Patient Load Effects on Response Time to Critical Arrhythmias in Cardiac Telemetry: A Randomized Trial

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Objectives: Remotely monitored patients may be at risk for a delayed response to critical arrhythmias if the telemetry watchers who monitor them are subject to an excessive patient load. There are no guidelines or studies regarding the appropriate number of patients that a single watcher may safely and effectively monitor. Our objective was to determine the impact of increasing the number of patients monitored on response time to simulated cardiac arrest.

Design: Randomized trial.

Setting: Laboratory-based experiment.

Subjects: Forty-two remote telemetry technicians and nurses from cardiac units.

Interventions: Number of patients monitored in a simulation of cardiac telemetry monitoring work.

Measurements and Main Results: We carried out a study to compare response times to ventricular fibrillation across five patient loads: 16, 24, 32, 40, and 48 patients. The simulation replicated the work of telemetry watchers using a combination of real recorded patient electrocardiogram signals and a simulated patient experiencing ventricular fibrillation. Study participants were assigned to one of the five patient loads and completed a 4-hour monitoring session, during which they performed tasks—including event documentation and phone calls to report events—similar to real monitoring work. When the simulated patient sustained ventricular fibrillation, the time required to report this arrhythmia was recorded. As patient loads increased, there was a statistically significant increase in response times to the ventricular fibrillation. In addition, 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.

Conclusions: As participants monitored more patients in a laboratory setting, their performance with respect to recognizing critical and noncritical events declined. This study has implications for the design of remote telemetry work and other patient monitoring tasks in critical and intermediate care units. (*Crit Care Med* 2015; 43:1036–1042)

Key Words: electrocardiography; heart arrest; physiologic monitoring; reaction time; telemetry; workload

Over 200,000 in-hospital patients are treated for cardiac arrest each year in the United States (1), with a reported survival rate of 17% (2). For patients suffering pulseless ventricular tachycardia or ventricular fibrillation (VT/VF), a strong association has been demonstrated between time to defibrillation and survival to discharge. The survival rate is approximately 40% for patients defibrillated within 2 minutes of recognizing arrest. However, risk for death increases 5–10% per minute of additional delay; and for 30% of patients, defibrillation is delayed more than 2 minutes from onset (3).

To increase the potential for timely detection of cardiac events, a growing number of at-risk patients are monitored remotely by cardiac telemetry watchers, who are dedicated to watching live patient electrocardiograms for long hours. There are no standards or guidelines regarding the optimal watcher-to-patient ratio; thus, the patient load varies among hospitals, and watchers may monitor as many as 72 patients at a time (4–6). Decisions regarding the appropriate number of patients that a single watcher may safely and effectively monitor are largely driven by financial considerations, available technologies, and system constraints and not by our understanding of human information processing limitations. Limitations of human visual memory and eye scan rates may place upper limits on the number of patients that a watcher can safely and effectively monitor (7). Detecting a critical arrhythmia among other rhythms can be considered a visual search for a target among distractors, and laboratory-based studies have revealed a strong effect of the number of distractors on response time and accuracy (8, 9). In addition, we know that humans are relatively poor at maintaining attention over long periods of time and quickly succumb to a vigilance decrement (10), a reduction in detection performance over time. Vigilance decrements generally appear within the first 15 minutes of a watch, and performance continues to degrade over time (11, 12). Research suggests that vigilance tasks, such as cardiac telemetry monitoring, are hard work and are stressful (12).

Although patient load effects on cardiac monitoring performance have not been studied, this topic has received attention in other continuous monitoring tasks. In air traffic control, traffic volume affected workload measures (e.g., controllers' performance or judgments), but not operational errors (13). In a visual search task simulating baggage screening, response times and error rates increased as clutter and the number of objects presented on the screen increased (14–16). Importantly, error rates also increased as target frequency decreased (16). Of these tasks, cardiac monitoring is perhaps more similar to baggage screening than to air traffic control in that it is a vigilance task with infrequent targets (critical arrhythmias) and high risk associated with missing a target. However, as in air traffic control, in cardiac monitoring, the operator is aided by alarms that highlight abnormal targets.

Because life-threatening arrhythmias are rare events, they are difficult to study in clinical practice, and it is also difficult to assess the effect of different patient loads on performance with respect to prompt response to these cardiac events (17). Given the fatal consequences of suboptimal performance, the goal of our research was to use simulation to study the impact of increasing the number of patients monitored on time to detect critical arrhythmias. To our knowledge, no prior research has addressed this question. Indeed, most efforts directed at reducing response time to cardiac arrest have focused on the time to achieve specific treatment objectives after an arrest is recognized and communicated. The critical point of detecting life-threatening arrhythmias has received little attention, perhaps because it is so difficult to measure in true patient care environments. Our work uses simulation to examine this initial arrhythmia recognition phase.

