ICU

MANAGEMENT & PRACTICE

INTENSIVE CARE - EMERGENCY MEDICINE - ANAESTHESIOLOGY

VOLUME 20 - ISSUE 2

The Night in the ICU

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Nine Nurse-Recommended Design Strategies to Improve Alarm Management in the ICU: A Qualitative Study

We asked intensive care nurses how they experience medical alarms in the critical care context and how they can help ideate strategies for better alarm management. Our study revealed that excessive medical alarms are one of the sources of discomfort at the workspace for critical care nurses and nurses' wellbeing is fundamental in providing better patient care. However, eliminating discomfort requires a collaborative approach in which nurses can provide valuable knowledge on existing and desired utilisations of medical alarms from their rich experiences within the critical care context.

Introduction

Critical care nurses are continuously exposed to sound in their workspace and have to rely on them for performing time-sensitive tasks that are crucial to ensuring patient safety. Missing important alarms, failing to extract crucial information from the sounds of organ-support devices, or misinterpreting the content of conversations can lead to loss of precious lives. While sounds in general have a functional role in our lives, excessive noise causes concern in the high-performance workspaces (Bluyssens 2014; Edworthy et al. 2018; Sousa et al. 2017; van Kamp et al. 2016). Nurses who are exposed to constant and excessive noise can suffer from fatigue, anxiety, and post-traumatic stress syndrome (Cvach 2012; Kristensen Edworthy and Özcan 2017; Horkan 2014; Sendelbach and Funk 2013; Topf and Dillon 1988). Moreover, especially excessive number of alarms has consequences on patient safety. It is reported that close to 600 patients may lose their lives in the span of one year due to audible alarms missed by healthcare professionals (The Joint Commission 2014).

Our paper focuses on understanding the experience of medical alarms from the perspective of critical care nurses. Critical care nurses are the backbone of intensive care units and they have first-hand information about how environmental factors affect the quality of patient care and patient experience of ICU stay. In this paper, with an observational study and interview with nurses, we aim to qualify the experience of nurses with sound sources, especially medical alarms. Based on our findings we propose quick fixes and long-term strategies to tackle sound-induced problems originating from patient monitoring technology, in the clinical setting.

What sounds can we expect to hear in intensive care units?

According to Konkani and Oakley, sound sources in the ICU can be categorised as operational (i.e. sounds that are generated by clinicians or medical equipment) and structural (i.e. sounds that are inherent to the hospital building such as ventilation, doors and central heating). The most prominent operational sound sources can be further divided into four more specific categories: conversations (amongst clinicians, patients and visitors); medical equipment alarms (i.e. patient monitoring alarms, technical alarms); caregiving activities (i.e. cleaning patients, administering medicines) and incidental sounds (i.e. door closing, phones ringing, objects falling) (Konkani and Oakley 2012). Another study related the sound producing events to patient treatment in the ICU (Birdja and Özcan 2019) such as patient monitoring sounds (mainly medical alarms) and life-support sounds (alarms as well as machinery sounds such as hissing of the mechanical ventilator). The 67-hour recordings of sound events at the intensive care department of the Jeroen Bosch Hospital (the Netherlands) gave insight into the distribution of aforementioned sound source categories found in intensive care units. With the patient involved noise (31%) excluded, the most prominent contributors to the critical care sounds were sounds caused by intensivists and nurses (57%) and alarms (30%), where the machinery sounds of life supporting devices had a relatively minor

contribution (13%). Although in this study different categories were identified than the aforementioned, it did illustrate that most of the noise created in the critical care soundscape may be attributed to (modifiable) human actions.

How can the soundscape of critical care change for better workflow that ensures patient safety and comfort as well as clinician work satisfaction and morale?

