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PRINCIPAL INVESTIGATOR: Marshall Smith, M.D.

CONTRACTING ORGANIZATION: Banner Health
Greeley, CO 80631

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Marshal Smith, M.D.

E-Mail: mark.smith@bannerhealth.com

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14. ABSTRACT
The advent of the Internet followed by the diffusion of Web 2.0 has the potential to revolutionize the delivery of clinical training in healthcare in both collocated and non-collocated clinical environments [1-4]. This is of significant relevance to the military given the shortage of healthcare providers and the disparate locations in which the military has to operate. The objective of this proposal was to design, develop and evaluate a socially relevant knowledge driven virtual collaborative training network. The scope of the project included non-collocated distributed clinical teams solving medical decision making problems with the help of Web 3.0 tools. We developed the collaborative virtual environments and defined clinical team activities for which the virtual worlds were used. Three different training modalities were utilized; traditional training, virtual training with persuasive techniques, and virtual training without persuasive techniques. Focusing on Advanced Cardiac Life Support training, we developed a virtual world platform to enable training of non-collocated teams on ACLS training, and then were tested on developed clinical scenarios. Then by coupling haptic devices with the virtual world, we enabled a multi-sensorial platform for team training. These results support the hypothesis that the collaborative virtual environment with persuasive techniques trains as well as current collocated methodologies and sets the stage for further evaluation of this virtual and socially relevant approach.

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INTRODUCTION:

The original project commenced in October 2008. From a financial perspective, many original quotes for equipment were no longer valid due to significant price increases of the equipment since the original proposal was submitted. This limited the ability to complete the proposed project for developing physical telemedicine connections across the western region of Banner. More importantly, the project did not have a clinical champion as the Principle Investigator and that would have been a major roadblock in accomplishing the goals of collaborative telemedicine. These factors were recognized within the first three months of the project, and at which stage TATRC was informed about the difficulties that had arisen. Arizona State University (ASU) continued to develop the web 2.0 backbone for the project, but the rest of the project was halted at that point. At this stage TATRC was contacted and engaged to better define a new project within the lines of military relevance and of importance to our organization. Banner Health presented a new plan to TATRC and it was approved on June 12, 2009. The actual project started in July 2009, and this is work presented herein.

The grant was slightly realigned in 2009 with a different research team under TATRC's guidance and formal approval. The primary goal of this project has been to design and develop a virtual interactive collaborative team training environment that persuades users to perform a sequence of cognitive as well as psychomotor actions in time-constrained environment. The events take place using a virtual learning environment which includes collaborative interactions by non-collocated users integrated with virtual environments called Collaborative Virtual Environments (CVE.) These provide immersive virtual environments where users can perform various actions while communicating and collaborating with other team members in the environment. Training in the CVE with Advanced Cardiac Life Support (ACLS) was evaluated for initial learning as well as retention and degradation of skills over time, and these results are compared to the learning and retention in the traditional classroom and collocated methodologies employed today. Virtual training not only has the ability to deploy more persuasive technologies with the potential of having a greater impact on changing behaviors, but also has significant economies of resources and time over more traditional methods of training.

OVERALL PROJECT SUMMARY:

After developing the initial framework for virtual worlds and developing the underlying architecture in the first two years, our experiment focused on improving the virtual experience of the user in the clinical area and on the development of algorithms in cardiopulmonary resuscitation. Cardiopulmonary arrest (i.e., cardiac arrest or sudden death) is the absence of mechanical activity of heart, or the abrupt loss of functionality of the heart. According to the American Heart Association, almost 80 percent of cardiac arrests occur out of the hospital setting and are witnessed at home by a family member [29].

Approximately 6.4 percent of the patients who have a cardiac arrest ultimately survive [29]. This shows the importance of Advanced Cardiac Life Support (ACLS) skills, which requires a team to perform various tasks within a few minutes of patients' arrival in the emergency room. It is a time-constrained, sequential procedure and a complex team event that requires fluid communication and coordination between the team members in order to save a patient's life. The ACLS team has only five minutes to perform the sequence of actions, both cognitive (e.g., decision-making such as diagnosis of treatment scenario and which medicine and dosage to give) and psychomotor (e.g., CPR using proper techniques of frequency and depth of compressions) in order to save the patient.

In most fields in which time is the most important factor and which require expertise in both cognitive and psychomotor skills for better decision-making, novices require an expert to disseminate knowledge and skills to them. Theoretical knowledge can be learned in classroom environments whereas procedural skills and communication skills require a more hands on practice to perfect. This approach of master-apprenticeship (or apprenticeship in common) model of education has been in existence for many years, where an expert performs a procedure and trainees carefully observe the procedures and practice them. In the case of learning psychomotor and communication skills, these are important because initially most of the trainees initially have limited skills and knowledge of the procedure. However, there exists a limitation to the number of trainees a trainer can train using the traditional collocated classroom methodologies employed today. [1].

Hamman, Beaubien, and Seiler [30] present the fact that errors in health care are directly related to the failures in the structure and function of the systems. The authors also mention that team training is given less preference than training an individual, although most of the care delivery is performed by teams of people. As mentioned earlier, ACLS is a team-based time critical event, so in order to deliver better care to the patients, it is important to understand the significance of team training as well as to consider more effective ways to provide training for these teams.

ACLS: current training approach

Almost all patient-care organizations provide or require regular ACLS training for emergency care providers to enhance their ACLS skills. In a typical training session, training team members have to take off work to attend a required class. When they congregate and start the class they initiate the process by assigning roles at first, then divide the tasks according to the roles, and follow the tasks. The team's performance is monitored and evaluated (subjectively) by an evaluator throughout the period. After the session, the evaluator gives a final score based on the team's performance, and later s/he debriefs what happened and what should have been done in the practice room. There might be a brief didactic session on ACLS too. After the debriefing session (and the didactic session when present,) the team will perform another test, and the team is expected to demonstrate improved performance over the previous session. The same evaluator will evaluate the second session as well for improvements.

