Virtual Airway Skills Trainer (VAST) Simulator

Doga DEMIREL[af1], Alexander YU[a], Tansel HALIC[a,2], Ph.D.,
Ganesh SANKARANARAYANAN, Ph.D.[c], Adam RYASON[c],
David SPINDLER, M.Sc.[d], Kathryn L. BUTLER M.D[b], Caroline CAO, Ph.D.[d],
Emil PETRUSA, Ph.D.[b], Marcos MOLINA, Ph.D.[e], Dan JONES, M.D.[e],
Suvranu DE, Ph.D.[c], Marc DEMOYA, M.D.[b], Stephanie JONES, M.D[e].
[a] *Department of Computer Science, University of Central Arkansas*
[f] *Department of Computer Science, University of Arkansas at Little Rock*
[b] *Department of Surgery, Massachusetts General Hospital, Harvard School of Medicine*
[c] *Department of Mechanical, Aerospace and Nuclear Engineering, Rensselear Polytechnic Institute*
[d] *Department of Biomedical, Industrial and Human Factors Engineering, Wright State University*
[e] *Department of Surgery, Beth Israel Deaconess Medical Center, Harvard School of Medicine*

Abstract. This paper presents a simulation of Virtual Airway Skill Trainer (VAST) tasks. The simulated tasks are a part of two main airway management techniques; Endotracheal Intubation (ETI) and Cricothyroidotomy (CCT). ETI is a simple nonsurgical airway management technique, while CCT is the extreme surgical alternative to secure the airway of a patient. We developed identification of Mallampati class, finding the optimal angle for positioning pharyngeal/mouth axes tasks for ETI and identification of anatomical landmarks and incision tasks for CCT. Both ETI and CCT simulators were used to get physicians' feedback at Society for Education in Anesthesiology and Association for Surgical Education spring meetings. In this preliminary validation study, total 38 participants for ETI and 48 for CCT performed each simulation task and completed pre and post questionnaires. In this work, we present the details of the simulation for the tasks and also the analysis of the collected data from the validation study.

Keywords. Virtual Reality, Simulator, Airway Management

1. Introduction

This paper describes the preliminary simulation for the Endotracheal Intubation (ETI) and Cricothyroidotomy (CCT) that are essential techniques in Airway Management (AM). AM is the set of guidelines and procedures performed to secure the airway of a patient. These clinical guidelines are frequently used in both operating and emergency

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[1] At the time of submission of the manuscript, the author was affiliated with University of Central Arkansas. The author is currently affiliated with University of Arkansas at Little Rock.

[2] Tansel Halic, Department of Computer Science, University of Central Arkansas, 201 Donaghey Avenue, Conway, AR, 72035, tanselh@uca.edu

room settings. Difficult airway develops when the standard ways to secure airway specified in AM becomes challenging to perform. Failing to establish the airway and provide sufficient oxygenation to the patient in difficult airway case could rapidly cause severe complications [1].

In the difficult airway [2], ETI is the widely used technique while CCT is the surgical alternative when intubation of nonsurgical techniques fail to secure the airway. In ETI procedure, the Endotracheal Tube (ETT) is inserted through the mouth into the trachea with the use of laryngoscope, in contrast to CCT where the ETT or tracheostomy tube is inserted through a small incision made by a scalpel on the cricothyroid membrane. In the situations where a patient is severely injured and ETI cannot be performed, the ability to perform a CCT is vital [2].

Common traditional training methods in AM have some deficiencies; practicing on cadavers is costly and limited to one time use only, while the mannequins are not realistic and cannot provide training for difficulty scenarios. In contrast, Virtual Reality (VR) simulators in AM can overcome these deficiencies by allowing low cost, risk free environment to repeatedly perform the procedures with quantitative feedback for performance assessment. VR simulators can also allow practicing in operating or emergency room settings.

2. Design & Implementation

The CCT and ETI simulators were developed using the SoFMIS [3]. In both simulators, we used Oculus Rift for immersive visual display to simulate the operating room experience. The instrument interaction in the CCT and the manipulation of patient's head in finding optimum angle in ETI task are performed using a Geomagic Touch haptic device. Figure 1 shows the trainee - simulator interaction.

Figure 1. Trainee - simulator interaction.

2.1. Endotracheal Intubation

The ETI procedure is divided into four main tasks: assessing the airway of the patient, placing the patient in the intubation position, performing the intubation, and securing the intubation tube. We developed two tasks of these tasks in our ETI simulator; Mallampati scoring and placing the patient in an optimal intubation position. Mallampati scoring is a classification to assess the difficulty of intubation. The assessment is accomplished as the patient is in a mouth open and tongue extended position. The Mallampati scoring is a subjective visual assessment of the mouth. In Class 1 for Mallampati scoring; the soft palate, uvula, and the pillars are clearly visible. In Class 2, only the soft palate and half of the uvula is visible. In Class 3, only the soft palate and hard palate are visible, while in Class 4 only the hard palate is visible. In some severe cases where intubation is not probable, the surgeon may opt other alternative techniques such as CCT instead.

