Design and Development of an Immersive Virtual Reality Team Trainer

for Advance Cardiac Life Support

by

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ABSTRACT

Technology in the modern day has ensured that learning of skills and behavior may be both widely disseminated and cheaply available. An example of this is the concept of virtual reality (VR) training. Virtual Reality training ensures that learning can be provided often, in a safe simulated setting, and it may be delivered in a manner that makes it engaging while negating the need to purchase special equipment.

This thesis presents a case study in the form of a time critical, team based medical scenario known as Advanced Cardiac Life Support (ACLS). A framework and methodology associated with the design of a VR trainer for ACLS is detailed. In addition, in order to potentially provide an engaging experience, the simulator was designed to incorporate immersive elements and a multimodal interface (haptic, visual, and auditory).

A study was conducted to test two primary hypotheses namely: a meaningful transfer of skill is achieved from virtual reality training to real world mock codes and the presence of immersive components in virtual reality leads to an increase in the performance gained. The participant pool consisted of 54 clinicians divided into 9 teams of 6 members each. The teams were categorized into three treatment groups: immersive VR (3 teams), minimally immersive VR (3 teams), and control (3 teams). The study was conducted in 4 phases from a real world mock code pretest to assess baselines to a 30 minute VR training session culminating in a final mock code to assess the performance change from the baseline. The minimally immersive team was treated as control for the immersive components. The teams were graded, in both VR and mock code sessions, using the evaluation metric used in real world mock codes.

The study revealed that the immersive VR groups saw greater performance gain from pretest to posttest than the minimally immersive and control groups in case of the VFib/VTach scenario (~20% to ~5%). Also the immersive VR groups had a greater performance gain than the minimally immersive groups from the first to the final session of VFib/VTach (29% to -13%) and PEA (27% to 15%).

DEDICATION

To my parents

ACKNOWLEDGMENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

INTRODUCTION

The advent of high speed networks and powerful personal computing systems has seen a marked increase in the dissemination of graphically intensive applications and softwares for purposes beyond the more traditional ones such as recreational gaming. The use of video games in education has been topic of much debate and research for some time. (Jenkins, 2003) (Squire, 2003) Games have been used to provide students with an engaging way to learn. The idea behind these learning games is to develop the skills, abilities, and critical knowledge that students may apply in the real world. (Mendiz, 2003) However, educational games are not simply reserved for children. Video games may be used to provide skills training and knowledge to adults as well. To that end the field of learning and computing has moved towards the notion of interactive computing environments. (Dickey, 2007) (The Serious Games Initiative) These environments can otherwise be thought of as effective learning environments where certain features of game development and design are used to provide immersive scenarios with clearly defined goals and possibilities for committing errors that encourages and enhances learning

Presented here is a methodology for the design and development of such a learning environment, specifically, to provide Advanced Cardiac Life Support (ACLS) protocol and team training. This chapter attempts to explain the general motivation behind this work. Chapter 2 provides a summary of the background of Advanced Cardiac Life Support and Chapter 3 presents some related work in the domains covered by this thesis. Chapter 4 describes the conceptual framework for the design of the simulator and Chapter 5 describes the methodology for its

development. Chapter 6 describes the experiments conducted to assess transfer of skill from the simulator to the real world and present the findings from the same. Finally, Chapters 7 and 8 present a discussion of the current work and conclusion along with the future work respectively.

1.1 Virtual Reality Simulation, Immersion, and Learning

Virtual reality (VR) can be defined as computer-generated, fully or partially interactive three dimensional environments. The design of virtual reality environments is not dissimilar to game design as a modern game can be thought of as being virtual reality. Therefore some of the features of game design and development that go into the making of effective learning environments as alluded to above can be used to design and develop virtual reality training environments. Some of these features are: social, research, problem solving, transfer, and experiential. (Oblinger, 2006) Social features foster a sense of community as well as competition. Research involves new players exploring and learning about the environment. Game environments allow for users to apply existing or learned skills and knowledge to overcome obstacles. Players may imbue in-game skills and apply them to real world problems. This can be viewed as the definition of transfer and finally experiential environments allow for multimodal feedback and settings consistent with the real world visually and otherwise. The combination of these features can be used to develop an immersive training environment.

Immersive environments allow the users to participate and inhabit the simulated worlds in ways that might otherwise be inaccessible to them. Immersion can be defined as being the subjective impression that one is participating in a comprehensive, realistic experience. (Stanney, 2002)

Immersion in videogames can be subdivided into two categories, diegetic and situated. (Taylor, 2002) (Amy Alexander, Tad Brunye, Jason Sidman, and Shawn A. Weil, 2005) Diegetic immersion is immersion in the act of playing the game and situated immersion is immersion not only in the game but also experiencing the existence of the game's virtual space. Another concept analogous to immersion is engagement. Engagement can be defined as the most fundamental level of involvement a user experiences with a simulation or game. (Cairns, 2004) Engagement in a subject matter can increase pleasure in that subject and this in turn enhances learning. (Hargadon, 2000)

This insight into immersive environments has contributed to the development of distributed virtual reality simulators. Distributed virtual reality is a simulated computing environment that adheres to the features of game development described above while providing the possibility for distributed access i.e. for remote users from various real world locations to be present in the same virtual space. This concept is inherently similar to that of an MMORPG (Massive Multiplayer Online Role-Playing Game). MMORPGs have been shown to foster motivation (Dickey, 2007) and learning. (Rosemary Garris, 2002) These virtual environments allow users to coexist spatially and provide means to communicate and interact as they would in the real world.

Figure 1: Users interacting within a virtual environment (www.virtualworld.com)

The modalities of interaction provided by virtual environments can be translated into training individuals or teams by allowing them to perform the required tasks within an environment with a predefined set of rules and obstacles. The performance of these users or teams of users can be recorded and analyzed to obtain patterns of teamwork and communication. In practice such virtual environments have been employed in domains such as aviation (Waag, 1998) and community building and socializing (Bell, 2004) among others.

1.2 Virtual reality in team based medical environments

One important application of virtual reality as described above that is apropos of this thesis is its use in medicine. (Neal E. Seymour, 2002) (T. P. Grantcharov, 2004) Specifically in the context of medical team based environments such distributed virtual reality environments can be used to impart

team and individual training, reduce the cost of equipment used to impart the same, make it easy for clinicians to receive training more often, and remove the need to travel to specific locations.

In order to design a team training environment certain aspects of team interactions needs to be considered such as situational and context awareness as well as communication. In order to provide comprehensive team training the environment must be designed to incorporate the above elements among others. Two other aspects of training environments in general is the ability to provide real-time and summative feedback. A virtual world is inherently capable of providing all of the above by adhering to game design guidelines described earlier as well as integrating a variety of tools that would provide the added multimodal feedback that is required. For example, in surgical virtual reality environments parameters such as smoothness of hand motion and penetration depth can be recorded and analyzed in real time. A summative analysis can then be performed on a single session and by means of debrief the current user's performance can be ranked according to the performance of other medical professionals or can be categorized in terms of expertise level. In the case of protocol and team trainers, measures such as adherence to protocol, time to initiate key events, failure to perform critical events, communication patterns can be assessed in real time as well as in summary. The added advantage of virtual team trainers is, as mentioned earlier, the ability to provide remote training. This can lead to clinicians receiving the particular intervention or training more times than is common using current training techniques.

However, there are distinct disadvantages to using existing virtual reality development tools and softwares such as:

1. Security of recorded information: Distributed Virtual reality requires the existence of central server that runs a version of the scenario and all the backend data collection tools since all clients need to exist in a centralized virtual space. The servers are usually restricted to clients and are in full control of the developer of the virtual world. Therefore, they have to be entrusted with the security of potentially sensitive medical information.

2. Restricted development capabilities: The functionality made available to the end users is constrained by the access and tools provided by the developer. Often, the developer restricts access to proprietary libraries therefore a lot of custom tools and softwares may not be usable with the virtual world. Moreover, the user is also graphically restricted by the capabilities of the environment.

3. Recurring expenditures: Virtual worlds like MMORPGs charge yearly or monthly fees. These expenses usually discourage users and organizations from adopting these technologies. Additionally, this will cause all scenarios developed within the environment to likely be highly restricted to users thereby reducing its scope.

Therefore, for the purposes of this thesis, a free for non-commercial development game engine, Unreal Development Toolkit (Epic Games) has been used along with open source libraries to integrate audio and haptic (touch) feedback as well as database access. The advantage of using the above game engine is that the development is done from scratch and therefore the developer also has full administrative authority over the server that runs the virtual world and this in turn gives the developers a high degree of customizability.

1.3 Objectives

In this thesis an immersive ACLS virtual reality simulation is designed and developed. In order to explore the potential of the simulator a study was designed. The objectives of the study are as follows:

1. To use expert defined metrics to show a transfer of skill from the ACLS simulation to real world mock codes.

2. To validate the effectiveness of the immersive components on the performance of the teams.

3. To collect system usability metrics from the users using questionnaires.

Chapter 2

BACKGROUND

This thesis is concerned with the development of a virtual reality simulator to train teams to perform a particular time critical clinical protocol, Advanced Cardiac Life Support (ACLS). This section presents background information on the ACLS protocol.

Advanced Cardiac Life Support (ACLS) refers to a set of clinical interventions intended to be employed to provide life saving measures during cardiac arrests and respiratory failures. ACLS is a time critical team based procedure that requires extensive medical knowledge and skill. ACLS may only be administered by qualified medical professionals such as nurses, physicians, paramedics etc. The 2010 ACLS protocol guidelines have been laid out by the American Heart Association. (AHA)

In hospitals Code Blue is the reserved emergency code for a patient requires resuscitation. A Code Blue indicates that the patient is suffering from a life threatening situation and the rapid and correct administration of ACLS is vital. Therefore, most hospitals require or strongly encourage medical staff to be trained in the ACLS protocol and larger institutions may even have ACLS experts for such a situation.

The ACLS code is a high stress, time critical scenario that requires each team member to have complete medical knowledge of the ACLS protocol and the ability to work as a team since missed tasks and miscommunication could be potentially fatal. Administration of ACLS by trained ACLS professionals has been shown to increase patient outcomes as much as 20%. (Moretti MA, 2007)

8

2.1 The Advanced Cardiac Life Support Team

When a Code Blue is called for a patient then an ACLS team assembles in the patient's room. ACLS teams are typically made up of five to six members depending on the size of the institution or the number of personnel available. At this point the medical personnel in the room are expected to assumer roles according to the tasks they will be performing during the resuscitation. The roles usually split according to the primary task each role is required to perform however the AHA does not prescribe a standard name for each role. For the purposes of this thesis six roles are considered and roles were named according to their primary task during ACLS. They are: Leader, Compressor, Medicator, Defibrillator, Respirator, and Airway Manager. Below is summary of the tasks each role performs, however the specifics of the ACLS algorithm are explored later on.

The Leader assumes responsibility for the code and oversees the actions and tasks of other team members. They are responsible for ensuring that critical tasks occur at appropriate times and that tasks are not missed. The Leader also ensures that team interactions are efficient and communication is clear and precise. The Compressor is responsible for performing Cardiopulmonary Resuscitation (CPR). CPR is the most physically intensive task in the ACLS protocol and the Compressor is expected to adhere to certain rules as described in the CPR guidelines within ACLS such as rate of compressions, depth, and recoil. The Medicator is responsible for administering the pharmacological interventions as prescribed by the ACLS guidelines. The Respirator and Airway Manager are responsible for ensuring that the patient receives a steady supply of Oxygen and that their airway is opened to allow the Oxygen to reach the lungs.

The Defibrillator is responsible for identifying the patient heart rhythm (EKG). There are two primary types of rhythms, shockable and non-shockable. The Defibrillator is also responsible for shocking the patient at regular intervals using the Mono or Biphasic defibrillator if the patient's heart rhythm is shockable. The AHA guidelines state that no single clinician should perform CPR for longer than two minutes at a time owing to physical effort required therefore one of the roles described above is required to switch roles with the compressor every two minutes. Usually this tends to be the role closest to the Compressor in the room.

2.2 The ACLS Algorithm

The flowchart below expands the general ACLS protocol for shockable and non-shockable rhythms. There are different types of abnormal heart rhythms (arrhythmias) namely: Ventricular Fibrillation, Ventricular Tachycardia, Sinus Bradycardia, Pulseless Electrical Activity (PEA) and Asystole among others. Arrhythmias are broadly classified into shockable and non-shockable rhythms. For the purposes of this thesis one Shockable and one non-shockable arrhythmia was considered.

Shockable Rhythm – Ventricular Fibrillation / Ventricular Tachycardia

Non-Shockable Rhythm – Pulseless Electrical Activity (PEA)

1
PULSELESS ARREST
- BLS Algorithm: Call for help, give CPR
- Give **oxygen** when available
- Attach monitor/defibrillator when available

2 Check rhythm
Shockable rhythm?

Shockable   Not Shockable

3 VF/VT   **9** Asystole/PEA

4
Give 1 shock
- Manual biphasic: device specific
  (typically 120 to 200 J)
  Note: If unknown, use 200 J
- AED: device specific
- Monophasic: 360 J
Resume CPR immediately

Give 5 cycles of CPR*

5 Check rhythm   No
Shockable rhythm?

Shockable

6
Continue CPR while defibrillator is charging
Give 1 shock
- Manual biphasic: device specific
  (same as first shock or higher dose)
  Note: If unknown, use 200 J
- AED: device specific
- Monophasic: 360 J
Resume CPR immediately after the shock
When IV/IO available, give vasopressor during CPR
(before or after the shock)
- **Epinephrine** 1 mg IV/IO
  Repeat every 3 to 5 min
      or
- May give 1 dose of **vasopressin** 40 U IV/IO to
  replace first or second dose of **epinephrine**

Give 5 cycles of CPR*

7 Check rhythm   No
Shockable rhythm?

Shockable

8
Continue CPR while defibrillator is charging
Give 1 shock
- Manual biphasic: device specific
  (same as first shock or higher dose)
  Note: If unknown, use 200 J
- AED: device specific
- Monophasic: 360 J
Resume CPR immediately after the shock
Consider **antiarrhythmics**; give during CPR
(before or after the shock)
  amiodarone (300 mg IV/IO once, then
  consider additional 150 mg IV/IO once) or
  lidocaine (1 to 1.5 mg/kg first dose, then 0.5 to
  0.75 mg/kg IV/IO, maximum 3 doses or 3 mg/kg)
Consider **magnesium,** loading dose
  1 to 2 g IV/IO for torsades de pointes
After 5 cycles of CPR,* got to Box 5 above

10
Resume CPR immediately for 5 cycles
When IV/IO available, give vasopressor
- **Epinephrine** 1 mg IV/IO
  Repeat every 3 to 5 min
      or
- May give 1 dose of **vasopressin** 40 U IV/IO to
  replace first or second dose of **epinephrine**

Consider **atropine** 1 mg IV/IO
  for asystole or slow PEA rate
  Repeat every 3 to 5 min (up to 3 doses)

Give 5 cycles
of CPR*

11 Check rhythm
Shockable rhythm?

Not   Shockable
Shockable

12
- If asystole, go to Box 10
- If electrical activity, check
  pulse. If no pulse, go to
  Box 10
- If pulse present, begin
  postresuscitation care

13
Go to
Box 4

During CPR
- **Push hard and fast (100/min)**
- **Ensure full chest recoil**
- **Minimize interruptions in chest
  compressions**
- One cycle of CPR: 30 compressions
  then 2 breaths; 5 cycles ≈2 min
- Avoid hyperventilation
- Secure airway and confirm placement

- Rotate compressors every
  2 minutes with rhythm checks
- Search for and treat possible
  contributing factors:
  – **H**ypovolemia
  – **H**ypoxia
  – **H**ydrogen ion (acidosis)
  – **H**ypo-/hyperkalemia
  – **H**ypoglycemia
  – **H**ypothermia
  – **T**oxins
  – **T**amponade, cardiac
  – **T**ension pneumothorax
  – **T**hrombosis (coronary or
    pulmonary)
  – **T**rauma

* After an advanced airway is placed,
rescuers no longer deliver "cycles"
of CPR. Give continous chest com-
pressions without pauses for breaths.
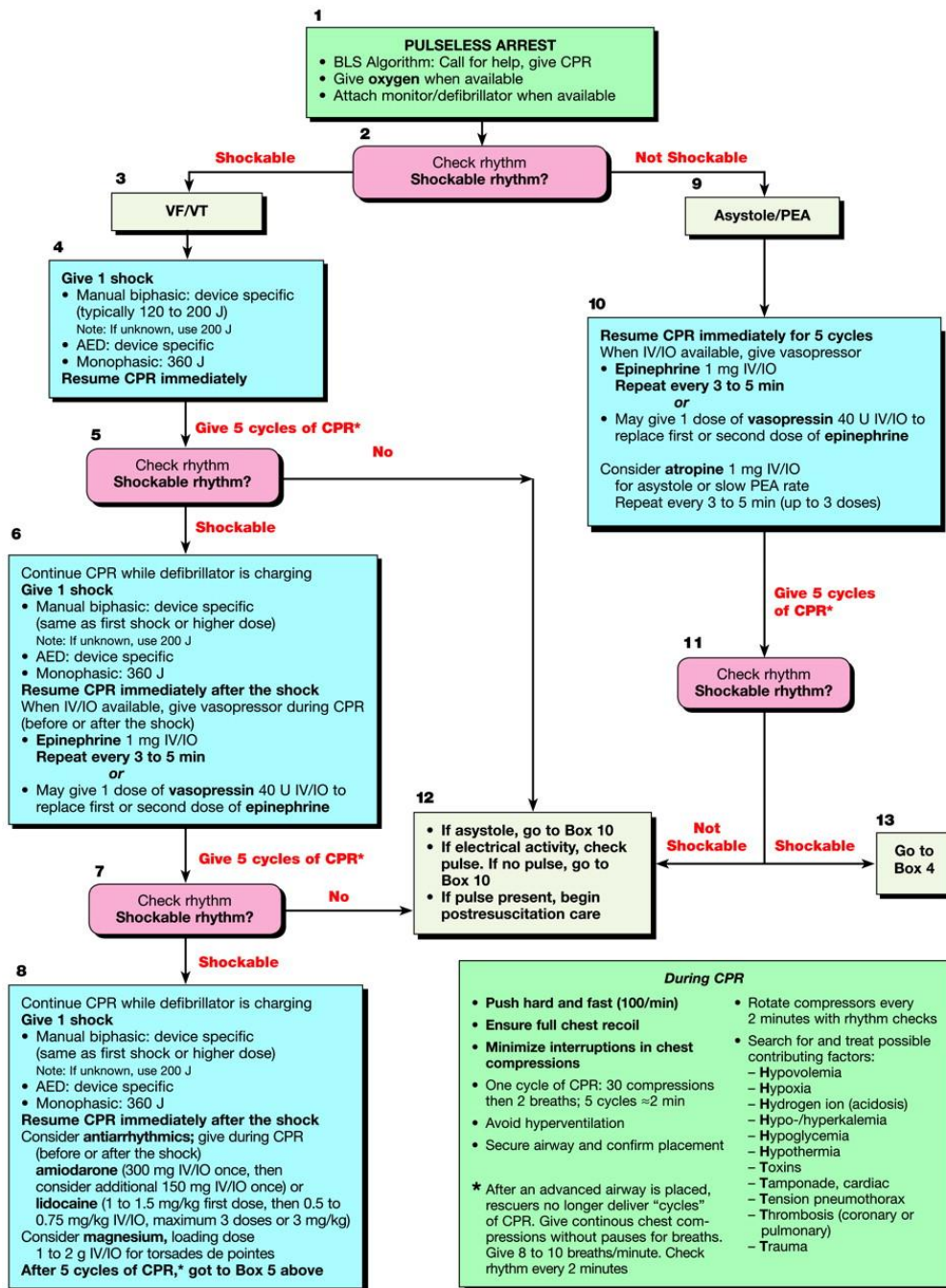Give 8 to 10 breaths/minute. Check
rhythm every 2 minutes.

