Theoretical Article

Simulation & Gaming
2019, Vol. 50(1) 6–22

DOI: 10.1177/1046878118820905
journals.sagepub.com/home/sag
SAGE

Virtual Reality Simulation Technology for Cardiopulmonary Resuscitation Training: An Innovative Hybrid System With Haptic Feedback

Omamah Almousa[1,2], Joana Prates[3], Noor Yeslam[3], Dougal Mac Gregor[3], Junsong Zhang[3], Viet Phan[3], Marc Nielsen[4], Richard Smith[3,5], and Karim Qayumi[2]

Abstract

Objective. Although **cardiopulmonary resuscitation (CPR)** skills are lifesaving skills, the gap between awareness and actual training remains significant. Advances in technology are shaping the future of education and innovative learning solutions are essential to facilitate effective and accessible training. This project objective is to develop a self-directed educational system for hands-on **CPR** training using **virtual reality (VR)** technology.

Methods. HTC VIVE was the chosen **VR** engine, and Unity3D was the software used for development. **CPR** skills including chest compressions, rescue breathing, and automated external defibrillator (AED) are taught in VR through focused instructions, demonstrations, and simulated interactive scenarios with hands-on training sessions. A tracking system was designed using virtual planes and VIVE-Tracker for accurate measurements of chest compressions (rate, depth, and recoil), hands' position and AED. A real mannequin was integrated in the **VR** space and overlaid with virtual 3D-human model for realistic **haptic**

[1]McMaster University, Canada
[2]University of British Columbia, Canada
[3]Centre for Digital Media, Canada
[4]Dania Games, Denmark
[5]Simon Fraser University, Canada

Corresponding Author:
Omamah Almousa, Resident in Vascular Surgery, McMaster University, 85 Robinson Street, Apartment 901, Hamilton, Ontario, Canada L8P 3G1.
Email: Omamah.Almousa@gmail.com

feedback and hands-on training. VIVE-controller was used for precise calibration between the mannequin location in real environment and the virtual human model in **VR** space.

Results. The **VR-CPR** prototype was designed to be generic, approachable, and easy to follow. Realism and interaction were achieved through 3D virtual scenes simulating common sites at which cardiac arrest may occur. Variety in scenarios and gamification features like scoring and difficulty levels of training were made to enhance users' engagement. The **VR**-mannequin **hybrid** system enabled quality training and immersive learning experience. Further, real-time feedback and scoring system are built for self-directed learning and optimal performance.

Conclusions. The developed **VR-hybrid** product is a structured educational tool for hands-on **CPR** training and ongoing practice. This innovative technology provides self-directed learning with no restrictions of time, place, or personnel, which are the main challenges with current traditional courses. This product is a promising **CPR** training initiative in the evolution of digital education.

Keywords
CPR, education, haptic feedback, healthcare, simulation, technology, virtual reality

Background and Rationale

Sudden cardiac arrest is one of the most common causes of death worldwide. In Canada, 35,000 to 45,000 people die of sudden cardiac arrest each year. Almost 80 percent of all cardiac arrests occur in homes and public places, and 35 to 55% are witnessed by a family member, co-worker or friend. Although prompt delivery of cardiopulmonary resuscitation (CPR) increases the probability of survival from sudden cardiac arrest by over 2-fold, the majority of people witnessing cardiac arrest do not perform CPR. As a result, the survival rates of victims of sudden cardiac arrest (outside of a hospital) remain significantly low, approximately 5 percent. Lack of immediate help at the critical time is a major contributing factor of death (Blewer et al., 2017; Heart and Stroke Foundation of Canada, 2010).

Even though cardiopulmonary resuscitation is a lifesaving intervention and the cornerstone of resuscitation from cardiac arrest, studies have clearly demonstrated lack of public knowledge and skills in providing CPR (Blewer et al., 2017). Awareness and hands-on training are essential pillars of successful CPR performance. Statistics have shown a shocking discrepancy between society perception of the importance of CPR training and actually pursuing one. In fact, 98% of Canadians believe in the importance of CPR, but only 18% have the knowledge and skills to provide it (Canadian Red Cross, 2012). Time and place restrictions with current traditional courses are major challenges for public members seeking training. The challenge of access to reliable hands-on training was also reported among learners who have received official CPR training and need to repeatedly practice their skills. These significant limitations with traditional educational methods have not only hindered public training, but also resulted in a large gap between knowledge of CPR skills and its optimal implementation among certified CPR providers (Meaney et al., 2013).

Practice is fundamental for skills' maintenance. Poor quality CPR is a preventable harm that could be avoided using effective training resources to optimize performance skills. Variations in CPR performance were also documented in clinical settings. Unfortunately, even professionals in healthcare begin to forget how to effectively administer CPR after a few months of no practice. Data have proved a significant deterioration in the quality-performance of CPR among professionals within a few months of initial training, which has a high impact on patient survival (Meaney et al., 2013; Semeraro et al., 2013).

