An Integrative Display for Patient Monitoring

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ABSTRACT

Anesthesiologists are highly trained professionals who must maintain high standards while performing difficult tasks in life-threatening environments. Monitoring the instrumentation needed to diagnose and intervene when emergencies occur is one of the most crucial of these tasks. Unlike systems such as nuclear power plants or aircraft in which the selection and placement of instrumentation is part of an integrated design process, an anesthesiologist's equipment is typically procured over time from a variety of vendors. As a consequence, the anesthesiologist's task is made more difficult by a diversity of instrument behaviors and display formats. Developmental research is being conducted at Presbyterian University Hospital to identify beneficial strategies for integrating displays and signals used in anesthesia monitoring. This paper describes an experiment comparing intervention decisions made viewing parameters presented in a separated strip chart format and in the form of an integrated geometric object. The object display was found to reduce response latencies and lead to intervention at less extreme parameter values without appreciable increase in false alarm rates.

INTRODUCTION

Anesthesiologists are highly trained professionals who must maintain high standards while performing difficult tasks in life-threatening environments. Anesthesiologists must make a variety of decisions, in real-time, based on inputs from a myriad of monitoring instruments in much the same way as pilots of high performance air craft or nuclear power plant operators. Unfortunately the design of their displays is generally much poorer. In a typical operating room (OR) or intensive care (ICU) environment, the patient, nursing staff, house staff, and attending physicians are surrounded by many independent machines, monitors, and instrument displays. Physiological variables such as heart rate, arterial blood pressure, venus blood pressure, oxygen concentration or electrical signals from EEG and ECG sensors are presented in the form of either waveforms or instantaneous numerical values. This information appears on independent devices located around the operating theater. Typically, an overhead monitor may be displaying four to eight analog waveforms, while small displays located at knee-height may indicate the status of different equipment and small digital display devices located at shoulder height display oxygen content, pulse rate, and other parameters. Furthermore, most of these devices provide only displays. Once the data has scrolled off the screen, or the digital value has changed, the data is lost forever.

The anesthesiologist's displays have individual alarms unlike the organized annunciator systems common in other monitoring tasks. In the close quarters of the operating room, it is up to the anesthesiologist to locate the instrument emitting the alarm, scan the other displays to determine where the problem is, and decide on a course of corrective action. This all occurs within the context of a monitoring task in which transient signals and false alarms may be rampant due to patient movements and interference with transducers.

Developmental research [1] is underway at Presbyterian University Hospital of Pittsburgh to correct these defects. An experimental patient monitoring system employing specialized data acquisition hardware and software to bring physiological waveform data and other parameters to a single display on a graphics workstation is currently being evaluated. The present system samples analog signals found on most monitoring devices to provide new capabilities for real-time analysis, rescaling, juxtaposing, and logging of physiological parameters.

The parameters monitored in anesthesiology, however, are coupled in complex ways through human physiology and require judgements based on the interrelations among parameters and associated trends. Bringing signals and alarms to a single location in consistent formats resolves many of the current problems associated with locating alarms, disparate viewing angles and distances, and operational differences among instruments. The replication of current display formats on a CRT, however, does not provide additional aid to the anesthesiologist's complex multivariate judgement task. This paper reports research aimed at extending the capabilities of the patient monitoring system through use of integrative display formats to support multivariate judgement tasks.

An object or polar star display similar to the SPDS design adopted by Westinghouse [2] for nuclear power plant monitoring is the first alternative being investigated. An object display was selected for initial testing because the correspondences among pulmonary, cardiac, and hemodynamic parameters allowed a design in which common physiological disturbances could be represented through meaningful geometric signatures.

In the object display (Figure 1) normal parameter values would closely approximate the dashed polygon generated by the

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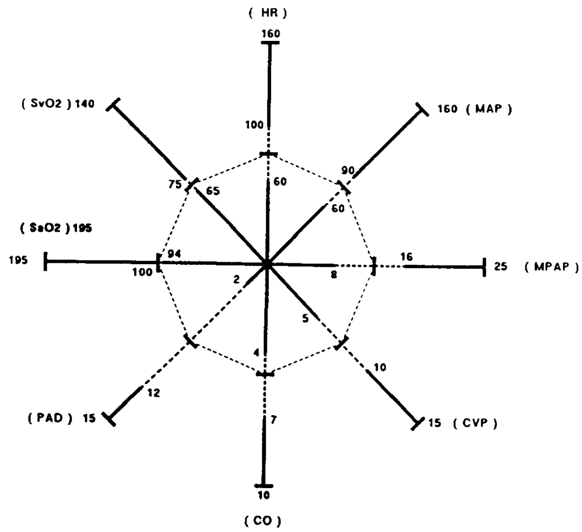