Figure 2: ACLS Algorithm in flowchart form (Streamdent)

2.3 ACLS Mock Codes

Mock codes are a means by which hospitals attempt to provide regular ACLS protocol training to its medical personnel. Training is commonly employed

using the concept of clinical simulation. (Diane B Wayne, 2006) Clinical simulation involves the steps of a particular procedure or protocol being performed on a patient substitute, frequently a human analog (i.e. manikin). An instructor is present during training who observes the team as they perform the required set of tasks. The scenarios are time limited, usually to five minute sessions. Once complete, a full evaluation of the team's performance is given to them by means of a debriefing session. In recent years high fidelity manikins have replaced the older manikins. The newer manikins can respond to the procedures performed on them and convey the information to a connected computer for post assessment.

However, there are certain issues with the current training methods:

1. The aspects of team interaction are not addressed by the training. Even high fidelity manikins only provide data about the specific tasks that were performed on it. However, the role played by team members in the success or failure of a session cannot be determined by the manikin alone since parameters of team interactions may include communication, quickness of response etc.

2. Owing to the lack of quantifiable data on team interaction an instructor is required to be present. However, the instructor still faces a number of problems such as needing to capture a large amount of information and keeping track of tasks at a reasonable level of granularity so as to provide effective feedback.

3. Due to the high cognitive complexity of monitoring multiple (often parallel) input streams of data, an instructor cannot effectively assess team communication and its dependencies.

4. High fidelity manikins are expensive due to which a team of ACLS trainees is required to convene at specified locations that own these manikins to receive training. This usually means that clinicians at most receive ACLS training twice a year.

5. The need to have every member of a team in the same place at the same time poses a logistical problem in itself owing to the often busy schedules of medical professionals. There have been efforts to correct that using internet based protocol training (ACLS-Algorithms) but these largely involve checklists and do not go deep enough into all aspects of ACLS training.

These issues among others have seen a rise of alternate training techniques virtual reality being one of them. Virtual reality simulations can provide a cost effective alternative to ACLS training. Virtual reality training can overcome the issue of scheduling as well as the need to travel to locations to train and hence ensure that medical professionals receive ACLS training more often. It can also provide a cheap alternative to high fidelity manikins. Moreover, a computer system can capture events within the simulation to any desired level of granularity and precision. By incorporating multimodal data collection team interactions can be studied in great detail along with adherence to protocol. The data collected from users and teams can be held at a central location that may be shared to create a large scale knowledge repository.

Chapter 3

RELATED WORK

Now that ACLS training has been placed in the context of virtual reality this section attempts to present related work in the various domains encompassed by this thesis namely:

1. Team training

2. Virtual reality training simulations in medicine

3. Immersion and learning

3.1 Team training

A team is a group of people assembled in the pursuit of a common goal. The achievement of the goal in question relies heavily on the team members performing their individual tasks, but also on working together. The analysis and assessment of team skills has been divided into these six components: cooperation, coordination, communication, cognition, leadership and conflict resolution. (Salas et al., 1992) Another concept related to team skills is that of team cognition. Kiekel et al., 2001 describe team cognition as the team analog of individual cognition i.e. the thoughts and knowledge of the team.

In healthcare team work is often vital to patient safety and outcomes and therefore healthcare organizations stress comprehensive team training. The Agency for a Healthcare Research and Quality (AHRQ) a branch of the U.S department of Health and Human Services developed a framework for team training known as TeamSTEPPS. (TeamSTEPPS) This system is used to improve communication and teamwork skills among healthcare professionals based on curriculums developed to integrate teamwork principles into healthcare. Smith-

Jentsch et al., 1998 describe the concept of Team Dimensional Training (TDT) as being a strategy for enhancing teams' ability to self-correct. TDT helps teams develop shared, accurate knowledge about the components of teamwork in an attempt to accelerate the mastery of targeted skills.

In ACLS and other team training scenarios the performance of individual team members is given precedence over the performance of the team as a whole. (Hamman, 2009) Some of the reasons for this discrepancy are that individual training, as mentioned earlier, is easier to conduct and logistically more feasible. However, team skills are vital to improving patient outcome and the incorporation of team metrics in simulations are required in order to provide the best possible guidance and training to healthcare professionals.

3.2 Virtual reality training simulations in medicine

Virtual reality has been shown to be effective in training psychomotor and surgical skills, specifically laparoscopic skills. Multiple studies have shown that virtual reality simulators can be used to predict expertise in surgeons as well as train, and assess skills. (Neal E. Seymour, 2002) (T. P. Grantcharov, 2004) (N Taffinder, Validation of virtual relaity to teach and assess psychomotor skills in laparoscopic surgery: Results from randomized controller studies using the MIST VR laparoscopic simulator, 1998) However, often these types of simulators are developed for medical procedures that have a psychomotor component along with a cognitive component to them. For this reason virtual reality research has largely overlooked procedures that have a minimal psychomotor component. In the case of protocol driven scenarios such as ACLS efforts have been made to provide online training (ACLS-Algorithms) but this type of training is usually presented in the form of checklists and makes allowances for neither the function

of team nor the cognitive stress induced by a real code situation or a simulated code. Due to this reason among others alternative distributed training techniques are being explored and virtual reality training, for the reasons described earlier, has seen an increase in focus.

Mantovani et al., 2003 describe the potential benefits of virtual reality based training to healthcare education as being able to provide experiential and active learning, provide a means to visualize a multitude of scenarios and commit and rectify errors without a fear of real world consequences, learning in contexts impossible or difficult to experience in real life such as locations within the human body, ability to create a motivating environment to enhance user learning, ability to learn collaboratively, the possibility for virtual reality to be tailored to the needs of individual users or a class of users and finally the ability to evaluate and assess performance in real time.

Distributed virtual environments, also known as Collaborative Virtual Environments (CVE) are powerful simulated environments capable of providing some or all of the features of virtual reality training mentioned above. CVEs can be used to create a process framework for Computer Supported Collaborative Learning (CSCL). CSCL has many important benefits in education (Tsiatsos, Andreas, & Pomportsis, 2010) and is different in several respects to e-learning which a much more straightforward and a less effective concept. (Stahl, 2006)

Current medical simulation technology can be classified into the following according to fidelity (Chodos, 2010): low-tech, simulated patients, screen-based computer simulations, complex task trainers, realistic patient simulators. They also describe two case studies of virtual world training systems developed for healthcare education. The first being an EMT/ER scenario simulation

implemented in a prototype Second-Life (Second Life, 2003) based system attempting to teach EMT students the procedures they are required to know and attempting to enhance their communication skills. An EMT/ER is an example of high stress, team based scenario making it similar in that respect to ACLS. The second case study is of a system called "InterD 410" which is a virtual environment aimed at creating a communication skills instructional program. This project, which is in its relative infancy, involves students using Second-Life to develop a patient interview plan with the help of an instructor present in the virtual world. The aim of the simulator is to facilitate collaborative learning using the virtual world.

Virtual world platforms such as Active Worlds (Active Worlds) and Second Life have been used to create other learning environments for medical and health education. (Maged N. Kamel Boulos, 2007) The paper provides two scenarios, 'HealthInfo Island' which is a project dedicated to health information in various forms. It aims at providing training programs and health resources and one-on-one support to second life residents. The target population of this project was people in Second Life medical groups such as stroke support and cerebral palsy etc. The second scenario is called 'Virtual Neurological Education Centre' in which people are able to actively expose the most common symptoms that a person suffering from a neurological disability may encounter. The sufferers of the disabilities are also provided information and support within the environment.

3.3 Immersive virtual reality

Some of the drawbacks of the existing virtual environments are that they are limited both visually and by the functionality provided. In order to enhance

the effect provided by learning simulations these simulations need to be designed to be engaging which may increase its usage and simultaneously increase the learning.

Immersion has been described as the degree to which an individual feels connected to an experience. (Amy Alexander, Tad Brunye, Jason Sidman, and Shawn A. Weil, 2005) Earlier, immersion was defined as consisting of two subtypes; diegetic immersion and situated immersion. Sandowski & Stanney, 2002 list a number of factors credited with inducing immersion such as levels of control, ease of interaction, video resolution, and social interaction. Situated immersion is also known by the term presence. (Slater, 2000) In the advertising domain experiments have been conducted to understand the impact of different types of stimuli provided within environments that enhance a sense of presence. (Dan Grigorovici, 2003) The studies found that the type of stimulus provided within the immersive environments could be used to alter perception and awareness of certain aspects of the virtual world.

Jackson & Fagan, 2002 describe an immersive virtual environment called Global Change World. The environment comprises of a selectively realistic representation of the city of Seattle, Washington. Selective realism has been described as virtual environments consisting of only those features of real world environments that are necessary to accomplish the exercises within the environment. The features of the world include the ability to navigate the virtual space and interact with the avatars of other participants within the virtual world. The objective of this world was to for middle school students to collaboratively study global warming. The students were split into three groups. Group 1 consisted of students exploring the environment alone, while Group 2 allowed

students to collaborate. Group 3 allowed students to collaborate with an instructor present within. The students were allowed to communicate using headsets within the virtual world and perform certain tasks related to measuring pollution and greenhouse gases. The study found that student engagement within the environment was largely dependent on the ability to collaborate. The students who reported being the most engaged were also highly communicative. They also found that a broader varied understanding of the concept of global warming was achieved by the group that communicated the most.

The effect of immersive virtual reality in transfer of skills and behaviors is an ongoing field of research. Carlin et al., 1997 found that virtual reality graded exposure was successful in reducing subjects' fear of spiders. Waller et al., 1998 found that sufficient exposure to virtual world training environments resulted in effective transfer of skill.

In the context of medicine and healthcare immersive virtual reality systems have been developed to deal with different aspects of straining such as skill or behavioral modification. Kizony et al., 2003 present a VR simulator designed to facilitate neurological rehabilitation in patients. Colt et al. found that the use of a virtual bronchoscopy simulation led to significant improvement in novice dexterity and accuracy. After training, some novices even exceeded the performance of skilled physicians.

Kanav Kahol, 2011, presented a framework for a virtual reality simulation designed to teach diabetes management and motivate exercise. The simulation allowed users to play through five different levels in the game each designed to provide different type of exercise. The patient was required to wear accelerometers that were the primary input mechanism used to control their

character in the game. The patients also had their heart rate monitored constantly and the same was displayed on the screen throughout the game. Lei Li et al., 2005 present a system called ERT-VR that trains emergency response teams with the help of a virtual instructor.

Dev et al., 2007 designed a computer based virtual emergency department simulator to train medical residents in managing trauma effectively. A primary focus of this system was distance training, teamwork, and leadership. A study of the users in this environment compared to on a human patient simulator showed comparable improvement from pre to posttest. However, virtual training could be provided from remote locations and at any time as opposed to the human patient simulator that posed several other restrictions.

Sainath Parab, 2011 developed a virtual reality simulator to provide distance training on the ACLS protocol. The simulator was developed on the Active Worlds platform and allowed users participate in a virtual mock code. The experiment to test the system consisted of a control and test group of four users each. Both groups were given a didactic session after which the test group was asked to use the virtual reality system a set number of times. Finally, the simulator was validated by running both groups through a posttest in the form of a real world mock code. The teams were evaluated on their adherence to the ACLS protocol. The results found that the percentage scores for the VR groups were significantly better than those of the control group.

Some of the main drawbacks of this ACLS simulator were that the users were given a single point of view and simulation administrators had no authority over the server of the virtual world. The virtual world was hosted on the Active world's server and limited the functionality provided to the developers.

Moreover, the scenario was not designed to be immersive and could therefore be was similar in functionality to a virtual checklist. The users tested on the system were non-clinicians and people who possessed no prior knowledge of the ACLS protocol and therefore it is not clear whether the same level of improvement would be seen in a group of clinicians. In order to create an engaging virtual scenario that trains the users in the ACLS protocol while attempting to inculcate aspects of team training, design must involve addition of immersive components along with raising the realism of the environment. This will theoretically increase the user willingness to use the system and therefore lead to an increase in the amount of training received.

Chapter 4

CONCEPTUAL DESIGN

4.1 ACLS Virtual Reality Framework

The primary objectives of the ACLS virtual reality simulator are to design and develop an immersive, engaging environment to provide distributed ACLS mock code and team training. To that end, a conceptual framework for the simulator was constructed. Firstly, a multiuser framework was developed for the ACLS simulator.
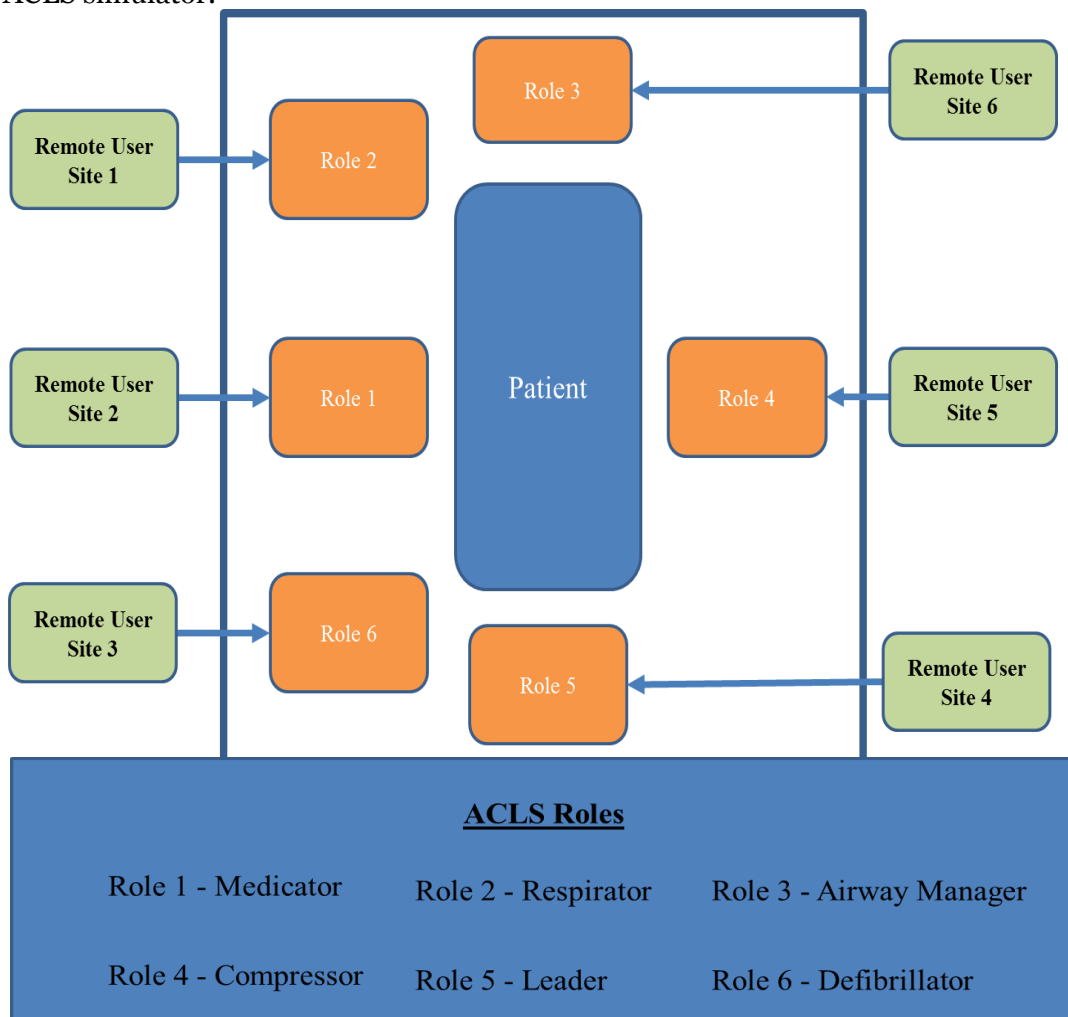

Figure 3: ACLS VR Framework

The VR environment consists of six roles as defined earlier. These roles occupy specific locations in the VR environment. The locations of these roles approximately reflect positions occupied by the corresponding roles in the real world.