Restrictions of time, place, and personnel associated with conventional courses and lack of alternative teaching methods limit access to initial CPR training and ongoing practice to maintain the quality of acquired skills. Despite the abundance of theoretical materials, reliable tools for hands-on CPR training are still deficient. Therefore, effective training resources that provide self-directed and immersive learning experience are in demand. An interactive education system with realistic training environment and real-time feedback assessment will improve CPR performance in training and clinical settings.

Novel technologies such as virtual reality provides a multisensory, and three-dimensional (3D) environments that enable users to become fully immersed in a simulated world. VR-simulators are validated teaching technologies and its use has expanded from entertainment industry to academic and clinical disciplines (Li et al., 2017). According to a leading VR researcher, Ken Perlin, VR glasses will replace smartphones in few years (Perlin, 2018), making them the chosen tools for future learning.

This paper describes the process and results of the development of a VR-hybrid system for self-directed CPR training. We will identify technologies, tools, and features implemented in the design of this VR-CPR application. A proof-of-concept prototype of an immersive and intuitive VR-hybrid training system was built and tested. Based on the test results, future technical and research directions are proposed.

Project Goal

Our goal is to serve the fundamental need of providing an accessible, self-directed and reliable hands-on CPR training tool to overcome challenges with current methods of training, using an innovative technology for exceptional educational experience.

Materials and Methods

The proposal of this project was reviewed and approved by faculty committees at University of British Columbia and Centre for Digital Media, in Vancouver, Canada. The product is a result of a collaborative work between the two institutions.

Project Objective

Our objective is to develop a Virtual Reality tool for simulation of CPR training with the following values:

- **Accessibility:** Portable and self-directed CPR training system, with no restrictions of time, place, or personnel.
- **Quality:** High-quality and reliable hands-on training tool with accurate feedback assessment for effective and independent learning.
- **Innovation**: Creative and immersive virtual training environments for realistic learning experience.
- **Cost-effectiveness**: VR application tool sharable between multiple users or centers for unlimited training.

Target population. Generic application for public training (above 13 years of age) and ongoing practice for healthcare professionals.

Project Development

Hardware and technical components. Project tools include HTC VIVE device, VIVE Tracker, Half-torso mannequin, and Unity3D software.

VR-engine and software. HTC VIVE is one of the best and most popular VR platforms in the current market, and therefore was the chosen engine for this project [Figure 1]. Unity3D was the software used for design and development.

Tracking system. To ensure hands-on quality training in the CPR simulation, we needed to develop a way to track the user's hands positions in the VR environment while keeping them free at the same time for CPR performance. After quality, comfort and usability tests of available options for wearable tracking devices, we decided to use the VIVE Tracker and attach it to a glove that can be worn on the dominant hand for comfort and precision of tracking [Figure 2]. By attaching the VIVE Tracker to the user's hand, it was possible for the application to track hands' movements, while keeping the user's hands free to perform chest compressions [Figure 3]. This enabled accurate measurement of compressions' variables (rate, frequency), and detection of hands positions on the mannequin/victim's chest.

Design of virtual planes for depth and recoil tracking. A successful chest compression is registered by the software based on two factors: Depth and Recoil. Measurement of compression depth was more complicated and required the design of virtual planes (deep and superficial) aligned at precise levels with the mannequin and triggered by the movement of the VIVE Tracker (attached to user's hand) to allow accurate recognition of depth (2-inch). This technique has also enabled detection of full chest recoil which requires the VIVE Tracker to pass through one of the virtual planes (superficial) for registration of chest recoil and thus successful compression. The virtual planes are

Figure 1. HTC VIVE Hardware.

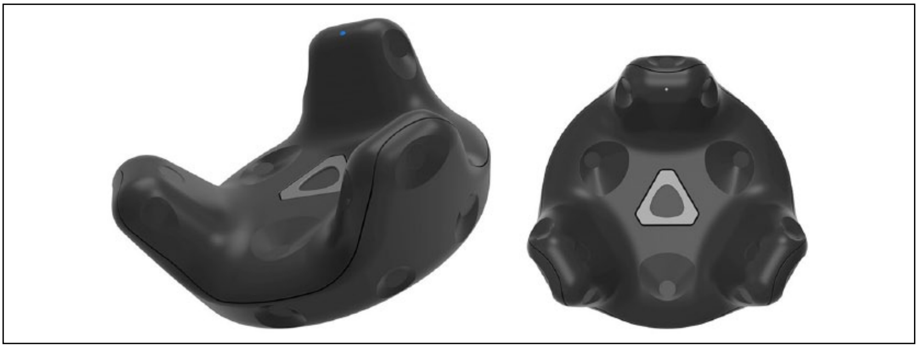


Figure 2. HTC VIVE Tracker.

Figure 3. HTC VIVE Tracker attached to a glove enabling accurate tracking without interference with CPR performance.

