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Ten Years Later, Alarm Fatigue Is Still a Safety Concern

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ABSTRACT

Ten years after the publication of a landmark article in *AACN Advanced Critical Care*, alarm fatigue continues to be an issue that researchers, clinicians, and organizations aim to remediate. Alarm fatigue contributes to missed alarms and medical errors that result in patient death, increased clinical workload and burnout, and interference with patient recovery. Led by the American Association of Critical-Care Nurses, national patient safety organizations continue to prioritize efforts to battle alarm fatigue and have proposed alarm management strategies to mitigate the effects of alarm fatigue. Similarly, clinical efforts now use simulation studies, individualized alarm thresholds, and interdisciplinary teams to optimize alarm use. Finally, engineering research efforts have innovated the standard alarm to convey information more effectively for medical users. By focusing on patient and provider safety, clinical workflow, and alarm technology, efforts to reduce alarm fatigue over the past 10 years have been grounded in an evidence-based and personnel-focused approach.
Key words: alarms, alarm fatigue, alarm management, clinical workflow, interdisciplinary

In 2013, the American Association of Critical-Care Nurses (AACN) published a landmark article by Sendelbach and Funk that called attention to the patient safety threat posed by alarm fatigue from physiologic monitors and other medical devices.[1] Ten years later, alarm fatigue continues to be an issue that researchers and organizations aim to remediate. Alarm fatigue contributes to missed alarms and medical errors that result in patient death, increased clinical workload and burnout, and interference with patient recovery.[2-5] All aspects of alarm

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fatigue have been further exacerbated by the COVID-19 pandemic and the global rise in clinician burnout.[6-8] Organizations such as AACN have established effective alarm management protocols,[9,10] and researchers have redesigned alarm technology. In this article, we highlight the continued need for patient safety, recent clinical and engineering advances in mitigating alarm fatigue, and next steps to finally conquer this pressing issue.

Background

To develop an understanding of alarm fatigue, it is important to consider the current challenges that alarms present and their definitions. Alarms are designed to alert staff of significant clinical changes (eg, a life-threatening arrhythmia) or a required action (eg, replacement of a probe that has fallen off the patient). Clinical alarms may be valid or invalid, and actionable or nonactionable. Valid alarms accurately reflect the physiologic status of the patient, for example, a bradycardia alarm for a patient with a truly low heart rate. Actionable clinical alarms are valid alarms that warrant either an observed clinical intervention or a consultation with another clinician at the bedside to determine the cause of the alarm and appropriate next steps.[11] Nonactionable alarms are, simply, alarms that do not meet the above definition of a valid, actionable alarm and instead warrant no action by the clinical care team. Invalid alarms (alarms that misrepresent the true physiologic status of the patient) are, by definition, nonactionable. Alarm fatigue occurs when a user becomes desensitized to alarms as a result of excessive nonactionable alarms, ultimately resulting in a delayed or no response.[1]

For example, a pulse oximetry monitor alarm for a patient with chronic obstructive pulmonary disease whose oxygen saturation has dropped from their baseline of 92% to 90% would be a nonactionable alarm, because this oxygenation level is relatively safe for such a patient and represents a very small change from baseline. One assessment of close to 1000 hours in the intensive care unit (ICU) found 85% of alarms to be clinically nonactionable.[12] In the pediatric ICU, 13% of alarms were actionable, whereas only 1% of alarms on the general pediatric floor were actionable.[2,13] The same study also demonstrated a dose-response relationship between alarm burden and response time, with response time slowing as nurses were exposed to higher rates of nonactionable alarms. A later study demonstrated similar low actionable alarm rates (as low as 0.5%)[11] but also showed that there was consistently a 15% prolongation of response time for each hour elapsed in a nurse's shift. Not only do these studies serve as a proxy for measuring the early onset of alarm fatigue, but such evidence is also highly demonstrative of the negative effect of frequent and nonactionable alarms on clinical staff, especially nurses.

