Design, Development and Evaluation of Collaborative Team Training Method in Virtual Worlds for Time-critical Medical Procedures

by

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A Dissertation Presented in Partial Fulfillment
of the Requirement for the Degree
Doctor of Philosophy

Approved February 2014 by the
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May 2014

ABSTRACT

Medical students acquire and enhance their clinical skills using various available techniques and resources. As the health care profession has move towards team-based practice, students and trainees need to practice team-based procedures that involve timely management of clinical tasks and adequate communication with other members of the team. Such team-based procedures include surgical and clinical procedures, some of which are protocol-driven. Cost and time required for individual team-based training sessions, along with other factors, contribute to making the training complex and challenging.

A great deal of research has been done on medically-focused collaborative virtual reality (VR)-based training for protocol-driven procedures as a cost-effective as well as time-efficient solution. Most VR-based simulators focus on training of individual personnel. The ones which focus on providing team training provide an interactive simulation for only a few scenarios in a collaborative virtual environment (CVE). These simulators are suited for didactic training for cognitive skills development. The training sessions in the simulators require the physical presence of mentors.

The problem with this kind of system is that the mentor must be present at the training location (either physically or virtually) to evaluate the performance of the team (or an individual). Another issue is that there is no efficient methodology that exists to provide feedback to the trainees during the training session itself (formative feedback). Furthermore, they lack the ability to provide training in acquisition or

improvement of psychomotor skills for the tasks that require force or touch feedback such as cardiopulmonary resuscitation (CPR).

To find a potential solution to overcome some of these concerns, a novel training system was designed and developed that utilizes the integration of sensors into a CVE for time-critical medical procedures. The system allows the participants to simultaneously access the CVE and receive training from geographically diverse locations. The system is also able to provide real-time feedback and is also able to store important data during each training/testing session. Finally, this study also presents a generalizable collaborative team-training system that can be used across various team-based procedures in medical as well as non-medical domains.

To my parents - Mrs. Goma Khanal and Late Prof. Kedar Nath Khanal,

to my wonderful wife, Prithu,

to my younger brother, Chandan,

and to all my teachers.

ACKNOWLEDGEMENTS

First and foremost, I would like to extend my deepest gratitude to my advisors, Dr. Vimla Patel and Dr. Robert Greenes for their guidance and support during my PhD journey. Their vision, knowledge, and encouragement always inspired me and helped me keep focused. I am highly indebted to them.

I would further like to extend a very special thanks to Dr. Marshall Smith for providing me an opportunity to work on a project under his supervision. Without him the research would not have been possible. He was the constant source of support throughout and provided me with any help he could, in order to achieve my research goal.

I would also like to thank Dr. Ashish Gupta for his immense support during the latter half of my PhD. His invaluable time and feedback during the analysis of the data collected during the research has made it possible to reach the conclusion of the study.

I would like to thank Dr. David Kaufman for his invaluable time and effort to help me fulfill the degree requirements.

A special thanks to Dr. Kanav Kahol, who helped me start my research career at Arizona State University. Dr. Kahol was the person who introduced me to the project that became an integral part of my dissertation. During the initial years of my PhD, his constant guidance helped me build a solid foundation for my research activities.

I would like to acknowledge Dr. Denise Drumm-Gurnee from Banner Health, Phoenix for her support during the preparation as well as modification of IRB protocol for my research project. She was also involved in the analysis of the data during the early stage of the research. Also from Banner, I want to thank Karen J, Linda, Karen Z, Nancy, Brian, Naomi, Patrick and Michael. Without their effort, it would never have been possible to complete the project on time.

I want to thank Dr. Daniel Katz and Dr. Samuel DeMaria from Mount Sinai Department of Anesthesiology for providing me an opportunity to collaborate with them on a project for CVC placement simulator .

I would like to extend my gratitude to the Telemedicine and Advanced Technology Research Center (TATRC) division at Department of Defense for funding my research project.

I am very grateful to my teammates Akshay, Aaron, Mithra, Cord, Sainath, Miguel, and Kai as well as my former colleagues Gazi, Susannah, Camilla, Cecil, Andrew, and Chris for their help and support.

Last, but not the least, I want to thank my loving family my mother, Goma Khanal; my wife, Prithu; and my younger brother, Chandan Khanal, for their immense love, support and care. Without them, I would never have been able to complete this or any other endeavor in life; and to my father, late Prof. Kedar Nath Khanal, without whose blessings and inspiration none of my achievements would have been possible.

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INTRODUCTION

1.1 Background

In medical education, apart from the cognitive aspect of education, developing psycho-motor skills is equally important. Medical students enhance their clinical skills using various available techniques and resources. Most of the common approaches rely either on practicing diagnostic and procedural skills on real patients and/or observation- based training at the bedside in the hospital wards (Rhienmora, 2007). The most common techniques in clinical skills training are based on the use of training manikins, standardized patients, and real patients (Rhienmora, 2007). All these available techniques are valuable for some aspects of the training, allowing students to practice using these techniques to enhance their clinical skills without a real patient. But, to practice on real patients, students must have skills in using tools and methods, as well as knowledge of anatomy, physiology and pharmacology. The knowledge and skills in using tools and methods to recognize the properties of organs gradually increase with practice. This creates a limitation for students to work with real patients until they are reasonably skilled and are knowledgeable. Clearly, it would be better if they could frequently practice various procedures that are relatively difficult to master without having to practice on real patients. My study addresses how to overcome these limitations and provides a validated method to resolve the problem.

Team-based procedures add more complexity to the aforementioned problems. A team-based procedure is any coordinated effort that is performed by a number of people in a team (Parab, 2010). Team-based procedures, in the context of medical education, can be surgical procedures, clinical care procedures, and/or protocol-driven procedures. All these procedures involve teamwork with proper coordination of team members with different sets of skills. Surgical procedures require greater level of psychomotor skills whereas clinical procedures such as physical examination, ordering and interpreting laboratory tests require more problem solving skills. On the other hand, protocol-driven team procedure requires a team to perform the tasks by following a strict set of rules that can be standardized. These can also be in a form of standards or guidelines. An example of protocol-driven team procedure is the protocol followed by an emergency medical team in a hospital to evaluate and stabilize a patient, which may include anything from triaging a patient to evaluating the severity of the problem and preparing for advanced procedures. In life-threatening emergency cases, the time required to diagnose and stabilize a patient is very critical. Although training the whole team together has been observed to be more effective in improving team performance, training a member individually is given more importance in clinical environments (Hamman 2004). As a result, very few team-based training sessions are scheduled for training. There are various reasons for this discrepancy. One reason is that it is often difficult to set up training sessions according to each individuals schedule, since a team may consist of members from disparate locations. In such a scenario, individual training is easier to conduct and requires less time, costs less and requires little co-ordination. The time criticality and various skills related with a team-based activity make it more difficult to provide team training as the team co-ordination and proper communication between the team members play a significant role.

In recent years, various virtual reality (VR)-based medical training simulators have been proposed and developed to provide better training/learning experience (Tsai et al., 2001; Mantovani et al., 2003). The VR-based training systems can be cost-effective compared to using expensive medical simulators (Aggarwal et al., 2007; Gupta et al., 2008). Moreover, since a VR-based system can be a distributed system (known as collaborative virtual environment- CVE), many users can login to the system simultaneously, which eliminates the cost incurred in the transportation of educators to different locations for training purposes. With access to the Internet, the participants as well as educators can login to the system remotely from any geographical location and practice or train together in protocol-driven medical procedures.

Another important feature that the VR-based systems can provide relates to the manner in which the feedback of the training procedure is provided to the participants. In addition to the summative feedback, which is provided at the end of each session, the VR-based systems are capable of providing feedback at various stages of a medical procedure. Using both kinds of feedback helps trainees to improve their learning and performance (Elberly Center, 2011).

The VR-based systems also facilitate storing the performance evaluations of individuals as well as teams in a centralized database, which is also accessible from anywhere on the Internet. This not only helps to compare the performance of the individuals and/or teams using various features, but also provides an opportunity to look at the users behavior or activity pattern during each training session as well as during an extended period of time during training.

In this research, we seek to a) design and develop a training system that utilizes the integration of sensors into a collaborative virtual environment (CVE) for time-critical medical procedures, and b) to evaluate the system by comparing the performances of teams trained using VR-based simulator to those trained using conventional method. The system will allow the participants to simultaneously access and receive training from geographically diverse locations. The system will also be able to provide both real-time (formative) and summative feedback during/after the training sessions. In addition to providing feedback, the system will be able to store important data during each training/testing session. These data can be used to create a model for automatic performance evaluation of teams. The data, which will be collected automatically during VR-based training sessions, will also be evaluated based on the ACLS guidelines.

1.2 Problem Statement

The conventional method used for providing training for any time-critical protocol-driven team-based medical procedure requires the physical presence of professional educators and very expensive manikins. Since the training is team-based and hence requires a physical gathering of multiple individuals (including the trainer), it is always difficult to schedule a common time slot for all trainees and trainers at a physical location. This limits the number of training sessions that can be held in any given period of time. Another problem with conventional training methods is that feedback is provided to the participants only after completion of each training session, and there is no efficient methodology to provide real time feedback to the trainees during the training session itself. Formative feedback such as this is important because it helps users to rectify any incorrect actions in real time during a procedure rather than waiting for the procedure to end.

At present, most of the collaborative VR-based training simulators for medical education require the presence of a mentor. The mentor will evaluate the performance of the participants by visually inspecting how they perform during training sessions (Chodos et al., 2010) or by evaluation using questionnaires before and after the training (Conradi et al., 2009; Boulos et al., 2007). Unfortunately such interactive simulators do not store the information related to each training session. Without such information on performance during training, quantitative analysis of the performance of the teams during training sessions cannot be accomplished. Another limitation of present collaborative VR-based medical training simulators is that they do not allow the use of various sensory devices, because of which, only cognitive skills can be provided. Such sensory devices (position, haptic, pressure sensors etc.) would provide more realism to the training environment in terms of learning psychomotor skills. Since we can observe and record data from these sensors, it is possible to monitor and evaluate the performance of the trainees. Based on the information, appropriate feedback can be provided to the trainees.

1.3 Hypotheses

The hypotheses of this dissertation are:

Hypothesis I:

VR-based training with adequate feedback and cues provides similar, if not better, training than conventional training

Hypothesis II:

Feedback and cues enhance the ability of the simulator to provide more effective training than without such feedback and cues.

1.4 Objective of the study

The major objectives of this research are listed below:

- Design, development and validation of a collaborative virtual environment (CVE), and a training system based on the CVE for the purpose of providing training on emergency medical procedures to clinicians, especially nurses and doctors.

- Integration of a sensory device for tactile (haptic) feedback in the CVE to train psychomotor skills such as maintaining rate, depth, and recoil during cardiopulmonary resuscitation (CPR).
- Development of a backend database as a repository of data related to the training, which can be accessible through the Internet.
- Development of a web-based performance evaluation form, and a summative feedback form that allows the users to track their own performance over time. In addition, these forms are also accessible to the evaluators to track the progress of the users. This is developed considering its potential use, however the usefulness is not evaluated during the study.
- Evaluation of performance during VR-based training with and without context aware feedback and cues.

1.5 Scope and limitations

In order to meet the objectives, the research will be confined to the following scopes:

- For the study of time-critical team-based activity, the focus is on the domain of Advanced Cardiac Life Support (ACLS) procedure. For the psychomotor skills, cardiopulmonary resuscitation (CPR) was chosen. CPR is a procedure in which a Compressor performs chest compression in order to maintain blood circulation in times of cardio-respiratory failure.[Note: Detail of ACLS is provided in Chapter 2]

- As an example of a sensory device, a haptic joystick will be used for the study. The haptic joystick gives the position of the device itself and provides force feedback to the users while performing cardiopulmonary resuscitation (CPR), which is an integral part of the ACLS procedure.

- This study focuses on providing training to a group rather than to an individual. However, individual performances can also be evaluated by identifying the tasks that were inaccurately performed by an individual (including the time taken to do a task). Individual training will be outside the scope of this study.

- The study includes two ACLS scenarios, one that requires shocking (the patient needs to be defibrillated) and one that does not require shocking (the patient should not be defibrillated). For this purpose, we choose two scenarios: ventricular fibrillation (V-Fib) and pulseless electric activity (PEA) for rhythms requiring and not requiring shocking, respectively..

- For the study, each participant will be assigned a specific role at the time of initial survey (Section 5.2.1) and will remain the same throughout the study.

1.6 Contribution

Practical

- The major contribution of this research is the design, development, and validation of a VR-based ACLS training simulator that can help groups of medical students and professionals to have simultaneous access to ACLS training sessions from geographically diverse locations. The VR-based training is expected to provide better or similar transfer of skills than that can be from the manikin-based training.
- Another contribution of this research is the study of real-time feedback during collaborative VR-based ACLS training. The VR-based training with real-time feedback and cues is expected to provide higher level of performance improvement compared to the VR-based training without feedback and cues.
- The team performance can be evaluated based on the tasks performed, and whether or not the team members perform tasks assigned to them within maximum allocated time.
- Development of a web-based repository for various parameters obtained from the training sessions so that conduction of longitudinal studies for an extended period of time will be possible. Users and teams will always be able to retrieve their information and view their performance at different points of time.

Scientific

- Lessons learned from this study on how to design, develop and validate a tool for a medical procedure, such as ACLS, can be used to develop similar tools to solve other problems in medical and non-medical domains.
- The web-based automatic evaluation tool eliminates the mandatory presence of evaluators thereby saving precious evaluator man-hours.
- The web-based repository of the performance data can be very useful for longitudinal study of various aspects of team training and medical education.

1.7 Organization of the dissertation

The rest of the dissertation is organized as follows: Chapter 2 provides detailed information on ACLS. Chapter 3 provides insights from past research in the field of medical education, including their limitation(s). We then present three different studies as proof of concept on resolving the issues that are present in current virtual reality based medical training simulators in Chapter 4. Chapter 5 describes the design methodology of the simulator as well as the experimental design for the evaluation of the simulator. Results with analysis of the data are provided in Chapter 6. Chapter 7 discusses the results, limitations of the study, and the future directions. Finally, Chapter 8 concludes the dissertation.

Chapter 2

BACKGROUND - ADVANCED CARDIAC LIFE SUPPORT

2.1 Advanced Cardiac Life Support

Advanced Cardiac Life Support (ACLS) refers to the clinical interventions intended to treat life-threatening medical emergencies in cardiac arrest and/or respiratory failure. ACLS is a time-critical team-based activity that requires cognitive and kinesthetic expertise. Mastering ACLS requires extensive medical knowledge, training and practice. Only qualified healthcare professionals such as physicians, nurses and paramedics can perform the ACLS procedure, since it requires several advanced skill sets such as performing cardiopulmonary resuscitations (CPR), understanding emergency physiology and pharmacology, managing the patients airway and interpreting electrocardiograms (Aelhert, 2006). The ACLS tasks must be performed in a coordinated manner, and the guidelines to perform proper ACLS, especially the first five minutes, are published by American Heart Association (AHA, 2010). The American Heart Association publishes ACLS guidelines every five years, and the current version of ACLS guidelines was published in 2010. Because of these features of ACLS, i.e., complex, collaborative, team-based, time-critical, and since it requires both cognitive and psychomotor skills, it makes the ACLS procedure one of the best candidate to be considered for this study.

2.2 How is ACLS performed?

In real-life emergency cases, an ACLS team is formed consisting of 4-7 members. Each member is assigned to one of the six roles. The most important roles, without any particular order, are: Leader, Compressor, Respirator, Airway Manager, Medication in-charge, and Defibrillator. Since these roles were not defined by AHA, we have coined the terms for the ease of understanding for participants during the study as well as to categorize the tasks according to the roles. Each role is associated with performing a specific set of tasks. The compressor, respirator and airway manager are responsible for performing high quality cardiopulmonary resuscitation (CPR) (AHA, 2010; Aelhert, 2006). The compressor performs chest compressions, the airway manager keeps the patients airway open and the respirator uses the ambu-bag to provide ventilation. The medicator administers the required medications. The defibrillator attaches the EKG leads to the patients chest to identify the arrhythmia and defibrillates the patients heart if necessary. The leader monitors the team interventions and guides the team through synchronous execution of the ACLS guidelines. The team members must have proper communication among them so that all tasks are performed in the correct order (Aelhert, 2006).

2.3 ACLS scenarios

The ACLS procedure requires proper identification of cardiac arrest, which often requires identifying the patients heart rhythm from an electrocardiogram (EKG)

(AHA, 2010). Pulseless ACLS rhythms can be broadly categorized into shockable and non-shockable rhythms (Sutphen, 2007). Patients with shockable rhythms such as ventricular fibrillation (VFib) and ventricular tachycardia (VTach) must be immediately defibrillated (shocked). However, rhythms such as asystole and pulseless electrical activity (PEA) are non-shockable rhythms, and hence these patients should not be defibrillated. VFib/VTach (12.8

2.4 Current ACLS training method

The traditional methods used for ACLS training include didactic teaching and training on low/medium-fidelity manikins, also referred to as simulators. According to the American Heart Association (AHA), for ACLS certification, participants must enroll in 10-12 hours of training sessions that include classroom training as well as hands-on skills training on manikins. These training sessions are qualitatively evaluated by the expert trainers, who are also present in the training/testing sessions. These methods have been in practice for a long time; however, certain aspects of these methods are in need of modifications and improvements. The first issue with the conventional training methodology is the time management between trainees and trainers. Since emergency team members in hospitals are busy most of the time, it is difficult to arrange a common time when they are all available together at one location to practice. Another issue is the lack of quantifiable data to evaluate the performance of the ACLS teams. Although a trainer (instructor) is present during the training, it is difficult for the trainer to keep track of all the users tasks in order to provide effective feedback. Additionally, the cost related to the training is one of the biggest obstacles since the conventional training method always requires professional educators and very expensive manikins for high-quality education.

ACLS procedure is a life-saving intervention. Moretti (2007) reported that ACLS procedure performed by group of ACLS certified professionals has shown to increase patient survival by as much as 20

As mentioned in Chapter 1, VR-based training simulators are a cost-effective method to provide medical training. Similarly, ACLS training can also be designed using virtual reality principles which will provide the opportunity to conduct and/or participate in frequent ACLS training. In the next section, we briefly explain some of the important principles of virtual reality and also present the past research studies reported in the field of medical education using virtual reality.

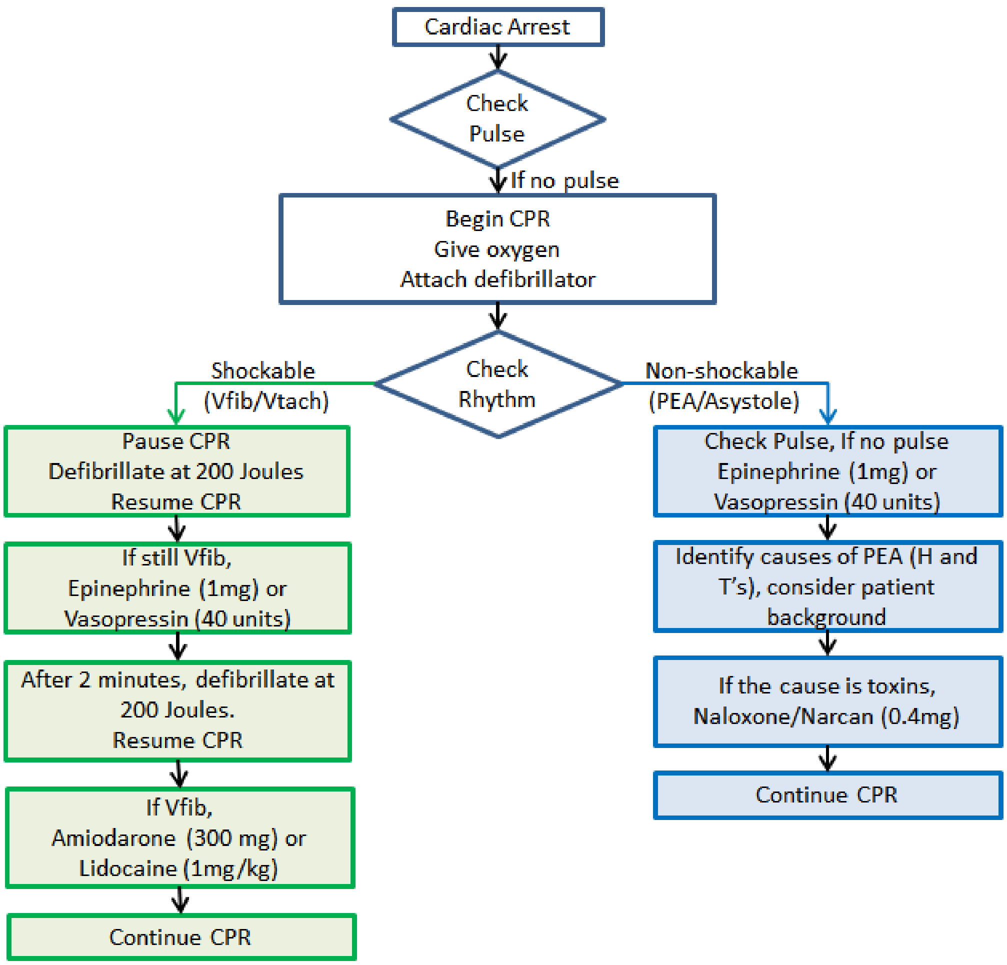

Figure 2.1: ACLS protocol for shockable and non-shockable rhythms. Ventricular Fibrillation/Tachycardia (VF/VT) for shockable and Pulseless Electric Activity (PEA) for non-shockable (adapted from AHA, 2010 see Appendix D).

