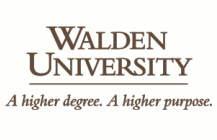

2019

Effectiveness of Physiological Alarm Management Strategies to Prevent Alarm Fatigue

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This is to certify that the doctoral study by

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has been found to be complete and satisfactory in all respects,
and that any and all revisions required by
the review committee have been made.

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2019

Abstract

Effectiveness of Physiological Alarm Management Strategies to Prevent Alarm Fatigue

by

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MSN, University of Pennsylvania, 1985

BS, University of Massachusetts Amherst, 1984

ASN, Laboure Junior College, 1979

Project Submitted in Partial Fulfillment

of the Requirements for the Degree of

Doctor of Nursing Practice

Walden University

August 2019

Abstract

There is limited clinical research on the effectiveness of alarm management strategies and nursing behaviors related to alarms in clinical settings. As many as 76% of physiological monitor alarms are overlooked as clinically insignificant by nursing staff. Excessive alarms may impact patient outcomes and cause cognitive overload for nurses that can result in medical errors and missed patient resuscitations. The purpose of this systematic review was to rate alarm management studies on level of evidence for interventions, nursing responses to alarms, and impact on alarm fatigue behavior. The nursing role effectiveness model guided this project. Twenty-seven studies were reviewed to analyze outcome effectiveness by addressing structure, process, and outcomes related to how the roles of the nurse affect nurse-sensitive patient outcomes. The Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) and the Cochrane guidelines guided study selection and analysis. A second reviewer collaborated on the search strategy and provided an independent review of the identified literature. The effectiveness of alarm management was difficult to determine because most studies were descriptive, cohort, or nonrandomized trials. Review findings did not support a relationship between the amount of alarms and increased alarm fatigue behaviors. Findings indicated that nurses' attitudes and alarm fatigue behaviors are present globally and have not significantly altered since reduction strategies were implemented. The findings may impact social change by decreasing nurses' stress levels related to cognitive workloads, improving patient outcomes, and supporting increased levels of nurses' workforce satisfaction.

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Dedication

A long time ago, soon after obtaining my RN, a family member once asked why I did not become a doctor instead of a nurse. My answer was I wanted to work with people to improve their health more holistically, and not just focus on one aspect and expect all to be well. My vision of nursing was always at the bedside, and then later impacting bedside care through evidence-based practices and staff instruction. It is ironic that I will now become a doctor. However, as a Doctor of Nursing practice, I remain involved with holistic care, patient populations, and influencing those who care for these populations. I get to have the best of all worlds!

This accomplishment could not have been possible without support. I offer this work in dedication to the never-ending patience of my husband, Keith, and understanding from my children, Cory, Chandra, Pam, Keith, Alex, Andrew, and Makayla. This accomplishment would never have happened without all your love, support, and encouragement.

Love Mom

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My deepest appreciation is given to my faculty instructors, Dr. Patrick Palmieri and Dr. Deborah Lewis, and my clinical mentor, Timothy Quigley. Additionally, special recognition and thanks must be given to Sharon, my longtime colleague, friend, and classmate from Penn for her invaluable help and courage to be my second reviewer! Each has been instrumental in offering ideas, opening doors that otherwise may not have been seen, and refocusing me during periods of derailment on this journey. Thank you for your ongoing dedication, visions, direction, and influence!

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Section 1: Nature of the Project

During the time period from 2005 to 2008, there were reported 566 patient deaths related to alarm fatigue (Emergency Care Research Institute [ECRI], 2014). From 2009 to 2012, the Joint Commission (2013) had 98 reported adverse events related to alarms, resulting in 80 fatalities and 13 permanent disabilities. In a 2011 report from one state agency, 31 out of 35 deaths related to physiological monitoring were due to human error (Guardia-LaBar, Scuth, Edworthy, Foss-Durant, & Burgoon, 2014). Alarm fatigue, human desensitization resulting from excessive alarms and sensory overloads (West, Abbott, & Probst, 2014), promotes the occurrence of operator errors that threaten the health and safety of patients (Solet & Barach, 2012). In response to this threat, the Joint Commission (2013) instituted a two-stage National Patient Safety Goal (NPSG) focused on improving alarm management strategies in acute care settings. However, developing effective evidence-based practices to combat alarm fatigue involves social changes in health care delivery systems along with skill adaptions.

Problem Statement

Hospitalized acute care patients are attached to and surrounded by a variety of devices eliciting different alarm sounds to notify nursing staff about physiological abnormalities or device malfunction. Between 76% and 99% of alarms are considered false or clinically insignificant by nurses, meaning the alarms do not require nursing intervention (Chambrin, 2001; Funk & Cvach, 2012; Graham & Cvach, 2010; Solet & Barach, 2012). This situation contributes to nursing alarm desensitization resulting in behaviors of delayed or no response (Funk & Cvach, 2012; Graham & Cvach, 2010;

Solet & Barach, 2012). Nurses are known to deactivate alarms to prevent what is perceived as nuisance or excessive false positive alarms. There has occurred significant reduction in alarm occurrence rates after implementing process improvement interventions focused on proper patient selection, electrode management, expanded but customized monitor alarm parameters, elimination of audible nonactionable alarms, and initiation of required response policies for actionable alarms (Cvach, 2012; Cvach, Biggs, Rothwell, & Charles-Hudson, 2013; Whalen et al., 2014). However, clinical alarms continue to be ignored (Gazarian, 2014; Morano, 2014). The true effectiveness of these interventions in reducing alarms and alarm fatigue is unknown.

There is sparse research about nursing behavior related to alarm fatigue (Gazarian, 2014; Gorges, Markewitz, & Westenskow, 2009; West et al., 2014). Much of the published literature on physiological alarm management or alarm fatigue includes overview summaries of research and/or performance improvement project reports (Cvach, Currie, Sapirstein, Doyle, & Pronovost, 2013; Funk & Cvach, 2012; Graham & Cvach, 2010; Guardia-LaBar et al., 2014; Horkan, 2014; Hyman, 2012; Morano, 2014; Pelletier, 2013; Purbaugh, 2013; Sendelbach & Funk, 2013; Solet & Barach, 2012; Stafford, Haverland, & Bridges, 2014; Tanner, 2013; Welch, 2009). Less than a handful of review articles have been published. Their focus has been on nursing perspectives, alarm effects on personnel and patients, and alarm management strategies, but the studies have not addressed the effectiveness of the implemented practices (Cvach, 2012; Konkani, Oakley, & Bauld, 2012; National Association of Clinical Nurse Specialists, 2013; Welsh, 2011). Inconsistent conclusions and knowledge gaps remain regarding

nurses' perceived barriers in improving alarm management, whether these barriers are consistent across nursing units (Cvach, 2012), what effect alarms have on nurses' cognitive work load (Christensen, Dodds, Sauer, & Watts, 2014), and what are the most effective alarm management strategies to increase nursing awareness and responses to alarms (Chambrin, 2001; Cvach, 2012; Gazarian, 2014; Graham & Cvach, 2010; Guardia-LaBar et al., 2014; Peterson, 2013). At the time of this study, there were no nursing related systematic reviews or meta-analyses that provide information on the effectiveness of implemented alarm management strategies.

Purpose Statement

There is limited clinical research on the effectiveness of alarm management strategies and nursing behavior related to alarms (Bonafide et al., 2017; Gazarian, 2014; Gorges et al., 2009; West et al., 2014). In a preliminary literature search of databases, I found 187 published articles from 2000 to May 2018 related to nursing alarm management. Of these, there were no meta-analyses or systematic reviews on alarm management or alarm fatigue. After general overview articles, editorials, and poster abstracts were excluded, the remaining articles were research studies or performance improvement projects focused on data collection of alarm numbers and types, interventions to decrease alarms, and studies addressing nurses' attitudes toward alarms, nurse responses to alarms, or factors impacting alarm fatigue. Five articles were research studies identifying numbers and types of audible alarms, but none addressed measures that impact nursing actions with alarms. Two articles were literature reviews of articles published on alarm fatigue (Cvach, 2012; National Association of Clinical Nurse

Specialists, 2014). Other reviews addressed monitor alarm characteristics (Paine et al., 2016), medical devices and alarm management from a biomedical engineer perspective (Konkani et al., 2012), effectiveness of nursing education and alarm management (Yue, Plummer, & Cross, 2016), and measurement of alarm accuracy (Ruppel, Funk, & Whittemore, 2018). Twelve articles were performance improvement projects or research studies on nursing interventions to decrease numbers of alarms. These studies involved primarily small samples and were conducted in single telemetry or intensive care units (ICU). Findings regarding nurses' attitudes related to alarms and alarm fatigue were addressed in nine studies. Several of these were in a longitudinal study repeated every 5 years (Korniewicz, Clark, & David, 2008; Funk, Clark, Bauld, Ott, & Coss, 2014; Ruppel et al., 2018). Research involving nurse response times to alarms was found in three studies (Bonafide et al., 2015; Bonafide et al., 2017; Gazarian, Carrier, Cohen, Schram, & Shiromani, 2014). Only two studies focused on the factors impacting measuring nursing alarm fatigue (Ashrafi, Mehri, & Nehrir, 2017; Deb & Claudio, 2015).

Due to Joint Commission regulations, hospitals have been required since 2013 to focus time, personnel, and expense toward developing alarm management programs that include multidisciplinary involvement, policy development, staff education, alarm audits, and purchase of expensive updated equipment and software packages. Clinical practice changes and long-term financial decisions have been required to be made on literature that, when reviewed, provided minimal evidence supporting practice changes. As of May 2018, there were no updated national statistics published regarding the outcomes of the alarm management programs. There was a knowledge gap regarding what alarm

management practices changes are statistically effective, what are contributing factors to alarm fatigue, and what data should be collected and analyzed to support practice improvements related to alarm management.

Nature of the Doctoral Project

A systematic review is a methodically structured, comprehensive synthesis of research used to determine the best evidence available addressing a specific nursing practice question. These reviews address the way studies are found, how relevant studies are analyzed in relation to the review question, and how the results of the studies provide an overall measurement of effectiveness (Higgins & Green, 2011). Due to the rigor of their methodology, systematic reviews are identified as one of the highest reference standards for synthesizing health care evidence, developing clinical practice guidelines, and making clinical decisions (Centre for Cognitive Aging and Cognitive Epidemiology [CCACE], 2013).

At the time of this study, there was no equivalent work addressing the effectiveness of practice interventions to decrease the phenomenon of nursing alarm fatigue. This project provided evidence-based knowledge to develop practice guidelines on alarm management that may be adopted or adapted for use across multiple nursing departments and internationally. Findings may be used to assist nurses and administrators in making quality improvement and cost-effective decisions regarding delivery of safe patient care.

Significance

Clinicians of multiple disciplines and policymakers face questions regarding how to determine what is effective, who should be consulted to provide such knowledge, and how to sort through findings and claims of practice approaches (Craig & Smyth, 2012). Evidence-based practice (EBP), as defined by Institute of Medicine (2001), is "the integration of best research evidence with clinical expertise and patient values" (p. 4). Best supported professional knowledge is research conducted methodologically that meets higher levels of evidence from expert opinions, case study reports, and controlled case studies through random controlled trials, systematic reviews, and meta-analyses (Craig & Smyth, 2012; Grove, Burns, & Gray, 2013b) as shown in Appendix E. At the time of this study, a review of evidence for EBP related to alarm management techniques that decrease nursing alarm fatigue was not available. Therefore, I concluded that health care providers did not have valid materials to accurately determine effective practice or develop policies that are identified as a national priority for patient safety.

The findings offered by a systematic review on alarm management may be incorporated into physiological alarm management programs at acute and subacute care facilities. Because the phenomenon of alarm fatigue is not unique to the United States (Bridi, Louro, & Lyra da Silva, 2014; Cho, Kim, Lee, & Cho, 2016; Christensen et al., 2014), findings may also be applicable to alarm management programs internationally. The findings have the potential to effect social change in alarm management, nursing workflow, and health care environmental design. The findings may also be used to identify impact on patient outcomes by independent nurse measures with alarm

management. Findings may promote further investigation on the impact of human factors involving nurse workload, alarm recognition, and responses with alarm fatigue behavior.

Summary

Patient safety is jeopardized due to nursing behaviors of missing, ignoring, or delaying response to alarms (ECRI, 2014; Joint Commission, 2013). Studies indicated that 76-99% of alarms are false or identified as clinically insignificant, nonactionable alarms for nurses (Cvach, 2012). Interventions based on limited or low levels of evidence have been implemented that have reduced 46-68% of the these alarms (Cvach et al., 2013; Whalen et al., 2013). However, the ratio of false to true alarms remains high, and nurses continue to exhibit behaviors of alarm fatigue (Baillargeon, 2013; Bonafide et al., 2015; Konkani et al., 2012).

Due to regulatory requirements from the Joint Commission, clinical and administrative decisions that have fiscal and nursing workflow impact are being made based on inconsistent conclusions and knowledge gaps regarding effectiveness of nurses' alarm management strategies (Gazarian, 2014; Gross, Dahl, & Nielsen, 2011; Guardia-LaBar et al., 2014). This systematic review was conducted to analyze and rate the level of evidence for the research on physiological alarm management strategies, and to identify gaps in knowledge to utilize in designing more robust research on alarm management, nurses' physical and cognitive responses to alarms, and alarm fatigue behavior.

Section 2: Background and Context

Concepts, Models, and Theories

Establishment of evidence-based nursing practices and measurement of the effectiveness of nursing care promotes nursing knowledge and advances the nursing profession (Grove et al., 2013b). Determining evidence-based practice involves enhancing delivery of care to improve patient outcomes and decrease incidence of complications. Quality improvement in nursing care can be traced to Florence Nightingale and is supported by the Institute of Medicine reports from 1999 and 2001 (Institute of Medicine, 2001). Nursing behaviors regarding alarm management directly impact patient outcomes (Cvach, 2012; ERCI, 2014; Joint Commission, 2013).

The nursing role effectiveness model (NREM) presents a framework that can be used when determining effectiveness of alarm management from the role of the nurse (Irvine Doran, Sidani, Keatings, & Doidge, 2002). This theory can guide examination of the contribution of nursing in a health care system (Irvine Doran et al., 2002) and may be used to devise strategies for quality improvement. NREM concepts are based on a structure-process-outcome model of quality care. The structure consists of the nurse, patient, and practice setting characteristics that influence health care processes and patient outcomes (see Appendix B). The nurse characteristics include work experience, education, and psychological factors. The patient characteristics include decision-making skills regarding care and capacity for good outcomes (e.g., age, education, health status, and health expectations). The practice setting factors are those that influence the nurse's role and performance, such as staffing, leadership, autonomy, and role clarity. The

process is separated into independent nurse's role, dependent nurse's role, and interdependent nurse's role. The independent role activities are those that are accountable only to the nurse and nursing process. The dependent role activities are those the nurse implements from medical orders and those related to clinical judgements. The interdependent role refers to the functions among the health care team, such as communications, care coordination, and care continuity. Outcomes are measured by patient's health status, patient's perceived health benefits from the nurse, and direct and indirect costs associated with nursing care (Irvine Doran et al., 2002).

The effectiveness of nursing alarm management strategies may be analyzed using the concepts of NREM. As listed in Appendix B, the concept of structure would include nurse physiological alarm management strategies, the monitored patient characteristics, and the influencing factors from the practice setting that impact alarm management and contribute to nursing alarm fatigue. The process would include independent, interdependent, and dependent nurse roles related to physiological alarms. Patient outcomes would be measured by decreased false and nuisance alarms, decreased noise, decreased nurse and patient interruptions related to alarms, and increased patient satisfaction without adverse clinical alarm related events. The NREM as a quality improvement model provided a framework for determining the effectiveness of studies in the systematic review even if the level of evidence was based on performance improvement projects, case reports, observational studies, and noncontrolled trials.

Relevance to Nursing Practice

Alarm fatigue has become a topic of interest within the past 10 years as media focus has pushed sentinel event cases related to alarm management into the public eye. ECRI (2014) included alarm hazards as its top hazard for 4 years, and improper customization of physiological alarms have remained in the top 10 as of 2019 (ECRI, 2018). In addition, the Joint Commission (2013) introduced alarm management as a 2014 National Patient Safety Goal. Researchers have made multiple attempts to define or describe alarm fatigue. West et al. (2014) used Walker and Avant's framework to perform a concept analysis of alarm fatigue. They provided detailed background and term definitions and offered defining attributes and consequences, but did not identify contributing factors for the onset of alarm fatigue (West et al., 2014). Further exploration is needed to understand the correlation of excessive and repeated alarms to decreased nursing motivation and diminished capacity for physical and mental work. Investigation into factors that impact nursing situational awareness and cognitive stacking may provide information that can be transferred to interventions to prevent conditions leading to alarm fatigue.