In addition to being caused by nonactionable alarms, alarm fatigue can result from frequent invalid alarms.[11] Invalid alarms occur as the result of device artifact or error, such as an electrocardiographic (ECG) result reporting ventricular tachycardia when the patient is actually in sinus rhythm and has a loose ECG lead.[14] Invalid alarm rates have been measured to range from 85% to 99.4% of all clinical alarms.[15-20]

When alarms are consistently nonactionable or invalid, a user's priority to respond may be lost or replaced with exasperation, resulting in an accumulation of desensitization and dissatisfaction among health care staff. In fact, alarm fatigue, in combination with working conditions and staff individuality, is cited as a major cause of poor staff performance.[21] Whereas individual personality traits and workload are not easily modifiable, alarm tones and alarm thresholds are, making alarm research and innovation an important avenue for reducing alarm fatigue and desensitization.

Beyond clinicians, patients and family members suffer from constant alarms as well. The hospital is often a high-stress environment for patients and their families, and alarms add to causes of concern. Contributing to this, as previously described, is that alarms are often ignored or dismissed. Patients and families experience a cycle of concern in which they perceive the health of their loved one to be at risk, and then that risk is ignored. Furthermore, alarms sound at all hours of the day, especially in an environment like the ICU, resulting in frequent sleep disruption for patients and families. In fact, sleep disruption has been strongly linked to the development of post–intensive care syndrome (PICS),[22,23] a condition similar to posttraumatic stress disorder. Upwards of 70% of ICU patients develop PICS,[24] which unnecessarily prolongs the psychological stress of

Table: AACN Alarm Management Strategy

2013 Alarm Management Strategy[9]	2018 Alarm Management Update[27]
Optimize skin preparation for device leads.	Bedside nurses should check alarm settings at the start of every shift.
Customize alarm parameters and threshold settings.	Re-emphasizing of customization of alarm parameter settings for individual patients
Provide ongoing education about devices with alarms.	Interprofessional teams should address issues related to alarms, develop unit-specific alarm parameters and policies, and focus only on monitoring patients with a clinical indication for monitoring.
Limit alarming monitors to patients with clear, clinical indications for monitoring.	

Abbreviation: AACN, American Association of Critical-Care Nurses.

the hospital stay. Currently, instead of alarms identifying legitimate health declines, the acoustic environment of the ICU results in deleterious effects on patient sleep and overall anxiety.

These factors converge to exacerbate alarm fatigue and subsequent effects of nonoptimal medical alarms. Fortunately, efforts are underway from safety organizations and through clinical workflow and engineering innovations to prevent and combat these workplace and patient risks.

Patient Safety

Sendelbach and Funk[1] mention multiple patient-safety-focused organizations that have prioritized alarm fatigue and redesign as crucial barriers to conquer. These same councils continue to name alarm fatigue as a pressing issue for research and intervention. Addressing alarm fatigue is important not only for patient safety and to prevent consequences like PICS but also for clinician well-being and to prevent burnout.[8,25] A recent systematic review identified that ICU nurses perceive excessive alarms to be burdensome and to interfere with patient care, requiring strategies for alarm management.[26] AACN released an alarm management strategy in 2013 (later updated in 2018) that has been used by clinical groups to successfully reduce the quantity of nonactionable alarms (Table).[9,10,27] Using these recommendations, one research group was able to reduce alarms by up to 30%.[10]

In addition to AACN, other nursing and safety regulatory bodies have for years focused on addressing alarm fatigue and the impact of alarms on patients. For example, The Joint Commission has named alarm fatigue a top 10 safety priority every year since 2013.[28] The organization ECRI (originally founded as the Emergency Care Research Institute) has named missed alarms and alarm overload as one of the "Top 10 Health Technology Hazards" every year from 2012 to 2020.[29] In 2011, the Association for the Advancement of Medical Instrumentation (AAMI) held a Medical Device Alarms Summit focused on alarm challenges, patient safety, and alarm research. Since then, AAMI has offered various webinars and research grants to support investigation and innovation in the field of alarm fatigue prevention.