Although the current training methodology looks comprehensive, there are various issues that are sub-optimal. The cost associated with overall setup is significant, and the time taken for training takes about two to three hours to complete. Much of this time is due to the large amount of orientation needed for training. In the context of learning, the training participants are not guided during the practice session. So, they have to recall what they had learned previously in the didactic session. There are rarely adequate trainers to provide training to the trainees, and frequently the trainees have limited time to practice the procedures properly. In addition, the scheduled ACLS training sessions are usually available only on a limited basis, which leads to insufficient training and practice considering the criticality of the ACLS skills.

Learning in virtual worlds

With rapid development of computer storage, memory, processors, and high speed network infrastructure, it is now possible to create a virtual reality based simulations in a networked (distributed) environment that helps users to learn team coordination skills. Computer Supported Cooperative Work (CSCW), in general terms, is considered to be a collaborative work done by users who are located at different sites. Telemedicine, tele-health, and tele-conferencing all are examples of CSCW. When CSCW is integrated with the term Virtual Reality (VR), the environment is called as Collaborative Virtual Environments (CVE), or simply "Virtual Worlds". These virtual environments provide immersive environments where users can perform various actions, and can also communicate and collaborate with others in the environment. CVEs have been used in various fields like gaming [4], online community building or socializing [4, 5], educational or working environments [6, 7]. CVEs are able to convey the social dynamics like turn taking, cooperation, appraisal, or communication to users in a proper manner. In addition, users can be assigned different roles like doctor, patient, trainer, trainee, etc. Current CVEs also support different media required for communication (text, audio, video), which are very important for group discussions.

How virtual worlds can persuade users to change their behavior and attitude

Because of the features that virtual worlds provide, they have potential to change behavior and/or attitude at different situations and different circumstances. Fogg mentions that there are many reasons that computers can be better persuaders than humans [8]. Some of the important reasons are: computers are more persistent; they provide greater anonymity, they can offer various modalities, their programs can be re-scaled as per users' need, and the most important reason….a computer can be ubiquitous! Virtual worlds provide all these features. They are more persistent; they are able to hide users' information; various input output methods can be integrated with the virtual worlds; and can be modified as per the requirements. With access to the Internet, virtual worlds can be accessed from any part of the world. Hence, we can say that CVEs are an integral part of persuasive framework in various fields like gaming (e.g. World of Warcraft), communications (e.g. virtual shops: Amazon.com, eBay.com), training systems for physical exercise (e.g. virtual trainers: TripleBeat, Wii Fit.) With all these advanced abilities, computerized virtual reality based interactive systems have the potential to persuade human users in the field of education as well.

Advantage(s) of training in virtual worlds

The most important advantage of use of computer based simulation in the field of education is that it can motivate students to learn and practice in a safe environment [9]. Simulation also enables students to practice different procedures in different contexts and different situations. Chodos et. al. suggest that virtual world simulations consume less resources and are capable of providing safe and realistic environment to practice [1]. The added persuasion in the computer simulation allows trainees to learn what persuasive elements are effective and their impact. This persuades students to enhance their skills on role-playing, and changing their attitudes towards different perspectives [8].

Contribution and hypothesis

In this study, we attempt to address the issue of team training in time critical events (ACLS in our case) and also the learning behavior of participants in different scenarios, with and without persuasive elements. Finally, we also see whether the participants can retain the skills in the virtual world. We also discuss the novel approach of integration of haptic device to the virtual world for time critical activities that requires psychomotor skills. Entering this study, our hypotheses were:

> Hypothesis 1#: Virtual worlds are at least as effective in delivering team training.
>
> Hypothesis 2#: Virtually trained participants will retain the skills as long as or longer than traditional methods.
>
> Hypothesis 3#: Virtually world training with persuasive elements will train more effectively than Virtual Worlds without persuasive elements.

Objectives

CVEs have a huge potential to provide training to many users in a virtual environment simultaneously. Our primary goal of this study is to design and develop an interactive collaborative team training simulator that persuades users to perform a sequence of cognitive as well as psychomotor actions in time-constrained environment.
The study also focuses on the following important issues:

- Evaluate the validity of virtual worlds in delivering team training and retention and retention of the knowledge.
- Monitor and record activities (and hence performance) of users while performing a collaborative task.
- Create an online result sheet, which can be accessed from anywhere to view performances..

Related Work

We sub categorize this section into three parts: Team Training, Training in Virtual Worlds, and Persuasive Technologies.

Team Training

Any coordinated effort, performed by a number of people in a group is termed as team work. Communication, coordination, and cohesion are some typical characteristics of a team. All the team members should possess these skills in order to carry out assigned task, and team training is usual crucial if well-coordinated team work is required.

Today, almost every single case of care delivery in hospitals or outside hospitals involves a team of healthcare professionals, yet individual training is given more importance in real life [27]. It is often hard to set up training sessions according to each individual's schedule, and health care professional trainees often work or reside in disparate locations. These healthcare training programs need to increase training experience of working in interdisciplinary teams for every individual caregiver. Hamman et al demonstrated that identifying and focusing on team critical tasks and events prior to and during the training actually do lead to significant performance improvement in teamwork skills [23].

Implicit coordination is one of the characteristics of high performance teams, where overhead communication is more explicit because the participants have access to the information without asking [24]. Communication overhead is typically the cost of communication and/or interaction measured in time, Internet bandwidth, etc. [25]. Another aspect that vitally affects an individual's ability to work in a team is shared mental models. As team members engage in a group activity, they tend to have similar thoughts/ideas in order to accomplish the task which ultimately results in less communication across the team [26]. These aspects are essentially a part of team dynamics which is important to be considered in a design phase of any experimental groupware activity.

A competitive score is an important factor in motivating participation. Toups Z et al observed that if points are given based on team efforts, participants try harder to work as a team and accomplish the task in a well-coordinated and organized team effort [27].

Advanced Cardiac Life Support (ACLS) is a time-critical activity carried out by a dedicated high performance team. Training for such high performance teams in real life scenarios is neither possible nor advisable since it is a life or death outcome to the patient, whereas simulation training is one of the best possible solutions available as it is consequence free. According to Wayne et al simulator training has shown significant performance improvement in a team of physicians while performing ACLS [28].

