

Determining the Impact of an Alarm Management Program on Alarm Fatigue among ICU and Telemetry RNs: An Evidence Based Research Project

SAGE Open Nursing
Volume 8: 1–13
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DOI: 10.1177/23779608221098713
journals.sagepub.com/home/son



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Abstract

This evidence-based research project provides an appraisal of current research on how an alarm management program impacts alarm fatigue among registered nurses (RNs) in both intensive care units (ICUs) and telemetry units. Alarm fatigue is a major problem recognized by both the American Association of Critical-Care Nurses (AACN) and the Joint Commission. RNs are the primary caretakers of critically ill patients in ICUs and telemetry units and therefore are at the greatest risk for alarm fatigue.

The researchers performed an evidence synthesis to determine the impact of an alarm management program on alarm fatigue among ICU and telemetry RNs. A literature search was conducted using scientific databases such as PubMed, CINAHL, Trip, Cochrane Review, and Google Scholar. Our search strategy included the following terms: adult registered nurse, inpatient registered nurse, ICU registered nurses, RNs, Nurse Practitioners, alarm fatigue, alarm management strategy, education, cardiac monitor alarm, alarm strategies, alarm bundle, telemetry alarm, and cardiac monitor. Any studies involving the pediatric population, pulse oximeter alarms, and ventilator alarms were excluded. Due to the lack of available randomized control trials and cohort studies, the authors included two quality improvement (QI) projects. Finally, six studies were taken into consideration for review. The authors appraised each of the six articles using the Critical Appraisal Skills Programme Checklist (CASP) Tool. This tool allowed the authors to synthesize information based on the outcomes and determine the level of the evidence of each article in order to make evidence-based practice recommendations on implementing alarm management programs. **Conclusion:** Despite extensive literature highlighting the astronomical prevalence of alarm fatigue in RNs, there was a lack of current high-quality data related to implementing alarm management programs. Therefore, more research is needed to support the utilization of alarm management programs in ICUs and telemetry units to improve alarm fatigue among RNs.

Keywords

alarm fatigue, registered nurse, telemetry, icu nurses, alarms

Received 30 December 2021; accepted 15 April 2022

Introduction

Full physical examination by medical providers has always been the primary method of patient assessment. Throughout the 21st century, medical technology has provided healthcare workers with an abundance of real-time information and continuous physiological monitoring to alert health care providers when a serious problem occurs. Walking onto any hospital floor, it is easy to quickly become overwhelmed by the hums of ventilators and the blaring of alarms. These devices are designed to inform healthcare providers of critical medical situations, but can actually be hazardous and create alarm fatigue. This in

turn, can hinder medical care and lead to adverse patient outcomes (Bach et al., 2018).

Research has suggested that approximately 80–99% of alarms are falsely activated due to a combination of human, organizational, and technical factors (Bach et al., 2018).

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Per the Joint Commission, 85–99% of alarm signals do not actually require clinical intervention (Seifert et al., 2021). Siebig et al. (2010), analyzed real-time data in an ICU to establish the clinical validity of the monitoring devices used in their specific institution and found that only 16.9% of monitoring alarms were appropriately set off to either identify a patient's change in status or identify a problem with the machine. On the other hand, 43.6% of these alarms were set off as a false positive, and 44.2% were set off as a result of patient movement or manipulation by the medical providers.

Alarm fatigue is defined as desensitization and apathy of healthcare providers to the sound of an overwhelming number of repetitive or simultaneous alarms (Lewis & Oster, 2019). This is a major problem recognized by both the AACN and the Joint Commission. Between 2009 and 2012, the Joint Commission received 98 alarm-related adverse patient event reports, 80 of which were fatal and 13 caused permanent loss of function (Lewis & Oster, 2019). A retrospective study was published in 2011, which determined that 216 inpatient deaths between 2005 and 2010 across the US were linked to either delayed or absent responses to activated alarms. Additionally, between 2005 and 2008, the United States Food and Drug Administration database received 566 reports of inpatient deaths related to alarm fatigue (Bach et al., 2018). These studies demonstrate an unreasonably high prevalence of adverse events in hospitalized patients. Therefore, in 2014, the Joint Commission made alarm management a national patient safety goal, aiming to reduce the prevalence of alarm fatigue in nurses to ultimately prevent adverse patient events.

In addition to adverse events, desensitization to healthcare alarms is costly to health care systems. Nurses are the primary healthcare provider responsible for close patient monitoring and therefore are at the forefront for developing alarm fatigue. The primary intervention to reduce alarm fatigue is through alarm management (Lewis & Oster, 2019). According to Turmell et al. (2017), implementing an alarm management strategy has the potential to save hundreds of thousands of healthcare dollars. Additionally, it can collectively save RNs hundreds of hours of time, so they may focus more on direct patient care.