The tasks associated with each role in the ACLS scenario are performed by remote users in the real world. Remote users who may log into the environment from distributed locations. The users may interact with the environment and they receive feedback in the form of animations and messages. Each role has a has a unique Heads Up Display (HUD) that is used as a part of the feedback delivery system as well as a method of performing certain actions by clicking on icons. Each user role is represented within the virtual environment by an avatar i.e. a 3D human model capable of visually representing tasks performed by the users in the form of animations. The tasks that each role is required to complete have been described in the overview of the ACLS protocol in the background section and will be delved into further in the methodology section.

4.2 System Design

The system has been designed using the server-client architecture. The simulated environment is hosted on a server and six clients can be connected from remote location. Figure 4 depicts the design of the simulator from the perspective of a single local user. Each client connected to the VR simulation consists of a unique User Interface (UI). Each UI consists of a graphical user interface (GUI) consisting of the role specific HUD and the feedback system, a method for inter user communication via headsets using the TeamSpeak VOIP API (TeamSpeak, 2002), and a modified Novint Falcon haptic joystick (Novint, 2000) required to perform CPR. Each user's UI also comes with a performance

23

evaluation module represented in the form of a patient outcome meter. This meter reflects the expected outcome of the patient that is assessed according to an adherence to the ACLS protocol. The patient outcome meter is common to all users along with the rendered environment. The outcome meter reflects the result of evaluation of all user performance in the scenario.
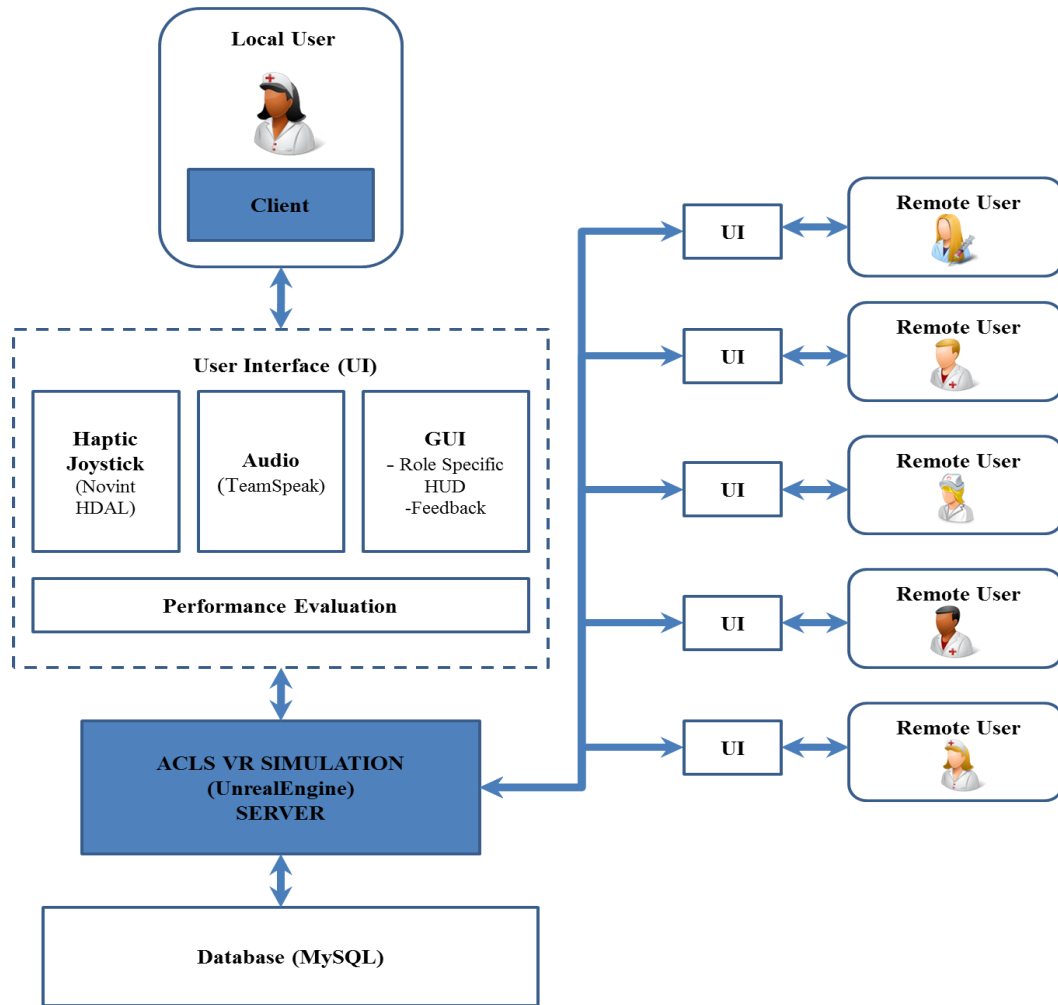

Figure 4: ACLS System Architecture

The communication is hands-free i.e. voice activated. Each user can speak to all other users in the VR environment. The current speaker is identified according to their ACLS role and this information is displayed on HUD of all

24

users. The Novint Falcon was modified to mimic the tactile pressures associated with compressing the chest of a patient. This was accomplished by integrating a Laerdal spring used in CPR manikins. All data from simulation is stored in an online database by integrating MySQL into the development environment API.

4.3 Platform

The ACLS simulator was implemented using the UnrealEngine3 via the Unreal Development Toolkit. (UDK, 1998) UDK is a free for non-commercial use game development kit that provides a means to create, edit, and deploy high fidelity 3D environments with sounds, animations, feedback via HUDs and menus, and allows for the integration of custom third party software libraries using C++ dynamic linked libraries. The custom libraries being used in for the ACLS scenario are TeamSpeak API for voice communication, Novint SDK for CPR feedback using the haptic joystick and finally MySQL integration using cSQL libraries to provide database functionality. A major advantage of UDK over virtual world softwares is that UDK is free to use and allows the developers to create dedicated servers that may hold the database and run the simulation centrally. This results in the developers having complete control over all information collected in the simulation and also gives users the ability to rapidly customize the scenario if required. Furthermore, UDK allows for the creation of scenarios at a much higher level of fidelity than any existing virtual world software. Finally, UDK is a mainstream game development toolkit and therefore contains extensive documentation and support, features that are missing from virtual world development softwares and this helps in quick deployment of new simulations or modifying existing simulations.

The environments are created using the UDK editor which allows for real time content creation and the backend scripting is done using native UDK script called UnrealScript. The C++ dynamic linked libraries required for third party APIs are called within UnrealScript classes.
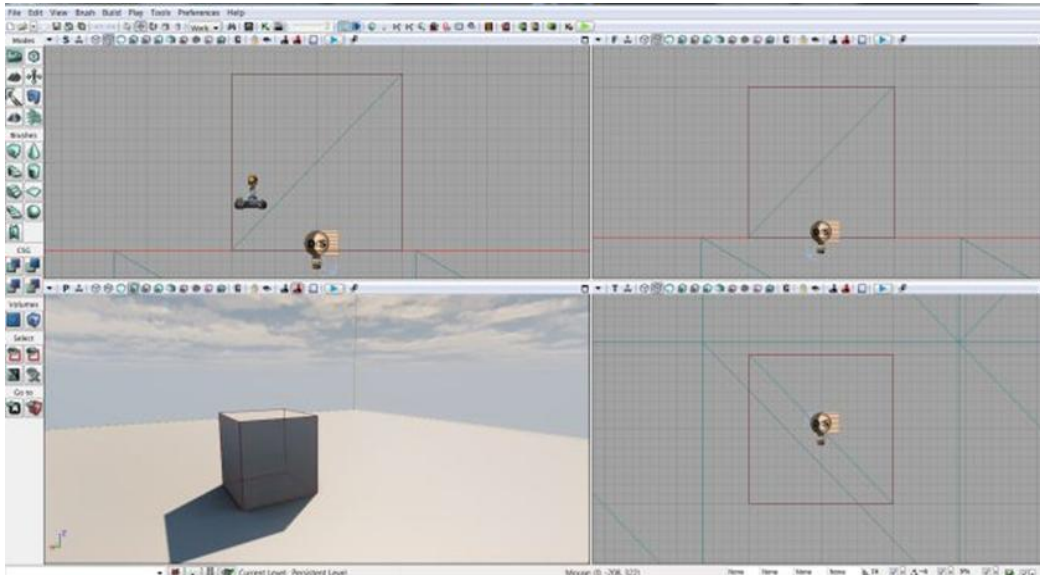

Figure 4: UDK Editor

4.4 ACLS Scenarios

As mentioned previously two types of ACLS code cases will be considered for this project- Shockable Rhythm : Ventricular Fibrillation (VFib) or Ventricular Tachycardia (VTach); Non-Shockable Rhythm: Pulseless Electrical Activity (PEA). The phrases 'code case', 'code scenario', and 'rhythm type' are used interchangeably in this document and are meant to indicate either a shockable or non-shockable rhythm.

Each rhythm type has a set of steps in common within the ACLS protocol and steps that vary depending on the type. The algorithm pertaining to each case has been shown in Figure 2 in the background section. The tasks required to be

performed by the team in each case will be listed in the methodology section. Upon logging into the simulation the users are given one of two cases based on a random selection and they are required to identify the case and proceed accordingly.

The scenario consists of six roles as mentioned earlier and for the purposes of this project the Compressor and Airway Manager roles are required to switch with each other every five cycles and perform CPR on the haptic device. The ACLS code is a time critical scenario therefore all events within are time dependent.

4.5 Immersive Components

The ACLS simulation incorporates components that add situated immersion. In order to do so, a number of factors have been considered that are hypothesized to contribute to a sense of Presence (situated immersion). (Witmer B.G. and Singer M.J., 1998) The following are a subset of the full list of hypothesized immersive components but were the only ones considered owing to time and functionality constraints of available software. The components have been categorized into four groups, control factors, sensory factors, distraction factors, realism factors.

Control Factors	Sensory Factors	Distraction Factors	Realism Factors
Mode of control	Sensory Modality	Distraction Factors	Scene Realism
Degree of control	Degree of movement perception		Information consistent with real world
Anticipation	Active Search		Meaningfulness of experience

Table 1: Immersive Factors

The various terms are defined below based on the definitions in Witmer B.G. and Singer M.J., 1998 and the implementation of these components is discussed in the methodology section.

1. Control Factors

    a. Mode of control – Presence may be enhanced by the way a user interacts with the environment. If the mode of control is artificial or especially if it requires learning new responses in the environment, presence may be diminished until those responses become well learned.

    b. Degree of control – Greater the degree of control a user has over the environment greater the sense of presence.

    c. Anticipation – If a user is able to predict what will happen next then presence is enhanced.

2. Sensory Factors

    a. Sensory Modality – Since most of our information comes through visual channels, visual information strongly influences presence. However, presence can be enhanced by supplementing it with a hierarchy of modalities.

    b. Degree of movement perception – If the observer perceives self-movement through the virtual environment then presence is enhanced.

    c. Active Search – An environment will enhance presence if it permits users to control their view point or search the environment haptically.

3. Distraction Factors

a. Selective Attention – The users' willingness to focus on the virtual environment stimuli affects presence.

4. Realism Factors

   a. Scene Realism – Presence should increase as a function of the realism of the virtual environment.

   b. Consistency of information with objective world – The more consistent the information delivered in the virtual environment to the real world more the sense of presence.

   c. Meaningfulness of experience – Presence should increase as the situation presented becomes more meaningful to the user. Meaningfulness is related to factors such as motivation to learn and task saliency.

Chapter 5

METHODOLOGY

5.1 User Interface (UI) construction

The primary input devices for all users are the mouse and keyboard. The Compressor and Airway Manager roles are provided with a Novint haptic device to perform CPR. Upon starting the simulation the user is expected to log in using a user ID and team ID as well selecting a role. The various components making up the user interface are discussed below.

5.1.1 Graphical User Interface (GUI)

The ACLS simulation GUI consists of all the visual elements incorporated into the simulation from the ACLS mock code setting to the heads up display that provides the users with the interface required to interact with the environment. The main components of the GUI are as follows:

1. Environmental assets and avatars

2. Role specific points of view and heads up display

3. Messages and feedback

5.1.1.1 Environmental assets and avatars

The VR environment is rendered centrally on the dedicated UDK server and is replicated to all clients. Figure 6 presents a screenshot of the virtual room. The environment has been designed to resemble a standard hospital room used to run ACLS mock codes with the minimum amount of medical equipment required to successfully complete the two code cases that may be run in the VR mock code (selective realism). The avatars (character models) representing each

role were purchased and all other objects within the environment were created using Autodesk Maya. (Autodesk, 1998) The avatars are capable of animations that act as visual confirmations of tasks being performed. An example of the requirement of animations is that users are required to press and hold the control key on the keyboard when they wish to clear the patient when a shock is to be delivered. When the control key is pressed the avatars associated with the role controlled by the user perform a hand raise animation. This provides a visual cue to the defibrillator that the shock can be delivered safely.

Figure 5: VR environment with six roles

The environment also consists of audio cues to simulate the real world such as defibrillator charging and shocking and the hissing of oxygen gas escaping from wall mounted nozzle. These sounds were recorded in-situ in the SimET center at Banner Good Samaritan Medical Centre and imported and placed in the simulated environment. The purpose of these audio cues is to add scene realism and a sense of urgency. Another important role of audio cues is feedback, for example when a defibrillator is charged then the distinct capacitor

charging sound of the same is played to all users and they might then realize that a shock is about to be delivered and their hands need to be moved away from the patient. The viewpoint shown in Figure 6 does not represent the viewpoint of each user within the simulation. The role specific views are discussed below. The images shown below contain no user avatars. The avatars have been removed to demonstrate the point-of-view of each user as clearly as possible.

5.1.1.2 Role specific viewpoints and heads up display

5.1.1.2.1 Medicator

Figure 6: Medicator View 1

Figures 7 & 8 show the two primary views associated with the Medicator role. View 1 is the primary angle that affords the role a view of the patient as well as tasks being performed by other users in the scenario such as compressions or respiration. The top of the screen consists of a clock and a variety of icons. Figure 7 also shows the purpose of each element in the HUD.

Figure 7: Medicator View 2

Figure 8: Medicator View 3

Clicking on the View Medicine Cart icon takes the user to View 2 (Figure 8). The highlighted medications correspond to the medications that can be selected

depending on the ACLS scenario in question (Ventricular Fibrillation/Ventricular Tachycardia or Pulseless Electrical Activity). Clicking on the appropriate medication switches view to Figure 9. Here a vial is selected and the appropriate dose is measured by drawing the required amount using the arrows. After completion of the above the confirm dosage icon is clicked. When the user is ready to inject the dosage that has been drawn the ready to deliver medication icon is clicked on the HUD. The confirm delivery icon is now replaced by an Administer dose icon. The medications available to the Medicator are as follows: Epinephrine, Amiodarone, Naloxone, Vasopressin, and a fluid flush.

The role specific animation for the Medicator consists of a sequence created within the scenario to indicate to all users that medication is currently being administered. The animations consist of the avatar bending to inject the dosage into the arm of the patient.

5.1.1.2.2 Respirator

Figure 10 shows the respirator view. The user responsible for this role is expected to place the ambu bag (air bag) and give two breaths every thirty compressions performed by the Compressor (the compression to breaths ratio as stated in the ACLS protocol is 30:2). The talk indictor, patient outcome meter and alerts are all common elements that exist for all roles and are explained in the feedback section.

The respirator HUD consists of a check pulse icon, an icon to view the defibrillator which gives the user the ability to review the rhythm type. The view defibrillator icon can be toggled to switch back and forth between the two views for all users. The Compress Ambu Bag icon is used to give a breath. The duration of icon press corresponds to the duration of compression of the ambu bag i.e. an

34

icon press for x seconds corresponds to keeping the ambu bag compressed for x seconds. The animation associated with the Respirator involves the compression of the ambu bag when the icon is clicked on the HUD.
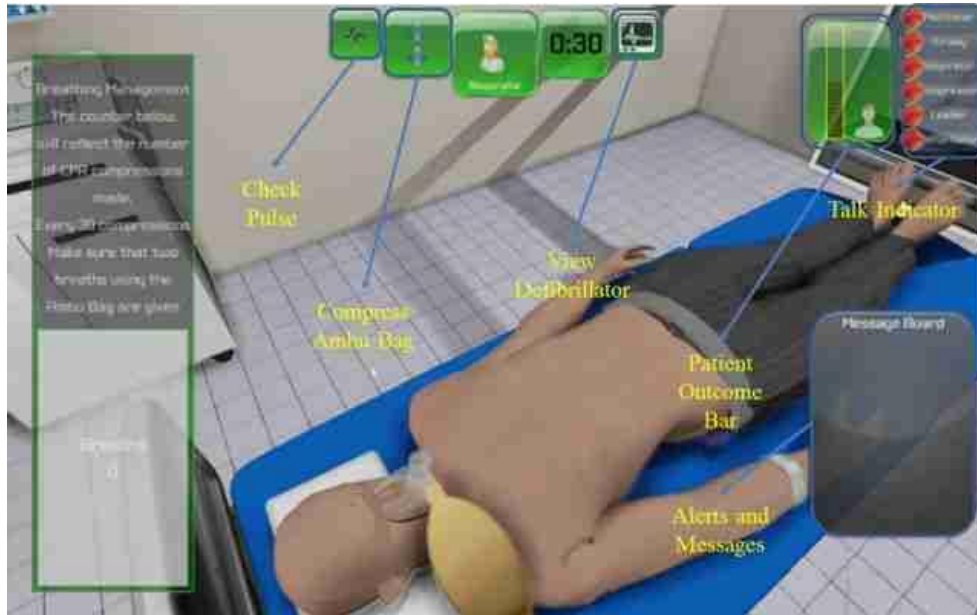

Figure 9: Respirator View
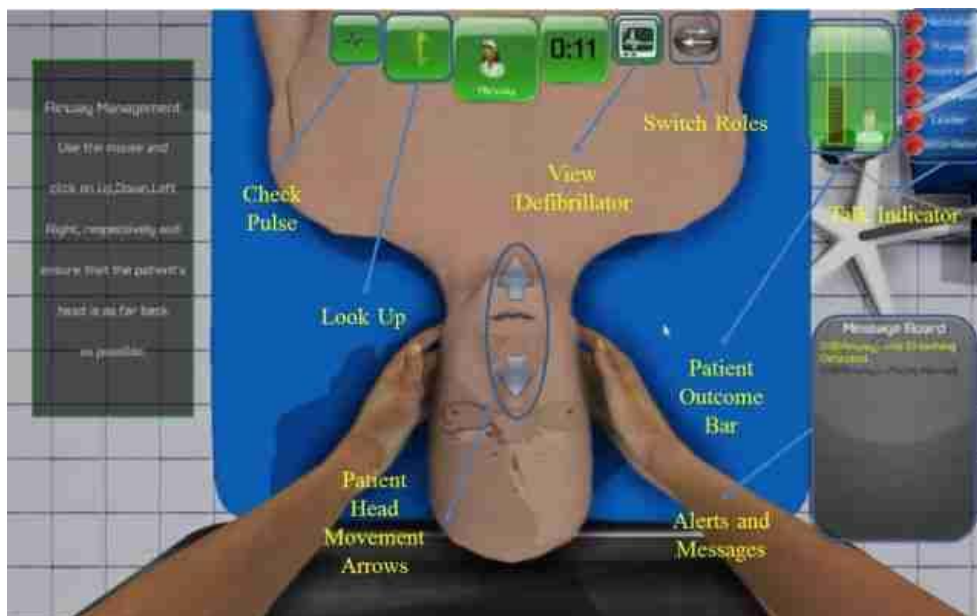
5.1.1.2.3 Airway manager

Figure 10: Airway Manager View

Figure 11 shows the Airway Manager HUD. The user playing this role is expected to tilt the patients head as far back as possible and maintain that position. The head is tilted using the up and down arrows. The patient head slowly moves upward as compressions are performed and the user is responsible for maintaining the tilt throughout. This role can also check pulse and view the defibrillator waveform and look up and at the room. This view can be used to ensure that other team members are performing appropriate tasks. The airway manager is also expected to switch roles with the compressor every two minutes. Therefore the Airway Manager and Compressor HUDs consist of a switch roles icon that needs to be clicked twice to switch roles. The first click transfers the role to a neutral view and the second click switches the user to the appropriate role.

