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Research Article

The impact of a noise reduction bundle on ICU staff: A stepped-wedge cluster randomized clinical trial

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ABSTRACT

Objectives: To determine the effectiveness of a multicomponent intervention bundle on sound levels in the ICU.
Methods: A stepped-wedge cluster randomized clinical trial was conducted in four intensive care units during a period of 14 months. A multicomponent intervention bundle aimed at reducing sound levels—consisting of education, equipment interventions, designated quiet times, and feedback—was implemented as a standard of care.
The main outcome measures were: A-weighted sound levels (LAeq), alarms/day/bed, annoyance ratings (numeric rating scale 0–10), and the number of observed nurse distractions during medication preparation. Differences in outcomes between the intervention and control periods were tested. For the primary outcome, the minimal clinical importance difference of 3 LAeq was used, as this level is audible to humans.
Results: LAeq control vs intervention, LAeq decreased from 53.7 (±5.8) to 52.9 (±5.9) dBA ($p < 0.001$) at the central nursing station. The median [IQR] number of alarms/day/bed decreased from 228 [IQR 176–290] during control to 194 [IQR 148–249] during intervention ($p < 0.001$). Nurses' annoyance rating control vs. intervention changed from median 3.0 [IQR 2.0–5.0] to median 3.0 [IQR 2.0–4.0] ($p < 0.001$). Distractions decreased from 73 % during control period to 61 % ($p < 0.001$) during the intervention.
Conclusions: Use of a multicomponent intervention bundle led to a statistically significant reduction in sound levels— though not to a clinically relevant degree. Importantly, there were statistically significant improvements in the number of alarms, as well as in nurses' annoyance and distractions, compared with the control period.

Introduction

Sound levels in intensive care units (ICUs) have been steadily rising over the last 50 years with recommendations set by the World Health Organization (average sound pressure levels < 35 dB [dBA]) [1] being exceeded with sound levels of 70–80 dBA [2–4]. Due to the sophisticated and complex nature of the ICU workplace with increasingly advanced medical technology, excessive noise emissions are prevalent. At the same time there has been a noticeable increase in the recognition of the adverse effects of these sound levels on ICU healthcare professionals, such as sensations of annoyance, fatigue and increased stress [4]. Consequently, ICU professionals face the challenge to perform high-risk procedures amidst elevated sound levels [5], which may hinder communication and concentration thereby endangering patient safety [6]. Moreover, it is well known that ICU staff becomes desensitized to alarms due to frequent non-urgent alarms, also known as'alarm fatigue' [7]. The most disruptive noises originates from conversations and care-related activities [8]. These are primarily due to the behavior of staff and visitors, making them potentially modifiable [9,10]. However, given the multifactorial nature of the causes, achieving a sustainable reduction in noise requires implementing an intervention bundle based on minimizing the disrupting impact of these noise sources [11]. In a recent pre-post design study, a noise reduction bundle was piloted, and a noticeable decrease in the number of alarms and annoyance ratings was observed [12]. To strengthen the evidence, we conducted a stepped-wedge interventional study to determine the effect of a multicomponent

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intervention bundle, with sound levels as the primary outcome and nurses' annoyance levels and distractions as secondary outcomes.

By conducting a stepped-wedge randomized clinical trial design across multiple ICU clusters, this study builds on prior observational work and offers stronger causal inference regarding the impact of environmental interventions in clinical practice.

Methods

Design

The NOISY study—centered on Noise, Optimization, Intervention, Strategies, and Yield—was conducted as a stepped-wedge cluster randomized clinical trial across four intensive care units at a university hospital in the Netherlands, spanning from July 2022 to September 2023. The units were randomized using the List Randomizer tool [13] to determine the order of the implementation period. Each unit began with a control period of at least 3-months, followed by a two-month implementation phase according to the randomized sequence, after which the intervention period commenced, during which the bundle became the new standard of care. The bundle was implemented in an additional ICU unit every two months, ending with 3 months follow-up (Supplemental 1. Fig. 1).