Chapter 3

RELATED WORK

In this chapter, we highlight some earlier research studies reported using virtual reality in the field of medical education. First, we describe the use of VR-based simulators for individual training, then discuss the importance of team-based training, and finally explore some existing collaborative VR-based simulators and discuss their limitations.

3.1 Virtual reality based medical training simulators

Learning and retaining clinical skills (cognitive and psychomotor) as well as the utilization of these skills to manage medical problems require a significant amount of practice. Part-task trainers (simulators that are used to provide specific medical procedure) and manikins are the most commonly available tools to practice hands-on skills, in particular in surgical and clinical skills (Sahu and Lata, 2010). However, they can be very expensive, and these tools also deteriorate over time. In recent years, a great deal of research has been reported in the field of medical education using VR-based training systems. A brief description of the VR systems and their advantages has already been presented in Section 1.1. In this section, we present various studies that have been performed using VR-based systems in the field of medical education (VR-based is a common term used for both virtual reality and augmented reality).

3.2 Virtual reality and individual training

Virtual reality can be defined as a computer-generated, fully or partially interactive three-dimensional environment (Pratt et al., 1995). However, in order for a VR environment to be suitable for training, Oblinger et al. (2006) lists five key features that VR training environments should possess - social, research, problem solving, transfer, and experiential. ***Social*** features foster a sense of community or competition during training; the ***Research*** feature motives the participants to explore and learn about the virtual environment; ***Problem solving*** facilitates applying existing or learned skills to perform various tasks in order to reach a desired goal; the feature ***Transfer of skills*** can be defined as one that enables applying the skills learned in virtual environment to solve real world problem(s); ***experiential environments*** allow for multimodal (visual, auditory, haptics) experience to the users for real world observations.

The most common applications of VR-based medical training integrating ***"experiential environments"*** are confined within a small subset of medical training involving individual users such as bone/tooth drilling/cutting (Vankipuram et al., 2010; Morris et al., 2007; Liu et al., 2008), and laparoscopic simulators (Gor et al., 2003; Crochet et al., 2011;Seymour, 2002; Grantcharov, 2004; Taffinder, 1998). These studies have shown that virtual reality simulators can be used to train and assess clinical skills. It is to be noted that these simulators focus on individual training as well as on the procedures that have dominant psychomotor components.

3.3 Importance of team training

Teamwork is a critical component for patient safety and outcomes; therefore healthcare organizations suggest comprehensive team training (AHRQ, 2013). Risser et al. (1999) reported that improved teamwork could reduce medical errors in emergency departments. In their study, they analyzed fifty-four incidents of emergency cases from eight hospitals, and found that an average of 8.8 team-based tasks per emergency case that were either not performed or performed incorrectly. Furthermore, the authors suggested that caregivers must improve teamwork skills in order to reduce errors and improve care quality. Patel and colleagues in their most recent work show the mechanism of error correction through teamwork in critical care medicine (Patel et al., 2014). The Agency for Healthcare Research and Quality (AHRQ), a branch of U.S. department of Health and Human Services, developed a framework based on curricula developed to integrate teamwork principles into healthcare. The framework, known as TeamSTEPPS (AHRQ, 2013), is used to improve communication and teamwork skills among healthcare professionals. Shetty and her colleagues evaluate the use of cognitive basis of effective team performance in simulated cardiac resuscitation. The authors report that adherence to the exact sequence of the ACLS protocol was not a characteristic of the successful team. During ACLS, a team is successful only if it can revive a patient or if the team members can perform all the tasks correctly based on the ACLS guidelines. In addition flexible leadership that encouraged contributions and suggestions served to establish greater situation awareness (i.e. perception of the surrounding with respect to space and time) and maintain a two-way flow of communication in the successful team (Shetty et al., 2009). Teams perform better has also been shown by other researchers (Hamman, 2004; Hamman et al., 2009; Wayne et al., 2006). The adverse effect of lack of team communication and coordination was shown to be associated with patient safety in intensive care unit by Knaus et al. (1986), and in operation room by Mills et al. (2008).

Communication, coordination and cohesion are typical characteristics of a team and team members must possess these skills in order to efficiently carry out the required tasks (Parab, 2010). One of the primary advantages of effective teamwork is that it allows for distribution of cognitive work, which is necessary given the complexity of modern health care However, this distribution requires that all members of a patient care team develop and maintain shared cognitive representations of the problem under consideration, the underlying causes of a patients current state, the overall plan of care, and the allocation of responsibilities among team members. Such shared representations, commonly referred to as Shared Mental Models (SMM), have been shown to have positive impact on team performance in a variety of settings and domains. Cannon-Bowers et al. (2001) reported that SMM are the key aspects that critically affects an individuals ability to work in a team, and also presented strong correlation between robust SMM and improved clinical performance. Mathiu et al. (2000) conducted an experiment to study the influence of SMM on team performance using a virtual reality based flight simulator. Before the experiment, the teams were trained on individual task responsibilities and basic team processes (coordination of activities). During the experiment, the teams (two members) had to shoot down enemy planes and also had to fly a preset route. The results based on the performance of the teams displayed a strong correlation between the team performance and SMM.

The studies mentioned above suggest limitations of individual training, and importance team-based training. Technological advancement in the field of computer and the Internet hardware and software laid the foundation to create collaborative virtual environments, which would allow users to communicate and perform coordinated tasks from remote locations. Section 3.4 investigates the use of such collaborative virtual environments in the field of medical training/education.

3.4 Virtual reality in medical education and team training - use of collaborative virtual environments

Collaborative virtual environment (CVE) is a shared virtual environment where a group of individuals connect in order to perform collaborative tasks (Benford et al., 2001). Users can represent themselves in a CVE using their own avatars, can interact with the virtual objects within the environment, and can also communicate with other users that are present in the CVE (Dickey, 2005). CVEs, which are more commonly known as Virtual Worlds (VW), provide two major functions to the users 1) content/information sharing, and 2) social interaction. The possibility of sharing various media - auditory, visual, and textual using the CVEs makes these environments very good candidates for use in the fields of training and education.

Although the concept of VW evolved from gaming (digibarn, 2010), there are many VWs (AlphaWorld, WorldsAway, ActiveWorlds, Second Life) that allow users to create their own virtual environment. Second Life (SL, www.secondlife.com) and ActiveWorlds (AW, www.activeworlds.com) are the most popular VWs at present that allow users to create customizable environments. These VWs are gaining popularity in wide range of fields including, but not limited to, social interaction, games and entertainment, business and e-Commerce, healthcare, and education and training.

A dominant section of work on the applications of 3D VWs in healthcare and medical education focuses on the behavioral treatments for mental health problems. For example, Gorini et al. (2008) created an island, Eureka, in SL to use 3-D virtual worlds for online mental health applications and identifies addiction as one possible area of intervention. Eureka was designed to motivate and teach users to improve their living habits and also as a tool for addiction prevention and treatment. Since VWs provide a platform to involve both patients and their therapists, they have already been in use providing behavioral healthcare to patients. SECTER (Simulated Environment for Counseling, Training, Evaluation and Rehabilitation) is a customized VW where patients are assigned roles and can communicate with the avatars of their therapists (Frenkel, 2009). These environments are being used for treatment of troubled teens, patients with Aspergers syndrome (Phillips, 2008), anorexia and bulimia, anxiety disorders, post-traumatic stress syndrome, alcoholism, and disabilities in stroke victims

(Frenkel, 2009). Support for Healing Island (Parsons, 2008) offers various ongoing activities in SL where patients can login to various virtual spaces and meet people similar to them. This feature offers the patients a virtual environment to socialize and get information about their physical and cognitive disabilities.

Chodos et al. (2010) presented two case studies; Emergency Medical Training/ Emergency Room (EMT/ER), training simulation and InterD-410 course. The EMT/ER training simulation focuses on providing training to EMT/ER personnel on basic procedures for assessing and stabilizing accident victims before transferring them to the hospital (for EMR personnel). For ER personnel, this simulator focuses on providing training on receiving, assessing and starting the treatment for the victims. This simulator also provides training on the handoff process that involves information exchange by the EMT personnel to the ER personnel. The Inter-D410 course simulation highlights the idea that health delivery is a team activity and thus aims to demonstrate this concept to the medical students. The authors mention that they have not yet evaluated the effectiveness of the simulator, and also state that pre- and post- study questionnaires on attitudes towards using the VR-simulator in training would be the part of the evaluation.

The paramedic training simulator designed by Conradi et al. (2009) is an interactive training simulation consisting of seven different scenarios. According to the authors, manikins were interactive in their system. In their study, the authors provide results of only the usability evaluation. The efficacy of the simulator isnt investigated in the paper. Schmidt and Stewart (2009) explain how SL can be used to familiarize nursing students with various public health services as well as public health nursing interventions. They created various scenarios inside SL. To mention a few - Nutrition Activity, Virtual Support Groups, Disaster Scenario, Public Health Resource, and Education Library. The students had to work in a team on each scenario during the training sessions. Play2Train (Boulos et al., 2008) is another problem-based learning (PBL) where participants are trained on assigning various roles to complete a set of tasks in emergency conditions.

Another manner in which VWs can be helpful in providing medical education is organizing didactic sessions in the VWs. This is similar to a tele-conference; however, VWs provide better interaction with all the participants. Second Health is one such project where users can learn about using medical devices in hospital settings (NMC, 2009). An interactive clinical scenario is provided for medical device training in a simulated clinical environment. The participants are provided with both formative and summative feedback during the training session. However, the system does not provide a clinical-skills training component in a collaborative environment where multiple users make a team and perform a collaborative task. Ann Myers Medical Centre (2009), and nursing program at Duke University (Johnson et al., 2009) use a VW to create a meeting place in order to present virtual lectures and educational materials to the students, and interact with each other.

Mels-Palazn et al. (2012) work designed a Continuing Professional Development (CPD) program for primary healthcare professionals in Second Life. In their study, two training workshops for healthcare professionals from nine health centers were organized. The virtual training was divided into several sessions based on different fields such as preventive medicine, family and community medicine, prescription drugs, and new technologies. However, the authors mention that less than half of the participants considered SL to be equal or superior to face-to-face methods. Wiecha et al. (2010) describe their work on the development of a teaching tool for continuing medical education in SL. In their study, 10 participant physicians attended a 40-minute talk on insulin therapy. Two mock patients were also introduced to the session. The analysis of a questionnaire on insulin therapy before and after the talk displayed significant improvement in the participants knowledge of insulin therapy. This system is designed to provide classroom-based (didactic) training, hence is not interactive.

Boulos et al. (2007) describe the potential use of Second Life in medical and health education. The authors provide two scenarios, Virtual Neurological Education Centre and HealthInfo Island. The former demonstrates a scenario where users are exposed to most common neurological disability symptoms. Apart from the symptoms, they are also provided with related information, events, and facilities in Second Life. The latter involves providing training programs for virtual communities. It also provides support to Second Life residents by giving them opportunities to participate in different medical groups dealing with stroke support and cerebral palsy. However, the study only reported the feedback from users regarding the system, and lacked the quantitative evaluation of the system.

3.5 Limitations of previous research on team-based collaborative medical training

The previous research on team-based collaborative medical training laid a very good foundation for the usage of CVEs in the field of medical training and education. However, the existing simulators still require a lot of improvements to be deemed suitable for providing training on collaborative, time-critical procedures like ACLS that require cognitive as well as psychomotor skills. Following are the major limitations of the present day virtual reality based simulators that render them unsuitable for VR-based medical training for procedures like ACLS:

- Most CVEs focus on cognitive aspects of emergency training rather than integrating psychomotor skills into the training.
- Simulators for team-based training should have specialized visual interfaces for each participating user based on his/her role in the team-based procedure. None of the current day simulator takes this into account and each uses a common visual (graphical) user interface for all participating roles.
- An important milestone on taking these VR-based simulators to the next level is to make advancements in the automatic performance evaluations performed by the simulators. Current day simulators lack advanced features on performance

evaluation of the participants. Automatic real-time performance evaluation during training and the capability to provide tools to track user performance over extended periods of time are two examples of such advanced features.

Finally, apart from the limitations on the feature sets and capabilities of present day simulators, there is one major limitation on the past research on VR-based medical training simulators - lack of robust evaluation methodology for validating the efficacy of the simulator in transferring skills similar to the conventional counterpart using manikins. We believe that it is prime requirement to address these issues while designing a VR-based medical training simulator for it to be deemed suitable for training.

Chapter 4

PROOF OF CONCEPTS

In order to meet the objectives of this research, there are two major aspects that we first needed to gain expertise on:

1. Design a CVE and integrate a haptic device into the CVE in order to provide hands-on training for cardiopulmonary resuscitation (CPR) procedure.

2. Extend the CPR training simulator to provide a collaborative VR-based ACLS team training.

Prior to this research, various training simulators have been designed in order to provide hands-on skills on dental procedures and/or bone drilling procedures. These procedures vary from drilling femur (Vankipuram et al., 2010) to preparing tooth surfaces (Rhienmora et al., 2010). These virtual reality based training simulators also accommodate haptic devices to provide realistic force feedback to the users during the training. However, these (force feedback) devices have not been used in providing training on life threatening procedures that require both cognitive and psychomotor skills.

The first section in this chapter provides proof of concept on how a haptic device could be used to provide training for CPR procedure in ActiveWorlds. The second section focuses on the extension of the CPR training simulator so as to provide collaborative VR-based ACLS training.

4.1 Virtual World based Cardiopulmonary Resuscitation Training Simulator

4.1.1 Background

Cardiopulmonary Resuscitation, CPR, is a manual emergency procedure in which blood circulation is attempted to restore when the heart stops functioning. According to the AHA (Heart.org, 2013), "About 92 percent of sudden cardiac arrest victims die before reaching the hospital. Furthermore, the AHA mentions, Immediate CPR can double, or even triple, a victims chance of survival." This shows the importance of CPR in saving valuable lives. Clearly, the more people know about CPR, the more lives can be saved. CPR can be performed in two different situations - when there is only one person, and when there are more than one persons to take care of the victim. When there is only one person, the CPR must be performed by continuously maintaining one hundred (100) compressions per minute, each compression must be at least two inches (2") deep. In the case when there are two or more people, the person who is doing CPR must complete 30 compressions maintaining 100 compressions per minute maintaining a depth of compressions of two inches. After 30 compressions, the compressor should pause for two ventilation periods, which should then be used to provide oxygen to the patient by another person. In our study, we designed a CPR training simulator in a virtual world that focused on only the chest compression part of the CPR procedure with a goal to re-train users who already knew how to perform a CPR, but hadnt practiced it for some time (Khanal and Kahol, 2011). The major objective of this study was to understand the effect of real-time feedback during VR-based training. We expected that real-time feedback and cues would improve the CPR performance of the users, as well as help them to retain the learned skills after the training.

4.1.2 Design

Figure 4.1 displays the system design architecture of the CPR training simulator. The simulator consists of two major components: a visual component (collaborative virtual environment), and a haptic component.

Visual Component The visual component includes all visual objects, avatars, and animation sequences in the CVE. We used Active Worlds (AW) as our CVE. A virtual hospital was created by using as the model the original floor plans of a Banner Good Samaritan Medical Center, Phoenix, Arizona. We then created various objects and custom avatars of doctors and nurses using Maya®, and 3D Studio Max®. The avatars are the visual representations of the users in the virtual environment. Multiple users can log into the AW simultaneously. They can select their own avatars, and navigate around the virtual hospital. The avatars can perform various gestures like flying, running, chest compression, and checking the pulse of the patient. Changes in a virtual scene are visible to all users who are logged into the scene.

Haptic Component The haptic component is responsible for measurement of the CPR rate during training. We used the Novint Falcon®haptic joystick (Novint, 2013) for the system. The major objectives of the haptic component are: 1) interaction with the haptic device, and providing proper force feedback to the user who is performing

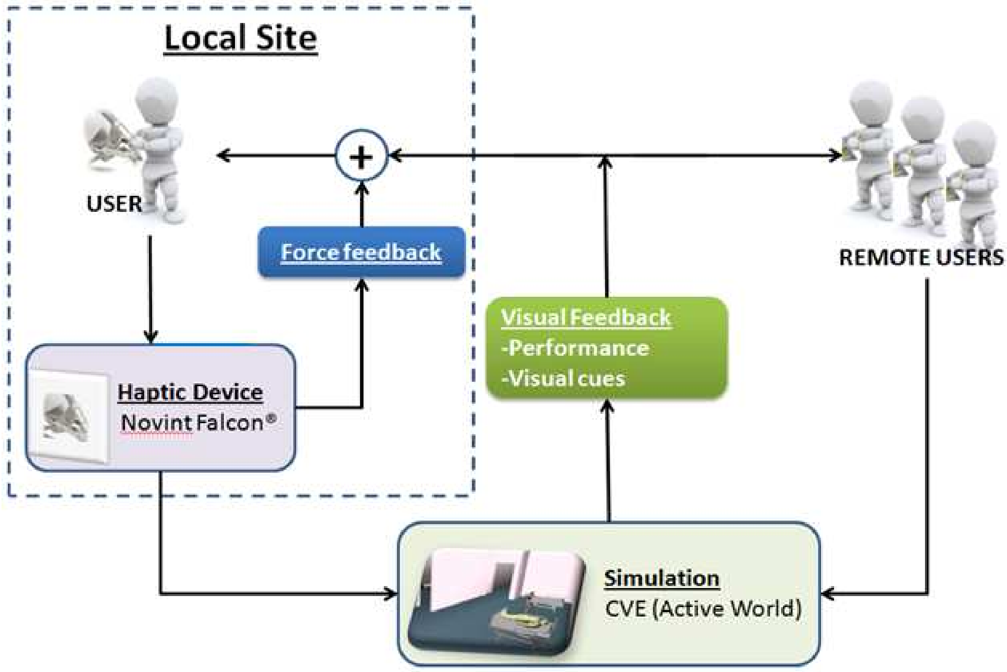

Figure 4.1: System Design - CPR training simulator in ActiveWorlds®

CPR using the device; and 2) sending responses from the haptic device to the AW and triggering various action events in the Active World. Since the force resolution of the haptic device is less than required, we also attach a spring on the head of the joystick so that it can provide realistic hardness during chest compression. The participant, who has access to the haptic device, must maintain the rate of 100 compressions per minute while performing a CPR with the haptic device. The haptic device provides a force feedback to the user. This triggers her avatar to perform the chest compression gesture in the AW, which is visible to all users who are logged in to the scene. At the same time, the rate of the compressions is also recorded. One of the objectives of this study was to check whether the participants retain the CPR skills afterwards.

Although other users can login to the virtual world at the same time, they are not allowed to interact with the system. However, they can view and communicate with the participant who is performing CPR using text messages inside the virtual world.

4.1.3 Experiment

The experiment was conducted at Human Machine Symbiosis (HMS) lab in Department of Biomedical Informatics at Arizona State University (ASU). Twelve ASU student volunteers (3 females, 9 males) were randomly chosen to participate in the experiment. All participants had basic CPR skills and had prior training in CPR. In particular, each of the participants already knew that he/she needed to maintain the rate of 100 compressions per minute. However, they hadnt performed CPR at least for the last two months. Moreover, only five of participants had prior experience using a haptic device, all others were using a haptic device for the very first time.