Figure 1: Object display

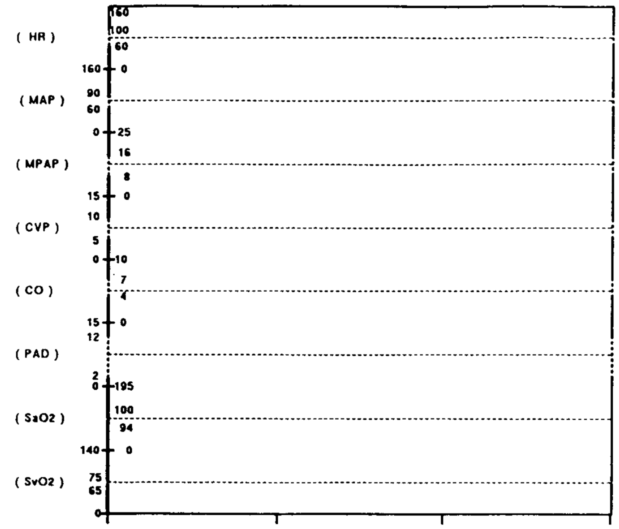

Figure 2: Strip chart display

connection of physical parameter values found at the end of each axis. Any deviation (increase or decrease) from normal operation appears as a distortion in the resultant polygon. The display not only denotes this distortion but conveys the direction in which the parameters of the system are advancing by displaying the four most recent physiological polygons. The most recent polygon has the thickest interconnecting lines while the oldest of the four has the thinest. Each spoke is labeled with the physiological parameter it represents along with numerical labels for normal limits. Segments of the "spokes" within these limits were drawn in green while those outside were drawn in red. The polygon is drawn in blue. A time stamp presenting the time in which each polygon was acquired was also presented.

A "strip chart" format (Figure 2) similar to the separated displays commonly used in anesthesiology for monitoring waveforms was used as a control condition. In this format parameter values were plotted on the vertical axis against time on the horizontal axis. Vertical axes were labeled for parameter, its values, and normal limits which were redundantly indicated by red (exceed)/green (within) color coding of the vertical axis. Physiological parameters were plotted in blue as interconnected line segments.

Both displays provide analog, limit referenced presentation of parameter values and trends. The strip chart format provides the clearest (spatially ordered) presentation of trend but does not explicitly integrate parameters. The object display integrates parameters but provides a less compatible (line thickness) depiction of trend. The experiment investigates the latency, tolerated deviation, and effect of trend on diagnostic judgements using these display formats. The physiological parameters used for this experiment are graphical presentations of summary measures provided numerically on waveform displays commonly used in anesthesiology.

Staff anesthesiologists participated as experimental subjects. Simulated physiological data were used in order to avoid confounding of physiological trends with the physician interventions present in our logs of actual operations. These data sets simulated the behavior of transducers in an operating room or intensive care unit environment but excluded nonphysiological transients.

METHODS

Simulation

Stimuli simulating physiological parameters sampled at a .17 Hz rate were constructed for 5 minute time segments of simulated operations. Data sets reflecting abnormal physiological changes associated with myocardial infarction (MI), hypovolemia, and hypoxemia and two data sets reflecting variation which remained with acceptable limits were used in the experiment. Each data set contained fifty entries corresponding to hemodynamic values of heart rate (HR), mean arterial blood pressure (MAP), mean pulmonary artery blood pressure (MPAP), central venous blood pressure (CVP), cardiac output (CO), pulmonary artery diastolic blood pressure (PAD), percentage of saturated arterial oxygen (SaO_2), percentage of saturated venous oxygen (SvO_2). Entries were generated at six second intervals to provide experimental sequences of five minutes. Abnormalities were introduced into the sequences at times ranging from 4 min 18 sec (MI) to 2 min 42 sec (hypovolemia). Each data file was presented to the experimental subject twice, once in the strip chart format and once in the object format. Presentation formats were alternated and subjects received a a fixed counterbalance ordering of sequences. An experimental session consisted of viewing the five previously generated data sets presented in the two display formats.

Subjects

Six staff anesthesiologists from Presbyterian University Hospital participated as subjects in this study. A brief interactive computer tutorial session was presented to each subject describing the displays and outlining the task at the start of the session. Subjects were instructed to do nothing if the physiological parameters presented, were within acceptable ranges but to press a button located on the track-ball if the physiological parameters displayed represented a "life threatening" situation in which they would medically intervene. The presentation of the tutorial and the recording of display presentation times along with any intervention times were done on the Apollo Workstation used to generate the displays.