Setting

Two units were general ICUs, one cardiovascular ICU, and one pediatric ICU unit. These four units share a similar architectural design, each comprising eight exclusively single patient rooms arranged in a U-shaped configuration surrounding an open Central Nursing Station (CNS). The CNS has a central monitoring system (Philips IntelliVue Information Center YX, Philips Healthcare; Amsterdam, The Netherlands). In an open section of the central station, a medication desk is situated where ICU nurses prepare medications, which unfortunately makes this process subject to errors, as shown in Supplemental 2, Figure 2. Only a limited number of medications are routinely prepared and supplied by the pharmacy. Patient room doors are typically kept slightly open for observation, except for patients requiring isolation. Nursing staff perform handover procedures at three 8-hour shifts. The nurse-to-patient ratio in the ICU is 1:1 during the day shift and 1:2 during evening and night shifts.

The intervention; multicomponent intervention bundle

The intervention bundle was developed based on a systematic literature review [11] and preliminary tested in a pilot study [12] in line with the Medical Research Council (MRC) framework for developing and evaluating complex interventions [14]. This framework is particularly relevant given the multifaceted nature of the intervention, which can be classified as complex due to several characteristics: the number of components involved; the range of behaviors targeted; expertise and skills required by those delivering and receiving the intervention; the number of groups, settings, or levels targeted; or the permitted level of flexibility of the intervention or its components [15]. The bundle elements targeted modifiable noise sources in the ICU, including equipment alarms, designated quiet times from 12 to 2 PM, noise from staff conversations at the nursing station—a busy area for handovers and medication preparation-—telephones and the unit's doorbell (Fig. 1, Supplemental Table 1). The inclusion of education and feedback on sound levels and noise behavior was supported by findings from a systematic review of the literature [11].

Implementation

A multidisciplinary team—including ICU nurses and physicians, physiotherapists, engineers, an audiologist, a safety officer, and unit managers—collaborated to identify barriers and facilitators before and during implementation, guided by an implementation expert. These insights informed unit-specific adaptations to bundle elements such as monitor settings, SpO2 sensor type, and quiet hour scheduling. Results of our previous pilot study were incorporated into the ICU bundle where the smart alarm delays also extended to the ABP (Arterial Blood Pressure) alarms [12]. A smart alarm delay in patient monitoring for SpO2 or ABP alarms temporarily suppresses alerts during minor fluctuations to reduce unnecessary notifications. Frequent alarms in identified patients highlight the importance of skilled ICU nurses in adjusting alarm