Alarm fatigue is a human response to machines and a result of impaired situational awareness from cognitive overload and missed perceptions (Guardia-LaBar et al., 2014). The consequence is human error, and the ramifications have been patient harm. Beyond strategies to reduce alarms and improve their recognition, there is a gap in research regarding patient outcomes related to improving the human response through interventions to reduce alarm fatigue. Baillargeon (2013) conducted a controlled

observational study to explore whether medical-surgical nurses on a telemetry unit were at risk for and experienced alarm fatigue. Methodology consisted of 1-hour observational periods during all shifts, and data collection of monitor strips, level type of alarms, false or true alarms, nurse's response times, and reoccurring alarms (Baillargeon, 2013). Findings indicated that an alarm occurred about every 2 minutes, 52% of the alarms were false or nuisance, and over 70% of the alarms were due to clinically insignificant arrythmias (Baillargeon, 2013). Baillargeon concluded that nurses were definitely at risk for alarm fatigue. The presence of alarm fatigue seemed evident in the delayed response of a mean 7.01 minutes for leads off (Baillargeon, 2013). Limitations included tool validity, sample size, and observation involving only two telemetry units at one hospital (Baillargeon, 2013). Although the behaviors noted were also reported by other researchers observing clinician responses, there was no attempt to investigate nurse work or critical thinking processes during the observational periods, so no assumptions can be made regarding the relationships between alarms and cognitive stacking or workload. However, Baillargeon suggested there needs to be heightened awareness of staff risk for and exhibiting of alarm fatigue behaviors.

Clinical implications of alarm fatigue are directed at staff behaviors and effective methods to prevent the behaviors, the environmental factors that contribute to nurse responses, ensuring patient safety, and technology design and functions. Strategies for prevention and improvement need to involve clinician workloads, equipment complexity, lack of standardization of alarm signals, and liability related to alarms (Morano, 2014). Researchers have focused on types and occurrences of alarms, interventions to reduce

false and nonactionable alarms, and technology to improve detection of changes in patient conditions (Cvach, Currie et al., 2013; Whalen et al., 2014; Solet & Barach, 2012). Though legal and ethical limitations impact potential alarm management research, further evaluation should focus on higher levels of evidence in nonrandom and random selection controlled trials (Grove, Burns, & Gray, 2013a).

Local Background and Context

Nurses use monitoring of patients with the intention of detecting early or sudden signs of changes in physiological conditions. Monitoring of patients of all ages is now conducted across many units within a hospital, including emergency departments, outpatient units, perioperative units, acute care medical-surgical units, and intensive care units. Technology and notification systems vary according to type of unit and patient's age, impacting nurses' critical thinking processes and workflow. The optimal interaction of nurse to machine is required to obtain quality care and maintain patient safety (Konkani et al., 2012). It is important to understand factors that influence the ability of the nurse to interact with monitoring devices to create an environment that promotes optimal patient healing and safety (Konkani et al., 2012).

To identify current knowledge regarding alarm management by nurses, I conducted a preliminary literature search using CINAHL, Medline, Cochrane Database, Pubmed, and Google Scholar. Search terms included *alarms*, *clinical alarms*, *alarm management*, *nursing alarm management*, *alarm fatigue*,and *nursing alarm fatigue* in titles and topics limited to English medical, nursing, and medical technology peer-reviewed journals. References lists from articles were manually reviewed for potential

pertinent additional sources. Also, online studies available from graduate nursing programs were considered.

From all articles reviewed, I found four themes: alarms and solutions to reduce, technology related to alarms, nurse perceptions and response to alarms, and implications for clinical practice. Overview articles addressed definitions, the significance of excessive sounds, the concept of alarm fatigue, and summaries of current reduction strategies. Performance improvement projects addressed methods trialed to reduce excessive alarms and case study evidence of potentially effective solutions to reduce alarms. Studies were primarily descriptive, often prospective in nature, of good to excellent quality but often having small samples and focusing on one type of care unit. Most were uncontrolled cross-sectional or longitudinal studies that had weaknesses of internal validity due to biases from self-selection or samples of convenience, and development of new tools without demonstration of validity and reliability.

Alarms and Solutions to Reduce

Addressing excessive alarms and resultant alarm fatigue is a challenge involving human factors interacting with devices, systems, and workload and workflow demands. False alarms are generated due to bad data. Nonactionable or not clinically significant alarms are intentional but serve to cause distractions and interruptions, and often are perceived as nuisance alarms (Welch, 2011). False and nuisance alarms constitute 76-98% of alarms (Chambrin, 2001; Cvach, 2012; Graham & Cvach, 2010). Noise has been a constant environmental element due to the variety of alarm-producing medical devices.

The offenders most often cited by nurses are cardiac monitors, IV pumps, oxygen saturation alarms, and ventilator alarms (Gross et al., 2011; Welch, 2011).

The number of recorded alarms per patient per day has ranged from 17.5 to 79.5 (Gross et al., 2011; Peterson, 2013; Welch, 2011). Seventy-four percent (n = 4278) of clinicians who responded to a nationwide online survey in 2011 agreed that nuisance alarms continued to occur frequently and disrupted patient care (Funk et al., 2014). Other studies localized to specific telemetry or intensive care units reflected similar findings of 74-81% of excessive alarms that impacted nurses and the safety of patients (ECRI, 2014; Christensen et al., 2014; Way, Beer, & Wilson, 2014).

Strategies to reduce the numbers have focused on patient preparation, equipment adjustments, and workflow management. Johns Hopkins began an initiative in 2006 to identify causes of nuisance alarms and incrementally implemented practice changes to reduce alarms (Cvach, Currie et al., 2013). Through a multidisciplinary collaborative program, an alarm inventory was collected and strategies such as daily electrode change, widening alarm parameters, and customizing alarms to individual patient patterns reduced cardiac monitoring alarms from 37% to 79% (Cvach, Biggs et al., 2013)). Types of alarms have been evaluated and alarm levels have been adjusted to reflect desired actionable levels (crisis, warning, or system warning), which produced a 43% cardiac monitor alarm reduction (Graham & Cvach, 2010). Whalen et al. (2013) implemented a similar improvement project that included daily electrode change and altered alarm setting default parameters and notifications. Performance measures evaluated included alarm types and numbers, incidence reports related to alarm management, code blues and

rapid response calls, nurses' perception of noise, and patient and staff satisfaction ratings (Whalen et al., 2014). No incidents related to alarms and no change of rapid response calls occurred during the trial, and code blues decreased 50% (Whalen et al., 2013). Pre- and post trial data demonstrated an 89% reduction in total audible alarms on one 24-bed unit; a 93% reduction in brady, tachy, and heart rate limit alarms; a 91% decrease in arrythmia alarms; and a 36% decrease in system status alarms (Whalen et al., 2014). The results substantiated work by Cvach, Biggs et al. (2013). Analysis by Peterson (2013) related to adjusting parameters alarms indicated lowering heart rate parameters to 40 had a 93% reduction in alarms, and increasing heart rate parameters to 140 had a 78% actionable alarm reduction.

These studies indicated that implementation of daily electrode changing protocols, alarm parameter adjustments, alarm notification adjustments, and/or changing audible alarms to notify only actionable alarms reflected outcomes from individual units in academic teaching hospitals. Specific implementation interventions varied among sites and studies and each improvement trial included specialized staff education. Results were replicated in three alarm-reduction studies reviewed by Cvach (2012) and the National Association of Clinical Nurse Specialists (NACNS, 2014), but the studies were performance improvement or nonrandomized control studies and would be classified as Level of Evidence IV or IIIB.

A final strategy related to overmonitoring or unnecessary arrythmia monitoring studied by Funk and Seder (as cited in NACNS, 2014) offered Level IIIB evidence as a way to decrease alarms without increasing patient risk of experiencing a missed adverse

cardiac arrythmia. In a multisite, random selection, prospective observational study of 17 cardiac units at hospitals in the United States, Canada, and Hong Kong that included 1816 monitored patients, 90% had indications for monitoring per the American Heart Association guidelines, and 84% had no indications (Atzema, Schull, Borgundvaag, Slaughter, & Lee, 2006) . Of those with indications for ST segment monitoring, only 34% were monitored, and of those with corrected QT segment (QTc) monitoring, only 29% had documented QTc in the record during the previous 24 hours (Atzema et al., 2006). Findings indicated that patients were overmonitored, early detection of patient conditions was not being enhanced, and there would have been fewer alarms if criteria for monitoring was followed more stringently (Atzema et al., 2006)..

Data indicating decreased number of alarms supports controlling the amount of false and nuisance alarms by managing electrodes, limiting the types of audible actionable alarms, adjusting the alarm limit parameters, educating staff on the optimal use of monitor capabilities, and selecting the patients for monitoring based on valid criteria (Cvach, Biggs et al., 2013; Cvach, 2012; Gorges et al., 2009; Graham & Cvach, 2010; Healthcare Technology Safety Innovations, 2012; Welch, 2011; Whalen et al., 2013). However, the level of evidence has been primarily Level III or below from studies providing expert opinion, case studies, performance improvement, and nonrandom controlled studies with selection biases (see Appendix F). There has been difficulty discerning false from true alarms when using data mining software that provides lists of types, times, and durations of alarms, but can not elicit whether the alarm was accurately true (Bridi et al., 2014; Cvach, 2012; Cvach, Currie et al., 2013; Peterson, 2013, Ryan,

2014). Initial reductions in alarms have been dramatic, but do vary based on current practices and specifications of equipment models (Cvach, 2012; NACNS, 2014). Studies using methodology of higher levels of evidence are needed on alarm management strategies that will decrease the remaining false alarms. Higher levels of evidence studies are also needed on measures of human-alarm interface, nurses' alarm response times and nurses' cognitive processes employed when managing alarms.

Technology Related to Alarms

Literature reviews and studies about technology related to alarms primarily addressed audibility, types of sounds best recognized by clinicians, and equipment design for most accurate analysis of monitored data. Chambrin (2001) stated that alarms in most monitoring systems were perceived as unhelpful because of the high incidence of false alarms and clinically insignificant alarms. Based on the Funk et al. (2014) study, the statement remains true more than ten years later. Common problems identified were the algorithms used to determine true alarms, the audibility of alarms being too loud and not consistently perceived, and the lack of integration with other devices (Cvach , 2012; Dyell, 2011; Konkani et al., 2012; Logan, 2011; Solet & Barach, 2012).

Monitor alarms must compete with a multitude of other alarms and environmental noises on patient care units (Bridi et al., 2014; Welch, 2009). Nurses must be able to discern the monitor alarm, identify its meaning and source, and respond appropriately in a timely manner based on the real or perceived urgency of the situation (Cvach, 2012). Studies found alarms were often double the maximum decibels recommended by World Health Organization (Solet & Barach, 2012). These noises produced stress for the

caregivers that may manifest in physical symptoms as headache and fatigue, and in emotional symptoms of impaired thought processes and burnout. Excessive noise has also been linked to impaired patient healing (Welch, 2009).

Humans can discriminate only five to seven different categorical sounds. As a result, there has been ongoing controversy regarding optimal alarms sounds (Cvach, 2012; Konkani et. al., 2012). First, the alarm must be audible for clinicians to hear. Hospitals struggle with balancing patient National Database of Nursing Quality Indicator (NDNQI) satisfaction to 'environment was quiet during night hours' and ensuring that staff can detect and locate pertinent alarms which may not be audible behind closed doors (Cvach et al., 2013; Konkani et al., 2012). Perception to sounds has been shown to be influenced by the duration and the urgency a person connects with the sound (Bliss, Fallon, & Nica, 2007). Nurses adjust their responses, not just to a sound, but to their perceived interpretation of its meaning, their workload, patient condition, and task complexities (Bliss et al., 2007; Gorges et al., 2009; Gross et al., 2011). Recommendations have been for medical devices to have auditory and visual features that notify of its occurrence, and to have distinct sound features. A study by Lacherez, (reported by Konkani et al., 2012) examined how accurately and quickly nurses could identify melodic alarms and determine priority. Only two of fourteen nurses identified all alarms correctly. This study and similar ones suggest melodic sounds have not proven easy to learn or were not attached to an urgent response by clinicians despite International Organization for Standardization guidelines to this effect (Dyell, 2011; Konkani et al.,

2012). Further research is required to determine how alarm sounds are perceived and responded to by nurses in relation to situational awareness, workloads and workflows.

Other technology reviews discuss pros and cons of device design, and mono vs multi source algorithms to trigger alarms (Hravnak et al., 2013). Also discussed in the literature are types of mobile notification systems that connect with nurses via phone or portable computer notepad devices (Dyell, 2011; Healthcare Technology Safety Innovations, 2012). However, no notification system has eliminated the source of false and nuisance alarms, instead the alarm messages have been forwarded to the nurse; therefore, increasing demands for nurse intervention, or continuing to add interruptions that may not require immediate attention in the workflow (Dyell, 2012; Konkani et al., 2012). In summary, research on smart alarms and monitoring involving multiple parameters before triggering alarm signals to clinicians remains inconclusive.

Nurses' Response to Alarms

Only four studies were found in the literature search examining actual nurse responses to alarms. The graduate student research by Baillargeon (2013) was discussed previously buts offered data that replicated findings on alarm frequency and validity found in other studies reported by Cvach (2012), NACNS (2014) and Whalen et al. (2014). The nurse response data provided limited insight into delays without recognition of environmental influences or nursing rationales for their actions. Bliss et al. (2007) had investigated the role of alarm duration as a cue for alarm validity in a lab environment with non-clinical university students. The study was a random controlled experiment with independent variables of short or long duration signals, and the dependent variable being

the participant response frequency and reaction time. Each study group was assigned and informed regarding the percentage of true alarms that would occur (60 % or 80%). Bliss et al.'s findings suggested that long duration of signals were perceived as more representative of true alarms. However, responses did demonstrate a relationship between expected frequency of true alarms and the frequency and reaction time of participants. In other words, if the participant expected 60% true alarms, then there was approxiamately a 60% frequency in response, with longer duration signals being considered more frequently as a cue for a true alarm (Bliss et al., 2007). This study results have been cited in multiple literature references as an explanation for frequency of nursing response to alarms. It also has been used as a basis for the recommendation to make all audible alarms actionable, so nurses will not have to critically decide whether to respond, but will know a response is required for all alarms (Cvach, 2012; Whalen et al., 2014).

The response of nursing staff with alarms was studied in a medical intensive care unit for the purpose of identifying a means to reduce the number of alarms (Gorges et al., 2009). In this study, all alarms and all clinician tasks were documented for one randomly selected patient bed over a three hour time. Alarms were classified as effective, not effective or ignored based on the clinician response. Of 1271 alarms, Gorges et al. found only 23% of alarms were effective, and 41% were actively ignored or silenced. Researchers stated that since the mean duration of alarms was 17 seconds, two-thirds of the ignored and ineffective alarms could have been avoided if there had been a 19 second delay to alarm onset. This study was one of a few studies that collected data on multiple types of alarms; however, the criteria to determine false or nonactionable has not been the

same as other studies therefore limiting comparison of data. As with most of the other study methodologies, this one was conducted in just one unit though Gorges et al. did include 200 hours of data collection on actions of twenty two staff participants. Gorges et al. offered no discussion addressing data tool validity or reliability. Also, since multiple disciplines were observed providing care and the purpose of the study was to identify an alarm reduction strategy, no specific discussion of nursing responses or rationales for behavior were included. The researchers did report the time impact on patient care related to alarm mangement which may be used to make assumptions related to interruptions in workflow (Gorges et al., 2009).

In an aim to describe the work a registered nurse performs in managing a telemetry patient, nine nurses participated in a structured observation study (Gazarian, 2014). Each nurse's assigned patients had alarm data collected with a scaled rating of 0 to 5 reflecting what response occurred for each alarm. The researcher trialed the tool prior to use in the study unit to establish tool validity and reliability. Results reported frequency and types of alarms, and the extent nursing provided interventions to alarms (Gazarian, 2014). Gazarian also discussed what influence routine nursing practices had regarding cardiac monitoring in relation to the occurrence of system alarms, the observed difficulties of managing the alarm system and the competing demands of managing multiple alarms and prioritizing tasks. The researcher did note that the cognitive work of the nurse was not captured in the data for this study, so there remains a knowledge deficit in understanding why certain actions were or were not performed in relation to alarms (Gazarian, 2014).

