Workload effects on response time to life-threatening arrhythmias

Principal investigator: Noa Segall, PhD

Team members: Christopher Granger, MD
Melanie Wright, PhD
Gene Hobbs, CHT
Alberto Bonifacio, RN, BSN, MHA, CEN
Jeffrey M. Taekman, MD
Amanda Anderson, BA, CNA

Organization: Duke University

Project dates: 4/1/2012 – 3/31/2013
No-cost extension 4/1/2013 – 3/31/2014

Program Officer: Kerm Henriksen

Acknowledgement: This project was supported by grant number R03HS021332 from the Agency for Healthcare Research and Quality. The content of this report is solely the responsibility of the author and does not necessarily represent the official views of the Agency for Healthcare Research and Quality.

Grant number: 1R03HS021332-01

Abstract

Purpose: We used simulation to assess cardiac telemetry monitoring performance. Our objective was to determine the impact of increasing the number of patients monitored on response time to cardio-respiratory events.
Scope: Between 370,000 and 750,000 cardiopulmonary resuscitations are attempted each year in US hospitals. For many patients, pulseless ventricular tachycardia or ventricular fibrillation (VT/VF) is the first monitored arrhythmia, which may be treated successfully with prompt defibrillation (within 2 minutes of onset). To increase the potential for timely detection of cardiac events, more and more at-risk patients are now monitored remotely by cardiac telemetry technicians. However, decisions regarding the appropriate number of patients that a single technician may safely and effectively monitor are primarily based on technological capabilities and not on our understanding of human information processing limitations.
Methods: We designed simulation that replicates the work of cardiac telemetry technicians using a combination of real patient data and a simulated patient experiencing a VF event. We carried out a randomized controlled trial to determine the impact of increasing the number of patients monitored on response time to VF. We compared response times across five conditions: 16, 24, 32, 40, and 48 patients.
Results: The difference between patient loads was not statistically significant, but frequency of failure to meet a response time goal of less than 20 seconds was significantly higher in the 48-patient condition than in all other conditions. Task performance decreased as patient load increased.

Keywords: cardiac telemetry, ventricular fibrillation, response time, number of patients, simulation.

Purpose

There is a critical need to improve response time to life-threatening arrhythmias in the hospital setting. We used simulation to assess human-system performance in the context of cardiac telemetry monitoring and detection of these rare events. The objective of the proposed research was to determine the impact of increasing the number of patients monitored on response time to cardio-respiratory events. We hypothesized that response times will increase as the patient load increases.

The contribution of the proposed research is in using high-fidelity simulation to empirically determine the impact of the number of patients monitored by technicians on the latency of their detection of critical arrhythmias. This contribution is significant because it will inform efforts to study this problem in real-world cardiac telemetry and guide the development of evidence-based standards for remote monitoring. The application of such standards is expected to improve survival after in-hospital cardiac arrest. Additionally, if they are applied to ambulatory patients monitored outside the hospital, the potential to save lives could be greater.

Scope

Between 370,000 and 750,000 in-hospital resuscitations are attempted each year in the US.[1] Reported survival rates vary significantly, from 0% to 29%.[1] The American Heart Association describes speed of response as key to improving survival, including early access to emergency medical support and early cardiopulmonary resuscitation (CPR), defibrillation, and advanced life support. They recommend that a defibrillator be ready within 1 to 2 minutes.[2] For patients suffering pulseless ventricular tachycardia and ventricular fibrillation (VT/VF), a recent study revealed a strong association between time to defibrillation and survival to discharge.[3] The survival rate was approximately 40% for patients defibrillated within 2 minutes of recognizing arrest, with 5%-10% increased risk of death per minute of additional delay.[3] However, research on this topic often starts at the point of arrest recognition rather than at the time the arrhythmia actually begins. To our knowledge, the time prior to recognition has not been examined (i.e., no studies have assessed time to detection of a dysrhythmia or how often detection is delayed). Prior research assumes timely detection, but sentinel event data suggest this is probably a risky assumption. In addition, there is evidence to show that survival rates are much higher (85%-100%) when the initial cardiac arrest is witnessed by medical personnel during supervised exercise programs[2] and that patients who are witnessed having cardiac arrests have five times higher survival rates than patients in whom the arrest is not witnessed.[4] These data point to the critical importance of effective patient monitoring and early detection of life-threatening arrhythmias.