Alarm management can be accomplished through a combination of evidence-based interventions, including educational programs, development of policies and procedures, reducing over-monitoring of patients, and customizing alarm parameters. Literature suggests that implementing alarm management programs decreases the likelihood of alarm fatigue in nurses in the inpatient setting. These programs may include daily reassessment of need for each monitoring alarm, proper skin preparation prior to applying adhesive-based monitoring technology, and frequency of changing or recalibrating monitoring devices (Lewis & Oster, 2019) This has the potential to improve patient safety and significantly reduce sentinel events in the inpatient population.

Method

A literature search was conducted using databases such as PubMed, CINAHL, Trip, Cochrane Review, and Google Scholar. Our search strategy included the following terms: (adult registered nurse OR inpatient registered nurse OR ICU registered nurses OR RNs OR Nurse Practitioners) AND (alarm fatigue OR alarm management strategy OR education OR telemetry alarm OR cardiac monitor alarm OR alarm strategy OR alarm bundle OR telemetry alarm OR cardiac monitor). The authors excluded any studies involving the pediatric population, pulse oximeter alarms, and ventilator alarms. The authors also planned to exclude articles that were QI projects, but due to the lack of recent higher-quality studies, two QI projects were included.

Of the 79 studies found, 13 duplicates were removed. Of the remaining 66 articles, all four authors reviewed titles and abstracts for relevance, but only two of the four authors were required to include or exclude each article by title and abstract. After excluding 44 irrelevant articles based on their titles and abstracts, all four authors performed a full-text review of the remaining 21 articles; however, only two of the four authors were required to include or exclude each article during this stage. Of these 21 articles, two authors reached a consensus to include six studies according to the criteria listed above. Of the six articles, each author reviewed two articles independently and two articles collaboratively in pairs and critiqued them based on study purpose, sample size, statistical data analysis, conclusions, limitations, and implications for future practice. Due to the lack of available randomized control trials and cohort studies, the authors included two QI projects. Using this data, we determined the level of evidence and the quality of these articles.

Please see the Prisma Flow Diagram (Figure 1) for reference.

Results

The authors used the CASP tool to characterize the articles based on their individual quality, strength, and limitations. Each CASP tool was chosen based on the design of the corresponding study. The tool has ten to twelve questions that each highlight a different aspect of the study. Each question considers whether the methods used were appropriate, if their findings were significant, and if the results can be applied locally.

Of the six articles, each author reviewed two articles independently using the necessary CASP tool and created a table of evidence. Each author then reviewed two articles that another author independently reviewed, and the paired authors compared their findings. The paired authors determined the qualities and levels of the studies they reviewed and summarized their findings in the table of evidence. After grading each study based on the above criteria, the authors synthesized the evidence to make best-practice recommendations. Please see Table of Evidence (Table 1) for reference.