MATERIALS AND 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, for example, cardiothoracic ICUs, from Duke University Hospital and three surrounding hospitals. Technicians and nurses who indicated they were trained and experienced in interpreting electrocardiogram rhythms were eligible to participate. Participants received compensation for taking part in the study. Their average age was 33. Thirty-seven of the 42 participants, including all of the technicians, had over 1 year of experience in cardiac patient monitoring. 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 set up one display with 15 true patients and one simulated patient (**Fig. 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 **Fig. 2** for the 48-patient setup). We recorded both audio and video data for these screen setups for 4 hours. Recordings included visual and auditory alarms set to Duke University Hospital's default limits and variables. These included four alarm levels to represent different levels of urgency. All patient identifiers were removed from the video recordings and replaced with numbers (Fig. 1).

The technical implementation of the simulated patient involved connecting an electrocardiogram rhythm simulator

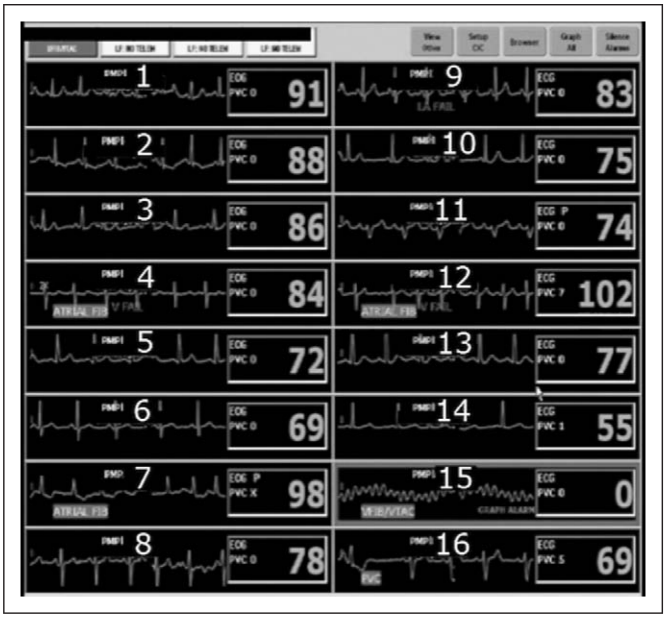

Figure 1. Simulated ventricular fibrillation patient (number 15) embedded with real patients.

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. Since multiple patients are monitored simultaneously, the simulated signal is displayed on the monitor among many signals from true patient data (Fig. 1). We timed the VF to be well into the data collection period (after over 3 hr), 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. There was a 5-second lag between VF onset and the auditory alarm.

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 were told they would be asked to monitor "virtual" patients, but were not informed of the study goals until they completed the study. Specifically, they were not told that one of the simulated patients would experience a critical event or that their response times will be recorded. They received instructions on the task and completed a training session before the 4-hour monitoring session. During the training and experiment sessions, participants worked alone performing the work of telemetry technicians, including rhythm strip interpretation, documentation, and phone calls to patient units as necessary (Fig. 2). For instance, if a recorded patient experienced bradycardia (defined as a heart rate < 45 beats/min), 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). The number of patient events, that is, arrhythmias, leads on/off, discharges, and artifacts that occurred for each patient load, is presented in **Table 1**. 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).

After a 20-minute practice session, during which participants monitored 16 patients, they completed the 4-hour experiment session, during which each participant monitored their randomly selected number of patients. 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

Figure 2. Experimental setup for 48 patients. One patient is simulated with a ventricular fibrillation arrhythmia (on the left display). Electrocardiograms for the remaining 47 patients are real (prerecorded).

TABLE 1. **Number of Patient Events for Each Patient Load During the 4-Hour Session**

No. of Patients Monitored	Total No. of Patient Events
16	51
24	65
32	68
40	82
48	113

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, that is, 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. This response time goal was selected based on prior experience with simulated life-threatening arrhythmias in true patient care environments (18) and based on expert recommendations that hospitalized patients with VT/VF receive defibrillation within 2 minutes of recognition of cardiac arrest (19, 20). 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, where multiple tasks are associated with each patient event (**Supplemental Digital Content 1**, http://links.lww.com/CCM/B232). Events that required a response included leads on, leads off, patient discharge, tachycardia, bradycardia, changes in rhythms, new or increasing ectopies, poor rhythm tracing, VT, VF, and asystole. Tasks were weighted based on importance, for example, 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.