Although not all arrhythmias can be treated, treatable VT/VF arrhythmias occur in about 24% of in-hospital arrests.[5] To increase the potential for timely detection of cardiac events, a growing number of at-risk patients are being monitored remotely by cardiac telemetry technicians. The telemetry technician is dedicated to sitting in front of a display continuously for long hours while monitoring live patient ECGs – often between 16 and 50 at a time (at Duke hospitals and elsewhere[6,7]). Limitations of human visual memory and eye scan rates may place upper limits on the number of patients that a technician may safely and effectively monitor.[8] In addition, we know that humans are relatively poor at maintaining attention over long periods of time and quickly succumb to a vigilance decrement,[9] a reduction in detection performance over time. At Duke Hospital, we estimate that our technicians see a life-threatening VT/VF rhythm about once or twice a month. Because these are rare events, they are difficult to study in clinical practice, and it is difficult to assess the effect of different patient loads on performance with respect to prompt response to these life-threatening cardiac events.[10] In our own institution, attention to patient safety in the context of remote telemetry has been heightened in recent months because of events in which detectable arrhythmias were apparent in recorded data from the physiology monitor but not responded to in a timely fashion, resulting in patient harm. Popular press reports of sentinel events suggest that Duke is not alone in struggling with safe patient monitoring. Given the fatal consequences of suboptimal performance, there is an urgent need to develop evidence-based approaches to assess and improve cardiac monitoring performance in US hospitals. Simulation provides such an opportunity to prospectively study responses to critical cardiac events.

Methods

Design and Participants

The design was a randomized trial in which participants were randomly assigned to one of five patient loads – 16, 24, 32, 40, or 48 patients – and their response time to a simulated VF was measured. Participants were 15 remote telemetry technicians and 27 nurses from cardiac units (e.g., cardiothoracic intensive care units) from Duke University Hospital and three surrounding hospitals. Eight participants each completed the task in the 16-, 32-, and 40-patient conditions, and nine participants each completed the task in the 24- and 48-patient conditions. Their average age was 33. Thirty-seven of the 42 participants, including all the technicians, had over 1 year of experience in cardiac patient monitoring. Participants received compensation for taking part in the study. The study was approved by the Duke University Institutional Review Board for research involving the use of human subjects. Written informed consent was obtained from all participants.

Simulation Design

We designed a novel and realistic laboratory-based simulation that replicated the actual tasks performed by remote cardiac telemetry technicians at Duke University Hospital. We video and audio recorded true patient data with a single simulated patient embedded in the patient set. The technical implementation involved connecting an ECG rhythm simulator into the hospital's network that transmits physiologic signals to remote telemetry monitors. The signal appears exactly as it would appear for a real patient. Because multiple patients are monitored simultaneously, the simulated signal is displayed on the monitor among many signals from true patient data (Figure 1).

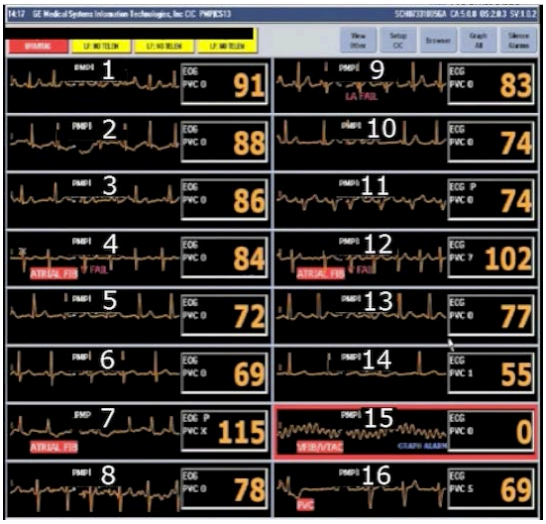

Figure 1. Simulated VF patient (number 15) embedded with real patients.