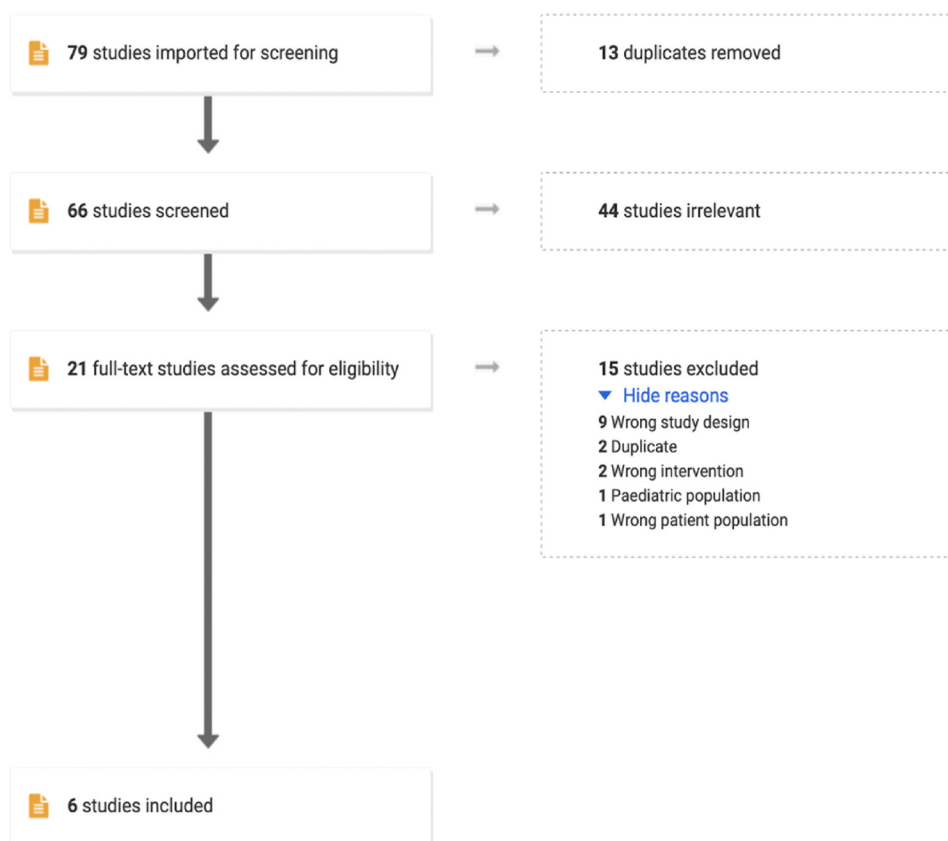


Figure 1. Prisma flow diagram generated by Covidence software highlighting the process for including and excluding articles in this literature review. Note: Covidence systematic review software, Veritas Health Innovation, Melbourne, Australia. Available at www.covidence.org.

Discussion

Six articles were reviewed by the authors to determine the impact of alarm management programs on alarm fatigue among RNs. All articles indicated that alarm fatigue causes a significant impact on ICU and telemetry RNs and is the biggest contributor to alarm-related adverse events (Bach et al., 2018). Nurses from all around the world agree that alarms disturb patient care, are burdensome, and diminish trust in alarm systems (Lewandowska, et al., 2020). Lewandowska, et al. (2020), highlights the negative impact of alarm fatigue and points to the importance of an alarm management system to alleviate this burden. This qualitative systematic review does not show the impact of an alarm management system, it only assumes that implementing one would lessen alarm fatigue in RNs based on the negative perceptions of nurses about alarm fatigue.

Bach et al. (2018) identified a gap between knowledge of alarm standards and their translation into practice. After performing a literature review, the researchers defined alarm standards as an umbrella term that encompasses three domains: machine learning, alarm configuration, and alarm designs. Machine learning refers to utilizing “smart” alarms

that use specific algorithms to determine if the alarms were alerting RNs of critical information or if they were falsely activated prior to generating a sound. Alarm configuration refers to the ability of RNs to alter the alarm parameters to meet patient-specific needs to reduce the number of unnecessary alarms. Finally, alarm design refers to the standardization of alarm sounds based on the machine’s perception of urgency, so each sound correlates with a different level of urgency. They emphasize that it is not enough to simply know the domains of alarm standards, but it is crucial for RNs to actually apply this knowledge into their practice to effectively reduce alarm fatigue. The researchers suggest that this gap is due to the lack of collaboration among technical, human, and organizational factors in alarm management programs. However, this study does not propose an alarm management program that may bridge this gap, so it is not feasible to predict what the impact of such a program would have on alarm fatigue in RNs.

One QI project suggested that implementing educational programs to improve the nursing staff’s understanding of cardiac telemetry nuisance alarms will positively impact alarm fatigue (Karapas & Bobay, 2021). After the nursing

staff completed the educational intervention, there was a statistically significant increase in nursing knowledge about alarm management; however, there were no statistically significant differences in the number of nuisance alarms. Evidently this educational program was beneficial in providing the nursing staff with knowledge about the concept of alarm fatigue. Although, it is possible that it was not clear in teaching them how to apply this knowledge to practice which may be responsible for why there was no statistically significant reduction in nuisance alarms. Graham and Cvach's (2010) QI project suggests that combining an RN education program with technology-based interventions will decrease the number of unnecessary and/or duplicate cardiac alarms. Unfortunately, they did not perform any statistical analysis to determine significance or which intervention applied was the most influential. Although both QI projects showed promise in providing a positive impact on alarm fatigue, they lacked statistical significance, generalizability, and the rigor required to be considered strong, reliable evidence.

Only two of the six studies demonstrated a statistically significant reduction of alarm fatigue in RNs by implementing an alarm management program. Bi et al. (2020), implemented an alarm management education program using a single-blind, randomized controlled trial with two parallel groups. They created a 4-week training program based on both the "Update to Practice Standards for Electrocardiographic Monitoring in Hospital Settings" published by the American College of Cardiology (ACC) and "Managing alarms in acute care across the life span: electrocardiography and pulse oximetry" published by the AACN. This training program was implemented specifically for RNs in the ICU. After the RNs completed it, there was a statistically significant reduction in inactionable telemetry alarms. Using a Likert scale, these nurses reported an overall decrease in their alarm fatigue after experiencing this structured training program. Lewis and Oster (2019) created the Communication, Electrodes, Appropriateness Setup Alarm Parameters and Education (CEASE) bundle based on the 2013 AACN Alert for Alarm Management recommendations. They implemented this patient-specific monitoring bundle in a quasi-experimental study in the ICU which significantly decreased alarm fatigue among those RNs (Lewis & Oster, 2019). Both of these studies showed a high level of evidence, good reliability, and strength of evidence thereby supporting the authors' evidence-based practice recommendations.