The issues healthcare has with medical sounds, especially with audible alarms and general noise, is well acknowledged in the literature. Existing literature quantifies acoustic quality of noise, defines sound categories (e.g. alarms, speech, interaction sounds), and enumerates types or function of medical alarms (Cvach et al. 2014; Drew et al. 2014; Konkani and Oakley 2012; Ryherd, Waye and Ljungkvist 2008). These results are then projected to establish strategies to improve the quality of healthcare, for example the night routine and sleep experience of patients (Birdja and Özcan 2019). Thus, provided innovative solutions, technical or legislative, are based on quantitative approaches with little input from nurse's actual experiences of the sound environment. Very few studies considered the human experience of critical care sounds (Deb and Claudio 2015; Sowan et al. 2015). In a survey, Sowan et al. (2015) investigated nurses' perception and attitude towards clinical alarms in a cardiac intensive care unit. Among others, nurses' concerns were found to be the following: alarms are too many, distracting and therefore ignorable; the indication for urgency is not well configured for visual and audible alarms; the technology behind monitoring systems is unreliable and there is lack of training on alarm settings. Studies such as ours allow nurses raise their voice and actively take part in the improvement of alarm systems (Özcan, Birdja, Edworthy 2019). As a result, the system designed and the technology chosen will adapt to nurses' actual needs in the workspace rather than top-down decisions taken by hospital management or policy makers that feel empowered with the possibilities of technology but may overlook its unwanted effects.

Observations in the ICU and Interviews with ICU Nurses

We were interested to discover ICU nurses' experience of clinical sounds, with specific focus on alarm sounds and alarm management with the help of qualitative research methods (observation, sensitising participants and in-depth interviews). Accordingly, we intended to uncover psychological, social and cultural reasons why certain clinical sounds fail to be part of the core values of critical care. Through the questions in the interview and observations, we explored nurses' work culture, tacit knowledge, experienced feelings, and architectural setup and protocols observed in the intensive care units. Therefore, this research approaches the problem holistically by looking at context, daily life activities and emotions of nurses and their coping strategies with sound and noise in general.

> **"non-actionable alarms defy the purpose of alarm systems and train nurses to ignore, mistrust, and misinterpret alarms"**

Method and Data Analysis

We conducted two observations at the Adult ICU of Erasmus Medical Centre Rotterdam (the Netherlands) in order to be prepared for the interviews with nurses focusing on the sound events in the intensive care units. Two researchers observed at two different times during the day; one in the morning and one in the afternoon. We also conducted seven interviews with (former) ICU nurses. Four male and three female nurses participated with 13.6 years of experience on average (years of experience ranging from 1.5 years to 25 years) to provide us with first-hand insights into alarm experience. All interviewees were sensitised (i.e. made sensitive to sound) using booklets and audio recorders. The nurses were asked to record any sound that made any impression on them during the week before the interviews took place and took notes and made drawings on the booklets explaining what they heard, when, where and why a particular sound was worth mentioning. Furthermore, nurses were asked to answer one question a day. The sensitising booklet contained questions such as 'describe the different sound moments throughout your work shift,' 'record the most remarkable sounds at the ICU' and 'what are in your opinion related factors towards alarm management?' These continuous questions required nurses to become extra aware of clinical sounds that belonged to their own workspace. Participants brought their booklet to the interviews.

Semi-structured interviews in the context itself allowed direct questions about real time events and mental triggers for nurses to explain about their experience with the recorded sounds in the unit. Nurses were encouraged to think along with the researchers for optimal interactions with medical alarms. The questions were the following:

- What is good alarm management in the view of ICU nurses?
- Which factors enable/disable them to perform good alarm management?
- How do ICU nurses experience alarm fatigue in practice?
- Which factors can in their opinion influence alarm fatigue positively/negatively?

Data was clustered into insights and big themes by going through the content of the booklets and the interview transcriptions. Finally, nurses' suggestions for better alarm management resulted in nine

strategies which are clustered under five big intervention domains.

Big Themes Representing Nurses' Negative Experience of Alarms

Non-actionable auditory alarms

Not all alarms that a nurse hears are medically actionable. Many of the alarms a nurse hears fails to represent a task that they immediately have to take care of. These alarms can eventually start causing a 'boy who cried wolf' effect and hereby cause alarm fatigue. Non-actionable alarms defy the purpose of alarm systems and train nurses to ignore, mistrust, and misinterpret alarms. Furthermore, nurses can actively switch off alarms in advance of a treatment or because the majority requires no action. If nurses let the non-actionable alarms sound for an extended period of time, tension amongst nurses arises due to lack of sound hygiene or personal consideration in the unit.