Prior to the intubation step in ETI, physician needs to tilt the head back in order to align the oral axis, the pharyngeal axis, and the laryngeal axis in parallel to adjust the patient's head for the optimal intubation angle [4]. This facilitates obtaining a clear view of vocal cords and epiglottis when using the laryngoscope.

2.1.1. Endotracheal Intubation Simulation: Mallampati Scoring Task

The first part of the simulation, airway assessment, requires the user to assess the Mallampati score of the patient. Four different scenarios, one for each Mallampati class, are created. The user is immersed in the 3D environment with Oculus Rift to examine the patient in order to estimate the difficulty. In each trial, a patient with a random Mallamapti score is shown to the user. Figure 2a illustrates a patient with a Mallampati score of 1.

2.1.2. Endotracheal Intubation Simulation: Optimum Angle Task

For the second part of the ETI simulation, the head needs to be optimally positioned. In order to simulate the motion of the patients head, an articulated skeleton structure was developed [5]. The skeleton was attached to the surface mesh using the linear skinning algorithm. The joints of skeletons were placed at the top and bottom of the neck to simulate the movement of the cervical vertebrae and thoracic vertebrae respectively. The top joint is responsible for the rigid movement of the head, while the bottom joint simulates the movement of the vertebrae and neck in a constrained motion. In order to keep the movements of the head realistic, several constraints were added to the joints. The top joint allows for roughly 60 degrees of horizontal motion and roughly 15 degrees of vertical movement. The bottom joint allows for about 45 degrees of vertical movement and 10 degrees of horizontal movement. Figure 2b shows an attempt to align the oral axis with the pharyngeal axis and laryngeal axis.

Figure 2a. Patient with Mallampati score of 1.

Figure 2b. User attempting to align the oral axis, hidden during the data collection, represented with a blue tube.

2.2. Cricothyroidotomy

The CCT procedure consists of six main tasks: identification of landmarks, skin incision, dilation of the CCT, insertion of the ETT, and securing the intubation tube. The simulator currently has two main tasks, the identification of landmarks and skin incision. Identification of the landmarks task is the first essential step prior to the skin incision task. Inability to identify the landmarks correctly can cause an incision at a wrong location, which can result in morbidity or mortality in some cases [6]. After correct identification of landmarks, the next step is to perform an incision at cricoid membrane.

2.2.1. Cricothyroidotomy Simulation: Landmark Identification Task

In the landmark identification task, the user is asked to place a virtual pin at each of the physical landmarks. The virtual marker is manipulated with the haptic device. Haptic feedback is integrated so the user can identify their location besides the anatomical visual cues. The simulator records the location of all the markers and calculates the accuracy (vector offset) of the placement. In Figure 3a, the Oculus Rift eye (left eye only) of the simulator is shown, where the user has attempted to identify all the landmarks.

2.2.2. Cricothyroidotomy Simulation: Incision Task

The incision in our simulator is realized by removing the pixels on the skin in the fragment shader. We used an ellipsoid formula in Eq. (1) to simulate the incision;

$$\frac{(x*cos\beta+y*sin\beta)^2}{a^2}+\frac{(x*sin\beta-y*cos\beta)^2}{b^2} \qquad (1)$$

where β is the angle of rotation, a is the radius in the x direction and b is the radius in the y direction. This technique allows performing a realistic incision regardless of the model complexity. The incision can be visualized with no impact on the performance. The incision starts as the tip of the scalpel penetrates the skin (e.g. when the scalpel collides the skin with a certain depth threshold is achieved) and the incision ends when the penetration of the skin comes to an end (e.g. when a certain depth threshold is not satisfied anymore during the translational scalpel motion). The incision is continuously rendered on the skin until the incision is completed. During a sudden change in the incision orientation, a new incision is created at that point.

As there are fat layers between the outer skin and the cricoid membrane, the incision should simulate the visual appearance of the layered cut. Therefore, each layer is given a unique identification number. This identification number determines which layer the user is allowed to cut at any specific time. The inner layer cut is allowed only once the outer layer is cut or the cutting pressure is beyond a threshold value. Each layer has a different ellipsoid formula which influences the size of the incision. Figure 3b shows the CCT scene after the incision in Oculus Rift eye view.

Figure 3a. CCT Scene with landmarks identified.

Figure 3b. CCT Scene after the incision in Oculus view.

3. Results

Both simulators were IRB approved for data collection. CCT and ETI simulators were used in Society for Education in Anesthesiology (SEA) and Association for Surgical Education (ASE) meetings, respectively. Two questionnaires were provided for the users, one before and one after the simulator tasks were performed.