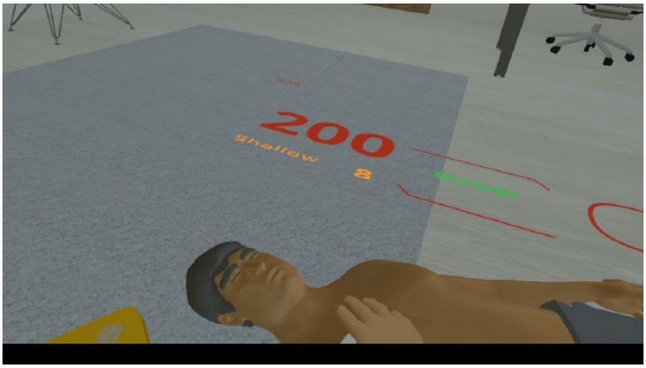


Figure 4. 3D model of realistic human victim overlay the mannequin in VR space.

programmed in the software and not visible in the VR space, therefore, will not affect the realism of the learning experience.

Real object integration and VR calibration (hybridization). To ensure high-quality training and accuracy, we decided to integrate a real object (CPR half-torso mannequin) in the VR environment for realistic haptic feedback (feel and resistance), which resulted in a hybrid technology. The mannequin was calibrated in the VR space using HTV VIVE controller for precise location setting, while a 3D model of a realistic human body was designed to overlay the mannequin in the VR space [Figure 4].

Educational and Training Components

- The VR-CPR training application was designed in accordance with the American Heart Association 2015 guidelines and recommendations.
- Concise educational material in the form of infographics, audiovisual features, and 3D instructional characters were designed to guide the trainee though the VR-CPR learning experience.
- A brief refresher quiz in the form of multiple-choice questions with explanations and focused educational information following each question was formulated.
- Simulated virtual scenarios resembling actual situations are crafted in different locations, such as a bedroom, living room, or a public place like a lobby.
- Different levels of difficulty were designed for each scenario to allow more practice and confidence in CPR performance. The various scenarios and levels were also factoring gamification and engagement. The difficulty levels were designed as the following:
    - Level one (Easy): Real-time feedback and audiovisual guidance.
    - Level two (Medium): Emotional and stressful audiovisual distractions with real-time feedback but no guidance.

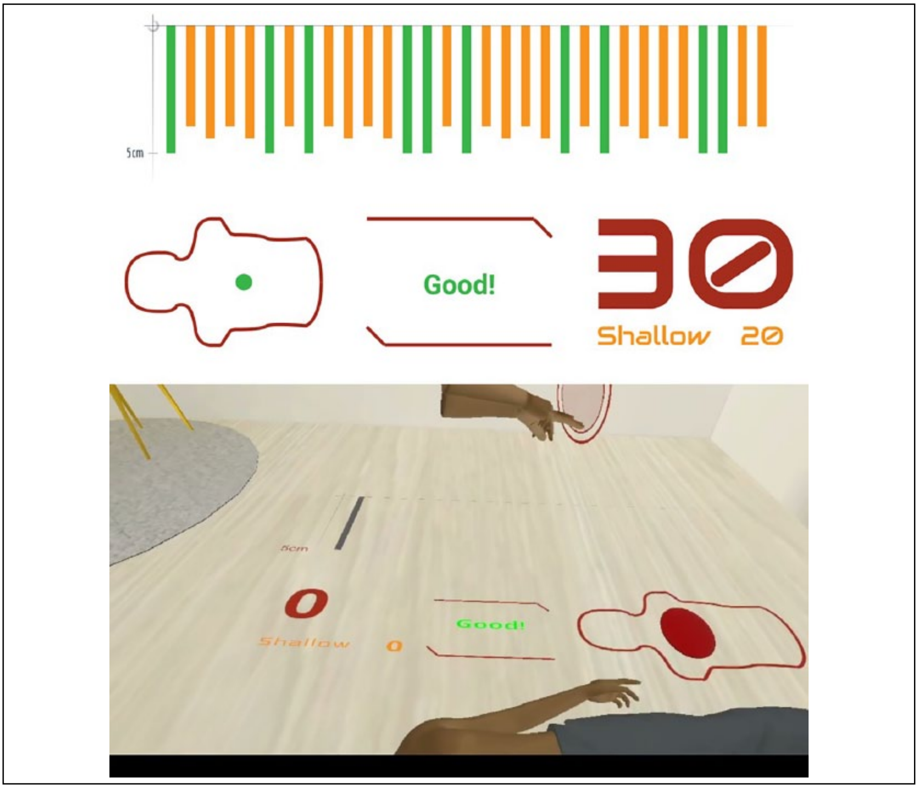


Figure 5. Real-time feedback of CPR performance.