During the experiment, each participant had to perform three CPR trials, and maintain the rate of 100 compressions per minute. In the first trial, the participants had to perform a CPR without any visual feedback. In the second trial, the participants were provided with feedback (information about recently performed task) and visual cues (suggestions for performing the next task) so that they could synchronize their rhythm of compressions with the visual cues provided on the screen. A "Press icon was used as a visual cue, which appeared/disappeared maintaining the rate of 100 per minute. Participants had to perform compressions whenever the "Press icon appeared on the screen, and recoil when it disappeared. In addition to the visual

Figure 4.2: Screenshots from the system: Green board for correct compression-rate (left); Red board for lower compression-rate (right).

instructions, the participants were also given feedback on their performance. Their compression-rates, number of compressions and a message (if needed) were shown during the compressions. If their compression-rates were less than 90, a feedback message saying "Go Faster! would be displayed, and then the participants would need to increase the rate of compressions. Similarly, when the compression-rate was more than 110, a feedback message saying "Go Slower! would be displayed. These two messages were shown in a red background, indicating that they were deviant from the actual rate. If their compression was between 97 and 103 compressions per minute, the current compressions-rate and the number of compressions was shown in a green background. The third trial was similar to the first one; no visual cues and feedback were provided during the training.

Figure 4.3: Experiment Setup: CVE shown at the left and haptic device at the right.

For each trial, the number of compressions, time taken for each compression (in seconds), and the rate of compressions were recorded. Prior to the trials, each participant was briefed about the system, and what they needed to do during the trials. Each participant was also given some time to practice using the simulator. When they were ready, the first trial was performed. An interval of approximately one minute separated the trials. Figure 4.3 shows the setup of the system for the experiment.

4.1.4 Result

Figure 4.4 displays the number of compressions in each trial performed by each participant. The safe range (90 to 110 compressions per minute) is highlighted in the figure. For each trial, performance metrics of each participant, like number of compressions, time, and rate of compressions, were recorded. Almost 60% of the participants could not maintain their rate within the range of 90-110 compressions per minute. The results showed that when no visual cues were given, people who knew about CPR, but did not practice it often, tended to make mistake in maintaining the required compressions-rate. The compressions rate varied from 76 to 126 per minute. The second trial was performed in presence of visual cues and performance feedback. In this case, all participants were able to maintain the compression rate between 90 and 110. The range of number of compressions per minute varied from 95 to 104 in the second trial. Participants performed better in the third trial as compared to the first one. All of them were able to maintain the compression between 90 and 100. The compression rate varied from 90 to 110. We initially hypothesized that the participants should maintain the rate between 90 and 110, and that providing them with visual cues and feedback would improve their performance. In the visual cues condition, we displayed their compressions-rate, and whether they are going fast or slow, in real time, so that even if they were maintaining the required rate, they could further improve their performance to get to a better rate of 100 compressions per minute. Our hypothesis was confirmed in that when they were provided with the cues, participants performed better than when they were not provided with any feedback. The compressions rate varied from 95 to 104, which was much better than the compressions rate when not providing with feedback. In the third trial, we wanted to check if the participants could retain their acquired skills and still perform well if now no visual cues are provided. From the outcome of the third trial, it is safe to say

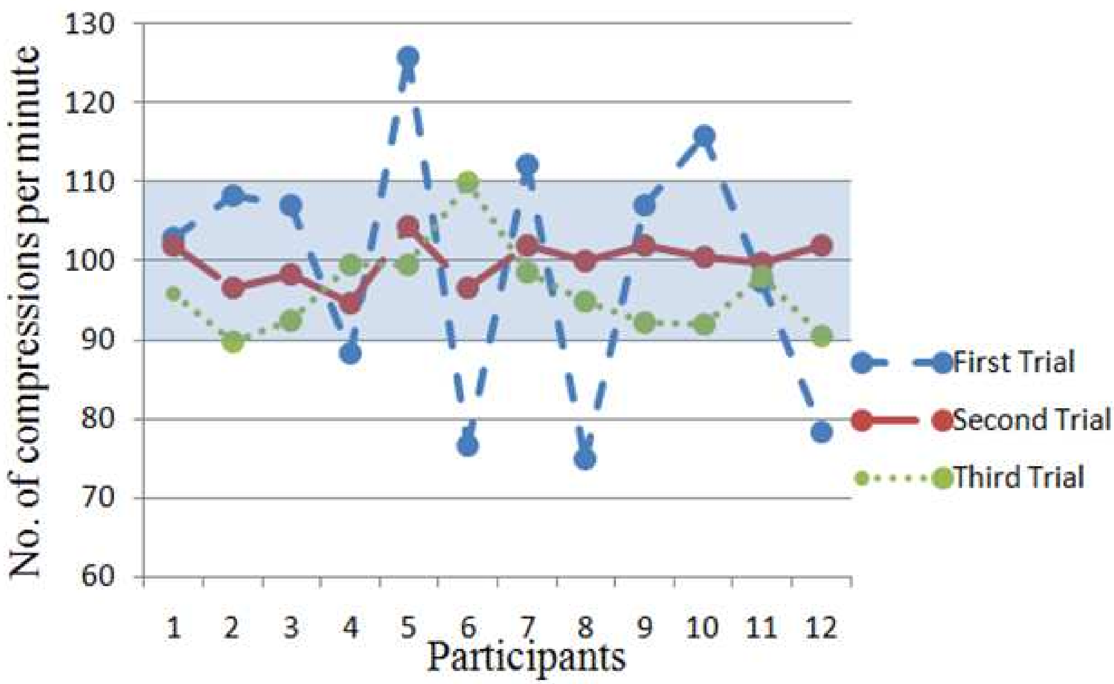

Figure 4.4: Performance of 12 participants on each trial (safe-range is highlighted).

that they did retain the skills immediately after the practice mode. In this trial, each participant could maintain a range of 90-110 a value much better than the results of the first trial where more than one half of them could not maintain the desired range. Although we showed immediate retention, we did not investigate the retention of these skills over a long period of time.

4.1.5 Conclusion and future work

This study focused on the design and implementation of an interactive collaborative CPR skills training simulator for the purpose of re-training the users, and evaluating the construct validity of the system. . A demonstrated a novel approach of integrating a haptic device and a CVE by localizing haptic feedback and transferring the positions of the device to the server located at a remote site. The experiment results showed that the there was greater deviation among the participants in their performance without real-time feedback than when they were provided with real-time feedback. The simulator also helped participants in retaining their learned skills immediately after the training.

Although this study was performed as the proof of concept of using a sensory device (haptic device in this case) in a virtual world for CPR training and importance of feedback and cues during VR-based training, it opens up various possibilities of using haptic and other sensory devices in virtual reality based medical training simulators. The possibilities include - using the design concept of this simulator to create a simulator that provides a team-based training for other medical procedures; creating a database server to record participants performance that can be accessed online with valid credentials; using the simulator as a virtual assessment tool for CPR skills.

4.2 Virtual World based Advanced Cardiac Life Support (ACLS) Training Simulator

4.2.1 Background

After performing proof of concept for integrating sensors such as haptic devices into virtual worlds for medical education, we then attempted to understand the effect of virtual world based team training for time critical scenarios that require both cognitive as well as psychomotor skills to solve a medical problem (Khanal et al., 2013).. Advanced Cardiac Life Support (see Chapter 2 for more information on ACLS) was chosen as the case study to be implemented in the virtual world. The virtual world based ACLS training simulator, which includes a CPR training component, provides training for the ACLS procedure in a collaborative virtual environment or a virtual world. Unlike the case of CPR training simulator, this simulator allows multiple participants to form a team and then to work together and communicate with each other in order to complete a given task. An ACLS team must perform cognitive and psychomotor tasks within five minutes with proper coordination between the team members to be able to save a patient. However, we focused only on the procedural training of the ACLS procedure, i.e., training participants on step-by-step tasks till the completion of the procedure. The tasks included in the training did not involve the clinical skills like injecting needles and/or placing oxygen-bag properly on patients face.

4.2.2 Design

The ACLS training simulator is designed based on the design principle of the CPR training simulator (section 4.1.2) with some additional components. Figure 4.5 shows the design of the virtual reality based ACLS training simulator. The visual and the haptic components are similar to what was implemented for the CPR training simulator. Additional components include a voice component, a database component, and a feedback component.

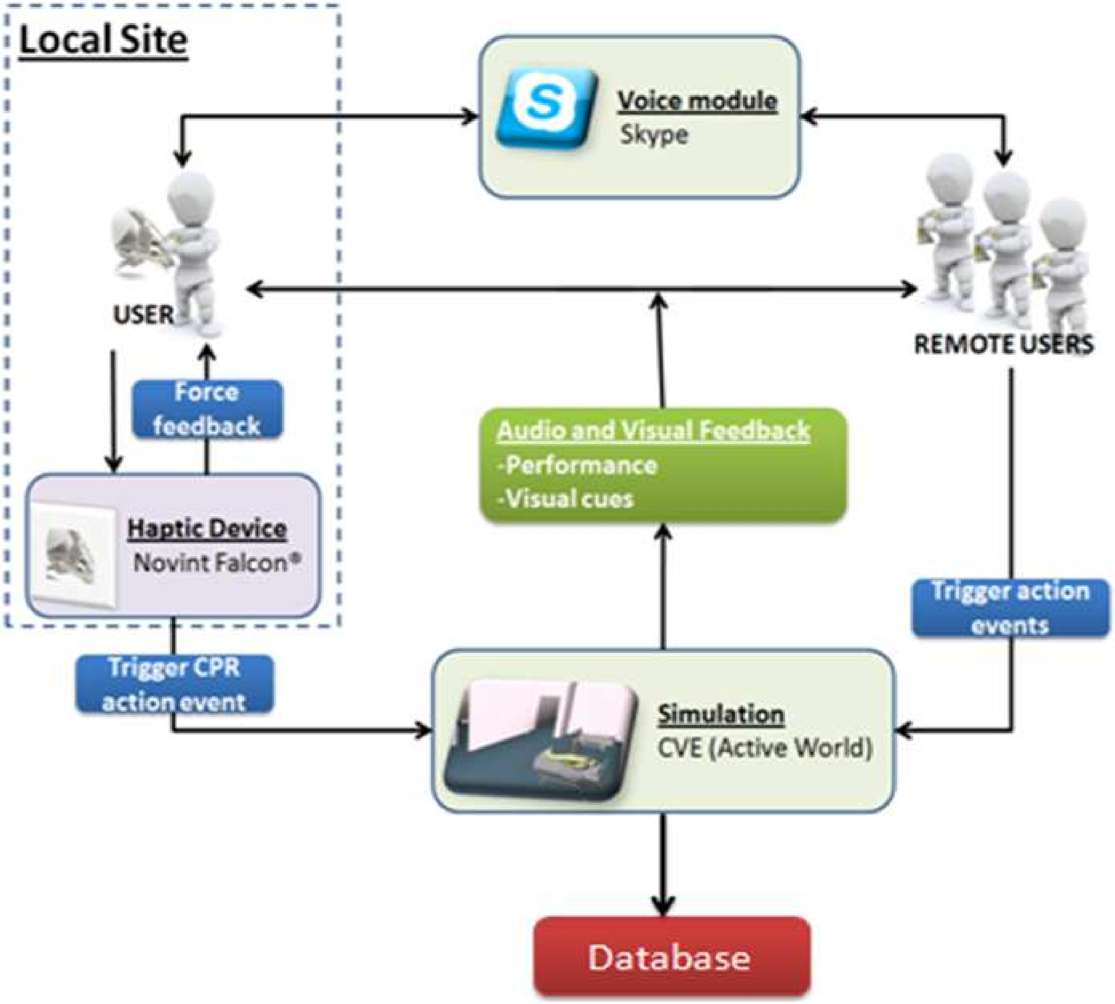

Figure 4.5: System design - ACLS training simulator using ActiveWorlds.

The visual interface of the ACLS simulator is different than that of the CPR training simulator, which is shown in Figure 4.6. The visual interface consists of a virtual mock-code room, which is equipped with virtual objects such as a medication cabinet, a defibrillator, and even a virtual patient. The virtual objects in the scene are click enabled and corresponding events (or tasks) are triggered on each click. All the triggered events are stored in the remote database server.

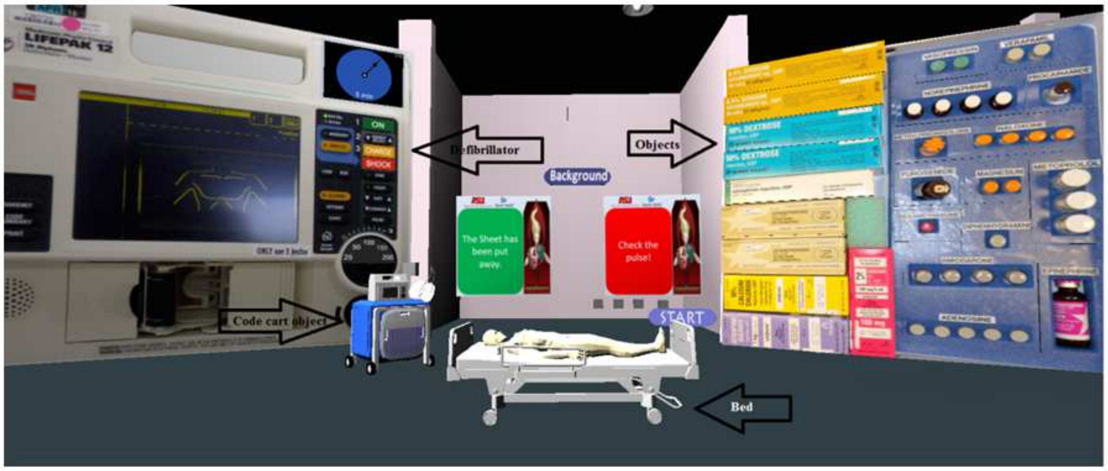

Figure 4.6: Virtual ACLS training room with virtual objects such as patient, defibrillator, medicine cart, feedback/cues.

Voice Component The voice component consists of Skype (www.skype.com), which runs separately from the main components. We chose Skype because of better quality voice communication it provides between multiple parties.

Database Component The database component is used to record the task performed by each user during a session. We use a MySQL server, which is setup in a machine separate from the machine hosting the other components of the simulator. The information regarding users, tasks performed, relative time of tasks performed, and the scores are stored in the database. The main purpose of using the database was to monitor the performance of users in the subsequent virtual training sessions; and also for inter-group comparison of performances.

Feedback Component The training system used two different methods for feedback - formative and summative. Formative feedbacks are those provided to the users at various stages during the training; whereas, summative feedback is only provided at the end of the training.

Various alerts are provided based on the performance of the teams during the training. The alerts pop up relative to the teams performance. If the team is lagging behind in time when performing a certain task, alerts would pop-up to inform the team that they are lagging. If they are performing the task within the pre-specified amount of time, alerts with appreciation are displayed to motivate them to perform better. Scores are also displayed to inform them that they are performing well.

At the end of a training session, the team is shown a happy faced character if the patient was saved; or a sad faced character if the patient did not survive. In addition to the final messages, the team members are also provided with a webpage link that shows the summary of their performance. The summary page shows the total points that the team scored, whether or not the patient was saved, and the overall performance of the team. A summary table is also shown that lists the users id, tasks performed by each user, duration of the performed task, and points earned for the performed task. There is also an option available to view the individual performance of a user. The summary of the overall training session is retrieved from the database. Figure 4.7 (left and right) shows examples of implementation of summative feedback and formative feedback respectively.

Figure 4.7: Summative feedback (left) and Formative feedback (right) in the virtual ACLS training system.

4.2.3 Experiment

Twenty four student volunteers from ASU, with no knowledge on ACLS prior to the experiment, participated in the study. We randomly grouped the participants into six groups of four each. We asked each participant to take a quiz, with ten multiple choice questions related to the ACLS procedure, prior to conducting the experiment, in order to verify that the participants are at the same level of expertise on ACLS.

The experiment consisted of two general groups: control group and experimental group. Each of the groups had two sub-groups of four participants each. All six groups were provided with a 30- minute didactic training session on ACLS, separately. The experimental group was provided with additional virtual world training. The experimental group was further divided into two more groups: procedural (non-persuasive) and persuasive. Persuasive groups were trained in the virtual world with persuasive elements like timely alerts (feedback) and scores enabled in it. Procedural groups were provided with training for the virtual world but were not provided with any persuasive elements and formative feedback elements. The didactic training and the VR-based training was provided in the HMS lab at ASU.

In the first phase of the experiment, the experimental groups (both procedural and persuasive groups) were first introduced to the AW, and then the virtual hospital. After 3-5 minutes of exploring in the virtual hospital, they were ready to start the training sessions. The experimental groups were provided with two training sessions and a test session for each case (VFib and PEA) in the virtual world. In the training sessions, both the groups were provided with step by step instructions to perform the set of tasks. The test sessions for both persuasive and procedural groups did not get any alerts, scores, or instructions. All the information during the training and the testing sessions were stored in the database server. After training and testing in the virtual hospital settings, the participants of experimental groups were asked to fill out isometric questionnaire regarding the look and feel of the training system, and the quality of learning in the virtual environment.

The second phase of the experiment was the testing for the transfer of skills from virtual world training to actual training room (Figure 4.8) at Banner Health SimET Center, Phoenix, Arizona. The next day after the first phase of the experiment, the groups were taken to the real ACLS training/testing center to test whether the groups

Figure 4.8: Participants in the real training/testing room with high fidelity manikin.

could transfer the learnt skill to the actual training/testing room. At the center, each group was introduced to the tools, equipment and medications that needed to be used during the testing session.

After the exposure to the required tools/equipment/medications, the groups were randomly brought into the testing room. Each group was provided with two ACLS cases chosen at random. The testing sessions were organized in the presence of certified ACLS trainers who were in-charge of evaluating the teams performances. Since no participants were familiar with the clinical procedures like injecting syringes for medication, we were more focused on observing the procedural aspects of the training. The procedural aspects included tasks like identifying rhythms, identifying cause, providing proper medications, team communication, and the sequence of the tasks performed. The two evaluators evaluated the performance of each group and noted the time taken by each group for performing each task. The final evaluation for each group was calculated using the average values of the evaluations by each evaluator. The time taken by each group, as per the final evaluation calculated, was used to derive a generic score that would differentiate the performance of each group.

4.2.4 Results and Discussion

Since the participants did not have prior ACLS skills, we provided them with didactic training, and also tested each individual with a quiz comprising of 10 questions related to ACLS. The average score of the control, persuasive, and procedural groups after the didactic training was 8.4 ± 1.5, 8.25 ± 0.85, and 8.75 ± 0.25 respectively. This shows that all three groups were in same level of ACLS skills at the end of didactic training.

During the second phase of the experiment, all groups were trained and tested in the ActiveWorlds. All the groups were provided with two training sessions with a testing session for each case. All the important training and testing data gathered in all sessions were stored in the secure database. For each ACLS case, average score for training and testing modes were calculated separately for all groups. The resulting scores were then averaged for persuasive and non-persuasive groups. The final percentile score was calculated by dividing the final average score by the maximum possible score for the corresponding ACLS case.

The average CPR rates maintained by the persuasive and the non-persuasive groups, in the training mode for VFib case, were 82 and 59 respectively. In the test mode, the groups maintained comparatively better rates at 87 and 75 respectively. For the PEA case, in the training mode, the persuasive and the non-persuasive groups maintained 82 and 69 rates per minute; whereas in the test mode, they maintained the rates of 98 and 82 respectively. These numbers suggest that the persuasive groups performed better in maintaining CPR rates than the non-persuasive groups. However, it should be noticed that both the groups were not able to maintain 100 compressions per minute during CPR as suggested in the CPR guidelines (AHA, 2010).

The final phase of the experiment was conducted in the actual training room at a real training/testing center. The training room was fully equipped with all necessary tools and equipment required for the testing. The participants had to perform CPR on a high-fidelity programmable manikin, which was constantly monitored by an instructor. The instructor changed the settings as the teams progressed during the test sessions. Each team was selected at random, and presented with an ACLS case. The process continued until all the groups were tested for both VFib and PEA cases. Figure 4.9 shows the performance of each group for each case.