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 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

Pearson correlations and linear regressions were used to assess the relationship between patient loads and 1) response times, 2) task performance scores, and 3) rhythm interpretation scores. Significant tests were followed up by the Student *t* test for pairwise comparisons. Fisher exact 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. Based on response time data from the first 16 participants, a group size of 6 was calculated to provide 80% power to show an overall significant difference between the five groups at an α level of 0.05. All data analyses were performed using JMP Pro version 11.0 (SAS Institute, Cary, NC). Descriptive statistics are provided for the simulation realism survey.

RESULTS

Forty-two participants completed the study. Participant characteristics are summarized in **Table 2**. Their response times are shown in **Figure 3**. The number of patients monitored was found to be positively correlated with response time ($r = 0.35$; $p = 0.024$). The linear regression showed patient load to be a significant predictor of response time ($t = 2.34$; $p = 0.024$). The regression variable estimate was 0.13, indicating

TABLE 2. **Participant Characteristics by Patient Load**

Patient Load	Total Participants	No. of Females	No. of Technicians	No. of Experienced Participants[a]
16	8	7	2	7
24	9	7	4	9
32	8	6	3	6
40	8	7	2	6
48	9	7	4	9

[a]At least 1 yr of experience in cardiac patient monitoring.

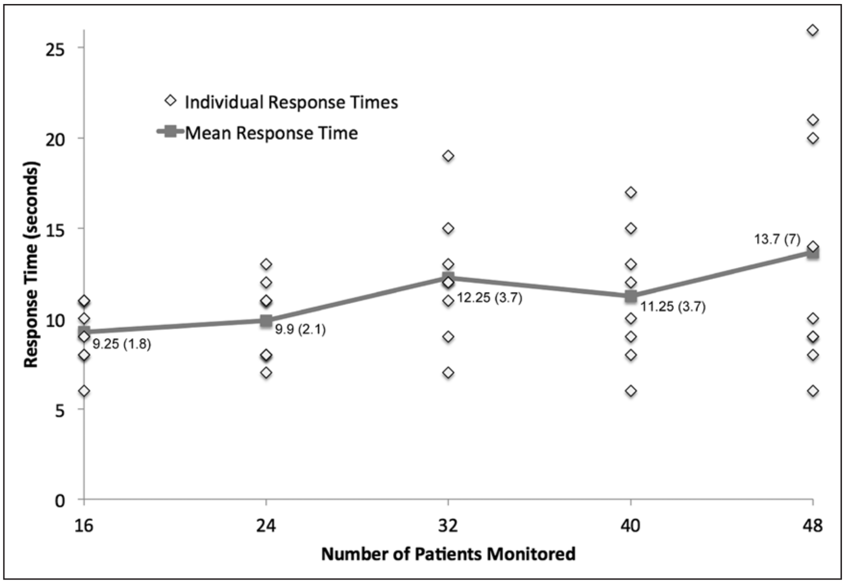

Figure 3. Response times (and SDs) to a simulated ventricular fibrillation.

that each additional patient monitored by the participants led to a 0.13-second increase in response time. Pairwise Student *t* tests revealed that no pairs of patient loads were significantly different with respect to mean response time.

To analyze clinically meaningful performance degradation, we compared the number of participants in each patient load whose response time passed a 20-second threshold. Out of nine participants in the 48-patient condition, three required 20 seconds or longer to recognize the arrhythmia, whereas all response times were less than 20 seconds for participants who monitored 16–40 patients. Fisher exact test revealed that the number of responses in the 48-patient condition that were 20 seconds or longer was significantly different from the other conditions ($p = 0.029$) (Fig. 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. The number of patients monitored was found to be negatively correlated with task performance ($r = -0.71$; $p < 0.0001$), that is, a general downward trend in task performance occurred as the patient load increased. The linear regression showed number of patients to be a significant predictor of task performance ($t = -6.44$; $p < 0.0001$). The regression variable estimate was –0.008. Pairwise tests revealed 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 32-, 40-, and 48-patient conditions. 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 3**. Most participants perceived the simulated arrhythmia to be realistic, and 12 of 15 telemetry technicians rated the simulation similar to their work environment.