The animations associated with the airway manager are those of the avatar arms as seen above as well as the patient head. The arms move as the head is moved by the user. The position of the patient head is visible to all users.
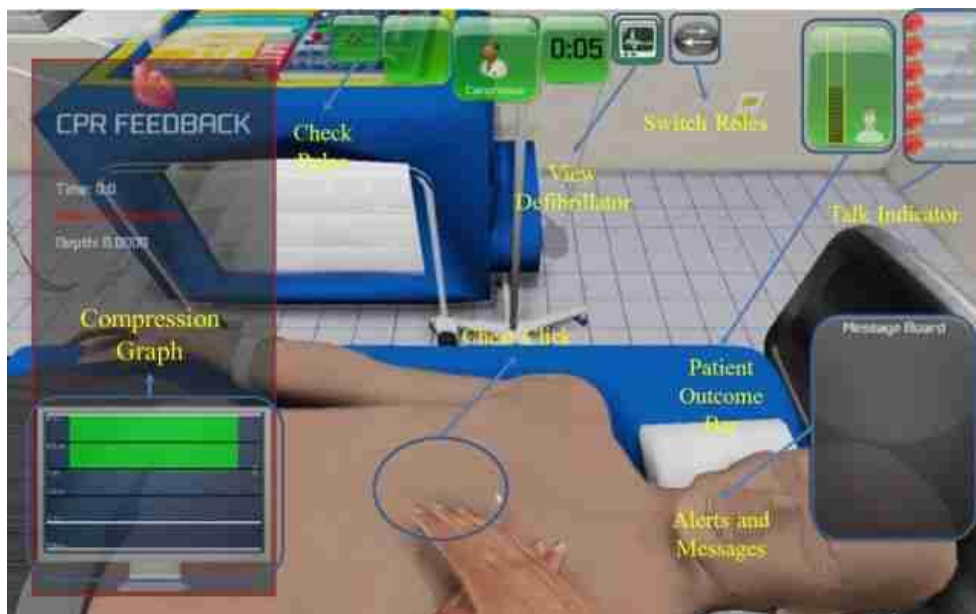
5.1.1.2.4 Compressor

Figure 11: Compressor View

36

Figure 12 shows the compressor view. The compressions are performed on the Novint Falcon haptic device. The device is initiated by clicking on the patient chest. The HUD modules on the left give real time feedback on the compression rate, depth and recoil. The compression graph moves between the highest position of the device and a depth of two and half inches as defined by the ACLS guidelines as maximum depth of compressions. The rate value flashes red when the required average rate of compressions is not achieved for a cycle of 30 compressions (100 compressions/minute). The compressor role is required to switch with the airway manager every two minutes. The compressor animation involves the avatar compressing the chest of the patient which is in turn dependent on the rate and depth of compressions performed on the haptic joystick.
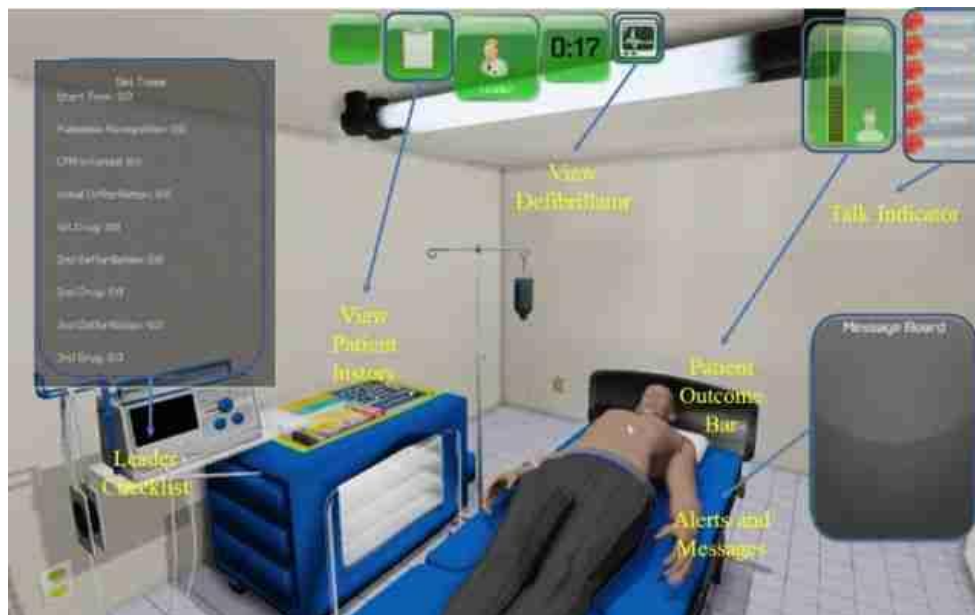
5.1.1.2.5 Leader

Figure 12: Leader View 1
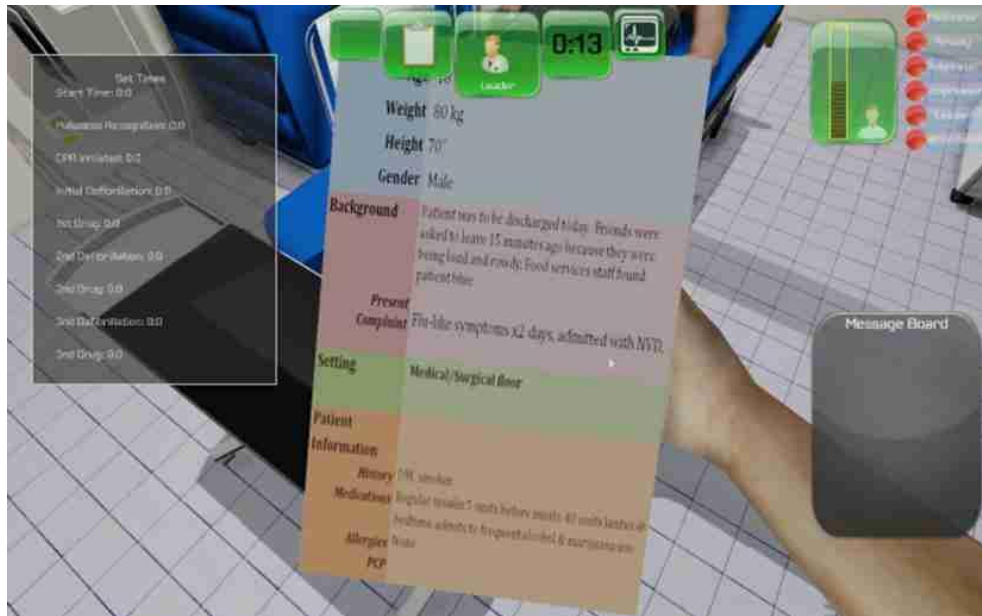
Figure 13: Leader View 2

The Leader HUD is shown in Figure 13. The leader is responsible for monitoring the scenario. The HUD consists of a clickable checklist that the leader uses to annotate times associated with particular events. The Leader is also responsible for reading and conveying the patient history (Figure 14) to the team to make a diagnosis if required. The ACLS scenario consists of six different patient histories, three for each code scenario. The patient history chart seen by the leader is also selected randomly as is the code scenario itself. The patient history is required to diagnose the cause of PEA and requires the Leader the history to the team.

The role of Leader is important in ACLS in terms of encouraging team communication, coordination, and ensuring task completion. Moreover, as mentioned previously ACLS is a time critical scenario and the Leader is

38

responsible for ensuring that tasks are completed and started at appropriate times.

5.1.1.2.6 Defibrillator

Figure 14: Defibrillator View 1
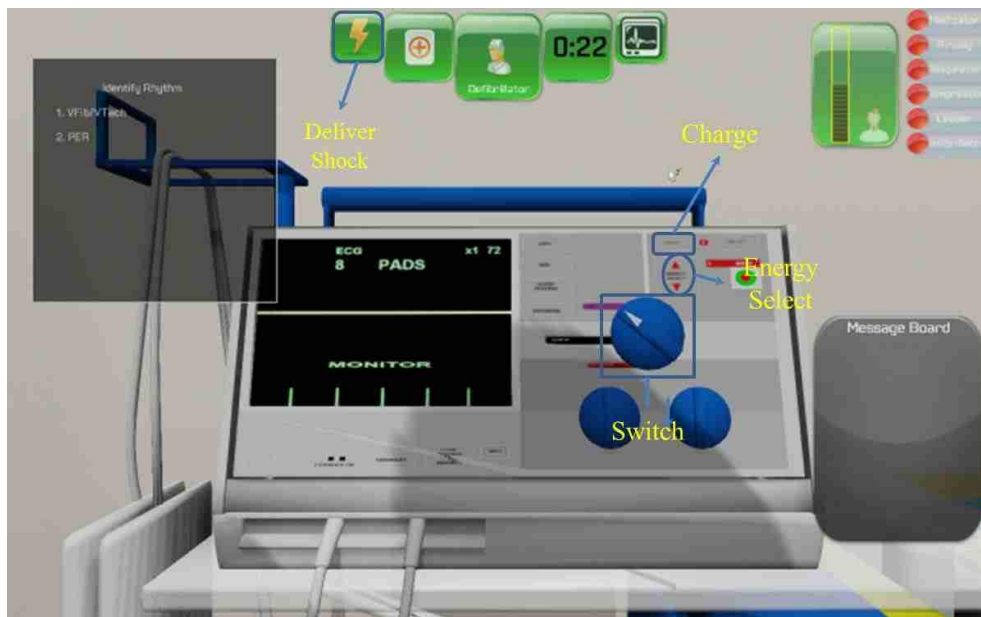
Figure 15: Defibrillator View 2

The Defibrillator is responsible for plugging in the defibrillator and placing the patches on the patient as shown in Figure 15. Figure 16 shows the view of the defibrillator as seen by all the roles above that have access to the defibrillator icon. Only the user playing the Defibrillator role is allowed to interact with the defibrillator. When the defibrillator is plugged in the plug icon is replaced by the deliver shock icon.

The rhythm displayed on the defibrillator responds to compression and the defibrillator patches i.e. if the patches are not applied then a flat line is displayed.

Figure 16: Heart Rhythms

The various rhythms displayed by the defibrillator according to the specific ACLS code are shown in Figure 17. The flat line shown in Figure 16 is replaced by one of the above rhythms depending on the code case, when the defibrillator is plugged on, and the patches have been placed.

5.1.1.3 Messages and Feedback

Real time feedback is provided in the form of messages that flash across the center of the screen for three seconds. The messages are divided into two types: Affirmatory an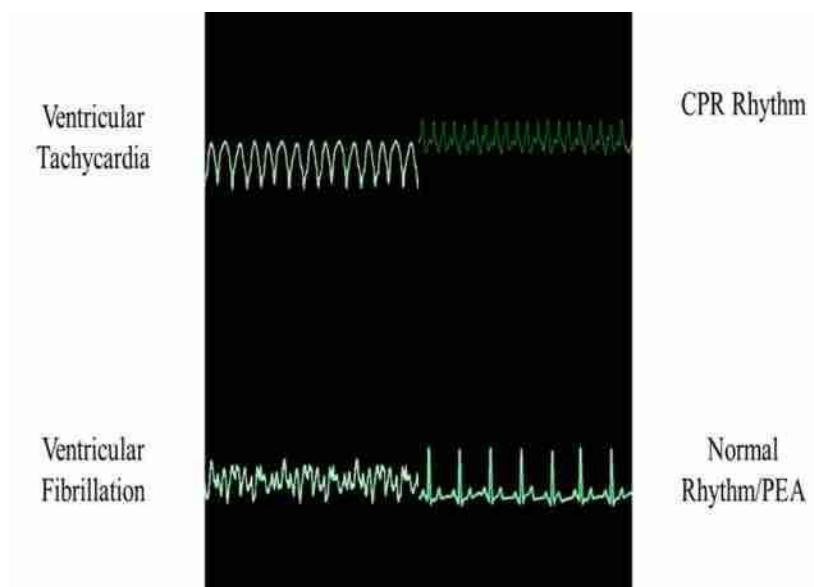d Persuasive. Affirmatory messages are displayed in a white colored font and are used to confirm to the user that a particular task or action was completed and Persuasive messages (black font) are used to remind the user to perform a certain action or coordinate with a team member. Persuasive messages are unique to every user and are therefore only displayed locally for each role. Affirmative messages consist of messages that are both local and global. The universal affirmatory messages i.e. messages that pertain to the entire team are displayed in the alerts and messages box on the bottom right corner of the screen as shown in Figures 7 through 16. The persuasive messages also provide a means to encourage teamwork. For example, the Leader is instructed to remind the Defibrillator to check the rhythm or the defibrillator is instructed to ask the team to clear the patient before the shock is delivered.

The second feedback mechanism is the patient outcome meter. This meter corresponds to an internal variable called NetScore. The NetScore of a simulation is computed by analyzing the performance of a team with respect to adherence to the ACLS protocol as well their performance on team based tasks. The scoring metric used to update the patient outcome meter has not yet been validated and hence the meter does not currently reflect a validated scoring metric. It will however rise and fall depending on the performance as assessed by scoring metric used in the system. A validated the patient outcome meter presents a means by which real time team performance evaluation can be presented to the users.

Finally, sounds and animations are also a part of the feedback system as they convey auditory and visual cues regarding performance of a task or action.

5.1.2 Haptic Joystick Module

The haptic module was developed in order to simulate the tactile feedback received by the user when CPR is being performed. In order to achieve the correct amount of feedback from the compression a Laerdal spring was added to the base of the haptic joystick head as seen in Figure 18. Laerdal springs are used in CPR manikins and therefore provide the appropriate amount of feedback.

Figure 17: Novint Falcon

The Novint Haptic joystick was integrated into the simulation by calling Novint SDK functions defined in C++ dynamic linked libraries using UnrealScript. The positional data sent from the device is scaled to find depth and recoil of compression. The rate is derived from these parameters and time taken to complete 30 compressions.

5.1.3 Communication Module

The communication backend was created using TeamSpeak. The TeamSpeak 3 (TS3) SDK libraries were used to create a C++ dynamic linked library that was integrated into the development environment. The main purpose of creating an internal communication module is that the identity of the user who is currently speaking can be determined and conveyed to all other users.

The TS3 integration consists of two DLLs, server side and client side. Figure 19 demonstrates the architecture of the TeamSpeak communication module. The TS3 server is initialized upon starting the UDK server. Each client is initialized as a client logs into the system a selects a role in the ACLS scenario. The communication module is not always turned on since then it may become susceptible to echoing and noise feedback therefore communication is initialized when the user begins speaking. TS3 allows for voice activity detection and when the voice activity level exceeds a threshold then communication is triggered. By detecting which client initialized the voice communication at any instance the identity of current speaker is determined and simultaneously conveyed to other users by on screen widget. The talk indicator bar, with the role name displayed on it, shown in Figures 7 through 16 glows red when a particular initialized role is speaking.