Patient/nurse induced alarms

Certain alarms are caused by a movement of a patient or when a patient is touched, and/or equipment is handled by nurses or doctors. In such cases the alarm does not represent what is happening to the patient. A sound that should usually be associated with a problem with one of the patient's vital signs, can now actually mean a patient is responding as expected to medication. Alarm systems and the attention they ask of the nurse do not consider how much information a nurse already has.

Limitations of sensors

Sensors that are used for monitoring patient vitals may get disconnected or may malfunction. For example, the oxygen saturation sensor on the patient's finger gets disconnected very frequently. Though it is important to know that all sensors are attached and they do function, alarms also occur when nurses know the sensor has come off during treatment. The systems the sensors belong to are not context aware or they fail to recognise the tasks or procedures nurses are involved in.

Incomplete information from the patient monitor

The patient monitor triggers an alarm based on a range of vitals that are measured. Since each of these values has a set of boundaries, the alarm will often go off when just one of these values exceeds a boundary. The nurse, however, needs more nuanced information about the combination of several values to be able to judge the urgency of the problem. Nurses cannot monitor patients from a distance with the help of auditory information and are forced to make sense of the visual content in the display.

> "nurses' low performance was found to be influenced by a combination of alarm fatigue, working conditions and staff individuality"

Personal preferences in alarm management

Nurses can influence the number of alarms they hear by changing the boundaries at which the monitor triggers an alarm for a certain value. Each nurse has their own approach to these settings. A nurse's approach may depend on their professional experience (novice or experienced), hearing sensitivity, or their personality traits (disciplined or nonchalant).

The issues nurses rose during the interviews are in line with the existing literature (Cvach 2012; Edworthy et al. 2018; Özcan and Birdja 2018; Guillaume et al. 2003; Hellier, Edworthy, and Dennis 1993; Mondor and Finley 2003; Momtahan, Hetu and Tansley 1993; Sanderson et al. 2006). However, the most interesting finding was the nurses' personal preferences in alarm management and especially how this could further mitigate the factors contributing to alarm fatigue. To our knowledge there is particularly one study that emphasises on nurses' individual differences (Deb and Claudio 2015). Nurses' low performance was found to be influenced by a combination of alarm fatigue, working conditions and staff individuality. In our case, nurses expressed individual needs for managing alarms and displayed almost cultural differences in their attitude towards alarms and sounds in general. This finding also legitimised our choice to inquire nurses' opinion for improving alarm management by giving the voice and platform to people who actually utilise medical devices and therefore have in-depth knowledge on the use context.

Nine Nurse Recommended Design Strategies for Better Audible Alarm Management

In the focus groups with nurses, nurses expressed more possibilities, i.e. nine different design strategies, to improve the aforementioned five big themes representing alarm issues. These individual strategies can be found in **Figure 1** within the context of ICU set-up. The multiplicity of the ideas is an indication that nurses, while doing their daily tasks, also think of ways to improve their situation. Below, we categorised the suggestions into five themes representing all nine design strategies.

Human-sensitive technologies

1. Create easy ways to react to alarms on devices (mute/acknowledge): The equipment nurses use does not optimally provide different ways to manage alarms while they are treating patients. Interfaces of devices should encourage properly muting and acknowledging alarms when they tend to unnecessarily go off during treatment. The way monitoring or life-support devices communicate with nurses via their user interfaces should be better optimised for the nurse's workflow and encourage them to properly manage alarms. For instance, (1) the mute button needs to be more accessible in the user interface

design at the bedside, (2) it should be easier to check off/turn off alarms in case nurses have acknowledged an alarm but are unable to go to the monitor. This will help them keep the disturbances from audible alarms to a minimum.

2. Improve quality of sensor connections to patients' body: Many alarms occur due to malfunctioning sensors or sensors that get accidentally disconnected due to movements of the patient. These alarms are bothersome because they do not represent a medical problem but do require action. This leaves an opportunity for an improvement in the design of these sensors. Sensors and their connections should be more robust to cause fewer technical alarms or they should be better fitting to the anatomy of the patient body. The way that sensors are connected should be designed with more attention to the patients' comfort to avoid the patient becoming irritated or confused and attempting to remove them.