3.1. Cricothyroidotomy Results

Out of the 38 participants; 26 were attending surgeons, 4 of them were medical students and 8 were post graduates. The participants described themselves as active gamers in the questionnaire had a 21.25% (14.4 seconds) faster results in skin incision task than those who were not active gamers, while the number of incisions for the active gamers were 9.27%(1.45 attempts) less than non-active gamers. Figure 4 shows the comparison of active and non-active gamers' times in the incision task. In the identification of landmarks task, the active gamers were 21.76% (21.87 seconds) faster in identifying the landmarks. Figure 5 shows the comparison of active and non-active gamers' times in the identification of landmarks task.

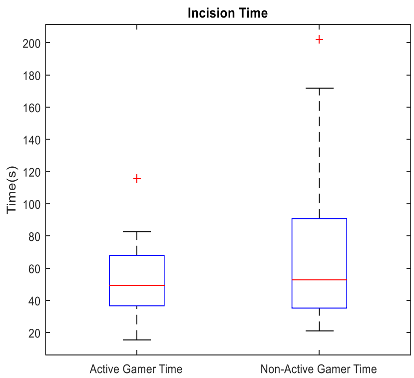

Figure 4. Comparison of Active Gamer a Non-Active gamer time in the incision task.

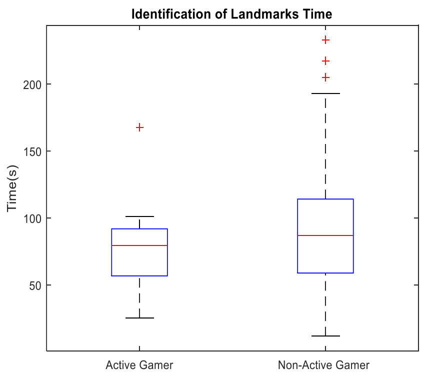

Figure 5. Comparison of Active Gamer and Non-Active gamer time in identification of landmarks task.

The participants trained on the Advanced Trauma Life Support (ATLS)[7], had a 17.92% (13.83 seconds) faster skin incision time than those who were not trained on ATLS. The participants that were not trained on the ATLS used 23.56% (average 11.8 attempts) more incisions during the skin incision task, than who were trained on the ATLS. This result shows that the ATLS trainees are faster but less number of incisions during skin incision. The Pearson's correlation test shows that for the ATLS trainees that there is a strong positive correlation (R=0.8652, p=0.026032) between number of incisions and the incision time. The participants with mannequin simulator training were 16.85% (11.4 seconds) faster than participants without mannequin training. The participants with mannequin training had 13.73% (2.3 attempts) more incisions during the skin incision task in comparison to participants that were not trained on mannequin simulators. Figure 6 shows the comparison of the ATLS trainee and Mannequin trainee time in the incision task.

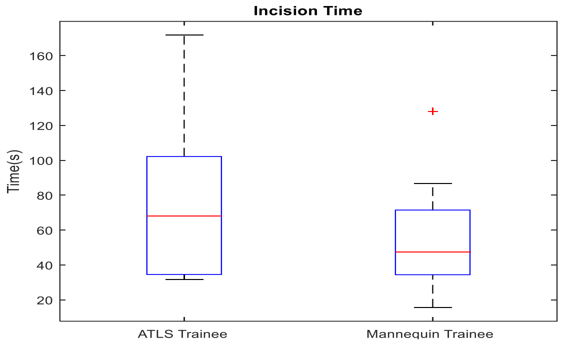

Figure 6. Comparison of the ATSL trainee and Mannequin trainee time in the incision task.

3.2. Endotracheal Intubation Results

Out of 48 participants, 33 were attending anesthesiologists, 14 were post graduates and one was a medical student. The Mallampati scoring was performed 51 times in among 48 participants, at least one by each participant. There were total 16 incorrect classifications made. While the average time for an incorrect Mallampati classification was 16.58 seconds, for a correct classification the average time was 9.62 seconds. After the Mallampati scores were determined, the participants were asked to adjust the patient's head to find the optimum angle for an intubation [4]. With the available 3D model, the optimal angle for intubation was determined to be 115°. The average angle for attending anesthesiologists was 114.93° and the average angle for post graduates was 114.35°. These results showed that the optimal angle in the simulator was nearly identical to those of attending anesthesiologists and post graduates.

4. Conclusion and Feature Works

We developed preliminary simulations for the ETI and CCT tasks and performed initial study in the ASE and SEA meetings. Our results indicated that in the skin incision task, active gamers are faster and also more accurate with their incisions than the non–active gamers. Active gamers also completed the task faster in identification of landmarks task.

We plan on implementing bleeding during skin incision task and an option for user to adjust the operation table to increase the realism. Instead of using Geomagic Touch haptic device, we are looking to integrate a custom developed haptic glove that could give force feedback during the palpation of the skin to identify landmarks. At present, we have one base difficulty scenario. Our goal is to create various difficulty scenarios to train the physicians for a realistic experience as well as for life critical cases.

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