

Research paper

Teaching cardiopulmonary resuscitation using virtual reality: A randomized study

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ARTICLE INFO

Article history:

Received 17 April 2023

Received in revised form 17 July 2023

Accepted 14 August 2023

Keywords:

Nurse

Innovation

Cardiopulmonary resuscitation

Virtual reality

Serious gaming

Salivary alpha-amylase

Clinical simulation

ABSTRACT

Background: The main functions of nurses include training and health education. In this sense, we must be able to incorporate new technologies and serious game to the teaching cardiopulmonary resuscitation.

Methods: a multicenter, comparative and cross-sectional study was carried out to assess the learning of resuscitation of a group that was trained with the use of serious gaming with virtual reality, as compared to a control group trained with conventional classroom teaching.

Results: the mean quality obtained in chest compressions for the virtual reality group was 86.1 % (SD 9.3), and 74.8 % (SD 9.5) for the control group [mean difference 11.3 % (95 % CI 6.6–16.0), $p < 0.001$]. Salivary Alpha-Amylase was 218.882 (SD 177.621) IU/L for the virtual reality group and 155.190 (SD 116.746) IU/L for the control group [mean difference 63.691 (95 % CI 122.998–4.385), $p = 0.037$].

Conclusion: using virtual reality and serious games can improve the quality parameters of chest compressions as compared to traditional training.

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1. Introduction

The European Resuscitation Council (ERC) recommends training the general population on basic life support (BLS) skills [9]. The annual incidence of Out-of-Hospital Cardiac Arrest (OHCA) in Europe is between 67 and 170/100,000 inhabitants [18]. Early cardiopulmonary resuscitation doubles the rate of survival, but on some occasions, those who could provide help when needed do not act for various reasons, mainly the lack of training (3,4) and the stress created. A recent systematic review evaluating psychological and behavioral factors inhibiting laypersons' willingness to perform CPR identified the strong emotion of the situation as a factor that prevented initiation of CPR. Elements of emotional distress, such as panic, discomfort, and stress were identified in up to 42% of calls in which callers expressed reluctance. Other limitations for not initiating CPR were beliefs of physical incapacity of the rescuer, lack of confidence, feeling unprepared, fear of harming the person or legal consequences, as well as unfavorable environmental context or fear of infection among others (Farquharson et al., 2023).

Therefore, one of the main questions in health is: how can we improve training in cardiopulmonary resuscitation (CPR)? Perhaps the use of technology, using serious games, will help us answer this question, especially with children and adolescents. Serious games have been shown to help health students develop and apply their learning in situations that they may encounter in the future, as that the risks to the students and the users of the service are reduced [16]. VR was described successful to teach echocardiography (Mahmood et al., 2018) or the placement of a central venous catheter (Huang et al., 2018). In addition, high-fidelity simulation systems aimed at CPR training significantly improve both the acquisition and retention of knowledge and skills over time in nursing students (Aqel et al., 2014).

2. Theoretical framework

The main objective of the present study was to analyze the effect of a serious game on quality of chest compressions, through the use of Virtual Reality (VR) goggles to provide CPR training, as compared to a group who was trained with a traditional training. The second objective

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<https://doi.org/10.1016/j.auec.2023.08.002>

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was to analyze if there were differences in the level of stress generated by each education activity.

CPR training should start in schools as recommended by the ERC in its KIDS SAVE LIVES program where it concludes that basic life support training for school children has the potential to educate entire generations to respond to cardiac arrest and increase survival (Schroeder et al., 2023).

This training should be a combination of theoretical and practical training where the use of virtual learning environments as part of a time and place independent, self-directed learning approach is a recommended option for all levels of CPR courses [9].

These new technologies arouse more interest and increase learner motivation (Bransford et al.). In this sense, the use of new technologies such as serious games or virtual reality could be used as a tool to teach an increasing number of people, improve the level of acquired skills and knowledge, and provide more comfortable and frequent learning opportunities for learners. VR provides an immersive experience for users, resulting in improvements in procedural memory [12], speed, accuracy and transfer to real-life situations, compared to instructor-led training [10].

Serious games are educational games developed to stimulate learning in an interactive and intuitive way, accelerating critical thinking skills needed to address clinical complications and care planning (Johnsen et al., 2016; Romero et al., 2015). These are one of the most prominent technological strategies for teaching CPR (Lewis et al., 2016; Saunder & Berridge, 2015).

Despite their advantages, new technologies have serious limitations for BLS teaching. Different studies have evaluated the learning of CPR, and the long-term continuity of knowledge. Some indicate that this skill is forgotten in the first 3–6 months after initial training (Aksoy, 2019; Sena et al., 2019).