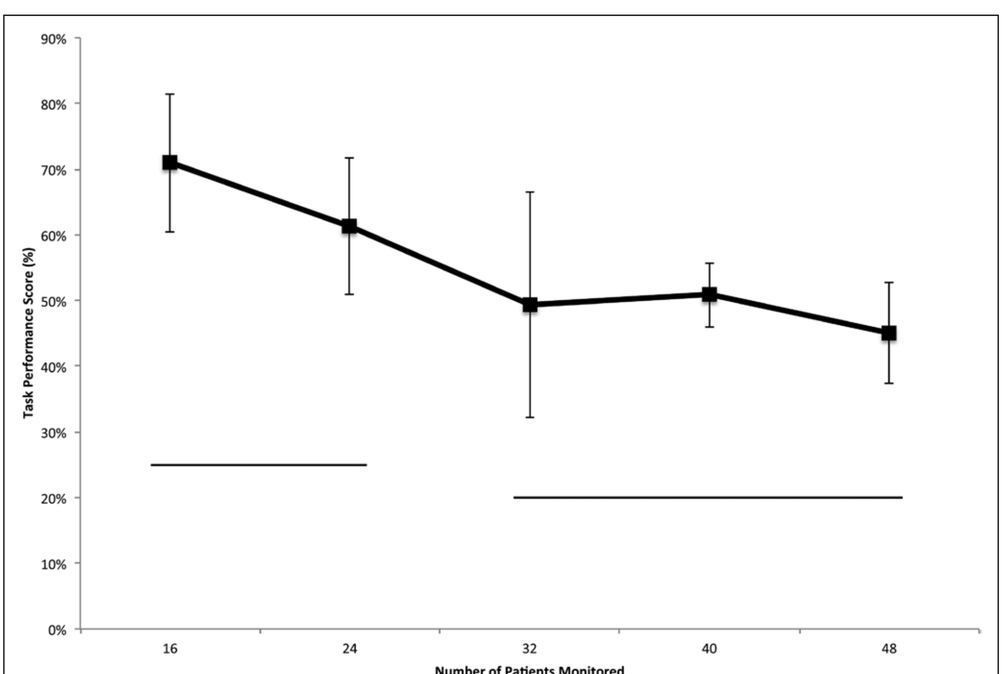

Figure 4. Task performance scores (and SD bars). Means grouped by a *horizontal line* are not significantly different.

DISCUSSION

In general, participants found the simulation to accurately replicate different aspects of telemetry technicians' work. Our primary test showed that an increase in patient loads led to an increase in response times to the life-threatening arrhythmia. This finding supports other research on visual search tasks (8, 9, 14–16). The increase was not linear, perhaps due to an outlier in the 32-patient load, an inexperienced nurse whose response time was 19 seconds. In addition, variability significantly increased with increasing patient loads. Accordingly, the frequency of failure to meet a response time goal of less than 20 seconds was significantly

TABLE 3. Simulation Realism Survey Results

Survey Item	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

VF = ventricular fibrillation.
For survey items that are relevant to cardiac monitoring but not to nursing, nurse responses are excluded.

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, 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. In our experiences with in situ simulations in true care settings, 61% of critical care nurses ($n = 28$) were able to recognize and respond to (arrive in the patient's room) unannounced simulated critical arrhythmias within 20 seconds. Response times in the context of remote telemetry monitoring were slower, with 50% of telemetry technicians responding (from initiation of the arrhythmia to the phone ringing on the unit) within 20 seconds ($n = 14$) and a median of 65 seconds for a nurse to arrive in the room ($n = 15$) (18). (For these simulated arrhythmias, it is Duke University Hospital's expectation that, on average, technicians call the unit within 15 s.) We also expected that response time in the simulated setting would be faster than in a live clinical care setting. Although it is our opinion that recognizing and communicating a life-threatening arrhythmia within 20 seconds in a controlled simulation environment is a reasonable and feasible goal, we are not aware of any replicated 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. Further, 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 (e.g., observers may have been biased to expect slower responses in high load conditions and, unconsciously, erred or rounded in that direction) in the response time measures.

CONCLUSIONS

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 (Fig. 3), further research is required to confirm this finding and to determine whether it is generalizable to true care settings. This research does, however, provide information that may inform industry standards to limit patient load in the context of remote cardiac telemetry monitoring. There may also 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, that 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 beneficial. This may include developing ways to reduce the burden associated with responding to and documenting nonlethal events, especially in care settings where watchers are expected to manage high patient loads.

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