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Alarm Response in Critical Care: Obstacles for Compliance

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Abstract. Clinicians who are exposed to noisy environments are more likely to suffer from alarm fatigue, stress or sleep deprivation, and can finally become inefficient in the moment to respond to a critical situation. In other words, a lack of compliance or an inappropriate response to alarms is constantly observed in clinicians operating in critical care. In this paper, we introduce the issue of lack of compliance with medical alarms in critical care by contrasting the mandatory approaches stemming from safety and efficiency purposes (i.e., study of (cognitive) ergonomics) with a motivational approach (i.e., a user-centred study focusing on contextual inquiry). Based on *in-situ* observations carried out in intensive care units and the relevant literature review we define the obstacles for compliance deriving from psychological and contextual constraints and provide relevant insights to help designers and clinicians to fight with. Our aim is to initiate discussions regarding the main purpose of medical alarms and how to integrate them better in clinician workflow.

Keywords: Compliance · Alarm fatigue · Alarm design

1 Introduction

Clinicians who are exposed to noisy environments are more likely to suffer from alarm fatigue, stress or sleep deprivation, and can finally become inefficient in the moment to respond to a critical situation [1–3]. Hospital settings contain a plethora of alarms that overwhelm operators. A large number of these alarms are false, unnecessary or clinically non-actionable [4] due to the fact that clinicians either stop hearing alarms (i.e., desensitization) or lack interest in responding to them. In other words, a lack of compliance or an inappropriate response to alarms is constantly observed in clinicians operating in critical care. Non-compliance means that clinicians ignore important actions or fail to follow the procedures and instructions, confused by message and the real meaning associated with the alarm. Missing or inappropriate actions on alarms is a potential hazard on patient safety resulting in a significant number of accidents caused by human errors [5]. Thus, we feel urged to understand what causes lack of compliance

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with medical alarms in an attempt to improve the working conditions for healthcare providers while ensuring the safety of the patient.

The standards for designing alarms are excessively strict in technical requirements, mostly related to high frequency band specifications and loudness to ensure that the alarm is heard even with background noise or above other overlapping sound events. Although standard organizations encourage the embodiment of better clinical alarms, alarms designed following only technical requirements rarely fit in the human needs and preferences in complex clinical ecosystems [6]. That is, authorities are driven by patient safety but not on how these alarms are actually emotionally experienced and utilized in daily contexts by clinicians.

Treating alarms from the clinician perspective as well as patient safety motivates the interest in developing an alternative soundscape for clinical environments, based on preventing health risks but also on clinician-centred principles that consider human factors and context of use. A pleasant, quieter and engaging environment can enhance the alarm response by clinicians and in particular by nurses. This paper presents an introduction to the topic of alarm compliance in critical care. In our contribution, we especially define the obstacles to address the issue of lack of compliance and provide (alarm) designers with insights to help clinicians overcome ambivalence towards clinical alarms. The presented obstacles are the result of the literature review but also of the *in-situ* observations carried out in intensive care units conducted by both authors. We conclude that contrasting the mandatory perspective with the clinician-centred motivational design approach as well as embracing their unique contribution for critical care provides us with insights to design better medical alarms.

2 Compliance in Healthcare

Compliance is a term commonly used in business world to refer to a set of procedures and good practices adopted by organizations to identify and classify the operational and legal risks they face. This term has its origin in the Anglo-Saxon private business sector and in the establishment of internal mechanisms for prevention, management, control and reaction against them [7]. Compliance has in many cases ceased a voluntary option and is implemented in the legal framework of standards and protocols to respond to potential risk situations. Increasing complexity in socio-technological environments and increasing restrictions in legislation have led to its insertion within the regulatory framework of companies and institutions to avoid the risk of suffering sanctions or a reputational damage.