Summary

Of the literature reviewed, I found a mixed consensus of case study, observational and controlled study data regarding effective interventions that reduce cardiac monitor and oxygen saturation alarms. Studies consist of performance improvement project data, observational studies, prospective studies and a few controlled studies. There have been a variety of interventions explored with inconsistencies in methodology, samples and selection. Most studies have population biases, and, likely, equipment biases. Little information is included related to possible confounding factors such as impact from education required with performance improvement implementations, or sustainability of results that may define actual effectiveness of current alarm management strategies. Understanding of the environmental, cultural, social and nursing workload factors that contribute to alarm fatigue behaviors is important for planning patient care, ensuring patient safety and designing strategies to optimize nurse productivity and effectiveness (Gazarian et al., 2014). There remains a need, as provided with a systematic review and meta-analysis, for higher level synthesis of published and peer reviewed studies to clarify the impact of alarms on patients, clinicians, patient outcomes, and on effective nursing measures to prevent alarm fatigue.

Role of the DNP Student

My role as the DNP student for this systematic review was to perform an independent literature search, coordinate the findings with those of the second reviewer, provide analysis of results, and make recommendations for future research and practice.

Role of the Project Team

In order to support reliability of the systematic review results, a second reviewer was used for the DNP Project. The second reviewer performed an independent literature search using the same key words and protocol as the DNP Student.

Section 3: Collection and Analysis of Evidence

A systematic review is a methodically structured, comprehensive synthesis of research to determine the best evidence available to address a specific nursing practice question. Researchers describe the way studies are found, how relevant studies are in relation to the review question, and how the results of the studies provide an overall measurement of effectiveness (Higgins & Green, 2011). Due to the rigor of their methodology, systematic reviews are identified as one of the highest reference standards for synthesizing health care evidence, developing clinical practice guidelines, and making clinical decisions (CCACE, 2013).

At the time of this study, there was no equivalent work addressing the effectiveness of practice interventions to decrease nursing alarm fatigue. This project provided evidence-based knowledge to develop practice guidelines on alarm management that may be adopted or adapted for use across multiple nursing departments and internationally. Findings may assist nurses and administrators in making quality improvement and cost-effective decisions regarding delivery of safe patient care.

Practice-Focused Question

Conducting a systematic review to evaluate research on effectiveness of nursing practices requires delineation of the focus of evidence-based practice. Identification is needed for the criteria employed in the literature search as well as the search process to be used (Grove et al., 2013b). The PICOT question format (patient/population, intervention, comparison, outcome, and time) offers a structure to produce an answerable clinical question regarding the EBP focus (Fineout-Overholt & Johnson, 2005).

The purpose of this project was to create a systematic review to examine the current status of evidence-based practice related to nursing alarm management. Using the PICOT format, the practice-focused question was:

P - For the population of research studies focused on acute and critical care physiological alarm occurrences and management strategies published between 2000 and 2018,

I - that were critically analyzed on quality, quantity, and strength of evidence

C - to determine their level of evidence supporting effective alarm management strategies that positively impacted nurses' responses to alarms and decreased alarm fatigue behaviors, thereby improving nursing-sensitive patient outcomes,

O - (a) what was the rating of the research studies according to level of evidence of effectiveness of alarm management strategies, nursing responses to alarm, and impact in decreasing alarm fatigue behavior, and

(b) what were the gaps in current knowledge that can be used to design more robust research on alarm management, nurses' physical and cognitive responses to alarms, and alarm fatigue behavior

T - from the research studies published between 2000 and 2018?

For the systematic review, I collected the literature using the search process recommended for development of Cochrane Systematic Reviews (see Appendix C; Higgins & Green, 2011), and synthesized the materials following guidelines from the

Preferred Reporting Items for Systematic reviews and Meta-Analyses for Protocols 2015 (PRISMA-P; see Appendix D; Moher et al., 2015). The systematic review consisted of time required for data collection, analysis, and synthesis. An expedited or exempt status was obtained from the Walden University institutional review board (approval number 02-05-17-0443650) because this project involved collection of existing study data that were publicly available or the data were recorded so subjects could not be identified (Grove et al., 2013a).

Sources of Evidence

A comprehensive literature search was conducted using guidelines from the Cochrane Handbook (Higgins & Green, 2011). Key search words were *alarms*, *clinical alarms*, *alarm management*, *nursing alarm management*, *alarm fatigue*, *nursing alarm fatigue*, *physiological alarms*, *false alarms*, and *nuisance alarms*. I used the Cochrane Database of Systematic Reviews, DARE, CCTR, PubMed, Joanna Briggs Institute Systematic Database, and Ovid Medline. Ovid Medline included access to CINAHL, Ovid Nursing Database, Evidence Based Medicine (EBM) Reviews, and Allied and Complementary Medicine (AMED). I also reviewed reference lists from literature review articles and from published nursing dissertation studies to find additional research studies (see Appendix A). Publication dates for included articles were 2000 to 2018. Additional inclusion criteria were peer-reviewed, published studies or performance improvement studies that followed a research format. The research needed to be conducted in a clinical setting using physiological monitoring alarms, be clinically related to nursing care, and involve physiological alarms or nurses' management of physiological alarms.

The selected articles were examined according to the PRISMA-P 2015 checklist that had three main sections (administrative information, introduction, and methods) and 26 items to promote consistent data retrieval, accountability, research integrity, and transparency of the final review (as listed in Appendix D; Moher et al., 2015). To establish reproducibility, reliability, and validity of content, a DNP-prepared nurse was a second reviewer who completed an independent review by following my established protocol. Results of both reviewers were compared, discrepancies were discerned and discussed, and resolution was determined.

Analysis and Synthesis

The recommendations for alarm management strategies were based on limited research and performance improvement studies. There was continued presence of alarm fatigue behavior by nurses after implementation of alarm fatigue prevention strategies. The NREM provided a framework to determine how effective currently implemented nursing alarm management strategies were in preventing alarm fatigue.

Definition of Terms

To analyze the effectiveness of alarm management strategies to prevent nursing alarm fatigue, it was necessary to clarify the definition of terms. Part of the difficulty in measuring alarm fatigue was related to differences in definitions of the term.

The phenomenon of alarm fatigue was derived from individual definitions for *alarm* and *fatigue*. Alarm refers to a sudden anxiety or fear of something very bad happening, a warning signal that gets immediate attention, or a device that produces a signal or alert (Cambridge University Press, 2015a; Meriam-Webster, Inc., 2015a). For a

medical perspective, the Joint Commission (as cited in Baillargeon, 2013) defined a clinical alarm as “any alarm that is intended to protect the individual receiving care or alert the staff that the individual is at an increased risk and needs immediate assistance” (p. 1).

Fatigue is defined as a state or condition of being very tired (Cambridge University Press, 2015b) or the tendency to break after being bent or moved many times (Meriam-Webster, Inc., 2015b). Stedman’s Online Medical Dictionary (as cited in West et al., 2014) defined fatigue as “the state following a period of mental or bodily activity, characterized by a lessened capacity or motivation for work and reduced efficiency of accomplishment”(para. 11).

Alarm fatigue has been described by the Emergency Care Research Institute (ECRI, 2014) as a condition that occurs when caregivers become overwhelmed trying to respond to alarms, so they become desensitized leading to missed alarms or delayed responses that put patients at risk. Tanner (2013) explained that alarm fatigue results from excessive auditory exposure causing a desensitized response to alarm sounds and a slower response time of the clinician. Hannibal (2011) stated that alarm fatigue is a type of human error that occurs when a practitioner is desensitized to the alarm alerts. The Joint Commission (2013) described clinician desensitization as a result of constant beeping creating an overabundance of information transmitted by medical devices. The result of this overwhelming sound exposure is failure to recognize and respond to true alarms that require clinical intervention (Welch, 2009). For the purpose of this study, alarm fatigue referred to the lack of response due to excessive numbers of alarms

resulting in sensory overload and desensitization (Cvach et al., 2013). *Management* is the act or skill of controlling and making decisions about something (Meriam-Webster, Inc., 2016). Alarm management is controlling and making clinical decisions regarding the use of physiological alarms in the acute care clinical setting.

Summary

Given the considerable amount of nursing-related information available in peer-reviewed publications (printed and online), unpublished works including capstone projects from masters and doctoral nursing programs, and conference presentations, it is difficult to review all of the work within a specific topic and ensure clinical practice remains up to date based on the best evidence. Patient safety and positive patient outcomes are related to effective nursing care (Irvine Doran et al., 2002). The systematic review can best address the difficulty regarding specific research questions, especially after multiple studies have been published and there are discrepancies with results (CCACE, 2013).

There have been multiple studies and performance improvement projects with data analysis focused on nursing alarm management. However, findings were limited, studies were inconsistent, and low levels of evidence were provided. Due to regulatory pressure, hospital-wide decisions are required to be based on the results from this research. As of the time of this study, no systematic review had been published regarding effectiveness of nursing physiological alarm management strategies and prevention of alarm fatigue behavior. This systematic review of current available studies was conducted

to ensure safe patient practices, support EBP at bedside, and provide direction for administrative decisions and future research.

Section 4: Findings and Recommendations

Clinical physiological monitoring of patients of all ages is now conducted across many units within a hospital, including emergency departments, outpatient units, perioperative units, acute care medical-surgical units, and intensive care units, with the intention of detecting early or sudden signs of changes in physiological conditions. Between 76% and 99% of alarms are considered false or clinically insignificant by nurses and require no action by the nurse (Cvach, 2012). The term alarm fatigue is used to describe nurses' behaviors of deactivating alarms and delaying or not responding to patient alarms when perceived nuisance or excessive false positive alarms occur (Chambrin, 2001; Funk & Cvach, 2012; Graham & Cvach, 2010; Solet & Barach, 2012). There is limited clinical research on the effectiveness of alarm management strategies and nursing behavior related to alarms. This systematic review of the literature was performed using the nursing role effectiveness model (NREM) to determine what nursing-related alarm management interventions are effective in decreasing alarm fatigue behaviors. Additionally, the purpose of this review was to identify knowledge gaps related to alarm management strategies and nursing alarm fatigue to direct more robust future research.

Findings and Implications

A systematic review was conducted by electronic search of publications dated from January 2000 to May 2018. Key search terms were *alarms*, *clinical alarms*, *alarm management*, *nursing alarm management*, *alarm fatigue*, *nursing alarm fatigue*, *physiological alarms*, *false alarms*, and *nuisance alarms*. I used the Cochrane Database

of Systematic Reviews, Database of Abstract Reviews of Effectiveness (DARE), Cochrane Central Register of Controlled Trials (CCTR), PubMed, Joanna Briggs Institute Systematic Database, and Ovid Medline. Ovid Medline included access to CINAHL, Ovid Nursing Database, Evidence Based Medicine (EBM) Reviews, and Allied and Complementary Medicine (AMED). I also used articles found from manual review of reference lists from selected publications, available graduate research studies, and schools of nursing postings to find additional research studies (see Appendix B).

The initial search yielded 174 items. From this list, duplicate entries and sources not related to alarm fatigue and nursing interventions, physiological alarm management, or physiological alarm monitors were excluded. Inclusion criteria included research or performance improvement studies with quantitative or qualitative analysis addressing effectiveness of nursing interventions to improve control of audible alarms, identification and/or measurement of nurses' responses to electrocardiographic (ECG) physiological alarms, nurses' perception of alarms, or factors impacting alarm fatigue behaviors. Abstracts of 115 articles were reviewed. Editorials, poster abstracts, and general overview articles were excluded, leaving 48 articles for full text review. From manual searching of reference lists and from searching graduate study publications from university sites as digital commons, 13 additional articles were included to review. Final selection excluded studies that provided only data on amounts and types of alarms not involving ECG alarms, or no statistical analysis related to nursing management of the physiological alarm or alarm fatigue. The final selection consisted of 27 studies focused on three categories: nursing interventions to reduce alarms, nurses' perspectives to

alarms, and nurses' responses to alarms and the impact of alarm fatigue (see Appendix A). Due to the limited research studies available, performance improvement projects that included statistical analysis were included in the final selection. Because the Joint Commission NPSG on alarm management was implemented in January 2014, selected articles were grouped according to studies published before and after 2014 to reflect possible changes in practice that may have occurred related to the NPSG.

The selected studies were analyzed according to the seven levels of evidence ranking from expert opinion to systematic reviews and meta-analyses (Fineout-Overholt, Melnyk, Stillwell, & Williamson, 2010; see Appendix E). The studies reviewed were synthesized based on the components of NREM: structure, process, and outcome. The structure component addressed factors influencing the nurse, the patient, and the practice environment. The process component consisted of independent, dependent, and interdependent functions of the nurse's roles. The outcome component included patient-centered outcomes related to perceived satisfaction, decreased noise and interruptions, overall wellness, and patient safety as indicated by absence of adverse clinical events related to alarms (see Appendix B).

Categories of Studies

Alarm Interventions

For the period of 2006 to 2012, performance improvement and research studies focused on quantity and types of alarms in ICU and telemetry settings. Upon analysis of data in comparison to nurse interpretation of alarms, the extent of nuisance, false, and nonactionable alarms was recognized. Based on individual institutional data of types of

alarms, assumptions were made regarding managing the alarms via technology adjustments, then with health care team interventions and policy implementations. The inclusion criteria for the 27 selected studies included addressing nursing involvement in reducing alarms and/or nurses' perceptions of the impact of alarms on the delivery of patient care or patient outcomes. Attempts at identification or measuring alarm fatigue were included due to the assumption by researchers that the quantity of alarms directly results in the development of this phenomenon. Analysis of the selected studies indicated three major topics. Eleven studies addressed research or performance improvement projects that involved implementation of one or more interventions to reduce alarms. Seven studies focused on nurse responses to alarms. Nine studies addressed nurses' perspectives toward alarms.

Initial strategies to reduce the quantity of alarms focused on the major types of alarms that occurred, what nurse response was required (action or nonaction), and safe adjustments with the goal to minimize or eliminate nonactionable (nuisance) alarms and to minimize false actionable alarms. I found 11 studies that qualified: eight performance improvement studies and three research studies. In a performance improvement study conducted in 2006-2007 in a tertiary care medical intensive care unit, Graham and Cvach (2010) first implemented retraining of staff and then collaborated with a multidisciplinary alarm management task force to revise crisis level default settings and parameter limits of alarms. With increased compliance of nursing staff (up to 94%) in adjusting parameter limits, there was a 46% reduction in physiological alarms and a perceived alarm noise level rating decrease from 3.1 to 2.97 on scale of 5 being the highest noise level (Graham

& Cvach, 2010). All studies were conducted on a telemetry or intensive care unit, usually a single unit, though three studies included multiple units at the same institution. Only one study involved pediatric patients. Unit sizes ranged from 16 to 55 beds. Samples were small, and were convenience samples related to patient census during the time of study.

Six intervention studies were conducted before 2014 (Cvach, Biggs et al., 2013; Dandroy et al., 2014; Graham & Cvach, 2010; Peterson, 2013; Sendelbach, Wahl, Anthony, & Shotts, 2015; Whalen et al., 2013). Cvach's projects were rapid sequence performance improvement trials that included previously collected alarm data to determine intervention outcomes from adjusting of default parameters, making all audible alarms become actionable (nurse has to respond to alarm to deactivate it), eliminating duplicate alarms, and implementing daily electrode changes. Results indicated a 43% overall reduction of alarms with the bundled changes (Graham & Cvach, 2010) and 46-47% reduction in low and medium priority alarms with electrode changes (Cvach, Biggs et al., 2013).

