarms or delay alarms. While this may help to reduce the number of alarms, it may also reduce the nurses' sense of control. A balance between effective alarm management, patient safety, and nurses' experience is essential.

In preparation for a transition to single-bed rooms, handheld devices were introduced in one of four NICUs open bay units, along with a customised alarm architecture to reduce patient monitor alarms. This study aims to evaluate the effects of an adapted alarm architecture on the total number of alarms, the number of critical cardiorespiratory events, as well as the duration and depth of the decreases in oxygen saturation and heart rate. In addition, we investigated the nurses' safety experience working in this adapted environment.

2 | Methods

2.1 | Clinical Environment and Study Population

The level IIIc NICU of Erasmus MC—Sophia Children's Hospital (Rotterdam, the Netherlands) consists of four open bay units, with a total of 35 beds. This study was conducted in only one of these units, which has eight beds, two of which are in separate isolation rooms. Data on all admitted patients were collected from September to November 2021 (control) and March to May 2022 (intervention).

2.2 | Contemporary Alarm Architecture

All NICU beds were equipped with the Infinity M540 and C700 patient monitoring system (Drägerwerk AG, Lubeck, Germany). All eight beds were monitored on a central screen positioned at the unit's central nursing station. The monitor measured and alarmed for the following parameters: oxygen saturation (SpO_2), pulse rate from the pulse-oximeter (PLS), heart rate from the ECG (HR), respiratory rate from the ECG (RESP), body temperature (Ta) and invasive or non-invasive blood pressure (ART or NIBP). Appendix A lists the standard alarm settings that could be adapted based on the patient's individual clinical status.

The monitor system generated an audible and visible alarm on both the bedside monitor and the central screens (Figure 1). The alarm sound and colour indicate the alarm's priority: a red alarm indicates a critical situation, yellow denotes a warning, and blue alarms are frequently technical alarms. When multiple alarms occur simultaneously, the highest priority alarm is activated.

2.3 | Adapted Alarm Architecture Using Handheld Devices

With the introduction of handheld devices, the alarms on the bedside monitor remained visible but not audible. The alarm was transmitted from the bedside monitor to the central station, where it remained audible, and to a gateway. The alarms were then forwarded to the Medical Device Data Gateway (Itémedical, Tiel, The Netherlands), where they could be delayed and filtered. The alarms were then routed through IQ Messenger (Dordrecht, The Netherlands) and distributed to the nurse's handheld devices (Spectralink Versity 9553, Boulder, CO, USA). The alarm was audible and visible on the device, showing the type of alarm, the patient and its location, and the parameter's measured value (Figure 2).

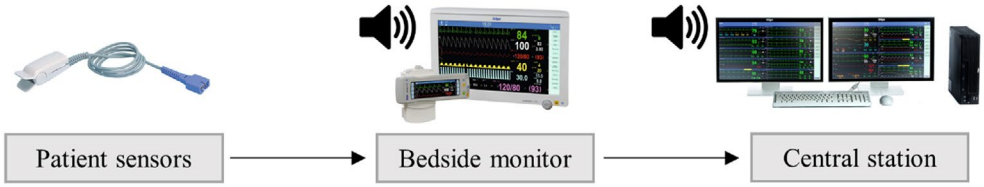

FIGURE 1 | Contemporary alarm architecture.