It can be seen in Figure 4.9, the performances of the experimental groups, both persuasive and non-persuasive, were much better than those of the control groups. The persuasive groups (P1 and P2) outperformed non-persuasive groups (NP1 and NP2) when they were presented with the VFib case. In the case of PEA, one of the

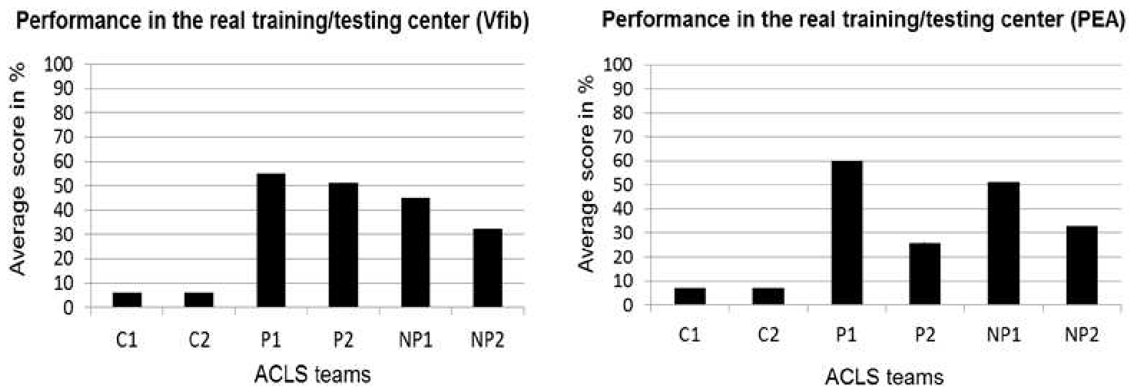

Figure 4.9: Performance of the groups in the actual training room at a real ACLS training/testing center: for VFib (left) and PEA (right). [C1, C2: control groups 1 and 2; P1, P2: persuasive groups 1 and 2; NP1, NP2: non-persuasive groups 1 and 2].

persuasive groups (P1) outperformed the non-persuasive groups. The performance of persuasive group (P2) in PEA case is worse than that of both non-persuasive groups. This was due to some technical problems related to defibrillator that prevented the group from following the procedure within the pre-specified time interval.

After the training and testing in the virtual hospital settings, the participants of experimental groups were asked to fill out feedback questionnaire regarding the look and feel of the training system, and the quality of learning in the virtual environment. Twenty-one different questions were asked in six different categories, targeted to obtain feedback about the system in order to evaluate its advantages and limitations. Each question required the participant to rate one of the features of the system on a scale of 1 to 10, 10 being the best score. The six different categories were:

- ease of use of the simulator;
- quality of force feedback during CPR simulation on haptic joystick;
- lag experienced in the system;
- aid provided by persuasive elements during training sessions;
- improvement in ACLS skills due to training using this simulator;
- overall rating

We took the average of the scores given for each category. The user feedback summary suggests that the participants felt that use of simulator helped them to learn the basic concepts of ACLS procedure in an interesting way. They also felt that the simulator was easier to use, use of haptic device was helpful for CPR training, and proper feedback components helped them to act faster and in a correct manner. However, they also suggested that the simulator would be easier to use if the simulators response time for various activities during the training could be reduced. The high response time is mainly because of the Internet, speed so, when a participant clicks on some objects on the scene, the effect is seen at least one second later.

4.2.5 Limitations and what is required in the next study

Our study shows that virtual world training can be a huge supplement to conventional method of training. This is the beginning of the design of training systems that integrate multisensory devices to a virtual, collaborative training environment for time critical procedures. We foresee a vast array of improvements that can be made to the simulator. In this section, we briefly describe some of those improvements:

Include experts on ACLS training to validate the simulator In this study, we enrolled novice participants for the validation procedure. Therefore, we saw a huge difference between the performance of the control groups and the experimental groups. Now that it has been observed that virtual world training aids in conventional training for novice participants, it needs to be further validated with the actual practitioners in the hospitals who are experts in ACLS procedure. Although it is likely that in such testing scenarios of practicing clinicians the difference in performance between the control groups and experimental groups will decrease; nevertheless, we believe that the major hypothesis that virtual world based team training will improve the performance of a team will still be evident.

Other implementation-related issues The major implementation issue for this simulator was the necessity of the Internet connectivity. Since the ACLS virtual world is designed and stored in the Active Worlds server, there is always connectivity required in order to download and display the contents (virtual objects) on each participants machine. The simulator will not work if the computers are connected only in a local intranet without Internet connectivity. Apart from the connectivity, the system also requires high Internet bandwidth to perform collaborative tasks in real time. As mentioned before, during the experiment, participants experienced increased response times in the system in the absence of high-speed Internet connectivity. These high response times introduced some confusion among the individuals during the team training. From the statistics on the feedback questionnaire, we found that the participants experienced significant response times during the training sessions. A better interaction with the training system would require improvements in the response times for various activities in the simulator.

The study on VR-based ACLS training simulator was helpful to understand the potential of CVE as a medical training tool. But, due to the implementation related issues, participants mentioned that it was sometime difficult to follow the visual instructions during training in the VR-based simulator. As a result of which, they were not able to fully engage in the VR-based training. In order to address the issues, we had to choose a different platform which would facilitate creating our own CVE and would a) provide real-time feedback without significant delay, and b) allow the simulator to run over the Internet as well as a local intranet.

With the advancement in computer networks and gaming, multiplayer online role playing gaming are becoming very popular. Multiple participants can login simultaneously in a virtual gaming environment and perform tasks based on their chosen roles. Online gaming is gaining popularity as an educational tool for training (DeFreitas and Griffiths, 2007) .The use of such technology for medical training simulator would probably address the aforementioned issues. In the next section, we provide the details of design and evaluation of a medical training simulator for central line placement (also known as central venous catheter placement) procedure using one of the popular gaming engines Unreal Engine®.

4.3 Virtual Reality based Central Venous Catheter (CVC) Placement Training Simulator

4.3.1 Background

Annually five million CVCs are placed (Gould and McGee, 2003) and approximately 5% to 26% of them lead to complication (Merrer et al., 2001). Failure to follow the aseptic techniques properly during placement is one of the leading causes for complications. In this study, we design a virtual reality-training simulator for central line or central venous catheter (CVC) placement procedure using Unreal Development Kit (UDK), which is based on Unreal gaming engine. The major focus of the game is to train residents on the aseptic method of CVC placement to help reduce the complications that might arise during the procedure. The game can be played in a computer running windows operating system as well as in devices using iOS operating system (such as iPad, iPhone) by Apple®. Performance of each user is stored in a centralized database as well as in a local device, which can be evaluated by trainers at any time. The users can also track their own performance during the entire training period.

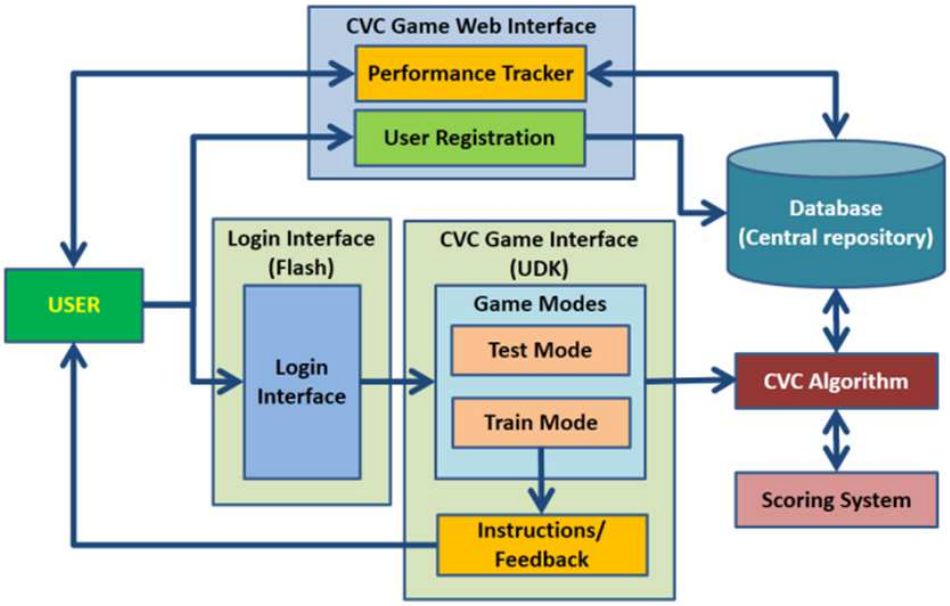

Figure 4.10: System design of the Central Venous Catheter placement simulator.

4.3.2 Design

In this section, we present the architecture design of the system. The conceptual design of the CVC training simulator is presented in Figure 4.10. The CVC game design consists of four major components: a Game Interface, a Database, a CVC Algorithm and Scoring component, and a web-portal for registration and performance tracking.

User Interface The graphical user interface (GUI) of the simulator is designed using Unreal Development Kit 3(UDK). UDK is a game development toolset that is based on Unreal Engine 3 (UE3). UE3 is an award-winning 3D game engine that provides toolsets to develop video games (Epic, 2013). Unreal Script (Uscript) is a programming language that is used to interact with the graphical objects in the

Figure 4.11: Central Venous Catheter (CVC) game virtual environment with virtual CVC placement kit.

simulator. The complex graphical objects are first designed using MAYA®and then integrated into UDK environment. The animation sequences are developed using Unreal Kismet, one of the toolsets that UDK provides.

The virtual environment, as shown in Figure 4.11, consists of heads-up display (HUD) and the gaming window. The top HUD is placed in order to provide formative feedback to the users. The users can track their performance in terms of time elapsed so far, current score, and overall progress during the training. The main gaming window consists of a virtual hospital room where a patient is lying on a stretcher. The central line kit and other objects such as wash basin, patient file holder, masks, and gloves are placed on the virtual walls. Text indicators for activities such as “Start”, “Trendelenberg position”, “Reverse Trendelenberg”, and “Complete” are displayed in the window in such a way that they do not obstruct the view of other objects. The gaming window also displays the instructions to the users, a pointer (an arrow) to the object that is required for the immediate task and an alert message if a user is taking too long to complete the tasks.

Database Component The database component stores the user information provided during registration (using web-portal) and their performance data during training and testing sessions in a central repository. The information stored in the database are user ids, mode of operation - training or testing session, CVC placement tasks, tasks completion date and time, and scores, which are important attributes to monitor performance of the users. The information is retrievable using the credentials that the users create during registration. With this stored database, users can track their own performance over time.

CVC algorithm and scoring system The CVC placement simulator has been designed by incorporating current best practices for CVC placement specified in the American Society of Anesthesiologists and the Institute for Healthcare Improvement Central Line Bundle. The back-end of the CVC game is an expert system that follows the CVC placement requirement checklist presented by Dong et al. (2010). The checklist is shown below:

- Pre-procedure ID verification

- Informed consent communication
- Trendelenberg position
- Operator maximal barrier precautions
- Hand hygiene
- Chlorhexidine skin antisepsis
- Sterile gloving and gowning
- Patient maximal barrier precautions
- Ultrasound sterile technique
- IJ compressibility by ultrasound
- Procedural pause
- Successful independent IJ Venipuncture
- Transduction/Manometry to verify venous access
- Correct securing of the catheter
- Successful independent SC venipuncture

4.3.3 CVC Training Simulator Intervention

Prior to the start of the CVC game, users are required to register themselves using unique user names and passwords at our web portal. The users have to use the same credentials to log in to the game. During the login process, users can select one of the two game modes- training or testing.

4.3.4 Experiment

Twenty-two second year residents (PGY - 2) from the Department of Anesthesiology at the Icahn School of Medicine at Mount Sinai were selected and agreed to voluntarily participate. Participants in the intervention group were given access to a serious game, aimed at teaching proper placement of central lines while participants in the control group underwent standard teaching in the Department of Anesthesiology at the Icahn School of Medicine at Mount Sinai. Traditional training consisted of random availability in the operating room and a week of "line service" during their ICU rotation wherein the resident placed between 2 and 5 central lines per day. Prior to randomization, a baseline CVC placement proficiency was established for all participants, who were graded using a previously validated checklist (Dong et al., 2010). Sixteen weeks after baseline data was collected, participants were again graded on their central line placement technique against the same checklist.

4.3.5 Results and discussion

Baseline characteristics between the two groups were similar, with no statistical difference between the two groups in regards to prior experience placing central lines or baseline score (P=0.60) (Table 4.1).

Table 4.1: Baseline performance of Control and Gaming groups (Katz et al., 2013)

Baseline CVC Placement	Control Group (n=11)	Gaming Group (n=11)	P value
Score, Mean (SD)	16.45 (1.54)	16.77 (1.69)	0.60
Time, seconds, Mean (SD)	1102 (194)	1249 (217)	0.40

The majority (81%) of users reported using the game at least once per month, 9% reported using the game weekly, and 9% reported using the game twice during the study period. After sixteen weeks, those who had access to the game showed significant differences in the primary outcome measures of checklist score and a decrease in overall time when compared to their counterparts in the control group (Table 4.2). Overall satisfaction with the serious game was high, and participants felt as though access to the game enhanced their ability to perform the procedure (Table 4.3).

There could be various factors for the difference in the performance between the Control and the Gaming groups. To begin with, those with access to the game had the advantage of gaining familiarity with the process of central line placement in a controlled and presumably low workload setting (i.e., non-clinical setting). They were also able to examine the different parts of the central line kit in the game and were potentially more familiar with kit itself allowing them to set up their equipment more efficiently. Furthermore, those in the gaming group had the opportunity to

Table 4.2: Performance of Control and Gaming groups after sixteen weeks (Katz et al., 2013)

	Control Group (n=11)	Gaming Group (n=11)	P value
Mean Score Change (SE))	0 (0.64)	3.2 (0.51)	0.0004
Mean Total Time Decrement, sec (SE)	108 (33.5)	270 (53.8)	0.014
Mean Time Per Step, sec (SE)	61 (3.2)	49 (4.3)	0.0005

place as many central lines as they wanted, while ordinarily over a two month span a resident would likely place one or no central lines unless they were on line service, or a rotation where central lines are routinely placed (e.g., cardiothoracic anesthesiology). Likewise, because our game was on multiple portable platforms, residents were able to play the game whenever they saw fit from any location and in an anonymous competition with their colleagues. This likely increased the amount of time spent playing the game.

The participants were also provided with the questionnaire regarding the CVC game on 1-5 likert scale. The response of the participants is shown in Table 4.3:

Table 4.3: Usability questionnaire for CVC game.

Statement	Average rating (n = 11)
Having access to the game increased my comfort with placing central lines.	3.4
After using the game I would feel more comfortable teaching another clinician the procedure.	3.4
I was satisfied with the CVC game.	3.1
Having the game raised my awareness about the potential pitfalls of the procedure.	3.4
Having the game made the process of placing central lines more safe.	3.6

4.3.6 Limitations

The study has several limitations. The sample size for this study was very small which may overestimate the effects seen. Likewise, the study population consisted of only one class of residents at a single academic center which lessens the generalizability to other groups of practitioners or other institutions. Although effort was taken to ensure that residents had no knowledge of the date of their second line placement, occasionally delays were encountered due to scheduling constraints that may have allowed those with access to the game to use it just prior to the placement of their second central line. While this may also be seen as a limitation, it might actually be a strength of the study as well, demonstrating how serious gaming might be used as a warm-up tool, a concept which has been shown to enhance performance in other studies (Lendvay et al., 2013; Plerhoples et al., 2011).

4.4 Conclusion

The studies performed in sections 4.1, 4.2, and 4.3 provide an insight on the potential of virtual reality based training simulators on various medical procedures, including life-saving critical scenarios. Furthermore, we also discovered various advantages as well as disadvantages of using virtual worlds such as Active Worlds. With Active Worlds, the major hurdle arises when there is no Internet connectivity during the training. To solve this problem, for the implementation of the virtual reality based ACLS simulator, we used a gaming engine, Unreal Engine, which allows the simulator to run during absence of the Internet as well. Although our study on CVC training simulator tests for a single user training mode, it provides us an opportunity to understand the strength of gaming engines and how they can be used to address the limitations of using the Internet-based virtual worlds for medical training simulators.

Our major objectives of conducting aforementioned studies were to a) integrate a haptic device to a CVE, b) provide collaborative training in a CVE for time-critical medical procedure, and c) provide prompt feedback during VR-based training and enable the training over local intranet as well. These studies layout the design guidelines that should be followed while designing/creating training simulators for time-critical medical procedures such as ACLS. In the next chapter, we provide the detail description of the ACLS training simulator, which was designed using Unreal Development Kit (UDK) and is based on the Unreal gaming engine.

Chapter 5

METHODOLOGY

This chapter provides the detail of how the advanced cardiac life support (ACLS) training simulator was designed using a gaming engine. Furthermore, the chapter also presents the details of the experiment conducted for validating the ACLS training simulator.

5.1 System Design and Architecture

In this section, we describe the design and implementation of the virtual reality simulator in detail thereby describing various features of the ACLS VR simulator. We then outline the design of the experiment conducted to assess the performance of care providers when trained using the ACLS VR simulator vs. when using traditional face-to-face training.

5.1.1 Conceptual Design

The conceptual design of the system is shown in Figure 5.1. Since the major objective of the virtual reality based ACLS simulator is to allow users to access the system from virtually anywhere (in presence of Internet connectivity), the figure depicts the layout of the virtual world corresponding to the real world. In the figure, we can see that users can be virtually anywhere in the real world, however they will be virtually present at the same virtual training room within the simulator.

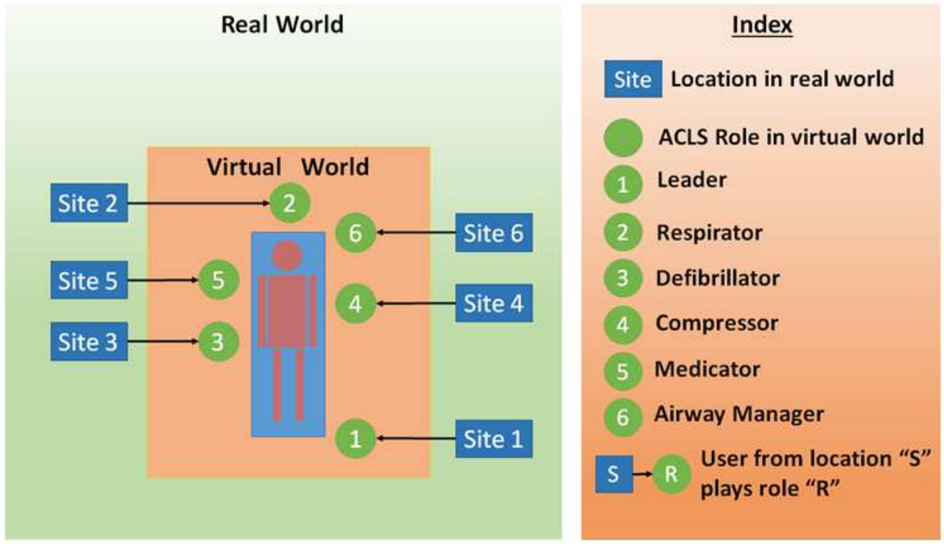

Figure 5.1: Conceptual design of the VR-based ACLS training simulator.

Prior to the development of the game, we consulted with four ACLS trainers regarding the optimal number of members that needed to be present in an ACLS team. Following the suggestions provided by the trainers, the final number of members in an ACLS team was selected to be six. The six members would play six different ACLS roles - Leader, Respirator, Defibrillator, Compressor, Medicator, and Airway Manager.

5.1.2 System Architecture

Figure 5.2 shows the system architecture of the VR-based ACLS training simulator that displays various important layers and components of the system. The architecture is based on four different layers - roles, user interfaces, real-time feedback components, and ACLS servers. Each layer comprises of individual components

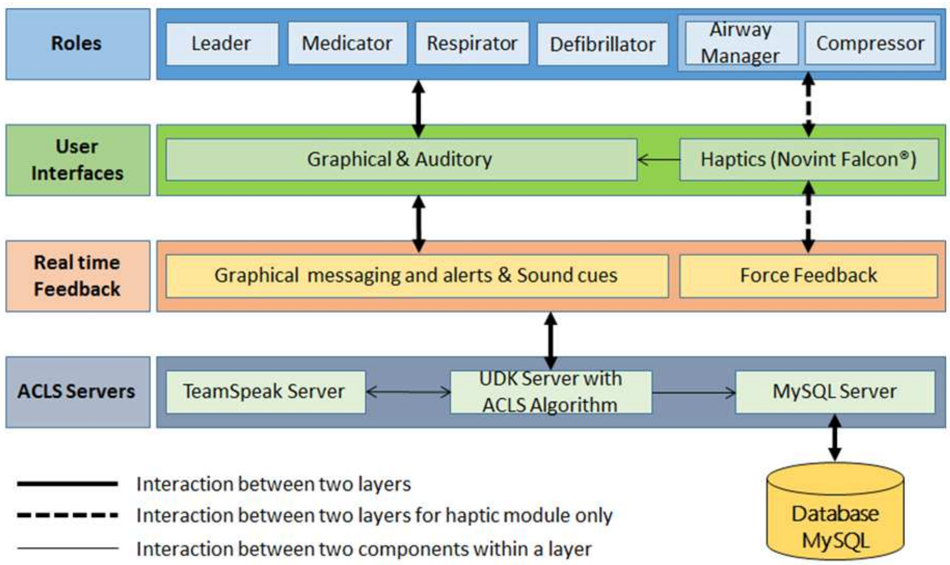

Figure 5.2: System architecture of the VR-based ACLS training simulator.

that interact with each other. The six different roles within the ACLS *roles* layer interact among themselves and also with the system using various user interface modules from User Interfaces (UI) layer. The UI layer provides timely alerts and feedback, which are originated from the Real-time Feedback layer using the feedback module, to the users in the roles layer. The ACLS server layer consists of various servers that form the building blocks of the simulator. The *Unreal Development Kit* (UDK, Epic Games, 2013) server in this layer integrates the ACLS algorithm module that triggers the real time feedback. The *MySQL* (Oracle, 2013) server sends the data to a remote database server using the database module. The four key modules used in the simulator are - user interface module, algorithm module, database module, and feedback module.