We set up one display with 15 true patients and one simulated patient (Figure 1), two displays with 16 true patients each, and one display with eight true patients to simulate 16, 24, 32, 40, and 48 patients on up to three displays (see Figure 2 for the 48-patient setup). We recorded both audio (alarm) and video data for these screen setups for 4 hours. All patient identifiers were removed from the video recordings and replaced with numbers (Figure 1). During the audio and video recording period, we simulated one VF arrhythmia. We timed the event to be well into the data collection period (after over 3 hours), to allow participants to become comfortable with the task environment and to possibly experience a vigilance decrement due to a long time on the task, similar to daily work conditions of telemetry technicians.

A subject matter expert – an experienced cardiac telemetry technician – noted all tasks required of technicians who monitored the recorded patients throughout the 4-hour period. These included interpreting the cardiac rhythms of current and new patients, making phone calls to units to report patient events (some of which were time constrained, depending on the urgency of the event), documenting these events, and printing their rhythm strips. We also obtained all documentation, rhythm strips, and other artifacts created during care for these patients. The subject matter expert interpreted the rhythm strips, documenting the PR interval, QRS duration, QT interval, heart rate, and heart rhythm for each patient.

Procedure

For the experiment, study participants were randomly assigned to one of the five patient loads. In our laboratory, they received instructions on the task and completed a training session before the 4-hour monitoring session. During these sessions, participants performed the work of telemetry technicians, including rhythm strip interpretation, documentation, and phone calls to patient units as necessary (Figure 2). For instance, if a recorded patient experienced bradycardia (defined as a heart rate < 45 beats per minute), participants were to call the patient's nurse within 1 minute, print two rhythm strips, document the event on one strip, and send the other strip to the patient's nurse (put the strip in a paper tray). A study coordinator provided rhythm strips when requested (i.e., when a participant asked to print strips) and received and responded to calls made by participants to "the nurse" or "the unit coordinator." Responses to calls were scripted. Participants were given instructions to call one number for routine calls and a different number for urgent calls (a button press to choose a line).

Figure 2. Experimental setup for 48 patients. One patient is simulated with a VF arrhythmia (on the left display). ECGs for the remaining 47 patients are real (pre-recorded).

After the practice session, we started the 4-hour recorded session, and the participants performed the required tasks. During this session, the simulated patient sustained VF, with all participants exposed to the same arrhythmia at the same time. The time required for participants to call in response to the arrhythmia was recorded by an observer using a stopwatch. The observer started the watch at the time the arrhythmia appeared, which was known to the observer, and stopped the watch when the phone rang. Participant actions and response times were recorded manually in real time, and performance of documentation tasks was assessed after the experiment. Following the monitoring session, participants completed a survey regarding the realism of the simulation.

Measures

The primary dependent variable was response time (i.e., time lapse from the point at which the arrhythmia began to the time of the urgent call). We also defined clinically meaningful performance degradation as a detection time that is 20 seconds or longer and compared the number of participants in each patient load whose response time passed this threshold. Although 20 seconds may seem like a brief period of time, it is

important to remember that it only represents time to identify an arrhythmia; it does not reflect time to then alert the nurse, check the patient, call a code, and apply defibrillation.

Two secondary measures were a task performance score and a rhythm interpretation score. For the task performance score, participants received a score of 0 (not performed) or 1 (performed) for each required task, for which multiple tasks are associated with each patient event (Table 1). Tasks were weighted based on importance (e.g., a larger weight was assigned to the task of making a phone call to report an event than to the task of sending a copy of a rhythm strip to the patient's nurse). A weighted score was calculated for each patient event, and the overall task performance score was derived by averaging the weighted scores for all patient events.

Table 1. Experimental tasks and weights (for calculating a task performance score).