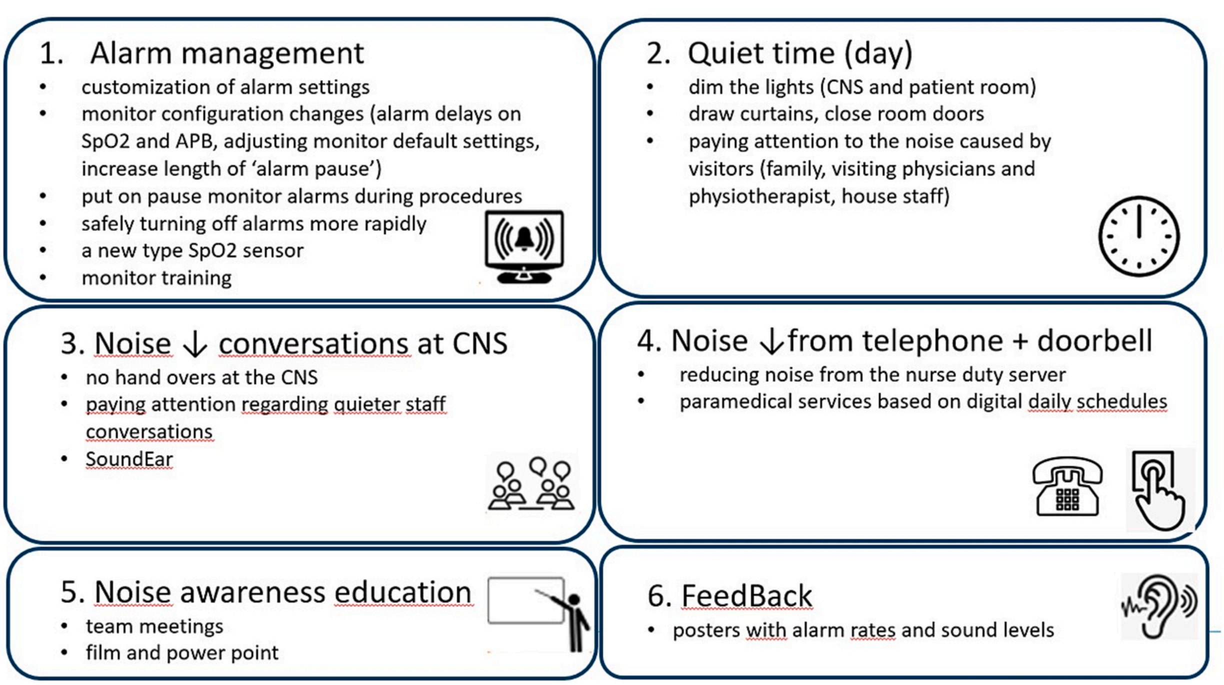

Fig. 1. Multicomponent intervention bundle.

settings. A select group was trained as key nurses to support colleagues in customizing alarm parameters. They provided hands-on guidance and helped troubleshoot alarm issues during clinical shifts.

During implementation, categories were introduced gradually (Supplemental 3), with weekly education and evaluation sessions to support all components of the intervention bundle. These sessions addressed alarm management, noise reduction, and workflow adjustments, with regular feedback on sound levels and alarm frequency to guide implementation and reinforce engagement.

Once implemented, the bundle became standard care, marking the start of the intervention period, which continued until the study's end.

Outcome measures and data collection

The primary outcome was the sound levels in the central nursing station. Secondary outcomes were the number of monitor alarms, annoyance ratings, and the number of distractions.

For the primary outcome, sound was measured monthly over one week according to a fixed measurement schedule, using two Class 2 type NSRT MK3 sound level meters (ABC-Geluid, Netherlands), calibrated by the manufacturer. Noise levels were recorded continuously at 1-second intervals using A-weighted, slow-response settings. Devices were placed 1.20–1.50 m high at two ICU locations: the central nursing station's medication preparation area and a randomly selected patient room adjacent to the noisy CNS (Supplemental 2. Fig. 2). Patient rooms were randomly chosen per measurement on the condition that the room should be occupied. Although interventions targeted noise reduction in the CNS, patient room levels were also monitored to assess broader effects. Data were downloaded weekly and aggregated into 15-minute epochs. Sound was reported as A-weighted equivalent continuous levels (LAeq), with L90 and L10 representing levels exceeded during 90 % and 10 % of the time, respectively.

For secondary outcomes, alarms were collected and categorized as red (life-threatening), yellow (threshold exceeded), and blue (technical issues, e.g., lead disconnections). The most frequent alarms— transcutaneous oxygen saturation (SpO2), arterial blood pressure (ABP), and heart rate (HR)—were targeted for intervention. Annoyance among nurses regarding their acoustic work environment was rated at the end of their shift using a 0–10 numerical scale. The scores were then categorized into three levels: no or hardly annoyed (0–3), somewhat annoyed [4–6] and severely annoyed [7–10]. Responses were submitted anonymously via distributed forms.

Distractions during medication preparation were defined as externally triggered shifts in attention, such as alarms, telephone calls, or colleague interactions, as evidenced by observed behavior [16,17]. Two trained ICU observers used a predefined protocol and a structured data collection form to assess these events. To ensure reliability, the initial 70 observations were conducted independently and simultaneously by both observers, yielding a Cohen's kappa of 0.84. Subsequent observations were performed individually across randomly selected day and evening shifts.

Assessing bundle elements compliance

During implementation, compliance with key bundle elements-dimming lights during quiet time periods, and the handover processes in or in front of the patient room-was assessed through randomly selected instances per unit, recorded on a checklist, by the researcher or assistant researcher. Nurses completed an anonymous self-assessment questionnaire indicating their adherence to the bundle's work agreements, using a 3-point Likert scale: always/often, sometimes, rarely/never.

Statistical analyses

Depending on their distribution, descriptive data are presented as mean (SD) or median (25th–75th interquartile range [IQR]) for continuous and discrete variables and percentage for categorical variables. Mean (SD) sound levels were calculated by linearizing the decibels, then averaging and converting them back to decibels through log transformation. The mean LAeq, was used as average across all units. The primary outcome was defined as a clinical relevant reduction of 3-decibels, measured at the central nursing station rather than at the patient level. Therefore a power calculation is not possible.