5.1.3 Interface Module

In addition to various basic interface components such as mouse and keyboard, the design interface has three major components - visual, voice, and haptic (i.e. touch-based).

Visual Interface The visual interface, or the graphical user interface (GUI), allows the user to interact with the training simulator, to follow the instructions provided on the screen, and to perform the required tasks using a mouse or a keyboard. The visual interface also displays feedback to the users. The visual user interface is different for each role (Figure 5.3) and has been designed using the UDK gaming engine. Appendix I shows the screenshots for all roles in the simulator. The visual interface includes several design artifacts, which can be sub-divided into three major categories:

Avatars: Avatars are the representation of real people in the virtual environment. After initially working with building our own avatars, we later decided to purchase pre-designed 3D avatars and adding animation sequences to them by ourselves.

Objects: Most of the things in the VR training simulator other than the avatars are "objects". There are various objects, which are incorporated to provide a realistic feel during training, such as a virtual ACLS training room, tools and equipment that are required during an ACLS session, and the buttons through which the users interact with the system.

Figure 5.3: Role-based user interfaces in VR-based ACLS training simulator using UDK. (top left to right: leader, respirator, defibrillator; bottom left to right: compressor, medicator, airway manager)

Animation: Animations are parts of action sequences. These are required during virtual training sessions to provide realistic feedback. Examples of action sequences can be movement of the compressor while performing CPR actions; moving the hand of a member (avatar) while checking the pulse of the patient. All the visual components (avatars, objects, animation sequences) are designed in Maya®and later imported to UDK.

Auditory Interface Another major component for a training simulator is communication; especially voice communication. The auditory interface allows the users to communicate with each other during the ACLS training session using a headset connected to each computer. With the help of this module, all users can communicate with each other simultaneously. This interface has been developed using *TeamSpeak*® (TeamSpeak, 2013) API, which is then integrated into the UDK environment.

Haptic Interface The haptic interface is designed to provide psychomotor skills training to the users, which is the CPR compression in this study. The haptic device simulates a patients or a manikins chest where a nurse performs the CPR procedure. Since the force resolution of the haptic device is not sufficient to provide the same amount of force feedback as that of a manikin, we added a spring to the haptic device. The spring was custom made and its spring constant was similar to that used in a CPR training manikin. The haptic module mainly comprises the controlling of haptic device and sending messages from the haptic module to the visual interface. The haptic device was integrated into the system to simulate the CPR action in the virtual training room. We used the Novint Falcon®(Novint, 2013) haptic device and integrated it with the training system so that the number and the depth of the compressions during the CPR procedure could be recorded. The haptic device provides force feedback only to the user who is performing the CPR. When the user is performing the CPR action, the positional data sent from the device is scaled to track the depth and recoil of compressions, which are then displayed in the form of a compression meter seen on the bottom left corner of Figure 5.4. The rate is calculated for every interval of time taken to complete 30 compressions. As a result of this feedback, the users avatar performs the CPR actions in the virtual environment, which is visible to other members participating in the session.

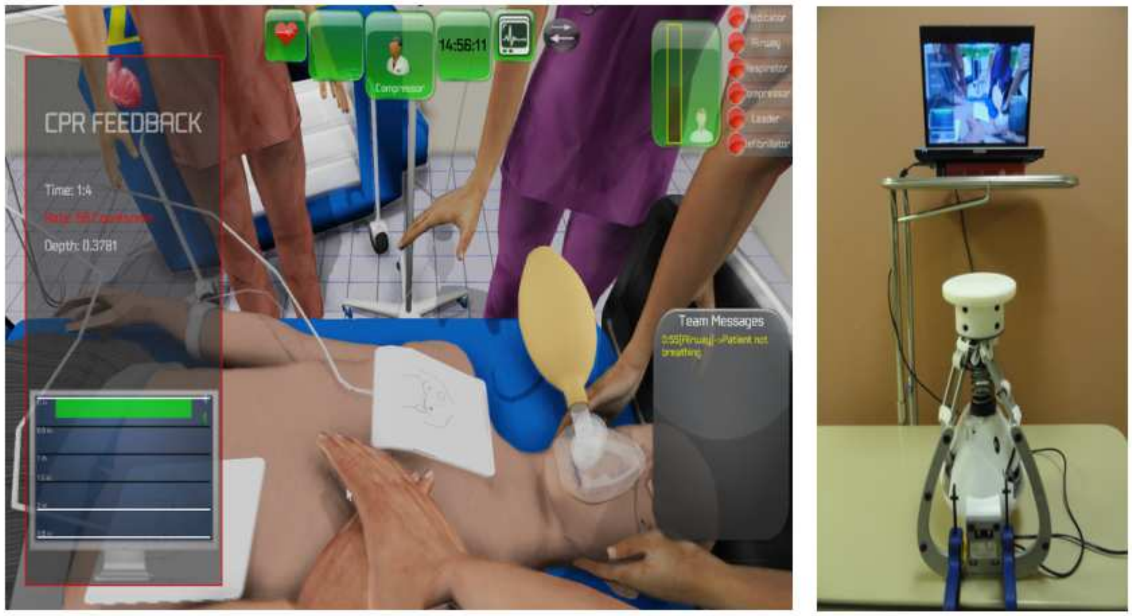

Figure 5.4: Role-based user interfaces in VR-based ACLS training simulator using UDK. (top left to right: leader, respirator, defibrillator; bottom left to right: compressor, medicator, airway manager)

5.1.4 Algorithm Module

The algorithm module consists of rules that are based on the traditional approach of evaluating the performance of a team in a face-to-face environment where human evaluators are used. These evaluators assess the task performance and record task completion times for various tasks during the ACLS procedure. These rules are fired when a task processing is underway or completed (refer to 5.4 for a complete list of tasks and timing rules). Based on these rules, each correctly performed task in a training session is assigned a score, which is then stored into the database and also displayed to the users as the patient-health outcome using the feedback module.

5.1.5 Database Module

The database module is based on *MySQL* database management system and holds all the data generated related to the training sessions such as the user performance details. The system has been designed to strictly maintain the confidentiality of the participants so that their coworkers and/or employers cannot access their performance results. Personal identifiers (i.e. name, date of birth, address, and other identity numbers) are not stored in the database. Instead, each user is assigned a unique randomly generated ID at the time of enrollment.

5.1.6 Feedback Module

The feedback module is responsible for providing visual (including textual) and auditory feedback to the users during and after the training session, based on their performance during the training. The feedback includes various text-based instructions and alerts to assist participants in completing their task on time and also a communication bar that identifies who is speaking during the virtual training session. The real-time feedback is provided after the information is obtained through the *algorithm* module and immediately dispatched to the visual interface. This module retrieves the information from the database module, and displays the feedback summary to the user through the visual as well as the auditory interface.

Figure 5.2 also shows the information flow from one module to another in the system. The haptic feedback is used by a locally stationed user is performing the

CPR on the haptic device. When a participant starts performing CPR, it triggers the CPR animation sequence in the CVE, which is visible to all the participants who are currently playing other roles in the ACLS training. In addition to activating the animation sequences, the system also provides visual cues and instructions on what actions for the participant(s) are next, such as delivering medications to the patients, putting oxygen bags, etc.

5.1.7 Development tools and Implementation

Summary of the various hardware and software tools that were used for the development and deployment of the simulator are listed below.

Hardware Table 5.1 shows the hardware components that were used during the development of the VR-based ACLS training simulator. It also lists the devices that were used during the experiment.

Software Table 5.2 lists various software components and tools that were used during the development of the VR-based ACLS training simulator.

Implementation Cost The cost of setting up ACLS training using VR-based simulator is shown in Table 5.3. The software used for the development of the simulator are free, and the simulator is free to use as well.

5.2 Experimental Design and Setup

The study was approved by the Institutional Review Board (IRB) board of Arizona State University (ASU) and Banner Health, Phoenix, Arizona. IRB approval

Table 5.1: Hardware required for the development and the experiment.

Item	**Quantity**	**Description**
Development		
Desktop Computers	2	Processor: Intel Core2Duo 2.6 GHz, RAM: 4 GB, Graphics: Nvidia 9500GT
Training		
Laptops (for users)	6	HP, Processor: Intel Core2Duo, 2.26 GHz, RAM: 2 GB
Server (Desktop)	1	Assembled, Processor: Intel Core2Duo 2.6 GHz, RAM: 2 GB
Haptic Devices	2	Novint Falcon
Network-switch	1	8 ports for Ethernet cables
Ethernet cables	7	CAT6 Ethernet cables
Headsets	6	Headsets with microphone

Table 5.2: Software tools required for the development and the experiment.

Item	**Description**
Operating system	Windows 7
Gaming engine	Unreal Development Kit (UDK)
Programming languages	Unreal Script, C/C++
Visual objects/animations development	Autodesk Maya, Adobe Flash
APIs	
Voice communication module	TeamSpeak API
Haptic module	Haptic Device Abstraction Layer (HDAL) Library
Database module	cSQL Connector API

letter from ASU and Banner Health are given in Appendix II. The experiment was conducted at Banner Health Simulation Education and Training (SimET) Center, Phoenix, Arizona. We enrolled one hundred fifty six ACLS certified participants from Banner Health, Arizona forming twenty six teams. Each participant was randomly assigned to one of the six ACLS roles: compressor, medicator, defibrillator, airway manager, respirator, and leader. Each role is associated with performing a specific set of tasks. Though the AHA guidelines do not specify names for each role, we assigned the roles oriented names to the avatars designed in the ACLS CVE.

Table 5.3: Cost of setting up VR ACLS training [development cost not included]

Item	**Quantity**	**Cost per unit (in USD)**	**Total cost**
Laptops (for users)	6	1100.00	6600.00
Server (Desktop)	1	700.00	700.00
Haptic Devices	2	215.00	430.00
Network-switch	1	27.00	27.00
Ethernet cables	7	6.00	42.00
Headsets	6	15	90.00
		Total	7889.00

Each team was randomly assigned into one of the three treatment groups - control, persuasive, or minimally persuasive. The teams in the control group were provided with traditional manikin-based training, whereas the ones in other two groups were provided with trainings on our virtual reality based simulator. The teams in the persuasive group were provided with visual aids such as communication bar, instructions, task completion messages, and alerts that are available for all team-members as well as the ones that are specific to each role during the VR-based training, whereas the teams in the minimally persuasive group were provided with only text-based task completion messages for each role. Alerts and instructions were not provided to the teams in the minimally persuasive group.

Each team was ideally set to have six members playing different roles. Variations in the team sizes occurred due to unanticipated cancellations and no-shows from participants. This resulted in three teams with five members and two teams with less than five members. This is similar to situations that are often encountered in real life hospital scenarios. In-hospital resuscitations efforts by teams having fewer than six clinicians occur frequently. To guarantee the proper functioning of the virtual reality platform, teams with less than five members were not included in the study. In case of teams with five members, medicator and defibrillator roles were assigned to one person from a team. Thus, eight teams were distributed across the three treatment groups. The different phases of the experiment are shown in Figure 5.5.

We now describe the different phases of the experiment.

5.2.1 Initial survey

In this phase, the participants signed the consent form and filled out an initial survey, which was designed to capture participant's demographic information, prior experience with in-hospital resuscitation, years of training in CPR and ACLS, self-assessed proficiency in each and prior exposure to computer games. This demographic information was collected for future study on the retention of learned skills.

5.2.2 Pre-test phase

Each team's ACLS skills were tested prior to providing any kind of training, which served as the baseline measure. The teams were tested for two ACLS scenarios, V-Fib

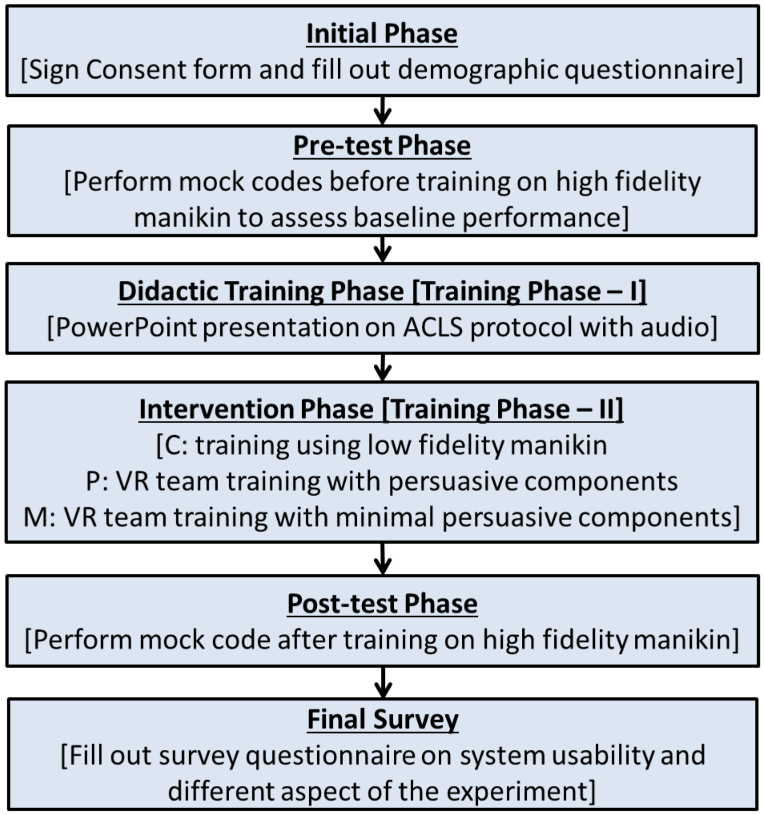

Figure 5.5: Different phases of the study: (C: control; P: Persuasive; M: Minimally Persuasive).

and PEA, on a high-fidelity manikin in order to assess their baseline performance as evaluated by two expert ACLS trainers. These served as the two variations of tasks that ACLS teams performed. The evaluators were blinded to the group formation. The order of the scenarios was randomly chosen. Each mock-code lasted for approximately five minutes or whenever the team had completed the appropriate resolution point for the scenarios: third shock in case of VFib/VTach and the administered drug is Narcan for toxicity in case of PEA. For each team, the evaluators recorded the time for each task in an electronic checklist.

5.2.3 Didactic training phase

Teams from all three treatment groups were provided with a twenty five (25) minute didactic lecture designed by expert ACLS trainers and delivered through an automated presentation with pre-recorded voice support. This lecture was the first part of the training during this experiment and was common to all teams. It provided the participants a refresher on the key points of the ACLS guidelines that each participant was originally exposed to and tested on during their previous certification. The content covered included responsibilities for each role, current guidelines for basic life support (BLS) and ACLS, including arrhythmia dependent differences in the ACLS algorithm, delivery of medications, the essentials of team work and communication.

5.2.4 Intervention phase I: Control vs. Virtual Reality

In this phase, the treatment groups were provided with hands-on training. The training intervention varied across different treatment groups. In this phase, the teams in the control group were provided with traditional face-to-face training using low fidelity manikin facilitated by a trainer in the same room. The participants from the control group practiced the airway, respirator, compressor and defibrillator roles for at least 2 minutes per role. The airway role is responsible for opening airway and inserting oral airway; the respirator role for giving two breaths (ventilation) over one second each; the compressor role for managing proper compressions rate of 100 per minute maintaining 30:2 compression to ventilation ratio, and maintaining proper depth and recoil; and the defibrillator role focused on applying patches on the manikin, using an automated external defibrillator (AED or defibrillator in common) device, analyzing the rhythm and delivering shock appropriately.

The other two groups received training sessions in a virtual reality environment an environment that they had no prior exposure in. Therefore, each team underwent a twenty minute guided single-user tutorial to familiarize with the new user interface. Members also watched a video that introduced them to their specific roles. Two separate rooms were allocated to spread the team members across different locations as would be the case when training remotely through a VR platform. Four of the participant roles medicator, defibrillator, respirator, and compressor were located in one of the rooms while the remaining two roles airway manager and leader were located in a separate room. This was done to provide a sense of perceived virtual environment to the participants while undergoing ACLS training through CVE. None of the users were able to see the screens of other users. However, they were able to communicate with each other using headsets and the audio application integrated into the simulator.

The persuasive group was provided with real-time feedback components (confirmation of recently performed tasks, and cues for next task to be performed) as mentioned in the System Design section. The treatment group designated as minimally persuasive used CVE integrated with certain assistive features such as help menu that were also included for the persuasive treatment group. Participants in both persuasive and minimally persuasive groups were trained individually on how to perform various ACLS related tasks (corresponding to their respective groups) in the virtual reality simulator. Each participant was trained individually for twenty minutes. Technical support was provided to all VR participants whenever there was any unforeseen difficulty using the simulator.

The teams in the persuasive and the minimally persuasive groups were provided with team ACLS trainings through a five-minute virtual reality mock code. The participants were required to login from different systems simultaneously and perform the tasks in a coordinated manner to save a virtual patient. No technical support was provided during this phase. This session typically lasted for thirty minutes. Each team was provided with randomly selected scenarios with different patient histories and one of two arrhythmias, V-fib or PEA. Modeling a comprehensive scenario representing all the large number of factors that could cause PEA is difficult, hence we modeled the PEA task based on only one contributing factor drug overdose. However, the teams were unaware of this.

5.2.5 Post-test phase

A post-test trial that was similar to the pre-test in the design was performed immediately after the completion of the *intervention phase*. In this phase, all the teams were tested on the high fidelity manikins in front of human evaluators. They were provided with randomly selected ACLS scenarios (either PEA or VFib/VTach). The patient information for the scenarios in the post-test was changed from the pre-test. Two evaluators were present to evaluate the performances of the teams during the test sessions.

5.2.6 Intervention phase - II: VR training with and without persuasive messages

We also performed an experiment to investigate the importance of persuasive messages during VR training. We created a second VR group, which will be termed as minimally persuasive, but we limited the various feedback components to study how the participants react with lesser feedback during the training.

The only kind of messages that we provided to minimally persuasive group was task-completion messages. A user would get notified only by the completion message for the task performed by the same user. S/he would not be able to get such completion messages for the task performed by other users. We also removed persuasive messages, such as “give medication”, “charge to 150 joules” and so on, that would help users to remind about the next task to be performed in order to save the virtual patient. In addition to the messages, the users in minimally persuasive group could not see the communication-bar, which was shown in the HUD to show who was speaking during the VR training. All other visual and voice/auditory components were identical to that was provided to the persuasive group.

During the time of enrollment, we randomly selected 48 participants and formed eight teams for the minimally persuasive group. They went through the same study phases as that of control and persuasive groups. The results of their performance in different phases of the study are explained below.

5.2.7 Final survey

In the final survey, the participants were asked to answer the questionnaires regarding the training experience. The questionnaire was a means of objective data collection that would be used in future studies. The experiment session ended after the participants submitted their answers to the final survey questions. The test sessions (pre and post) were also video recorded, which enabled us to verify that the times noted by the evaluators were accurate, by manually calculating each teams time from the recorded video sessions. With the recorded sessions, we were also able to fill in time values for teams that were missing in the evaluators checklist.

5.3 Scoring metric

ACLS experts were used as evaluators for the participants and used an assessment tool to evaluate the teams. The assessment tool, an electronic checklist, was developed and validated internally by a team of expert ACLS trainers within Banner Health. It was built in MS Excel®and includes items deemed critical for the assessment of team performance by human observers. These items were primarily tasks that correspond to AHA guidelines for ACLS. Due to the intense cognitive load placed upon evaluators observing teams with multiple members performing task in series and parallel, efforts were made to minimize the complexity of this tools interface. Therefore, simple checklist having mouse-activated buttons that could easily record time stamps was used. This checklist was then provided to the researchers, who utilized the instrument to store observed actions. Efforts were made to increase the objectivity of assessments. To this end, video recording of the training session was also used to tally evaluators recorded observations with the events recorded on video. In case of any inconsistencies, it was reported to the evaluators and appropriate measures were taken to understand and resolve the conflict. A scoring metric was then created based on the teams adherence to the ACLS guidelines created by AHA. According to these guidelines, each task must be completed within a specified time frame. Since the guidelines do not provide exact times required for performing various ACLS tasks, we used the expert opinions of ACLS trainers to determine the acceptable times required to complete each task in the ACLS test. The scoring metric and the tasks used are listed in Table 5.4. The top level tasks such as medication and defibrillation were complex tasks composed of sub-tasks such as choosing identifying correct levels of energy while delivering shock for defibrillation, choosing correct medications, and ordering the correct dosage for the medication. In order to get a full score on the main level task, a team needed to perform all the sub-tasks for the main task correctly.