	Required Tasks	**Weights**
Patient off the monitor (leads off)	Call HUC	5
	Make phone call within 3 minutes	4
	State correct problem	4
	Print a blank rhythm strip	1
	Document the patient's number, the current time, the HUC's name, and the patient location	1
Patient returns (leads back on)	Print a rhythm strip	1
	Document the patient's number, the current time, and that the patient is back on the monitor	1
Patient discharged	Print a blank rhythm strip	1
	Document the time of the discharge phone call and the discharge order	1
Tachycardia (a 30-bpm increase from baseline)	Call HUC	5
Bradycardia (< 45 bpm)	Make phone call within 1 minute	4
Converting to a different rhythm (e.g., Afib)	Ask to speak to the patient's nurse	3
	State correct problem	4
	Print rhythm strips	1
	Send one strip to the patient's nurse	1
	Document the patient's number, the current time, the nurse's name, and the rhythm	1
New/increasing ectopy, including more than eight PVCs, PACs, or PJCs per minute, first-degree heart block, runs of Afib	Call HUC	5
	Ask to speak to the patient's nurse	3
	State correct problem	4
	Print rhythm strips	1
	Send one strip to the patient's nurse	1
	Document the patient's number, the current time, the nurse's name, and the rhythm	1
Continuous poor rhythm tracing (artifact or broken signal for more than 1 minute)	Call HUC	5
	Ask to speak to the patient's nurse	3
Return to a normal sinus rhythm	State correct problem	4
	Print a rhythm strip	1
	Document the patient's number, the current time, the nurse's name, and the rhythm	1
Ventricular tachycardia (VT)	Call HUC	5
Ventricular fibrillation (VF)	Make call using 'red' phone	4
Asystole	Stress urgency and gravity of event	5
	State correct problem	4
	Print rhythm strips	1
	Send one strip to the patient's nurse	1
	Document the patient's number, the current time, the HUC's name, whether someone was sent to the patient's room, and the rhythm	1
	Call HUC again	5

	Required Tasks	Weights
Asystole	Make call using 'red' phone	4
	Make phone call within 1 minute of previous call	4
	Confirm that a nurse/doctor is in the patient's room, and that a code was called	4

HUC, health unit coordinator; bpm, beats per minute; Afib, atrial fibrillation; PVC, premature ventricular contraction; PAC, premature atrial contraction; PJC, premature junctional contraction.

Participants were asked to interpret the baseline rhythm of each patient once during the session, at a time that was convenient for them. In calculating a rhythm interpretation score, the PR interval, QRS duration, QT interval, and heart rate were scored as correct (1) if the participant's answer was within 20% of the correct value or as incorrect (0). The rhythm type was scored as correct (1), partial answer (0.5), or incorrect (0). An average score was calculated for each rhythm strip, and the rhythm interpretation score was obtained by averaging all rhythm strip scores.

We also asked participants to complete a brief survey regarding the realism of the presentation of the data, task, and task environment.

Statistical Analysis

A one-way analysis of variance (ANOVA) was used to compare response times, task performance scores, and rhythm interpretation scores across the five patient loads. Significant ANOVA results were followed by Tukey's post-hoc test for multiple pairwise comparisons. A χ^2 test was used to compare the number of participants whose response time was 20 seconds or longer across patient loads. A p value of 0.05 was considered significant. Descriptive statistics are provided for the simulation realism survey.

Results

Forty-two participants completed the study. Their response times are shown in Figure 3. As the data violated the homogeneity of variances ANOVA assumption (Levene's test for equality of variances [$F = 5.98$, $p < 0.001$]), a power transformation was applied before performing the ANOVA. Test results showed that the difference between patient loads was not statistically significant.