Please see the Level of Evidence Table (Table 2) and the Outcome Synthesis Table (Table 3) for reference.

Implications for Practice

Alarm fatigue is a major problem recognized by both the AACN and the Joint Commission (Lewis & Oster, 2019). Based on the literature review, critical appraisal, and

synthesis of evidence it is clear that implementing an alarm management program shows clinical significance in decreasing alarm fatigue among ICU and telemetry RNs. Both of the higher quality studies utilized experimental research designs to assess their educational interventions. Both of their training programs significantly reduced nurses' alarm fatigue (Bi et al., 2020 & Lewis & Oster, 2019). Additionally, Bi et al. (2020) educational program did not interfere with the nurses' judgment of true crisis alarms while simultaneously building their alarm management skills. Overall, both educational programs showed promising results that a structured alarm management program reduces inefficient or invalid behaviors.

Please see the Evidence-Based Practice Recommendation Table (Table 4) for reference.

Limitations

Unfortunately, the available literature is extremely limited. For example, coming across only one randomized control trial and one quasi-experimental study is disheartening because it is unclear if their results are generalizable. Future research must replicate these educational interventions in the desired population to make a more comprehensive practice recommendation. These studies also do not show if their specific alarm management programs apply to both ICU and telemetry RNs. The authors also may have been limited by their strict exclusion criteria and narrow PICO question which focused only on telemetry alarms.

Outcome Recommendations/Conclusion

Many studies have shown that the presence of excessive alarms is a significant issue among RNs; however, there have been limited high-quality studies documenting the impact of alarm management programs on alarm fatigue (Bach et al., 2018). Although limited, the evidence supports that alarm management programs positively impact alarm fatigue in ICU and telemetry RNs. However, the lack of knowledge, skills, and mentors are key barriers to implementing evidence-based practice (Melnyk & Fineout-Overholt, 2018). Specialized clinical training and education would provide RNs with an opportunity to not only augment their knowledge but also to transform their practice (Bi et al., 2020). Lewis and Oster (2019) suggest training RNs to become expert clinical leaders called "champions." This is a strategy to expand knowledge related to alarm management throughout the various shifts and departments within the hospital. This allows the champions to mentor the RNs in ICUs and telemetry units who are experiencing the burden of alarm fatigue. On the other hand, too much training can be burdensome and therefore utilizing the theory of planned behavior, an alarm management program can also focus on "reshaping behaviors" by training

Table 1. Table of Evidence.

Study	Study Design	Setting	Population	Research Question or Hypothesis (Study Aim)	Sampling: Technique Size Characteristics	Measurement of variables (Scales)	Statistical Data Analysis (Appropriate to answer research question)	Study's Findings / Author's conclusions	Evidence Level/ Quality Rating Grade	Reviewer's Comments: Strengths/ Limitations, Potential for practice change
Bach, Tina, Alissa, et al. Managing Alarm Systems for Quality and Safety in the Hospital Setting	Qualitative study	Norway-face to face and phone interviews	clinicians in clinical care N = 21 studies included N = 26 clinician interviewed	How to improve alarm safety in the hospital setting by incorporating human, organizational and technical factors	Interviewees were recruited using a convenience and snowball sampling.			The reviews identified 10 themes of improvement to tackle alarm problems. Each improvement element was categorized as either a human, organizational or technical factor. Nine reference themes of improvement elements were identified in the interview response. Study proposes a step-by-step guide to optimise implementation of the improvement elements using and end users, indicating need of further education by manufacturers interview findings were used to support, complement or confirm the findings of the literature reviews rather than as independent findings limit of 10 countries during interview- limits generalizability	Level V Very Low	Limitations regarding how the sample of interviews was found- convenience, snowballing. Unclear what articles are considered relevant (exclusion/inclusion of that definition) Does not discuss the impact of each literature review article and improvement elements. Did show a gap between technical using and end users, indicating need of further education by manufacturers interview findings were used to support, complement or confirm the findings of the literature reviews rather than as independent findings limit of 10 countries during interview- limits generalizability
Bi, Jiasi, et al. "Effects of Monitor Alarm Management Training on Nurses' Alarm Fatigue: A Randomised Controlled Trial."	This study was a single-blind, randomized controlled trial with two parallel groups.	The First Bethune Hospital of Jilin University, Changchun City, Jilin Province, China	RNs engaged in critical care n= 68 (34 experimental & 34 control)	How does an alarm management training program reduce alarm fatigue in intensive care nurses? However there is also a secondary outcome that implementing this management training will also reduce total alarms, non actionable alarms and true crisis alarms	Nurses were recruited from the Department of Critical Care Medicine of a tertiary A-level hospital. Set inclusion and specific exclusion criteria inclusion criteria were set. A minimum number of sample participants were determined via g ² power. Participants were randomly divided into two groups by random number by author. It was impossible to blind the participants in this	Independent variable- nurses behavior Dependent variable-Alarm fatigue for intensive care nurses. Secondary dependent variables- the number of total alarms, non actionable alarms and true crisis alarms Clinical alarms questionnaire, which was compiled by the Japanese Occupational Health Federation. Which uses a likert scale. This was given to participants at baseline and 12 weeks post intervention. On the basis of Cvach's survey of alarm numbers,	Reliability of likert scale used using Cronbach's α coefficient The normality of data was also tested using the Shapiro-Wilk test, and the mean (standard deviation) was used for statistical descriptions of the interval data with a normal distribution; median (interquartile range) was used for statistical descriptions of the interval data with a skewed distribution.	the alarm fatigue decreased and was statistically significant, number of total alarms and non actionable alarms decreased and was statistically significant. The results from the study indicated that the training caused no interference in the judgment of true crisis alarms. The training helped nurses to build their alarm management skills and helped them to avoid inefficient or invalid behaviors. Nurses were trained to	Level I Grade High	Strengths- using the theory of planned behavior to help decrease alarm fatigue and lowering the number of alarms. Limitations include generalizability as this was only conducted in the ICU. Inability to blind the control group due to practical reasons is a limitation due to possible contamination of control group. Total alarms was recorded but non actionable/crisis alarms were judged by experts and are subject to