Training in Virtual Worlds

Based on their purpose, Collaborative Virtual Environments (CVEs) or virtual worlds can be categorized into one of the following types: gaming, socializing or online community building, and educational or working environments [19, 20] that outline the various factors that need to be present in a virtual world to be suitable for educational purpose. The authors compare various CVEs and come to the conclusion that selection of a particular CVE depends on the purpose of the training system. Below, we will briefly explain the research on CVEs that focus on healthcare and emergency training.

Wiecha et al explored the potential of a virtual world, Second Life (SL), as a delivering tool for continuing medical education (CME) [10]. In their study, participants had to select and adjust insulin level for patients with type 2 diabetes. For that purpose, participants had to listen to an instructional 40-minute insulin therapy talk. Two mock patients are also included in the study so that the participants can interact with the patients, and discuss within themselves. A questionnaire was provided to the participants before and after the talk session. The study shows that virtual world is very helpful for CME education by showing significant increase in the score after the talk as compared to prior to it.

Losh [15] lists several research srudies done by the Interactive Media Laboratory at Dartmouth Medical School based on virtual environments. Virtual Clinic is one of such work where a virtual clinic is designed by following the master floor plan. The main objective of this work is to allow learners to learn about social behavior and various procedures in clinical environments. The Virtual Terrorism Response Academy (VRTA) is a simulation based game to train users on how to act during crisis. The simulation focuses on providing rescue efforts when hazardous materials are involved. Before starting the game, users have to choose and assign themselves to a role. Based on the role, which can be a fireman, emergency medical technician, etc., training is provided in a didactic learning space. Quizzes and interactive videos are also included in order to engage the users. In an experimental session, a scenario is provided to the users and the main objective of the users is to practice with radiation meters and see how the exposure levels change when nearing hazardous objects.

Similar to VRTA is Play2Train [18]. It is a virtual hospital and town environment which is created by Idaho Bioterrorism Awareness and Preparedness Program (IDAPP). The realistic virtual environment of Play2Train provides various kinds of emergency preparedness videos in virtual classrooms, and also supplements several training exercises to prepare users in case of emergency situations. After the practice sessions, the procedure followed by the students can be debriefed by the instructor to clarify the experiences; an essential part of simulation-based training.

Callaghan et al use Second Life to create a virtual learning environment for engineering education. They demonstrate various interactive simulations that are part of engineering education [12]. Apart from the simulations, a virtual lecture theater is also present in the virtual world which contains interactive mini/main lecture slideshow viewer, media center for streaming video content and message centers for feedback. As Second Life does not provide SDK, the authors use open source e-learning software SLOODLE that links Second Life with a course management tool named Moodle. After demonstration of the simulations, the participants are asked questions: if they answer it incorrectly, they have to run the simulation again and answer the questions correctly.

However, this study lacks the assessment and the evaluation of the participants and they mention that these shortcomings will be their main focus in the future. Boulos, Hetherington, and Wheeler [16] describe the potential use of Second Life in medical and health education. The authors provide two scenarios – 'Virtual Neurological Education Centre' (VNEC,(http://www.vnec.co.uk) and 'HealthInfo Island' (http://infoisland.org/health_info).

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 intends to provide support to Second Life residents by providing them opportunities to participate in different medical groups dealing with problems such as stroke support or cerebral palsy.

The research study performed by Chodos et al [1] focuses on the development of a research based virtual environment to enhance communication skills for health science education. They provide two case studies. The first one is the development of EMT/ER training simulation, which delivers an environment to train EMT/ER personnel on taking care of accident victim before taking him to a hospital. This case also focuses on exchange of patient information between EMT and ER personnel. The second case is designed to teach various competencies to students like rehabilitation medicine, nutrition, physical education etc. For the second case, the authors design a simulation in order to increase communication between the students to develop a home-care plan for elderly patients. Based on the case studies, they discuss the expectations of students towards virtual world based learning and the quality of learning.

There are several other projects that focus on virtual healthcare system. Second Health is one of such projects where users can learn about how to use medical devices in hospital settings [12]. An interactive clinical scenario is provided to learn medical device training in simulated clinical environment. The participants are provided with both formative and summative feedback during the training session. However, the system does not provide clinical-skills training component in a collaborative environment where multiple users make a team and perform a collaborative task. Similarly, the Ann Myers Medical Centre [13] and the nursing training program from Duke University [14] provide meeting places for medical educators and students, where instructors can present lectures and present educational materials, and students can interact with each other.

Persuasive Technologies

Various researchers have worked on finding appropriate way to persuade users to perform various activities. Fogg [8] defines persuasive technologies as "interactive computing systems designed to change people's attitudes and behaviors." He lists various persuasive technology tools (terminologies) that can be an integral part of any system in order to either encourage or discourage users to perform some actions within the system and change their attitude and/or behavior while doing so. In medical training/education, persuasion is one of the most important factors that can affect the performance of trainees/students. Use of meaningful persuasive components (rewards, realism, social presence etc) enhances the learning where as bad design of persuasive components hinders it. In this section, we will mention some of the research work that has been done to encourage users to perform activities within a given system.

Conradi et. al. [17] propose an idea of collaborative learning through problem-based learning (PBL) in Second Life, which they call PREVIEW. Researchers prepared five virtual patient scenarios for learners, which were later delivered to the learners through the

Second Life platform. The main objective of the study was to find whether computerized simulation based PBL can be more effective than classroom based PBL. To engage students effectively in training the environment provided greater realism, active decision making, and suitable collaboration environment where the participants can interact with each other. The study shows that realism and a suitable interaction environment provided by Second Life engages students effectively in learning.

Our initial work on the development of CPR training simulator (Khanal, 2011) in a CVE called ActiveWorlds® (ActiveWorlds Inc., 1995) showed that the integration of haptic joystick with CVE is possible to provide training on CPR skills. The results from the study showed that the participants were able to improve their hands on skills to maintain rate of 100 compressions per minute after the training. However, the system was designed to provide individual training and the participants suggested that feedback on their performance during the training would be more engaging and helpful during training.