These patient-safety-focused organizations remain dedicated to improving the clinical environment, with a primary focus on innovating medical alarms. As a result of their dedicated safety initiatives and the research conducted throughout the globe, numerous advancements in medical practice and alarm design have been accomplished and are still underway.

Clinical Interventions to Reduce Alarm Fatigue

Since the publication by Sendelbach and Funk,[1] numerous studies have aimed to identify promising clinical interventions to reduce alarm fatigue. Ten years ago, the main clinical interventions were early starts toward individualizing alarm parameters, optimizing ECG electrodes, and using interprofessional teams and human factors. Since then, many developments have been made in these and other areas. In this section, we explore the improvements and developments made to reduce alarm fatigue in the clinical setting.

Measurement of Alarm Fatigue

In the past 10 years, there has been tremendous progress in the objective measurement of

alarm fatigue, the results of which have shown the grossly disproportionate number of nonactionable alarms in the clinical setting. For example, to better understand nurses' decision-making regarding alarm response, Schondelmeyer[30] observed a general pediatrics unit.The researchers shadowed nurses for 2 hours and asked them to "think aloud" when an alarm was received. Nurses who chose not to respond to an alarm typically stated that this was because of the alarm being short in length, staff or family members being at the bedside monitoring, or their having just checked on the patient. Within this study, only 7% of the alarms responded to were actionable, thus furthering the evidence of the large number of unnecessary clinical alarms.

Progress has also been made in measuring how alarm fatigue affects systems response and response time for critical events. Using in situ simulation and human factors engineering expertise, Kobayashi et al[31] simulated an arrhythmia in an empty emergency department room marked as "occupied." The simulation was done without the awareness of the clinical team, and the research team documented alarm response. These simulations made it possible to measure systems response in real time and to determine any weaknesses present. Interventions that followed included revisions to the emergency department telemetry system in place, adjustments to alarm parameters to improve signal-to-noise ratio, and adjustments to system hardware and accessibility (eg, repositioning of alarm system hardware). After the intervention, the researchers conducted the simulations again to assess the success of the interventions. This method of simulation is an ideal way to evaluate patient safety concerns such as alarm fatigue and has been used as a model by other research groups.

As an example of the use of this simulation-based design, Children's Hospital of Philadelphia organized a quality improvement project aimed at measuring alarm fatigue within the interdisciplinary Patient Safety Learning Laboratory (PSLL). This project (which is currently underway) adapted Kobayashi et al's simulation on medical surgical units and ICUs while using secondary notification devices (mobile devices to communicate alarms directly to staff).[31,32] The initial results of the use of this modified simulation methodology are encouraging; final analyses are pending.

Individualizing and Redesigning Alarm Parameters

Although it is remarkable that researchers have found ways to consistently measure alarm burden, what is more important is what has been done with that knowledge. With this understanding, a large area of research over the last few years has focused on redesigning and individualizing alarm parameters. In fact, individualizing alarms was found to reduce critical alarms by 43%.[18] Various other research groups have approached this topic, each with a unique and varied approach, as we describe below.

A helpful first step to individualizing alarms is determining which patients require continuous monitoring, such as telemetry. In certain clinical cases, patients may not meet the criteria for continuous monitoring (and thus risk false alarms) but nevertheless remain on monitors. In fact, because patients are so often left on telemetry monitoring unnecessarily, the American Heart Association released updated practice standards for ECG monitoring in 2017 that focused on the indication and duration of monitoring.[33] Using these new guidelines, one hospital was able to reduce unnecessary telemetry monitoring from 37% to 17%.[34] Substantial improvements in alarm rates and clinical workflows can be made by confirming whether patients require continuous monitoring.

