PULMONARY METAPHOR DESIGN AND ANESTHESIA SIMULATION TESTING

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Abstract

Medical decision making is a crucial process to successfully treat a critical medical emergency. During an unexpected medical event, astronauts, like anesthesiologists, must react quickly in a complex environment. Tools, such as the pulmonary metaphor display, were created to aid the medical caregiver's decision making process. The pulmonary metaphor display is designed to help the caregiver collect and integrate pulmonary data to provide a more accurate, quicker diagnosis and treatment. The following outlined anesthesiology simulation study will provide the data to prove that the pulmonary metaphor display is beneficial to medical decision making.

Introduction

Medical decision making is as important in space as it is on earth. Improving the clinician's accuracy and response time to patient care improves their decision process. In space, health care facilitators are impeded by the lack of on board clinicians. Therefore, these health care facilitators would be able to benefit directly from tools designed to aid in the medical decision process. Tools such as the pulmonary metaphor display would help providers collect and interpret pulmonary data resulting in an increase in medical decision accuracy and a decrease in response time. The domain of anesthesiology was chosen to develop the pulmonary metaphor display because anesthesiologists work in a time critical and complex environment similar to the environment created in space during a medical emergency.

Anesthesiologists rely on the assimilation of monitored patient data in order to determine the patient's true clinical status. 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 and other critical care clinicians to successfully detect and treat the anomaly before the patient is injured. Therefore a better representation and integration of data would aid the clinician's decision process of developing an accurate hypothesis[1-4]. The pulmonary metaphor display was developed to help clinicians identify and diagnose pulmonary events in anesthesia.

Our multi-disciplinary research team at the University of Utah designed a pulmonary metaphor display that presents critical information about the respiratory system in a graphical way[5]. In this study the assumption will be tested that the display improves anesthesiologists' ability to diagnose the cause of a critical event correctly and, as a consequence, to timely administer treatment. The pulmonary metaphor display shows functional respiratory physiology by integrating related pulmonary variables into a graphical object with gestalt like qualities. As part of an iterative design process, earlier evaluation of this display by clinicians using static pictures helped to optimize the display and improved intuitiveness of the object. Further, the results indicate anesthesiologists were able to diagnose different scenarios using a multiple choice test.

The goal of this study is to evaluate the effect of the pulmonary display on diagnostic and treatment performance of anesthesiologists. To evaluate the effect of the display, five pulmonary scenarios and a control scenario will be used. Additionally, we plan to run some participants using an eye-tracker to evaluate the impact of the pulmonary display on monitoring respiratory variables. The eye-tracking data will provide qualitative and quantitative information concerning participant's usage of the pulmonary metaphor display.

In this paper, first, the intuitive testing results of the final pulmonary metaphor display will be reviewed. Next, the study design and hypotheses for the anesthesia simulation testing of the pulmonary metaphor display will follow.

Background

The final pulmonary metaphor display development results

Our team has adopted a process for developing information displays, which promotes design as a function of human behavior and the interaction between subjects and object. The design approach is based on the concept of a "hermeneutical circle", described in Snodgrass and Coyne[6, 7]. The hermeneutical circle concept is an iterative process of implementing a design, learning and understanding from discussion and feedback, and subsequent design refinement.

The pulmonary metaphor development began by characterizing which set of variables was important in diagnosing different pulmonary events. As a result, the following set of variables were defined as necessary to the pulmonary metaphor: tidal volume, respiratory rate, fractional inspired oxygen, end tidal carbon dioxide, fractional inspired oxygen, airway resistance, and compliance. The initial shape of the first pulmonary display is shown in figure 1.

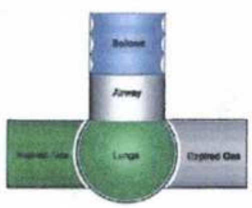

Figure 1: Initial pulmonary metaphor design

Next, the three-step protocol comprised of three paper-based tests, which were developed to test the pulmonary metaphor's intuitiveness and diagnostic efficiency. For each of the tests, the subjects were informed that the metaphor represented data from a mechanically ventilated patient. The tests comprised pulmonary metaphor images in a variety of states.

The data from the three paper-based tests were assembled into a confusion matrix, which lists the intended answers in the left column and the user's answers along the top row. An intended answer that matches the subject's answer forms a data point on the matrix diagonal. Thus answers deviating from the diagonal are tagged as potentially confusing features. With the analysis of the subject's answers, the design weaknesses began to emerge.