First we developed pilot work where we developed a prototype for ACLS team training (Khanal, 2013). The training system pilot integrated various persuasive components such as real-time feedback, timely instructions, scores, and time which were used to motivate the participants during training. The comparison of performance between the teams that were provided with VR-based training (with and without persuasive components) and the teams provided with traditional classroom based training showed that the teams trained in VR, with and without persuasive components, performed slightly better than the teams with traditional training. And the teams provided with persuasive components during VR training performed better than the ones without it. However, the participants felt significant lack of system responsiveness during VR training which was caused by the delay in internet connectivity. Another limitation of the study was that the participants did not have ACLS skills prior to the training.

Platform

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

The virtual training environment has been designed using the server-client architecture. The simulated environment is hosted on a server and six clients can be connected from remote location. Figure 1 depicts the design of the simulator from the perspective of a single local user. Each client connected to the VR simulation consists of a unique User Interface (UI). Each UI consists of a graphical user interface (GUI) consisting of the role specific HUD and the feedback system, a method for inter user communication via headsets using the TeamSpeak VOIP API (TeamSpeak, 2002), and a modified Novint Falcon haptic joystick (Novint, 2000) required to perform CPR. Each user's UI also comes with a performance evaluation module represented in the form of a patient outcome meter. This meter reflects the expected outcome of the patient that is assessed according to an adherence to the ACLS protocol. The patient outcome meter is common to all users along with the rendered environment. The outcome meter reflects the result of evaluation of all user performance in the scenario.

Fig. 1. Novint Falcon with CPR adaption

ACLS Scenarios
Two types of ACLS code case scenarios were created-, 1) Shockable Rhythm : Ventricular Fibrillation (VFib) or Ventricular Tachycardia (VTach); and 2)Non-Shockable Rhythm: Pulseless Electrical Activity (PEA). Each rhythm type has a set of steps in common within the ACLS protocol and steps that vary depending on the type. Upon logging into the simulation the users are given one of two cases based on a random selection and they are required to identify the case and proceed accordingly.

The scenario consists of six roles (Leader, Airway Manager, Respirator, Medicator, Compressor, and Defibrillator) as seen in Figure 2. The ACLS code is a time critical scenario therefore all events within are time dependent.

Figure 2 shows the system architecture of VR-based ACLS training simulator. The architecture is based on four different layers: roles, user interfaces, real-time feedback components, and ACLS servers. Each layer comprises of individual components 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.

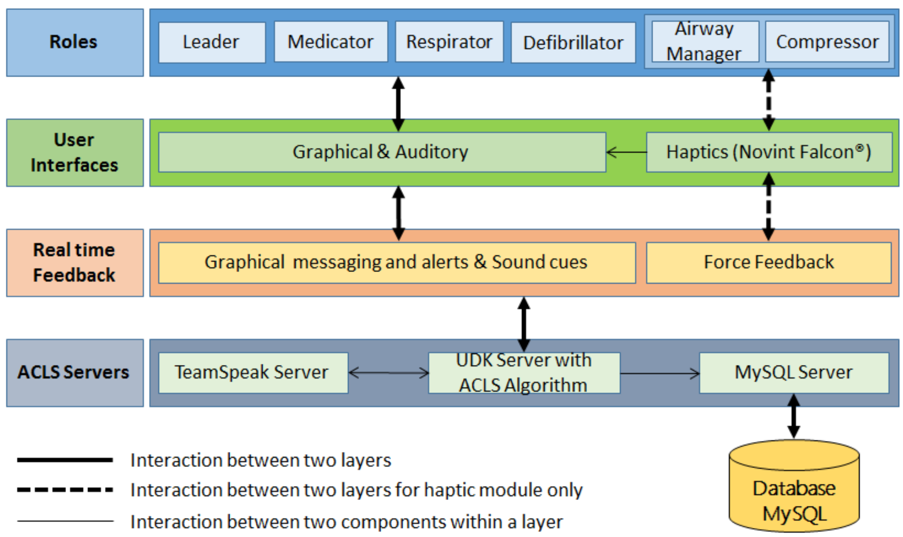


Fig. 2. System Architecture.

The UI layer provides timely alerts and feedback, which are originated from the Real-time Feedback layer using 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 UDK server in this layer integrates the ACLS algorithm module that triggers the real time feedback.

The MySQL 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.

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). The visual interface allows the user to interact with the training system, 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 (Figure 3) has been designed using the *Unreal Development Kit*® (UDK) (Epic Games, 1998) gaming engine. The visual interface includes several design artifacts such as a virtual ACLS training room, tools and equipment that are required during an ACLS session, and the avatars that represent different characters controlled by the real individuals playing specific roles in ACLS. The auditory interface allows the users to communicate with each other during the ACLS training session. This interface has been developed using *TeamSpeak*® (TeamSpeak

Systems, 2002), which is then integrated into the UDK environment. The haptic CPR interface is designed to provide psychomotor skills training to the users. We used the *Novint Falcon*® (Novint Technologies Inc., 2000) haptic device and integrated it with the training system so that the number and 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, and was calibrated to have a similar pressure to an normal adult. As a result of this feedback, the user's avatar performs the CPR actions in the virtual environment at exactly the same rate and compression as the participant, which is also visible to other members participating in the exercise.

The algorithm module consists of rules that are based on the traditional approach of evaluating the performance of a team in face-to-face environment where human evaluators are used. These evaluators assess the task performance and record task completion time. These rules are fired when a task processing is underway or completed.