In an attempt to understand the partnership and support needed with nursing for the implementation of customized alarm parameters, several studies have been done in various hospital units. In 2019, nurse researcher Halley Ruppel and colleagues[35] conducted interviews with ICU nurses to better understand the clinical reasoning around alarm customization. They determined that health care systems must consider various factors, such as unit culture around alarms, nursing expertise and comfort, personal motivation to customize, and an understanding of customization, before implementing alarm customization guidelines. Ruppel and colleagues also evaluated the impact of software for customizing alarm parameters (IntelliVue Alarm Advisor; Phillips) in the ICU.[36] The software assists nurses with visual notifications on the monitor for repeated alarms with the same violations, which are triggered and silenced within a certain period of time. Ruppel et al found that use of this software significantly reduced the number and duration of various physiologic alarms. Additionally,

nonactionable alarms placed less of a time burden on unit nurses after implementation of the software, thus improving workplace conditions for staff.

Similarly, in 2016, Sowan et al[37] altered ICU cardiac alarms to expand and individualize parameters; they then evaluated the impact of the customization on the overall alarm rate and nursing attitudes. These parameter changes involved tightening or increasing thresholds (ie, adjusting the time at which an alarm is triggered to expand or reduce the range), adding a period of delay between detection and the alarm, disabling unnecessary or nonactionable alarms, and adjusting volume according to priority. Although they found a significant reduction in alarm rates (from 87.86 to 59.18 alarms per patient per day), they reported no clinically meaningful changes in nurse attitudes for any items related to alarms. Furthermore, the researchers reduced critical alarms by 43%, notably by adjusting or customizing the alarm parameters and by implementing an interdisciplinary monitor policy.[18] This study was highlighted by the AACN as an example of evidence-based solutions to impact alarm management and responses.[38]

To assist with customizing alarm parameters, Poole and Shah[39] created a model using data from years of vital sign monitoring. The model serves as a reference for personalized thresholds, making it possible for alarm thresholds to accurately represent individual patients. In their 2018 study, Poole and Shah used data from a patient's first 24 hours of monitoring to determine the patient's own 1st and 99th percentiles. With use of the personalized thresholds, Poole and Shah demonstrated a reduction of alarm counts by approximately 50% for low heart rate and by approximately 35% for high heart rate.[39]

Another group of researchers from Cincinnati Children's led by Colleen Pater were able to significantly reduce alarm notifications per bed per day by 68% in the acute care cardiology unit over a 3.5-year time frame (from 71.0 to 22.4) by transitioning to a secondary notification system and introducing middleware technology (Connexall) that made alarm customization possible.[40] These customizations included alarm delays (ie, alarm threshold must extend over a certain amount of time before the alarm is sent) and the removal of nonactionable default system alarms. Pater et al also reviewed who was receiving the notifications and created a staged alarm notification system. After only 3 months, only 44% of nurses reported that "nuisance alarms occur frequently," compared with 92% of nurses previously. This result was paired with many other nursing satisfaction improvements.

Interprofessional Teams

Ten years ago, Sendelbach and Funk emphasized that interdisciplinary teams are crucial for organizing efforts against alarm fatigue; along this vein, one impactful effort has been the Agency for Healthcare Research and Quality's (AHRQ's) PSLL initiative.[1,41,42] The PSLLs are grounded in interdisciplinary team design and follow a systems engineering approach to patient safety research. The AHRQ has funded a total of 30 PSLLs at various institutions around the country between 2014 and 2019, and each PSLL has had its own emphasis area of patient safety. For instance, the PSLL at Children's Hospital of Philadelphia emphasized redesign of the physiologic monitoring systems to enhance patient safety by reducing alarm fatigue.[32,43] This PSLL team consists of physicians, clinical nurses, human factors engineers, physician informaticists, statisticians, nursing researchers, and clinical research staff. The funding and implementation of these PSLLs has been instrumental in fueling the work needed to tackle alarm fatigue and other patient safety concerns—work that can spread to other institutions by way of research, publications, and conferences.