(continued)

Table 1. Continued.

Study	Study Design	Setting	Population	Research Question or Hypothesis (Study Aim)	Sampling: Technique Size Characteristics	Measurement of variables (Scales)	Statistical Data Analysis (Appropriate to answer research question)	Study's Findings / Author's conclusions	Evidence Level/ Quality Rating Grade	Reviewer's Comments: Strengths, Limitations, Potential for practice change
Griham, K. C., & Coach, M.	Descriptive pretest-posttest Quality improvement project	ICU	N = 30 RNs	Does individualizing the parameters of a pt's cardiac monitor [?] the # of unnecessary crisis, warning, and system cardiac alarms in the MPCU?	study for practical reasons. In addition, the assistant used sealed opaque envelopes to assess the results. Assistant was blinded for the group assignment. During the data collection, outcome assessors were blinded to the participants' group allocations.	the "ICU Monitor Alarm Quantity Questionnaire" was prepared after on-site interviews with ICU nurses and discussion with the research team members. Expert opinion provided for any uncertainty of alarm classification. Nurses supervised the alarm recording within their work time, according to the alarm record of the monitor and the actual situation. The leader of working group supervised the nurses when filling in the questionnaire and recording the alarms within 24 h daily from 7:00 a.m.–7:00 a.m. of the next day, according to the alarm record of the monitor and the actual situation.	None! Probably should have used an ANOVA to determine causality based on 2 separate interventions (RN education & technology-based interventions)	RN education program & technology-based interventions [?] # of unnecessary &/or duplicate cardiac alarms Posttest: education RN compliance with assigning pt-specific VS parameters Problem = no statistical analysis which intervention was actually successful	Level VI Low quality Small sample size No statistical analysis of data cannot draw conclusions that intervention was successful No true process to determine pt-specific "normal VS range?" Future practice Application in CCU Studying PVC, ST change, & SpO ₂ alarms	Strengths 77% pretest response rate Limitations 53% posttest response rate No statistical analysis of data cannot draw conclusions that intervention was successful No true process to determine pt-specific "normal VS range?" Future practice Application in CCU Studying PVC, ST change, & SpO ₂ alarms
Karapas, E. T., & Bobby, K.	Quality improvement project One group pretest-posttest	Telemetry unit n = 34 RNs	52 staff members (34 RNs & 18 PCAs) N = 34 RNs experimental	staff knowledge of EBP r/t daily care for pts on a cardiac monitor [?] # of nuisance alarms [?] # of calls from	Sample 52 nursing staff members 34 RNs & 18 PCAs Convenience sample Experimental group Control group None 30 in sample & 30 in experimental	Dependent variables # of nuisance alarms # of calls from CTC to nursing unit Independent variable 45-min education session:	Paired t-test Appropriate to assess pretest-posttest survey = causality P < .0001 w/ 95% CI	Statistically significant in RN knowledge after education No [?] in nuisance alarms	Level VI Low-quality Small sample size Limited	Strengths 73.24% of total staff on this unit participated in intervention Significant in RN knowledge r/t

(continued)

Table 1. Continued.