After developing the scoring metric, the next step was to assign appropriate weights to each task for different scenarios so that correctly completing a task of higher importance would award a team higher point compared to correctly performing a lower weight task. The metric consisted of nine different tasks for VFib/VTach cases and six different tasks for PEA cases. The study utilized ten ACLS expert trainers to rate the tasks on a nominal scale of 1-5, 1 being the least priority tasks

Table 5.4: Tasks used in scoring metric for quantitative evaluation of the simulator

Task Id	**Tasks**	**AHA Guideline**	**Time threshold in seconds**
T1	Time of Pulseless Recognition:	As soon as possible	T1 $\leq$ 20
T2	Time CPR/BLS Initiated:	within 10 seconds of pulseless recognition	T2 - T1 $\leq$ 10
T3	Initial Rhythm Recognized:	within 60 seconds of code cart arrival	T3 $\leq$ 60
T4	Time of Initial Defibrillation:	within 15 seconds of rhythm recognition	T4 - T3 $\leq$ 15
T5	Time of 1st Drug:	within 3 minutes	T5 $\leq$ 180
T6	Time of 2nd Defibrillation:	within 2 minutes of first defib	105 $\leq$ T6 - T4 $\leq$ 135
T7	Time of 2nd Drug:	within 2 minutes of first drug	T7 - T5 $\leq$ 120
T8	Time of 3rd Defibrillation:	within 2 minutes of second defib	105 $\leq$ T8 - T6 $\leq$ 135
T9	Time of 3rd Drug:	within 2 minutes of second drug	T9 - T7 $\leq$ 120

Table 5.5: Tasks list and priorities according to 10 ACLS experts (1- lowest, 5 highest) (p PEA, v VFib/VTach)

Description	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**E9**	**E10**	**Avg**	**Weight**
Time of pulseless recognition (p,v)	5	5	4	3	3	4	5	5	5	2	4.1	0.11
Time of CPR/BLS initiation (p,v)	5	4	4	5	3	5	5	5	4	4	4.4	0.12
Time of initial rhythm recognition (p,v)	5	4	4	4	3	4	5	4	4	4	4.1	0.11
Time of initial defibrillation (v)	5	4	4	4	4	5	5	5	5	5	4.6	0.12
Time of first drug (p,v)	4	3	4	5	4	4	4	3	3	4	3.8	0.10
Time of second defibrillation (v)	4	3	4	4	4	3	4	3	4	5	3.8	0.10
Time of second drug (p,v)	4	3	4	5	4	4	4	3	3	4	3.8	0.10
Time of third defibrillation (v)	4	3	4	4	4	2	4	3	4	5	3.7	0.10

Description	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	Avg	Weight
Time of third drug (p,v)	4	3	3	5	4	3	4	3	3	4	3.6	0.1
											Total	36.4

and 5 being the highest priority tasks. The ACLS experts provided the ratings based on the AHA guidelines on the ACLS procedure. The various tasks (first column) and their evaluator ratings are shown in Table 5.5. The first row represents the 10 different raters (E1 to E10). The weights provided by the experts for all tasks were found to have very similar scores with range varying from 0.100 to 0.128 and mean of 0.111 $\pm$ 0.009. Therefore, we assigned equal weights to all the tasks performed during the ACLS training sequence. In Table 5.5, there are six tasks for PEA and nine tasks for VFib/VTach selected for performance evaluation (marked by "p" and "v") in terms of percentage score. Since all tasks have equal weights, each correctly performed task in a PEA scenario has a score of 16.6 points (total score, 100, divided by the number of tasks in PEA, 6); and each correctly performed task in a VFib/VTach scenario equals a total score of 11 points (total score, 100, divided by the number of tasks in VFib/VTach, i.e., 9).

Chapter 6

RESULTS AND ANALYSIS

We used IBM SPSS Statistics version 19 (IBM, 2013) to analyze the data. The teams were first tested in a mock-code training scenario using high fidelity manikins in order to obtain their baseline performance before the training. The treatments groups were randomly distributed across two ACLS task scenarios - PEA and VFib/VTach.

6.1 Initial survey

Total of one hundred and forty eight (148) participants were enrolled into the study out of which only ten (10) were males. The average experience of the participants on ACLS in terms of years was 7.0 $\pm$ 6.4 (range: 0 - 38). The distribution of the experience across the groups were: 7.5 $\pm$ 7.4 (range: 1 - 30) years for control group; 7.1 $\pm$ 5 (range: 1 - 20) years for minimally persuasive group; and 6.6 $\pm$ 6.7 (range: 0.5 - 38) years for persuasive group. Similarly, the average height of the participants was 65.48 $\pm$ 3.3inches (range: 59 - 76) (control: 66.4 $\pm$ 3.3 (range: 61 - 76) inches; minimally persuasive: 65.2 $\pm$ 3 (range: 60 - 72) inches; persuasive: 64.8 $\pm$ 3.5 (range: 59 - 74) inches), and the average weight of the participants was 159.4 $\pm$ 39.9 lbs. (control: 159 $\pm$ 30 (range: 116 - 220) lbs. ; minimally persuasive: 166 $\pm$ 44.4 (range: 105 - 300) lbs.; persuasive: 153.9 $\pm$ 43.1 (range: 104 - 280) lbs.).

6.2 Pre-test phase

The pre-test performance of all three groups is shown in Table 6.1. One of the major objectives of this study is to assess the performance of the ACLS CVE for training purposes. Adherence to the guidelines provided by the AHA when performing various tasks in the entire ACLS procedure is an important criterion in determining the level of team performance. The performance of the teams during the pre-test indicated that the teams were highly non-compliant with AHA guidelines for the ACLS procedure. After pre-test, we found that only 39.4 % of total 360 tasks (control 39.1%, 47 out of 120 tasks; persuasive 35.8%, 43 out of 120 tasks; minimally persuasive 43.3%, 52 out of 120 tasks) were performed correctly.

We performed Shapiro-Wilk test to assess normality for our data. The results showed that data violated the normality assumption. Mann-Whitney U test, which does not require data to be normally distributed, was performed to understand the difference in pre-test performance between two groups at a time. We compared the pre-test performance of the three treatment groups which did not show any statistically significant difference (control vs. persuasive: $P = .78$ for PEA and $P = .55$ for VFib/VTach; control vs. minimally persuasive: $P = .55$ for PEA and $P = .51$ for VFib/VTach; persuasive vs. minimally persuasive: $P = .38$ for PEA and $P = .36$ for VFib/VTach).

Table 6.1: Performance of Control, Persuasive and Minimally Persuasive groups in pre-test

Study group	PEA Score Mean (SD)	VF/VT Score Mean (SD)
Control	37.3 (17.1)	38.5 (15.4)
Persuasive	35.2 (16.4)	35.7 (20.15)
Minimally Persuasive	41.5 (21.7)	44 (13.14)

6.3 Intervention phase - performance during VR-based training

During this phase, persuasive and minimally persuasive groups were provided with VR-based training. Teams in the persuasive group were provided with feedback (confirmation) for recently performed tasks and cues for upcoming tasks during training, whereas teams in the minimally persuasive group were provided with feedback only. Looking at the performance of persuasive and minimally persuasive groups during VR-based training, the average performance of the persuasive group was better than that of the teams in the minimally persuasive group. Figure 6.1 shows the performance of the two groups during VR-based training sessions. This could be due to the more effectiveness of persuasive elements of the VR-based ACLS simulator.

Timely interventions that were presented to persuasive group might have helped to improve their performance. We limited the training duration to thirty minutes for the VR group, which may not have been sufficient to become accustomed to the virtual environment while simultaneously learning the ACLS skills. Future studies are

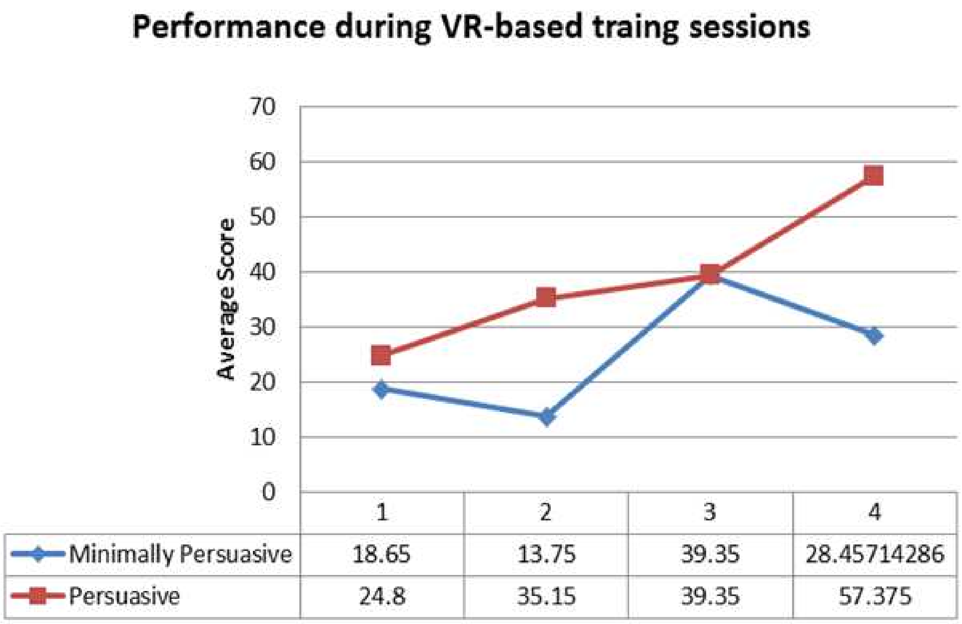

Figure 6.1: Performance of persuasive and minimally persuasive groups during VR-based training sessions.

required to understand the importance of persuasive messages by including a longer training duration.

6.4 Post-test phase

After the pre-test was performed, didactic training as well as hands-on skills training (explained in Intervention Phase) was provided to the participants, followed by the post-test. Their performance was evaluated after the post-test. The average score of each group during post-test is shown in Table 6.2. We performed the Mann-Whitney U Test to understand the difference between the performances of the control and persuasive groups. We did not find the differences in the performance to be statistically

Table 6.2: Performance of Control, Persuasive and Minimally Persuasive groups in post-test

Study group	PEA Score Mean (SD)	VF/VT Score Mean (SD)
Control	66.4 (17.7)	68.7 (11.4)
Persuasive	60.2 (15.2)	55 (16.6)
Minimally Persuasive	47.7 (16.4)	49.5 (21.2)

significant (P = .37 for PEA; P = .10 for VFib/VTach). Similarly, the difference in the performances between the persuasive and minimally persuasive groups (P = .10 for PEA; P = .63 for VFib/VTach) was also found to be statistically insignificant. However, the difference in the performances between the control and minimally persuasive groups was found to be statistically significant (P = .05 for PEA; P = .02 for VFib/VTach).

The results showed that the performance of the persuasive group and the control groups were at-par whereas the performance of the minimally persuasive group was par below that of the control group. After under-going thirty minute training session, we also noticed that the adherence to the AHA guidelines increased on an average to 58.3%, n = 360 360 (control 68.3%, 82 out of 120 tasks; persuasive 57.5%, 69 out of 120 tasks; minimally persuasive 49.1%, 59 out of 120 tasks). Figure 6.2 presents the performance of the three study groups in pre and post-test sessions.

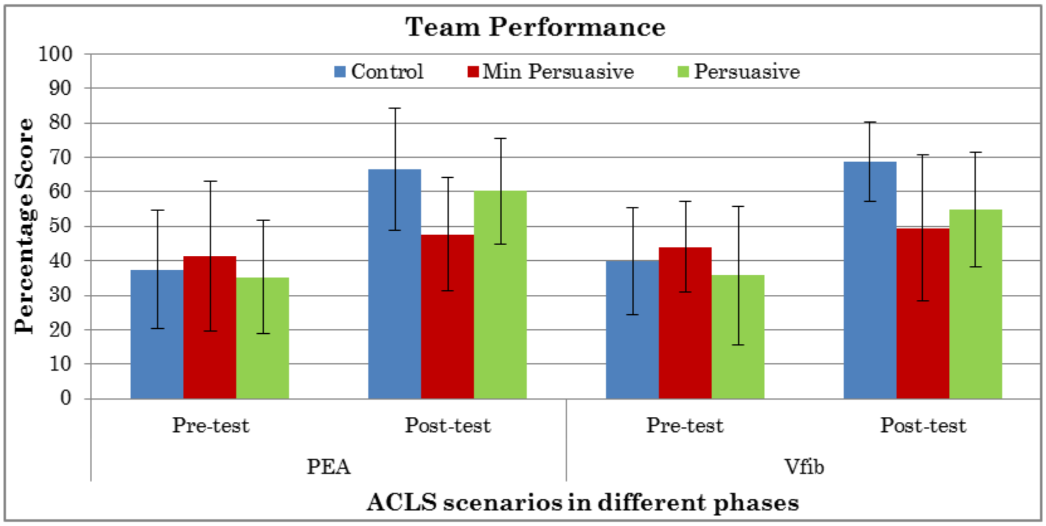

Figure 6.2: Performances of three different treatment groups in VFib/Vtach and PEA scenarios.

Finally, we used the Wilcoxon signed rank test to compare the pre-post performance of teams within each treatment group. All three groups were found to have improved their average performance during the post-test sessions in comparison to the pre-test sessions. The performance of the control group improved significantly during the post-test sessions compared to the pre-test sessions (P = .02 for PEA; P = .01 for VFib/VTach). The performance improvement of the persuasive group was also statistically significant (P = .02 for PEA, P = .048 for VFib/VTach). However, the performance improvement of the minimally persuasive group was not statistically significant for both scenarios (P = .45 for PEA, P = .46 for VFib/VTach).

Table 6.3: Comparison of performance of Persuasive (P), Minimally Persuasive (M), and Control (C) groups.

Comparison groups	Test (Pre/ Post)	Statistical significance in Difference (PEA)	Statistical significance in Difference (VFib/VTach)
C vs. P (b)	Pre	No difference (P = .78)	No difference (P=.55)
C vs. M (b)	Pre	No difference (P = .55)	No difference (P=.51)
P vs. M (b)	Pre	No difference (P = .38)	No difference (P=.36)
C vs. P (b)	Post	No difference (P=.37)	No difference (P=.10)
C vs. M (b)	Post	**Significant difference (P=.05)**	**Significant difference(P=.02)**
P vs. M (b)	Post	No difference (P=.10)	No difference (P=.63)
C (pre vs. post) (w)		**Significant difference (P=.02)**	**Significant difference (P=.01)**

Comparison groups	Test (Pre/ Post)	Statistical significance in Difference (PEA)	Statistical significance in Difference (VFib/VTach)
P (pre vs. post) (w)		**Significant difference (P=.02)**	**Significant difference(P= .05)**
M (pre vs. post) (w)		No difference (P=.45)	No difference (P=.45)

6.5 CPR Performance

Cardiopulmonary Resuscitation or CPR is the most critical part of the ACLS procedure. There are various tasks that need to be performed properly in order to perform the CPR correctly. Each CPR cycle consists of five CPR sessions that includes 30 compressions and 2 ventilations. Each compression should be minimum of two inches deep. Once the desired depth is reached, the chest of the patient should be recoiled back to the original position. The compressions (and corresponding recoils) should be performed by maintaining a rate of 100 compressions per minute. Within each CPR session, after 30 compressions the compressor should pause for two seconds (approximately) for proper ventilation. The compressor must switch his/her role to another team member so that fatigue of the compressor does not negatively affect the CPR procedure. However, throughout the entire ACLS procedure, no pause of compressions should last more than 10 seconds. The evaluators observed and subjectively evaluated the CPR performance of each team during the test sessions (pre and post). The major criteria for the evaluation included a) rate, depth, and recoil of the CPR; b) compression to breath (ventilation) ratio; c) compressor changed in each CPR cycle; and d) time without CPR compression (which should not be more than 10 seconds). During evaluation, the evaluators assigned "PASS" grade for each CPR cycle when all the criteria were met and "FAIL" if not. The evaluation of CPR performances of VR and control groups is shown in Table reftable:resCPR. The table presents the number of correctly performed CPR cycles based on the evaluators evaluation. The last column is divided into two sub columns, which reports the number of CPR sessions (total and correctly performed) by the study groups. It is to be noted that the expected number of CPR cycles was 24 for each group (3 CPR cycles in each ACLS scenarios for 8 groups).

Table 6.4 shows the performance levels of the teams in all three groups based on the experts evaluation. During pre-test sessions, all three groups were not able to perform any of the CPR sessions correctly during PEA; however, in case of VT, the teams in the persuasive group were able to perform 2 out of 18 CPR cycles correctly, the teams in the control group were able to perform 2 out of 19 CPR cycles correctly, whereas the teams in the minimally persuasive group were not able to perform any correct CPR cycles.

During the post-test PEA sessions, the teams in the control and the persuasive groups performed 21 CPR cycles and the minimally persuasive group performed 19

Table 6.4: CPR performances of three different treatment groups in VFib/Vtach and PEA scenarios.

Test session	CPR sessions performed	Evaluator	Number of CPR sessions		
			Persuasive	Control	Minimally Persuasive
Pre PEA	Total		18	20	19
	Correct	1	0	0	0
		2	0	0	0
Pre VT	Total		18	19	18
	Correct	1	2	2	0
		2	2	2	0
Post PEA	Total		21	21	19
	Correct	1	11	11	4
		2	9	10	4
Post VT	Total		18	20	20
	Correct	1	9	10	6
		2	10	11	6

CPR cycles. The teams in the persuasive group performed an average of 10 correct CPR cycles whereas the control group performed an average of 10.5 correct CPR cycles. However, the minimally persuasive group was able to perform an average of only 4 CPR cycles in the post PEA sessions. For post VT sessions, the persuasive group performed an average of 9.5 correct CPR cycles (out of 18), the control group performed an average of 10.5 correct CPR cycles (out of 20), whereas, the minimally persuasive group was able to perform only 6 CPR cycles (out of 20).

6.6 Final survey

Forty eight participants who used the VR-based ACLS training simulator with persuasive messages were provided with a questionnaire focusing on various perceived measures during the training using VR simulator. These measures were developed and validated by other researchers, and we modified them to meet our requirement (references to the studies are shown in tables 6.6, 6.7, 6.8). The perceived measures were categorized into various sub-categories, and each category consisted of various questions. Each question was answered on 1(strongly disagree) to 5 (strongly agree) likert scale. The summary of the results of the perceived measures are shown in Table 6.5. The second column list the measures; the third column is the average rating for each measure, and the forth column presents the number of participants who gave rating of 3 or more (neutral to completely agree) for corresponding measures.

The perceived measures can be categorized into three generic groups: Usability, Complexity, and Satisfaction.

6.6.1 Usability

The survey question categories that address the questions related to the usability of the simulator and its components are grouped together in this group. The categories in this group are: location awareness, task awareness, system usability (visual), and system usability (haptics). ***Location awareness*** consists of the questions relating to whether or not the participants were conscious of the virtual objects on the

Table 6.5: Perceived measures, for the evaluation of VR-based ACLS training simulator

Code	**Perceived measures**	**Average rating**	**No. of participants who gave rating of 3 or more**
C	Perceived task complexity	2.99	25
IO	Information Overload	2.60	18
E	Ease of Use	3.38	33
LA	Location Awareness	3.72	41
M	Motivation	4.44	48
PS	Process satisfaction	3.63	42
SP	System Usability (Other)	3.08	11
TA	Task Awareness	3.42	37
U	System Usability (Visual)	3.32	31
G	Group Outcome Perception	4.14	46
IU	Intention to Use	3.29	33

scene while performing the tasks. The average score for location awareness is 3.53 and more than 41 participants gave the rating more than or equal to 3, which is an average rating. Based on the ratings, it can be inferred that most of the participants thought that they were aware of the objects required to perform virtual tasks and were also able to locate the objects in the virtual ACLS room. On the other hand, ***task awareness*** consists of questions that focus on whether the various cues (textual, auditory, and visual) in the environment were helpful to the participants to perform the tasks. Thirty seven participants gave the rating of 3 or more, with the average score of 3.36, which means that the system was usually able to convey the information to the user properly in order to perform the required tasks. The third category in this group is ***System usability (visual)***, which focuses on questions regarding overall capabilities (not including haptics) of the system such as whether or not the system incorporated the required features and/or capabilities, and whether or not the information provided by the system was easy to understand and effective. The average rating for this category was 3.24, and 31 participants gave average rating of 3 or more for this category. Although the participants thought that the system was able to incorporate important functionalities and to provide the required information for problem solving, they were not very satisfied with the organization and layout of information on the screen. ***System usability (haptics)***, on the other hand, focuses on whether or not performing CPR on the haptic joystick was easy and comfortable, and provided realistic force feedback. Based on the ratings provided by the participants, we can see that the use of haptic device was not easy and comfortable. However, the participants also indicated said that the force feedback provided by the joystick was similar to that provided by a physical manikin. The average ratings for each of the questions in each category are shown in Table 6.6.

