THE EVALUATION OF A GRAPHICAL PULMONARY DISPLAY IN ANESTHESIOLOGY

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Abstract

We have developed graphic technology to display data from the respiratory monitors used during anesthesia. The display uses color, texture, shape and emergent features to highlight abnormal pulmonary physiology. Nineteen anesthesiologists participated in a simulator based evaluation (METI, Sarasota, FL.). Half the subjects used the metaphor display and half did not. Each subject was trained for 10 minutes on the pulmonary display. The time difference during the obstructed endotracheal tube did prove significant (p=0.02) in favor of the pulmonary display condition. During the intrinsic PEEP scenario, the subjects treated the patient earlier (positive trend p=0.1) with the pulmonary display compared to the control condition. The group that used the pulmonary display treated a restricted upper airway more quickly (2.3 min vs. 3.9 min). Subjects liked the simplicity of the design. In future studies, we hope to further reduce the time for the detection and treatment of all scenarios by improving the design's intuitiveness, integration, and emergent features.

Introduction

Despite today's technological advances, human error is responsible for the majority of accidents and mishaps across all industries.[1] In anesthesia, Cooper et al. concluded that an alarming 82% of preventable patient injuries are caused by human error.[2] Patient injury due to human error falls into many categories[3], one of which is vigilance.[3,4]

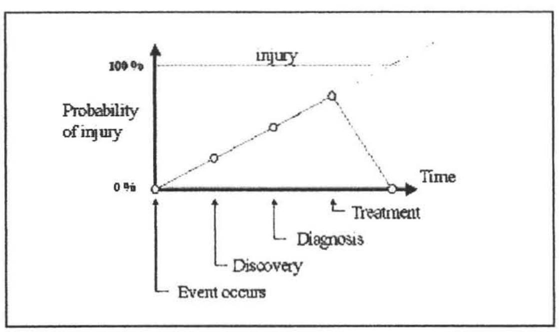

Figure 1: Etiology of an unexpected event

The ability of anesthesiologists to discover and correct problems before injury occurs depends, in part on their ability to obtain the patient's true status by means of the assimilation of the monitored data (see figure 1). Upon the onset of a critical event, the anesthesiologist's goal is to accurately and quickly develop a differential diagnosis. An accurate hypothesis will allow the anesthesiologists to successfully detect the anomaly, accurately diagnose the situation, and adequately treat the patient before the patient is injured. We have developed a pulmonary display which anesthesiologists are able to identify the anatomical and measurement features and diagnose pulmonary mechanical events without prior training on the pulmonary display.

Background

The pulmonary information display graphically represented respiratory related variables during anesthesia. By combining aspects of both cognitive and ecological graphical displays, the pulmonary display focused on data representation, emergent features, and reference frames.

Through unique combinations of simple shapes and colors, our goal was to develop a pulmonary display that had an intuitive look and feel of the pulmonary system.

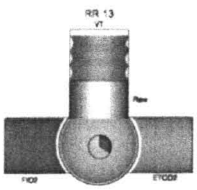

Figure 2: Design

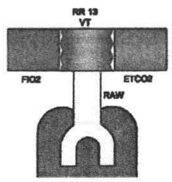

Figure 3: Design #5

A second goal was to add clinical relevance to the pulmonary display through presentation of pertinent information at just the right moment to support diagnosis. Distinguishing normal from abnormal, a reference frame that surrounds each emergent feature, defined the current state and allowed the user to identify changes from normal. The pulmonary display progressed through an iterative development cycle that began with the figure shown in figure 2 to the figure shown in figure 3. With each development cycle, the users where asked to identify features of the pulmonary display. The subjects' choices were compared to the intended choices that influenced the design changes. Five design iterations were needed to develop an intuitive display. The cumulative results of the all three categories of features for each of the design iterations are shown in figure 4.

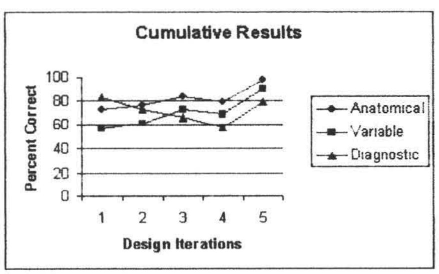

Figure 4: Cumulative results for five design iterations of the pulmonary display

Methods

Design: The study is designed as a 2 (display condition) X 6 (scenarios) repeated measurement design with scenario as repeated factor. Subjects will be randomly assigned to experimental condition, and the sequence of scenarios will be counterbalanced for yoked pairs of subjects.

Subjects: Nineteen anesthesiologists (CA-2, CA-3, and faculty) with a range of clinical experience participated in this study from University of Utah and University of Arizona. Ten subjects were randomly assigned to the control group and the remaining to study group. The study session lasted approximately 60 minutes. The participants received $50 in compensation. One faculty member of the department of anesthesiology supported the recruitment process and took over the responsibilities of the participant during the time of the subject's participation. The faculty member was paid $1000 / day for breaking out participants.