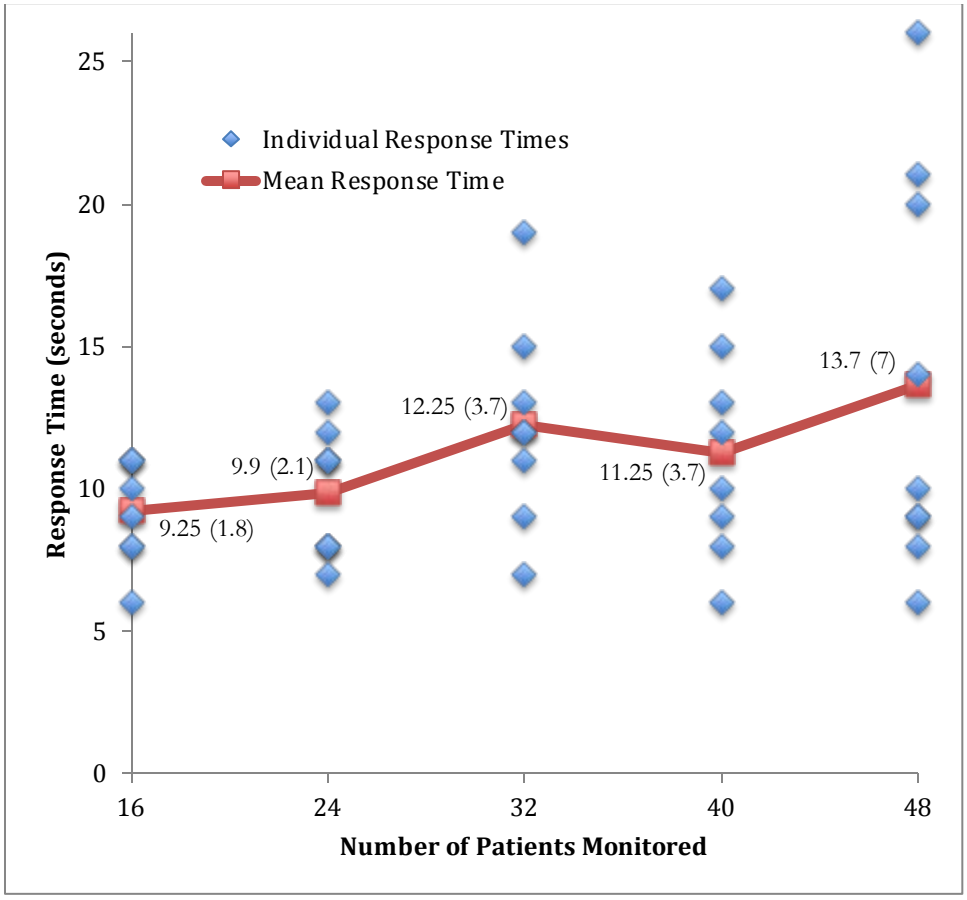

Figure 3. Response times (and standard deviations) to a simulated VF.

Out of nine participants in the 48-patient group, three required 20 seconds or longer to recognize the arrhythmia, but all response times were less than 20 seconds in groups that monitored 16-40 patients (χ 2[4, N = 42] = 11.85, p = 0.019; Figure 3).

Task performance scores are shown in Figure 4. Scores were primarily a function of degree of responsiveness to patient events. That is, low scores usually reflected fewer detections of patient status changes rather than incomplete task performance for detected changes. Task performance differed significantly across the five patient loads ($F(4,37) = 12.55$, $p < 0.0001$), with a general downward trend in task performance as the patient load increased. Tukey's test showed that 1) the task performance score for the 16-patient condition was higher than for the 32-, 40-, and 48-patient conditions; and 2) the task performance score for the 24-patient condition was higher than the score for the 48-patient condition. Performance of the real-world monitoring tasks reached only about 70% for the lowest patient load condition and 50% at higher loads.

Rhythm interpretation scores were not significantly different across the patient loads. Survey results are summarized in Table 2. Most participants perceived the simulated arrhythmia to be realistic, and 12 of 15 telemetry technicians rated the simulation similar to their work environment.