The communication module is the most important in the context of team skills. Users are encouraged to make decisions as a team and communicate the same. An example of this is that the Defibrillator is expected to vocalize the fact that they are ready to shock the patient. This information is not conveyed to any other user. If the Defibrillator fails to do so then the event is considered a critical failure.
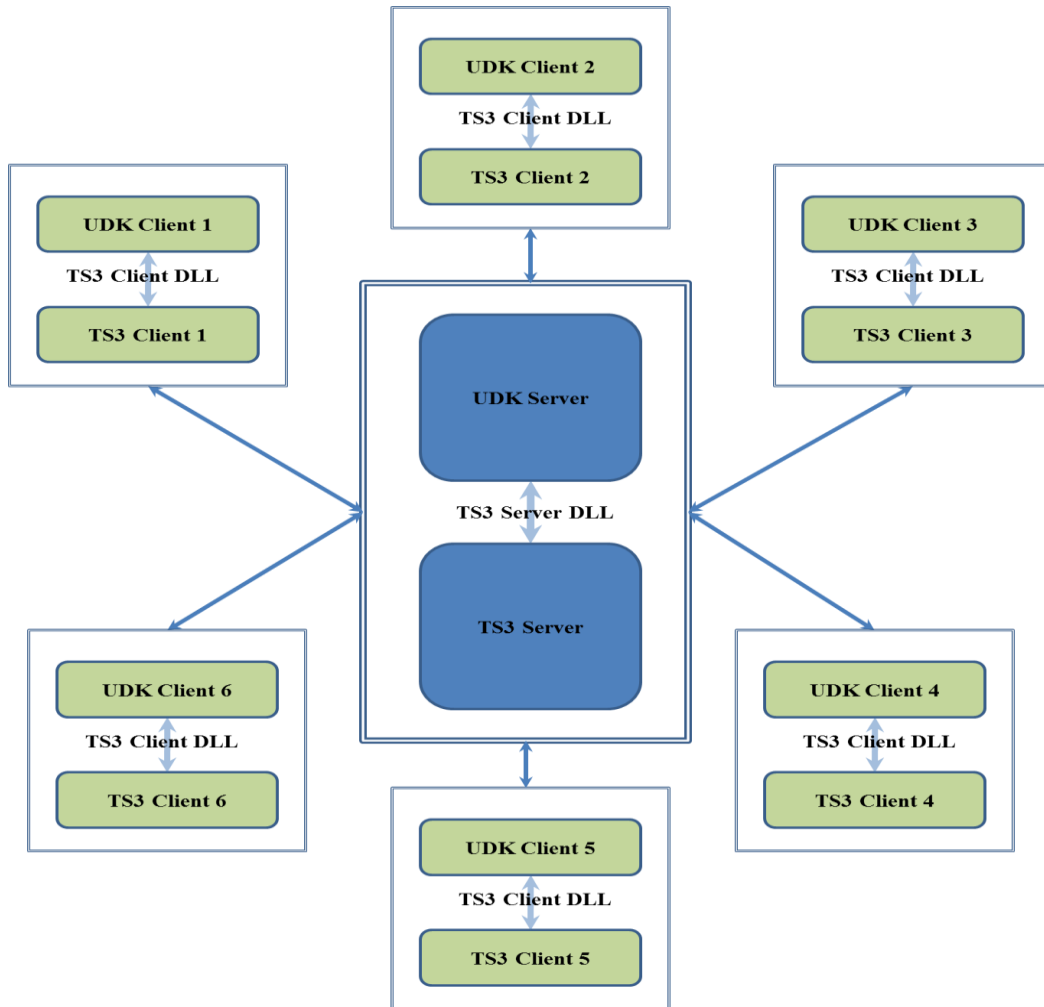
Figure 18: TeamSpeak Module

5.2 Networking and Multiplayer

An important part of the framework of a team trainer is the ability of the system to support multiple users simultaneously. UDK allows the developers the freedom to create a custom dedicated server on which to host the game however this means that the functionality by which all users connected to the system can see certain actions and events occur when instigated by a single user must be provided manually i.e. the event trigger needs to ensure that the other users are notified of the event and all users must have an ability to respond to an event

notification. For example, if the chest is being compressed then a variable corresponding to the rise and fall of the chest must then be replicated to all users from the Compressor client. Then all clients must be able to modify their own copies of the variable to be able to see the compressions being performed on their own clients.

This is not the case with virtual world softwares such as Active Worlds and Second Life. In those environments data is always sent to all clients within a world if they have authorization to access the environment. UDK handles certain lower level aspects of networking internally but the developer is responsible for indicating what data needs to be sent across the network to some or all users. This process is known as replication. UnrealScript allows replication of functions and variables. The methods of replication are covered in UDK documentation. In the case of the ACLS simulator, animations, messages, HUD elements, and event confirmations are the elements that need to be replicated in the form of functions or variables of differing data types in order to convey the information globally to all users in the scenario. The easiest way to achieve this is to create a class that is replicated in its entirety and contains all variables that need to be replicated or alternatively UnrealScript provides native replication classes that may also be used.

Task ID	Task Description	Expected Role	Task instigation
1	Check Pulse	Any	check pulse icon
3	Get and place board	Any	under the patient
4	Compress Chest	Compressor	chest of patient
5	Check airway	Airway	mouth of the patient
6	Head tilt chin lift	Airway	Up and down arrows on the mouth of patient
7	Place ambu bag	Respirator	place ambu bag icon
8	Ventilate	Respirator	compress ambu bag (up-down arrow) icon
9	Switch to airway	Compressor	switch roles icon
10	Switch to CPR	Airway	switch roles icon
11	Remove pillow	Any	pillow
12	Place patches	Defibrillator	patch icon
13	Plug in defibrillator	Defibrillator	plug icon
14	Turn on defibrillator	Defibrillator	defibrillator switch
15	Identify rhythm	Defibrillator	defibrillator HUD
16	Select 200 Joules	Defibrillator	energy select button on the defibrillator
17	Charge the defibrillator	Defibrillator	charge button on the defibrillator
19	All clear	Any	press and hold the control key
20	Remove ambu-bag	Respirator	press and hold the control key
21	Deliver shock	Defibrillator	shock icon
22	Administer drug	Medicator	drug icon in the medical tray on
23	Give post-drug	Medicator	syringe icon
24	Identify cause of	Defibrillator	H's and T's table on the HUD
25	Check patient	Leader	clipboard icon
26	Check Pupils	Airway	patient's eyes

Table 2: ACLS VR Task List

5.3 ACLS VR scenario task list

Table 2 shows the list of tasks that may be performed within the VR environment. The tasks were validated using expert review. Each of these tasks can be completed by one or several roles. Each action is evaluated according to the time taken to initiate the task, time taken to perform the task, and dependencies i.e. other tasks that need to be completed before the current task is performed. The table shows all the possible tasks that may be completed within the ACLS environment. However, depending on the code scenario only a subset of these tasks may be performed. For example, no shock should be delivered if the heart rhythm is non-shockable. However, by giving the users multiple choices certain critical errors such as shocking a non-shockable rhythm, that may otherwise not have been recorded, may be seen.

The task instigation column in Table 2 refers to the method by which the corresponding task may be completed in the ACLS environment. The main means of interaction in the scenario is the mouse.

The tasks in Table 2 are all individual, however a lot of the tasks are dependent on the completion of other tasks to be deemed completed according to the ACLS guidelines. The users are allowed to perform any task when they choose but the feedback system encourages team communication and the success of a scenario is dependent on the dependencies being satisfied.

5.4 Database Module

The simulation is connected to a centralized MySQL database using a cSQL DLL. All information from within the simulation such as time a particular task was performed, task ID from Table 1, Role of user who performed task, scoring of a task based on correctness and role specific information such as drug

given along with time and compression rate, depth, and count is stored in the database.

All the data collected can be used to create a data repository of ACLS team performance in the virtual scenario in order to study long term trends or give summative feedback on a single session.

5.5 Immersive component implementation

In the conceptual design section, certain factors were listed and defined that were hypothesized as contributing to situated immersion or presence. (Witmer B.G. and Singer M.J., 1998) In this section the implementation of those factors discussed.

Control Factors

The main input devices required to run the simulation are the mouse and keyboard. This ensures that most users are already familiar with the input system. The CPR joystick has been designed to provide the same kind of feedback that is expected from a manikin and the top of the joystick has been fitted with a palm rest area that is approximately the area of the chest where the hands would rest while performing CPR. Therefore the mode of control of the scenario is as intuitive as possible.

While the control over the environment is restricted to the tasks that the particular role can perform within it, the users are still given multiple choices to make throughout. For example the Medicator has at any time access to all mediations remaining in the cart although certain medications may not be given for a certain code scenario. This may lead to the perception of having a greater degree of control over the tasks.

Anticipation is created by placing the users in an environment that is time critical. The persuasive messages also warn the users of impending tasks and the scenario deals with ACLS code scenarios which ACLS trainees are familiar and therefore know what to expect.

Sensory Factors

The simulation provides three sensory modalities to the users; visual, auditory, and haptic. The combination of these three factors may lead to a heightened sense of presence.

The animations performed by the avatars as visual representation of the tasks to all users creates a sense that the environment is alive. Other aspects of the environment such as movement of the patient's chest when compressions are being performed and tilting of the patients head may also raise the degree of movement perception.

All roles except the Leader have multiple views and they may switch seamlessly to any view as many times as they desire. This contributes to the active search factor.

Distraction Factors

Each user has a unique viewpoint. This means that they may observe the tasks occurring around them or alternatively they may choose to focus on their specific tasks and messages.

<u>Realism factors</u>

The ACLS room has been designed based on mock code rooms at the SimET at Banner Good Samaritan Health Centre. The avatars were created using 3D models of nurses and medical professionals. Moreover, each user has a unique viewpoint as they would in the real world. These aspects coupled with the auditory cues and the high visual fidelity of the UnrealEngine contributes to a high level of environmental realism and ensuring that the information is consistent with the real world.

The patient outcome depends on the performance of a team in the mock code and certain critical errors such as shocking a non-shockable rhythm or shocking the patient if all users have not moved away from the patient are penalized by immediately ending the scenario. These aspects contribute to increasing the meaningfulness of the experience.

Chapter 6

EXPERIMENTAL RESULTS

6.1 Experimental Setup

As mentioned earlier, the objectives of this accompanying study are three fold: to demonstrate a transfer of skill from ACLS virtual training to real world mock codes, to validate the effectiveness of the immersive components on the overall performance in the simulation, and to collect user evaluation of the system using questionnaires.

The participant pool for this study consisted of nurses and medical professionals affiliated with the Banner Good Samaritan system. The participants (54) were split into 9 teams of 6 members each and the 9 teams were subdivided into three study groups:

1. Fully Immersive VR group - 3 teams

2. Minimally Immersive VR group – 3 teams

3. Control Group – 3 teams

The minimally immersive group was used as a control for the immersive components and the control group was used to control for the performance gained from pretest to posttest.

The study was conducted in four phases.

1. Phase 1

The first phase involved the teams performing two pre-training tests that were ACLS real world mock codes for each of the two code scenarios (VFib/VTach & PEA). The evaluation of the teams' performance was used as a baseline for the performance in the VR. The evaluation was

performed by two ACLS certified trainers using an ACLS checklist used in standard mock codes and the final score was the average of the rater scores.

2. Phase 2

    The teams were initially given a 20 minute video tutorial on the simulation and allowed to perform on a single user standalone version of the ACLS simulation followed by the 4 ACLS VR training sessions.

    The automated performance of the teams in the ACLS VR training was done using the same evaluation metrics used in phase 1.

3. Phase 3

    Upon completion of ACLS VR training, the teams were again made to complete two ACLS real world mock codes as a posttest to assess change in performance from the baseline. The evaluation was performed in the same manner as phase1.

4. Phase 4

    The final phase involved the users filling out a feedback questionnaire.

6.1.1 Fully and Minimally Immersive VR groups

In order to understand the effect of immersive components on the teams, the groups were given two version of the ACLS VR simulator. The fully immersive VR simulator consisted of all the components mentioned in the Methodology section. To create the minimally immersive VR simulator a number of components were removed from the full simulator.

1. All persuasive messages were removed, which may have reduced the sense of anticipation and urgency.

2. The alerts and messages box was removed to prevent the users from seeing any global affirmation messages. This may have increased the sense of isolation and confusion.

3. The communication bar on the top right corner of the screen was also removed in an attempt to prevent users from knowing which role was speaking at any given time. This may have lowered the situational awareness of the users and increase their sense of confusion.

4. The patient outcome meter was also removed. This prevents the users from knowing trending changes in their performance during the simulation. However, the simulation did not provide a validated real-time performance evaluation, only a reasonable indicator of guideline adherence.

The fidelity of the simulation does not change between versions since it was not a functionality provided by the platform.

6.1.2 Performance Evaluation

The performance of the teams in the ACLS mock codes as well as in the VR training was evaluated using the same metrics that were developed by ACLS experts at Banner Good Samaritan Medical Centre. The evaluation sheet consists of 9 basic tasks in an ACLS code as well as 2 parameters associated CPR evaluation metrics. All the basic tasks in the scenario are weighted according to criticality and each task consists of a pass condition

The performance of the VR teams is evaluated using the above metric by using the session data recorded in the database. For each task the conditions are used to determine if the task is successfully completed or not. There are separate sets of weights for the two different code scenarios because defibrillation is not

performed in case of PEA and therefore the weights associated with this task are zero in that scenario.

The weights of completed tasks are multiplied by 100 and summed together and in order to obtain the percentage score for each scenario this sum is divided by the total sum of all weights and multiplied by a 100. The CPR depth and rate parameters do not have weights associated with them since CPR evaluation is done by observation and is therefore qualitative.

Task	Condition	Weights	
		VFib	PEA
Time - Pulseless Recognition	0-20 from previous step	0.1	0.1
Time - CPR/BLS Initiated	0-10 from previous step	0.05	0.1
Initial Rhythm Recognized	0-60 from cart arrival	0.05	0.2
Time of Initial Defibrillation	< 3 minutes & 0-15 sec from previous	0.25	0
Time of 1st Drug	0-120 from initial defib or from rhythm recognition	0.05	0.15
Time of 2nd Defibrillation	105-135 from 1st defib	0.125	0
Time of 2nd Drug	0-120 from 1st drug	0.05	0.15
Time of 3rd Defibrillation	105-135 from 2nd defib	0.075	0
Time of 3rd Drug	Variable time?	0.05	0.15
CPR Depth	> 2 inches		
CPR Rate	95 to 105 compressions/min		

Table 3: ACLS Mock Code Task List

The VR simulator, as seen in Table 1 captures 25 different tasks and Table 2 is a subset of Table 1. Therefore the same metric described is applied to the VR simulation in order to score the performance in the VR ACLS scenario.

54

6.1.3 Feedback Questionnaire

Upon completion of the posttest, each participant was asked to fill out a questionnaire aimed at capturing usability metrics for the system. The questions were classified into eight main categories and the questions within each category were extracted from validated metrics found in literature. The eight categories are:

1. Ease of Use (E) (Venkatesh. V., 2003)

2. Information Overload (IO) (Moore J.E., 2000)

3. Perceived Task Complexity (C) (Maynard D.C. and Hakel M.D., 1997)

4. Location Awareness (LA) (Goel L, 2011)

5. Task Awareness (TA) (Goel L, 2011)

6. Intention of use (IU) (Malhothra N.K, 2004)

7. Group Outcome Perceptions (G) (Goel L, 2011)

8. System Usability (U)

The questionnaire consisted of 39 questions divided into the above categories and consisting of positive and negative phrasings as well as an additional set of 3 questions related to the CPR setup. The likert rating scale was employed. The questionnaire can be found in appendix A. In order to quantify the responses, each response was rate from 1 (Strongly Disagree) to 5 (Strongly Agree). Each rating was then multiplied by -1 or 1 depending on a negatively or positively phrased question respectively. The score of each category mentioned above is the aggregate of the scores of each question in that category.

6.2 Institutional Review Board (IRB) approvals

The study described above was conducted at Banner Good Samaritan Health Centre in Arizona as part of a joint grant (with Arizona State University (ASU)) from an organization affiliated with the Department of Defense (DoD) called Telemedicine & Advanced Technology Research Center (TATRC). The original grant was issued in 2009 and an IRB approval was subsequently obtained. An ASU application for social and behavioral human subject research approval was also submitted and obtained.

The protocols described above were part of a series of modifications made to the original study in order to include the complete system redesign (from a previous version designed by Sainath Parab, 2011) described as part of this thesis and to simplify the ability to recruit a participant pool of clinicians. The most significant change made to ensure the latter was the incorporation of a 75$/hr. remuneration for study participation. Therefore, a new IRB approval was sought and obtained for the modifications and a continuing review form was submitted to inform ASU of the changes.

The materials required for the new approval (documents can be found in Appendices B & C) included a document outlining the various changes made (as described in this thesis) along with a new informed consent form for participants and the aforementioned continuing review form for ASU. Finally, in order to participate in the study as a researcher involved with human subjects we were required to obtain CITI social and behavioral certification.

All the required approval confirmations were received prior to the commencement of data collection.