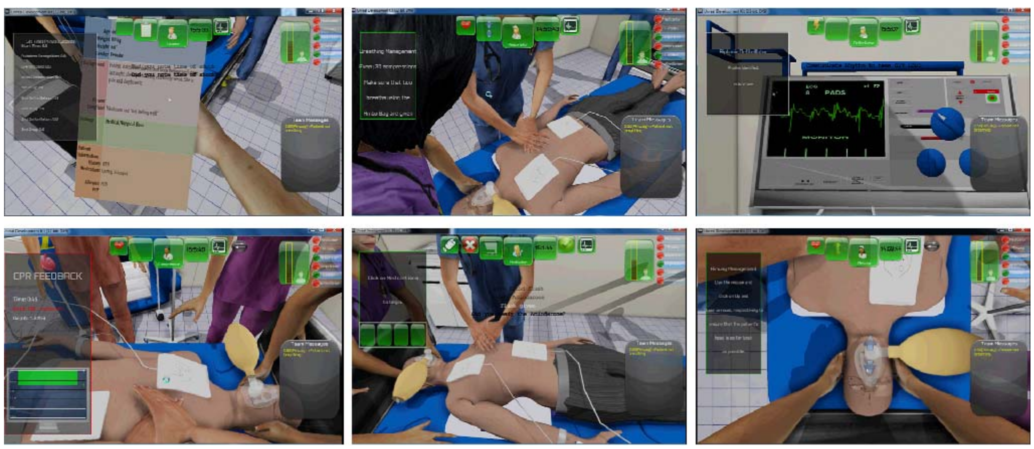


Fig. 3. Role-based user interfaces (top left to right: leader, respirator, defibrillator; bottom left to right: compressor, medicator, airway manager)

(Please refer to Table I 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 stored into the database and also displayed to the users in terms of patient-health outcome using the feedback module.

The database module is based on *MySQL*® (MySQL, 1995) 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 co-workers and/or employers cannot access their performance results. Personal identifiers (i.e. name, date of birth, address, and other identity numbers) were not stored in the database. Instead, each user was assigned a unique randomly generated ID at the time of enrollment.
The feedback module involves the task of providing visual (including textual) and auditory feedback to the users during and after the training session, based on their performance during a training session. The feedback includes various text-based instructions and alerts

to assist participants in completing their task on time and 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 auditory interface. Thus, the feedback data is displayed back to the participant in near real time, allowing for formative feedback.

Figure 3 also shows the information flow from one module to another in the system. The compressor participant is performing the CPR on the haptic device, and receiving haptic feedback from the 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 using playing other roles during 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.

Experimental Design and Setup

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. The compressor, respirator and airway manager are responsible for performing high quality cardiopulmonary resuscitation (CPR). The compressor performs compressions, the airway manager keeps the patient's 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 patient's chest to identify the arrhythmia and defibrillates the patient's heart if necessary. The leader monitors the team interventions and guides the team through synchronous execution of the ACLS guidelines.

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 training 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 6 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. For 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 3. We now describe the different phases of the experiment:

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. The demographic information was collected for future study on the retention of learned skills.

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 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 the team had completed the appropriate resolution 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.

Didactic training phase. Teams from all three treatment groups were provided with a 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.

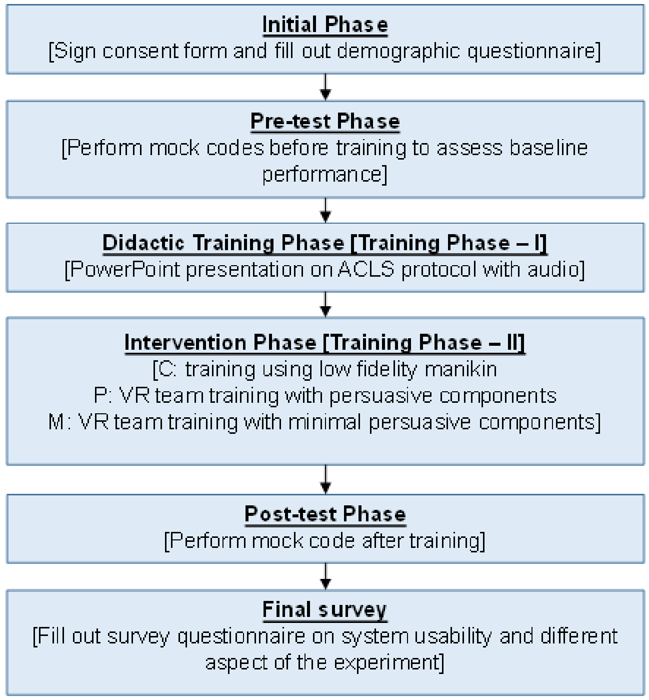


Fig. 4. Phases of the Experiment

The delivered content included responsibilities for each role, current guidelines for basic life support (BLS) and ACLS, including arrhythmia dependent differences in the ACLS algorithm, choice and delivery of medications, and the essentials of team work and communication.

Intervention phase. This phase lasted for 30 minutes in which 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 airway, respirator, compressor and defibrillator roles for at least 2 minutes per role.

The airway role focused on opening airway and inserting oral airway; respirator role included training on giving two breaths (ventilation) over one second each; for the compressor role, major objective was to manage proper compression rate of 100 per minute maintaining 30:2 compression to ventilation ratio, 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 in a virtual reality environment for which they had no prior exposure. Therefore, each team underwent a twenty minute guided single-user tutorial to familiarize with the new user interface. Each member 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 as mentioned in 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 training 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. However, the teams were unaware of this.

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 and evaluated on the high fidelity manikins by human experts in ACLS. The participants were provided with randomly selected ACLS scenarios (either PEA or V-Fib/Tach). 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.

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 the times noted by the evaluators by manually calculating each team's time from the recorded video sessions. And we were able to fill in time values for teams that were missing in the evaluators' checklist.

Scoring Metrics

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 tool's 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 evaluator's 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 American Heart Association (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 1. 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.

Task Id	Task	AHA Guideline	Time threshold (rules)
T1	Time of Pulseless Recognition:	As soon as possible	$T1 \leq 20$ seconds
T2	Time CPR/BLS Initiated:	within 10 seconds of pulseless recognition	$T2 - T1 \leq 10$ sec
T3	Initial Rhythm Recognized:	within 60 seconds of code cart arrival	$T3 \leq 60$ seconds
T4	Time of Initial Defibrillation:	within 15 seconds of rhythm recognition	$T4 - T3 \leq 15$ seconds
T5	Time of 1st Drug:	within 3 minutes	$T5 \leq 180$ seconds
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	$T7 - T5 \leq 120$ seconds
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	$T9 - T7 \leq 120$ seconds

Table 1. Tasks and Scoring Metrics

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 be awarded a team higher point compared to correctly performing a lower weight task. The metric consisted of nine different tasks for V-Fib/Tach 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 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 II. 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 ± 0.009. Therefore, we assigned equal weights to all the tasks performed during the ACLS training sequence. In Table II, 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, 9,).