These studies became the basis for replicating studies conducted by Peterson (2013), Sendelbach et al. (2015), Srinivasa, Mankoo, & Kerr (2017), Walsh-Irwin and Jurgens (2015), and Whalen et al. (2014). Whalen et. al. implemented parameter limit changes and altered audible crisis alarms with a reported 89% decrease in audible alarms from 2 week pre and post interval alarm data collections. Walsh-Irwin and Jurgens changed electrodes 24 hours after admission and measured the pre and post number of alarms. Walsh-Irwin and Jurgens reported an alarm decrease of 44% after t test

adjustment by bootstrapping due to small sample size (N = 15). Srinivasa et al. collected baseline data over 21 days, implemented premature ventricular contractions (PVC) limit changes, and collected post data for another 21 days to find a 54% decrease in overall alarms and a significant noise level decrease. Data were lost for Peterson, so statistical outcomes were not available related to changing default parameters. Qualitatively, Peterson reported that daily electrode changes did not reduce leads off alarms, and the practice was stopped. Sendelbach et al. reported a decrease of 28.5 alarms/patient/day to 3.29 alarms/patient/day (88% decrease) with bundling changing default parameters, deleting duplicate alarms, customizing patient alarms, implementing daily electrode changes, and using disposable ECG leads. Dandoy et al. (2014) initiated small tests of change over 11 months involving standardized orders, daily electrode changes, daily customized parameter assessments, and appropriate monitor discontinuation. Findings indicated that as intervention compliance increased from 38% to 95%, the median number of alarms per patient per day dropped from 180 to 40, and false alarms decreased from 95% to 50% (Dandoy et al., 2014).

Sowan, Tarriela, Gomez, Reed, & Paper (2016) studied pre and post alarm numbers after implementing staff education, new monitors, and parameter changes. Sowan et al. found a decrease in ECG-related alarms, especially PVC pairs (11.31 alarms per patient day to 0.19), PVC runs (2.94 alarms per patient day to 0.03) and arrythmias (atrial fibrillation 2.02 alarms per patient day to 0.04). However, Sowan et al. observed that other alarms per patient per day remained frequent or were noted to increase (arterial blood pressure 38.05 to 33.67, noninvasive blood pressure 95.02 to 4.77, and pulse

oximetry 9.64 to 9.95). Sowan, Tarriela et al. also found that total overall alarms decreased from 87.86 to 59.18 alarms per patient day (24% reduction, $p = .01$).

Each of these studies was done prior to or as the Joint Commission NPSG was being implemented. Immediate results indicated reduction in audible alarms. The exact amounts are difficult to cross-tabulate because the data were collected and analyzed in a variety of methods. Some data were taken from monitor equipment data mining that may have included varying types of audible and nonaudible alarms from different facilities, and did not include data collected manually during other studies. Other data were manually collected.

Though all studies included ECG alarms, four studies also included data on other central monitor alarms such as blood pressure and pulse oximetry not related to ECG (Peterson, 2013; Sendelbach et al., 2013; Sowan, Tarriela et al., 2015; Speich, 2016) . The analysis of results varied between alarm counts to alarms per patient per day. Only six studies included statistical analysis to identify significance (Dandoy et al., 2014; Peterson, 2013; Speich, 2017; Srinivasa et al., 2017; Walsh-Irwin & Jurgens, 2015; Whalen et al., 2014). Some researchers implemented one change, but most researchers implemented two or more changes simultaneously. Therefore, it was not clear whether a specific intervention had a greater impact on alarm reduction. Adjustments of alarm parameters, elimination of duplicate types of alarms, making all audible alarms actionable, and/or eliminating nonactionable alarms, resulted in decreased total alarms (Peterson, 2013; Speich, 2017; Srinivasa et al., 2017; Walsh-Irwin & Jurgens, 2015; Whalen et al., 2014). The broader the parameter changes were, the greater the reduction

of alarms (Graham & Cvach, 2010; Peterson, 2013; Whalen et al., 2013). However, there was no standard of acceptable parameter ranges, and only two studies indicated patient safety data (Graham & Cvach, 2010; Whalen et al., 2014). Findings regarding daily electrode change were not statistically significant in Peterson's (2013) study, and this intervention was not consistently practiced in Whalen et al.'s (2013) study. Also, researchers have noted that patients have refused daily changes due to discomfort when electrodes removed, so support for this practice remains unclear.

Due to differences in interventions, data collection times, and data collection measures among studies, the only conclusion that can be made is that these interventions impact the numbers of audible alarms. According to the Levels of Evidence (Fineout-Overholt et al., 2010), these studies of nursing interventions reflect one randomized control study (Level of Evidence II), five nonrandomized control studies (Level of Evidence III), and four Level of Evidence IV cohort studies. No conclusion can be made regarding which interventions are more reliable or have the greatest effectiveness. The higher alarm reduction rates reported by Whalen et al. (2014) and Sendelbach et al. (2015) may be related to the fact that no previous interventions had been implemented at their study sites, while Cvach et al.'s (2013) site had already implemented previous monitor-related changes. Other considerations that may impact results by Whalen et al. and Sendelbach et al. are data collection methods, influence of staff education prior to practice change, and presence of Hawthorne effect. Only Whalen et al. addressed patient outcome by reporting there were no adverse patient safety events after practice change and there was a decreased number of patient cardiac arrests. Whalen et al. were also the

only researchers to report increased staff and patient satisfaction regarding noise levels and perception of decreased alarms. These findings demonstrate methods to decrease the number of alarms, though no conclusion can be made regarding the effectiveness of any one method. None of the researchers measured nurse response to alarms or nursing perspectives of the impact of alarms on delivery of patient care. Additionally, there was no inclusion of impact on nurse workflow addressed in these studies involving nurse interventions to reduce alarms and prevent alarm fatigue.

Nursing Perspectives Regarding Alarms

The purpose of monitoring patients is to provide a warning when there is a change in condition that the health care staff should be aware of (Cvach, Biggs et al., 2013). Interventions to decrease cardiac-related alarms have reduced but not eliminated the numbers and types of audible alarms. Data reflect continuation of nuisance and false alarms (Baillargeon, 2013; Ruppel et al., 2018). This issue is evidenced in studies on nursing perspectives regarding alarms and alarm management. The literature search indicated 10 studies related to nurses' attitudes toward alarms. Three of the studies were conducted outside of the United States, indicating that the hazards of alarms are not unique to the United States. Four of the research studies report serial quantitative studies conducted in 2006, 2011 and 2016 on nurses' attitudes and perspectives related to alarms (Funk et al., 2014; Honan et al., 2015; Korniewicz et al., 2008; Ruppel et al., 2018). Three other studies include nursing attitude surveys in studies exploring alarm fatigue at specific institutions (Casey, Avalos, & Dowling, 2018; Cho et al., 2016; Christensen et al., 2014).

Published data collected regarding nurses' attitudes about alarms spans the decade from 2006 to 2016. The initial study (Korniewicz et al., 2008) was an online survey administered by the American College of Clinical Engineers Healthcare Technology Foundation (HTF). It was developed by a multidisciplinary task force and consisted of four main sections: participant demographics, statements rating level of participant agreement regarding clinical alarms, issues ranking barriers to alarm management, and open comments section (Korniewicz et al., 2008). The survey was distributed online and in paper form through professional organizations and health care institutions with 1327 respondents. Demographics indicated majority of respondents were registered nurses (54%) with respiratory therapists (14%) and engineers (15%) also participating. Participants were experienced practitioners with only 8% having less than 3 years experience (Korniewicz et al., 2008).

The researchers reported that greater than 90% respondents agreed or strongly agreed on the purpose of alarms and the need to prioritize and easily differentiate alarms (Korniewicz et al., 2008). Additionally, respondents agreed or strongly agreed frequent false alarms were a problem (81%), nuisance alarms disrupted patient care (77%) and these alarms caused healthcare workers to distrust and disable alarms (78%) (Korniewicz et al., 2008). Attitudes related to complexity of setting alarm parameters were split from disagreement to agreement. Highest ranked perceived issues related to alarms were frequent false alarms that reduce nurse attention to patient, and inadequate staffing to respond to alarms when they occur (Korniewicz et al., 2008). Lowest ranked issues were the difficulty setting alarms, and perceived overreliance on alarms to call attention to

patient problems (Korniewicz et al., 2008). This survey was conducted as studies were starting to identify the amount and types of alarms, and as incidents of patient harm related to clinical alarms were being reported. Limitations of the survey include the data collected were respondent opinion not quantitative facts, the participant pool, though a national survey, was a convenience sample and had perspectives from multiple disciplines, in addition to, direct patient care providers who are surrounded by the alarms on a continual basis (Korniewicz et al., 2008).

A follow up survey to the 2006 HTF study by Korniewicz et al. (2008) was conducted in 2011 to determine if there had been changes in attitudes and practices related to alarms. The 2011 survey added new agreement questions on whether adverse patient events related to clinical alarms occurred, monitor watchers were used, improvement initiatives have been implemented, and new technology solutions were implemented (Funk et al., 2014). The survey was distributed online and in paper form through multiple healthcare organizations. There were 4278 respondents with the greatest percentage of respondents being respiratory therapists (42.21%) and registered nurses (37.83%), and with a continued high level of experienced respondents, 84.72% with greater than 6 years (Funk et al., 2014). .

Most of the statements revealed no significant difference between the years, though a slightly greater number in 2011 agreed or strongly agreed that alarms should differentiate priority, and felt less strongly that nuisance alarms occurred frequently, disrupted patient care and reduced trust in alarms (Funk et al., 2014). The ranking of issues had the frequency of false alarms ranked first, and the difficulty in hearing and

identifying alarms increasing in importance (Funk et al., 2014). New question answers found 18% of respondents were aware of adverse events related to alarms at their institution, 47% of respondents used monitor watchers and a little less that 20% of respondents had alarm inititatives at their institution (Funk et al., 2014). Limitations for this study were the convenience sample, and the bias due to the distribution through professional organizations. Though there was a greater number of respondents, they were a small disproportionate representation of the actual clinicians in the field who experience continual alarms (Funk et al., 2014).

In addition to the quantitative analysis of the 2011 HTF survey, there was a qualitative analysis completed on content from 790 comments by 406 nurses (Honan et al., 2015). Seven interrelated themes were identified by Honan et al.: auditory dissonance and aural desensitization, impact of noise causing patient panic, sleep deprivation and delirium, accountability in responding to and managing alarms, requests for autonomy for nurses to address alarms, the realization that alarm management can improve patient safety but there is not one intervention that solves all, and hope for what future technology might offer. Comments advocated for nurse involvement in reforming policies, developing technology, and making alarm management decisions. Nurses also proposed suggestions for changes to reduce nuisance alarms (Honan et al., 2015).

Five studies done since the 2011 HTF survey address nursing perspectives at individual institutions around the world. Researchers explored at a regional ICU in Australia nursing staff perspectives related to nuisance alarms, nursing alarm setting practices, and feelings about altering another nurse’s patient’s alarms (Christensen et al.,

2014). Results indicated clinicians described a nuisance alarm as a false positive or a clinically irrelevant alarm. More than 50% of respondents identified they silenced or altered alarm limits because the nurse was absent from the area (Christensen et al., 2014). However, 48% respondents indicated they would not change alarm limits because of perceived negative responses from the primary nurse. There was overwhelming agreement (93%) that desensitization leads to decreased alarm reaction time and inappropriate disabling of alarms (Christensen et al., 2014). Results reiterated findings of the United States HTF 2006 and 2011 surveys related to nuisance alarms and offered a human factor consideration regarding what influences nurse decisions in responding to audible alarms. Though Christensen et al.'s study is biased by the convenience sample and culture influences of the participating unit, the factors identified by researchers that affect nurse prioritizing and decision making need to be considered when determining alarm management protocols.

Sowan, Tarriela et al. (2015) conducted a quality improvement project on a 20-bed transplant unit (TCICU) after implementation of new monitoring system. An adapted 2011 HTF survey was distributed to registered nurses of the unit with 39 respondents (100% response rate). Demographics were similar to previous experience levels in previous studies. Results of the TCICU, had higher agreements than the 2011 HTF survey regarding nuisance alarms occurring frequently (95% vs 77% respectively), alarms disrupting patient care (98% vs 71%) and numbers of alarms reducing trust (98% vs78%) (Sowan, Tarriela et al., 2015). The TCICU respondents also had a higher percentage perceived alarms were confusing to identify and properly setting alarm

parameters was complex (Sowan, Tarriela et al., 2015). Attitudes related to central alarm management, smart alarms and alarm integration into communication systems reflected national survey attitudes (Sowan, Tarriela et al., 2015).

Sowan, Tarriela et al. respondents were in less agreement than the 2011 survey regarding effectiveness of unit policies and whether newer monitoring systems solve previous problems. Ranking of issues indicated nurse difficulty in discerning and prioritizing alarms ranked higher for TCICU staff than the national survey frequent false alarm issue (Sowan, Tarriela et al., 2015). National survey respondents rated 'needing more education' low, while 59% in Sowan, Tarriela et al.'s study felt the need for more training. This result was probably due to the TCICU respondents had underwent equipment changes just several months prior to the survey. Though aspects of the findings correlated with the HTF 2011 survey, differences in TCICU results likely reflected the level of knowledge and confidence nurses had of the monitoring equipment at the time of the survey.

Speich (2017) conducted a quality improvement research study to explore nurse's attitudes toward alarms and the current state of strategies in alarm management. A pre-intervention survey using a shortened version of the 2011 HTF survey was conducted with 30 nurses in one critical care unit. Following the survey, education and an intervention bundle were introduced. The HTF survey was not repeated after intervention implementation. Results were from 12 nurses who responded to the pre-intervention survey (Speich, 2017). Demographics indicated all responders had greater than 3 years' experience. Responses were supported of the 2011 survey findings since Speich's

respondents strongly agreed (83%) nuisance alarms occur frequently, disrupt patient care (91.7%) and reduce trust in alarms (91.7%). Speich's unit responders differed from national survey findings by disagreeing that staff was sensitive to alarms and responded quickly, and that environmental noise interfered with alarm recognition. Speich's findings conducted in 2016 support the previous 2011 national survey and indicated an ongoing perception by nurses that nuisance alarms continued to be an issue even two years after The Joint Commission NPSG initiative was implemented. It was not specified by Speich what interventions nursing had implemented prior to this study. The implemented interventions described by Speich included electrode change protocol, reinforcing nurse's autonomy to adjust alarm parameter limits, and the addition of an 'alarm check' by two nurses during hand off. Though the study is entitled "Reducing Alarm Fatigue", only nursing attitudes regarding alarms were measured. No measure of alarm fatigue was provided.

A cross-sectional survey of 10 departments in six hospitals in Ireland used an adaption of the HTF survey in 2016 (Casey et al., 2018). Results from 250 ICU, post anesthesia care unit and high-dependency unit responders found demographics to be like the United States survey respondents. Most nurses (88%) stated familiarity with alarm fatigue and its causes (84%), but were uncertain (52%) of how to prevent its occurrence (Casey et al., 2018). As with the United States surveys, nurses agreed nuisance alarms occur frequently (90%), disrupt patient care (91%) and reduce trust in alarms (81%) causing nurses to disable them (Casey et al., 2018). Customizing alarms ranked 4th highest issue and was related to nurse's knowledge of preventing alarm fatigue, which

also was related to implementation of new technology and clinical alarm improvement initiatives during preceding 2 years (Casey et al., 2018). Perceptions regarding smart alarm technology, difficulty in identifying and understanding alarms also reiterated the United States survey trends (Casey et al., 2018). A higher percentage of nurses (62%) in Casey et al.'s study felt background environmental noise interfered with alarm recognition. Overall, findings of this study reflected results of the United States surveys. Limitations stated by Casey et al. included influences from one site being significantly different than other sites and having had an adverse event with subsequent education and implementation of new practices. However, results do indicate that alarm management issues occur globally and factors impacting alarms and nurse perceptions to alarms expand internationally.

A broader attempt to study device alarms, nurses' alarm fatigue and alarm recognition, and obstacles to alarm management was conducted by Cho et al (2016) in Korea during 2014. This study adapted Baillargeon's (2014) observational instrument to count the number of alarms. Additionally, ICU nurses were surveyed using an adapted version of the HTF survey and a revised instrument to measure symptoms of fatigue. Alarm data from multiple devices were collected for nine days in 5 ICUs using random bed selection. Seventy seven nurses were surveyed on alarm fatigue, recognition of alarms, and obstacles to alarm management (Cho et al., 2016). Nurse demographics for Cho et al. differed from the United States surveys since Cho had higher percentages of masters prepared nurses (26%) and more nurses with less than 3 years' experience (36.4%). Results reported 1788 patient monitor alarms with only 37.5% being valid.

False alarms had 45.1% technical and 17.4% non-technical causes (Cho et al., 2016). A 5 point Likert scale was used to rate nurses perceptions of alarms. The highest response rankings were alarms should alert staff to a hazardous patient condition, and alarm sounds should differentiate type and priority of the alarm (Cho et al., 2016). Perceptions that nuisance alarms occurred frequently, reduced trust and disrupted patient care ranked 4.0, 4.0 and 3.8 respectively (Cho et al., 2016). Cho et al. reported the lowest rankings statements were regarding the impact of environmental noise on alarm recognition, and the difficulty setting alarm parameters. Same as United States results, Cho et al.'s top ranked obstacle to proper alarm management was frequent false alarms.