The term *compliance* in critical care requires a broader approach, beyond compliance policies in a business and management context, that reflects on a deeper understanding of the entire ecology of healthcare systems and human procedures. Compliance applied to critical medical alarms should concern operators (i.e., nurses) referring to their timely response to the message that the alarm conveys. Almost every medical device embodies alarms that convey information about a pathology event or a technical malfunction. These alarms are normally part of a medical protocol designated by regulatory agencies, policy makers or device manufacturers, and are implemented in the design of complex auditory systems. Available clinical studies propose strategies

focused on alarm management in order to reduce these effects and including a variety of approaches: customization of manufacturer's default ranges and priority-based levels; personalization of alarms based on the patient's history; reduction of the noise caused by the internal parts of the device, joints, mechanisms or ventilators; display improvement based on human factors engineering principles; machine learning and smart advanced technologies [4, 8, 9].

Then, why is there still a lack of compliance in the response to alarms? And, what are the obstacles for compliance? The approaches mentioned above are based fundamentally on alarm management measures but ignore underlying issues related to context and how alarm protocols and patient care procedures actually take place relating to individual preferences on alarm utilization. We already know some of the problems related to alarm management and device utilization such as non-actionable alarms (not corresponding to a pathological problem), false alarms (out of context with patient care) or technical alarms (induced by the movement of a patient, a sensor coming off or a technical malfunction), among others. However, it is necessary to add a clinician-centred approach, understanding their behaviour in critical care context and attitudes towards alarm response. Observing critical care units in order to identify the causes and clustering the problems is the first step to understand how nurses respond to alarms.

3 Obstacles for Compliance in Healthcare

As we mentioned above, research contributions rarely address the problem of alarm compliance from a broader ecology of socio-technological environments. We understand that it is necessary to add a clinician-centred approach and those aspects context-related that affect their response to alarms. Based on direct observations of critical care nurses and their daily routines in critical care, we distinguish between those obstacles that are inherent to the personal or psychological constraints of those in charge of the alarms (i.e., nurses), and contextual constraints, which includes both existent physical obstacles and other external aspects of the ecosystem itself.

3.1 Psychological Constraints

Psychological constraints are personal obstacles self-imposed voluntarily or involuntarily and are about aspects related to one's own expertise and learnings from previous experiences and how they affect their response to alarms. Some of them can be relatively easy to improve with training. Others are deeper and more difficult to manage, as those related to cultural heritage, personal vocation, or the local concept of care.

Perception and identification. An auditory (or visual) alarm presented in an attended location will be perceived more quickly and accurately than alarms that are not initially attended [10]. At the same time, compliance rates are much higher to auditory warnings. An auditory alarm is the natural warning modality for the most critical events since sounds have an omni-directional nature [11]. However, the level of interference that an auditory alarm produces during a task is related to the kind of auditory information and the previous learnability of alarms in the recognition of them

[12, 13]. When the high workload of a nurse in an ICU requires extra resources, the identification of auditory alarms compete with other cognitive processes. This results in a deterioration of performance on other tasks and a lower compliance level. The high level of similarity between sounds and the lack of associative link between sounds and their functions is the main reason for a learning difficulty [14]. The prioritization of alarms should convey the level of urgency of the critical event to which it refers; this is a key point to improve the recognition and identification of an auditory warning when nurses hear it [15, 16].

Individual differences. "Each nurse adjusts the range of parameters for alarms according to each patient but also from their own experience." This is a common insight in conversations held with nurses and exemplifies how they relate to alarms. Expertise, learning and level of training undoubtedly affect their choice for setting alarm limits. Novice nurses have a preventive attitude and set narrower alarms limits. Experienced nurses are able to cross-link patient variables and rely on their experience and therefore set wider alarm limits. These nurses are more flexible to follow-up of the protocol. Thus, personality influences critical situations such as making careful decisions under fatigue, coping with stress or dealing with alarm compliance [17].

Complexity of decision making. Critical care units are high workload environments that demand complex tasks and the attention to overlapped critical events. These processes are affected by personal aspects such as the relationship between the clinical staff, levels of hierarchy and responsibility, competence, experience, and issues of trust and leadership. According to Hancock [18], findings in the observation of nurses' decision-making show a pragmatic behaviour rather than a clinically response. He states how a traditional approach based on a discipline-based knowledge contrasts with the real clinical practice. The know-how transcends the know-what especially in the day-to-day practice that involve a particular interpersonal sensitivity. Therefore, decision-making processes must be addressed as a complex pattern of events, studied from a human-centred and evidence-based approach, involving the intrinsic motivations of the entire ecology and its inhabitants.