Differences between control and intervention period were tested using appropriate statistics depending on the characteristics of the variables and their distribution. Due to potential confounders related to patient differences in cluster randomization, adjusted analyses were performed as well. Adjusted outcomes were regarded as the primary outcomes. Linear regression was applied to obtain adjusted LAeq values and to estimate the effect of the bundle, incorporating covariates. For LAeq and alarms, adjustments were made for unit, bed occupancy, patient severity (Acute Physiology And Chronic Health Evaluation [APACHE IV] for adults, and Pediatric Risk of Mortality [PRISM3] for children), and nurse carry-over effects. Annoyance levels were adjusted for unit and nurse experience (years), while distractions were adjusted for unit alone because of the observation measurement method. All tests were two-sided, with statistical significance defined as $p < 0.05$. Analyses were performed using Python 3.8 and SPSS 29.0.

Ethical approval

The Medical Ethical and Research Committee approved the study (number 2019–5541) and waived the need for informed consent as it involved a change in standard care not requiring explicit patient consent under Dutch law. This study adhered to the Consolidated Standards Of Reporting Trials (CONSORT 2025)[18].

Results

In total 233 ICU (100 %) nurses participated in the study with a mean age of 41.8 (±12.3) years, and 175 (74.8 %) were female. (Table 1). During implementation, 229 (98.1 %) nurses actively participated in the educational sessions conducted in collaboration with physicians.

The mean bed occupancy (±SD) for the control and intervention groups was 5.6 (±1.6) and 5.3 (±1.5), respectively. Among adult patients, present at the time of the measurements, their mean APACHE

Table 1
Contextual ICU and Nurse Characteristics.

ICU	ICU characteristics and patients	Nurses (N = 233)
Rooms, single, *n*	34 (26 adult, 8 pediatric rooms)	
Beds, *n*	34	
Bed occupancy (mean, SD)		
Control/intervention	5.6 (1.6) vs 5.3 (1.5)	
ICU Frailty (severeness of illness)		
Adults: APACHE* score (mean, SD)	57.1 (6.7)	
Pediatric: PRISM3**score (mean, SD)	5.4 (2.6)	
Family visiting hours	24/7	
Characteristics of ICU nurses and their experiences		
Age in years, mean (SD)		41.8 (12.3)
Female, *n* (%)		175 (74.8)
ICU nurse		
Certificated (registered) *n (%)*		205 (87.6)
Trainee ICU nurse, *n* (%)		28 (12.4)
Nurse/patient ratio, *n* day/evening/ night		1:1/1:2/ 1:2

*APACHE-score: daily average APACHE score of the patients, ** PRISM3-score: daily average PRISM3 score of the patients.

score was 57.1 (±6.7), while the mean PRISM III score for pediatric patients was 5.4 (±2.6) (Table 1).

Post-implementation, compliance with the 'quiet-time' element exceeded 80 %, while adherence to 'no handover at the central nursing station' varied between 39 % and 91 % (Supplemental Table 2).

Primary outcome

After the bundle implementation, LAeq decreased from 53.7 (±5.8) to 52.9 (±5.9) dBA ($p < 0.001$) at the central nursing station and from 50.3 (±6.8) to 49.9 (±6.5) dBA ($p < 0.001$) in the patient room (Table 2). Unadjusted sound levels are shown in Supplemental Table 3.

Daytime sound levels at the central nursing station were comparable (55.3 vs. 55.0 dB), but adjusted analysis revealed significance ($p < 0.001$). Evening and night levels were consistently lower with intervention, showing significant differences in both adjusted and unadjusted analyses ($p < 0.001$) (Supplemental Table 4).

Daytime levels in the patient room were similar (52.6 vs. 52.3 dB), yet adjusted results were significant ($p < 0.001$). Evening and night shifts showed modest reductions, with consistent significance ($p < 0.001$) (Supplemental Table 4). Unit-specific sound levels, are shown in Supplemental Table 5.

Secondary outcomes

Alarm data were collected over a total of 1593 days. The median number of alarms per day per bed decreased statistically significantly ($p < 0.001$) from 228 [IQR 176–290] to 194 [IQR 148–249] (Table 2, and unadjusted results in Supplemental Table 3).

The median NRS-annoyance score before and after implementation of the bundle was 3 [IQR 2–5] versus 3 [IQR 2–4] ($p = 0.001$), respectively (Table 3). Fig. 2, showing a noticeable shift towards lower values in the intervention group, illustrates the impact of the intervention. Scores per shift are presented in Supplemental Table 6.