Cho et al. (2016) reported nurse fatigue measure according to 8 statements taken from a table of subjective symptoms of fatigue revised by the Japanese Occupational Hygiene Association and applied by Kim and Sung. Content validity was established, and reliability was estimated to be Cronbach A coefficient 0.79 (Cho et al., 2016). The top rated (mean $\pm$ SD on scale of 5) statements reported in the study by Cho et al. (p. 49) were: 'I am bothered in everything by clinical alarms' (3.9 ± 0.8), 'I feel anxious due to clinical alarms' (3.7 ± 0.8), and 'I feel out of my mind due to clinical alarms' (3.6 ± 0.9) with the total fatigue score being 24.3 ± 4.0 out of 35. However, these are subjective opinions not direct measurement of alarm fatigue.

These studies on nurses' perspectives related to alarms provided repeating themes globally. Nurses have consistently identified nuisance alarms as occurring frequently, being disruptive to patient care, and causing distrust of alarm systems (Korniewicz et al., 2008; Funk et al., 2014). A third HTF survey was conducted in the United States by

Ruppel et al. (2018). Of the 1241 respondents, Ruppel et al.'s study had more who were employed outside an ICU (58.7%), were registered nurses (60.65%) or repiratory therapists (30.36%), and had greater than 11 years experience (75.37%). However, even for this study, conducted ten years after the Korniewicz et al., high percentages agreed or strongly agreed that nuisance alarms occurred frequently (87.25%), disrupted patient care (85.79%) and reduced trust in alarms (82.55%; Ruppel et al., 2018). Each year of the survey indicated a greater percentage of nurses identifying nuisance alarms as a continued alarm issue despite interventions that, since 2014, were to address the NPSG, and to decrease nonactionable alarms. An issue still to be determined, is whether the upward trend reported in these HTF studies is related to increased staff awareness or to ineffectiveness of alarm management interventions.

Ruppel et al. (2018) reported that the setting of alarm parameters continues not to be seen as difficult, and the majority of respondents continue to agree that alarms on their unit are adequate to alert staff. However, the respondents were neutral or disagreed that the newer monitoring systems have solved previous alarm problems (Ruppel et al., 2018). Ruppel et al.'s survey was the first to indicate less agreement that staff were sensitive to alarms and responded quickly (68.88 % in 2006, 66% in 2011, 48.32% in 2016, $p < .001$), and to report more agreement that environmental noise interfered with alarm recognition (43.18% in 2006, 42.41% in 2011, 51.04% in 2016, $p < .001$). Also, the results indicated less agreement with the use of smart alarms and alarm intergration effectively reducing alarms, and the policies and procedures were effectively managing alarms (Ruppel et al., 2018). . These results do not provide a positive trend when considering the responses to

Ruppel et al.'s survey questions tripled the number of respondents whose institutions had developed alarm improvement initiatives over the previous 2 years (21.09 % in 2011 to 62.41% in 2016), and more than doubled the initiation of new technological solutions (18.89% in 2011 to 42.03 % in 2016).

The studies on nurses' perspectives and attitudes related to alarms reflect five studies providing qualitative or descriptive information (Level of Evidence VI) and four studies that are cohort studies determining development of an outcome (Level of Evidence IV). See list in Appendix F. The data collected provided subjective descriptions and trends of nurses' perceptions regarding alarms, but did not directly address nurses' responses to alarms or alarm fatigue behaviors. Alarm hazards was not included in the 2019 ECRI Institute's top 10 technology hazard list, though consequences from customized alarm parameters due to alarm management interventions was listed (ECRI, 2018). The question remains regarding what has been the effectiveness of interventions such as adjusting parameter limits, customizing alarms for individual patients, changing electrodes daily, addressing excessive alarms during safety huddles, making all audible alarms actionable, and ensuring appropriate monitoring and discontinuance policies. Initial numbers of alarms have decreased, but data still indicates nuisance and false alarms remain (Sendelbach et al., 2015; Ruppel, Funk, & Whittemore, 2018). Nurses' perspectives regarding the extent and impact of clinical alarms has not significantly improved (Ruppel et al., 2018). There is a need to explore beyond the numbers and types of alarms, and to seek more detail about factors that influence the nurse who is managing patient care and the monitoring equipment.

Nurse Response to Alarms

The concern regarding alarm fatigue is that nurses who become desensitized to or who deactivate audible alarms will miss an alert indicating a change in patient condition (Joint Commission, 2013). Such actions involve nurses' responses to patients and alarms. The assumption from studies on the types and numbers of alarms, the interventions to reduce audible, nonactionable alarms and the focus of nurses' attitudes towards alarms is the sheer number of alarms produces a situation that overwhelms the nurse who consciously or unconsciously ignores the alarms (Cvach, 2012; Welch, 2009). The literature search found seven studies that explored nurse response to alarms and potential relationships to the alarm fatigue.

The Baillargeon (2013) observational study collected on a telemetry unit monitor alarm data included the number and types of alarms and the nurses' responses to the alarms. Researchers used stop watches to record the length of time taken by the nurse to respond to critical and leads off alarms. If a 'leads off' alarm exceeded 10 minutes, the recorder just used the 10 minute time to allow for recording of other alarms. A total of 6 hours 2 minutes of data was collected with 36 nurses involved. Baillargeon calculated one alarm occurred approxiamately every 2.08 minutes. Three critical alarms occurred with response time ranging from 2.6 to 10.2 seconds, mean 6 seconds, eight leads off alarms occurred with a range from 1 minute 20 seconds to 10 minutes, mean response time of 7.01 minutes, and five alarms (62.5%) being greater than 10 minutes until response (Baillargeon, 2013).. Discussion by Baillargeon supported Bliss et al. (1995) findings that alarm response matched expected probability of true alarms. Baillargeon

used delayed response (defined as greater than three minutes) to identify alarm fatigue behavior, and concluded, based on the leads off response demonstrated, the nurses were experiencing alarm fatigue There was no exploration of why nurses took the time they did to respond to the alarms.

Gazarian (2014) conducted a prospective, descriptive study to determine how nurses identify and respond to monitor alarms. Like Baillargeon, data were collected on numbers and types of alarms on an adult medical-surgical telemetry unit. For Gazarian's study, individual nurses (*N*=9) were recruited to be observed for two 3 hour periods during one week. During the observation period, the researcher collected monitor alarm events and noted response action(s) by the nurse. Responses included no action, visual patient check, monitor check, nurse intervention with patient, or modification of care plan. More than one action might be noted. Response times were not documented. After the observation period, the researcher reviewed and validated the data with the nurse for clarification.

Gazarian (2014) reported 205 alarms with 109 (46.8%) no response to alarms. System status alarms related to technical issues (such as leads off, artifact, or oxygen saturation probe problem) constituted 44 alarms. There was no nurse response to 58.9% of these alarms (Gazarian, 2014). Of the 161 patient status alarms, Gazarian noted there were 17 crisis alarms that received a 70% nurse response rate. Nurses' responses were 11 times checking the monitor (64.7%), one time checking the patient, and five times (30%) no response (Gazarian, 2014). Response rates for lesser alarms were: warning 33%, advisory 46%, and message 38%. The researchers noted that in 7 of the 18 observations,

the nurse did not check alarm parameters or volumes at beginning of shift, which might have corrected some of the system status alarms (Gazarian, 2014). Overall, 32.9% of patient status alarms were artifact and represented nuisance alarms and interruptions in nurse workflow (Gazarian, 2014).

Gazarian's (2014) study was conducted before inititation of the Joint Commission NPSG, but after facility specific alarm reduction strategies such as individualized alarm limits and adjusted default parameters, were implemented. Discussion by Gazarian indicated the observations revealed the nurse was impacted by workflow, difficulty and complexity of alarm systems, and competing tasks that required prioritizing. Limitations of Gazarian's study included sample size, inability to collect precise data due to simultaneous and overlapping alarms, and possible Hawthorne effect since participants were aware of being watched. Despite the amount of alarms not responded to, findings did indicate the range of work nurses perform associated with monitoring patients (Gazarian, 2014). Nurses' responses to alarms involved patient assessment, team collaboration and consultation, and equipment management with overlapping activities also impacting nurse response and workflow (Gazarian, 2014).

Gazarian et al. (2014) published separately the qualitative descriptive data regarding decision-making of nurses managing the ECG monitors. For this phase of the study, nurses were interviewed using a cognitive task analysis method to retroactively describe the nurse's thinking and decision-making process related to a recorded alarm during the observation period. A four step analysis was followed that coded data into

seven categories: information, experience, guidance, decision-making, perceptual cues, goals, and technology (Gazarian et al., 2014).

Gazarian et al. (2014) described nurses used information related to the patient in 33% of responses, were influenced by the nurse's experience in 22% of responses, sought guidance from others 18% of the time, had judgement of options impacting 16% of the responses, and were affected by perceptual/sensory cues and technology barriers for the remaining alarm events. Gazarian et al. also identified that understanding how nurses interact with monitor alarms is a component to improving alarm management and providing insight into nurse decision-making. The different categories from this analysis revealed a broader nurse response process than just identifying and interpreting alarms (Gazarian et al., 2014). There is a need to consider the alarm in a context of the patient's situation, the nurse's experience and the environmental influences. Limitations included the small sample size of younger than mean age nurses at one institution who knew they were being observed (Gazarian et al., 2014). Additionally, the interview was done retrospectively which may have biased responses even though verification of events by retelling techniques was utilized to strengthen results. Finally, though there was a measure of alarms of one nurse's patients, there was not a total all alarm measurement counted during the observation periods, and there was no direct connection to alarm fatigue behaviors mentioned (Gazarian et al., 2014).

Krinsky's (2016) study focused on nurse fatigue with the purpose to correlate fatigue and alarm fatigue. This descriptive, correlational study was conducted of critical care nurses who were attending a national conference. The sample was a non-probability

convenience one of 195 nurses who worked full time giving direct patient care in critical care units using cardiac monitoring. Participants completed a demographic tool, the Occupational Fatigue Exhaustion Recovery Scale (OFER), the National Aeronautics and Space Administration-Task Load Index (NASA-TLX) and the HTF survey. The instruments were to assess chronic and acute fatigue and intershift recovery: to evaluate workload responding to alarms using dimensions of mental demands, physical demands, temporal demands, performance, effort and frustration; and to examine issues related to alarms (Krinsky, 2016).

Krinsky's (2016) demographic results used exploratory, univariate analysis to assess associations between demographic and work variables, and between chronic, acute, and intershift fatigue and the total workload responding to alarms. Participants were female (85.6%), had mean age of 42.6 years, worked in intensive care (90.3%), were baccalaureate prepared (57.4%), and had a mean of 13.2 years critical care experience (Krinsky, 2016). Demographics also included living situation, people in household, shift worked, hours worked per week, and successive days worked. Krinsky's study results of these critical care nurses (N=195) found a low/moderate level of chronic fatigue (49.35 [SD $\pm$ 24.83]), and a moderate/high acute fatigue level (63.86 [SD $\pm$ 20.06]). Chronic fatigue had moderate positive correlation with acute fatigue (p<.0001), and nurses with chronic fatigue had higher rates of acute fatigue (Krinsky, 2016). Higher chronic fatigue or acute fatigue had a negative moderate correlation to nurse intershift recovery (p=.0001). The workload of responding to cardiac monitor alarms (range of 1 – 20) found temporal workload the greatest at 13.89 (SD $\pm$ 4.35), followed by frustration at

12.55 (SD $\pm$ 5.25), and effort at 11.85 (SD $\pm$ 4.90). Issues of importance differed from data previously reported since more importance was focused by Krinsky's respondents at alarm sounds being distinct, alarms may be missed, confusion among sounds, and difficulty setting or hearing alarms There were some significant correlations between age and chronic fatigue, and acute fatigue and age of household persons. Other findings related chronic fatigue to working day shift or working over 40 hours (Krinsky, 2016). Finally, a correlation was found (p=.001) between nurses working four or more successive shifts had higher chronic fatigue and higher total workload responding to cardiac alarms. Krinsky's study concluded critical care nurses have high rates of fatigue and find the task of responding to cardiac alarms temporal and frustrating. The study does not measure alarm fatigue, or behaviors associated with alarm fatigue. The study does reinforce importance of understanding more comprehensively how fatigue impacts nurses and potential patient outcomes and safety.

Two studies conducted at a children's hospital sought to explore the relationship between nurse exposure to nonactionable physiologic monitor alarms and response time to alarms. A pilot study was done in a pediatric intensive care unit and a medical ward over 11 months from 2012 to 2013 (Bonafide et al., 2015)). Patients were selected based on whether they were in top 25% of alarm rate events over the 4 hours prior to observation. The nurse response times were measured to nonactionable alarms over a 2-hour period. Video recording offered monitor time stamp data to associate with the alarms and nurse response. It was hypothesized that alarm fatigue would be strongest in highest alarm patients. The researchers also hypothesized that nurses might not exhibit

alarm fatigue unless inundated with alarms. Statistical analysis was done of the relationship between nonactionable alarms and nurse response. Data were collected on a total of 40 patients - 20 sessions each in an ICU and a general ward during weekdays (Bonafide et al., 2015).

Bonafide et al. (2015) results documented 2445 clinical condition alarms – 12.9% were actionable in PICU, 1% actionable on medical ward. Of these alarms, 1185 occurred while the nurse was out of the patient room and were analyzed for response time. Median response time was 3.3 minutes in PICU and 9.8 minutes on the ward (Bonafide et al., 2015). Response time was then analyzed between critical alarms while nurse not in room and the number of nonactionable alarms during the preceding 2 hours. Based on Kaplan-Meier plots there was a positive incremental relationship between nonactionable alarm exposure and increasing response times (Bonafide et al., 2015). Limitations were related to the limited sample of patients and nurses, and days and times observations conducted. A multivariate analysis of a larger sample might have provided insight into other variables than nuisance alarms and response (Bonafide et al., 2015). Additionally, four nurses did admit to responding more quickly due to being observed, so Hawthorne effect was present. Conclusion of Bonafide et al.'s (2015) findings indicated an association between nurse prior exposure to nonactionable alarms and delayed response time to future alarms being representative of alarm fatigue behavior.

Bonafide et al. (2017) built upon the 2015 work by conducting a prospective cohort study using 551 hours of video recording 100 patients and 38 nurses to identify factors associated with physiologic monitor alarm response time. Multivariable

accelerated failure-time models were used to adjust for clustering within patients (since patient selection was randomized, some patients were observed more than once). Associations were evaluated between alarm exposures and response times to alarms occurring while the nurse was outside the patient's room. Results obtained by Bonafide et al. (2017) found of 11,745 alarms in 100 children, 50 (0.5%) were actionable. Median response time for patients on complex care service was 5.3 minutes versus 11.1 minutes on general ward. Bonafide et al.'s study also found response times were less if family were away from bedside than if present, time for the nurses with less than a year experience was half the time of the more experienced nurses, the nurse with single patient assignment responded in 3.5 minutes versus 10.6 minutes for a nurse with multi-patient assignment, and prior alarms requiring interventions were responded to in about half the time as those that didn't require previous intervention. Lethal arrythmia alarms (all were false) were responded to in 1.2 minutes versus 10.4 minutes for other conditions. Also noted, there was an associated increased response time with the longer the time into a nurse's shift (Bonafide et al., 2017). Finally, the result from Bonafide et al.'s (2015) previous study indicating a positive correlation between number of nonactionable alarms and increased delay in response to future alarms was not supported in this study's results (Bonafide et al., 2017).

These results indicated there were variable factors nurses used to assess whether an alarm represented a life-threatening condition. Factors that impact response time were nurse:patient ratio, nurse experience and possibly physical/mental fatigue based on hours into a shift (Bonafide et al., 2015; Bonafide et al., 2017; Gazarian et al., 2014; Krinsky,

2016). The number of alarms was not supported as directly correlated to delayed responses (Bonafide et al., 2017). Bonafide et al.'s study findings do not support the assumption that alarm numbers result in desensitization leading to alarm fatigue, so reducing audible alarms will prevent alarm fatigue.