  - evel three (Hard): Emotional and stressful audiovisual distractions with no real-time feedback or guidance.
- Basic CPR skills are taught in each scenario including; chest compressions, rescue breathing and AED. A demonstration of each skill is performed by an instructor guiding the trainee with simplified steps and clear language. A practice session following each skill is provided with real-time feedback and audiovisual guidance to allow for self-assessment and correction for optimal performance.
- Real-time feedback is projected in VR space during CPR performance and includes accurate measurement of chest compression's rate, frequency (optimal 100-120/min), depth (2-inches), and full chest recoil. The feedback also provides information about correct hands' position (chest center), and shallow/failed compressions [Figure 5].
- AED steps are explained and practiced in the virtual scenario through clear instructions.
- Scoring system with informative feedback about the trainee performance is provided at the end of the learning experience, for complete assessment and refinements [Figure 6].

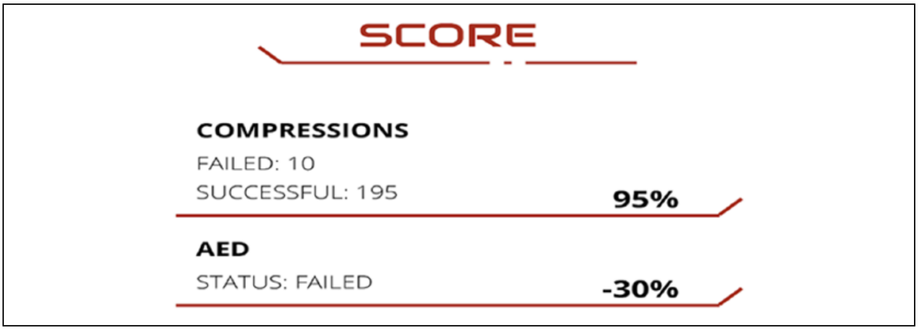


Figure 6. Scoring system with informative feedback and assessment.

- The application allows collection of performance data for effective evaluation and management of training by the trainee himself or an instructor.

Results and User Tests

In order to assess the functionality and accuracy of the proposed VR application, user tests were carried out during the development process to guide future strategies and iterations. The purpose of user tests was to guide with the developmental process and technical aspect of the application and was not for research purposes. Like any newly developed application or game, tests are done to make sure that the general design and features are functional, easy to follow and comprehend, and perceived correctly by public users. Research studies to measure the validity and effectiveness of this VR-hybrid system in comparison to other CPR training methods will be conducted in future at a later stage.

We had two formal user tests during the development process, with 10 participants per each test. User tests were structured to allow 30-40 minutes for each participant to fully experience the VR-app. Participants were then interviewed with open-ended questionnaires to allow free and detailed feedback [Figure 7]. Those questions were formulated to be specific to our VR-app and its features with the goal to assess users' 1) engagement and immersion, 2) ergonomics and performance, and 3) skills' confidence and relevant behavior change. In addition, observational notes were recorded by a team member on participants' behavior with each prototype testing. Key points from both questionnaires and observational notes were summarized to direct our work with necessary alterations to achieve project goal and objective [Table 1].

The VR-CPR application designed to be generic, friendly, approachable and easy to follow. This hybrid CPR simulation technology was designed to provide the following features:

1- Realism and Interaction

Realistic 3D virtual scenes simulating common sites at which cardiac arrest may occur are provided and the trainee can choose one of the sites. Active interaction was

A sample of 10 subjects were interviewed following the Test of the prototype.

Questionnaire

General

- What is your age?
- What is your occupation?
- Have you had CPR training before?
- Have you had previous experience with VR technology?

Engagement

- Can you describe your overall experience with this CPR training?
- On a scale from 1 to 5, how engaging was the experience?
  - o 1 means extremely boring
  - o 2 means moderately boring
  - o 3 means neither boring nor engaging
  - o 4 means moderately engaging
  - o 5 means highly engaging

  a. Would you tell us more about why you gave that answer?

  b. What could be improved to make it more engaging?

Comprehension and Performance

- Can you describe what you learned with this CPR training?
- How did the videos impact your experience? Did they help or not, and why?
- On a scale from 1 to 5, how easy was it to follow the instructions and navigate through the VR-app? and why?
  - o 1 means extremely difficult
  - o 2 means moderately difficult
  - o 3 means neither difficult nor easy
  - o 4 means moderately easy
  - o 5 means very easy
- Was there any part of the VR-app that you could not understand or was difficult to follow? Please explain.

Ergonomics

- On a scale from 1 to 5, how comfortable are you physically with our prototype?
  - o 1 means extremely uncomfortable
  - o 2 means moderately uncomfortable
  - o 3 means neither comfortable nor uncomfortable
  - o 4 means moderately comfortable
  - o 5 means highly comfortable
- Would you tell us more about why you gave that answer?

Overall experience

- Can you describe your overall experience with this CPR training?
- Did the VR-simulation have an impact on your willingness to perform CPR in real life?
- What would enable or encourage you to perform CPR in real life?
- Is there anything else you would like to add?

Figure 7. User tests questionnaire.

Table 1. VR-CPR Prototype User Tests Key Points.