The quantitative measures of cardiopulmonary resuscitation (CPR) skills such as rate, depth, and recoil of CPR are beyond the scope of this study. The primary focus of this paper is on assessing the impact of a VR-based collaborative training simulator on procedural training aspects of ACLS.

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	0.114
Time of CPR/BLS initiation (p,v)	5	4	4	5	3	5	5	5	4	4	4.4	0.123
Time of initial rhythm recognition (p,v)	5	4	4	4	3	4	5	4	4	4	4.1	0.114
Time of initial defibrillation (v)	5	4	4	4	4	5	5	5	5	5	4.6	0.128
Time of first drug (p,v)	4	3	4	5	4	4	4	3	3	4	3.8	0.106
Time of second defibrillation (v)	4	3	4	4	4	3	4	3	4	5	3.8	0.106
Time of second drug (p,v)	4	3	4	5	4	4	4	3	3	4	3.8	0.106
Time of third defibrillation (v)	4	3	4	4	4	2	4	3	4	5	3.7	0.103
Time of third drug (p,v)	4	3	3	5	4	3	4	3	3	4	3.6	0.1
Total											**36.4**	

Table 2. Tasks list and priorities according to 10 ACLS experts (1- lowest, 5 – highest)

(p – PEA, v – VFib/VTach)

Results and Discussion

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. Only 38% of PEA (non-shockable) tasks and 40% of VFib/VTach/VTach (shockable) tasks were performed per the guidelines. The level of teams' compliance improved to 58% after ACLS training.

We used IBM SPSS Statistics version 19 (IBM, Released 2010) 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. We performed Shapiro-Wilk test to assess normality for our data. The results showed that data violated the normality assumption (p 0.031). 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 .781 for PEA and p .555 for VFib/VTach); control vs. minimally persuasive: p .548 for PEA and p .514 for VFib/VTach; persuasive vs. minimally persuasive: p .377 for PEA and p .363 for VFib/VTach)

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. 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 significant (p .375 for PEA; p .1 for VFib/VTach). Similarly, the difference in the performances between the persuasive and minimally persuasive groups (p .1 for PEA; p .629 for VFib/VTach) was also found to be statistically insignificant.

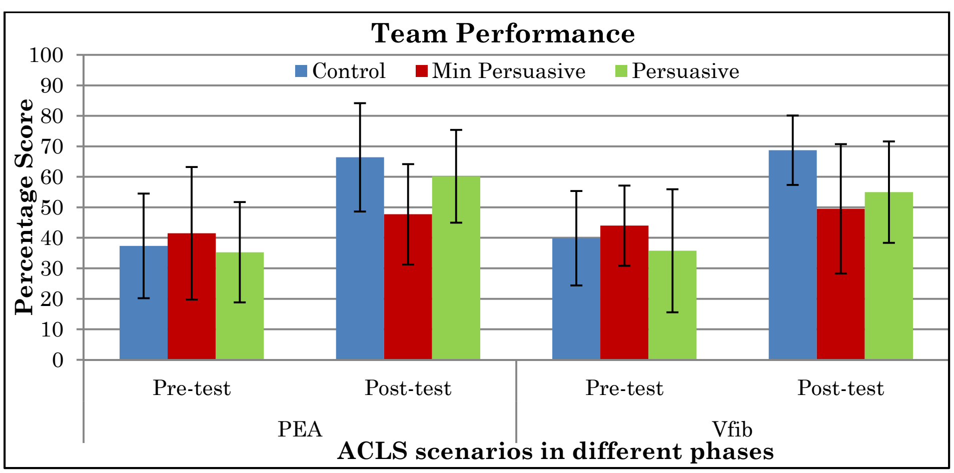


Fig. 5. Overall performances of three different treatment groups in the study.

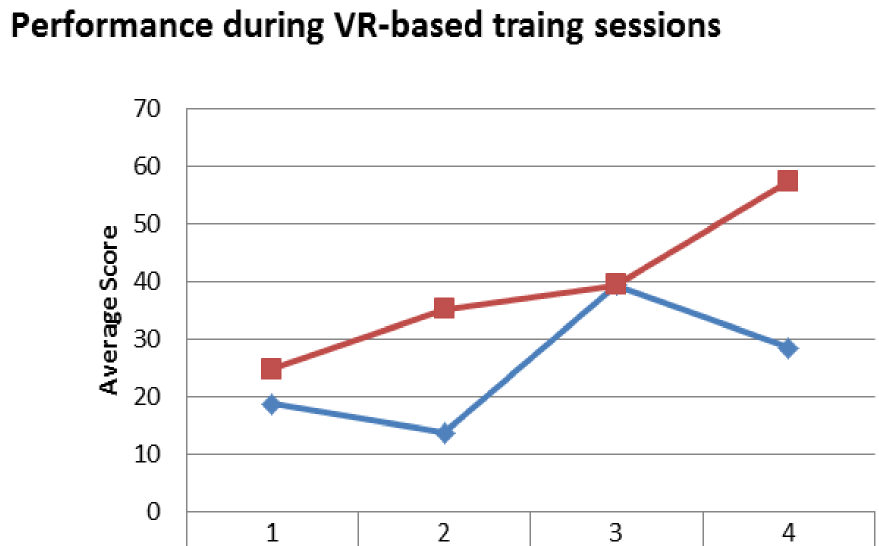
However, the difference in the performances between the control and minimally persuasive groups was found to be statistically significant (p .05 for PEA; .02 for VFib/VTach). This shows that the performance of the persuasive group and the control groups were at-par whereas the performance of the minimally persuasive group was par below that of the control group. Pre-test data collected prior to providing any form of training during the experiment suggests that ACLS skills not only degrade over time but also reflect the importance of a thirty minute training session. We found that only 39.3 % (control – 39%; persuasive – 36%; minimally persuasive – 43%) of the tasks were performed correctly. After under-going thirty minute training session, we noticed that the adherence to the AHA guidelines increased on an average to 58% (control – 68%; persuasive – 57%; minimally persuasive – 48%).