Motivation. Medicine and nursing are highly vocational professions. Critical care nurses are especially interested in the advanced technology and its utilization. However, the very technology that makes critical care attractive for them also creates an acoustically hostile environment. Nurses often find themselves in a dilemma with caring for the patient as well as appropriate utilization of the technology. When technology cannot cater for their needs and their own way of patient care, they can lack interest and motivation to interact with the medical devices. Hence, medical alarms are often seen as nuisance when 86 to 98% of the alarms are either false or non-actionable [2].

Burnout syndrome and alarm fatigue. A state of emotional, mental, and physical exhaustion may be caused by excessive and prolonged stress to alarms (alarm fatigue) but also by pressures from other sources. Such psychological disorders occur when the user feels overwhelmed and unable to meet constant demands. As the stress continues, users begin to lose the interest or motivation that led you to take on a certain role in the first place. The excessive amount of stimuli from all these alarms creates a stressful sound environment. As a consequence, patients' mental and physical health as well as clinicians' well-being and work efficiency are threatened [3].

3.2 Contextual Constraints

Critical care poses a complex environment that involves the interaction of multiple users but also the compliance of procedural requirements, the alarm management into different medical devices, overlapping critical events and the processing of large amounts of data. In this context, audible alarms are the main source of medical alerts to warn clinicians of potentially hazardous events. Medical alarms are fundamentally designed to be a crucial work tool for clinicians, and to make them really efficient they should be designed in relation to the context and the type of action that they require of the nurses. Clinical contexts limit the number of valid alarm design solutions, either by the rules and regulations on technological specifications, the physical and environmental requirements, or by the limitations of a highly demanding complex environment that leaves little time and space for calm-decision making. Below we list the obstacles related to the clinical context that immediately impact alarm compliance.

Technological limitations. Modern healthcare and technological advances in critical units facilitate the improvement of medical care and patient safety. Nevertheless, this development is associated with an increasing number of monitoring and organ support devices and therefore, a greater number of alarms that threat clinician workflow, patient rest, comfort or recovery. However, researchers, with exception of alarm fatigue syndrome, have not yet covered the negative consequences of high-tech environments on clinicians as well as on patients extensively. A human-centred and technology-driven approach should involve all critical care inhabitants but also stakeholders outside the critical care [3]. Policymakers, standard offices, manufacturers, and hospital management must collaborate in the design process to favour further research and develop viable alarm solutions for a safe, calm, and satisfying environment [19].

Regulative standards. Alarm compliance is mostly addressed from an ergonomic discipline, as adhering to requirements, standards, laws or regulations that relate to alarm management. As a result, clinical environments have become over regulated in order to guarantee the patient safety. Considering that strict protocols and traditional procedures fail to help clinicians to react to alarms in a timely and relevant fashion. Alternative approaches are need to convince clinicians that the alarm is true and needs a specific action. Policies not only affect medical protocols but also standardization requirements for devices. Furthermore, policies can create a bottleneck for medical innovation that caters for well-being as the main focus is on safety.

Physical arrangement. Clinical environments have certain requirements already implemented, but the role that the physical space can play is specifically relevant when looking the spatial layouts and also the social interactions of the inhabitants, materials or lighting [20]. Nurses response is affected by the alarms perceived but also by the characteristics of their space of work. Well-designed physical settings play an important role to address compliance. Environmental factors related to medical error include noise, light, and acuity-adaptable patient rooms [21]. Thus, novel aspects are being incorporated into the master planning of healthcare as new design layout trends with a user centred-care approach: distribution of beds and devices; healthcare facilities with technology-driven features; environmental sustainability (heating, ventilation, and air conditioning, natural lightning); scalable allocations for staff and family; and

working paths [22]. Therefore, when these design guidelines are applied, there will be better working environments that can increase compliance rates and prevent medical errors, in order to enhance the safety and quality of healthcare.