The observational studies on nurse response actions and times were conducted between 2012 and 2015. Gazarian's (2014) study was a qualitative descriptive study with a small sample at one institution, so would be classified as Level of Evidence VI. Krinsky's and both Bonafide et al.'s 2015 and 2017 studies are quantitative descriptive studies of a cohort that can be considered Level of Evidence IV. It is difficult to directly compare results as methodology differs with one study rating nurse responses and the other studies using time. Gazarian et al. (2013) and Bonafide et al. (2017) began to explore other variables that may have impacted human factors of the nurse – alarm interactions. Data were not substantive enough to draw absolute conclusions. However, the response findings bring to question how alarm fatigue can be accurately measured. The definitions provided by Cvach (2013) and Joint Commission (2013) indicated the presence of alarm fatigue is due to overwhelming amount of alarms that create a desensitization, therefore, delays in response to or deactivation of alarms. After implementing interventions that have successfully reduced the amount of audible alarms, studies still reported higher percentage of nuisance alarms than valid alarms (Cvach, Biggs et al., 2013; Speich, 2017; Walsh-Irwin & Jurgens, 2015). Nurses' attitudes from 2006 through 2016 after alarm numbers had been reduced, reported that nuisance alarms continued to be an important issue (Ruppel, Funk, & Whittemore, 2018). Nurse responses

at one institution after alarm management strategies implemented did demonstrate delayed responses but did not correlate with the alarm numbers (Bonafide et al.,2017). These findings suggest management of alarm fatigue needs to include broader human factors.

An observational study by Deb and Claudio (2015), attempted to define alarm fatigue in terms of mental workload and affect (affect being the feeling of emotion), and to verify whether alarm fatigue is the cause of staff performance resulting in adverse clinical incidents. For Deb and Claudio's study, numbers of alarms, staff:patient ratios, time into shift, alarm types and urgency, noise level, task priority and staff personality were considered variables. To measure alarm fatigue, data were collected on response to alarms, and on response times and numbers. Participants were six unit clerks who did monitor watching and 18 registered nurses who worked on an eight bed ICU. Each participant completed a Clinical Alarm Survey developed by the Association for the Advancement of Medical Instruments (AAMI) to evaluate attitudes of staff towards current alarm monitoring system. The Hierarchical Task Analysis (HTA) that levels tasks into goals, task or action was also completed and analyzed separately for unit clerks and nurses. A 15-minute observation of a randomly generated sample provided work sampling of participants. Alarm and noise data were collected from telemetry monitors, the work vicinity and the patient rooms. Unit clerk and nurse responses and times were documented. At the end of the shift, mental workload was evaluated by completion of the Subjective Workload Assessment Technique (SWAT) and the NASA-TLX tools, both validated instruments to measure mental workload. Alarm fatigue was measured by

measuring affect factors that make staff desensitized – boredom, apathy and distrust. Validated tools were used to measure boredom and apathy, and a created tool of three questions was used for measuring distrust. The final component to the study had participants complete the Big Five Personality Test online to determine whether personality affected how quickly the participant became overwhelmed.

Statistical analysis consisted of initial correlation analysis, regression analysis, variable reduction analysis or non-parametric, non-linear regression analysis, if applicable. Results of Deb and Claudio's (2015) study mirrored HTF results by confirming 84.6% of respondents agreed that nuisance alarms occurred frequently, disrupted patient care (84.6%) and caused distrust (53.8%). As in the HTF studies, respondents to Deb and Claudio also disagreed (46.2%) that staff were sensitive to alarms and responded quickly to alarms. The alarm data collected of 1109 alarms over 4 day and 4 night shifts found an average 116 alarms/patient/day with 88% being false alarms (Deb & Claudio, 2015). Noise levels ranged 50 – 70 dB, higher than the recommended 30-45 dB (Konkani et al., 2012). Based on alarm fatigue definitions used by other reviewed studies, this unit was at risk for its presence (Baillargeon, 2013, Cvach, 2012, Guardia-LaBar et al.).

Deb and Claudio (2015) found the HTA results indicated a significant difference between responsibilities of unit clerks and nurses responding to alarms. This result had not been noted previously so analyses were done separately for these two subjects. HTA for both clerks and nurses found task distribution important, and task priority a factor to include in alarm fatigue causation factors (Deb & Claudio, 2015). It was identified that

prioritizing tasks sometimes caused a delay in alarm response or other alarms being ignored that, in turn, increased mental workload leading to fatigue (Deb & Claudio, 2015). Deb and Claudio's analysis of results supported that all variables included in the study needed to be considered in defining alarm fatigue. Unit clerks exhibited increased mental workload and distrust with increased number of alarms, while extraverted nurses were more easily fatigued in terms of mental workload and affect (Deb & Claudio, 2015). Evaluation of alarm fatigue measures on unit clerk and nurse performance found an association of working conditions and staff individuality with performance (responses); however, only working conditions and individuality resulted in a best fit model to determine nurse response to alarms (Deb & Claudio, 2015). Discussion by Deb and Claudio offered an explanation that the nurse's role is to care for patients even when the nurse is fatigued. Nurses know alarms at patient's room effect the patient, so they respond sooner to room alarms, and nurses also take preventative measures to adjust true and false alarms. Results indicated nurses who had taken preventative measures, knew the alarms to be false so took longer to respond to alarms. In this case, actions were not related to alarm fatigue but due to staff individuality and prioritizing within the working conditions (Deb & Claudio, 2015). Deb & Claudio's work supports Bonafide et al.'s (2017) finding of delayed response does not correlate with alarm fatigue and response time is not a measure of alarm fatigue. Conclusion from Deb and Claudio's study was responses to alarms were not a measure of alarm fatigue but a consequence. Performance is affected by working conditions and staff individuality, not alarm fatigue. Responses were based on workload, time elapsed in shift, personality, experience, mental workload

and affect – each related to human factors, not the amount of alarms (Deb & Claudio, 2015).

Nursing Role Effectiveness Model (NREM)

The utilization of NREM for alarm management may provide a framework for determining the effectiveness of studies discussed in this systematic review even with the levels of evidence based on performance improvement projects, case reports, observational studies and noncontrolled trials. NREM incorporates the three concepts of structure, process and outcomes into determination of the effectiveness of the nurse role (Irvine Doran et al., 2002). For alarm management, the structure is comprised of nurse characteristics, patient characteristics and practice setting characteristics. The process considers the nurse's independent role functions, dependent role functions that require orders or policy direction, and interdependent functions that involve the healthcare team. Assessment of the effectiveness is based on the outcomes, which are patient focused and measured by increased patient satisfaction and absence of adverse clinical alarm related events. However, outcomes of decreased noise, false or nuisance alarms and patient care interruptions can be measured from both the patient and the nurse perspectives (See Appendix B).

Evaluation of each of the categories of the systematic review provided a summary of the effectiveness of physiological alarm management to prevent alarm fatigue. Eleven studies, both research and performance improvement, focused on interventions to decrease alarms. Each study did successfully decrease numbers of varying audible alarms up to 89% by addressing structure components of NREM. Nurse demographics of the

studies were similar – majority of nurses were female, had over 3 years experience, had mean age range from 29 to 42 years old with variety of degrees though the majority were baccalaureate prepared. Each intervention study included some nursing education or re-training regarding alarm management. Patient characteristics for studies were primarily adult intensive care or telemetry patients, with 2 studies involving a pediatric population. All patients were acutely at risk for potential clinical changes that could be detected using physiological monitoring. The characteristics of the practice settings, the third component of the structure concept, included types of equipment used during the study, information on staffing patterns and use of monitor technicians, size of unit(s), and number of patients. The interventions implemented affected the practice setting and included one or more of the following interventions: adjusting default limits and eliminating duplicate alarms (all studies), altering categories of audible alarms (4 studies), changing electrodes daily (4 studies),implementing a safety huddle (1 study), customizing patient parameter limits (4 studies), and/or implementing secondary notification systems (1 study). Except for the secondary notification system and varying outcomes with daily electrode change protocols, all the practice setting intervention results were positively supported using moderate to high levels of evidence II, III, or IV (see Appendix F).

The process component included the independent role of the nurse involved with daily electrode changes and customization of patient parameter limits. Interdependent nurse roles were involved with collaborative work to have default limits adjusted, duplicate alarms eliminated, and crisis audible alarms altered. Dependent nurse roles

involved patient selection for monitoring, specific monitoring orders, and the compliance to new protocol policies.

The outcome concept was addressed in each study in regards to reductions in the number of total alarms, false or nuisance alarms, or alarms per patient per day. Two studies measured whether occurrence of adverse clinical outcomes due to alarms (Graham & Cvach, 2010; Whalen et al., 2014). One study reported decreased noise levels (Srinivasa et al., 2017) and only Whalen et. al., (2014) documented increased patient satisfaction scores and no adverse clinical alarm events.

Based on these findings, there are positive outcomes of the structure and process components from alarm management interventions. The extent of effectiveness can not be determined from these studies as there were varying methodologies employed with different statistical analyses, samples were usually small sizes, convenience and limited to one or a few locations. There was no measure of alarm fatigue behaviors as defined by ignoring or deactivating alarms, so effectiveness of these interventions in preventing alarm fatigue is able to be determined.

In relation to NREM, the reviewed nursing perspective and attitude studies covering from 2006 through 2016 indicated that nurses remained dissatisfied with the amount of nuisance alarms, the interruptions into patient care due to alarms, and the ongoing distrust of alarms. In the more recent studies, an increased number of nurses had reported a disagreement that staff were sensitive to alarms (Honan et al., 2015; Ruppel et, al., 2018; Speich, 2017). From the nursing perspective these studies reflected, the work with structure components of alarm management that have been done to decrease false

and nuisance physiologic alarms have not produced outcomes to effectively resolve the issue of alarm fatigue.

Finally, studies evaluating nurses' responses to alarms describe inconsistencies in nurse response times (Bonafide et al., 2015; Bonafide et al., 2017; Gazarian, 2014; Gazarian et al, 2014; Krinsky, 2016). The original assumption by Gazarian (2014) and Bonafide et al. (2015) was that delayed response times of nurses to alarms was directly related to the number of alarms and can be a measure of alarm fatigue. Gazarian et al. (2014) noted there were other structure factors influencing the decision making of the nurse when considering their response to an alarm. Bonafide et al., (2017) also had data to indicate that the nurse:patient ratio, nurse experience, presence of family members, and time of shift influenced nurse alarm response, not the number of alarms experienced. Krinsky (2016) identified workload and nurse fatigue correlated with increased alarm response delays. Deb and Claudio's (2015) findings supported nurse factors as work experience and personality, patient factors as acuity, and practice setting factors as workload, noise and role expectations impacted nurse responses. In particular, work conditions and individuality of the nurse not number of alarms correlated with increased alarm response time (Deb & Claudio, 2015). These findings, though not providing definitive instruction on what alarm management strategies may effectively prevent alarm fatigue, have offered insight into other factors to consider as effective interventions to decrease alarm fatigue behaviors.

Recommendations

Alarm fatigue has been described as a condition that occurs when caregivers become overwhelmed trying to respond to audible alarms, so they become desensitized leading to a type of human error of missed alarms, deactivated alarms, or delayed clinician responses that put patients at risk (ECRI, 2014; Hannibal, 2011; Tanner, 2013; Joint Commission, 2013). The result of these overwhelming sounds is failure to recognize and respond to true alarms that require clinical intervention for patient safety (Welch, 2009). Alarm fatigue is a human response to machines, and a result of impaired situational awareness from cognitive overload and missed perceptions (Guardia-LaBar et al., 2014) To decrease or prevent alarm fatigue, it is important to understand factors that influence the nurse's dependency and interactions with monitoring devices, and how to create an environment promoting optimal patient healing and safety (Konkani et al., 2012).

Most studies focused on alarm management strategies to reduce numbers of audible alarms and to improve their recognition were done prior to or at the implementation of the Joint Commission NPSG. Results indicated reduction in audible alarms, though, the exact amounts were difficult to cross tabulate as the data were collected and analyzed in a variety of methods. Only one study measured patient safety and satisfaction data (Whalen et al., 2014) Except for one study that was of high level of evidence (Dewan et al., 2017), the studies provided moderate level of evidence on the effectiveness of specific interventions in reducing alarms. There has been no direct evidence from these studies that the interventions reduce alarm fatigue. No conclusion

can be made regarding which interventions are more reliable or have the greatest effectiveness. At the time of this review, there was no standard of acceptable parameter ranges identified. Alarm hazards listed as the No. 1 Health Technology Hazard by ECRI in 2013 is not in the 2019 list (ECRI, 2018). However, improper customization of parameters that may lead to a missed alarm is listed as No. 7 in the 2019 Top 10 Health Technology Hazards (ECRI, 2018). A recommendation is to conduct studies using random controlled trials to evaluate the effectiveness of the different interventions, and to determine safe customized parameters appropriate to patient age. There is a gap in research examining patient outcomes related to improving the human response through alarm management interventions. There needs to be included in study results such measures of patient outcomes as patient satisfaction, valid alerts of patient condition changes, and missed alarms related to the interventions.

Multiple serial and individual local surveys have been conducted through 2016 exploring nurses' perspectives and attitudes towards alarms and alarm fatigue. Results indicated there was limited or no improvement in the perceived presence of nuisance alarms, their interruptions in patient care and their fostering of distrust in alarms. Nurses seem to feel that education and the complexity of the monitoring systems are not a priority factor causing false or nuisance alarms (Ruppel et al., 2018). The national alarm perception surveys have different samples for each study, while the local studies provided baseline data but no follow up data after other alarm management interventions were implemented. Beyond measuring the reduction in alarms, a recommendation to determine effectiveness of interventions would be to conduct longitudinal study of nurses'

perspectives using the same respondent pool at 6 and 12 month intervals after alarm management interventions implemented, and include questions related to the nurse's perception of improved patient outcome measurements (such as less interruptions, increased time for patient care, missed events, and perceived or measured decreased noise).

Studies by Bonafide et al., (2017) and Deb and Claudio (2015) exploring nurse responses to alarms have created questions regarding the definitions and measurement of alarm fatigue. Measures of the number of alarms and delays in response time do not accurately measure alarm fatigue behaviors. Nurse response studies identified human factors that may be components involved in alarm fatigue behaviors (Bonafide et al, 2017; Deb & Claudio, 2015; Gazarian et al., 2014; Krinsky, 2016). Nurse workload, cognitive load, mental workload, personality, levels of chronic and/or acute fatigue, experience, and patient condition all have been identified as influencing nurse responses to clinical alarms. The studies conducted have incorporated psychological instruments to investigate these factors. Validity and reliability of the tools for the purpose of detecting or measuring alarm fatigue still needs to be determined. Repeating studies as Bonafide et al.'s (2017) and Deb and Claudio's on a larger scale and with other patient populations is a recommendation, but may be prohibitive due to the time, effort and complexity of tools involved during these studies. A content valid composite instrument needs to be developed to more easily measure factors identified to influence alarm fatigue. Deb & Claudio results demonstrated working conditions and staff individuality affected response time, not alarm fatigue. They summarized variables that influenced the nurse's mental

workload and affect. Bonafide et al.'s (2017) work supported the presence of the same variables of physical workload, time into shift, alarm type and criticality, cognitive workload, and task priority as influencing clinical decisions and alarm response times. There has been research on the multi-tasking nurses are required to manage and the effects of cognitive stacking and nurse errors, especially medication errors (DeLucia, Ott, & Palmieri, 2009). More detail is needed to be studied on the role of these factors and nurse interactions with clinical alarms.

Future interventions can focus on modifiable variables as nurse staff workloads, work environment, hours of work, and factors as interruptions and noise levels that stress the cognitive workloads and mental fatigue. For these interventions to be successful requires a culture change in the acute and critical care settings. Support must come from the administrative level and evidence-based success should be shared across healthcare systems globally. The goal is for improved patient satisfaction and outcomes. Future research needs to clarify what comprises alarm fatigue, develop means to more accurately measure its presence, and measure effectiveness of alarm management strategies by patient outcomes not just changes in alarm numbers and nurse attitudes.

Contributions of the Doctoral Project Team

The second reviewer conducted an independent search of the literature using key words identified by the primary reviewer and available search engines from a university affiliated hospital organization. The original search was conducted through December 2016, however, due to delays in synthesizing data, an updated search was completed through May 2018 with additional results added to the original timeframe. The primary

and second reviewers used the Cochrane Template for Systematic Review of Literature (see Appendix C) to document search results and analysis of each study. The templates of primary and second reviewers were compared. Discrepancies between the reviewers' results were addressed via discussion. There was a difference in search results that had one reviewer finding four different additional studies. This was determined to be related to the ability to access certain biomedical journals and university graduate dissertation postings by only one reviewer's search engine. Each discrepancy was discussed, and a mutual consensus was achieved before a study was selected for inclusion in the review.