Study	Study Design	Setting	Population	Research Question or Hypothesis (Study Aim)	Sampling: Technique Size Characteristics	Measurement of variables (Scales)	Statistical Data Analysis (Appropriate to answer research question)	Study's Findings / Author's conclusions	Evidence Level/ Quality Rating Grade	Reviewer's Comments: Strengths/ Limitations, Potential for practice change
evidence-based interventions				Central Telemetry Center (CTC) to nursing unit	52 nursing staff members 34 RNs & 18 PCAs Control group None	proper skin preparation & electrode placement	No statistical analysis to determine if education impacted # of nuisance alarms or # of calls from CTC to nursing unit	Small [7] in calls from CTC to nursing unit	statistical analysis of data	Limitations Small sample size Short data collection No statistical analysis for all dependent variables Quality improvement project Future practice Implement educational program on other units
Lewandowska, Katarzyna, et al. "Impact of Alarm Fatigue on the Work of Nurses in an Intensive Care Environment—a Systematic Review	Systematic review-mixed method	Medical University in Gdansk, Poland	Nurses in ICU N = 356-nurses Quantitative Portion N = 33-nurses Qualitative Portion	What is the impact of clinical alarms on nursing perception in the ICU environment	7 descriptive correlation and 2 qualitative studies systematic review of literature was carried out according to the PRISMA guidelines. The content of PubMed, OVID, EBSCO (electronic databases), ProQuest Nursery, and Cochran Library was searched Two studies were carried out using a semi-structured interview [28,29]; five had the form of a descriptive, cross-sectional survey [9,11,25-27]; including four using the same HTF questionnaire study tool [9,11,26,27] and one a questionnaire created by the author	Systematic Review – no variables Nurse perception of alarm fatigue and alarm exposure. Rating of 9 issues.	Quantity data were analyzed based on the HTF (Healthcare Technology Foundation) study. The importance of clinical alarms were assessed using a five-point Likert scale with nine positions and were calculated for the four articles (weighted average values).	Nurses from different parts of the world agree that burdensome alarms occur too frequently, disturb their care of patients, and reduce their trust in alarm systems Alarm fatigue may have serious consequences, both for patients and for nursing personnel. It is necessary to introduce a strategy of alarm management and for measuring the alarm fatigue level	Level V Grade Low	The results of the studies are the opinion of healthcare personnel. They are a necessary element to describe the final results; however, they may cause bias. The main limitation of the study was its inability to pinpoint the type of fatigue and determine the level of alarm fatigue caused by the alarms. Another limitation was the limited number of articles which forced them to use both quantitative and qualitative reviews. An experienced research team made an attempt to systematize the data. It turned out to be problematic to match the appropriate tool to assess the quality of the studies included in the review due to their diversity.
Lewis, Carmencita Lorenzo, and Cynthia A. Oster. "Research Outcomes of Implementing Cease.	Non randomized control trial quasi-experimental without-comparators design	36-bed ICU/SDU unit The hospital is a 368-bed, not-for-profit, Magnet-designated acute care facility located in an urban	N = 74 ICU/SDU registered nurses	In a 36-bed ICU/SDU unit with continuous hemodynamic and respiratory monitoring, does application of an evidence-based, patient-customized monitoring bundle compared with	Convenience sample	Independent Variable-CEASE bundle Dependent-Alarm fatigue, Number of alarms- number of alarms, duration of auditory monitoring	Statistical analysis was performed using SAS version 4.0 (SAS Institute, Cary, North Carolina) software. Frequency distributions and descriptive statistics describe the data. Comparisons before	CEASE is helpful to decrease alarm fatigue. Level 1 and 3 statistically significant. Level 2, was not. Level 1, low-priority events such as low battery alerts and artifact. Level 2, moderate-priority	Level III Grade Moderate	Good study. Needs to consider further variables of noise. Not generalizable due to convenience sample Poor post test compliance of nurses. No Confidence Interval- limits generalizability

(continued)

Table 1. Continued.

Study	Study Design	Setting	Population	Research Question or Hypothesis (Study Aim)	Sampling, Technique Size Characteristics	Measurement of variables (Scales)	Statistical Data Analysis (Appropriate to answer research question)	Study's Findings / Author's conclusions	Evidence Level/ Quality Rating Grade	Reviewer's Comments: Strengths, Limitations, Potential for practice change	
		area in the western region of the United States		existing monitoring practice lead to less alarm fatigue as measured by the number of hemodynamic and respiratory monitoring alarms? In a 36-bed ICU/SDU with continuous hemodynamic and respiratory monitoring, does application of an evidence-based, patient-customized monitoring bundle compared with existing monitoring practice lead to less alarm fatigue as measured by duration of alarms?		perception of alarm fatigue with pre and post test	and after intervention were made using χ^2 and independent-group Student's t-test, with $P < .05$ considered statistically significant. A power analysis was not conducted as there was no control group.	events such as high/low blood pressure, irregular heartbeat, paired beats and high/low SpO ₂ ; and Level 3, high-priority or life-threatening events such as apnea, asystole, ventricular tachycardia or fibrillation, and rapid oxygen desaturation.			
				In a 36-bed ICU/SDU with continuous hemodynamic and respiratory monitoring, does application of an evidence-based, patient-customized monitoring bundle compared with existing monitoring practice lead to less alarm fatigue as measured by nurse perception?							