The percentage of healthcare providers experiencing no or hardly annoyance (NRS 0–3) increased from 50.8 % before to 62.2 % ($p < 0.01$) (Table 3).

Observed distractions decreased statistically significantly from 73 % during baseline to 61 % after implementation ($p < 0.001$) with colleague-related distractions remaining the most frequent (Table 3).

Table 2
Comparison of sound pressure levels and alarm count per day/bed.

	Control	Intervention	p-value adjusted
LAeq Central Nursing Station			
LAeq (dBA) Mean (SD)	53.7 (5.8)	52.9 (5.9)	< 0.001
L10 – percentile	58.5	58.0	
L90 – percentile	45.3	43.9	
LAeq Patient room			
LAeq (dBA) Mean (SD)	50.3 (6.8)	49.9 (6.5)	< 0.001
L10 – percentile	56.5	56.0	
L90 – percentile	39.0	39.9	
Alarms/day/bed	746 days	847 days	
Median [IQR]	228 [176–290]	194 [148–249]	< 0.001
RED*	18 [12–26]	16 [11–25]	0.55
YELLOW*	108 [80–141]	74 [43–99]	< 0.001
INOP*	100 [74–143]	96 [68–135]	0.64
SpO2-YELLOW	18 [12–24]	9 [6–12]	< 0.001
SpO2 – INOP	25 [17–38]	25 [17–41]	0.01
ABP – YELLOW	37 [23–52]	30 [19–43]	< 0.001
ABP- INOP	41 [24–73]	37 [21–63]	0.04
HF – YELLOW	20 [12–30]	15 [9–24]	< 0.001

*Red for life threating situations, Yellow for a parameter that has exceeded its threshold, INOP for sensors/leads that have fallen of. SpO2 = transcutaneous oxygen saturation, ABP = arterial blood pressure, HR = heart rate.
Adjusted for unit, length of stay (LOS), severity of illness (measured by APACHE score for adults and PRISM3 score for children), nurse mismatch (carry-over effect), and bed occupancy.

Table 3
Annoyance and observed distractions.

	Control (N = 1086)	Intervention (N = 1391)	p-value
Annoyance NRS (0–10)			
Median [IQR]	3 [2-5]	3 [2-4]	<0.001*
0–3 (no or hardly), n (%)	552 (50.8 %)	865 (62.2 %)	< 0.01
4–6 (somewhat), n (%)	382 (35.2 %)	409 (29.4 %)	0.27
7–10 (severe), n (%)	152 (14.0 %)	117 (8.4 %)	0.18
Distractions**	(N = 409)	(N = 309)	
n (%)	299 (73 %)	187 (61 %)	
Sources distractions, n (%):			<0.001*
– healthcare professionals	292 (98 %)	178 (95 %)	
–others (alarms, telephone, doorbell)	7 (2 %)	9 (5 %)	

* Adjusted: annoyance: adjusted for unit and nurse experience years, distractions: adjusted for unit.
**during medication preparation.

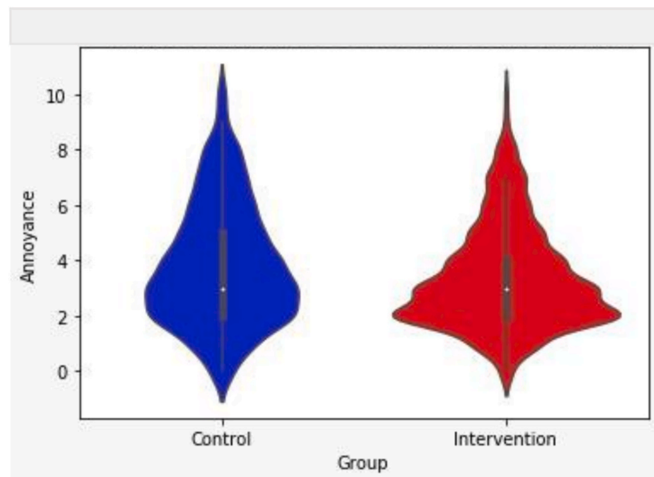

Fig. 2. Annoyance (NRS) distribution control versus intervention.