These key studies and many more have proven that new technology and alarm parameter customization can have a profound impact on the alarm atmosphere of a hospital. Additionally, working with interprofessional teams has proven to be a successful way to mitigate alarm fatigue by collating many perspectives. Collectively, this research demonstrates that we are approaching the best implementation strategies, measurement tools, technology interfaces, and interprofessional teamwork.

Engineering Interventions to Reduce Alarm Fatigue

In addition to clinical adjustments, researchers have approached innovation of the actual alarms to make them more learnable, communicative, and tolerable as an important area for improvement. The engineering and alarm innovations presented here are a key difference

from the literature presented by Sendelbach and Funk[1] and should be seen as a success in the research realm. In this section, we summarize the engineering developments aimed at reducing alarm fatigue.

In 2006, the International Electrotechnical Commission (IEC) established an international standard for medical alarms (IEC 60601-1-8).[44] According to this standard, alarms use the same melodic structure. After investigation, these melodic alarms were shown to be difficult to learn and distinguish from concurrent alarms.[45-48] As a result, a group of researchers created auditory icons as an alternative to the standard auditory alarms.

Auditory icons mimic or represent the parameter that they are monitoring. For example, instead of the monotone beeping of a standard heart rate monitor, an auditory icon sounds like the "lub-dub" of a heartbeat. These auditory icons were found to be easier to learn and more localizable than the traditional alarms tested.[45,46,49,50] During clinical simulations, participants were better able to discriminate between simultaneous alarms and to identify alarm type when using auditory alarms.[51] Participants have also been found to have faster reaction times and higher accuracy when responding to auditory icons than when responding to conventional alarms. Furthermore, these participants had 27% greater odds of correctly answering a concurrent cognitive task.[52] As a result of this strong supporting evidence, the IEC updated 60601-1-8 in 2020 to include auditory icons as a supported medical auditory alarm.[53] By incorporating auditory icons, alarm systems can optimize their notification designs in an evidence-based manner. The third edition of IEC 60601-1-8 is targeted for publication sometime after 2024 and will continue to innovate medical alarms for improved performance.

In addition to alarms being difficult to learn, annoyance with the alarm sound itself has been documented as a contributor to alarm fatigue in clinicians. The *amplitude envelope* describes the "structure" of a sound, in which a flat envelope (that of a typical alarm) has a quick onset and offset, and a decaying envelope (such as the noise of clinking wine glasses) has a quick onset followed by a gradual alarm decline. The literature has shown that use of a decaying amplitude envelope significantly reduces alarm annoyance without interfering with learning or performance and while preserving an alarm's melodic and rhythmic structure.[54,55]

Even simpler than reengineering the auditory alarm structure, decreasing the volume at which an alarm is delivered has shown great benefits. At baseline, hospitals are noted to regularly exceed the World Health Organization's recommendations for clinical environment noise volume.[56] However, alarms delivered at lower volumes may still elicit similar accuracy of alarm identification. One study by Schlesinger et al[57] found that participant performance differed minimally when an alarm was delivered at a volume 11 dB below the background noise compared with the typical 4 dB above. Decreasing alarm volume also benefits patients, who, as discussed above, experience constant interruptions and anxiety from alarms and develop conditions such as PICS. Innovations in guidelines and alarm sounds, structure, and volume improve user performance and preference and contribute to the effort to reduce and prevent alarm fatigue.