Table 2. Levels and Types of Evidence of Relevant Studies.

	Bach et al., 2018	Bi et al., 2020	Graham & Cvach, 2010	Karapas, E. T., & Bobay, K	Lewandowska et al., 2020	Lewis & Oster 2019	Comments
Level I: Systematic review or meta-analysis							
Level II: Randomized Controlled Trial		X					<p>Bi et al., 2020</p> <ul style="list-style-type: none"> Strengths- using the theory of planned behavior to help decrease alarm fatigue and lowering the number of alarms. Limitations include generalizability as this was only conducted in the ICU. Inability to blind the control group due to practical reasons is a limitation due to possible contamination of control group Total alarms was recorded but non actionable/crisis alarms were judged by experts and are subject to human error and omissions. Time- this was a short study with no longer term followup
Level III: Non Randomized Controlled Trial						X	<p>Lewis & Oster 2019</p> <ul style="list-style-type: none"> Poor post test compliance of nurses. No Confidence Interval- limits generalizability
Level IV: Case-control or cohort study							
Level V: Systematic review of qualitative or descriptive studies	X				X		<p>Bach et al., 2018</p> <ul style="list-style-type: none"> Limitations regarding how the sample of interviews was found- convenience, snowballing. Unclear what articles are considered relevant (exclusion/inclusion of that definition) Does not discuss impact of each literature review article and improvement elements. Did show a gap between technical using and end users, indicating need of further education by manufacturers interview findings were used to support, complement or confirm the findings of the literature reviews rather than as independent findings limit of 10 countries during interview- limits generalizability <p>Lewandowska et al.,2020</p> <ul style="list-style-type: none"> The results of the studies are the opinion of healthcare personnel. They are a necessary element

(continued)

Table 2. Continued.

	Bach et al., 2018	Bi et al., 2020	Graham & Cvach, 2010	Karapas, E. T., & Bobay, K	Lewandowska et al., 2020	Lewis & Oster 2019	Comments
							to describe the final results; however, they may cause bias.
							<ul style="list-style-type: none"> The main limitation of the study was its inability to pinpoint the type of fatigue and determine the level of alarm fatigue caused by the alarms. Another limitation was the limited number of articles which forced them to use both quantitative and qualitative reviews. An experienced research team made an attempt to systematize the data. It turned out to be problematic to match the appropriate tool to assess the quality of the studies included in the review due to their diversity.
Level VI: Single qualitative or descriptive study (includes evidence implementation projects)		X		X			Karapas, E. T., & Bobay, K <ul style="list-style-type: none"> Strengths <ul style="list-style-type: none"> 73.24% of total staff on this unit participated in intervention Limitations <ul style="list-style-type: none"> Significant in RN knowledge r/t Small sample size Short data collection
Level VII: Expert Opinion or consensus							Graham & Cvach, 2010 <ul style="list-style-type: none"> Limitations <ul style="list-style-type: none"> 53% posttest response rate No statistical analysis of data cannot draw conclusions that intervention was successful No true process to determine pt-specific "normal VS range"?

Table 3. Outcome Synthesis Table Studies.