6.3 Experimental Results

6.3.1 Transfer of Skill

Figure 20 represents the performance of the teams at the pretest and posttest for each scenario. The ACLS VR trainer is the intervention that separates the pretest from the posttest for the immersive and minimally immersive groups.
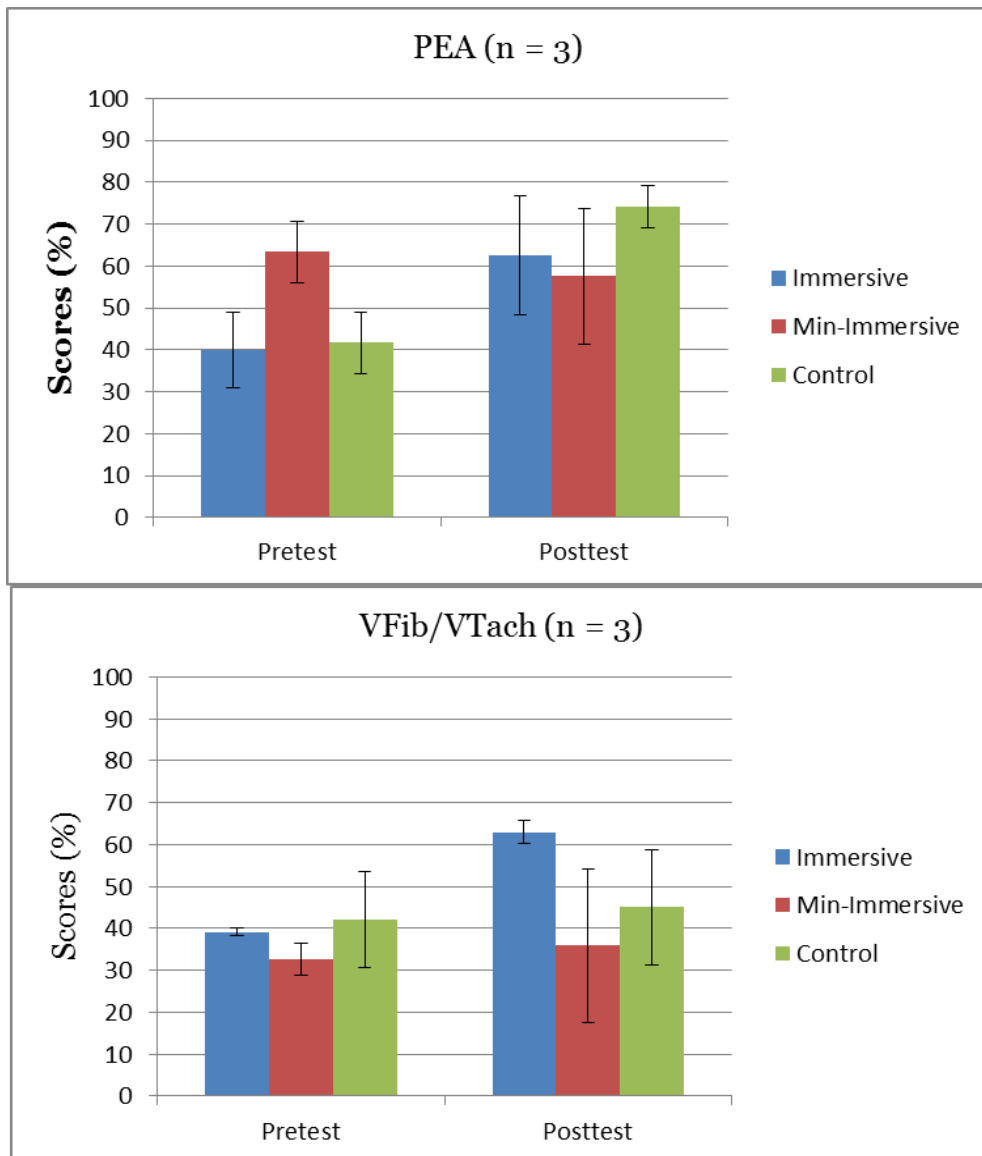

Figure 19: ACLS pretest and posttest scores

The scores in Figure 20 show that there is an improvement in the performance of the teams from the pretest to posttest for both VR groups. In order to control for the gain in performance in posttest due to the pretest the control group scores are shown. It shows that while the PEA performance gain was higher for the control, the VFib/VTach performance gain was greater for the immersive VR group. From this we can hypothesize that the VR training does not have a detrimental effect on the performance of the teams and even sees performance increases in VFib/ VTach. The simulator has the added benefit of users being able train on ACLS much more often than using the regular mock code training.

6.3.2 Performance gain in ACLS VR (immersive vs. minimally immersive)

Phase 2 of the experiment involved allowing the teams to perform 4 sessions in the ACLS simulation. In order to focus on the most intensive guideline minutes i.e. the time within which most vital tasks are expected to be performed, a time limit of 5 minutes was imposed per session of VR.

Figure 21 represents the performance of the performance of the immersive and minimally immersive groups in the first and last sessions of VFib/VTach and PEA respectively. The data was separated according to ACLS scenario type because the data suggests that PEA baselines are generally higher than that of VFib/VTach and therefore would make direct comparison more difficult.
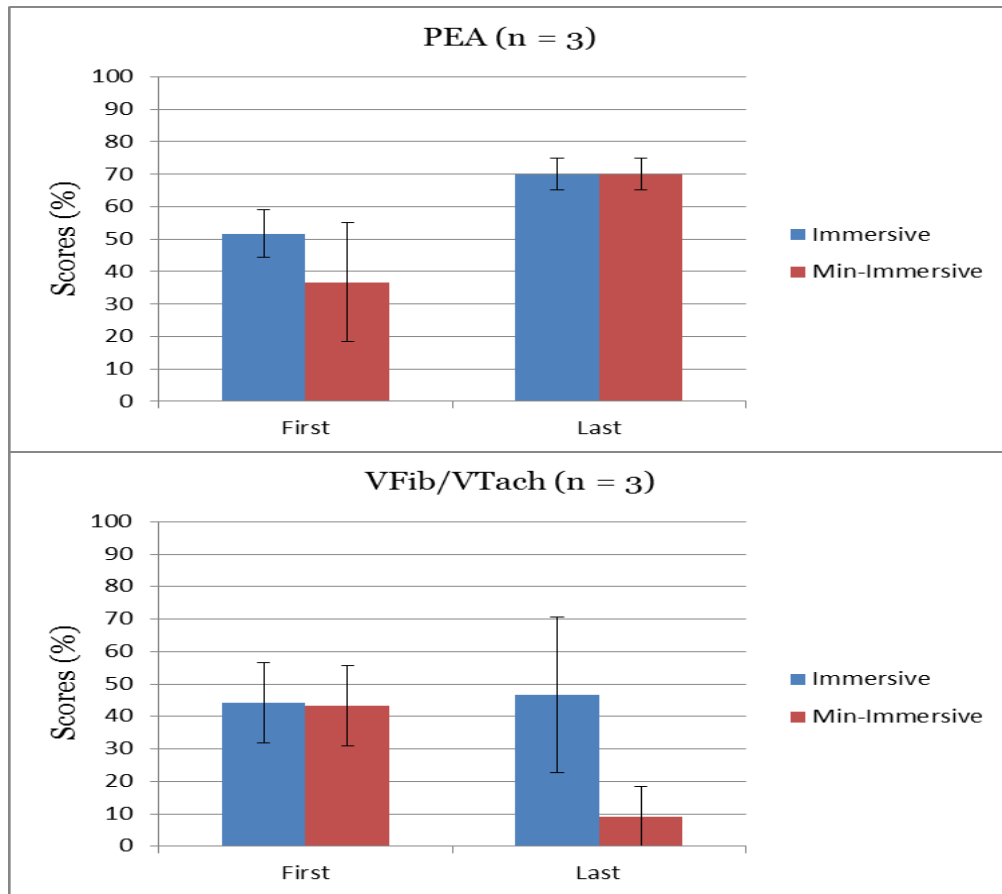
Figure 20: Performance gain from first to last session of VR
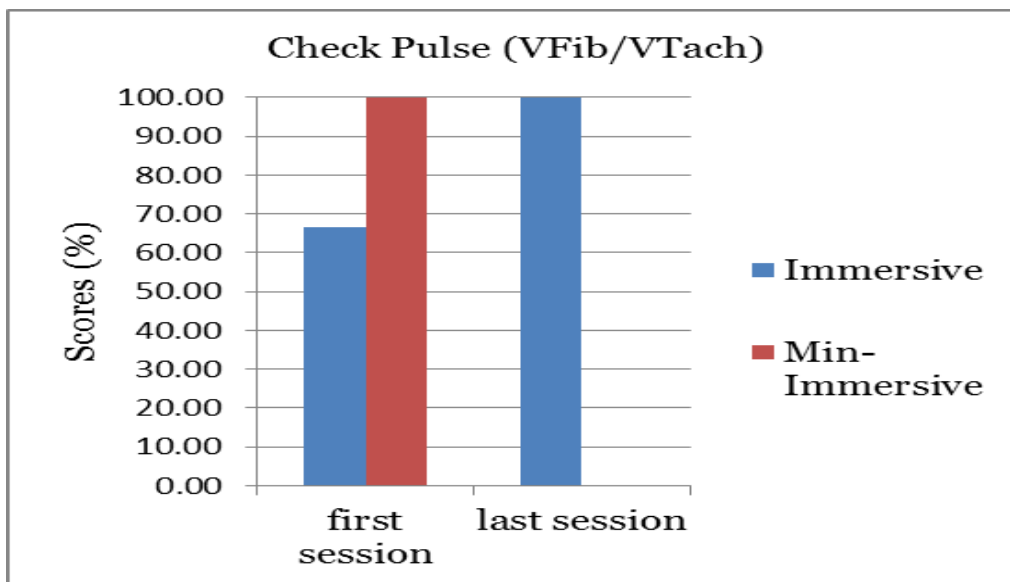
Figure 21: Pulseless Recognition in VR

The performance gain in the immersive group exceeds that of the minimally immersive group in both scenarios indication that the learning achieved in the immersive VR may exceed that of the minimally-immersive VR simulation.
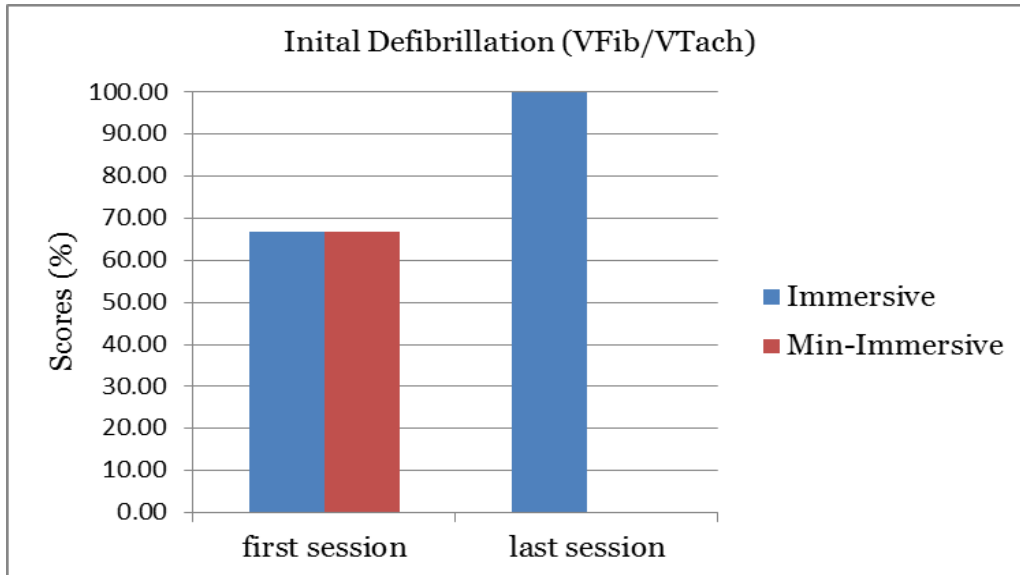
Figure 22: Initial Defibrillation in VR

The performance of the minimally-immersive groups in the last session of VFib/VTach was lower than the scores in first session. In order to explain this further, Figures 22 and 23 were plotted to demonstrate the individual tasks that describe the most distinct difference in the final session performance gain between the two VR groups. The two tasks selected were Check Pulse and Initial Defibrillation.

6.3.3 Compressor Performance

An additional feature of the ACLS VR simulator is its ability to record the compression performance of the users. In real world mock code performance

metrics, the evaluators assess the teams' CPR performance subjectively based on observations alone.

Figure 24 shows the two CPR metrics assessed as listed in Table 3. The percentage of successful compressions is computed by assessing the average depth and recoil of the session. A compression is deemed successful when the depth exceeds 2 inches and the recoil is lesser than 0.5 inches.

The depth and recoil is stored every 30 compressions (the compression breathing ratio in ACLS is 30:2) and therefore the percentage of successful compressions is the number of successful compressions performed in the current cycle divided by 30 multiplied by 100. The rate of compressions is recorded per cycle of 30 and is computed by the equation (60 seconds * 30 compressions) / time taken to complete 30 compressions.
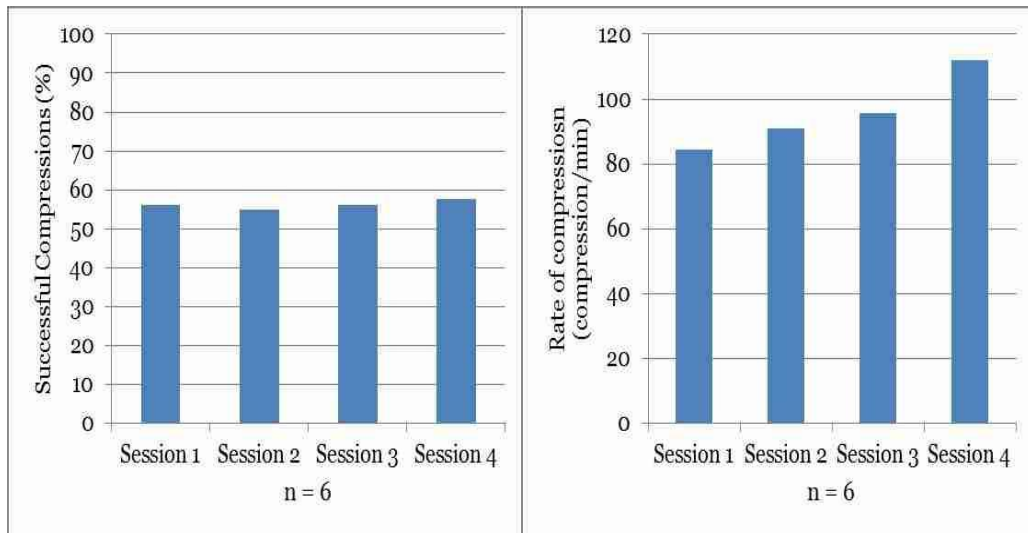

Figure 23: ACLS VR CPR performance scores

The average rate of compressions in session 3 is the closest to the required number (100 compressions per minute) as stated in the ACLS guidelines. The

percentage of successful compressions on average is 56% which is well below the required 75% and above.

6.3.4 User Feedback

The likert scale rating (-2 to 2) used in the questionnaire is converted to a scale of 0 to 10 in order to make the Y axis of the graph more visually coherent. The X axis represents the various categories of feedback and is represented using the shorthand for each category as mentioned above. The higher the rating the more positive the feedback related to the category.

Apart from the general usability, a section of the questionnaire pertained to the CPR setup. The questions were used to understand the users ease and comfort level with the rig as well as how closely they felt the force required to perform CPR on the joystick mimicked that of the real world manikins.

The value of the perceived task complexity (C) score of the minimally immersive set is greater than that of the fully immersive set. This implies that the fully immersive set was rated as being more complex than the minimally immersive set.

The feedback shows that the group outcome perception is greatly improved in the immersive set possibly owing to the presence of group messages and the talk-indicator bar. Overall, the feedback scores for each set are similar with the scores slightly in favor of the immersive set.

The CPR rig feedback indicates that while the users did not find the rig to be easy to use or comfortable, their rating for the force required to use the setup mimicking the manikin in the real world was higher indicating that the rated the feedback as being close to that of the manikin.
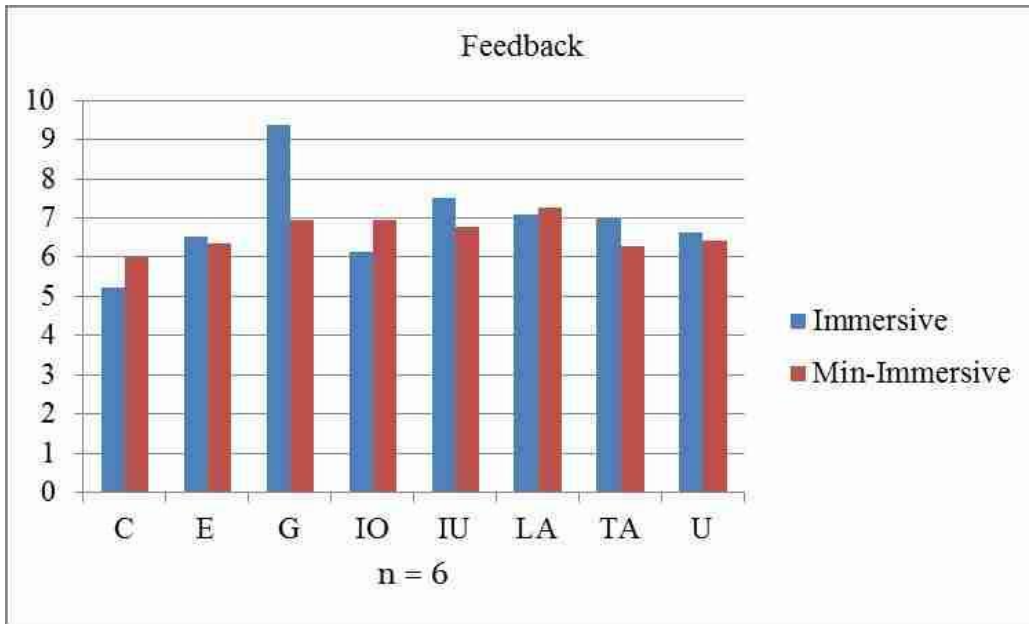
Figure 24: User Ratings

C – Perceived task complexity; E – Ease of Use; G – Group Outcome
Perception; IO – Information Overload; IU – Intention of Use; LA – Location
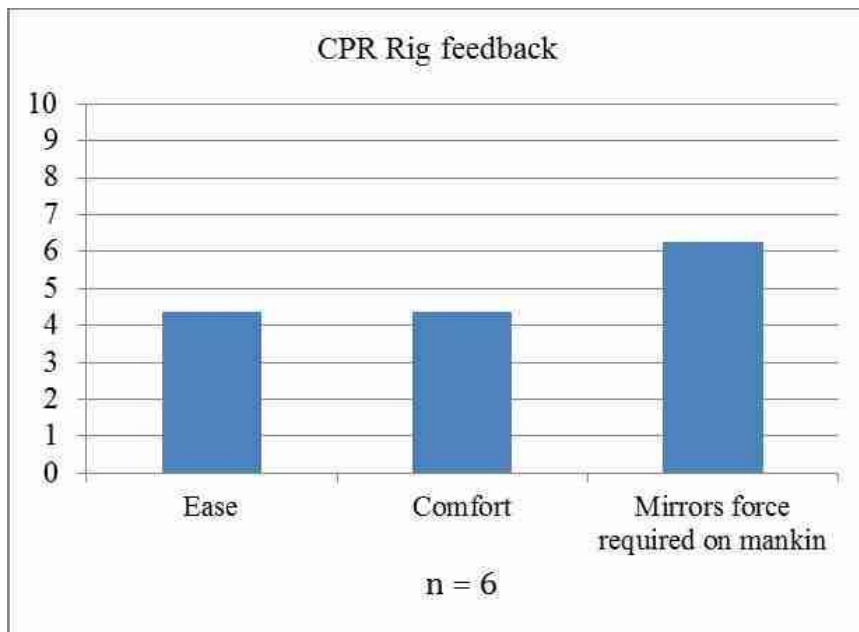Awareness; TA – Task Awareness; U – System Usability

Figure 25: CPR setup feedback metrics

Chapter 7

DISCUSSION

The aim of this thesis was to present the design and methodology for the development of a virtual reality simulator for ACLS training. To that end, the conceptual background of the simulator was presented in order to place the design decisions in the context of the central goal. The simulator is aimed at providing distributed training to ACLS teams while incorporating immersive components to raise the level of engagement derived in an attempt to get users to train on the system more often while being able to record their performance metrics for review and analysis.