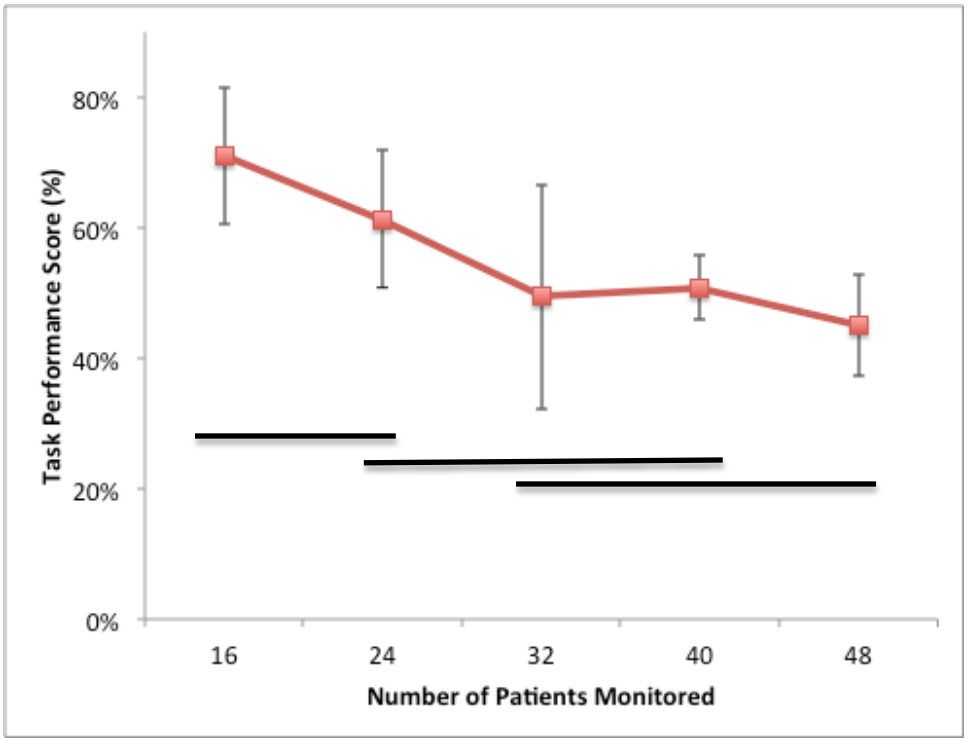

Figure 4. Task performance scores (and standard deviation bars). Means grouped by a horizontal line are not significantly different.

Table 2. Simulation realism survey results. For survey items that are relevant to cardiac monitoring but not to nursing, nurse responses are excluded.

	Strongly Disagree/ Disagree	Neutral	Agree/ Strongly Agree
The experiment was long enough to accurately assess my workload	1	0	39
The lethal rhythm (VF) was realistic (similar to a real VF)	1	0	41
The waveforms were clear enough to interpret	3	5	34
The pace of patient events was realistic	0	1	41
My documentation tasks were realistic (technician responses only)	0	2	13
The phone conversations were realistic (technician responses only)	1	0	14
Overall, the experiment was realistic (similar to real cardiac monitoring) (technician responses only)	1	2	12

Discussion

In general, participants found the simulation to accurately replicate different aspects of a telemetry technician's work. Our primary measure of response times to the life-threatening arrhythmia showed no significant difference among the patient loads. This is likely due to insufficient power, as a post-hoc power analysis revealed that the number of participants in the study provided only 44% power to detect a significant difference at $p = 0.05$. However, variability did significantly increase with increasing patient loads. Accordingly, the frequency of failure to meet a response time goal of less than 20 seconds was significantly higher in the 48-patient condition than in all other conditions. Regarding secondary outcome measures, task performance scores decreased as patient load increased. Because this score was primarily driven by missed events, these findings suggest that increasing patient load also impacted detection of patient events in general. The rhythm interpretation task, which was self-paced in that participants could perform it at any time during the session, was not impacted by number of patients monitored.

This study has several limitations. First, it was conducted in a laboratory environment. Although the simulation was perceived to be realistic, most participants stated, after the session, that they expected to be exposed to at least one lethal rhythm during the session. Further, participants worked alone without distraction, which represents, in some ways, a "best case" scenario for remote cardiac telemetry monitoring. In general, then, performance with respect to recognizing the lethal rhythm is expected to be better in the simulation session compared to a real-world setting. Other unknown factors may also affect the generalizability of the simulated task to the work environment. Second, the simulation mimicked the monitoring protocol currently performed by technicians at Duke University Hospital. There may be differences in these tasks at other hospitals or care settings that would impact generalizability of the findings.

Third, our study was underpowered to detect a difference in mean response time to a life-threatening arrhythmia across patient loads, our primary performance metric. Also, the decision to compare performance to a standard of 20 seconds is somewhat arbitrary, although grounded in the expectation that defibrillation within 2 minutes is feasible. Although it is our opinion that recognizing and responding to a life-threatening arrhythmia within 20 seconds is a reasonable and feasible goal, we are not aware of any data or industry consensus to support this.