RESULTS

All abnormal operation segments viewed led to intervention decisions. Three false alarms occurred in which intervention was selected during sequences reflecting normal variation. Two were by the same subject under object/normal-2 and strip/hypoxia conditions and another in the object/hypoxemia condition at an adjacent time stamp suggesting that these decisions reflect individual differences in conservatism rather than effects of the display formats.

Response Time

Response latencies measured from the point at which an evolving abnormality was introduced into the simulation are shown in Figure 3. A repeated measures analysis of variance found a significant effect of display format on response times across the sequences ($p < .02$), however, only the myocardial infarction ($p < .01$) was found different when events were considered individually.

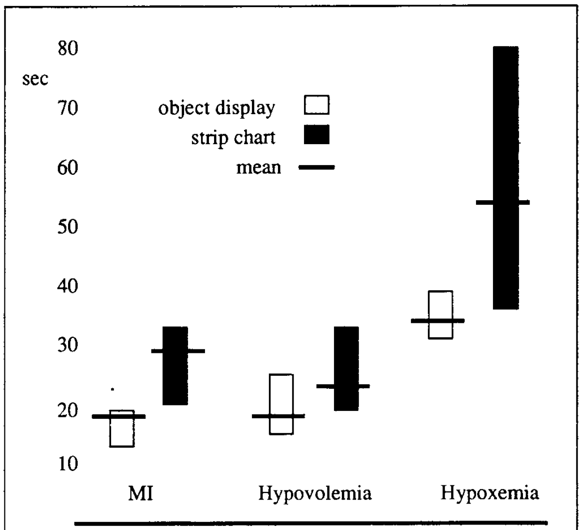

Figure 3: Time to intervention

Parameter Excursion

The tolerated deviation in physiological parameters was examined by transforming values at intervention into Z scores based on variation present in the preceding "normal" data segment. Only parameters which exceeded their earlier mean by more than three standard deviations were considered in this comparison. Figure 4 presents these data. Significance levels listed by event identifiers are based on the T^2 statistic found in a multivariate analysis of variance examining the effects of display format on the set of considered parameters. Those listed by parameters reflect the corresponding univariate tests.

DISCUSSION

This study investigated the detection of idealized physiological events each presenting its classic symptoms. Anesthesiologists using unfamiliar displays rapidly recognized these emergencies under either display format, usually within 30 seconds. The rapid divergence of monitored parameters following the failure of physiological function serve to amplify differences in intervention times. This amplification is appropriate, however, if we wish to assess sensitivity in detecting abnormality associated with the display formats. It should be noted that for each abnormal data set the object display condition contained the shortest intervention time, the strip chart condition contained the longest intervention time and the object display condition always resulted in the shortest average intervention time.

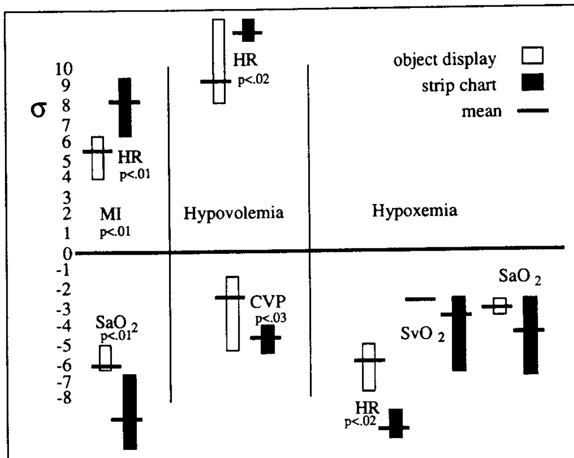

Figure 4: Parameter excursion at time of intervention

In the course of their normal duties anesthesiologists must perform a variety of concurrent tasks while monitoring patients presenting less clearly defined symptoms. It is under these conditions of increased noise and workload that even slight improvements in displays may provide substantial benefits. While response times were short, early indications of physiological distress, such as the divergence of heart rate and CVP in hypovolemia appear to have been less salient than the extreme values reached shortly thereafter. Whether latencies can be reduced still further with additional practice using this display requires investigation.

In this experiment an object display integrating measurement summaries led to greater sensitivity in detecting massive failures. This use of the polar star format to explicate extreme abnormalities is consistent with the function of the Westinghouse SPDS (cite) after which it was modeled. This experiment suggests that an of object display format may be useful for presenting summary information in conjunction with alarms currently used in anesthesia monitoring.

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