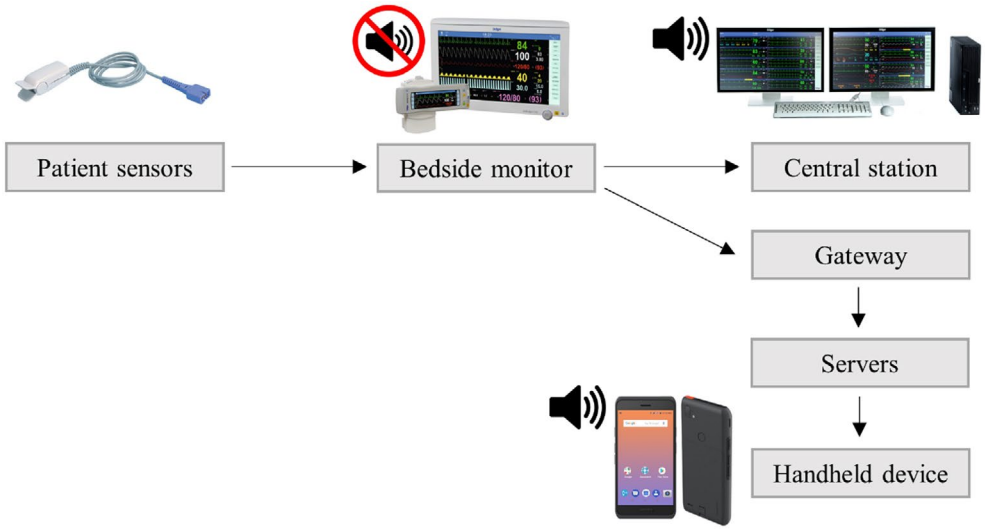

FIGURE 2 | Adapted alarm architecture including handheld device.

TABLE 1 | Delayed alarms on the handheld device.

Alarm message	Delay (s)
ART M > alarm limit	180
ART M < alarm limit	180
HR > alarm limit	180
SpO_2 > alarm limit	174
SpO_2 < alarm limit	170
SpO_2 sensor off	60
SpO_2 sensor unplugged	60

Abbreviations: ART M, mean invasive blood pressure; HR, heart rate from the ECG; SpO_2, oxygen saturation.

A focus group meeting with NICU nurses and doctors was arranged to evaluate whether alarms should be forwarded to the handheld device immediately, after a delay, or not at all, based on their clinical experience. Some ART M, HR, and SpO_2 alarms have been delayed (Table 1). The delay for the SpO_2 passing limit differs from the others since the patient monitor itself already delays the alarm by 6 or 10 s validation time to ensure that a slight decrease in oxygen saturation does not cause a false alarm. In addition to the delay, some alarms were filtered. Furthermore, the asystole, apnoea, and ventricular fibrillation red alarms were filtered because these are always false alarms for the neonatal population admitted to this unit, according to medical professionals. Appendix B offers a complete list of all active alarms and the ones that have been filtered out.

2.4 | Measurements

Alarms generated by patient monitors and those sent to handheld devices were recorded and kept in SQL databases. The following characteristics were saved: time of occurrence, alarm priority, alarm message, parameter, and alarm duration. This data was used to calculate the number of alarms, categorised by priority or message, as well as the duration of the alarms. In addition to the alarm event data, the patients' trend data and alarm settings were stored. The trend data contains all of the patient's measurable parameters, recorded every second. The number of events per 24 h was calculated using the length of stay based on the first and last moments the monitor registered the parameters.

The number of alarms per alarm message was counted to determine the reduction in the number of alarms. The number of alarms on the handheld devices was compared to the number of alarms generated by the patient monitor during the intervention period.

The number of critical cardiorespiratory events, including desaturation (SpO_2 < 80%) and bradycardia (HR < 100BPM or HR < 80BPM depending on gestational age at birth and postnatal age), for both patient groups was compared. Different event duration categories (1–10 s, 11–30 s, 31–60 s, 61–180 s and 181-max. s) were considered to determine whether there was a significant difference for one of these categories.

Each patient's trend data for saturation and heart rate was analysed to determine whether the intervention group saw more, longer, or deeper decreases in these parameters. By comparing the trend data to the alarm settings, episodes of decrease could be detected. For each episode, the duration, lowest measured value, and area under the alarm limit (AUAL) using the trapezoidal rule, which approximates the area under a curve by dividing it into trapezoids, calculating their areas, and summing them up, were determined. Also, the total number of episodes was noted. For each patient, the median (IQR) of these measurements is reported. The validation time (delay) for both SpO_2 and HR, integrated into the patient monitor, is taken into account when determining these decreases.