Strengths and Limitations of the Project

One strength of this systematic review is the breadth of literature that was searched including journals of other professional organizations as physicians, informaticists, human factor specialists and bioengineers. Another strength is the results were replicated by a second reviewer with discussion and consensus over discrepancies. Finally, validated levels of evidence were used to analyze the data and determine conclusions and recommendations.

The availability of publications was limited to published findings in English language found through the professional online search engines, and the availability of full text articles. Due to the limited number of actual research studies accessible, performance improvement projects that statistically analyzed clinical data results were included in this review, so there is possible concerns of validity and reliability of data for these projects.

Section 5: Dissemination Plan

The systematic review protocol was submitted for PROSPERO registration. There is opportunity for presentation of findings locally at Boston Colleges of Fenway symposium, and nationally or internationally at Sigma Global Nursing national events as Global Health Initiatives or the Biennial Convention during 2020. The final systematic review will be developed into a manuscript for publication into a Scopus-indexed journal directed at health care quality improvement, nursing and human factors, and/or biomedical topics. There is also interest expressed by editors of American Journal of Critical Care and AACN Advanced Critical Care regarding this review's conclusions regarding effectiveness of alarm management interventions and the influence of human factors and cognitive workload on practices by the bedside nurse.

Analysis of Self

When I embarked on this DNP journey, my perceived time frame, based on my experience with pursuing my MSN degree, was to finish in 3 years. This journey has taken a delayed route as I near the end of my sixth year. I came into this process with substantial experience as a clinical nurse specialist adept at project management. My vision at the beginning was to earn my DNP and return to the patient's bedside to implement evidence-based practice, promote quality health care improvements, and improve patient outcomes.

As the journey continued, I found appreciation for the time and detail required for completion of quality products. As obstacles presented themselves, I learned to turn frustration into thoughtful perseverance. There have been periods of losing the vision as

unexpected demands of family, work, and health took precedence. The cliché "It takes a village" is pertinent in my successfully reaching the conclusion of this journey. It has taken colleague and family support, instructor direction, and self-redirection to reach the endpoint. I have improved skills in understanding complex systems, recognizing potential and actual challenges, identifying ways to overcome challenges, and directing improvements for positive outcomes. I now look more at the global picture than the local view. I have grown personally in my world perspectives and how to influence change more effectively. The view at journey's end has altered. It is now broader and, I believe, will allow me to become a more effective leader for the nursing profession.

Summary

The number of clinical alarms has substantially increased to over 42 different types with the purpose to alert nursing staff to potential harmful change in patient condition or medical device function. Research since 2006 has indicated that between 76% and 99% of physiological alarms were considered false or clinically nonactionable and a nuisance by nurses (Chambrin, 2001; Funk & Cvach, 2012; Graham & Cvach, 2010; Solet & Barach, 2012). Sentinel events reported to regulatory agencies through 2012 demonstrated that the state of alarm management and the presence of alarm fatigue had serious negative patient outcomes (Joint Commission, 2013).

Nuisance alarms continue to constitute 46% to 88% of audible alarms after implementing process improvement interventions focused on proper patient selection, electrode management, customized monitor alarm parameters, elimination of nonactionable alarms, and initiation of nursing staff culture changes directed by policies

for actionable alarms (Cvach, 2012; Cvach, Biggs et al., 2013; Whalen et al., 2013). There has been a significant reduction in physiological alarm occurrence rates, but clinical alarms continue to be ignored or receive delayed responses (Bonafide et al., 2017, Gazarian, 2014; Morano, 2014). Nurses' attitudes toward alarms have altered little after a decade of work to reduce the technological hazard (Funk et al., 2014; Ruppel et al., 2018). The problem of alarm overload and the impact on nurses and patients is found worldwide in acute and critical care units (Ashrafi et al., 2017; Bridi et al., 2014; Casey et al, 2018; Cho et al., 2016; Christensen et al., 2014). The purpose of this systematic review was to offer information on evidence-based practices that support effectiveness of alarm management strategies, and to identify gaps in current knowledge on alarm management, nurse's physical and cognitive responses to alarms, and alarm fatigue behavior.

Research and performance improvement studies reviewed for this project indicated that most evidence regarding alarm management interventions came from small samples with few crossovers to multiple institutions to allow for generalization of results. Studies often included multiple interventions implemented simultaneously, and researchers used different methodologies. Studies were rated at Level of Evidence V (descriptive or qualitative studies), IV (cohorts), III (nonrandomized trials) and II (randomized controlled trial). More recent studies offered moderate to high levels of evidence of interventions to reduce the number of alarms (Bonafide et al., 2017; Dewan et al., 2017). Intervention studies indicated some nursing role effectiveness based on the NREM middle range theory I used for evaluation (see Appendix F). However, only a few

studies addressed patient outcomes to determine the extent of nursing role effectiveness in relation to the patient population, which is the final measure for nursing care.

The studies did not address the reduction in number of nuisance alarms, improved nurse responses to alarms, and prevention of alarm fatigue behavior (Bonafide et al., 2017; Deb & Claudio, 2015; Ruppel et al., 2018). Other factors such as nurse work conditions, cognitive workload, experience level, patient condition, and nurse fatigue were identified as influencing nurse responses to clinical alarms (Bonafide et al., 2017; Deb & Claudio, 2015; Gazarian et al., 2014; Krinsky, 2016).

The most recent report from ECRI (2018) indicated a change in focus regarding physiological alarms. Researchers have not identified a solution to the problem of excessive alarms. There continue to be multiple types of alarms with multiple sounds requiring identification and interpretation by the nurse. Nursing perspectives continue to indicate the presence of alarm fatigue behaviors. In this review, I did not find a validated and reliable instrument to measure the presence or extent of alarm fatigue. A valid tool needs to be developed that incorporates human factors that address nurse-monitoring device interactions, not just observed or perceived nurse response to alarms. Future practice changes should address the human factor components, which will require social changes to health care systems. Based on studies from outside the United States, there are similar alarm-related issues in other countries and cultures. Therefore, global social change to health care delivery systems needs to be implemented to ensure the goal of safe patient outcomes. From such changes, the nurse may experience increased work satisfaction and decreased stress related to cognitive workloads. However, it is the end

consumer, the patient, who is at the mercy of the health care environments that include clinical alarms, and who will benefit the most from improved alarm management and clinicians understanding methods to prevent alarm fatigue behaviors.

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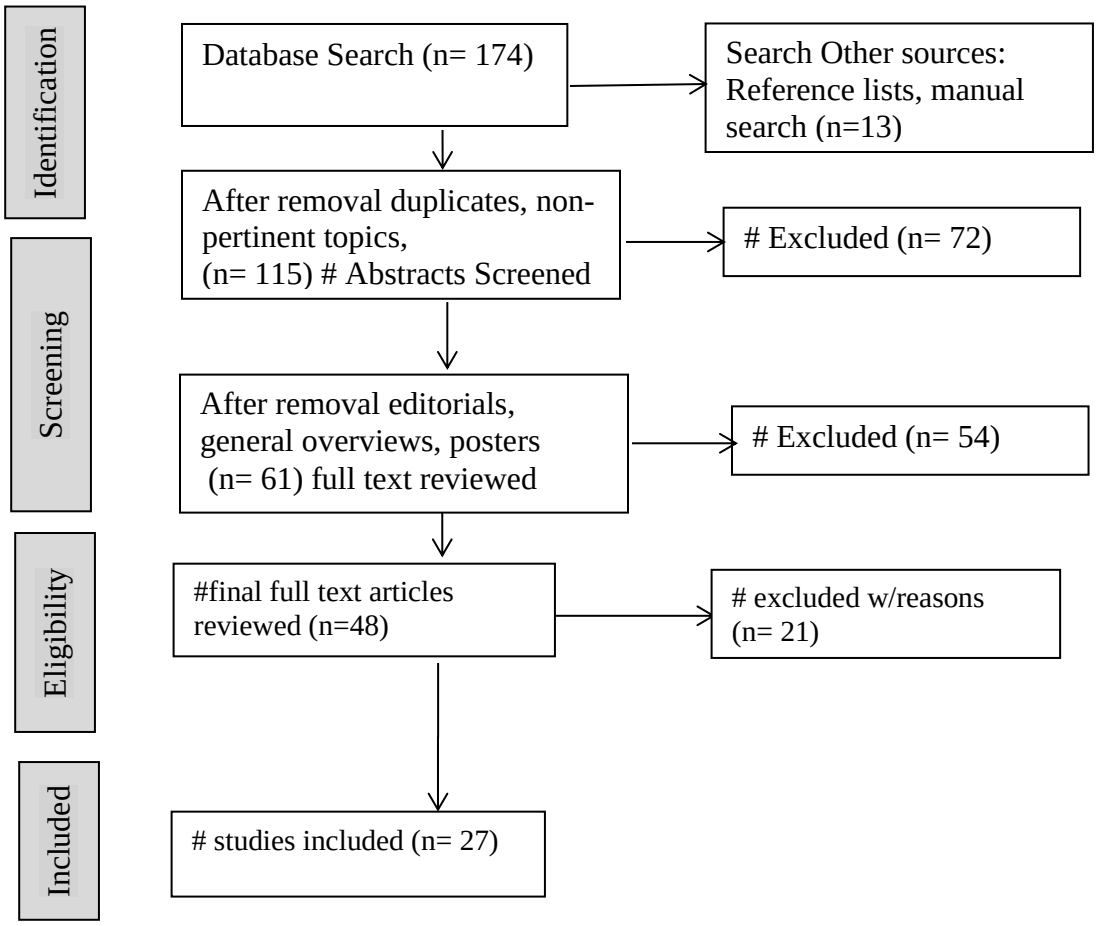
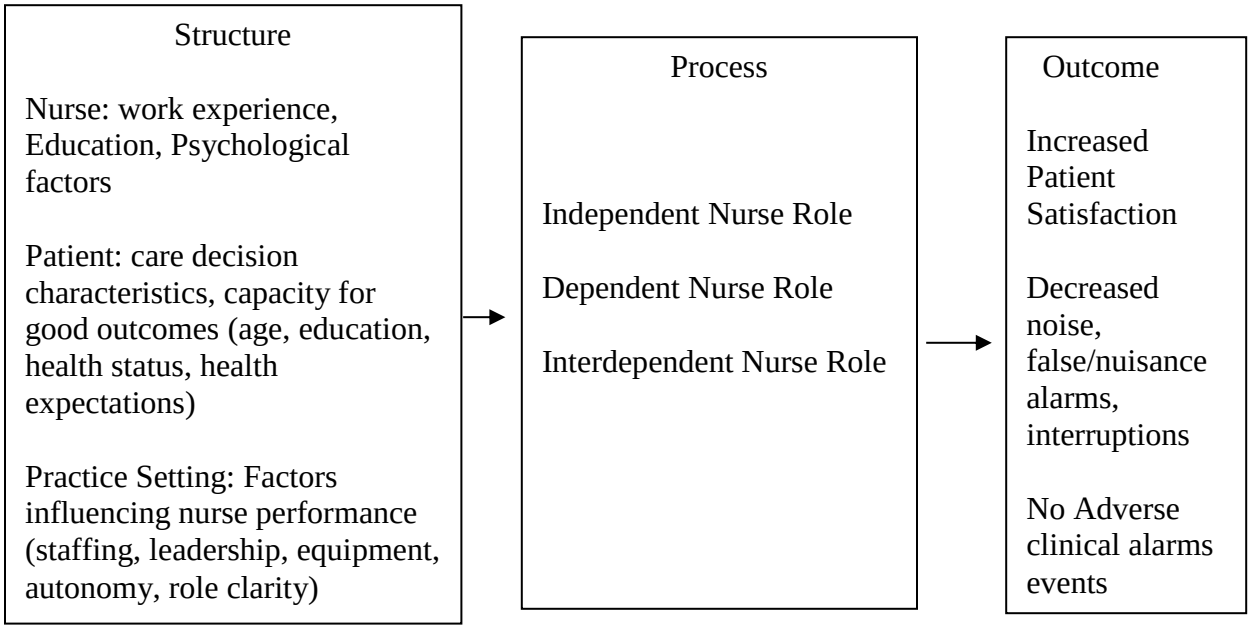
Appendix A: PRISMA Systematic Review Flow Chart



From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *P*referred *R*eporting *I*tems for *S*ystematic Reviews and *M*eta-*A*nalyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

Appendix B: Nursing Role Effectiveness Model



Appendix C: Matrix Template for Systematic Review

Author(s)	Report	source	citation	author's institution	contact address	author contacted	report type	focus	study design	IRB approval	Trial method

data item variables	sample	sample size	statistical analysis techniques	Tests appro priate	outcomes	risk of Bias	strength of evidence	weakness	level of evidence	further recommedation s by authors	Report excluded	Reason excluded

Appendix D: PRISMA-P 2015 Checklist

Section	#	Checklist Item
Administrative Information		
Title:		
Identification	1a	Identify the report as a protocol of a systematic review
Update	1b	If the protocol is for an update of a previous systematic review, identify as such
Registration	2	If registered, provide the name of the registry (such as PROSPERO) and registration number
Authors:		
Contact	3a	Provide name, institutional affiliation, e-mail address of all protocol authors; provide physical mailing address of corresponding author
Contributions	3b	Describe contributions of protocol authors and identify the guarantor of the review
Amendments	4	If the protocol represents an amendment of a previously completed or published protocol, identify as such and list changes; otherwise, state plan for documenting important protocol amendments

Support:		
Sources	5a	Indicate sources of financial or other support for the review
Sponsor	5b	Provide name for the review funder and/or sponsor
Role of sponsor or funder	5c	Describe roles of funder(s), sponsor(s), and/or institution(s), if any, in developing the protocol
Introduction		
Rationale	6	Describe the rationale for the review in the context of what is already known
Objectives	7	Provide an explicit statement of the question(s) the review will address with reference to participants, interventions, comparators, and outcomes (PICO)
Methods		
Eligibility criteria	8	Specify the study characteristics (such as PICO, study design, setting, time frame) and report characteristics (such as years considered, language, publication status) to be used as criteria for eligibility for the review

Information sources	9	Describe all intended information sources (such as electronic databases, contact with study authors, trial registers or other grey literature sources) with planned dates of coverage
Search strategy	10	Present draft of search strategy to be used for at least one electronic database, including planned limits, such that it could be repeated
Study records:		
Data management	11a	Describe the mechanism(s) that will be used to manage records and data throughout the review
Selection process	11b	State the process that will be used for selecting studies (such as two independent reviewers) through each phase of the review (that is, screening, eligibility and inclusion in meta-analysis)
Data collection process	11c	Describe planned method of extracting data from reports (such as piloting forms, done independently, in duplicate), any processes for obtaining and confirming data from investigators

Data items	12	List and define all variables for which data will be sought (such as PICO items, funding sources), any pre-planned data assumptions and simplifications
Outcomes and prioritization	13	List and define all outcomes for which data will be sought, including prioritization of main and additional outcomes, with rationale
Risk of bias in individual studies	14	Describe anticipated methods for assessing risk of bias of individual studies, including whether this will be done at the outcome or study level, or both; state how this information will be used in data synthesis
Data		
Data synthesis	15a	Describe criteria under which study data will be quantitatively synthesized
	15b	If data are appropriate for quantitative synthesis, describe planned summary measures, methods of handling data and methods of combining data from studies, including any planned exploration of consistency (such as I2, Kendall's τ)

	15c	Describe any proposed additional analyses (such as sensitivity or subgroup analyses, meta-regression)
	15d	If quantitative synthesis is not appropriate, describe the type of summary planned
Meta-bias(es)	16	Specify any planned assessment of meta-bias(es) (such as publication bias across studies, selective reporting within studies)
Confidence in cumulative evidence	17	Describe how the strength of the body of evidence will be assessed (such as GRADE)

From: Shamseer, L., Moher, D., Clarke, M., Ghersi,D., Liberati, A., Petticrew, M., Shekelle, P., & Stewart, L. (2015). PRISMA-P Group. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: Elaboration and explanation. *British Medical Journal*. Jan 2; 349. g7647.