The final pulmonary metaphor, (see figure 2) anatomically represents the bellows, airway, lungs, inspired gas, and expired gas. The bellows is a gray/blue color similar to the bellows in the ventilator. The bellows moves in the y direction representing tidal volume. The airway is picture as a simplistic anatomical picture of the trachea and the branched bronchi. An obstruction in the lower airways (such as bronchospasm) is depicted as a narrowing in both of the two lower bronchi (see figure 2). An obstruction in the upper airway (such as obstructed endotracheal tube) is depicted as a narrowing of the upper trachea (see figure 2).

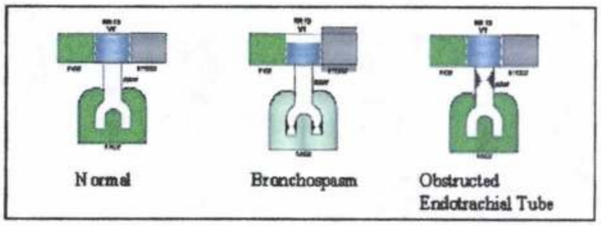

Figure 2: Final pulmonary metaphor design shown during three different states

The lung object is shaped as a bi-semi-elliptical sphere. The shade of green is mapped to the amount of oxygen in the alveoli (FAO2). The green box (upper left) represents inhaled oxygen (FIO2). The gray box (upper right) represents exhaled CO2 and the box's width is mapped to ETCO2.

With the pulmonary metaphor display defined, the next step is to test the metaphor with realistic pulmonary scenarios. The METI anesthesia simulator (METI, Sarasota, FL.) at the University of Utah was chosen to provide a realistic controlled environment to test the clinical relevance and features of the pulmonary metaphor display.

Methods

Design

The anesthesia simulation study is designed as a 2 (display condition) X 6 (scenarios) repeated measurement design with scenario as a repeated factor.

Subjects will be randomly assigned to an experimental condition, and the sequence of scenarios will be counterbalanced for yoked pairs of subjects.

Subjects

Thirty anesthesiologists (CA-2, CA-3, and faculty) and certified registered nurse anesthetists with a range of clinical experience will participate in this study. One-half of the subjects will be assigned randomly to the pulmonary metaphor display condition and the remaining one-half will be assigned to the control condition, with equal numbers of attending anesthesiologists and CRNAs assigned to each group. The study session lasts approximately 90 minutes. The participants will receive $100 in compensation. One faculty member of the department of anesthesiology will support the recruitment process and take over responsibilities of the participant during the time of the subject's participation. The faculty member will be paid $1000 / day for breaking out participants.

Materials

Figure 3: The METI Simulator at the University of Utah

The METI anesthesia simulator (METI, Sarasota, FL.) at the University of Utah Center for Patient Simulation will be used to conduct the display evaluation (see figure 3). An AS/3 anesthesia monitor (Datex, Helsinki, Finland) will display the traditional electrocardiogram (ECG), arterial blood pressure (BP), pulse oximeter (SpO2), and capnogram (CO2) waveforms. Digital values for heart rate (HR), blood pressure (BP), oxygen saturation (SpO2), end-tidal carbon dioxide (FetCO2), and fraction of inspired oxygen (FiO2) will be displayed. The pulse oximeter tone will also be provided. All standard monitor alarms will be enabled initially at default limits, but may be modified by the subjects according to their preferences. A CO2SMO device will be added to provide and collect pulmonary information such as pressure, flow, respiratory rate, and tidal volume. The numeric and wave form data collected from the CO2SMO device will be displayed on the CO2SMO monitor.

At any time during the scenario, the participant will be able to manually set the following values on the ventilator: respiratory rate (RR), inspiratory flow rate, inspiratory to expiratory flow rate (I:E Ratio), peak end expiratory pressure (PEEP), and tidal volume (TV).

The pulmonary display (see figure 4) will be shown on a 17-inch monitor placed beside the AS/3 monitor. The pulmonary metaphor display will provide digital and graphical information about the following variables: tidal volume (TV) (grey bellows, center top), fraction of inspired oxygen (FiO2) (green rectangle, left top), end-tidal carbon dioxide (ETCO2) (grey rectangle, right top), fractional alveoli oxygen (FAO2) (shade of green of lung object, center bottom), upper airway resistance (black wedge, center below bellows), lower airway resistance (black wedges, bottom end of pink hemisphere), and lung compliance (black cage surrounding lung shape). The pulmonary metaphor display is mapped to the values of each of the above measurements and is designed to change shape or color with the changing values of these measurements. The changing shape of the pulmonary metaphor display will produce a specific pattern for particular scenarios. Each of these shapes will be easily discriminatory from each other.