2.5 | Survey on Perceived Experience

A survey was conducted to assess whether nurses working on this unit experienced different levels of alarm pressure and perceived

safety compared to other units within the NICU where alarm settings remained unaltered (for a full survey, see Appendix C). Only nurses regularly assigned to the unit and who were familiar with using the handheld devices were invited to participate in the survey. The survey included questions on alarm fatigue and how alarms are experienced using handheld devices.

2.6 | Statistical Analysis

Categorical variables were described using absolute numbers and frequencies. Continuous variables were described using medians and interquartile ranges because of non-normal distributions. Statistical analysis was performed using R (R Core Team (2017), Vienna, Austria). The Chi-squared test was used for categorical variables, and the Mann–Whitney *U* test was used for continuous variables. For all tests, a *p*-value of <0.05 was considered significant.

3 | Results

3.1 | Demographics

From September to November 2021, 54 patients were admitted to Unit 4 of the NICU. During the intervention period, which ranged from March to May 2022, 47 patients were admitted. The characteristics of the included patients are presented in Table 2.

During the control period, 352.313 alarms were included, yielding a total of 3.872 alarms per 24 h. The intervention period had 349.740 alarms, approximately 3.802 alarms per 24 h. Adjusted to the nurses' 8-h shifts, this means they were exposed to nearly 1.300 alarms during a shift. Each nurse usually takes care of 2 or 3 patients, which means 430–650 alarms directed to a nurse individually per shift.

3.2 | Number of Alarms

The number of alarms on the handheld devices using the adapted alarm architecture during the intervention period was 56.561, which resulted in an average of 615 alarms per 24 h and only 205 alarms throughout the nurse's shift for all the patients on the unit, which is an 84% reduction in alarms throughout this period (Table 3). The amount of blue and yellow alarms has been reduced the most. Only a few false red alarms are filtered out; thus, the number of these alarms is nearly equal to the original number of alarms. Figure 3 shows the distribution of types of alarms for the normal and adapted alarm architecture. When looking at the handheld devices, it is clear that yellow alarms are far less common and red alarms make up the majority of the alarms. This is because most yellow alarms are delayed or filtered, whereas red alarms are still passed on directly.

3.3 | Patient Safety

For all the duration groups of the critical cardiorespiratory events, there are no significant differences reported (Figure 4). The boxplot for the 181-max seconds is not included in the figure since the number of desaturations per 24 h was too small. Only a few patients had one or two desaturations, and in both groups, there was one patient with 16 or 15 desaturations per 24 h. In the control group, there was one patient who had three bradycardias per 24 h, whereas all the others had zero bradycardias. The intervention group consisted of one patient who had one bradycardia per 24 h.

There was also no significant difference in the measurements of episodes of decreased oxygen saturation and heart rate between the control and intervention groups (Figure 5).

TABLE 2 | Characteristics of the study population.

Characteristics	Control ($n=54$)	Intervention ($n=47$)	*p*
Gestational age (weeks)	32.71 (28.86–38.21)	31.43 (28.36–36.71)	0.4023
Birth weight (grams)	1985 (1001–3030)	1850 (1215–2920)	0.7801
Length of stay (days)	8 (3–20)	8 (4–50)	0.3329
Gender			1.0000
Male	32	28	
Female	22	19	
Maternal hypertension			0.5286
Yes	9	8	
No	4	36	
Unknown	2	3	
PPROM			0.1600
Yes	7	9	
No	45	34	
Unknown	2	4	
Number of steroids			0.4117
0	26	23	
1	7	7	
2 or more	17	12	
Unknown	4	5	
Mechanical ventilation			0.5235
Yes	23	23	
No	31	24	
Mechanical ventilation days	5 (2–7)	5 (3–20)	0.4332
Monitor alarms per 24 h	354 (206–567)	358 (229–587)	0.5333

Abbreviation: PPROM, preterm premature rupture of membranes.

TABLE 3 | Number of alarms for the control and intervention group.