Discussion

In this stepped-wedge cluster randomized clinical trial, the use of a multicomponent intervention bundle in the ICU resulted in a statistically significant but minimal decrease in sound levels, as well as a reduction in alarms, annoyance ratings, and distractions.

After implementing an intervention bundle, sound levels decreased on average by less than 1 dB. As a change of 3 dB is generally considered the minimum perceptible difference to the human ear [3,19], the observed reduction may have limited perceptual or clinical impact. Sound levels in ICUs are mainly influenced by health professionals behavior during routine tasks and conversations [10,20,21], so measures aimed at changing the noise behavior, like staff education, designated quiet times, and audio-visual noise alerts, are standard components of noise-reduction programs in ICUs. Although several studies report positive effects [22–25], other investigations—including ours—found that sound levels remained consistently high despite implementing similar interventions [26–28]. Furthermore, the beneficial role of ICU redesign in mitigating noise is now widely accepted [29,30] as we also previously demonstrated by installing a partition wall that reduced sound levels by over 3 dBA [12].

Monitor alarms are a major source of staff annoyance and distractions, raising the risk of medical errors [23] for which alarm management was a key component in our strategy [31]. Reducing non-actionable alarms—especially YELLOW alarms like SpO2—was achieved by widening default thresholds, a change that proved effective. However, a recent ICU review found alarm settings were based on monitored vital signs rather than patient-specific factors like age or medical history, highlighting the need for individualized alarm configurations rather than relying solely on standard thresholds [32]. Reducing non-actionable alarms not only minimizes staff distraction and annoyance, but also contributes directly to patient safety by lowering the risk of alarm fatigue and missed critical events. Despite an unchanged median (25 → 25), the adjusted analysis for SpO_2-INOP alarms showed significance ($p = 0.01$), underscoring the impact of covariates on the alarm outcomes. Adjusting for factors like unit, patient severity of illness score, length of stay, nurse mismatch, and bed occupancy reveals their strong influence on outcomes such as noise levels and alarm frequency, which may otherwise be obscured.

Notably, although sound reduction was limited, the percentage of nurses experiencing little to no annoyance increased from 50.8 % to 62.2 %. Noise annoyance is shaped by both acoustic and non-acoustic factors such as unpredictability, urgency, and timing; sudden loud alarms are especially disruptive for nurses [33–35]. Our study suggests that reduced annoyance is likely due to fewer disruptive alarms and loud noise events (L10) rather than to a lower average sound level (LAeq).

Observed distractions, decreased significantly from 73 % to 61 % ($p < 0.001$). Notably, colleagues were identified as the primary source of distraction, as confirmed by others [36]. Given the established link between distractions and medication errors [17,36], the focus should shift towards minimizing work distractions (e.g., due to alarms) rather than merely reducing sound levels.

Strengths and limitations

This study has several strengths. First, it employed a robust stepped-wedge RCT design across four clusters. Second, the thorough bundle implementation was closely tracked via compliance rates, ensuring a reliable evaluation of its impact (see Supplemental Table 2). Separately, a qualitative process evaluation was conducted [37]. Third, the study accounted for each ICU's unique context, emphasizing the value of tailored strategies and active staff engagement to address unit-specific challenges.

Also, some limitations should be noted. First, this study was conducted at a single center, although measurements were taken in four distinct ICU locations. Despite the single-center design, our findings on sound reduction align with earlier studies, underscoring the wider applicability of such interventions in ICU environments (2, 10, 30). Second, we measured sound levels, alarms, nurses' annoyance, and distractions rather than medical errors, limiting conclusions about patient safety. Third, although measurements were conducted over 14 months, sustaining noise-reducing behavior may require a longer monitoring period (11). Fourth, we did not examine sound frequencies. Although opinions vary on whether high- or low-frequency noise dominates in the ICU, most studies suggest that higher frequencies are more prevalent (20).

Conclusion

Use of a multicomponent intervention bundle led to a statistically significant reduction in sound levels— though not to a clinically relevant degree. Importantly, there were statistically significant improvements in the number of alarms, as well as in nurses' annoyance and distractions, compared with the control period. These findings underscore that reducing nurses' annoyance and distractions—particularly by minimizing non-actionable alarms—is at least as critical for patient safety as lowering ambient sound levels.