Feature	Prototype-A Test	Prototype-B Test
Age	90% aged 19-30 years old	85% aged 25-35 years old
VR Experience	90% had experienced VR previously	70% had experienced VR previously
CPR Training	50% had received previous CPR training	30% had received previous CPR training
Engagement	30% found the experience engaging	90% found the experience engaging
Theoretical Videos	80% found videos too long and boring for VR	Videos were removed
Quiz	70% found the quiz helpful, and requested explanations	100% found the quiz and explanations very helpful (explanations added)
Holographic Effect	100% did not find the effect immersive or engaging	Holographic effect removed
Practice Time	100% requested more time for practice	100% stratified about practice time (Practice time increased from 30% to 80%.)
3D-CPR Skills Demonstration	Not available	100% found them very useful and engaging
Interface	60% liked the interface	95% liked the interface
Audio and visual effects	60% found them immersive	100% found immersive
Scenarios	30% found them realistic	90% found them realistic
Gamification (Difficulty Levels of Scenarios)	Not available	100% liked the idea and found it exciting and engaging
Haptic Feedback (Mannequin)	100% found the haptic feedback very realistic but had difficult time finding their hands in VR space.	100% found the haptic feedback realistic and hands were easy to position in VR space (3D virtual illustration of hands added)
Performance Feedback	100% liked the real-time feedback, and requested feedback summary at the end.	100% liked the real-time and summary feedback.
Performance Guidance	Video, audio-visual guidance, real-time feedback	3D-Demonstrations, audio-visual guidance, real-time and summary feedback
Confidence in CPR Performance Post-training	30% felt confident to perform CPR after VR training	85% felt confident performing CPR after VR training
Ergonomics and Timing	100% found theoretical videos too long and exhausting for VR experience, but happy with the rest of the equipment.	100% were happy with the set-up environment and the training time (videos removed)
Comprehension and Navigation	70% found the prototype easy to navigate, but requested instructional demos, audiovisual guidance, and more practice time	100% found the prototype easy to navigate, understand, and follow through (instructional demos, audiovisual guidance, and practice time were added)
Gamification (Scoring System and Leader Board)	Not available	100% found it encouraging and engaging.

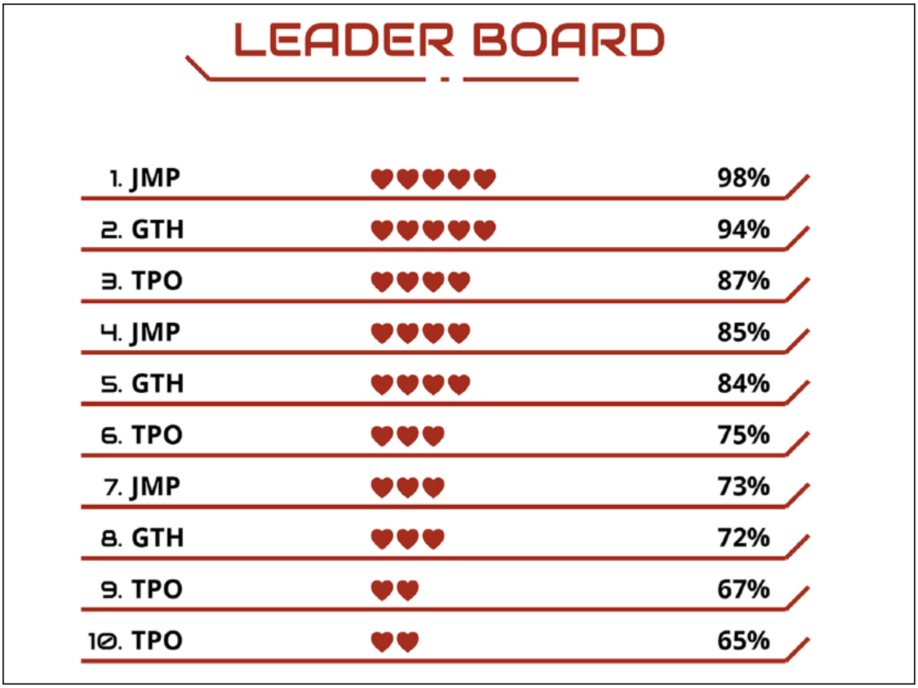


Figure 8. Leaderboard for gamification and engagement.

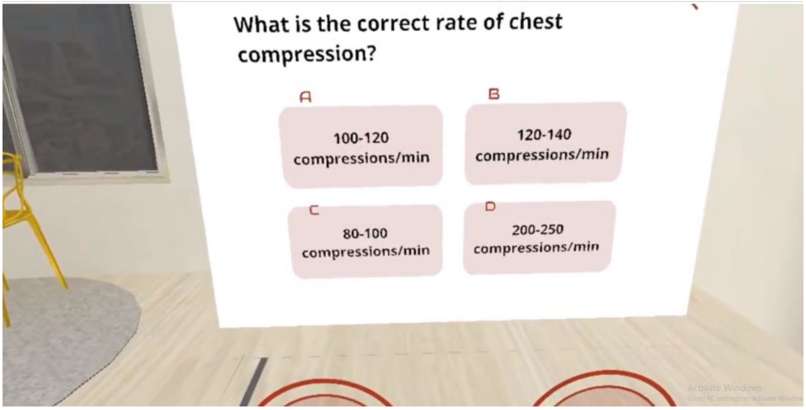
maintained during the course of training through visual and auditory feedback regarding the user action.