3. Reduce the amount of alarms/sound level of non-informative alarms: One of the key factors that influence alarm fatigue is the sheer amount of false alarms. There are several alarms that provide no valuable medical information to the nurse or require a medical action, but still go off and disturb the nurse - e.g. sounds during the start-up of a device. The meaning and need for these alarms should be evaluated. With this evaluation it can be decided if the (little-/non-informative) sounds can be reduced or have a lower sound level. As new technologies such as Artificial Intelligence are developing, it would be interesting to see how alarm devices could become smarter in recognising and notifying useful alarms.

Sound design

4. Make auditory information informative: Many of the alarms have a similar sound and do not provide more information than an alarm boundary has been exceeded. Therefore, nurses have to look at other information to understand the meaning of the alarm. There is an opportunity to increase the level of information that sounds on the ICU carry. Alarms that nurses currently work with merely summon them to further investigate the situation while they could convey a much richer meaning for a more proactive workflow.

5. Design pleasant alarm sounds: This research showed that intensive care nurses think that many of the current alarms do not have a pleasant sound. This causes frustration and negative feelings about sounds. Designing sounds that are less startling and more pleasant to listen to can help reduce alarm induced stress and fatigue.

Alarm culture

6. Redesign the alarm safety net: There is a difference between nurses in how they manage alarm settings. Their different alarm setting styles can be dependent on their sensitivity to sounds, experience with alarm settings, being neat and resistant to stress. Some nurses tend to set boundaries

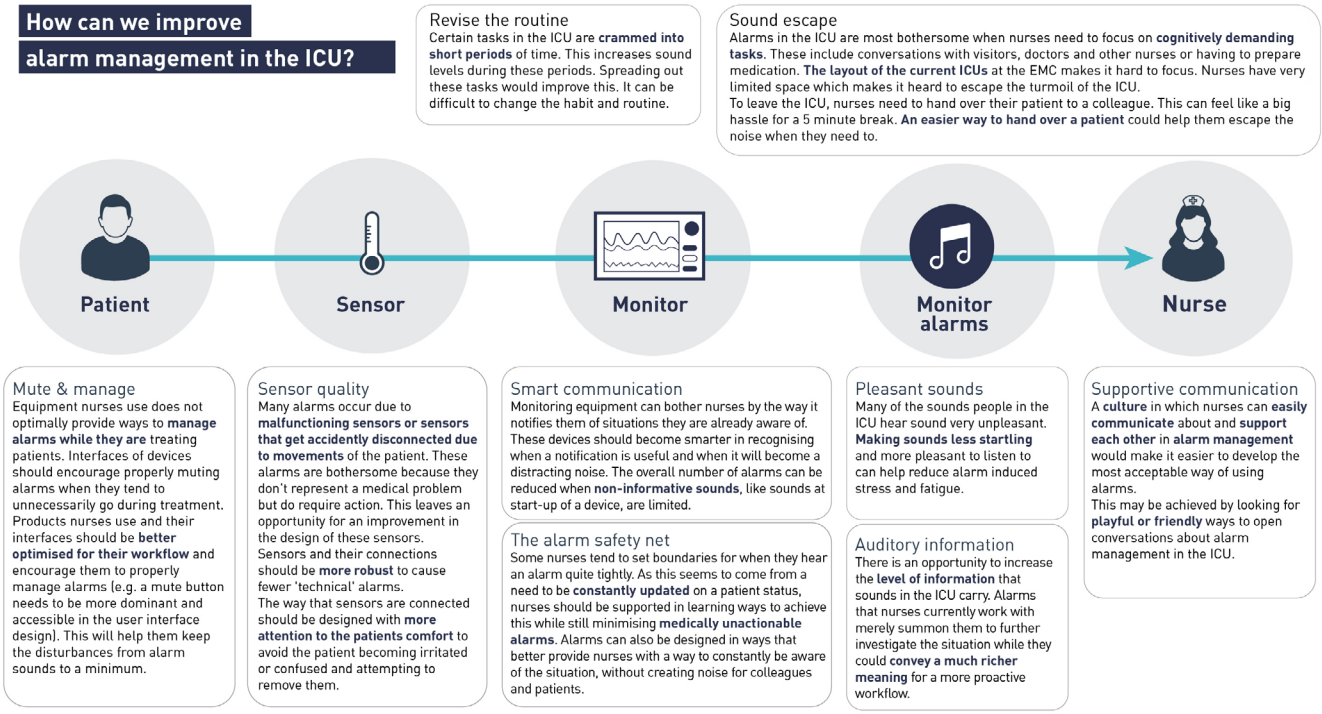

Figure 1. Nine nurse recommended design space for better alarm management.