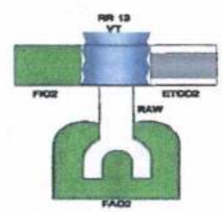

Figure 4: The final pulmonary display in a state of hypoventilation

Training

Subjects will be trained in both conditions on the pulmonary metaphor display. The training will describe the pulmonary metaphor and how the metaphor responds to changes in monitored values. Subjects will be allowed to ask questions until they state they are comfortable with the pulmonary metaphor display.

A minimum amount of training is required with the high fidelity simulator because most subjects are already familiar with the simulator. Subjects will receive information about the simulator and will be encouraged to ask questions about its function. Subjects will be asked if they are familiar with the set up of the standard monitoring and drug administration equipment and supplies.

All subjects will be instructed in the use of the CO2SMO device. Training is completed when the subject reports feeling comfortable with the information provided by the CO2SMO monitor.

In both conditions, after explaining the simulator, the subjects will be reminded that they are to administer anesthesia and provide care for the simulator patient as if he/she was treating a real patient. The experimenter will answer all questions concerning the use of the monitors, the procedure, etc. On average, the training is expected to take 10 minutes.

Study Procedure

Initially participants will arrive at the Center for Patient Simulation and be required to fill out a questionnaire assessing demographic variables of interest including job experience, number of hours worked prior to study, age and visual acuity. Next the participant will be given some general information about the study and asked to read a brief description of the protocol and consent to participate as a voluntary paid participant. After informed consent is obtained, the participant will then be oriented to the METI simulator and begin the scripted training procedure. All participants will be instructed in the use of the METI simulator, CO2SMO device/monitor, and interpretation of the pulmonary metaphor display. Once the training is complete participants will begin the experimental scenarios

Prior to the onset of each of the six scenarios, subjects will be given an anesthetic record. They will be instructed to carefully read it and to assess the patient's pre-anesthetic evaluation form, which includes the patient's medical and surgical history, labs, baseline vital signs, planed surgical procedure, and the expected duration of the surgery. The subjects will be instructed to play the role of an attending anesthesiologist who got called by a resident because of an unspecified problem with the patient. After subjects entered the OR they will be instructed to gather all the information available without interacting with the equipment and to verbalize as fast as possible the most likely hypothesis of what caused the problems with the patient. After verbalizing the hypothesis they can start administering treatment to the patient.

When each of the 6 scenarios has ended, participants will be asked to fill out the NASA-TLX and another questionnaire addressing specific questions regarding the scenarios. At the end of the experimental session, additional questionnaires will be administered.

Scenarios

Six scenarios will be used in each condition. Subjects will be called to the room by a junior resident (confederate) who is having an unspecified problem with the patient. The resident will verbally provide patient background. Previous values will be obtained by the subject from the written anesthesia record.

<u>Scenario 1 (Bronchospasm)</u>

The patient is a 32 year old female having laparoscopic cholecystectomy. She is obese 5'5" and 120Kg and has a history of asthma. She is allergic to penicillin. She has a Mallampati class 4 airway. She was induced with Pentothal and succinylcholine (rapid sequence) and was successfully intubated on the second attempt. Anesthesia is being maintained with isoflurane in oxygen and fentanyl. Paralysis is being maintained with rocuronium. She received cefazolin (antibiotic) at the surgeon's request prior to incision. Just after incision, the resident calls the attending to the room because the high-pressure alarm is sounding. *Note: She develops bronchospasm in response to the surgical stimulation of incision*

<u>Scenario 2 (Obstructed Endotrachial Tube)</u>

The patient is a 68 year old male having a hemicolectomy for colon cancer. He has hypertension treated with quinapril and smokes 2-packs of cigarettes per day (for 50 years). He is allergic to morphine, but Demerol works great. He was induced with Pentothal and cisatracurium, easily intubated, and anesthesia is being maintained with isoflurane in oxygen and fentanyl. Paralysis is being maintained with cisatracurium. Surgery has been progressing uneventfully for 2.5 hours. There is minimal blood loss and the patient has received 3500cc crystalloid. The resident calls the attending to the room because the high-pressure alarm is sounding. *Note: This obstruction will have occurred gradually due to drying of secretions in the endotracheal tube. The anesthesia record will show a gradual increase in airway pressure and in $ETCO_2$ prior to the sudden decrease in both. To simulate this, intubate the maniquin with an ETT that contains a foreign body obstruction.*