1	2	3	4	5	6
Bach et al., 2018	Bi et al., 2020	Graham & Cvach, 2010	Karapas & Bobay (2021)	Lewandowska et al., 2020	Lewis & Oster 2019
Outcomes					Comments
Outcome 1: Reducing alarm fatigue among RNs	↑*	° ↑	↓*°	° ↓	↑*
					<p>Bach et al., 2018</p> <ul style="list-style-type: none"> - Qualitative design, shows importance of integrated approach using themes to decrease alarm fatigue but no implementation or intervention included to show impact of alarm management program <p>Bi et al., 2020</p> <ul style="list-style-type: none"> - Significantly significant implementation of intervention to decrease alarm fatigue among RNs <p>Graham & Cvach (2010)</p> <ul style="list-style-type: none"> - Overall found an RN education program & technology-based interventions [?] # of unnecessary &/or duplicate cardiac alarm however there is no statistical analysis to determine significance or which intervention was the most helpful - Descriptive study on a small population with post-test. No statistical analysis performed. Quality improvement project <p>Karapas, E. T., & Bobay, K (2021)</p> <ul style="list-style-type: none"> - QI project - Statistically significant in RN knowledge after education but no decrease in nuisance alarms. Not statistically significant in nuisance alarms and calls from CTC to nursing unit - It is unclear how much the decrease in RN knowledge and education would impact overall alarm fatigue if nuisance alarms are still present - Unclear adherence to study protocol impacting results - Lack of statistical analysis <p>Lewandowska et al., 2020</p> <ul style="list-style-type: none"> - The results of the studies are the opinion of healthcare personnel. They are a necessary element to describe the final result. - They show that alarm fatigue does impact nurses but offer no intervention or resolution. - This particular study also had limited studies included resulting in both quantitative and qualitative reviews. An experienced research team made an attempt to systematize the data. It turned out to be problematic to match the appropriate tool to assess the quality of the studies included in the review due to their diversity. <p>Lewis & Oster 2019</p> <ul style="list-style-type: none"> - CEASE program is statistically significant to decrease alarm fatigue - Limited generalizability - CI not included

Code:

↑ improvement.

↓ no affect.

*statistically significant.

° statistical significances not reported, clinical significance.

Table 4. Evidence Based Practice Recommendation Table.

Recommendation (Quality, Strength): Implementing alarm management program shows clinical significance in decreasing alarm fatigue among RNs. However further research is needed as there are limited studies which support these programs and their impact on alarm fatigue in RNs.

Evidence Supporting Recommendation:

Relevant Source (Author, Date)	Level of Evidence	Quality & Strength of Evidence	Results Align with Clinical Question	Benefit vs. Harm Analysis	Additional Comments:
Bi et al., 2020	II	Grade High, Good reliability and strength of evidence	Yes, this study indicates clinical significance in the implementation of an alarm management program	The results from the study indicated that the training caused no interference in the judgement of true crisis alarms. The training helped nurses to build their alarm management skills and helped them to avoid inefficient or invalid behaviours. Therefore supporting that benefits outweigh harm.	Bi et al., 2020 - Small sample size - limited generalizability Lewis & Oster, 2019 - poor post test compliance - confounding variables- other noise
Lewis & Oster, 2019	III	Grade- Moderate, Good reliability and strength of evidence	Yes, this study indicates clinical significance in the implementation of an alarm management program	There is limited harm in this study as this study is based on the 2013 AACN practice alert recommendations and components of the 2018 AACN practice recommendations. This is one of the first studies to evaluate and show statistical significance on the effectiveness of a nurse-driven, patient-customized monitoring bundle based on all components of the 2013 AACN practice alert recommendations. The CEASE study takes into account the most current alarm management recommendation from the critical care nurses' professional association, the 2013 AACN Practice Alert for Alarm Management. In addition the CEASE bundle focuses on customizing a patient-specific approach in managing alarms with a large focus on the interdisciplinary team and education. The clinical nurse education/competency packet used in this study has been adapted and is now included in the new graduate nurse on-boarding curriculum. "The CEASE Bundle is an ongoing strategy in the ICU/SDU that has decreased non actionable alarms and made the alarms that do sound more meaningful without compromising patient safety."	

RNs' attitudes, subjective norms, perceived behavioral control, and awareness (Bi et al., 2020).

It is imperative for hospitals to develop evidence-based alarm management programs that are tailored to bridging the gap of simply knowing alarm management standards and actually applying them into practice (Bach et al., 2018). Applying the ACC and AACN alarm management practice recommendations enables a hospital to mold a specific alarm management program to their own organization (Lewis and Oster, 2019). The greatest barrier in the implementation of an alarm management program is the lack of an existing evidence-based standardized program due to insufficient high-quality evidence. Therefore, it is not possible to implement a specific alarm management program at this time. The John Hopkins Nursing Evidence-Based Practice Model (JHNEBP) is a circular conceptual model which, since there is no standardized alarm management program, would allow organizations to review relevant sources of new evidence and allow for their further investigation before determining what is truly the best practice.

The primary outcome in decreasing alarm fatigue can be quantitatively measured using a Likert scale pre- and post-intervention. Secondary outcomes include the overall decrease in nuisance telemetry alarms. Obtaining baseline data prior to implementation will allow the organization to see if the implementation of their customized alarm management program impacts overall alarm numbers on their desired units.

Conclusions

Despite extensive literature highlighting the astronomical prevalence of alarm fatigue in RNs, there was a lack of data related to implementing alarm management programs. Therefore, more research is needed to support the utilization of alarm management programs in ICUs and telemetry units to improve alarm fatigue among RNs.

Declaration of Conflicting Interests


The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: Hofstra

Northwell School of Nursing and Physician Studies paid for the open access for the article.

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