for when they hear an alarm quite tightly. As this seems to come from a need to be constantly updated on a patient status, nurses should be supported in learning ways to achieve this while still minimising medically non-actionable alarms. Alarm systems can also be designed in ways that better provide nurses with possibilities to constantly be aware of the situation, without creating noise for colleagues and patients. This would also induce a harmonised alarm culture when nurses interact with alarm systems.

7. Make supportive communication about alarm management accepted in the intensive care culture: Alarm settings are partly driven by regulations, medical professional advice and personal preference. It can be a struggle for nurses to discuss with their colleagues their different views on alarm settings. A culture in which nurses can easily communicate about and support each other in alarm management would make it easier to come to the most acceptable way of using alarms. This may be achieved by looking for playful or friendly ways to open conversations about alarm management on the ICU.

ICU set up and workflow

8. Provide a quick and easy sound escape for IC nurses: Alarms in the ICU are most bothersome when nurses need to focus on cognitively demanding tasks. These include conversations with visitors, doctors and other nurses, doing administration or having to prepare medication. The layout of the unit can make it hard to focus. Nurses have very limited space which makes it hard to escape the turmoil of the ICU. To leave the ICU, nurses need to hand over their patient to a colleague. This can feel like a big hassle for a short minute break. An easier way to hand over a patient and finding a designated place for a quiet time could help them escape the noise when they need to.

9. Revise the routine to distribute the workload & sound moments: Certain tasks on the ICU are crammed into short periods of time. Especially in the morning, in which nurses have their hand-over, patient treatment and check-up rounds of medical professionals. This increases sound levels and work pressure during these periods. Spreading out these tasks would improve this. However, our research also showed it can be difficult to change the habit and routine in the ICU.

Conclusion

We have presented nine design strategies under four themes: human-sensitive technologies, sound design alarm culture, and ICU set up and flow. These themes of design strategies address different stakeholders (hospital management, policy makers and regulatory agencies, device manufacturers, and patient-nurse community) that need to make a collaborative effort for better alarm management (Özcan, Birdja and Edworthy 2018; Özcan, Rietdijk and Gommers 2019). For example, device manufacturers would be demonstrating their sensitivity to human-technology interactions by providing better user interfaces, developing new sensors and better sounding and informative alarms. In relation to device manufacturers, hospital management could offer tenders that contain sound clauses representing nurses' needs. The management could also facilitate open platforms for nurses to discuss their needs around alarm settings and also to acknowledge the need for certain type of behaviour around sounds. Changing the ICU layout or offering tranquility rooms would help reduce stress around excessive noise. Policy makers could also pay more attention to professional needs within the critical context and readjust regulations that are often focused on patient safety and work-efficiency but not on nurse well-being. Thus, we invite all stakeholders to consider what nurses have to say to improve their work condition. Each of the proposed strategy is subject to further in-depth study to discover exact problems and corresponding technological, cultural, design, and architectural solutions.

Conflict of Interest

Authors declare no conflict of interest.

Acknowledgements

We would like to thank Rosel van der Berg and Koen Bogers for their contribution with the conducting of the observations and interviews in the ICU and Froukje Sleeswijk-Visser for valuable discussions in setting up observational research in the healthcare context. ■

Key Points

- An observational study and interview with nurses that aims to qualify the experience of nurses with sound sources, especially medical alarms.
- Not all alarms that a nurse hears are medically actionable. Many of the alarms fails to represent a task that needs an immediate response and can eventually start causing a 'boy who cried wolf' effect and cause alarm fatigue.
- Alarm systems and the attention they ask of the nurse do not consider how much information a nurse already has.
- Nurses can influence the number of alarms they hear by changing the boundaries at which the monitor triggers an alarm for a certain value.
- In the focus groups with nurses, nurses recommend nine different design strategies under four themes: human-sensitive technologies, sound design, alarm culture, and ICU set up and flow.

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