Fourth, it would have been beneficial to determine whether the performance degradation implied in this study at a patient load of 48 is replicated and/or increases at higher loads of 50, 60, or 70 patients. Duke University Hospital cardiac telemetry technicians currently monitor up to 32 patients. At the time of the study design, we were not aware that many hospitals operate with patient loads of 50-70. The fact that none of our participants had experience monitoring patient loads of 48 or more may be reflected in our data. Furthermore, we do not know whether training and experience in monitoring higher patient loads would lead to faster response times to life-threatening events at high loads. Finally, response time was manually documented, and observers were not blind to patient load conditions. This raises a potential for both error and bias in the response time measures.

To our knowledge, this is the first study of its kind. As such, it was exploratory in nature. We expected to see a trend toward increased response time with increasing patient load as well as a point in the curve at which degradation was visibly apparent and clinically meaningful. Although this expectation was generally upheld (Figure 3), our small sample size and lack of data for patient loads beyond 48 precludes a more definitive conclusion. Further research is required to confirm this finding and to determine whether it is generalizable to true care settings. This research does, however, raise questions about the need for industry standards to limit patient load in the context of remote cardiac telemetry monitoring. It also raises questions as to whether there may be user interface design improvements, such as better auditory alerting and better visual techniques for orienting watchers to the appropriate signal at the time of an event, which would support faster response times to life-threatening arrhythmias. Human-centered design approaches are warranted that focus on evaluating monitor designs in the context they are used. Attention to task design for monitor watchers may also be needed. This may include developing ways to reduce the burden associated with responding to and documenting non-lethal events, especially in care settings where watchers are expected to manage high patient loads.

Publications

Segall N, Hobbs G, Granger CB, Anderson AE, Bonifacio AS, Taekman JM, Wright MC. Patient load effects on response time to critical arrhythmias in cardiac telemetry: A randomized trial. Submitted to Circulation: Cardiovascular Quality and Outcomes.

Segall N, Hobbs G, Bonifacio AS, Anderson A, Taekman JM, Granger CB, Wright MC. Simulating remote cardiac telemetry monitoring. The Journal of the Society for Simulation in Healthcare. 2013; 8(6): 628.

Bibliography

1. Ballew KA, Philbrick JT. Causes of variation in reported in-hospital CPR survival: A critical review. Resuscitation 1995;30:203-15.
2. Cummins RO, Ornato JP, Thies WH, Pepe PE. Improving survival from sudden cardiac arrest: the "chain of survival" concept. A statement for health professionals from the Advanced Cardiac Life Support Subcommittee and the Emergency Cardiac Care Committee, American Heart Association. Circulation 1991;83:1832-47.
3. Chan PS, Krumholz HM, Nichol G, Nallamothu BK. Delayed time to defibrillation after in-hospital cardiac arrest. N Engl J Med 2008;358:9-17.
4. Hodgetts TJ, Kenward G, Vlackonikolis I, et al. Incidence, location and reasons for avoidable in-hospital cardiac arrest in a district general hospital. Resuscitation 2002;54:115-23.
5. Meaney PA, Nadkarni VM, Kern KB, Indik JH, Halperin HR, Berg RA. Rhythms and outcomes of adult in-hospital cardiac arrest. Crit Care Med;38:101-8.
6. ECRI Institute. Alarm notification models. Health Devices 2007;36:8-15.
7. Reilly T, Humbrecht D. Fostering synergy: A nurse-managed remote telemetry model. Critical Care Nurse 2007;27:22-33.
8. Moray N. Monitoring Behavior and Supervisory Control. In: Boff K, Kauffman L, Thomas EJ, eds. Handbook of Perception and Human Performance. New York: Wiley-Interscience; 1986:1-51.
9. Mackworth N. The breakdown of vigilance during prolonged visual search. Quarterly Journal of Experimental Psychology 1948;1:6-21.
10. Weil MH, Fries M. In-hospital cardiac arrest. Crit Care Med 2005;33:2825-30.