Appendix E: Levels of Evidence

Type of evidence	Level of evidence	Description
Systematic review or metaanalysis	I	A synthesis of evidence from all relevant randomized, controlled trials
Randomized, controlled trials	II	An experiment in which subjects are randomized to a treatment group or control group
Controlled trial without randomization	III	An experiment in which subjects are nonrandomly assigned to a treatment group or control group
Case-control or cohort study	IV	Case-control study: a comparison of subjects with a condition (case) with those who don't have the condition (control) to determine characteristics that might predict the condition. Cohort study: an observation of a groups(s) [cohort(s)] to determine the development of an outcome(s) such as a disease
Systematic review of qualitative or descriptive studies	V	A synthesis of evidence from qualitative or descriptive studies to answer a clinical question
Qualitative or descriptive study	VI	Qualitative study: gathers data on human behavior to understand why and how decisions are made Descriptive study: provides background information on the what, where, and when of a topic of interest
Opinion or consensus	VII	Authoritative opinion of expert committee

Fineout-Overholt, Melnyk, Stillwell, & Williamson,.2010. Critical appraisal of the evidence: Part I an introduction to gathering, evaluating, and recording the evidence. American Journal of Nursing. 110 (7). 47-52.

Appendix F: Included Studies

Key: Year = study year; Category = focus of nursing article; NREM theory (Refer to Appendix B): S= structure, Pract = practice settings, P = Process, Inde = Independent nurse role, Inter = Interdependent nurse role, depend = Dependent nurse role; O = outcomes, pt satis = Patient satisfaction, noise = decreased noise, false/ nuisance alarms, interruptions, events = no adverse clinical alarm events; LOE = Levels of Evidence

Author(s)	Title	Year	Study Type *Category*	Sample Outcomes	NREM	LOE
Baillargeon, E.	Alarm fatigue: A risk assessment	2013	Quantitative Observational *Nurses responses*	Sample: 36 RN medsurg tele unit, convenience observed 6 random selected monitors; study 6 hours over 6 weeks vary shift; Results: 174 alarms (56% nuisance, 13% false, 48% valid) RN response time 6 sec critical alarms, 7.01 min leads off. Nurses at risk for alarm fatigue	S: Pract	VI

Author(s)	Title	Year	Study Type *Category*	Sample Outcomes	NREM	LOE
Bonafide, C. P., Lin, R., Zander, M., Graham, C. S., Paine, C. W., Rock, W.,…Keren, R.	Association between exposure to nonaction-able physiologic monitor alarms and response time in a children's hospital	2013	quantitative observational *Nurses responses*	Sample: 36 RNs, 40 pedi ICU patients & tele unit, 210 hours observed, Results: 5070 alarms non-actionable, (87.1% PICU, 99% med unit); median response time PICU 3.3 min, med unit 9.8 min; time higher as non-action alarms increase	S: Pract	IV
Bonafide, C. P., Localio, A. R., Holmes, J. H., Nadkarni, V. M., Stemier, S., Macmurchy, M…. Keren, R.	Video analysis of factors associated with response time to physiologic monitor alarms in a children's hospital	2015	Quantative Prospective cohort observational study *Nurses responses*	Sample 38 RNs/ 100 pediatric patients, 551 hours observed Results – 48.9% valid alarms, 0.5% actionable; median response 10.4 min; response time not related to number nonactionable alarms, is influenced by other factors of patient, nurse, environment	S: Pract	IV

Author(s)	Title	Year	Study Type *Category*	Sample Outcomes	NREM	LOE
Casey, S., Avalos, g., Dowling, M.	Critical Care nurses' knowledge of alarm fatigue and practices towards alarms: A multicentre study	2016	cross sectional survey *nurse perspective*	Sample 250 critical care nurses in Ireland, 10 departments, 6 hospitals; Used HTF survey; Results: 90% agree nonactionable alarms frequent, 91% agree alarms disrupt care & build distrust; 31% agree alarms used effectively; 52% not sure how to prevent alarm fatigue;	S: Nurse	VI
Cho, O. M., Kim, H., Lee, Y. W., Cho, I.	Clinical alarms in intensive care units: perceived obstacles of alarm management and alarm fatigue in nurses	2014	Quantitative Descriptive observational study *Nurses perspective*	Sample: Korean random selection ICU bed for 1 hr observation, 48 hr total; N= 77 RNs completed survey, Alarm fatigue instrument, Results: Multiple types alarms, 2184 alarms (45.5 alarms/pt/hr); 36.2% valid; 18.8% alarms customized; alarm fatigue score 24.3 (+ 4) out of 35; greatest obstacle frequent false alarms result reduced responses; lowest issue – difficulty setting alarms;	S: Setting Nurse P: Inde	VI

Author(s)	Title	Year	Study Type *Category*	Sample Outcomes	NREM	LOE
Christensen, M., Dodds, A., Sauer, J., Watts, N.	Alarm setting for the critically ill patient: A descriptive pilot survey of nurses' percep-tion of current practice in an Australian Regional Critical care unit	2013	Descriptive pilot survey *nurses perspective*	Sample: 48 RNs in Australian ICU completed survey on alarms Results: themes – defining nuisance alarm, alarm setting practices, silencing or altering other nurse's alarms; 93% feel desensitization lead to disabling alarms;	S: Pract P: Inter	VI
Cvach, M.	Monitor alarm fatigue: An integrative review	2010	Integrative review from 1/1/2000-10/1/2011 *Intervention*	Sample: 1/1/2000 to 10/1/2010 lit review; themes: excessive alarms and effects on staff, nurse response to alarms, alarm sounds, technology to reduce alarms, alarm notification systems. Few RCTs, most evidence observational or qualitative, few address patient outcomes, samples small, self-select, single sites. Strategies to reduce alarm desensitization are non-research evidence.	S: pract P: inde-pend & inter O; event s	V

Author(s)	Title	Year	Study Type *Category*	Sample Outcomes	NREM	LOE
Cvach, M. M., Biggs, M., Rothwell, K. J., Charles-Hudson, C.	Daily electrode change and effect on cardiac monitor alarms: An evidence-based practice approach	2012	Quantitative performance improvement *Intervention*	Sample: 2 med units, 40 beds, implemented daily electrode change, Results: Overall decrease technical alarms each unit (32%, 56%), 46% decrease average alarms/day/bed, no patient outcomes addressed	P: Inde O: noise	III
Dandoy, C. E., Davies, S. M., Flesch, L. Hayward, M., Koons, C., Coleman, K., Jacobs, J. Weiss, B.	A team-based approach to reducing cardiac monitor alarms	2013	Quantitative time series performance improvement *Intervention*	Sample: pediatric transplant unit over 11 mo. Initiated small tests change with series data collection; Reverse correlation compliance increase, alarms decreased median 180/day to 40, false alarms 95% to 50%.	S: Patient, Nurse P: Inter O: Pt satis, noise, events	III

Author(s)	Title	Year	Study Type *Category*	Sample Outcomes	NREM	LOE
Deb, S & Claudio, D.	Alarm fatigue and its influence on staff perform-ance	2014	observational study *nurse response*	Sample: convenience ICU 6 clerks, 18 RNs; observation work sampling, participant surveys – HTF, Heirarchical task analysis, mental workload measure, affect measure, personality type; Results: Clerks prioritize alarms differently; RN response impacted by environment & staff individuality, not alarm fatigue	S: nurse, Pract P: inde	IV
Dewan, M., Wolfe, H., Lin, R., Ware, E., Weiss, M., Song, L., Macmurchy, M., Davis, D. Bonafide, C.	Impact of a safety huddle-based interven-tion on monitor alarm rates in low-acuity pediatric intensive care units patients	2015	Quantitative quasi experimental study *Intervention*	Sample: random select hi alarm, low acuity 55 bed PICU, Safety huddle held to address alarms, Control group different low acuity unit; Results: 48.5% reduction alarms after huddle vs 21.6% reduction historic control/ 34.4% reduction concurrent control	S: Patient & Pract; P: Inter O: noise	II

Author(s)	Title	Year	Study Type *Category*	Sample Outcomes	NREM	LOE
Funk, M. Clark, T., Bauld, T. J., Ott, J. C., Coss, P.	Attitudes and practices related to clinical alarms	2014	quantitative study *nurses perspective*	Sample: n=4278 HTF survey 2011, compared results to HTF survey 2006; Results: non-significant between both surveys; most important issue frequency of false alarms; more agree central techs helpful, more alarm management initiated	S: Nurse	IV

Author(s)	Title	Year	Study Type *Category*	Sample Outcomes	NREM	LOE
Gazarian, P. K.	Nurses' response to frequency and types of electrocard-iography alarms in a non-critical care setting: A descriptive study	2013	Qualitative descriptive study *Nurses responses*	Sample n=9, tele medical surgical units, 54 hours data collected on nurse's patient's alarms and nurse response; Results: 205 alarms, 46.8% alarms responded to; 44 system alarms, 39 not corrected, lead fail second most frequent alarm. No consistency noted for nurse to check alarms at beginning of shift to ensure on and audible. Of 161 status alarm, 53 (32.9%) were artifact. Observation noted nurse involved in cognitive work while responding, and presence of competing tasks to prioritize.	P: Inde	VI

Author(s)	Title	Year	Study Type *Category*	Sample Outcomes	NREM	LOE
Gazarian, P. K., Carrier, N., Cohen, R., Schram, H., Shiromani, S.	A description of nurses' decision-making in managing electrocar-diographic monitor alarms	2013	Qualitative descriptive observation study *nurses responses*	Sample: n=9 nurses, snowball sampling, observed for two 3-hour sessions. Time compared to alarm events during period. Post shift retrospective interview regarding decision making at time of alarm. Results: information, colleague guidance, nurse experience, technology management and decision-making contribute to nurse's alarm management; How nurse uses the information puts alarms into context of individual patient and influences decisions.	S: pract P: inde O: Events	VI

Author(s)	Title	Year	Study Type *Category*	Sample Outcomes	NREM	LOE
Graham, K.C., Cvach, M.	Monitor alarm fatigue: Standard-izing use of physiology-ical monitors and decreasing nuisance alarms	2006	Quantitative performance improvement *Intervention*	Sample: small tests of change in MPCU to re-educate nurses on alarm practice, adjust default settings, make alarms actionable and add secondary notification Results: increased nurse compliance up to 94% in adjusting alarms after interventions; 43% reduction physiological alarms	P: Inter O: noise	III
Honan, L., Funk, M., Maynard, M., Fahs, D. Clark, T., David, Y.	Nurses perspective on clinical alarms	2011	qualitative study *nurses perspective*	Sample: 790 comments from 2011 HTF survey analyzed using Krippendorff method for content analysis Results: 6 themes – dissonance and Desensitization pollution/panic/pathology, accountability, RN authority, clinical alarm management, future technology	S: Prac t	VI

Author(s)	Title	Year	Study Type *Category*	Sample Outcomes	NREM	LOE
Korniewicz ,D. M., Clark, T., David, Y.	A national online survey on the effective-ness of clinical alarms	2006	quantitative study *nurses perspectives*	Sample: 1327 respondents to national survey on nurse's perspectives about alarms; Results: 81% agree alarm occur frequently, 77% agree disrupt care and create mistrust, 78% agree frequent alarms can lead to disabling alarms	S: Pract	IV
Krinsky, R. S.	Fatigue and alarm fatigue in critical care nurses	2014	descriptive, correlational research study quantitative study *nurse responses*	Sample: Non-probability convenience staff critical care RNs at national convention; Completed surveys – occupational fatigue exhaustion recovery scale, NASA-TLX workload, HTF, demographics Results:positive correlation chronic fatigue with acute, critical care RN have hi rate fatigue, alarm response temporal & frustration	S: Nurse Pract	IV

Author(s)	Title	Year	Study Type *Category*	Sample Outcomes	NREM	LOE
Peterson, J. T.	An investiga-tion into the efficacy of alarm fatigue reduction strategies	2013	quantitative study *intervention*	Sample: 14 telemetry units at tertiary hospital. Variety of strategies to reduce alarms implemented on different units. Pre and post alarm data collected. Some data lost so extrapolated to obtain results. Greatest change unlatching alarms, unknown outcome with changed parameters, no significant change daily electrode changes	S: pract O: - noise	IV
Ruppel, H., Funk, M., Clark, T., Gieras, I., David, Y., Bauld, T. J., Coss, P., Holland, M.	Attitudes and practices related to clinical alarms: A follow-up survey	2016	Quantitative study *Nurses perspective*	N=1241; 3rd HTF compared to 2011 Results: Continue to agree frequent nuisance alarms, disrupt care; less agreement staff respond quickly, double number indicated adverse alarm related events past 2 years; less agreement with use of smart alarms and third party notification systems in 2016	S: Pract	IV

Author(s)	Title	Year	Study Type *Category*	Sample Outcomes	NREM	LOE
Sendelbach, S., Wahl, S., Anthony, A. Shotts, P.	Stop the noise: A quality improve-ment project to decrease electrocard-iographic nuisance alarms	2013	Quantitative performance improvement *intervention*	Sample: 16 bed adult ICU, pre & post measure of bundle interventions; Results: mean 28.5 alarms/ bed/day reduced to3.29, no change life threatening alarms, no change pulse ox alarms	S: pract P: Inter & inde	IV
Sowan, A. K., Gomez, T. M., Tarriela, A. F., Reed, C. C., Paper, B. M.	Changes in default alarm setting and standard in-service are insufficient to improve alarm fatigue in an intensive care unit: A pilot project	2015	Quantitative performance improvement *intervention*	Sample: 39 RNs one ICU; pre & post intervention measurement after changes default parameters & education; Results: decrease in ECG alarms, high alarms aline & O2Sat, HTF no significant change pre & post, 50% RNs indicate need more education	S: pract. Nurse P: Inter	IV

Author(s)	Title	Year	Study Type *Category*	Sample Outcomes	NREM	LOE
Sowan, A. K., Tarriela, A. F., Gomez, T. M., Reed, C. C., Rapp, K. M.	Nurses' perception and practices toward clinical alarms in a transplant cardiac intensive care unit: Exploring key issues leading to alarm fatigue	2014	performance improvement *nurses perceptions*	Sample: 39 RNs one TCICU, HTF survey after new monitors, results compared to 2011 HTF results. Results: 95– 98% agree false alarms frequent, disrupt care, reduce trust, cause disabling alarms, higher than 2011 HTF; significantly less TCICU agree staff sensitive to respond, have policies r/t alarms and are effective	S: Pract	VI
Speich, M. E.	Reducing alarm fatigue in the intensive care units: A quality improve-ment research	2016	Quantitative performance improvement *intervention nurses perception*	Sample: 12 RNs, 28 bed medsurg ICU; 4 point bundle education, pre & post observation data 5 days, 2 hr/d, HTF survey prior; Results: 88% agree alarms frequent, 91% disrupt, 66.7% distrust; Disagree clinical staff sensitive to alarms; hi post alarms ABP, NIBP, O2Sat; no significant change pre & post,discrepancy between manual data & software	S: pract P: Inde & Inter	IV

Author(s)	Title	Year	Study Type *Category*	Sample Outcomes	NREM	LOE
Srinivasa, E., Mankoo, J., Kerr, C.	An evidenced-based approach to reducing cardiac telemetry alarm fatigue	2014	Quantative performance improvement *intervention*	Sample: surgical telemetry unit; over 43 days data mine tele alarms and track noise levels over 21 days. Implemented PVC default setting changes. Results: 84% reduction PVC alarms, 54% decrease overall alarms, Significant decrease in noise levels	S: Pract O: noise	IV
Walsh-Irwin, C., Jurgens, C. Y.	Proper skin prepara-tion and electrode placement decreases alarms on a telemetry unit	2015	Quantitative prospective descriptive study *intervention*	Sample: Purposive sampling patients (n=15) adult telemetry unit, alarms counted 24 hrs after admission, EKG electrode change protocol done, alarms counted 24 hrs after. Results: t test with bootstrapping, alarms decreased 44% ($p<0.05$)	S: Pract	III

Author(s)	Title	Year	Study Type *Category*	Sample Outcomes	NREM	LOE
Whalen, D. A., Covelle, P. M., Peipenbrink, J. C., Villanova, K. L. Cuneo, C. L., Awtry, E. H.	Novel approach to cardiac alarm manage-ment on telemetry units	2014	Quantitative performance improvement Mixed study *intervention*	Sample: cardiac medical telemetry unit, data mining alarms 2 week pre & post & observation staff responses pre collected, Intervention of changing default parameters, altering alarm crisis levels so all audible alarms now actionable; Results: 89% (p<.0001) decrease total audible alarms, largest difference HR, no change in patient safety events	S: Pract P: Inter O: noise, events	III