Priority	Contemporary alarm architecture during control period	Contemporary alarm architecture during intervention period	Adapted alarm architecture using handheld devices	Alarms reduced during intervention period (percentage)
Blue	22.604	29.115	1.031	28.084 (96%)
Yellow	283.408	269.942	12.177	257.765 (95%)
Red	38.739	38.970	37.051	1.919 (5%)
Unknown	7.562	11.713	6.302	5.411 (46%)
Total	352.313	349.740	56.561	293.179 (84%)

Note: For the control group, only the monitor alarms are available; for the intervention group, both the monitor and the handheld device alarms. The table mentions unknown alarms; these are alarms that had been distributed to the monitor but were not registered completely in the alarm database. Most of the time, these are really short alarms. The unknown alarms for the handheld device are mostly alarms that did not occur in the testing phase but were first seen when the handheld devices were used in practice.

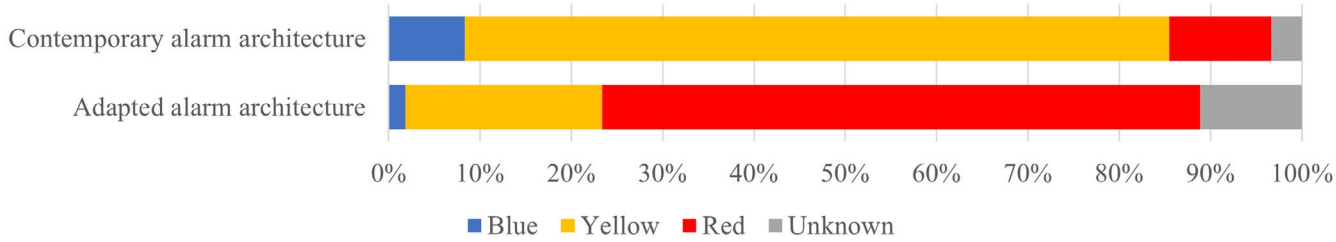

FIGURE 3 | The distribution of types of alarms for the contemporary and adapted alarm architecture.