Therefore, developing techniques to update and maintain CPR knowledge is just as important as teaching it. In this context, serious games can be adequate tools, as they are not only utilized to complement learning, but also to expose students to new situations, transmitting to them the feeling that they are in a specific place, and allowing them to interact and learn from their mistakes, thus updating and improving their knowledge [6,26]. Clinical simulation induces stress, both psychological and physical, and this stress seems to be even more pronounced than that associated with traditional learning, and even with daily clinical work [4,19]. Within the methods utilized to evaluate stress, we find the measurement of different biochemical stress mark-

ers, such as salivary alpha-amylase, whose concentration increases under psychological stress factors [22].

The main functions of nurses include training and health education, and in this sense, we must be able to incorporate new technologies to be at the forefront of teaching innovation.

3. Methods

A randomized study was carried out by a team of nurses who were also certified advanced life support instructors with experience in virtual clinical simulation. This team trained coaches from 15 football (soccer) teams, and analyzed their improvement in CPR quality after training with a serious game using VR goggles. The protocol was approved by the Ethics Committee from (blinded for review), with registration number CE022212, dated 02–25–2022.

The participants were randomly assigned to the Control Group (CG), who received training lasting 15 min, directed by a CPR instructor, or the Virtual Reality Group (VRG), in which a serious game was used through VR goggles, with the game lasting a maximum of 15 min as well.

3.1. Study population

A sample was obtained from a total of 75 coaches, belonging to 15 different football clubs from the Region of Murcia (Spain). The participants signed an informed consent form, and in the case of minors, the parent or tutors provided a signature. The following pathologies were defined as exclusion criteria: eye pathologies (i.e. correction glasses), neurological pathologies (i.e. epilepsy), age younger than 13 years old (as recommended by the VR goggle maker), or abandoning the study.

3.2. CPR training

The training of the members of the VRG was conducted with CPR simulator, a software program classified as a serious game and developed by the AAT VR® in collaboration with the First-8 (Fig. 1). In this game, the user wear VR glasses and picks up some haptic controls. The software allows several scenes (e.g. a room) but in our case the simulation starts in a park, with an unconscious person, with whom a chain of survival must be used: recognition of the lack of consciousness, calling 112, chest compressions, ventilation, and defibrillation with an automated external defibrillator (AED). The participant had to answer the



Fig. 1. Image of the experimental phase. On top, a participant from the virtual reality group, and on the right, screenshots of the CPR scenario the participant is watching. On the bottom, one of the control group participants performing CPR maneuvers. ERC: European Resuscitation Council.

questions asked by the system, at the same time that he or she moved the haptic controls to position the hands in the correct place manner to perform the techniques required (i.e., chest compressions). Si hay que ejecutar alguna acción concreta, el software presenta una sombra de manos para indicar como sería la acción. This action is activated when the user places his hands in the same position and place where the shadow is. The game can be programmed with different resources and CPR options. In our case, the student must first perform a complete cycle of 2 min of CPR before using the AED. The game ends if the student has correctly performed the steps, at which time the patient recovers consciousness and starts to talk. The following link demonstrates the serious game: <https://youtu.be/Hkg9NdFIG7A>. At the end of the simulation, the software offers a table with the results and time obtained during the simulation.

The training of the members of the CG was conducted in a classroom through a presentation projected onto a screen. The contents shown were the same as for the VRG, including the chain of survival: recognition of unconsciousness, calling 112, chest compressions, ventilation, and use of the AED. The training lasted 15 min and was divided into the following parts: (1) BLS theoretical presentation (2 min); (2) training conducted by a BLS instructor during the (8 min); (3) Clinical case and resolution of doubts (5 min).

3.3. Evaluation of the CPR quality

In this section, it was decided to only evaluate the percentage of correct compressions, eliminating the ventilations. The reason for this was to comply with the guideline of mandatory use of face masks that was in place when the study took place, due to the COVID-19 pandemic and the ERC [18], ILCOR and AHA ("Hands Only") recommendations in the case of out-of-hospital CPR, avoiding airway maneuvers (Couper et al., 2020; Edelson et al., 2020).

All the participants had to complete the chain of survival in its entirety and provide 2 min of CPR to a Resusci Anne QCPR® manikin (Laerdal Medical, Stavanger, Norway).