Implications for clinical practice

1. A multicomponent noise reduction intervention—comprising education, equipment modifications, designated quiet times, and feedback—reduced sound levels statistically significant, but not clinically relevant.
2. The intervention significantly decreased alarm frequency, contributing to a quieter acoustic environment.
3. Nurses' annoyance and distractions significantly decreased, indicating improved working conditions.

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CRediT authorship contribution statement

Jeanette Vreman: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Cris Lanting:** Writing – review & editing, Visualization, Validation, Supervision, Methodology, Formal analysis, Conceptualization. **Tim Frenzel:** Writing – review & editing, Validation, Supervision, Resources, Investigation. **Johannes G. van der Hoeven:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Joris Lemson:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization. **Mark van den Boogaard:** Writing – review & editing, Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Conceptualization.

Ethics approval

Approval was obtained from The Medical Ethical and Research Committee of the Radboud university medical center (number 2019-5541).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.iccn.2025.104306.

References

[1] Berglund B. New WHO guidelines for community noise. Noise Vib Worldwide 2000;31(4):24.
[2] Han E, Kang H, Jang Y. Noise reduction interventions in intensive care units: a systematic review. Intens Crit Care Nurs 2025;92:104234.
[3] Witek S, Schmoor C, Montigel F, Grotejohann B, Ziegler S. Sustainable reduction in sound levels on intensive care units through noise management - an implementation study. BMC Health Serv Res 2025;25(1):9.
[4] Ryherd EE, Okcu S, Ackerman J, Zimring C, Waye KP. Noise pollution in Hospitals: impacts on staff. J Clin Outcomes Manage 2012;19(11):491–500.

[5] Isfort M. Evaluation der Pflegebedingungen auf Intensivstationen. Medizinische Klinik - Intensivmedizin Und Notfallmedizin 2017;112(6):543–9.

[6] Kebapcı A, Güner P. "Noise factory": a qualitative study exploring healthcare providers' perceptions of noise in the intensive care unit. Intensive Crit Care Nurs 2021;63:102975.

[7] Jeong YJ, Kim H. Critical care nurses' perceptions and practices towards clinical alarms. Nurs Crit Care 2023;28(1):101–8.

[8] Khademi Gh IBNpiicuasraRCM-. Noise pollution in intensive care units: a systematic review article. Rev Clin Med 2015;2(2):58–64.

[9] Armbruster C, Walzer S, Witek S, Ziegler S, Farin-Glattacker E. Noise exposure among staff in intensive care units and the effects of unit-based noise management: a monocentric prospective longitudinal study. BMC Nurs 2023;22(1).

[10] Konkani A, Oakley B, Penprase B. Reducing hospital ICU noise: a behavior-based approach. J Healthc Eng 2014;5(2):229–46.

[11] Vreman J, Lemson J, Lanting C, van der Hoeven J, van den Boogaard M. The effectiveness of the interventions to reduce sound levels in the ICU: a systematic review. Crit Care Explor 2023;5(4):e0885.

[12] Vreman J, Lanting C, Frenzel T, van der Hoeven J, Lemson J. Reduction of sound levels in the intermediate care unit; a quasi-experimental time-series design study. Intens Crit Care Nurs 2024;85:103810.

[13] Haahr M. Haar, M n.d. List Randomizer. n.d. https://www.random.org/lists/. 1998.

[14] Craig P, Dieppe P, Macintyre S, Michie S, Nazareth I, Petticrew M. Developing and evaluating complex interventions: the new medical research council guidance. BMJ (Clin Res Ed) 2008;337:a1655.

[15] Skivington K, Matthews L, Simpson SA, Craig P, Baird J, Blazeby JM, et al. A new framework for developing and evaluating complex interventions: update of medical research council guidance. Int J Nurs Stud 2024.

[16] Craker NC, Myers RA, Eid J, Parikh P, McCarthy MC, Zink K, et al. Nursing interruptions in a trauma intensive care unit. J Nurs Adm 2017;47(4):205–11.

[17] Westbrook JI, Woods A, Rob MI, Dunsmuir WT, Day RO. Association of interruptions with an increased risk and severity of medication administration errors. Arch Intern Med 2010;170(8):683–90.

[18] Hopewell S, Chan A-W, Collins GS, Hróbjartsson A, Moher D, Schulz KF, et al. CONSORT 2025 statement: updated guideline for reporting randomised trials. Lancet 2025;405(10489):1633–40.