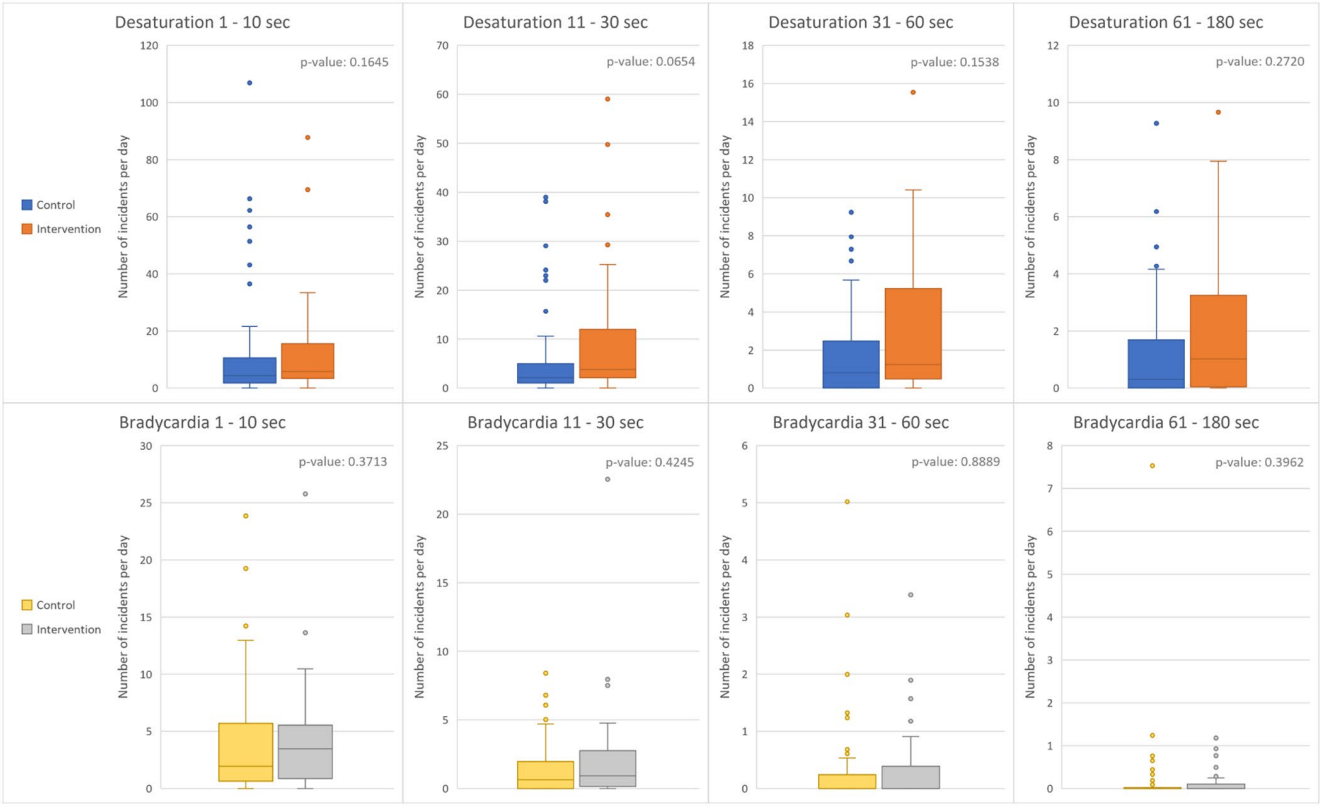

FIGURE 4 | Boxplots for the critical cardiorespiratory events desaturation and bradycardia.