6.6.2 Complexity

Three categories are included in this group: ***perceived task complexity, information overload,*** and ***ease of use***. These categories consist of questions related to complexity and information overload during the virtual training sessions. The questions under ***perceived task complexity*** queried the participants whether the tasks were challenging or not; how mentally demanding the tasks were. The overall rating for this category was 2.99, which is almost the average (not too complex, not too easy) ranking of the tasks. Most of the participants answered that they did not find the training tasks to be complex while performing the ACLS procedure on the simulator; and that the training did not require a lot of thought and problem solving skills while performing the tasks. ***Information overload*** category asked questions relating to whether or not the virtual training sessions was too daunting. The average rating given for this category was 2.57 and 18 out of 48 participants gave the rating of 3 or higher. Based on the feedback of the participants, they were not rushed during the training sessions and were able to perform the required work without any interference caused by information overload. Similarly, participants thought that the

Table 6.6: Questionnaire for usability of the VR-based ACLS training simulator

Statements	**Rating**
Location Awareness (Goel et al., 2011)	
I was aware of the location of objects related to the task.	3.75
I was aware of the objects related to the task.	3.69
Task Awareness (Goel et al., 2011)	
The textual (or verbal) and visual clues in the environment helped me to do the task.	3.40
Information in the environment, such as icons and labels, made it easy to figure out what to do.	3.35
The information given in the environment helped me understand my tasks better and share that knowledge with other team members.	3.52
System usability (visual)	
The information was effective in helping me complete the tasks and scenarios.	3.58
The organization of information on the systems screen was clear.	3.06
The interface of the system was pleasant.	3.35
This system has the functions and capabilities I expect it to have	3.27

Statements	Rating
System usability (haptics)	
Performing CPR on the computer joystick was easy.	2.93
Performing CPR on computer joystick was comfortable.	2.86
The computer joystick gave a reasonable amount of force feedback relative to a physical manikin	3.64

interaction with the simulator was clear and was easy to use (average rating for ***Ease of use*** is 3.38, 33 participants gave 3 or more rating).

6.6.3 Satisfaction

This group focuses on the categories that address motivation, satisfaction, and willingness to adopt the simulator in the future. The first category is ***motivation,*** which consists questions that measure how motivated the participants got to use the simulator. The average rating for this category by the participants was 4.44. According to the participants, the simulator was able to motivate them to perform well while performing the tasks. In addition, they also mentioned that they put a lot of effort into achieving the best possible outcome. The second category is ***intention to use,*** where participants had to answer whether they would use this training simulator in the future. The average rating given by the participants was 3.42, and 33 participants gave the rating of 3 or more. The third category in this group

Table 6.7: Questionnaire for complexity of using the VR-based ACLS training simulator

Statements	Rating
Perceived Task Complexity (Maynard and Hakel, 1997)	
I found the training tasks to be complex	2.66
These training tasks were mentally demanding	2.91
This training required a lot of thought and problem solving	3.04
Information Overload (Moore, 2000)	
I feel busy or rushed during the training session	2.54
I feel that the amount of work I do during training interferes with how well it is done.	2.60
Ease of Use (Venkatesh et al., 2003)	
The training system is easy to use	3.35
It is not easy to become skillful at using the training system (reverse coded)	3.48
Learning to operate the system is easy	3.40
My interaction with the system is clear and understandable.	3.29

Table 6.8: Questionnaire for satisfaction of using VR-based ACLS training simulator

Statements	Rating
Motivation (Maynard and Hakel, 1997)	
I was motivated to perform well on this task.	4.40
This task was interesting to me.	4.38
I put a lot of effort into achieving the best possible outcome	4.54
Intention to use (Malhotra et al., 2004)	
It is likely that I would use this training system	3.04
It is possible that I would use this system to train	3.17
I am unwilling to use this system	3.67
Process satisfaction (Green et al., 1980)	
I would describe the entire training process I just used as efficient.	3.56
I would describe the entire problem solving process I just used as coordinated	3.63
I would describe the entire problem solving process I just used as fair	3.67
I would describe the entire training process I just used as understandable.	3.75
I would describe the entire problem solving process I just used as satisfying	3.52
Group outcome perception (Goel et al., 2011)	
I am satisfied with the teams ability to gather and present relevant information (e.g. check pulse, read patient history, identify cardiac rhythm)	3.60
I am satisfied with the teams ability to follow the ACLS guidelines	4.17

Statements	**Rating**
I was satisfied with all my team members	4.38
I was pleased with the way my team members and I worked together	4.13
I was very satisfied working with the team	4.38
The cooperative work done by my team was of high quality	4.06
The effort exerted by my team during training was excellent	4.35
The final cardiac resuscitation task with my team was outstanding	4.04

is ***process satisfaction***. Various features that describe the training and problem solving process in the simulator are the focus of this group. These features include efficiency, coordination, understandability, and satisfaction. Forty two participants gave the rating of 3 or more with the average rating of 3.63. These ratings suggest that the participants found the training process as well as the problem solving process in the simulator to be efficient, understandable, and overall satisfactory. The fourth and the last category is ***group outcome perception,*** where participants were asked about how they thought of the overall performance of other team members. The average rating for the category was 4.14 (46 participants gave rating of 3 or more). This shows that the simulator was able to provide smooth communication between the team members during the VR training, and because of which, as participants mentioned, that the teams exerted excellent effort to resuscitate the virtual patient.

Chapter 7

DISCUSSION, LIMITATION, AND FUTURE WORK

This study attempts to highlight the issues related to the current approach in conventional ACLS training and to provide a potential solution to address such issues by presenting a VR-based ACLS training simulator. In this chapter we discuss the results and list some of the limitations of the study, as well as some the future possibilities that are opened by this study.

7.1 Discussion

The major focus of this dissertation is to present an alternative approach to provide medical training using the principles of virtual reality for collaborative, time-critical medical procedures such as ACLS. The conventional ACLS training is conducted by forming a group of clinicians in a common physical training room equipped with a manikin, mostly a low-fidelity manikin, and other expensive medical equipment. During the study, we designed and developed a VR-based ACLS training simulator, and also conducted an experiment with real ACLS certified clinicians in order to evaluate the efficacy of the simulator. In addition, we also conducted a study to analyze the effect(s) of the real-time feedback and cues on the performance of the ACLS teams. The theoretical rationale behind the study was the proposed importance of virtual reality and feedback in acquiring knowledge and improving performance. Studies have shown that some pedagogical approaches are better at retaining certain skills. Patel and her colleagues show in a set of empirical studies of medical students in various curricular settings that certain reasoning skills are acquired only when immersed in real world settings (Patel et al., 2009). Virtual reality is as close to real world as possible and it also has an added advantage of being flexible. The task in the VR was based on real world task such that it has ecological validity. Other studies have also shown a positive correlation between the feedback provided and an improvement in performance. Unlike conventional ACLS training, VR-based ACLS training can provide real-time feedback and cues during training. Based on the underlying principles of virtual reality and real-time feedback, our hypothesis were a) to observe similar or better performance in VR-based training compared to that in conventional training, and b) teams provided with proper real-time feedback perform better than the ones without such feedback. In this study we found that:

1. the VR-based ACLS training provided with proper real-time feedback and cues was able to provide training performance comparable to the conventional ACLS training,

2. the performance of the teams (Persuasive group) that were provided with proper feedback and cues during the VR-based training was better in the VR-based training sessions than the teams that were not (Minimally Persuasive group). In addition , the Persuasive group also showed an improved transfer of skills to real ACLS training.

We now discuss various results obtained from this study in the following subsections.

7.1.1 *Degradation of skills in conventional ACLS training*

According to the AHA, ACLS practitioners are required to renew their ACLS certification only once every two years, thus practitioners usually attend an ACLS training only once or twice every two years. And although ACLS is a team-based procedure, the ACLS certification doesnt require the ACLS practitioners to take the test in a team-based scenario. Hence, the communication and coordination skills that are required between the team members during an ACLS code is not tested. Various research studies have shown in the past that skills, be it ACLS or others, degrade over time (Christenson et al., 2007). We had similar observations from the pre-test data in the study. In this study, the average years of experience of the participants was 6.07 ± 4.60 (range: 0 23), but the pre-test data shows that the participants were able to adhere to less than 40 percent of ACLS guidelines. It is interesting to note that the average time of last ACLS training attended by the participants from the date of the experiment was approximately 273 days (or 9 months). This data shows that the ACLS skill of the participants might have degraded significantly over the course of 9 month period.

7.1.2 Importance of frequent training

After the pre-test, the participants were provided with a thirty minutes didactic training session followed by another thirty minutes hands-on training. The two groups, persuasive and minimally persuasive, were provided with respective VR training, whereas, the control group was provided with conventional ACLS training on a low-fidelity manikin. After the training, the teams were tested on a high-fidelity manikin. A noticeable improvement in adherence of ACLS guidelines was seen, which was increased to an average of 58.3%, n = 360 (control 68.3%, 82 out of 120 tasks; persuasive 57.5%, 69 out of 120 tasks; minimally persuasive 49.1%, 59 out of 120 tasks). Compared to the adherence of ACLS guidelines during the pre-test sessions, this was more than a 46% improvement. However, as discussed in section 6.1, we observed that on average the participants were not able to retain the skills after 9 months. Hence, it is very important to provide collaborative ACLS training more frequently than what is presently required.

7.1.3 Conventional ACLS training vs. Virtual Reality ACLS training pros and cons

The major focus of this study is to determine the efficacy of the simulator and to estimate the potential of a VR-based simulator to provide collaborative ACLS training. It is well understood that at present VR-based training cannot replace the conventional training. The conventional training provides various advantages such as face-to-face interaction between the team members, more advanced tools (manikins) to simulate various medical conditions, and human-like feedback (tactile and emotional) to name only a few. The conventional method provides in depth realistic scenarios to the practitioners, which they can practice upon. However, various factors make it unrealistic to conduct such training on a more frequent basis. The key factors are the time and cost involved with the training. On the other hand, VR training can significantly reduce the cost involved with the training, and allows users to login from any physical disparate location and still practice ACLS using the VR simulator collaboratively. It also saves a lot of time in doing so by reducing travel to another physical location. Hence, augmenting the conventional method of ACLS training with VR-based training will be a cost effective method of providing effective ACLS training and sustainment of skill levels without having to increase the number and cost of traditional in-person ACLS training sessions.

7.1.4 Conventional vs. VR ACLS training performance metrics

This study also provides quantitative measures to evaluate the performance of the teams. The metrics were developed incorporating the expertise of ten ACLS trainers. The teams were evaluated in a high-fidelity manikin by two evaluators during the pre and the post training sessions. The evaluation of performance data of the teams shows that all the teams improved their performance after the training, and that the performances of control and persuasive groups were comparable. In addition, the teams in both of these groups improved their performance in the post-test session significantly. And lastly, the CPR performance of these two groups was also similar. On the other hand, we found limited differences (not statistically significant) in performance across minimally persuasive group when compared to the other two groups, and the CPR performance was also not at the level of that of the other two groups. Similar results were provided by Lee and Anderson (2013) that virtual reality provided similar or better training as compared to the conventional training because virtual reality provided users with an interactive multi-modal (graphics, haptics, auditory) environment that allowed users to get fully immersed into the virtual environment.

7.1.5 Real-time feedback and evaluation

In specialized ACLS training using manikins, trainees are presented with a "megacode", which involves an ACLS scenario. The trainees have to work together and resuscitate the patient (manikin), and the entire session is monitored by one or multiple trainers. Once the training session is over, the trainees are taken to a debriefing room where strong and weak executions during the session are discussed in detail. There is no provision of real time feedback during the training session, the feedback is provided to the trainees only during debriefing. Research studies in the past have mentioned that feedback during the training itself aids in learning (Sadler, 1989; Black and Wiliam, 1998). Hence, we incorporated real-time contextual feedback and cues during VR training sessions, which allow performance evaluation even in the absence of the trainers. After the completion of the training session, participants can login to the web-portal where they can track their performance history throughout all their training.

In addition, Mathiu et al. (2000) and Cannon-Bower et al. (2001) presented that shared mental models have positive correlation with performance of the teams and provided insight on the importance of team-based training. Shared mental model, is an extension of the mental model concept, reflects the shared and collective knowledge of a team. SMMs provide mutual expectations, which allow teams to coordinate and make predictions about the behavior and needs of their teammates. In a complex dynamic medical procedure, such as ACLS, there is substantial differentiation in the roles of each team member (nurses, physicians). As a result, some of the knowledge about a patient is shared among team members (e.g., a patients respiratory status); however, much of this knowledge is complementary or distributed across team members. Overlapping knowledge is essential for negotiating common task goals and objectives. The VR-based ACLS training simulator facilitates the team members to communicate with each other, and provides an environment that enables sharing of ACLS knowledge among team members during virtual reality training sessions. As a result of which, they were able to improve their performance during the post-test than compared to the pre-test.

7.1.6 Support evaluators: performance tracking and online report generation

Another feature provided by the VR simulator is the automatic generation of performance reports. The performance report for each team is generated after their training sessions. As we mentioned earlier, the simulator is seamlessly connected to a database server. Each and every task performed on the VR simulator with mouse clicks or haptic joystick movements is stored in the database. Apart from the tasks performed, the simulator is designed to send additional data to the database server - information about the user, the time of the performed task, and the role played by the user. This not only allows the trainees to track their performance, but also allows the trainers to track trainee data and observe their performances and provide support for them on their weaknesses. Since the simulator stores the exact time of a task performed, it can assist trainers to evaluate performance according to ACLS guidelines based on the objective measures. Appendix B shows the screenshots of web pages displaying the automatically generated ACLS performance chart.

7.1.7 Economic evaluation

A collaborative ACLS training session requires mainly a medium to high fidelity manikin, a code-cart, a defibrillator, and an ambu-bag connected to a cylinder containing compressed air. The cost of the major equipment required for conventional collaborative ACLS training is shown in the Table 7.1.

Comparing the cost of setting up a conventional ACLS training vs. a VR ACLS training, we can see that the equipment costs of running a conventional ACLS training is eight (8) times costlier than that of VR ACLS training. It could be argued that cheaper manikins can be used for training purposes, however it has been shown that cheaper models (low, medium-fidelity) manikins are less suitable for collaborative

Table 7.1: Equipment required for conventional training

Item	**Price**
Manikin (with AHA ACLS scenarios)	60,000.00
Code Cart	2000.00
Defibrillator	1500.00
Ambu-bag/compressed air	100.00
Total	**63,600.00**

ACLS training (Rodgers et al., 2009). Comparatively, a VR-based ACLS simulator costs less than eight thousand US dollars (see Section 5.1.7) and is capable of providing effective team-training.

Although the cost of the VR ACLS training is much lower than that of the conventional ACLS training, we do not suggest replacing conventional training by VR-based training. Manikins still are the best training tools that provide realistic touch and feel during medical training. However, because of their higher cost it is not possible for everyone to use such manikins for more frequent collaborative ACLS training. This limits the number of practice sessions the medical practitioners can undergo, which is the main cause of degradation of their ACLS skills. Since the VR-based ACLS simulator is significantly less expensive than a high-fidelity manikin, it can easily be adapted by most of the health-care provider organizations to provide in-house

ACLS training more frequently, thus keeping up their ACLS skills between required recertification intervals.

7.2 Limitations

The simulator that we designed and evaluated is in its primitive form. Although the simulator works as desired within the scope of this study, in order for it to be widely adapted it will need to address the following limitations that were present in this research.

7.2.1 Limited sample size

One of the limitations of this study is that there were only eight teams in each treatment group. The study required extensive evaluation of the VR-based simulator by enrolling ACLS experts. Because of their conflicting or busy schedules, as well as the increasing cost involved to conduct the experiment, we were able to collect a less than planned number of ACLS participants (156) for this experiment. Out of these, eight participants did not show-up for the study. The lack of availability of immediate replacements for these absentee participants resulted in the reduction in our sample size to 148. The cost of recruiting the participants was another factor to the limited sample size. Each training session lasted for approximately 4 hours. Each participant was compensated by the rate of USD 75 per hour, which brought the total amount of compensation to almost USD 45,000. Since the cost of forming a single team was USD 1,800, it was not feasible to include more teams into the study. However, future studies conducted over a larger sample size will be required to provide a final validation and confirmation of these results.

7.2.2 Lack of quantitative measures as well as no evaluation of communication

This study did not focus on quantitative analysis of various ACLS measures and the qualitative analysis of communication among the team members. The quantitative measures include variables such as compression rate, depth, and recoil. With the given scenario for the evaluators during the test sessions, the chest compressions were evaluated by observing the participants actions. In the future studies, use of new high-fidelity manikin with functionality to measure such quantitative factors more accurately (manikins developed during the later phases of this experiment) would help to generate better evaluation reports. Shetty et al. (2009) reported that leadership flexibility and situational changes that were required in case of deviation from ACLS protocol were more important factors rather than the following the protocol itself. Although the analysis of communication between the team members is out of scope of the study, video observation done by us shows the similar pattern that Shetty and colleagues reported, i.e., the teams with better leader (in terms of communication) tend to perform better during the test sessions. The analysis of the communication between the team members during ACLS code could open various research possibilities in the future.

7.2.3 Limited ACLS scenarios and use of simulated remote locations

The VR ACLS simulator was designed to include 3 different ACLS scenarios: Ventricular Fibrillation, Ventricular Tachycardia, and Pulseless Electric Activity/Asystole. For Pulseless Electric Activity, the participants needed to identify the cause for lack of pulse, and it was confined to "toxins". Furthermore, this initial evaluation was a controlled study performed in the presence of instructors, hence it was not feasible to conduct the experiment at different geographical locations simultaneously. For this reason, we setup an experiment space in Banner Good Samaritan Hospital to simulate "remote" team-training sessions. The participants were placed in different rooms, so that they could not see or listen to what other participants were doing or saying.

Despite the limitations, the VR-based ACLS simulator developed is a novel approach of providing ACLS training. Our study shows that VR-based ACLS training can be an effective supplement to the conventional method of training. It demonstrates how various training systems that integrate multisensory devices into a virtual, collaborative environment for time critical procedures could be designed and effectively utilized. This opens various future opportunities that can be the future of medical education and training. A few such opportunities are discussed in the following section.

7.3 Future research opportunities

7.3.1 Development of VR training simulators for other collaborative medical procedures

This major objective of this dissertation was the design, development, and validation of a collaborative VR-based training simulator for ACLS procedure. The algorithm used, the specific roles, and the setup of haptic device for CPR were unique to the ACLS procedure. But, we foresee a vast array of systems that can be developed based on similar design concepts and architecture. The concept is generalizable to any procedure, individual as well as team-based, that has a fixed set of rules and/or guidelines. Examples of team-based procedures include Advanced Trauma Life Support (ATLS) and Pediatric Advanced Life Support (PALS) for which similar training simulators could also be developed.

The same design and implementation concept can be ported to mobile devices as we have shown in our CVC training simulator (Khanal et al., 2013). The proof of concept of using haptic device (sensor) can also be generalized to use other sensors such as accelerometer, thermometer, and pulse oximeter. At present, the use of a haptic device is restricted on mobile devices since the haptic devices themselves are not portable enough to carry around and use anywhere. However, in the future the users will be able to seamlessly participate in collaborative learning experiences using their handheld devices.

7.3.2 Training patients and general public

One very significant contribution of this research is the integration of a haptic joystick into a virtual world to provide time-critical medical training such as CPR. In this research, we focused on providing training to healthcare practitioners only. CPR is the most important procedure that can save life if performed properly. According to AHA (Heart.org, 2013), nearly 383,000 out-of-hospital sudden cardiac arrests occur annually, and 88 percent of those occur at home. Hence, it is very important to train the general public in CPR measures. To achieve these goals, discussions are presently underway for conducting a study on CPR training for patients/public.