The study conducted was designed to ascertain the transfer of skill from ACLS VR training to the real world mock codes and to validate the immersive components present in the virtual reality simulation. The study participants were clinicians and medical professionals and therefore had prior ACLS experience either in the form of mock code training or in real life situations. This means that any performance improvements that may be seen cannot be expected to be significant in 4 VR sessions. The purpose of the study is to show that a broader scale validation of the simulator and its components is justifiable i.e. with 15 to 20 teams. The results from the study were broken down into four main sections: transfer of skills, Performance gain in ACLS VR (immersive vs. minimally immersive), CPR performance, and performance scores.

The pretest and posttest scores show a greater gain in performance for the control group in the case of a PEA code while the VFib/VTach scores favor the ACLS VR simulation. A reason for this may be the fact that, in the PEA scenario the team members are required to diagnose the cause of the PEA and sometimes

this requires the need for extensive medical history, as well as lab test if the need arises. In the VR simulation, the only case presented was a PEA caused by narcotics. The users were not presented with this information beforehand and they therefore were under the assumption that any of the causes of PEA were equally likely. The delays caused by this uncertainty in VR may have seeped into the posttest mock code. In case of VFib/VTach a greater performance gain was observed in the VR group posttest over that of the control group. VFib/VTach is a shockable scenario i.e. defibrillation needs to be performed and therefore may requires a greater degree of team coordination. A higher performance gain for the VR group and specifically for the immersive VR group may indicate that the affirmatory messages along with the communications indicator bar may have played a part in the gain. Another reason for the discrepancy may be due to the fact that the control group consisted of a sample of three while there were six virtual groups which may have caused the scores to plateau. A larger scale study with greater sample sizes will help affirm some these hypotheses.

The comparison of the immersive and minimally immersive groups shows that the gain in performance from the first session to the final session for each ACLS scenario is steeper for the immersive groups. Over the 4 ACLS VR sessions the code case presented within the virtual world was randomized in each case and therefore the time lapsed and number of sessions between the first and final session for each code scenario is randomized as well. The performance of the minimally-immersive group in the final session on VFib/VTach is lower than the first session. In order to explain this, a graph of the scores pertaining to the tasks that contributed heavily to the performance drop off was plotted. The data shows that the minimally immersive groups failed in the pulse check and defibrillation

tasks. A reason for this may be because in order to check pulse or perform defibrillation correctly the compressions had to be paused. However, these tasks required the user performing them to communicate and ensure that the compressions were paused. A lack of synchronicity, possibly caused by the increase in isolation due to the lack of immersive components, between the pausing of compressions and performing these tasks would have required the users to redo the tasks causing delays and affecting the final score. Another reason for the drop off could be attributed to the fact that the scoring system consisted of strict rules and did not allow for any thresholds. A range based scoring system i.e. having multiple thresholds for correctness may have led to a better performance.

CPR evaluations in the current training methods are done by observation and the performance scores seen in Figure 24 indicate the necessity to employ quantitative techniques to evaluate CPR performance using simulators such as the one presented here. The success of compressions is dependent on both the rate as well the depth recoil ratio. However, the data presented here only attempts to show possible improvement in the two main parameters assessed in CPR evaluation. So they are treated as independent variables.

Finally, the general usability of the VR simulations once again favors the immersive group. The largest difference in score was obtained for the group outcome perceptions parameter suggesting that the incorporation of the communication indicator bar and global messages were valuable additions. The information overload was also lower for the immersive group alluding to the possibility that while the amount of onscreen content was lower for the minimally immersive group, the immersive components help contextualize the information

66

on the screen i.e. the persuasive messages, among other components presented explained the requirements of the VR scenario better than in case of the minimally immersive VR. The users also indicated that while the ease of use and comfort associated with the CPR rig was low, the feedback received was being similar to that experienced on the manikin.

Some of the limitations of the system were that a real time performance score was not conveyed to the users, owing to a lack of a validated scoring technique for the simulation, which may have aided in increasing the meaningfulness of the experience. Due to this fact, the simulation did not indicate to the users if the patient was saved by the team and every VR session ended in 5 minutes regardless of patient outcome. This may have curtailed the sense of achievement which could be an important aspect of engagement. Finally, the persuasive messages in the feedback system were created to encourage the user. However, owing to the depth of the ACLS protocol they were not able to cover every possible combination of responses to user instigated events. Further development and research will ensure that a lot of above components are incorporated into the system.

Overall, the data definitely indicates that the proposed simulator has potential for future development and research. An important future study would involve increasing the sample sizes by recruiting more participants and validate the simulator and VR training itself. The incorporation of this method of training will greatly increase the amount of the ACLS training received by clinicians. The data collected by the VR simulator far exceeds the data analyzed in real world mock codes. Therefore, the analysis of data from team performances in the scenario may help create a more comprehensive and standardized scoring system

67

for ACLS than may be incorporated into the VR itself in order to supplement the

existing simulation and ACLS training in general.

Chapter 8

CONCLUSION & FUTURE WORK

Presented in this work is the design and development of an immersive virtual reality ACLS simulator. The simulator was tested in using group of clinicians at Banner Good Samaritan health center. The simulator was designed to be a distributed ACLS trainer that was designed to be engaging as well as provide remote training to clinicians. The system records all user information for further analysis and review and provides quantifiable CPR feedback, a feature missing in regular ALCS training. The aim of the accompanying study was to show that a transfer of learning and skill to the real world occurred when the ACLS simulator was provided as a training intervention. The results largely showed that the simulator held a potential for further research and development and that the incorporation of immersive components led to greater performance gain over the minimally immersive system. The users also rated the system slightly higher in case of the immersive group.

Future work on the simulator involves creating an extended scoring metric based on the data the system is capable of collecting and to validate the same. The scoring metric can then be incorporated into future versions of the simulator to provide real time performance feedback for the whole team. Another aspect to be analyzed in further research is the retention of skill. An important advantage of distributed virtual reality trainers is their ability to provide users training more often than traditional training techniques. A study conducted to assess the loss in performance of teams who receive traditional ACLS training over a certain time period will help demonstrate the advantage provided by virtual reality training.

The communication backend may be extended to incorporate word detection to facilitate an evaluation of team communication. Currently, the system encourages team communication but does not evaluate the same. Incorporating voice analysis capabilities will broaden the scope of the system and evaluations may be conducted on teams based on cognitive science techniques as well. An important aspect of teams is the leadership. The above method can be employed to study pattern of leadership and the aspects of a strong leader.

ACLS consists of several scenarios besides that two incorporated into the system. The system may therefore be extended to include some or all of the different causes that are described in the ACLS guidelines. The two main advantages of this would be that the scope of the simulator will be increased and in giving the users more choices, there will be an increased potential for mistakes. Finally, a more portable CPR setup may be built to make the system more portable.

The ACLS protocol is required knowledge for medical professionals and the ACLS VR simulator presented above will ensure that clinicians receive ACLS training more often than they currently do and the immersive, multiuser setup will engage them in the experience and allow them to train from remote locations. The ACLS simulator design may be extended to other team scenarios in the medical field such as Advanced Trauma Life Support (ATLS) or a single user scenarios such as CVC (Central Venous Catheterization) where the environment and messaging and communication systems may be easily modified to suit the requirements of each scenario. This thesis has successfully shown a methodology to design such a training simulator and has put in place an implementation of

several of the components required to develop the same while also presenting accompanying data to show the potential of such a simulator.

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APPENDIX A

USER FEEDBACK QUESTIONAAIRE

Likert Scale				
Strongly Disagree 1	2	3	4	Strongly Agree 5

Ease of Use

The training system is easy to use

It is not easy to become skillful at using the training system

Learning to operate the system is easy

My interaction with the system is clear and understandable.

It is not easy to interact with the system

Information Overload

I feel busy or rushed during the training session

I do not feel pressured during the training

I feel that the amount of information I deal with during the training is more than I can process

I feel that the amount of work I do during training interferes with how well it is done.

Perceived task complexity

I found the training tasks to be complex

These training tasks were mentally demanding

This training required a lot of thought and problem solving

I did not find these to be challenging tasks

Location Awareness (LA)

I was aware of the location of objects related to the task.

I was aware of the objects related to the task.

I was conscious of elements in the training world around me

Task Awareness (TA)

The textual (or verbal) and visual clues in the environment helped me to do the

Information in the environment, such as icons and labels, made it easy to figure out what to do.

There were clues in the environment that made completing the task easy

The information given in the environment helped me understand my tasks better

Intention to Use

It is likely that I would use this training system

It is possible that I would use this system to train

I am unwilling to use this system

Group Outcome Perceptions

I am satisfied with the team's ability to gather and present relevant information

I am satisfied with the team's ability to gather and present relevant information

I am satisfied with the team's ability to follow the ACLS guidelines

I was satisfied with all my team members

I was pleased with the way my team members and I worked together

I was very satisfied working with the team

The cooperative work done by my team was of high quality
The effort exerted by my team during training was excellent
The final cardiac resuscitation task with my team was outstanding
System Usability (Visual)
I believe I could quickly become proficient on ACLS using this system
The information provided by the system was easy to understand
The information was effective in helping me complete the tasks and scenarios
The organization of information on the system's screen was clear
The interface of the system was pleasant
I liked using the interface of this system
This system has the functions and capabilities I expect it to have
CPR Rig Usability
Performing CPR on the computer joystick was easy.
Performing CPR on computer joystick was comfortable.
The computer joystick gave a reasonable amount of force feedback relative to a physical manikin

APPENDIX B

IRB DOCUMENTS

Office of Research Integrity and Assurance
660 S. Mill Avenue Suite 315
Arizona State University
Tempe AZ 85287-6111
(Mail Code 6111)
Email: researchintegrity@asu.edu
Phone: 480-965-6788
Fax: 480-965-7772

ARIZONA STATE UNIVERSITY

CONTINUING REVIEW FORM- IRB

- In accordance with Federal Regulations 45CFR46, the IRB must review nonexempt protocols at least annually, or more frequently if warranted.
- Please type your responses in the boxes provided. Use as much space as necessary (the boxes will expand). Please answer each question – if a question is not applicable, please put N/A in the box.
- Studies that are in the data analysis phase are considered open, researchers must complete this form.

Principal Investigator: **Dr. Robert Greenes**
ASU department address: **Department of Biomedical Informatics**   **Samuel C. Johnson Research Bldg**   **13212 East Shea Boulevard,**   **Scottsdale, AZ 85259**
E-mail address: **greenes@asu.edu**
Phone number: **480-884-0226**   Fax Number: **480-884-0239**
Co-Investigator(s) Name(s) and Contact Information: **Kanav Kahol (kkahol@asu.edu), Prabal Khanal (pkhanal@asu.edu)**

2a) Title of protocol: **Socially Relevant Knowledge Based Clinical Team Training**
2b) HS #: **1106006531**
2c) If project is funded or funding is being sought, provide list of all sponsors and grant numbers: Please indicate the grant status for each source of funding: ☒ **Active** ☐ Pending   **Department of Defense (DOD) Telemedicine and Advanced Technology Research Center (TATRC)**
2d) ASU account number/project number: **BMS0018**
2e) Location(s) of research activity: **Banner Health SimET Center, Phoenix, Arizona**
2f) IRB approval dates from additional institutions: **Banner Health, Phoenix, Arizona**   *Please note that copies of current IRB approvals from additional institutions are required.*   **IRB approval (revised) date : March 24, 2012 (Approval letter is enclosed)**

3a) Active: ☒ **Yes**   ☐ No (If no, submit a close out report: http://researchintegrity.asu.edu/humans/forms   3b) Please indicate remaining duration of the study: **10 months**

4a) Is this study closed to enrollment of new subjects: ☐ Yes ☒ **No**
4b) Total number of participants approved for the study (to be enrolled): **120**
4c) Number of participants enrolled (e.g. signed a consent form) during the **past approval period**: **108**
4d) Total number of participants enrolled **since study began**: **108**
4e) Total number of individuals screened (e.g. individuals that responded to study advertisements or other recruitment tractices and were questioned by investigators) in the past approval period (if applicable): **120** (this includes the number that was later enrolled)
4f) Of the total number of individuals screened in the past approval period, what percentage has been ineligible to participate in the study (if applicable)? **N/A**
4g) Number of enrolled participants who withdrew from the study: **N/A** Please state the reason(s) the participant(s) withdrew.
4h) Number of participants still to be enrolled: **12** (If this brings the sample to greater than what is listed in 4b, submit a request for modification see 7d).
4i) Participant enrollment breakdown by gender, age and ethnicity: (This information is required for all studies that are NIH-sponsored. It is recommended, but not required, that other researchers provide this information). **N/A**

☒	**Human subjects intervention with use of informed consent form**
☐	Discarded, identified pathological materials, no intervention
☐	Genetic analysis
☒	**Interviews or questionnaires**
☐	Medical records or other records from human subjects
☐	Other please specify:

6a) Have there been any complaints from subjects in the past approval period?
☐ Yes If yes, describe ☒ **No**

6b) Have there been any *adverse events* or unexpected problems in the past approval period?
☐ Yes ☒ **No**
If yes, please explain in detail and indicate when the IRB was notified of the event or problem. If the IRB was not notified, please explain why this was not done.

6c) Does the study have a Data Safety Monitoring Board (DSMB)? ☐ Yes ☒ **No**
If yes, please indicate the date of the last DSMB review:

Please note that investigators are required to submit DSMB reports to the ASU IRB at the time they are made available to the investigator.

Revised 12/11

7a) Have there been any modifications or revisions to the protocol in the past approval period?
☒ **Yes** ☐ No
If yes, please indicate the date of the approval from the Committee for the modification or revision and provide a brief description.

There have been some modifications in the Informed Consent Form. The changes were submitted to Banner Health IRB and were approved. The modified IRB protocol document, stamped Informed Consent form (revised), and the approval letter is attached herewith.

7b) Have there been any deviations from the approved protocol? ☒ Yes ☐ No
If yes, please describe to self-report the protocol violation.

There was a minor change in the experiment design. We added "pre-test" session where all the groups are taken to ACLS training room at Banner SiMET Center, Phoenix to get their baseline performance prior to the experiment. This was very important for determining the effectiveness of our system. We submitted the changes to Banner Health IRB for approval, and the changes are approved. The updated version of the IRB is attached herewith.

7c) Do you want to add any new co-investigators to the study? ☒ Yes ☐ No
If yes, submit their names and copies of the human subjects training required by the IRB:
http://researchintegrity.asu.edu/training/humans

Aaron Ashby, MS, Researcher, Dept. of Biomedical Informatics
Akshay Vankipuram , BE, Researcher, Dept. of Computer Science
Mithra Vankipuram, MS, Researcher, Dept. of Biomedical Informatics

7d) Do you wish to submit a modification at this time? ☒ **Yes** ☐ No
If yes, please describe the modification request and rationale for the changes:

In the original IRB, it is mentioned that the data will be stored securely in Dr. Kahol's (Co-PI) office at GWC building. Since the experiment is being conducted at Banner Health SiMET Center, Phoenix, all the information of participants (demographics, performance, questionnaire) will be kept in Dr. Smith's (PI from Banner) office in a secure cabinet.

The changes have been approved by Banner Health IRB, and the modified IRB and the approval is attached herewith.

8a) Please attach a copy of your current consent form for renewal if you are enrolling new subjects.

8b) Is this the original consent form or a revised form? ☐ Original ☒ **Revised** (If revised, please provide date of ASU IRB approval for the revision. Attach a copy of the stamped form and unstamped form)

This is a revised consent form which was approved by Banner Health IRB on March 24, 2012. The stamped consent form (from Banner Health) is enclosed.

Revised 12/11

83

9) Please submit a *detailed* progress report. The progress report must be substantive and complete, and include the goal(s) of the study, findings to-date, how data is being stored, and plans for the next year/review period. If this project is funded, please send a copy of the most recent progress report that was sent to the funding agency:

The detailed progress report is attached herewith.

10a) Have there been any presentations or publications resulting from this study during the past approval period?   ☒ **Yes** ☐ No   If yes, please submit a copy of the abstract, or the publication, with this application.

The following abstracts resulted from this study and were submitted to AMIA conference, 2012. The abstracts are attached herewith.

1. P Khanal, S Parab, K Kahol, K Josey, K Zittergruen, M Smith, Virtual Reality based Advanced Cardiac Life Support Training Simulator using Active Worlds, poster submitted to AMIA 2012
2. A Vankipuram, P Khanal, A Ashby, K Josey, M Smith Development of Virtual Reality based Advanced Cardiac Life Support Training Simulator in Unreal Development Kit, theatrical demo submitted to AMIA 2012.

10b) Have there been any recent findings either from this study, or a related study (through a literature review for example), that would have an effect on this study's risk/benefit analysis?   ☐ Yes   ☒ **No**
If yes, please describe and cite references:

11a) Does any member of the research team have a potential conflict of interest with this study that could affect study participants and/or study outcome? For more information about examples of conflicts of interests, please visit the ASU objectivity website: http://researchintegrity.asu.edu/coi
☐ Yes (If yes, please describe and disclose in the consent form)   ☒ **No**

11b) Does the PI or Co-I have a current conflict disclosure form on file at the ASU Office of Research Integrity and Assurance?
☐ Yes   ☒ **No**

11c) If there are conflicts of interests, please describe the ways in which you have and will minimize harm to research subjects and/or the objectivity of research.