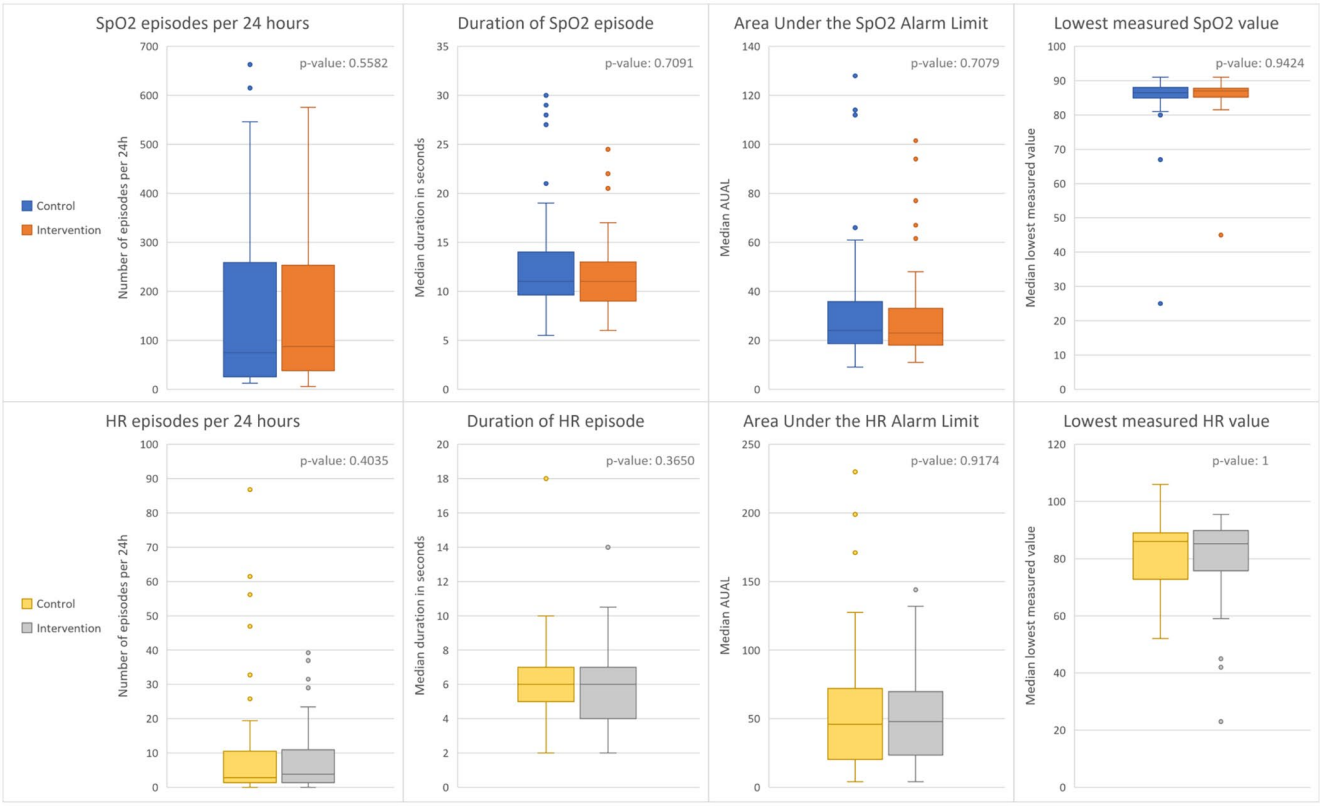

FIGURE 5 | Boxplots for the episodes of decrease in oxygen saturation and heart rate.

TABLE 4 | Answers to the yes/no questions of the survey sent to the nurses.

Question	Yes (%)
Do you feel that the alarm pressure on unit 4 is lower than on the other units?	5 (41.7%)
Do you think the alarms on the handheld device are helpful?	5 (41.7%)
Do you feel like you are missing important alarms when using the handheld device?	11 (91.7%)
With the current settings on the handheld device, would you dare to work in a single room in the future?	4 (33.3%)

3.4 | Survey on Perceived Experience

The survey was distributed to 24 nurses, with 12 nurses (50%) responding. The results for the yes/no questions are shown in Table 4. It is noticeable that 11/12 (91.7%) nurses expressed the feeling that they missed alarms when using the handheld device. This was exemplified with a nurse with the hands in the incubator, but the handheld device alarming for another patient that he or she is caring for. At this moment, they cannot see why it is alarming and lack context, and consequently must take out their handheld device to determine what kind of alarm it is. Another reason for having the idea of missing alarms is that it is still too many alarms that are sent to the device. "Too many alarms coming through, you cannot keep checking the handheld, so you miss alarms too", one of the nurses stated. The feeling of safety while working with handheld devices was −1 (IQR −2.25 to 0.25) on a scale of −5 to 5. This score is a combination of the feeling of missing alarms while the device is in their pocket, and because they are still using an open bay area in which the monitor alarms are heard and seen, while a filtered and delayed handheld device shows fewer alarms.

4 | Discussion

The purpose of this study was to evaluate how reducing alarms in a NICU using handheld devices affected patient safety and nurses' experience. The revised alarm architecture led to a markedly reduced number of alarms distributed on handheld devices, without an increase in critical alarms. Nurses were satisfied with the number of handheld alarms but were still exposed to the alarms in the open bay unit. Also, likely due to this *regular* alarm exposure in the open bay unit, they reported that they missed some alarms on the handheld device, which felt not completely safe.

Previous research has demonstrated that using handheld devices in a single-patient room is challenging, but possible [9]. Van Pul et al. Et al. focused on a safe alarm management system through a risk analysis and used filtering to only send red alarms to handheld devices, while yellow alarms were audible and visible only at the central station or via interbed monitoring. However, they did not concentrate on reducing the number of alarms or on patient safety. Our current study focused on reducing the alarms and included yellow alarms sent to the handheld devices, most of

which were delayed by 180 s. Patient safety was also assessed by analysing trend data to evaluate the effect on vital signs.

Other work by Varisco et al. showed that delaying alarms for oxygen saturation by 10 to 20 s is feasible, significantly reducing desaturation alarms per patient by adjusting both the averaging and delay times [10]. However, the nurses and doctors of our NICU decided not to delay red desaturation alarms, but only some yellow alarms.