Critical care soundscape. Intensive care units are complex sonic environments with many *sound producing events* (i.e., system events causing alarms, patient monitors, patient support devices, caregiving activities, cleaning, environmental noise) and *sound producing actors* (i.e., patients, clinicians, visitors, support personnel). All these activities create a high level of sensory stress for all actors involved. Nurses are devoted to pay attention to patient needs and detect any relevant system event occurring, when at the same time are exposed to excessive noise and constant sensory stimuli. Thus, lack of good soundscape design with clear roles for each sound-producing event can also hinder the detectability of certain alarms or critical events.

4 Discussion

From a theoretical approach, alarm environment in critical care can be described as an onion model with overlapping layers or tasks that occur simultaneously. In practice, nurses are required to respond to these alarms by prioritizing the events according to their criticality and level of urgency. Thus, the compliance rate is the level of success in responding in time to alarm events and acting on true alarms in a hierarchical fashion. In this sense, inherent limitations that underlie alarm compliance are the psychological and personal aspects of nurses but also the technical and technological constraints related to the context they inhabit. Once these obstacles have been considered, how can we move forward?

Ethnographic studies and design methodologies with a user-centred approach provide the necessary tools to empathize with user needs (both patients and nurses). The improvement cannot be made from only a standardized approach based on regulations and rules. The consequences of a human error ignoring an important action in an intensive care unit are life-threatening, but an excessive tightness can lead the unit to be inoperative. Hence the need to detect the origin and causes of why alarms are ignored or inadequate responses are given, before trying to solve the situation only with severe protocols. The well-being of the clinicians as well as patients should be considered in design teams and policy making processes. Manufacturers of medical devices will also benefit from insights into the negative consequences of technology and how to avoid them by motivational approaches. Medical devices will be more appreciated by clinicians if the devices are perceived as overcoming the aforementioned psychological and contextual obstacles.

The personal and psychological constraints of nurses that threaten alarm compliance are also conditioned by complex decision-making processes. According to Freudenthal et al., “not only conscious decision-making should be studied: deliberation-without-attention in many cases outperforms conscious decision-making in complex decision-making” [23]. This clarifies that the diversity of an environment inhabited by people requires an approach based on motivational principles that consider human factors and decision-making processes (automatic vs. conscious). The detection of patterns in tasks responding and how nurses assign meaning and interpret alarms

must be considered from different approaches such as the study and observation of nurse behaviour and routines without judgment or punishment; and involving them in the design and development of new medical devices based on their expertise and alarms preferences, as it was suggested by Özcan et al. [24]. Mandatory approaches can often undermine clinicians' expertise as they lead to non-conscious automated responses. A motivational clinician-centred approach favours responses to alarms consciously, enriching the knowledge of all critical care inhabitants. Therefore, new lines of research such as open innovation based on motivational psychology should be considered. That is, taking advantage of the expertise and knowledge acquired from users, making users participants in the design and decision-making processes.

Regarding to contextual constraints, any intervention on a part of the system (protocols, medical devices, space layout) should consider the effect on the others. The physical configuration of any clinical ecosystem is also a concern that affects the action on alarm performance. In addition to this, advance technology solutions and new layout design trends motivates the conceptualization of new healthy environments and a sustainable workflow. Similarly, these approaches based on human-centred principles presents an alternative beyond the conventional mandatory approach based on rules.

5 Conclusions

In this paper we introduced the issue of lack of compliance with medical alarms in critical care. We also presented the psychological and contextual obstacles as the result of the literature review but also of the *in-situ* observations carried out in intensive care units conducted by both authors. We discussed the potential of a clinician-centred and context-relevant approach to alarm compliance as a creative tool that engages nurses to voluntarily respond to alarms. Our approach addresses user needs in relation to the recent technological advancement in critical care and how people in general interact with high-tech medical devices [24]. Considering compliance from different perspectives (e.g., open innovation, future technologies, digitally advanced products such as wearables, new products promoting health and wellbeing and modern human needs) is essential to remove the constraints for clinical compliance and reach the optimal design space. With our contribution we hope to initiate further discussions amongst the community of alarm designers regarding the main purpose of medical alarms and how to integrate them in a better clinician workflow promoting a culture of integrity of all the parties involved.

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