12.The research team must verify completion of human subjects training within the last 3 years.

CITI training – Provide the date that the PI and Co-I's completed the training:
        The CITI training of Robert A. Greenes, Aaron Ashby, Akshay Vankipuram, Mithra Vankipuram, and Prabal Khanal are attached herewith.

Revised 12/11

If you completed **NIH** training prior to 9/15/10 this will be accepted. Provide a copy of the certificate.

Principal Investigator: _Robert C. Greenes_   Date: May 9, 2012

Banner Health
FWA #00002630
IORG #0004299

March 24, 2012

Marshall Smith, MD
Attn: Jane Hoverson, CIM, CRC
1111 East McDowell Road
Phoenix AZ 85006

RE: **Project # 01-11-0021**
        Socially Relevant Knowledge Based Clinical Team Training
        iRIS Reference # 011772
        IRB Approval –
        Continuation (Open to Accrual), Informed Consent (version 2.1 dated 3/21/12),
        Authorization to Use or Disclose PHI for Research

Dear Dr. Smith:

The Banner Health Institutional Review Board (Phoenix Panel) voted at their March 15, 2012 meeting to approve the continuation for the above referenced study pending requested changes to the Informed Consent. The IRB is now in receipt of those changes and has approved the study. The IRB review was in accordance with 45CFR46. This study has received approval for one year. The FDA requires that all studies be reviewed at least annually. The final approved, stamped Informed Consent is available electronically. You must use photocopies of this Informed Consent exclusively. A copy of the signed consent document must be placed in the patient's medical record.

The Board's approval to conduct your study will expire on **March 14, 2013**. The IRB requests that you submit a Continuing Review report one month prior to the **February 16, 2013** IRB meeting. This allows time for processing and review prior to the IRB expiration date of the study. Any fatal or life-threatening adverse drug/biologic experience must be reported to the IRB within 7 working days of the PI learning of the event. Any adverse drug/biologic experience that occurs that is both serious and unexpected must be reported to the IRB within 15 working days of the PI learning of the event. Any other adverse events that do not meet these reporting requirements may be summarized and provided to the IRB at the next continuing review.

Any changes in the study protocol or Informed Consent, unusual events, results of the study or any additional information relative to the study must be submitted to the Board. A Closing report is required upon completion of the project. In the event the study results are published, please send a copy to the Banner Health Research Administration so it may be included in the file. A copy of this letter will be placed in the study file.

Marshall Smith, MD
Project # 01-11-0021
iRIS Reference # 011772
March 27, 2012
Page Two

Thank you for your continued participation in research at Banner Health. If you have any questions, please contact Jessica Bradley, IRB Coordinator, at (480) 412-3969.

Sincerely,

Signature applied by Marc Lee on 03/27/2012 09:50:04 AM MST

Marc Lee, MD
Chair, Banner Health IRB (Phoenix Panel)

ML/jb
cc: Study File
        Facility Research Director

Office of Research Integrity and Assurance

To:	Robert Greenes Dept of Bi
From:	Carol Johnston, Chair Biosci IRB
Date:	06/11/2012
Committee Action:	**Renewal**

Renewal Date:	06/11/2012
Review Type:	Expedited F7
IRB Protocol #:	1106006531
Study Title:	Socially Relevant Knowledge Based Clinical Team Training
Expiration Date:	06/13/2013

The above-referenced protocol was given renewed approval following Expedited Review by the Institutional Review Board.

It is the Principal Investigator's responsibility to obtain review and continued approval of ongoing research before the expiration noted above. Please allow sufficient time for reapproval. Research activity of any sort may not continue beyond the expiration date without committee approval. Failure to receive approval for continuation before the expiration date will result in the automatic suspension of the approval of this protocol on the expiration date. Information collected following suspension is unapproved research and cannot be reported or published as research data. If you do not wish continued approval, please notify the Committee of the study termination.

This approval by the Biosci IRB does not replace or supersede any departmental or oversight committee review that may be required by institutional policy.

Adverse Reactions: If any untoward incidents or severe reactions should develop as a result of this study, you are required to notify the Biosci IRB immediately. If necessary a member of the IRB will be assigned to look into the matter. If the problem is serious, approval may be withdrawn pending IRB review.

Amendments: If you wish to change any aspect of this study, such as the procedures, the consent forms, or the investigators, please communicate your requested changes to the Biosci IRB. The new procedure is not to be initiated until the IRB approval has been given.

Please retain a copy of this letter with your approved protocol.

APPENDIX C

INFORMED CONSENT FORM

Banner Health   **Informed Consent to Participate in Research**

Socially Relevant Knowledge Based Clinical Team Training
Simulation Education and Training Center at Banner Good Samaritan Medical Center
Marshall L. Smith, MD, PhD – Principal Investigator

INTRODUCTION

The purpose of this form is to provide you (as a prospective research study participant) information that may affect your decision as to whether or not to participate in this research and to record the consent of those who agree to be involved in the study. Your participation is entirely voluntary and if you decide not to participate, then you do not have to participate.

This study is sponsored by the Department of Defense, US Army Medical Research and Materiel Command (USAMRMC) Telemedicine, Advanced Technology Research Center (TATRC),

STUDY PURPOSE

The main purpose of this study is to see if training in the virtual world environment improves clinical team training and if participants will retain the skills over a longer period of time than standard training. The training system is based in virtual worlds. A virtual world is a genre of online community that often takes the form of a computer-based simulated environment, through which users can interact with one another and use and create objects. In simple terms, it is an online graphical world where people can interact with graphical objects and themselves. In this research, we seek to study the applicability of virtual worlds to clinical training. Generally, clinical training has always been hands on and done through face-to-face meeting. In recent years, computer based simulations have emerged as a promising area for delivering didactic information in an interactive manner. We will study effectiveness of delivering education through the virtual world simulations. Through this study, we hope to contribute to possible ways that can augment the current capabilities of the medical education system.

NUMBER OF VOLUNTEERS

This is a single site study. For this study, we will recruit up to 120 subjects of both genders. We are not expecting a 50/50 representation because the participants will be coming from a clinician participant pool with a clear female majority.

Subject initials: _____

Banner Health **Informed Consent to Participate in Research**

Socially Relevant Knowledge Based Clinical Team Training
Simulation Education and Training Center at Banner Good Samaritan Medical Center
Marshall L. Smith, MD, PhD – Principal Investigator

DESCRIPTION OF RESEARCH STUDY

If you say YES, your participation will last for three hours at the Simulation Education and Training Center at Banner Good Samaritan Medical Center, Phoenix, Arizona. You will also be asked to participate again six months from the date of your first participation. This second visit will take about two hours. You will be asked to sign a consent form before participating in the experiment. After the consent signing, you will be randomly assigned to one of the following groups: Virtual Training Group 1; Virtual Training Group 2; or a Control Group.

Each group will have six members. As a participant, you will take part in training for Advanced Cardiac Life Support (ACLS) procedure. ACLS is a protocol designed to save a patient with sudden cardiac arrest. It is a group activity and is highly time sensitive. Based on the randomly chosen groups, the participants are provided with different training. All groups will participate in a pretest and post-test conducted with manikin based mock codes. The lists of steps for each group are as follows:

Virtual training group 1
Participants in this group will be provided with
- Pre-test with mannequin base mock codes
- a pre-recorded didactic lecture on ACLS protocol in classroom setting,
- tutorial on how to use the virtual world; what the different persuasive components in the virtual world are, what they signify and how they help during training sessions; and how different tasks in the virtual world can be performed,
- a training session on ACLS protocol in the virtual world,
  - virtual mock codes with assigned roles for different tasks required during ACLS procedure like medication, defibrillation, airway management, CPR etc.
- a test session on ACLS protocol in virtual world,
- a post training test session on ACLS protocol with mannequin based mock codes

Virtual training group 2
Participants in this group will be provided with
- Pre-test with mannequin base mock codes
- a didactic (traditional face to face) training session on ACLS protocol in classroom settings,
- tutorial on how to use the virtual world; and how different tasks in the virtual world can be performed; (they WILL NOT be shown the persuasive components in the virtual world beyond what is minimally required for environment to be intuitive to a new user)

Revised 3/21/12   Page 2 of 7

Subject initials: _____

Banner Health   **Informed Consent to Participate in Research**

Socially Relevant Knowledge Based Clinical Team Training
Simulation Education and Training Center at Banner Good Samaritan Medical Center
Marshall L. Smith, MD, PhD – Principal Investigator

- a training session on ACLS protocol in the virtual world,
    - virtual mock codes with assigned roles during the virtual world training session for different tasks required during ACLS procedure like medication, defibrillation, airway management, CPR etc.
- a test session on ACLS protocol in virtual world
- a post training test session on ACLS protocol with mannequin based mock codes

Control group
Participants in this group will be provided with:
- Pre-test with mannequin base mock codes
- a pre-recorded didactic lecture on ACLS protocol in classroom settings,
- Traditional ACLS skills training on low fidelity cpr trainer
    - The participants will practice the following 4 skills by rotating stations-At least 2 minutes per station. Remediation occurs if objectives are not met.
        1. Airway
           Opens airway, inserts oral airway
        2. Breathing
           Gives 2 breaths over 1 sec each
        3. Compressions
           Starts compression 30:2 with rate of 100, recoil. and depth of 2 inches
        4. Defibrillation
              Applies AED or Defibrillator
              If appropriate, defibrillates and clears after analyzing rhythm
- a post training test session on ACLS protocol with mannequin based mock codes

The training sessions will be provided to each group separately, except for didactic lectures because it is common to all groups. Once all the groups and their members are provided with appropriate training and testing sessions, they will be taken back to the location of their pre-test, i.e. mock code training room in Simulation Education and Training (SIMET) Center at Banner Good Samaritan Medical Center, Phoenix Arizona to test their skills on real world ACLS procedure to be performed on mannequin. The test in the real world training room will be monitored by ACLS trainers and educators, who will evaluate the performances of the groups.

Subject initials: _____

Banner Health **Informed Consent to Participate in Research**

Socially Relevant Knowledge Based Clinical Team Training
Simulation Education and Training Center at Banner Good Samaritan Medical Center
Marshall L. Smith, MD, PhD – Principal Investigator

Test for retention:

Six months after the initial session participants will return to the SIMET Center for the test of retention of the skills that they acquired six months back. They will complete a short questionnaire to identify if they have been involved in a further ACLS training, mock code training, or real code situations since last test date. The scenario for testing the retention of ACLS skills will be similar to prior scenarios involving a test on ACLS protocol through mannequin based mock codes.

RISKS

The training simulator consists of a few Virtual Reality (VR) situations. There is a possibility that some subjects might feel motion sickness and/or disoriented in real world. If at any stage of the study you want to withdraw your participation, you may stop immediately. Please inform the researcher. There will be no penalties if you withdraw from the study.

BENEFITS

Although there are no immediate benefits to you, continuous practice on the virtual ACLS training system might help you to enhance your skills on ACLS procedure. Another possible benefit of your participation in the research is increased knowledge of ACLS. In addition, the information obtained from this study will benefit other practitioners using social collaborative knowledge based clinical team training simulator in the future. At the end of the study, you will have the opportunity to discuss our results and ask detailed questions on how it affects you.

ALTERNATIVES TO PARTICIPATION

You may decide to participate in this study or not to participate in this study.

HOW LONG WILL I BE ON THE STUDY?

Participation in this study will last about three hours each for the first of two separate sessions, with the second being approximately 2 hours, a total of 5 hours.

CONFIDENTIALITY

Efforts will be made to keep your personal information private and confidential; however, we cannot guarantee absolute privacy and confidentiality. Confidentiality is an important matter for the investigators and special emphasis has been placed on addressing these issues. We will not share information about the performance of individual participants with the administration, nursing managers or any other individuals in Banner Health Medical Center or external sources. Representatives of the research team will have access to your research records, The Banner Health and ASU Institutional Review Boards, the U.S. Army Medical Research and Materiel Command, and Telemedicine & Advanced Technology Research Center are authorized to review

Revised 3/21/12   Page 4 of 7

Subject initials: _____

Banner Health **Informed Consent to Participate in Research**

Socially Relevant Knowledge Based Clinical Team Training
Simulation Education and Training Center at Banner Good Samaritan Medical Center
Marshall L. Smith, MD, PhD – Principal Investigator

research records as part of their responsibility to protect human research volunteers. Research records will be stored in a confidential manner so as to protect the confidentiality of your information.

The captured data will be kept on a password protected computer and only accessible to the 1-2 persons responsible for data acquisition and analysis. There will be a backup of the data on an external hard-drive stored in a secured location, accessible to Dr. Smith and main facilitator only. The software will provide a social collaborative knowledge based clinical team training simulator that will have a separate username password for each subject. This will only be shared with the concerned subject, the main facilitator of the experiment and the PI, Dr. Smith. At the end of the study, the data will be permanently deleted from any and all computers used in the training and analyses. Printouts of the database will not be allowed, and any original stored data will be deleted at the end of the trial, with only a condensed and de-identified copy to be password protected and kept by the PI for archival purposes. The archive shall be only accessed if granted IRB approval for retrospective analysis.

WITHDRAWAL PRIVILEGE
Participation in this study is completely voluntary. It is ok for you to say no. Even if you say yes now, you are free to say no later, and withdraw from the study at any time. Your decision will not affect your relationship with Banner Health and any other institution and it will not otherwise cause a loss of benefits to which you might otherwise be entitled. We will tell you about new information developed during the course of the study that may affect your health, welfare, or willingness to stay in this study.

EARLY TERMINATION OF RESEARCH
For your safety, your participation may be terminated by the investigators at any time without your consent. The investigators will terminate your participation if they feel it is in your best interest, for example, if you become uncomfortable in the virtual world. Your participation may also be stopped if you fail to keep the study visits or follow instructions as explained or if there is a protocol violation or early closure of the study.

COMPENSATION FOR ILLNESS AND INJURY
In the case of injury or illness resulting from this study, emergency medical treatment is available from Banner Health, but will be provided at the usual charge. No funds have been set aside to compensate you in the event of injury. You or your insurance company will be charged for continuing medical care and/or hospitalization.

Subject initials: _____

Socially Relevant Knowledge Based Clinical Team Training
Simulation Education and Training Center at Banner Good Samaritan Medical Center
Marshall L. Smith, MD, PhD – Principal Investigator

COSTS AND PAYMENTS

The researchers want your decision about participating in the study to be absolutely voluntary. There is no cost to you to participate in this study. You will be compensated $75/hour for your participation: 3 hours for the first session and 2 hours for the second. Note: If you are a salaried employee this has to be a day off.

WHOM DO YOU CALL IF YOU HAVE QUESTIONS

Any questions regarding the study or research-related injury, contact Dr. Mark Smith at 602-839-6507 during normal business hours, or (602) 448-8349 after hours. If unable to reach, then please go to the emergency department for immediate treatment.

If you have any questions about your rights as a research participant, contact the Banner Health Human Subject Protection Administrator at Research Administration at (602) 747-4719, Monday through Friday, from 9AM to 5PM. This study has been approved by a panel of the Banner Health Institutional Review Board (IRB).

This study has also been approved by Arizona State University (ASU). If you have questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk; you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Office of Research Integrity and Assurance, at 480-965-6788.

Intentionally left blank

Subject initials: _____

Banner Health **Informed Consent to Participate in Research**

Socially Relevant Knowledge Based Clinical Team Training
Simulation Education and Training Center at Banner Good Samaritan Medical Center
Marshall L. Smith, MD, PhD – Principal Investigator

VOLUNTARY CONSENT TO PARTICPATE IN RESEARCH

You are voluntarily making a decision whether or not to participate in the research study described above. Your signature indicates that you have read the information provided above and have decided to participate in this research project. You will be given a copy of this consent form to keep.

SIGNATURES

I agree to take part in this study.

_____	_____	_____
Subject's Signature	Printed Name	Date

_____	_____	_____
Legal Authorized Representative Signature (N/A)	Printed Name	Date

_____	_____	_____
Person Obtaining Consent	Printed Name	Date

Subject initials: _____

CITI Collaborative Institutional Training Initiative

Human Research Curriculum Completion Report
Printed on 5/7/2012

Learner: Akshay Vankipuram (username: avankipu)
Institution: Arizona State University
Contact Information Dr. Robert Greenes
                              Department: Bio-Medical Informatics
                              Phone: 4808840220
                              Email: avankipu@asu.edu
Group 2 Social & Behavioral Research Investigators and key personnel:

Stage 1. Basic Course Passed on 05/07/12 (Ref# 5539170)

Required Modules	Date Completed	Score
Introduction	01/29/11	no quiz
History and Ethical Principles - SBR	05/04/12	4/4 (100%)
Defining Research with Human Subjects - SBR	05/04/12	5/5 (100%)
The Regulations and The Social and Behavioral Sciences - SBR	05/04/12	4/5 (80%)
Assessing Risk in Social and Behavioral Sciences - SBR	05/04/12	4/5 (80%)
Informed Consent - SBR	05/04/12	5/5 (100%)
Privacy and Confidentiality - SBR	05/07/12	5/5 (100%)
Research with Prisoners - SBR	05/07/12	3/4 (75%)
Research with Children - SBR	05/07/12	4/4 (100%)
Research in Public Elementary and Secondary Schools - SBR	05/07/12	4/4 (100%)
International Research - SBR	05/07/12	2/3 (67%)
Internet Research - SBR	05/07/12	4/4 (100%)
Research and HIPAA Privacy Protections	02/02/11	11/11 (100%)
Vulnerable Subjects - Research Involving Workers/Employees	02/02/11	4/4 (100%)
Conflicts of Interest in Research Involving Human Subjects	02/02/11	2/2 (100%)
Arizona State University	02/02/11	no quiz

For this Completion Report to be valid, the learner listed above must be affiliated with a CITI participating Institution. Falsified information and unauthorized use of the CITI course site is unethical, and may be considered scientific misconduct by your institution.

Paul Braunschweiger Ph.D.
Professor, University of Miami
Director Office of Research Education

96