Additionally, several other studies have demonstrated that reducing saturation alarms, both red and yellow, through changes in alarm limit settings and alarm delays can lead to a 64%–78% reduction in SpO_2 alarms [11–13]. In addition to reducing the saturation alarms, our current study also focused on other alarms, such as heart rate. The other studies also did not focus on patient safety in the way of evaluating the vital signs; they only focused on the reduction of the numbers.

Our study also had some limitations. Most importantly, the nurses still worked in open bay areas, meaning they could still see patient monitors with vital signs and visual alarms as well as hear the alarm sounds. This may have had important effects on our results focusing on nurse experience and perceived safety. From their experience, it is more difficult to work with the handheld devices meant for when the patients are in single-patient rooms, which is reflected in the results of the survey. The nurses reported that they have the feeling of missing important alarms because they see the alarms on the monitor but do not receive them on their handheld device. In other research [14, 15], nurses are questioned about their experience with handheld devices, and they appear to be satisfied with how they are used and do not report missing alarms. However, these studies are conducted in single-patient rooms, which is likely to have a significant impact on nurses' experience and perceived safety.

Additionally, we had limited access to the alarm data, which resulted in only 3 months of data for both periods. With a smaller patient population, there is an increased likelihood that the data could be skewed by the presence of a few extremely ill patients. To reduce this potential bias, we conducted a comparison of the patient characteristics in the two groups. We tried to reduce the impact of each individual patient's condition on the overall results by ensuring that there were no significant disparities in demographics, baseline health status, or sickness severity. Despite these attempts, the fundamental restriction of the small sample size persists, and our findings should be regarded with caution.

For future work, it is recommended to also test this situation with filtered and delayed alarms in the single rooms. The nurses can now rely on their sight and hearing since the patients are in the open bay. The situation for both the patient and the nurse will be completely different when working with single rooms. This can also result in longer response times for the nurses and cause deeper dips or more critical events. Also, the choice of the kind of handheld device can be further investigated. Nurses now report the fact that they are busy with their hands in the incubator and therefore are not able to grab the device to see which patient and what kind of alarm is going on. If there is a possibility for showing the message on the top of the device, this can save the nurse time and make it easier to respond to an alarm.

5 | Conclusion

Alarms can be filtered and delayed to reduce the number of alarms and to prevent nurses from alarm fatigue. It leads to a safe reduction in the number of alarms, which makes it better workable when the open bay areas transform into single rooms. Patient safety is not at risk since the number of critical events and the decreases in oxygen saturation and heart rate do not differ significantly between the two groups. However, nurses do not experience a completely safe feeling at this moment, mainly because both the old and new alarm architectures are in use in the open bay setting.

Author Contributions

Melissa A. C. M. Kalden: writing – original draft, visualization, formal analysis, data curation, investigation. **Tom G. Goos:** writing – review and editing, methodology, resources. **Nico Kalden:** writing – review and editing. **Leo A. Groenendaal:** writing – review and editing. **Irwin K. M. Reiss:** writing – review and editing, conceptualization. **Jasper Van Bommel:** methodology, writing – review and editing. **H. Rob Taal:** writing – review and editing, methodology.

References

1. A. C. Bridi, T. Q. Louro, and R. C. L. Silva, "Clinical Alarms in Intensive Care: Implications of Alarm Fatigue for the Safety of Patients," *Revista Latino-Americana de Enfermagem* 22, no. 6 (2014): 1034–1040, https://doi.org/10.1590/0104-1169.3488.2513.

2. K. J. Ruskin and D. Hueske-Kraus, "Alarm Fatigue: Impacts on Patient Safety," *Current Opinion in Anaesthesiology* 28, no. 6 (2015): 685–690, https://doi.org/10.1097/ACO.0000000000000260.

3. K. R. Johnson, J. I. Hagadorn, and D. W. Sink, "Alarm Safety and Alarm Fatigue," *Clinics in Perinatology* 44, no. 3 (2017): 713–728, https://doi.org/10.1016/j.clp.2017.05.005.