Assessment of compressions was performed by connecting a SimPad PLUS® (a wireless device that provides real-time feedback, recording data and performing a comprehensive analysis of CPR performance) to the manikin with Skill Reporter® software (Laerdal Medical, Stavanger, Norway). The software SimPad PLUS with SkillReporter® calculates an overall performance score (compression rate and depth). Compression quality score (%), which is the composite score of the above parameters, was calculated and provided by the software. Participants received 100 % if the guideline criteria for each variable (compression rate of 100–120 compressions per minute; depth of 5–6 cm; complete chest recoil between each compression; optimal hand position) were executed accurately.

3.4. Analysis of salivary alpha-amylase (SAA)

The concentration of SAA was measured in all the participants. The test was conducted immediately after the evaluation of the CPR quality was finished. The saliva was obtained through a passive diffusion system into a tube, with an extraction time of 1 min. Saliva was centrifuged immediately after collection at 3000 g for 10 min. Then, samples were placed in Eppendorf tubes and frozen to 80 °C for storage until the time of analysis. Saliva was evaluated by a solid-phase, competitive chemiluminescent enzyme immunoassay (Immulite; Siemens, Erlangen, Germany), displaying within-run and between-run imprecision lower than 10 %, recovery rates between 92 % and 120 %, and a limit of detection of 0.2 nmol/l (32, 33). IgA was evaluated with a commercial ELISA kit (Bethyl, Montgomery, TX, USA), with a within-run and between run imprecision lower than 10 %, recovery rates between 91 % and 112 %, and a limit of detection of 0.05 mg/l. Adiponectin was evaluated with a commercial ELISA kit (Human Adiponectin ELISA, High

Sensitivity Kit; Bio Vendor Laboratorni Medicina, Brno, Czech Republic), which showed within-run and between-run imprecision lower than 15 %, recovery rates between 90 % and 115 %, and a limit of detection of 0.50 lg/l. The method had an inter-assay coefficient variation of less than 3 %, and a linear regression coefficient of 0.992.

3.5. Statistical analysis

The main variable analyzed was the percentage of correct chest compressions. This value is measured is provided by the software based on the depth of chest compressions, rhythm and chest decompression and hands placement. The secondary variables were: rate (compressions/minute) and depth of chest compressions (mm), and salivary alpha-amylase concentration. Also, demographic data were taken from the participants (e.g., gender, average age in years). The data are presented below as frequencies, means, confidence intervals (CI95%), and standard deviations (\pm SD). The data was checking for normal distribution with the Kolmogorov–Smirnov test ($p \leq 0.05$). To compare the results between the two study groups, once the normality of the data was determined, Student's t test for independent samples was utilized. All the statistical results were obtained using the SPSS statistical package version 21 (IBM Company, New York, USA). The results were considered statistical significant when $p \leq 0.05$.

4. Results

A total of 63 coaches participated in our study, from 13 football teams, who were randomized by order of registration, into (1:1) the CG ($n = 32$) or the VRG ($n = 31$). The volunteers included in the study were all male with an average age of 23.6 ± 6.5 years. The average age was 24.1 ± 8.3 years for the VRG and 23.1 ± 3.8 years for the CG, with no significant difference observed between groups (mean difference: 1.0, 95%CI: 1.6–4.3, $p = 0.533$).

The VRG obtained better results than the CG in the quality, rhythm, and depth of the chest compressions (Fig. 2). The mean chest compressions quality of the VRG was $86.1 \% \pm 9.3 \%$ and $74.8 \% \pm 9.5 \%$ for the CG [mean difference 11.3 (95%CI 6.6–16.0), $p < 0.001$]. The mean rhythm of the chest compressions was 102.1 ± 13.3 compressions/min for the VRG group, and 89.0 ± 12.1 compressions/min for the CG [mean difference 13.1(95%CI 3.3–19.4), $p < 0.001$]. Within the recommended rhythm (100–120 compressions/min) [18], we found 54.5 % (18/33) of the VRG, and 25.8 % (8/31) of the CG. The mean depth of the chest compressions was 4.1 ± 0.9 cm for the VRG and 3.3 ± 0.9 cm for the CG [mean difference of 0.9 cm (95%CI 0.2–1.2), $p = 0.001$]. Within the range of depth recommended (5–6 cm) [18], we found 18.0 % (6/33) of the VRG, and 6.4 % (2/31) of the CG.

Lastly, with respect to the stress of the participants (Fig. 3), the mean SAA concentration before the study was 218.882 ± 177.621 IU/L for the VRG group, and 155.190 ± 116.746 IU/L for the CG [mean difference of 63.691 (95%CI 122.998–4.385), $p = 0.037$].