Finally, we used 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 .017 for PEA; p .011 for VFib/VTach). The performance improvement of the persuasive group was also statistically significant (p .024 for PEA, p .048 for VFib/VTach). However, the performance improvement of the minimally persuasive group was not statistically significant for both scenarios (p .453 for PEA, p .457 for VFib/VTach).

Comparison groups	**Test**	**Statistical significance in Difference (PEA)**	**Statistical significance in Difference (VFib/VTach)**
C vs. P (b)	Pre-test	No difference (p .781)	No difference (p .555)
C vs. M (b)	Pre-test	No difference (p .548)	No difference (p .514)
P vs. M (b)	Pre-test	No difference (p .377)	No difference (p .363)
C vs. P (b)	Post-test	No difference (p .375)	No difference (p .1)
C vs. M (b)	Post-test	Significant difference (p .05)	Significant difference (p .02)
P vs. M (b)	Post-test	No difference (p .1)	No difference (p .629)
C (pre vs. post) (w)		Significant difference (p .017)	Significant difference (p .011)
P (pre vs. post) (w)		Significant difference (p .024)	Significant difference (p .048)
M (pre vs. post) (w)		No difference (p .453)	No difference (p .457)

Table 3. Comparison of performance between (b) and within (w) groups

We found limited difference in performance across minimally persuasive group when compared to the other two groups. When we look at the performance of persuasive and minimally persuasive groups during VR-based training, the average performance of the persuasive group performed better than the teams in the minimally persuasive group. Figure 5 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. Various features in persuasive groups help improve the performance due to timely interventions. We limited the training duration to thirty minute for the VR group, which may not be sufficient to get accustomed with the environment and learn the ACLS skills simultaneously. Future studies could be designed to include a longer training duration.



	1	2	3	4
Minimally Persuasive	18.65	13.75	39.35	28.45714286
Persuasive	24.8	35.15	39.35	57.375

Fig. 6. Performance of persuasive and minimally persuasive groups during VR-based training sessions.

Future research could benefit from this study in several ways. One of the limitations of this study is that there are 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, we had limited 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. Future studies ought to be conducted over a larger sample size for accomplishing greater validation of the results.

Finally, this study did not focus on the quantitative analysis of ACLS measures and the qualitative analysis of communication among the team members. The quantitative measures include variables such as compression rate, depth, and recoil. Unlike conventional ACLS training, VR-based training simulator ought to be able to record such quantitative measures, track the performance over prolonged periods of time, provide summative feedback to the users, and automatic evaluation of individuals as well as team performance.

Despite the limitations, 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 that integrates multisensory devices into a virtual, collaborative environment for time critical procedures could be designed and effectively utilized. We foresee a vast array of systems that can be developed based on the similar design concepts and the architecture. An example of this is the patient monitoring system in which patients can be monitored remotely using wearable sensors in a VR-based environment while preserving the privacy of the user. There are other team-based activities such as Advanced Trauma Life Support (ATLS), Pediatric Advanced Life Support (PALS) for which similar training simulators could also be developed.

KEY RESEARCH ACCOMPLISHMENTS:

1. Demonstration that non-collocated virtual world training, using multimodal sensory devices and persuasive feedback integration, provides training to the same level of knowledge and skills that is accomplished in the traditional collocated and didactic approach of Advanced Cardiac Life Support (ACLS).

2. Demonstration that non-collocated training with a virtual world and multimodal sensory device, without the use of persuasive feedback integration, does not train to the level of either the traditional method or virtual training with multimodal sensory input suggesting the criticality of persuasive elements in virtual training.

3. Linking of actions/skills on multimodal sensory devices to an avatar in a virtual world for CPR training, allowing for virtual world training with sensory input to the user.

4. Validation of the CPR training module.

5. Validation of Virtual World based training simulation for ACLS.

6. Development of Shockable Rhythm (Ventricular Fibrillation (VFib) or Ventricular Tachycardia (VTach)) and Non-Shockable Rhythm: Pulseless Electrical Activity (PEA) clinical scenarios for ACLS in the virtual world.

7. Development and proof of concept research on an electronic, weighted checklist specific for monitoring competency and skills in ACLS.

8. Determination that the majority of practicing providers who perform CPR in training scenarios in a major hospital system do not compress chest a full 2 inches or stay within the recommended frequency as described as critical in the 2010 Guidelines for ACLS by the American Heart Association.

9. Development of virtual world with avatars which is based on actual code cart contents, code cart medications at Banner Health, and EKG monitor.

10. Development of a Virtual Reality training program (Collaborative Virtual Environments) for training participants in ACLS in a non-collocated environment

that preliminarily appears to produce equal learning and skills as traditional and conventional training requiring collocated participants and higher costs. Further study will be required, but preliminary results are promising.

CONCLUSION:

This work presents a novel approach for conducting collaborative and time sensitive ACLS training using virtual reality principles that offer the capabilities to conduct a comprehensive and objective evaluation of a non-collocated care team. The study makes an important case for integrating the elements of persuasive technology into VR training sessions. It also reports on the integration of multimodal sensory elements into a virtual non-collocated training environment, now adding sensory input (haptics) to the VR trainee. Such elements can provide timely and near-real time feedback to the trainer, findings which have just been substantiated by a separate study team and was online and in press as this report was being prepared [33]. In fact, this study reports improved clinical outcomes in the form of an increase in survival of patients and favorable functional outcomes after out-of-hospital cardiac arrest with real-time audiovisual feedback in training. This further substantiates our findings that the same value and impact of persuasive feedback is effective in the virtual world as well.

