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Collaborative virtual reality based advanced cardiac life support training simulator using virtual reality principles

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ABSTRACT

Background: Advanced Cardiac Life Support (ACLS) is a series of team-based, sequential and time constrained interventions, requiring effective communication and coordination of activities that are performed by the care provider team on a patient undergoing cardiac arrest or respiratory failure. The state-of-the-art ACLS training is conducted in a face-to-face environment under expert supervision and suffers from several drawbacks including conflicting care provider schedules and high cost of training equipment.

Objective: The major objective of the study is to describe, including the design, implementation, and evaluation of a novel approach of delivering ACLS training to care providers using the proposed virtual reality simulator that can overcome the challenges and drawbacks imposed by the traditional face-to-face training method.

Methods: We compare the efficacy and performance outcomes associated with traditional ACLS training with the proposed novel approach of using a virtual reality (VR) based ACLS training simulator. One hundred and forty-eight (148) ACLS certified clinicians, translating into 26 care provider teams, were enrolled for this study. Each team was randomly assigned to one of the three treatment groups: control (traditional ACLS training), persuasive (VR ACLS training with comprehensive feedback components), or minimally persuasive (VR ACLS training with limited feedback components). The teams were tested across two different ACLS procedures that vary in the degree of task complexity: ventricular fibrillation or tachycardia (VFib/VTach) and pulseless electric activity (PEA).

Results: The difference in performance between control and persuasive groups was not statistically significant ($P = .37$ for PEA and $P = .1$ for VFib/VTach). However, the difference in performance between control and minimally persuasive groups was significant ($P = .05$ for PEA and $P = .02$ for VFib/VTach). The pre-post comparison of performances of the groups showed that control ($P = .017$ for PEA, $P = .01$ for VFib/VTach) and persuasive ($P = .02$ for PEA, $P = .048$ for VFib/VTach) groups improved their performances significantly, whereas minimally persuasive group did not ($P = .45$ for PEA, $P = .46$ for VFib/VTach). Results also suggest that the benefit of persuasiveness is constrained by the potentially interruptive nature of these features.

Conclusions: Our results indicate that the VR-based ACLS training with proper feedback components can provide a learning experience similar to face-to-face training, and therefore could serve as a more easily accessed supplementary training tool to the traditional ACLS training. Our findings also suggest that the degree of persuasive features in VR environments have to be designed considering the interruptive nature of the feedback elements.

Abbreviations: ACLS, Advanced Cardiac Life Support; AHA, American Heart Association; CPR, cardiopulmonary resuscitation; IV, intra-venous; EKG/ECG, electrocardiogram; VFib, ventricular fibrillation; VTach, ventricular tachycardia; PEA, pulseless electrical activity; VR, virtual reality; CVE, Collaborative Virtual Environment; SL, Second Life; UI, User Interface; UDK, Unreal Development Kit; SimET, Simulation Education and Training; lbs., pounds; BLS, basic life support; AED, automated external defibrillator; ATLS, Advanced Trauma Life Support; PALS, Pediatric Advanced Life Support.

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1. Introduction

1.1. Background

Cardiopulmonary arrest (more commonly known as cardiac arrest) is the abrupt loss of pulmonary and cardiac functionality. Advanced Cardiac Life Support (ACLS) is a time-constrained medical intervention that requires coordinated action and effective communication of team members to resuscitate a patient facing imminent death from cardiac arrest [1]. According to American Heart Association (AHA) guidelines for ACLS, the first five minutes of the ACLS is the most critical time frame for corrective action to save the patient's life. During this short window a team must perform the interdependent tasks required for successful resuscitation [1]. ACLS requires the application of both cognitive skills (e.g., decision-making related to diagnosis of treatment scenario, identifying correct medications etc.) and psychomotor skills (, i.e. chest compressions) to perform effectively [2]. Theoretical aspects of ACLS guidelines may be learned in a classroom setting, but the attainment of procedural and communicative skills requires more hands-on practice, which traditionally has been acquired through face-to-face training under the supervision of a clinician certified as an ACLS instructor [3].

Although ACLS is a team based procedure, literature review has demonstrated the paucity of research on team training as more efforts have been focused on individual training [4,5]. Some of the reasons for such discrepancies are caused by difficulty in organizing training sessions according to each individual's schedule; difficulty in bringing the team members from disparate locations, and ease of conducting individual training in less time [6]. Since most of the patient care is delivered by clinician teams, it is imperative to train providers in team settings. In addition, training a team together has been observed to be a more effective way to improve the team performance [4]. Although frequent team based training helps in ACLS skill and knowledge retention [7], training on time-critical activities in a team setting is more complex and time consuming due to team coordination and communication requirements.