Figure 5: The METI Anesthesia Simulator

Environment: The METI anesthesia simulator (METI, Sarasota, FL.) at the University of Utah Center for Patient Simulation and at the University of Arizona was used to conduct the display evaluation.

Training: Ten minute training on METI and on pulmonary display for both conditions

Pulmonary Display: Tidal volume (TV), fraction of inspired oxygen (FiO2), end-tidal carbon dioxide (ETCO2), upper airway resistance, lower airway resistance, intrinsic peak end-expiratory pressure (iPEEP), and lung compliance

Task: The subjects were instructed to play the role of an attending anesthesiologist who was called by a resident. The subjects were instructed to think aloud through out the scenario. Subjects were instructed to treat the patient as a first priority rather than teach the resident.

Scenarios:
Scenario 1: Bronchospasm
Scenario 2: OETT
Scenario 3: Endobronchial Intubation
Scenario 4: Intrinsic PEEP
Scenario 5: Hypoventilation
Scenario 6: Normal

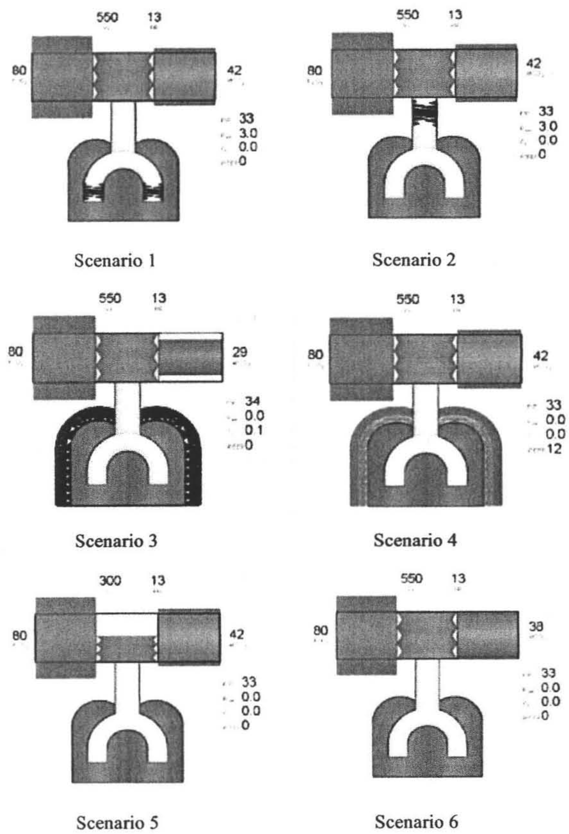

Figure 6: The pulmonary display showing the six different scenarios

Results

The times for treatment for each of the five scenarios was abstracted from the computer captured data for each scenario. Subjects' times were categorized by scenario and display condition. Averages for time to treat were recorded and graphed.

The overall time to treat patients averaged across all scenarios was not significant comparing the conditions with and with out the display. Further analysis of the data looking at each scenario showed time to treat patients decreased significantly ($p <= 0.02$) for scenario 2 (obstructed endotracheal tube) (see figure 7).

Overall, the subjective questionnaires indicate the display was perceived as facilitating performance in each scenario. In only one scenario (normal) the display was associated with a significant increase mental demand.

The NASA TLX questionnaire asked subjects about helpfulness of the display, their perceived frustration level, effort, performance, temporal demand, physical demand, and mental demand. Comparing the subjects in the two conditions with and without the display, subjects perceived an overall decrease in physical demand ($p<= 0.00$), a decrease in temporal demand ($p<=0.00$), a decrease in effort ($p<=0.03$), a decrease in frustration level ($p<=0.02$). Subjects in the display condition indicated that they perceived the display was helpful when performing the anesthesia tasks ($p<=0.00$).

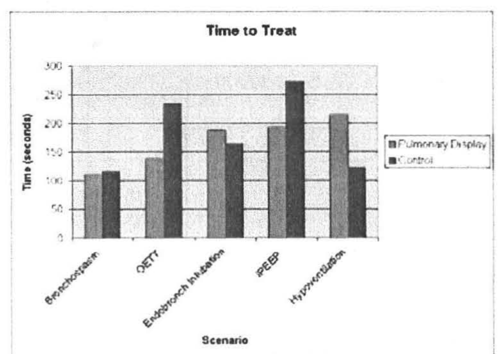

Figure 7: Comparing the results of time to treat with and without the display for the five scenarios. Normal scenario is excluded from the analysis as no interventions were expected.