7.3.3 Individual asynchronous training

So far, we have discussed about synchronous training between the team-members. The virtual reality simulator facilitates multiple users to get team-based ACLS training from disparate locations. In a team-based procedure, all tasks require individual training, however, the tasks must be performed as a coordinated effort. For example, in ACLS, CPR must be initiated when a patient is not breathing. So, the airway manager should inform the team that the patient is not breathing, and after receiving that information, the compressor should immediately start CPR. For this reason, communication between the team members is very important to perform a collaborative procedure (Shetty et al., 2009) for which team-based training is required.

In the VR-based ACLS training simulator, the team members must be logged in to the system simultaneously. However, this simulator can also be used for asynchronous training, i.e., without the members being present in the virtual environment at the same time. Instead of multiple users, we can use computer-agents or bots to perform various roles during a virtual training session. A user can choose a role to practice and then all other roles can be played by the computer-agents, which enables asynchronous individual training.

7.3.4 Integration of VR training in curriculum

At present, the training is provided to the emergency team practitioners in a technologically equipped room. Because of the cost involved with the equipment used in the training, it would be very difficult to provide an adequate number of these types of training sessions to all practitioners to maintain continuous skill levels in performing the ACLS procedure. The virtual ACLS training system has the potential to be a great cost-effective supplement to the conventional approach to training, and the participants can learn and practice the ACLS procedure individually or in a team. In addition to the learning process, evaluation of the learned skills is also an important feature provided by the system. For this reason, the virtual ACLS training system has a potential to be integrated into the conventional approach of training as a part of a training curriculum.

Chapter 8

CONCLUSION

In this research, we present a novel approach for conducting collaborative ACLS training using virtual reality principles that also offers the capabilities to conduct a comprehensive and objective evaluation of the ACLS teams. The study also explores an important case for integrating the elements of persuasive technology in VR training sessions. Such elements can provide timely and near-real time feedback to the users, which may have further implications for reducing errors even during more conventional training. Our findings suggest that while the performance of teams in the traditional face-to-face training was marginally better than the teams in the persuasive group; there was no statistically significant difference in the improvement of skills between these two groups. Past research studies have shown that the conventional method of delivering ACLS training is expensive and difficult to organize as presently all the ACLS trainees and evaluators are required to be present at the same location for undergoing traditional collocated training. On the other hand VR-based ACLS training simulator is significantly cheaper, easier to organize, and facilitates users to practice in a team from disparate locations. This can also be accomplished without requiring the physical presence of an evaluator as with this VR-based method an evaluator can generate the training report offline and provide feedback on the performance from a remote location.

There are also a few limitations of this study. The first limitation is that only two ACLS scenarios (V-Fib, PEA) are included in the study. Validation of a scenario will increase the number of training and test sessions as well as the time required for conducting the experiment. The second limitation is that a participant is assigned the same role throughout the training and testing sessions under study. These limitations can be addressed as future work on the training simulator where we can add more scenarios and design a study where a member can be given various roles in different trials.

To summarize, this study provides a theoretically based novel approach for training ACLS teams using a virtual reality based simulator. The generic design of this training simulator can be adapted to design training simulators for various other team-based procedures, including military training for dangerous missions. But while it is unlikely that the traditional method of ACLS training will ever be fully replaced by using VR simulators they can be effective in providing medical and other trainings similar to VR-based flight simulators, which have existed for a long period of time. VR-based collaborative medical training simulators are still in their primitive phases and more research will need to be done to fully embed it into the ACLS curriculum. However, the results from these studies are promising, and will contribute to the field of technology-based training education such as use of Virtual Reality-based programs and help to move forward to its wide adaptability beyond medicine.

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APPENDIX A

VIEW OF ACLS TRAINING SIMULATOR FOR EACH ROLE

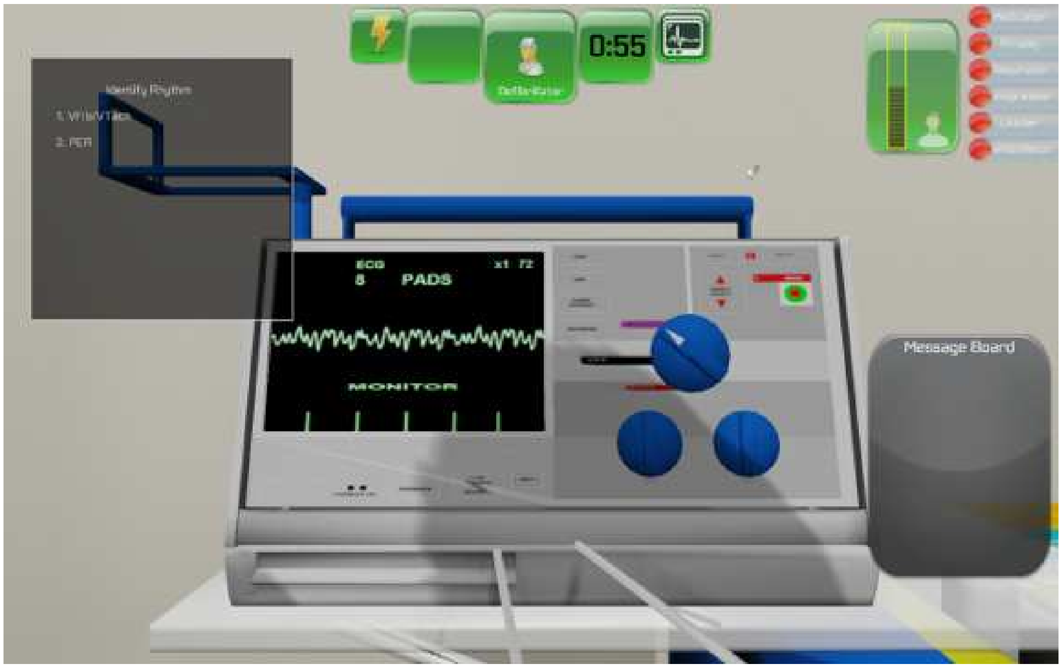


Figure A.1: Defibrillator displaying heart rhythm.

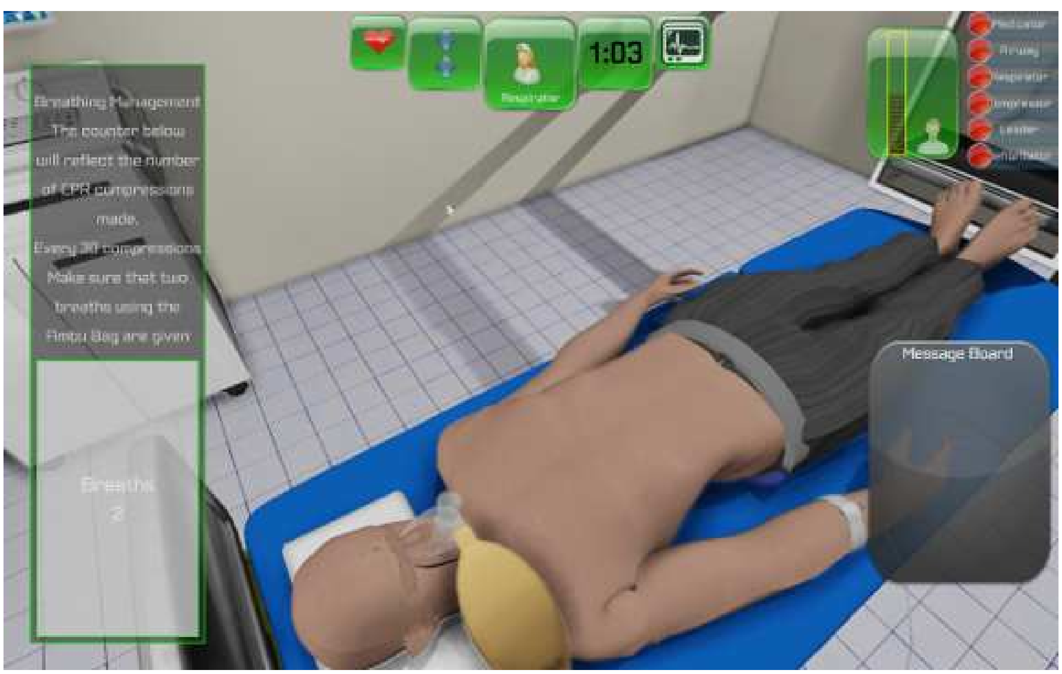


Figure A.2: View of “Respirator” during virtual ACLS procedure.

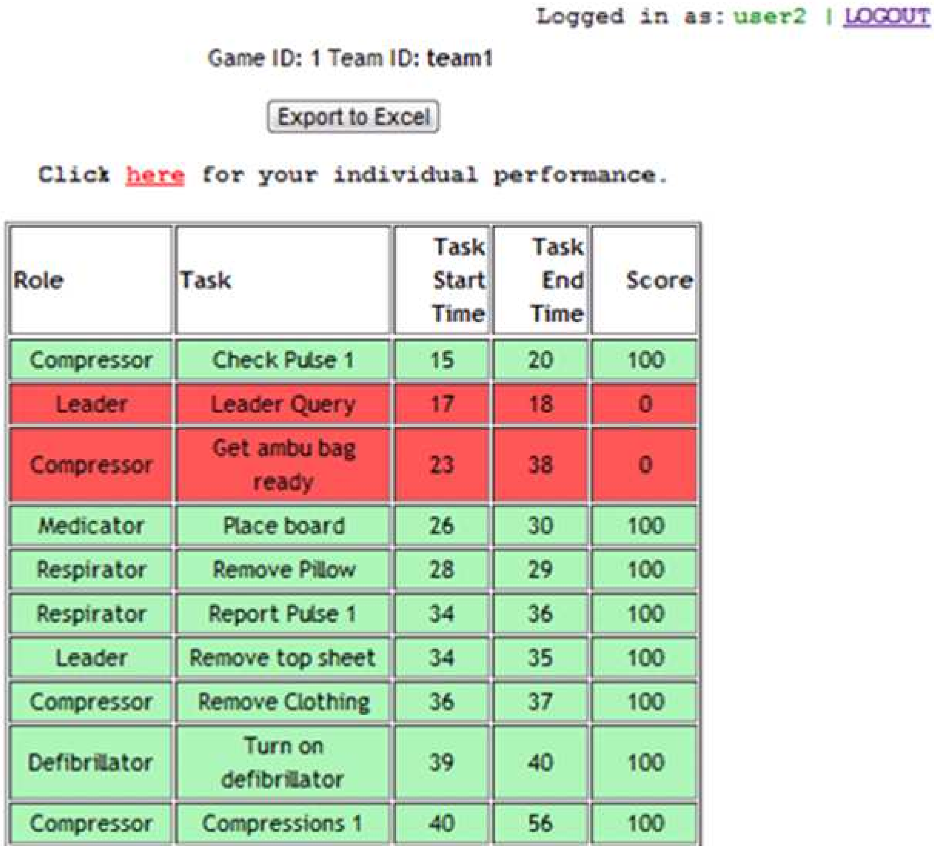
Figure A.3: View of “Medicator” during virtual ACLS procedure.

Figure A.4: Medical cart containing medicines.

Figure A.5: View of “Compressor” during virtual ACLS procedure.

APPENDIX B

PERFORMANCE EVALUATION CHARTS THROUGH WEB PORTAL



Logged in as: user2 | LOGOUT

Game ID: 1 Team ID: team1

Export to Excel

Click here for your individual performance.

Role	Task	Task Start Time	Task End Time	Score
Compressor	Check Pulse 1	15	20	100
Leader	Leader Query	17	18	0
Compressor	Get ambu bag ready	23	38	0
Medicator	Place board	26	30	100
Respirator	Remove Pillow	28	29	100
Respirator	Report Pulse 1	34	36	100
Leader	Remove top sheet	34	35	100
Compressor	Remove Clothing	36	37	100
Defibrillator	Turn on defibrillator	39	40	100
Compressor	Compressions 1	40	56	100

Figure B.1: Performance of a team displayed in tabular form.

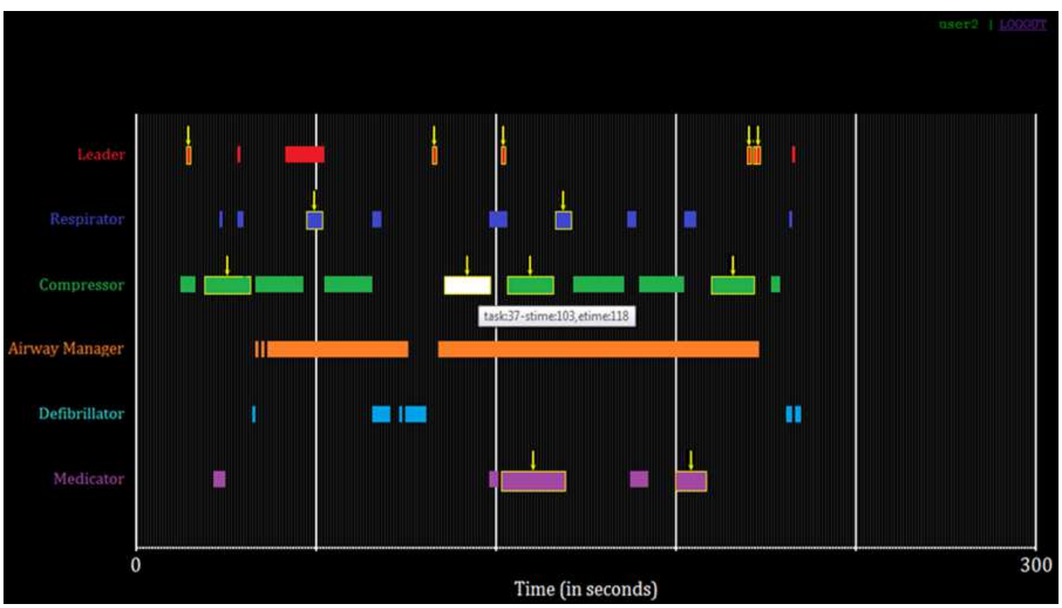


Figure B.2: Performance of a team in Gantt-Chart representation.

APPENDIX C

IRB APPROVAL DOCUMENTS

Banner Health®

FWA #00002630
IORG #0004299

March 08, 2013

Marshall Smith, MD
1111 East McDowell Road
Phoenix AZ 85006

RE: **Project # 01-11-0021** Socially Relevant Knowledge Based Clinical Team Training
iRIS Reference # 012842
IRB Expedited Approval - Continuation (closed to follow-up, data is complete from this site, data analysis continued)

- **No Informed Consent or Research Authorization**

Dear Dr. Smith:

This letter serves to notify you the above referenced **Continuation request** received expedited review and approval by Marc Lee, MD, Chair of the Banner Health Institutional Review Board (Phoenix Panel) on March 08, 2013. This study has received approval for one year. The FDA requires that all studies be reviewed at least annually. This review was performed in accordance with 21CFR56.110(b) and 45CFR46.110(b).

The Board's approval to conduct your study will expire on **March 7, 2014**. The IRB requests that you submit a Continuing Review report one month prior to the February 20, 2014 IRB meeting. This allows time for processing and review prior to the IRB expiration date of the study.

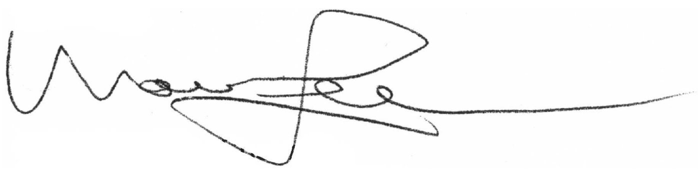
Any fatal or life-threatening adverse drug/biologic experience must be reported to the IRB within 7 working days of the investigator learning of the event. Any adverse drug/biologic experience that is both serious and unexpected must be reported to the IRB within 15 working days of the investigator learning of the event.

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.

As a reminder, please ensure the mandatory Banner Health Research compliance training through the CITI Program is completed by all study team members by the 4/15/13 deadline.

The Board appreciates your participation in research. If you have any questions, please contact Jane Hoverson, IRB Coordinator, at (480) 412-4083.

Sincerely,



Signature applied by Marc Lee on 03/08/2013 05:43:11 PM MST

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

ML/jh
cc: Study File
Research Director

ASU Knowledge Enterprise Development

Office of Research Integrity and Assurance

To:	Robert Greenes Dept of Bi
From:	Carol Johnston, Chair Biosci IRB
Date:	05/15/2013
Committee Action:	**Renewal**
Renewal Date:	05/15/2013
Review Type:	Expedited F7
IRB Protocol #:	1106006531
Study Title:	Socially Relevant Knowledge Based Clinical Team Training
Expiration Date:	06/13/2014

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 D

ACLS ALGORITHM FOR VFIB/VTACH AND PEA/ASYSTOLE

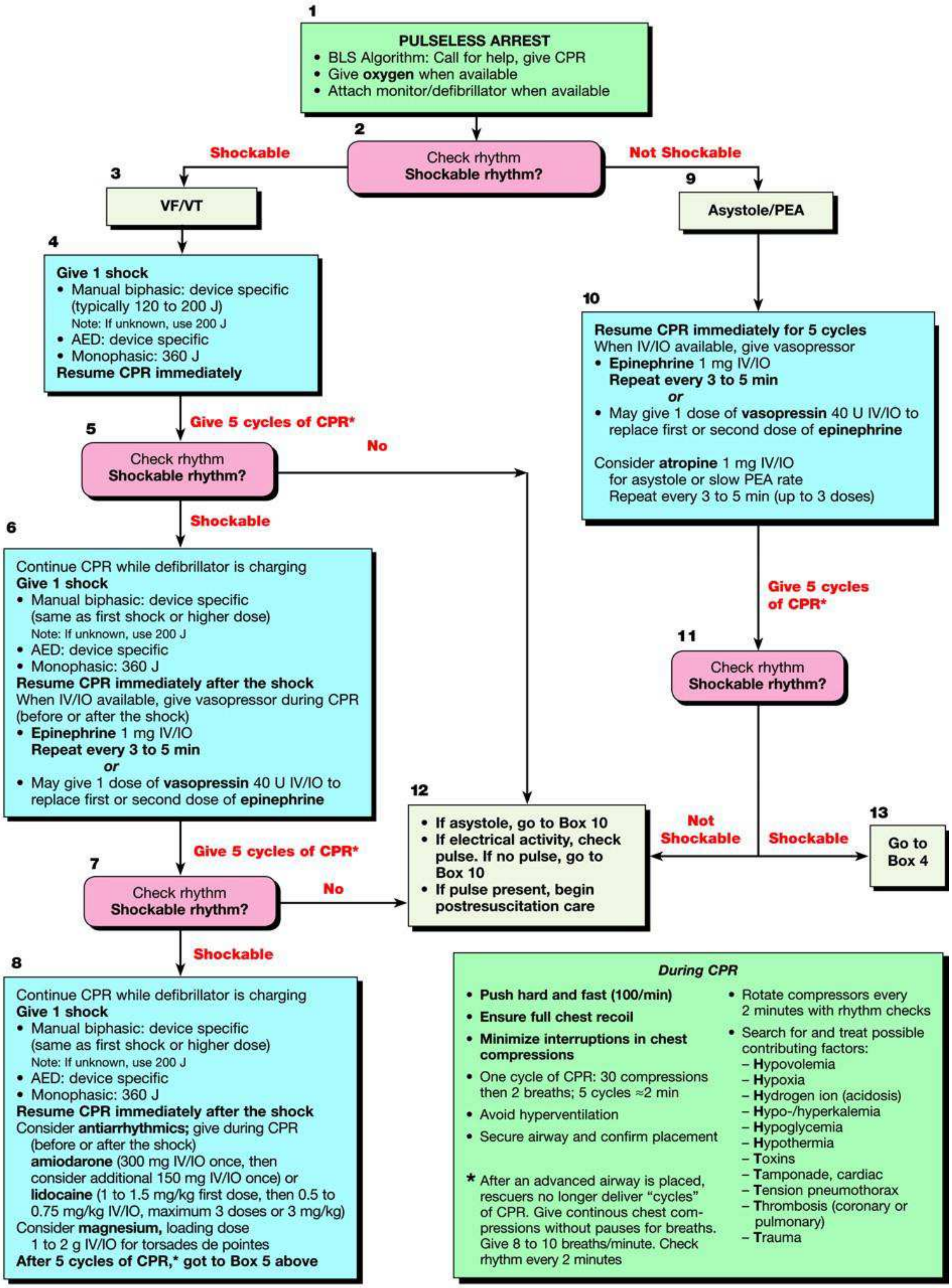


Figure D.1: ACLS algorithm for VFib/VTach and PEA. (adapted from AHA 2010)