Multisensory Alarms

Traditionally, medical alarms rely primarily on the auditory sense, with partial notification through visual stimuli, such as a monitor. To prevent alarm fatigue, the addition of other sensory stimuli in combination can increase alarm perception for the user, while decreasing the user's auditory burden and possibly lowering the volume and number of alarms throughout the clinical environment. Multisensory alarms also provide the opportunity for wearable notification systems, such as an ankle band or smart watch, or even for integration of the alarm with secondary notification devices. In a study in which tactile stimuli (such as vibration) were combined with auditory stimuli into a wearable ankle band, participants in the intervention group showed significant improvement in performance compared with a unisensory (auditory) cohort.[58]

Furthermore, another study found that the benefit of multisensory (auditory and tactile) alarms on participant performance persisted for 2 weeks after training.[59,60] These participants responded significantly faster, reported less cognitive demand, and felt more confident in identifying alarms compared with the unisensory cohort. Researchers have also created a wearable smart watch with trimodal sensory stimuli, ie, auditory, tactile, and visual.[61] With this device, participants showed significantly

better accuracy, faster reaction times, and decreased mental workload. These studies demonstrate that advancements and integration of multisensory alarms is feasible and may relieve the auditory burden of the medical environment and increase the overall quality of care and patient safety. Research and engineering teams dedicated to the modernization and innovation of medical alarms through auditory icons, adjustments to alarm character, and use of multisensory devices are crucial contributors to the prevention of alarm fatigue.

Smart Alarms

The use of smart alarms presents the opportunity to combine continuous monitoring with algorithmic processing and artificial intelligence to determine whether a patient's monitoring thresholds can be automatically adjusted or even turned off. Continuous monitoring systems risk a high number of false-positive alarms because of the high sensitivity and low specificity of the alarm thresholds. As a result, alarm management systems have been created to complement continuous monitoring with a process that filters out specific alarms. For example, the Visi Mobile System (Sotera Digital Health) delivers actionable alarms only by filtering out nonactionable alarms and has been well received by staff and patients for workflow and sense of safety.[62] Similarly, the Patient SafetyNet (Masimo) uses remote monitoring and secondary notification devices to send actionable alarm notifications directly to clinicians. Further, if the clinician does not respond, the device automatically escalates the notification to alert additional clinicians. By integrating this system, hospitals have been able to substantially decrease unplanned transfers by 50%.[63] Instead of adjusting alarm thresholds and notifications, the Dynamic Alarm Systems for Hospitals (D.A.S.H.) automatically adjusts alarm volume on the basis of the surrounding environment in an effort to reduce overly loud and disruptive alarms.[64,65] With the implementation of algorithmic monitoring and automatic adjustment to alarms, the clinical environment becomes dynamic and proactive, making it possible to help both providers and patients.

Future Work

We thank Sendelbach and Funk again for highlighting the need to intervene on alarm fatigue for clinicians and patients.[1] The medical and research communities continue to dedicate resources and investigations into innovation and optimization of alarms and the clinical environment. The developments described here are all helpful and useful, but advancements are still needed.

As they have throughout the past 10 years, safety organizations should continue to emphasize alarm fatigue as a top patient safety concern and maintain the investigation into alarm fatigue. Although some groups have attempted to quantify alarm fatigue, a need remains for the creation of a validated alarm fatigue measurement tool to objectively approach this safety issue.[66] Additionally, clinical investigations should continue to integrate evidence-based alarm tactics, alarm parameter customization, and interdisciplinary approaches to patient care. Finally, through the engineering of alarm design and devices, researchers should strive to integrate smarter and more dynamic alarms to provide more information to assist clinicians while enhancing patient safety.

Conclusion

Patients in all medical settings, but especially those in critical care, rely on the nursing staff to care for and react to all their medical needs. However, the demanding workplace environment currently challenges staff with suboptimal alarm technology, which contributes to alarm fatigue and burnout. Striving for excellence in workplace conditions and alarm technology will allow acute and critical care nurses to use their expert knowledge and experience to provide optimal care for their patients. By focusing on patient and provider safety, clinical workflow, and alarm technology, researchers, policy makers, and stakeholders at AACN and other organizations can transform the medical alarm realm into one that is evidence-based and personnel-focused. Much progress has been made in the past 10 years to address alarm fatigue. The next 10 years will undoubtedly result in continued improvements to mitigate the adverse effects of alarms in the clinical setting to enhance patient care and improve the clinical work environment.

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