Our findings show 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 the groups or in the retention of those skills. Past research studies have shown that conventional method of organizing ACLS training is expensive and difficult to organize. In addition, all the ACLS trainees and evaluators are required to be present at the same location for undergoing training, and it is only required every two years. On the contrary, VR-based ACLS training simulators are significantly cheaper, easier to organize, and facilitate users to practice in a team from disparate (non-collocated) locations without requiring an evaluator. The evaluator can always generate the training report offline and provide feedback on the performance from a remote location.

The VR-based ACLS training tool that we introduced and tested in this study can complement the state-of-the-art ACLS training methods used in hospitals rather than replacing it so that frequent and remote training sessions can be conducted. The VR-based ACLS training simulator, coupled with persuasive components, has a potential to be easily integrated with the conventional approach of providing ACLS training curriculum. In addition to providing an economic advantage, the VR-based ACLS training also provides the ability to objectively evaluate the learned skills of the participants. Each participant is able to monitor their scores during and after the tests, enabling them to observe the long-term improvement trend in their ACLS skills, which is not available in the traditional training formats.

Given the impending changes in healthcare with increased cost restrictions, concurrent with the demand for lower error rates and improved quality of patient care, newer ways have to be developed to provide equal if not improved training in team based events for non-collocated providers. New and innovative learning technologies must be integrated into learning processes for team training, both to improve the initial learning event as well as to increase the retention of these learned skills. Innovative technologies must be developed to remove the physical and geographical inefficiencies for the need for having team training in collocated environments, and there are increasing needs to be able to train medical teams more efficiently and effectively in non-collocated environments. This study is of increased significance for not only the private healthcare sector as it moves to the outpatient, ambulatory and home care setting for care delivery, but especially in the military with their healthcare units becoming more and more disparate and isolated in today's global deployments. If further work fully substantiates these preliminary results and conclusions, then this not only will revolutionize current methods of collocated provider skill training, but also open the door for training of health provider skills anywhere in the world with virtual reality training utilizing persuasive and multimodal elements. Perhaps someday healthcare educators in Education Centers in the United States can train non-collocated soldiers and medics in remote global deployments, midwives in rural India where there are unacceptably high maternal mortality rates, and AIDS providers in Nigeria…all in a single day and without ever leaving their own clinic.

PUBLICATIONS, ABSTRACTS and PRESENTATIONS:

Peer Reviewed Journal Articles

P Khanal, S Parab, K Kahol, Mark Smith; Collaborative, Time-Critical, Multi-Sensory Training in Virtual Worlds with Persuasive Elements; Computer Human Interaction (CHI), 2011

K Kahol, M Vankipuram, V Patel, M Smith, "Deviations from Protocol in a complex Trauma environment: Errors or innovations?", Journal of Biomedical Informatics, vol 44, 425-431, 2011

P. Khanal, A. Gupta, M. Smith, R. A. Greenes, Virtual Worlds in Healthcare: Systematic Review and Research Opportunities, *Annals of Information Systems special issue in Healthcare Informatics*, conditionally accepted, 2012.

Khanal, P., Vankipuram, A., Ashby, A., Vankipuram, M., Drumm-Gurnee, D., Gupta, A., Josey, K., Tinker, L., Smith, M., "Validation study of Virtual Reality based Advanced Cardiac Life Support Training Simulator", Transactions on Computer Human Interaction (TOCHI), submitted, 2013

Vankipuram, A., Khanal, P., Ashby, A., Vankipuram, M., Gupta, A., Josey, K., Drumm-Gurnee, D., Smith, M., "Design and Development of Virtual Reality Simulator for Advanced Cardiac Life Support Training", Journal of Biomedical and Health Informatics (JBHI), submitted, 2013.

Khanal, P., Gupta, A., Smith, M., Greenes, R. A., "Virtual Worlds in Healthcare: Systematic Review and Research Opportunities", Annals of Information Systems special issue in Healthcare Informatics, submitted, 2013.

Peer Reviewed Major Presentations

Marshall Smith, "Socially Relevant Knowledge Based Telemedicine", TATRC's Symposium Continuing Clinical Competence and Skills Deterioration, 18th Annual Medicine Meets Virtual Reality, February, 2011

Marshall Smith, "Virtual Reality in Team Based Training", Military Health System Research Symposium, Fort Lauderdale, August, 2012

Peer Reviewed Poster/Abstract/Demo:

A. Vankipuram, P. Khanal, A. Ashby, K. Josey, M. Smith, "Development of Virtual Reality based Advanced Cardiac Life Support Training Simulator in Unreal Development Kit®", *accepted*, Theatre-style demonstration, *AMIA 2012*, Nov 3-7, Chicago

P. Khanal, S. Parab, K. Kahol, K. Josey, K. Zittergruen, M. Smith, "Virtual Reality based Advanced Cardiac Life Support Training Simulator using Active Worlds", *accepted*, Poster, *AMIA 2012,* Nov 3-7, Chicago.

P. Khanal, A. Vankipuram, A. Ashby, K. Josey, A. Gupta, M. Smith, "Virtual World for Advanced Cardiac Life Support Training", submitted, *22nd Annual Workshop on Information Technologies and Systems (WITS)*, Dec 15-16, 2012, Orlando. **THIS PRESENTATION WON THE TOP RESEARCH PAPER AWARD OF THE MEETING THIS YEAR**

Thesis/Dissertations Supported

Sainath Parab, "Time Critical Team Training in Virtual Worlds", Masters of Science Thesis, Arizona State University, November, 2010,

Akshay Vankipuram, "Design and Development of an Immersive Virtual Reality Team Trainer for Advance Cardiac Life Support", Masters of Science Thesis, Arizona State University, 2012

Prabal Khanal, "Design, Development, and Evaluation of Collaborative Training Method in Virtual Worlds for Time-critical Medical Procedure - Case Study on Advanced Cardiac Life Support", PhD dissertation, Arizona State University, March, 2013

Aaron Ashby, "Analysis of Clinical Team Communication during Cardiac Resuscitations: A Network Perspective", PhD dissertation, Arizona State University
Expected graduation date: Aug, 2014

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APPENDICES:

No Appendices.