[19] Darbyshire JL, Young JD. An investigation of sound levels on intensive care units with reference to the WHO guidelines. Crit Care 2013;17:R187.

[20] Konkani A, Oakley B. Noise in hospital intensive care units—a critical review of a critical topic. J Crit Care 2012;27(5):522.e1-9.

[21] Darbyshire JL, Müller-Trapet M, Cheer J, Fazi FM, Young JD. Mapping sources of noise in an intensive care unit. Anaesthesia 2019;74(8):1018–25.

[22] Gupta P, Thomas M, Amer A, Joseph S, Louis I, George J, et al. Implementation of noise-reduction strategies and designated quiet time in an intensive care unit. Br J Healthc Manage 2023;29(2):1–9.

[23] Dennis CM, Lee R, Woodard EK, Szalaj JJ, Walker CA. Benefits of quiet time for neuro-intensive care patients. J Neurosci Nurs 2010;42(4):217–24.

[24] Duarte ST, Matos M, Tozo TC, Toso LC, Tomiasi AA, Duarte PAD. Practicing silence: educational intervention for reducing noise in the intensive care unit. Rev Bras Enferm 2012;65(2):285–90.

[25] Trask J, Yee J, Pak T. Implementation of a noise reduction bundle in a medical-surgical intensive care unit. Dimens Crit Care Nurs 2025;44(4):211–6.

[26] Pal J, Taywade M, Pal R, Sethi D. Noise pollution in intensive care unit: a hidden enemy affecting the physical and mental health of patients and caregivers. Noise Health 2022;24(114):130–6.

[27] Nannapaneni S, Ramar K, Elmer J. Noise reduction and sleep enhancement in the medical intensive care unit. American Journal of Respiratory and Critical Care Medicine Conference: American Thoracic Society International Conference, ATS. 2013;187(no pagination).

[28] Tronstad O, Patterson S, Zangerl B, Flaws D, Holdsworth R, Irvine L, et al. The introduction of a sound reduction bundle in the intensive care unit and its impact on sound levels and patients. Aust Crit Care 2024;37(5):716–26.

[29] Luetz A, Weiss B, Penzel T, Fietze I, Glos M, Wernecke KD, et al. Feasibility of noise reduction by a modification in ICU environment. Physiol Meas 2016;37(7):1041–55.

[30] Tronstad O, Patterson S, Zangerl B, Flaws D, Holdsworth R, Irvine L, et al. The introduction of a sound reduction bundle in the intensive care unit and its impact on sound levels and patients. Aust Crit Care 2024.

[31] Ruettgers N, Naef AC, Rossier M, Knobel SE, Jeitziner M-M, Grosse Holtforth M, et al. Perceived sounds and their reported level of disturbance in intensive care units: a multinational survey among healthcare professionals. PLoS One 2022;17(12):e0279603.

[32] Carencotte R, Oliver M, Allou N, Ferdynus C, Allyn J. Exploring clinical practices of critical alarm settings in intensive care units: a retrospective study of 60,000 patient stays from the MIMIC-IV database. J Med Syst 2024;48(1).

[33] Theuerkauf N-U, Putensen C, Schewe J-C. Konzepte zur Reduktion der Lärmbelastung auf der Intensivstation. Anasthesiologie, Intensivmedizin, Notfallmedizin, Schmerztherapie: AINS 2022;57(01):14–26.

[34] Kebapcı A, Güner P. "Noise Factory": a qualitative study exploring healthcare providers' perceptions of noise in the intensive care unit. Intens Crit Care Nurs 2021;63:102975.

[35] Karahan A, Kav S, Çevik B, Çitak EA, Ugurlu Z, Fulser B. Alarm fatigue among nurses working in intensive care and other inpatient clinics. Work-A J Prevent Assess Rehab 2023;76(2):793–801.

[36] See KC, Phua J, Mukhopadhyay A, Lim TK. Characteristics of distractions in the intensive care unit: how serious are they and who are at risk? Singapore Med J 2014;55(7):358.

[37] Vreman J, van den Boogaard M, van der Hoeven J, Lemson J, Tilburgs B. The Implementation of a noise reduction bundle in the intensive care unit: a qualitative process evaluation. Submitted 2025.