2- Engagement and Gamification

The application provides incentives for the users to engage in repeated use of the application, such as by providing different scenarios, events, environments, characters, or by incorporating gamification mechanics such as scoring and leaderboards [Figure 8].

3- Immersion and Haptics

To simulate realistic physical resistance of a victim's chest during CPR and to provide high-quality training, technical solutions were widely explored. Although VR-haptic gloves are not yet available in the market, several companies are currently developing haptic gloves for Virtual Reality applications. However, most of these gloves currently have three downsides or inconveniences: (i) Most of them have an ergonomic design that potentially interferes with necessary CPR hands positions and movements, (ii) Most gloves can track hand position in 3D space, some are capable of tracking fingers and hand gestures, but none seem capable of tracking acceleration or forces; and (iii) They are currently very expensive to consumers.



Video 1. Project final application prototype.
https://drive.google.com/open?id=1DpXahfhXpajPmNEk0qj_bw1tPvwc50Ik

The idea of adopting a physical object like CPR mannequin into the VR environment was then introduced and found to be the best current solution. This hybridization required a creative integration of a real object in the virtual environment as previously explained, which resulted in a realistic haptic feedback and resistance.

4- Accessibility and compatibility

VR-CPR application was designed to be accessed on common and popular platforms such as HTC VIVE or Oculus, and do not require any special hardware or equipment.

Video link to final project prototype https://drive.google.com/open?id=1DpXahfhXpajPmNEk0qj_bw1tPvwc50Ik

Discussion

Role of Digital Technologies and Virtual Reality in Healthcare and Education

Digital revolution and rapid evolvement of technology over the last three decades have greatly influenced the shape of education and provided promising tools for creative learning. The emerging formats of technology-enhanced learning, from e-modules to sophisticated simulations, are designed to improve academic knowledge acquisition and performance (Dankbaar, 2014). Therefore, the use of different technologies in education has grown rapidly to facilitate learning, skill coordination, perceptual variation, decision making, critical events practice and psychomotor skills (Guze, 2015).

In healthcare, the role of technology was developed primarily in response to challenges facing medical education and the need to demonstrate adequate competencies in the learner (Guze, 2015). The goal of modern teaching curricula is to educate trainees efficiently and in a safe learning environment (Barsom, 2016). Different means of technologies such as podcasts and videos, mobile devices apps, video games, simulations, virtual/augmented reality and wearable devices (google glass) are utilized to achieve this goal (Guze, 2015).

Simulation in medical and healthcare education covers a spectrum of sophistication, from simple 3D representations of body parts to complex high-fidelity human patient simulators with variable physiological features and capabilities. Virtual reality simulation refers to recreation of real environments and objects as a 3D complex and computer-generated image (Guze, 2015). VR is an innovative and emerging tool in healthcare providing a promising opportunity for training in surroundings where exploration and troubleshooting are safe. VR simulation modalities create digital environments and scenarios designed to resemble aspects of the real world, where trainees learn tasks in a setting closely mimicking relevant realistic situations. While augmented reality technology offers integration of virtual objects into the real-world environment, VR applications are completely immersive because they replace the surroundings with 3D virtual space projected inside a head-mounted display. Studies that assessed the effect of simulation on learners reported a marked increase in knowledge, technical skills, comfort, confidence, as well as transfer of skills to reality (Barsom, 2016). For those reasons, we chose a VR-based learning system over other technologies to achieve our project goal.

Value of Gamification and Immersive Features in Education and Learning

The immersive experience in VR along with other features such as gamification, and real time feedback have shown numerous benefits in education and clinical settings due to their unique engaging potential. This was proven in clinical studies for rehabilitation of post-stroke adult patients and challenging cases of pain management, showing several advantages over conventional therapy (Nicola, 2017). Gamification features were therefore designed in our VR-CPR application in the form of different difficulty levels of scenarios (easy to hard), scoring system and leaderboard. Gamification has shown to not only avoid boredom throughout the learning experience, but also enhance engagement, memory retention and recall process, thus improving overall performance over time. Moreover, feedback and assessment are critical in education, especially when learning something new, so learners can quickly adjust accordingly (Rego, 2018). Our VR application provides real-time feedback during CRP performance, allowing immediate self-awareness and correction while still in the mindset of learning (in real-time). Further, a detailed and informative feedback is outlined following each training session, for self-directed learning, reflection, and performance optimization.

Value of Interactive Features and Engagement in Education and Learning

Motion and gesture tracking are invaluable features which bridge the gap between the real and the virtual, making the VR learning environment extremely immersive and engaging, and significantly improves the quality of training. The interaction of a user with a VR environment empowers learning acquisition and creates an all-encompassing sensory experience (Eisenberg, 2017; Rego, 2018). This was accomplished in our application through an innovative integration of virtual planes design and a wearable device (VIVE Tracker).