<u>Scenario 3 (Endobronchial Intubation)</u>

The patient is a 28 year old female having laparoscopic tubal ligation. She is obese (5'2" and 100Kg), takes synthroid, and smokes 1/2 pack per day (12 years). She has no medical allergies. She has a Mallampati class 3 airway. She was induced with Pentothal and succinylcholine (rapid sequence) and was successfully intubated on the first attempt. Anesthesia is being maintained with isoflurane in oxygen and fentanyl. Paralysis is being maintained with rocuronium. She received cefazolin (antibiotic) at the surgeon's request prior to incision. Ten minutes into surgery, the resident calls the attending to the darkened room because the high-pressure alarm is sounding. *Note: She develops mainstem intubation when the table is placed into steep Trendelenburg position. The endotracheal tube is taped at 22cm at the teeth.*

Scenario 4 (Intrinsic PEEP – air trapping)
The patient is a 68 year old male having a prostatectomy for prostate cancer. He has hypertension treated with felodipine, has had one TIA (mini-stroke), and smokes 2-packs of cigarettes per day (for 50 years) even though his primary care physician has stressed that he really should quit. He has no medication allergies. He was induced with Pentothal and cisatracurium, easily intubated, and anesthesia is being maintained with isoflurane in oxygen and fentanyl. Surgery has been progressing uneventfully for 2.5 hours. The EBL is 750cc and the patient has received 3500cc crystalloid. The resident calls the attending to the room because the patient is tachycardic. *Note: This patient has emphysema and mild hypovolemia. There has been progressive tachycardia. The resident recently increased the respiratory rate because the $ETCO_2$ was high.*

Scenario 5 (Hypoventilation)
The patient is a healthy 28 year old female having laparoscopic tubal ligation. She has no medical allergies. Ten minutes into surgery, the resident calls the attending to the darkened room because the patient is tachycardic. *Note: the patient has a low tidal volume because the ventilator is set to pressure limited ventilation. With thoracic compliance decreased with institution of the pneumoperitoneum and the bellows is no longer emptying completely.*

Scenario 6 (Normal)
The patient is a 25 year old male having an appendectomy for acute appendicitis. He is otherwise healthy, smokes 1/2 pack of cigarettes per day (for 5 years), drinks alcohol socially, mostly on the weekends. He is allergic to penicillin. He was induced with Pentothal and succinylcholine, easily intubated, and anesthesia is being maintained with isoflurane in oxygen. A nasogastric tube was inserted prior to incision. Surgery has been progressing uneventfully for 0.5 hours. The resident calls the attending to the room to ask how much fentanyl should be administered during surgery for postoperative pain control. *Note: This patient has no pulmonary or cardiovascular symptoms.*

Expected Results

We hope that this anesthesia simulation study will prove our hypothesis. The hypothesis sates that the use of the pulmonary display will lead to:

1. A decrease in the time necessary to diagnose the critical event correctly.
2. An overall decrease in the amount of time necessary to administer appropriate treatment for each experimental
3. An overall decrease in the number of "false alarms".
4. A difference in the subjective questionnaire measures indicating an increase in perceived performance and a decrease in overall

Measures
Participants will be encouraged to talk aloud during the evolution of each scenario. In addition the confederate is asking them what they are doing whenever they are starting something new, or when they look at the monitors. By recording the experimental session, both video and audio information will be subject to analyses. Diagnosis time and treatment time will be determined. Further, we will be able to assess the quality of the treatment and score the efficiency of the administered treatment. Additionally, performance will be evaluated as a function of preliminary diagnosis and procedural steps taken to construct the correct diagnosis. During the control scenario false alarms will be measured and scored as the number of diagnoses, procedures, and treatment interventions given.

Questionnaires
The NASA-TLX will be administered to each participant to assess workload and performance differences between display conditions. Additionally a questionnaire measuring utility will be administered to evaluate the anesthesiologist's opinion of the pulmonary metaphor display. Open-ended commentary will also be solicited from the participants to suggest further improvements in the display design.

In conclusion, we hope the simulation testing of the pulmonary metaphor display will prove its benefit for the anesthesiologists and health care providers in space. The final pulmonary metaphor design has significant strengths according to our design development study. Subjects commented positively on the metaphor and indicated that it would add value to their current data. Subjects liked the simplicity of the metaphor. Most of the anatomical features and measurement variables were guessed correctly, possibly indicating the metaphor will be easy to learn and use. The normal state of the metaphor is easily recognized, possibly indicating a decreased time of discovering and treating an unexpected event. Finally, in earlier studies[5], most of the pulmonary events were guessed correctly, possibly indicating a decreased time of diagnosing a pulmonary event.

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