In a high fidelity ACLS training procedure, team members arrive at the practice room, which is typically equipped with a computer to control the training scenarios utilizing the higher fidelity manikin, a code-cart, IV-stand (intravenous), and wall ports for oxygen. The room has a layout that is typical of any patient room in the hospital. The ACLS team generally has 4–6 members [1], and the training procedure is initiated by assigning specific roles to these members. The performance of individual ACLS team members is monitored and evaluated by experts (instructors) throughout the training period.

The ACLS procedure requires the proper identification of cardiac arrest, which often requires identifying the patient's heart rhythm from an electrocardiogram (EKG). Pulseless rhythms can be broadly categorized into shockable (responds to electrical defibrillation) and non-shockable rhythms [8]. Patients with shockable rhythms such as ventricular fibrillation (VFib) and ventricular tachycardia (VTach) must be immediately defibrillated. However, asystole and pulseless electrical activity (PEA) are non-shockable rhythms, hence patients having one of these should not be defibrillated. VFib/VTach (12.8% occurrence) and PEA (41.6% occurrence) are the most common initial rhythms in hospitalized patients with cardiac arrest [9]. Additional interventions (i.e. administering medications) are provided according to the specific rhythm present.

1.1.1. State of the art ACLS training

Existing ACLS training predominantly involves face-to-face interactions among team members comprising of care providers. This is done through mock resuscitation codes. Hospitals use these to provide consistent protocol for regular ACLS training to their medical personnel. Such training is typically deployed using the concepts of clinical simulation performed on a patient substitute such as a manikin [7]. An instructor synchronously observes the team as they perform the required set of tasks for various scenarios, which are typically limited to five-minute sessions. The instructor performs a full evaluation of the team's performance during debriefing sessions conducted after the completion of the training session. Although high fidelity mock codes are the gold standard of ACLS training, there are a several issues that limit clinical professionals to learn or practice ACLS in short interval periods. For instance, the total cost associated with the overall setup for such a face-to-face training sessions is usually high due to prolonged setup times, training duration (3–4 h) and workers getting disrupted from their regular work schedules. The venues for such training sessions are also constrained by the availability of expensive training equipment.

Additionally, during conventional training, participants do not receive real time feedback despite getting observed synchronously. A majority of the feedback is provided during the post-training debriefing. Due to the limited availability of experts, scheduling the face-to-face ACLS training sessions is a challenge and thus is often provided to each clinician at a low frequency, usually once every 2 years when the ACLS class and certification are required.

1.1.2. Collaborative ACLS training using virtual reality

The recent advancements in computing power, storage and the availability of high speed network infrastructure has facilitated the use of virtual reality (VR) for performing collaborative tasks and team based training, especially in telemedicine domain. The development of Collaborative Virtual Environments (CVE) has provided users opportunities to perform various actions, while communicating and collaborating with others. CVEs have been used in various fields like gaming [10,11], online community building or socializing [12], advertising and e-commerce [13,14], educational and professional work [4,15–17]. CVEs are able to convey social dynamics like turn-taking, cooperation, appraisal, and communication to users. Additionally, users are given the flexibility to assume different roles like doctor, patient, trainer, trainee etc. Since ACLS is a team-based procedure with multiple roles, CVE is well-suited for designing an ACLS training simulator. ACLS team members can use a VR training simulator remotely, choose different roles, communicate with each other and perform tasks together. Such a training simulator provides various advantages over face-to-face ACLS training. Virtual ACLS training is a more cost-effective method for organizing ACLS training sessions, which could result in more frequent training. In addition, the ACLS trainees do not have to be present at the same physical location (distributed or non-collocated), which would save time currently required for travel to a common site for ACLS training. The simulator can provide real time feedback to the participants during training and can also generate performance reports, which allows trainers and/or evaluators to evaluate the performances without being present at the training sessions. CVEs are also capable of incorporating various persuasive components. Persuasive components are the interactive information technologies designed to change users' behavior or attitude [18,19]. Meaningful use of persuasive components such as real-time feedback, rewards, realism, and social presence enhances a learning environment [18]. Hence, unlike face-to-face training, VR based training can motivate users with novel means to reach the final goal during learning.

1.1.3. Objective of the study

We investigated the efficacy of using a virtual reality-based simulator intended for team training in ACLS. The design and implementation of the simulator was subjected to a comprehensive

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