Discussion

Examining the results of each scenario individually, the pulmonary display significantly ($p<=0.02$) enhanced performance for treating upper airway resistance problems (scenario 2). The NASA TLX analysis indicated that, in general, the subjects found the pulmonary display to be helpful, decrease physical demand, decrease mental demand, decrease temporal demand, reduce effort level, and reduce frustration level. In addition to the collected questionnaire data, subjects commented positively on the pulmonary display and its usefulness and intuitiveness. Each scenario emphasized particular features of the pulmonary display. Examining the data for each scenario provides possible suggestions to improve the pulmonary display.

Scenario 1 (Bronchospasm)
Bronchospasms are a common occurrence in the operation room and most anesthesiologists are very familiar and experienced with this scenario as indicated by our subject response to our questionnaire. It was observed in the videotapes that subjects commonly auscultated before concentrating on the monitors. In the scenario, bronchospasms generated bilateral wheezing sounds from the lung fields in the METI mannequin. Subjects' times to treat were similar regardless of the study group. In addition, subjects treated bronchospasm with the fastest time compared to the other 5 scenarios.

Scenario 2 (Obstructed Endotracheal Tube)
In this scenario, we simulated a mucus plug in the endotracheal tube that was indicated by an upper airway restriction element in the display. Without the display, subjects relied on an increase in airway pressures, elevated ETCO2, capnographed waveforms, and a passive resistance felt when the subject "squeezed the bag". It was shown that subjects significantly treated the obstruction quicker (1.6 minutes faster, $P <= 0.02$) during the display condition studies compared to the subjects performing without the display. The emergent feature of the upper airway restriction elements could have contributed to subjects' performance with the pulmonary display.

Scenario 3 (Endobronchial Intubation)
To begin the endobronchial intubation scenario, the simulated patient was prepped by placing the endotracheal tube down too far creating a right mainstem. The pulmonary display showed a decrease in lung compliance by the appearance of a thickened black cage surrounding the lung object. Subjects without the display were clued into the development by increased airway pressure (PIP), capnograph waveforms, increased ETCO2, and diminished breath sounds from the left lung field. The difference of treatment times between the two study groups did not prove to be significant. One possible reason is that some subjects admitted they were not accustomed to using a lung compliance measurements. Other subjects commented that with a right main stem scenario, they would have expected to see the display indicate a single lung being ventilated and the other unventilated. Time to treat comparison and subject comments may be an indication that the lung compliance emergent feature of the display may not be salient enough. The addition of lung sensors may add pertinent information to create a new emergent feature of the pulmonary display and may enhance performance.

Scenario 4 (Intrinsic PEEP)
The intrinsic peep or airtrapping scenario was created by setting the I:E ratio on the ventilator to 1:1. Subjects in the display condition study viewed an expanding lung emergent feature on the pulmonary display. Subjects without the display diagnosed and treated the problem by observing such variables as increased peak airway pressure (PIP), capnograph waveforms, and ETCO2. Comparing the treatment times between study groups, the time difference was lower but not significant with subjects using the pulmonary display compared to the control condition. It was observed that subjects who identified a PEEP problem may have been confused with the new measurement of intrinsic PEEP presented in the display with the more familiar measurement of extrinsic PEEP. Subjects were also seen manually turning on and off PEEP through out the scenario in an effort to possibly correct the accurately diagnosed problem. Some subjects commented that the expanding lung image did not make them think of air trapping. It is possible that the intrinsic peep emergent feature was not salient enough and refinement of the display may be necessary to improve performance.

Scenario 5 (Hypoventilation)
This scenario seemed to be the most difficult for the subjects based on both performance and collected questionnaires. Many subjects indicated a correct diagnosis but were unable to correctly fix the problem resulting in an increased time to treat measurement. The scenario was created by turning down the maximum pressure of the bellows thus reducing the amount of volume delivered to the patient. Upon accurately diagnosising the scenario to be hyoventilation, some of the subjects commented that they had experience with ventilator problems before and stated emphatically that "no one would do that to them again!" Other subjects admitted that they knew what the diagnosis was and suspected that it had something to do with a ventilator problem but had no idea as to how to fix the error. The time to treat data collected indicated that subjects performed worse with the pulmonary display but the time differences were not statistically

significant compared to the control study group. A possible explanation for the poor performance with the pulmonary display is the realization that the display does not indicate ventilator information beyond tidal volume, FIO2, and respiratory rate. The display lacks any information regarding leak in hose, pressure limit settings, and extrinsic PEEP settings. Therefore the subjects in the pulmonary display may have been distracted from their normal flow of error checking by the display. A possible improvement of the pulmonary display could include the integration of ventilator setting and ventilator alarm notifications.

Conclusion

In conclusion, the pulmonary display improved treatment time for upper airway restriction. In some cases the pulmonary display did not add a significant improvement, which may be an indication of new information unfamiliar to the subjects or that a display feature was not salient enough. Future studies will re-test a modified pulmonary design in a real patient setting.

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