4. B. D. Winters, M. M. Cvach, C. P. Bonafide, et al., "Technological Distractions (Part 2): A Summary of Approach-Es to Manage Clinical Alarms With Intent to Reduce Alarm Fatigue," *Critical Care Medicine* 46, no. 1 (2018): 130–137, https://doi.org/10.1097/CCM.0000000000002803.

5. T. Li, M. Matsushima, W. Timpson, et al., "Epidemiology of Patient Monitoring Alarms in the Neonatal Intensive Care Unit," *Journal of Perinatology* 38, no. 8 (2018): 1030–1038, https://doi.org/10.1038/s41372-018-0095-x.

6. D. C. Stevens, C. C. Helseth, P. A. Thompson, J. V. Pottala, M. A. Khan, and D. P. Munson, "A Comprehensive Comparison of Open-Bay and Single-Family-Room Neonatal Intensive Care Units at Sanford Children's Hospital," *Herd* 5, no. 4 (2012): 23–39, https://doi.org/10.1177/193758671200500403.

7. A. Almadhoob and A. Ohlsson, "Sound Reduction Management in the Neonatal Intensive Care Unit for Preterm or Very Low Birth Weight Infants," *Cochrane Database of Systematic Reviews* 2020, no. 1 (2020): CD010333, https://doi.org/10.1002/14651858.CD010333.pub3.

8. S. E. Szymczak and R. A. Shellhaas, "Impact of NICU Design on Environmental Noise," *Journal of Neonatal Nursing* 20, no. 2 (2014): 77–81, https://doi.org/10.1016/j.jnn.2013.07.003.

9. C. van Pul, H. P. M. E. van de Mortel, J. J. L. Bogaart, T. Mohns, and P. Andriessen, "Safe Patient Monitoring Is Challenging but Still Feasible in a Neonatal Intensive Care Unit With Single Family Rooms," *Acta Paediatrica* 104, no. 6 (2015): 247–254, https://doi.org/10.1111/apa.12907.

10. G. Varisco, H. van de Mortel, L. Cabrera-Quiros, et al., "Optimisation of Clinical Workflow and Monitor Settings Safely Reduces Alarms

in the NICU," *Acta Paediatrica* 110, no. 4 (2021): 1141–1150, https://doi.org/10.1111/apa.15615.

11. K. E. McCauley, A. A. Schroeder, T. K. DeBoth, et al., "Reducing Alarm Burden in a Level IV Neonatal Intensive Care Unit," *Pediatric Quality and Safety* 6, no. 2 (2021): e386, https://doi.org/10.1097/pq9.0000000000000386.

12. C. McClure, S. Young Jang, and K. Fairchild, "Alarms, Oxygen Saturations, and SpO_2 Averaging Time in the NICU," *Journal of Neonatal-Perinatal Medicine* 9, no. 4 (2016): 357–362, https://doi.org/10.3233/NPM-16162.

13. K. R. Johnson, J. I. Hagadorn, and D. W. Sink, "Reducing Alarm Fatigue in Two Neonatal Intensive Care Units Through a Quality Improvement Collaboration," *American Journal of Perinatology* 35, no. 15 (2018): 1311–1318, https://doi.org/10.1055/s-0038-1653945.

14. R. Joshi, H. van de Mortel, L. Feijs, P. Andriessen, and C. van Pul, "The Heuristics of Nurse Responsiveness to Critical Patient Monitor and Ventilator Alarms in a Private Room Neonatal Intensive Care Unit," *PLoS One* 12, no. 10 (2017): e0184567, https://doi.org/10.1371/journal.pone.0184567.

15. C. V. Benincasa, K. A. Bailey, and A. B. Eliades, "Alarm Fatigue Reduction in a Single Patient Room Neonatal Intensive Care Unit," *OJIN: The Online Journal of Issues in Nursing* 29, no. 2 (2024), https://doi.org/10.3912/OJIN.Vol29No02PPT23.

Supporting Information

Additional supporting information can be found online in the Supporting Information section.