Value of Haptic Feedback and Realism in Training and Performance

Touch and tactile sensation clearly add a vital and absent dimension to VR that has immense potential to transform the whole VR experience, enabling an advanced level of realism, engagement and immersive interaction with the educational task. A realistic training environment with haptic feedback -though is still in its infancy- is the ultimate learning experience in VR. Currently, the capabilities of VR-haptic devices are under development and far from consumers' hands (Microsoft blog Editor, 2018). The introduction of real-object (mannequin) in our VR application was designed to provide this tangible feature of haptics to enrich the learning experience and consolidate the training quality.

Value of Accessible VR-Hybrid System in CPR Learning and Training

The realism and potential of interaction with VR engines make them promising tools for innovative teaching in healthcare simulation such as CPR, where trainees can learn and practice their skills in realistic virtual scenes resembling common sites at which cardiac arrest may occur. Thus, providing emotional and psychological aspects to technical training, and offering almost real-world experience in a harmless virtual environment. Although theoretical based resources for CPR training are numerous, hands-on modalities offering quality training and practice are scarce. To date, traditional classroom courses are the primary source of CPR training. Conventional face to face teaching methods remains crucial, but also comes with limitations and challenges that could be solved with the aid of technology and VR tools. In fact, many researchers have suggested that VR training systems are proven effective, and with higher immersion, users can get better training results (Zhang, 2017). We designed our application to fill the gap in CPR training resources, providing self-directed learning system focused on technical skills and hands-on training, which could be used independently or as an adjunct to theoretical and traditional courses. This technology would facilitate CPR training for new learners and ongoing practice for old/experienced learners or healthcare professionals. In addition to its educational value, the accessibility, portability, and self-directiveness of this VR-learning system empowers learners to have a degree of control over time, pace and place of their learning. This is not only critical for individuals needing accessible education, but also very useful to organizations/institutions seeking CPR skills in their employees/students, saving time and cost with unlimited reusability.

Just like any other emerging technology, in recent years VR tech has progressed significantly in size, portability, cost, and potential, along with the growing interest of consumers in all industries. According to experts, VR is indeed the platform of tomorrow. It will dramatically influence health and education, reducing time and cost, and improving quality. Moreover, it won't supersede all traditional education methods, but it will augment them, just like the internet did.

Conclusions

We believe that the final prototype of this project has addressed concerns and limitations regarding current means of CPR training. Restrictions of time, place, and personnel are major challenges with conventional CPR courses. These courses are essential and valuable for CPR teaching, but alternative methods are required to facilitate access. Most of the digital resources for CPR training are based on theory and do not offer structured hands-on training. Nevertheless, ongoing practice is critical to build confidence to perform CPR when the situation requires.

Our VR-CPR system has the following strengths: 1) Accessible with no time, place, or personnel restrictions, 2) Self-directed learning and structured feedback system, 3) Reliable tool for both initial training and ongoing practice, 4) Hybrid technology with haptic feedback enabling realistic and immersive hands-on training.

Limitations

The main current limitation for wide adaptation of this technology by interested individuals is overall cost. Having said that, VR cost has fallen tremendously in recent years and expected to be quite affordable for public users in near future. As an innovative technology, the VR user-base is generally limited by cost and content. The rapid growth of content and adaptation by most industries will eventually lower the cost and expand the userbase. Other limitations include the lack of haptic feedback with AED steps and lack of sensors or an equivalent VR-technology for detection and evaluation of rescue breathing performance. VR-induced motion sickness could be a limiting factor in some individuals.

Future Directions

1- Research based validation of this technology in CPR training and comparison with existing traditional modalities is important.
2- With advancements in technology and development of VR haptic gloves, we hope to find an alternative for the mannequin while maintaining haptics and quality training.
3- The growth of this project would involve further development of high fidelity scenarios with diverse effects and situations.
4- The addition of debriefing system to training sessions, would optimize the learning benefit.
5- We look forward to exploring possibilities in collaborating with heart associations to augment current means of CPR training with this innovative technology.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

References

Barsom, E. Z. (2016). Systematic review on the effectiveness of augmented reality applications in medical training. *Surgical Endoscopy*, *30*(10), 4174-4183.

Blewer, A. L., Ibrahim, S. A., Leary, M., Dutwin, D., McNally, B., Anderson, M. L., ... & Callaway, C. W. (2017). Cardiopulmonary resuscitation training disparities in the United States. *Journal of the American Heart Association*, *6*(5), e006124. doi:10.1161/JAHA.117.006124

Canadian Red Cross. (2012). *Number of Canadians trained in first aid at dangerous low, suggests new poll*. [Online]. Retrieved from https://www.redcross.ca/about-us/media-news/news-releases/number-of-canadians-trained-in-first-aid-at-dangerous-low,-suggests-new-poll

Dankbaar, M. (2014). Technology for learning: How it has changed education. *Perspectives on Medical Education*, *3*(4), 257-259.