5. Discussion

The main results of our study show that the coaches who were trained by nurses with a serious game, through VR goggles, obtained better practical results in the chest compressions as compared to those who were taught through a theoretical class. These results are in agreement with other studies, such as that by Creutzfeldt et al. Creutzfeldt et al., (\$year\$) [5], which showed that a virtual reality game improved the learning of laypersons when faced with an emergency.

Better values were obtained by the VRG than the CG in the mean rhythm of compressions, as well as in their depth, although the recommendations from the most current ERC guidelines from 2022 were not achieved [18]. Similarly, in the study by Bohn et al., the participants were not able to obtain the recommended values either [2]. This indi-

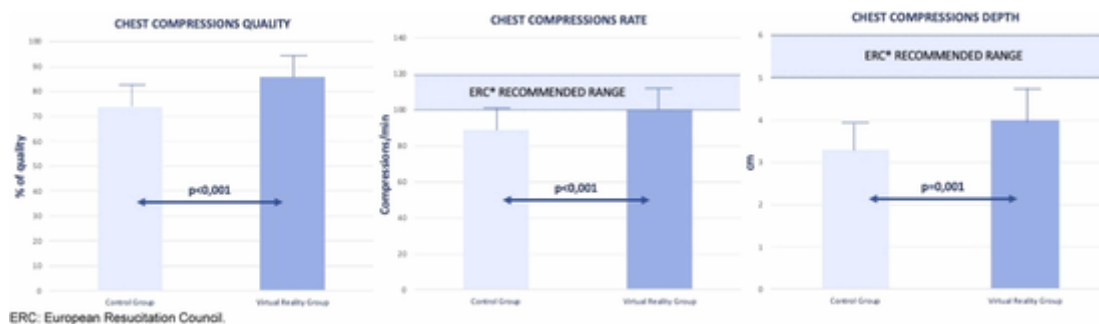


Fig. 2. Results on the quality, rhythm, and depth of cardiopulmonary resuscitation.

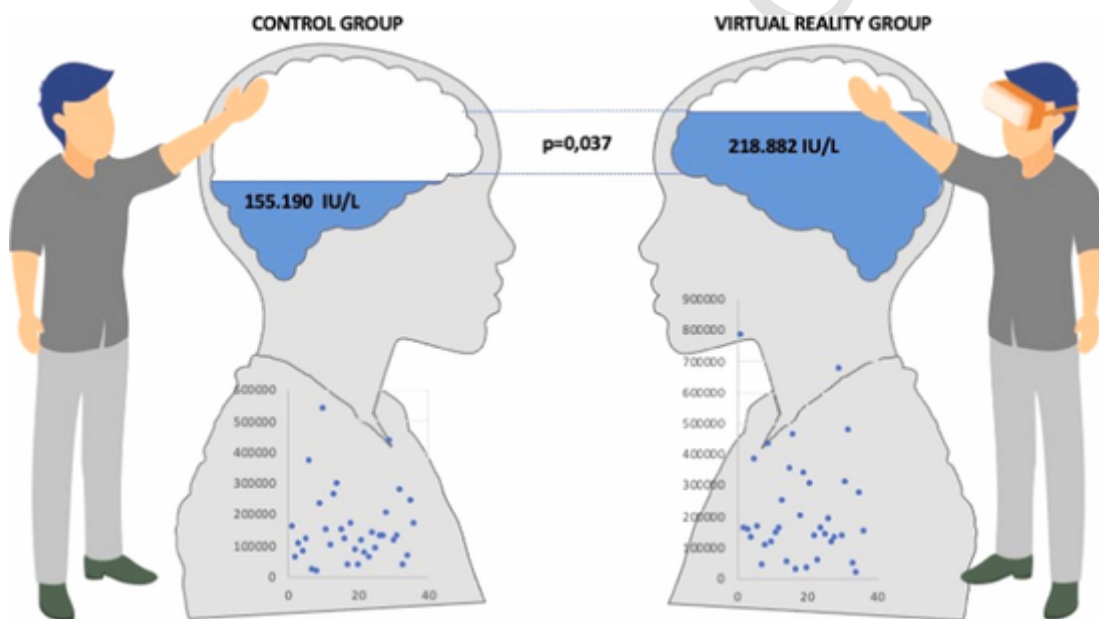


Fig. 3. Comparison of the mean results of the Salivary Alpha-Amylase concentrations between the Control and Virtual Reality Groups.

icates that improvements are needed in the design of the training or the game to re-enforce this concept; for example, students could receive immediate feedback to indicate possibilities of improvement, so that they can correct their technique immediately. It should be noted that there were low quality results of chest compression for the control group. This would justify the usefulness of CPR training. Specifically, the term cardiac massage (which may sound soft) should be eliminated and only the term chest compressions should be used. Using the term chest compressions helps the population understands that relatively high force and compression must be used in the technique.