Eisenberg A. (2017). *Gesture Recognition and Its Importance in VR. Retrieved from AppReal-VR*. [Online]. Retrieved from https://appreal-vr.com/blog/gesture-recognition-in-virtual-reality/

Guze, P. (2015). Using technology to meet the challenges of medical education. *Transactions of the American Clinical and Climatological Association*, *126*, 260-270.

Heart and Stroke Foundation of Canada. (2010). Position Statement on CPR. [Online]. Retrieved from https://resuscitation.heartandstroke.ca/guidelines/position/CPR.

Li, L., Yu, F., Shi, D., Shi, J., Tian, Z., Yang, J., Wang, X., … Jiang, Q. (2017). Application of virtual reality technology in clinical medicine. *American Journal of Translational Research*, *9*(9), 3867-3880.

Meaney, P. A., Bobrow, B. J., Mancini, M. E., Christenson, J., De Caen, A. R., Bhanji, F., ... & Aufderheide, T. P. (2013). Cardiopulmonary resuscitation quality: improving cardiac resuscitation outcomes both inside and outside the hospital: a consensus statement from the American Heart Association. *Circulation*, *128*(4), 417–435. doi: 10.1161/CIR.0b013e31829d8654.

Microsoft blog Editor. (2018). *Touching the Virtual: How Microsoft Research is Making Virtual Reality Tangible*. [Online]. Retrieved from https://www.microsoft.com/en-us/research/blog/touching-virtual-microsoft-research-making-virtual-reality-tangible/

Nicola, S. (2017). VR medical gamification for training and education. *Studies in Health Technology and Informatics*, *236*, 97-103.

Perlin K. (2018). *The Future Reality Lab Daily Blog*. New York University. [Online]. Retrieved from https://frl.nyu.edu/welcome-to-the-future-reality-lab-daily-blog/

Rego, S. (2018). Virtual reality gamification and the revolution of education. *Vectorsolutions*. [Online]. Retrieved from https://www.vectorsolutions.com/news-media/news/virtual-reality-gamification-evolution-education/

Semeraro, F., Frisoli, A., Loconsole, C., Bannò, F., Tammaro, G., Imbriaco, G., ... & Cerchiari, E. L. (2013). Motion detection technology as a tool for cardiopulmonary resuscitation (CPR) quality training: a randomised crossover mannequin pilot study. *Resuscitation*, *84*(4), 501-507. doi: 10.1016/j.resuscitation.2012.12.006.

Zhang, H. (2017). Head-mounted display-based intuitive virtual reality training system for the mining industry. *International Journal of Mining Science and Technology*, *27*(4), 717-722.

Author Biographies

Omamah Almousa is a physician surgeon training in Canada with an interest in utilizing new technologies to enhance surgical and medical education. She has participated and co-authored clinical studies in evolving surgical techniques and procedures. Also, she has directed few national health-related campaigns for training and awareness. Almousa believes in creative education and innovative learning experience.

Contact: Omamah.Almousa@gmail.com

Joana Prates is a UI/UX Designer. Joana Prates' first degree was a Bachelor of Architecture and Urban Planning. She has 6 years of experience in interior design before diving into the digital world.

Contact: joanamirandajm@gmail.com

Noor Yeslam is a Motion graphics designer from Saudi Arabia. She is currently a motion graphic designer at CanHealth International in Vancouver, Canada,

Contact: nooryeslam@gmail.com

Dougal Mac Gregor is a game and digital enterprise consultant who carries out market, industry, and user research to evaluate the potential and feasibility for new and innovative products and services.

Contact: dougalmgu@gmail.com

Junsong Zhang is a teaching and learning technology strategist at Kwantlen technology. He develops training and consult with faculty on the interface between technology and pedagogy. Junsong has a particular interest in e-learning, game-based learning and designing AR/VR/MR for education.

Contact: zhangjunso77@gmail.com

Viet Phan is a software developer. His majority of work was with software programming languages (C++, Python, Java, C# and Matlab). His main interest is in digital arts, especially in character design.

Contact: Viet_Phan@thecdm.ca

Marc Nielsen is a Danish Programmer enrolled at Dania Games, located in Grenaa (Denmark), where he studies Computer Science.

Contact: marc2036@student.eadania.dk

Richard Smith is the Director of the Master of Digital Media program at the Centre for Digital Media and a Professor in the School of Communication at Simon Fraser University.

Contact: smith@thecdm.ca

Karim Qayumi is a Professor of Surgery at The University of British Columbia and the Paetzold Chair of Technology Enabled Learning for Vancouver Coastal Health. Dr. Qayumi has completed a variety of research projects including the artificially intelligent interactive multimedia software called CyberPatient and an online learning delivery system, electronic Platform for Education and Research (e-PER).

Contact: akqayumi@gmail.com