The reproduction of virtual scenarios increases retention ability, with respect to traditional approaches [23]. Robert Kleinert et al. demonstrated this during the practical training of medical students through the use of immersive patient simulators, which included VR [13]. Another study described that the use of a simulated environment was applicable to diverse disciplines and allowed the learning of other skills such as communication, teamwork and decision-making in new situations [17]. Therefore, the present study confirms the results that were previously published in similar studies.

The duration of the sequence in this study was similar to a previous publication, in which the theoretical knowledge of students increased after watching a single 5 min video [7]. Marchiori et al. opted for longer videos (45 min), with similar results [14]. However, in our opinion, apart from an optimal duration, the most important aspect was that the system was able to ensure that students performed a better CPR, while at the same time motivated them in order to capture their atten-

tion, and to improve learning. If similar results were obtained in these studies, then shorter interventions could be utilized, as they have an added advantage in that they can be repeated more times and more often, thus favoring the performance of CPR skills through time, as recommended by the ERC [8,25]. Likewise, the need for less training time has other advantages, especially for re-enforcement training after some time has passed from the initial training. This decrease in time, in the work environment, could reduce costs and facilitate the integration of reminder courses.

With respect to the level of stress of the participants, a significant increase in the concentration of SAA after the VR simulation was observed. Takai et al. demonstrated, in their study with young healthy patients, that the levels of SAA significantly increased right immediately after watching a stressful video [22], just as Skosnik et al., in which a stressful videogame induced a 1.4 increase in salivary amylase [21]. More recently, it was shown that high-fidelity simulation scenarios induced the same changes in the concentration of SAA [1,24].

Our results are consistent with previous studies that showed that training with simulation was able to generate realistic stress [11,15,20]. Simulation training and the resulting emotional involvement can contribute towards the retention and consolidation of knowledge, and also the acquisition of appropriate behaviors during adverse events [3]. This interesting phenomenon has been described in the Yerkes-Dodson law, which states that performance increases with physical and/or mental stress, but only up to a certain point. When the levels of arousal are too high, performance decreases.

As the limitations of the study, we can point out the lack of knowledge about the previous training of the participants (no surveys were conducted to assess the previous level of theoretical knowledge) or level tests to assess their ability prior to training. The limited sample size in the study also poses a limitation for external validation. In addition, in this work we focus on the assessment of the performance of CPR and we do not use any theoretical evaluation of knowledge.

The present study demonstrates an improvement in practical skills in relation to traditional training, but without reaching the recommendations for depth and frequency of compressions established in the guidelines. Future lines of research should be aimed at assessing which digital training systems, including gamified learning, result in increased levels of CPR quality.

The reproduction of virtual scenarios increases retention capacity and VR, thanks to its immersive capacity, is capable of increasing the attention of users but, given the heterogeneity in the follow-up time of the studies and that some do not have subsequent follow-up, it would be interesting to conduct new studies to analyze the learning and forgetting curves with respect to knowledge and practical skills in CPR training.

Given that an adequate level of stress can contribute to the retention and consolidation of knowledge, it would also be interesting to determine the optimal levels of stress during training, without a loss of performance on the part of the trainee. Stress levels that would be optimal for improving learning performance without being detrimental are unknown. This is a future line of work that should be considered a priority for research groups.

6. Conclusion

Nurses should implement educational innovations, such as the use of virtual reality and serious games, as they can improve the quality parameters of chest compressions compared to traditional training. In addition, training with new technologies has the advantage of being able to reach more people in the same space of time, thus being a cost-efficient resource for population training in CPR compared to face to face training. The use of VR Glasses and Metaverse has a very big potential to enhance learning outcomes and address the limitations of traditional training methods. The students' experience through virtual reality also led to increased SAA concentrations in study participants, which could indicate a higher level of stress that could affect the acquisition and retention of knowledge.

Ethical Responsibilities

The study was approved by the Ethics Committee from the Catholic University of Murcia (UCAM), with registration number CE022212, dated 02–25–2022. All the participants provided their consent for participating in the study.

Funding

The present work was financed by research funds (PMAFI-09–2021) granted by the UCAM to the project entitled "Teaching innovation and inclusive didactic resources for the learning of Cardiopulmonary Resuscitation and First Aid of school-aged children". The authors declare that there are no possible conflicts of interest.

Declaration of Competing Interest

The authors declare that there is no conflict of interest in this work.

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