Evaluation of a 3D Serious Game for Advanced Life Support Retraining

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Abstract

Objective: Advanced life support (ALS) knowledge and skills decrease in as little as three months, but only a few ALS providers actually attend retraining courses. We assess the effectiveness of a 3D serious game as a new tool for frequent ALS retraining.

Methods: We developed a 3D serious game for scenario-based ALS retraining. The serious game, called EMSAVE, was designed to promote self-correction while playing. We organized a retraining course in which 40 ALS providers played two cardiac arrest scenarios with EMSAVE and took a test with 38 multiple-choice questions before and after playing. We administered the same test again 3 months later to evaluate retention. Participants also rated EMSAVE and the overall retraining experience.

Results: After using EMSAVE, the number of correct answers per participant increased by 4.8 (95%CI +3.4, +6.2, p<0.001) and all but one participant improved. After 3 months, despite an expected decrease in ALS knowledge and skills (-1.9 correct answers, 95%CI -0.6, -3.3, p<0.01), there was a significant retention benefit (+2.9 correct answers per participant, 95%CI +1.5, +4.2, p<0.001). Moreover, all but one participant regarded EMSAVE as a valuable tool to refresh ALS knowledge and skills, and 85% of participants were also willing to devote one hour per month to retrain with the serious game.

Conclusions: A 3D serious game for scenario-based retraining proved effective to retrain in ALS and supported retention of acquired knowledge and skills at 3 months. EMSAVE also positively engaged and motivated participants.

1. INTRODUCTION

Resuscitation Councils endorse *Advanced Life Support (ALS) training courses* in which *ALS instructors* (i.e., doctors and registered nurses who show distinguished ALS knowledge and skills, followed courses for instructors, and are regularly involved in ALS courses) train *ALS providers* (i.e., doctors and registered nurses who can be required to frequently or occasionally provide ALS to patients). More precisely, ALS instructors teach knowledge, decision-making and practical skills to new ALS providers or update already trained providers about new ALS guidelines, which are released every five years.

ALS training courses usually last a few days and effectively improve resuscitation competence,[1–3] yet there is invariably a significant decrease over time of the knowledge and skills acquired.[3–8] To ensure that ALS providers maintain their competence, *ALS retraining courses* (i.e., one-day courses in which ALS providers can refresh their knowledge and skills about ALS guidelines they are already trained on) are recommended.[9]

Unfortunately, although ALS providers are generally aware of their need for retraining, only a few actually attend ALS retraining courses.[10,11] Motivational and financial issues, along with time constraints imposed by work shifts, make it difficult to devote a full day to retraining. Moreover, even with sufficient resources, many centers plan retraining events once every two years, while several studies suggest that ALS knowledge and skills decrease in as little as 3 months.[8,12–14] Therefore, new approaches to facilitate compliance with the suggested retraining schedules and prevent knowledge and skills decrease are needed.

Computer-based training systems could offer a solution to these issues, since they allow trainees to follow different lessons individually and over time without the financial overhead and logistic issues involved in organizing a training course.[15–21] In addition, computer-based training systems can employ Virtual Reality (VR) techniques to create 3D virtual environments that are believable reproductions of the real world. In these environments, trainees can learn by directly interacting with virtual characters and objects as recommended by constructivist theories.[22,23] Moreover, they can take advantage of:

(i) realistic 3D graphics and sound that create an immersive experience which could be difficult and expensive to simulate in traditional training courses, (ii) different camera viewpoints and multimedia resources that illustrate important aspects of simulated patients, (iii) changes in virtual patients that give real-time feedback about trainees' actions, and (iv) animations that help in understanding complex situations and cause-effect relationships.[23]

VR systems for medical training have traditionally concentrated on the fidelity of the patient or organ simulation and of the actions that can be performed on them.[24–26] However, this may not be sufficient to motivate or engage learners.[27] Moreover, medical VR system often require expensive special hardware and software.[24,25] To overcome such limitations, there is a growing interest on building training systems, called *serious games,*[28] that employ video game techniques to better engage trainees and to be used on low-cost PCs.[29]

To build a serious game, an immersive and engaging story that embeds instruction is fundamental.[28] Moreover, serious games can exploit the familiarity of people with the interaction styles of entertainment video games to make the training system easier to use and more attractive. While playing, trainees may improve their skills with repeated attempts at completing game levels, failing and succeeding, understanding which strategies are successful.[27]

The aim of our study was to assess the effectiveness of a 3D serious game as a novel tool for frequent ALS retraining. In particular, the objective of the study was to assess the possible gain in ALS knowledge and decision-making skills after a retraining session with the serious game as well as retention three months later. In addition, we investigated the perceived effectiveness of the serious game and ALS providers' willingness to keep retraining with it.

2. METHODS

2.1 Serious game

The study used *EMSAVE*, a single-player serious game we designed to refresh trainees' ALS knowledge and decision-making skills by means of 3D scenario-based simulation. This section summarizes the main features of EMSAVE, which are also illustrated by a video in the supplementary material.

2.1.1 Gameplay

In EMSAVE, trainees control the leader of an ALS team that has to rescue a patient. The story behind each scenario begins with the trainee leaving the ambulance after being given the details of the phone call received by the emergency services. Scenarios can be set in different virtual environments such as a living room (Figure 1a) or a train station (Figure 1b). A game-controlled teammate has already found where the patient is in the environment. The trainees should navigate the virtual environment to reach the patient and then introduce themselves. The story evolves differently according to the scenarios. For example, additional characters such as relatives or bystanders can provide useful information, if asked properly. Trainees have to perform various examination (e.g., observe patient's chest, check for pulse or monitor vital signs), communication (e.g., elicit symptoms or medical history), and treatment tasks (e.g., ask the teammate to use a defibrillator or to administer a specific drug). To succeed in the serious game, trainees should choose appropriate tasks among several alternatives in an order recommended by ALS guidelines. If an appropriate task is selected, the serious game provides a multimedia presentation of its execution and effects (e.g., the breathing sound for the auscultation examination or the animation of the teammate administering a drug as in Figure 1b) and the trainee can advance in the scenario. If an inappropriate task is selected, the serious game considers the appropriate tasks already performed by trainees, the error made and current patient state, then it briefly summarizes the situation and provides hints for self-correction.

Figure 1: Two screenshots of EMSAVE: a) the trainee chooses a task to be performed on the patient in a living room environment; b) the teammate performs a task on the patient in a train station environment.

2.1.2 User interface

Preliminary studies (see Section 2.2) suggested us to prefer a point-and-click user interface that can be operated using only the mouse. In particular, during virtual environment navigation, mouse movement controls the rotation of the head of the trainee's character. Mouse cursor changes according to the target under it. The cursor is a white icon depicting small footprints when is over a position on the floor that can be reached by the trainee, a green star icon when over an interactive object or character, a red sign icon when over a non-interactive object.

When the icon is white, a left mouse click makes the trainee's character move towards the pointed position. When the icon is green, a left mouse click opens a pop up menu with which trainees can select a task to perform on the interactive target. For example, trainees can perform examination and communication tasks by clicking on the virtual patient and the associated menu (Figure 1a). Trainees can also click on the teammate to request the administration of specific treatments to the patient (Figure 1b), click on medical instruments to operate them (e.g., ECG monitor), and click on other characters to obtain further information about unconscious or non-cooperative patients.

A right mouse click opens the help menu, which allows trainees to review the list of appropriate tasks already performed as well as the textual description of examination outcomes. This is particularly useful for trainees who failed to understand an outcome (e.g., they did not correctly classify a breathing sound or a picture of airway condition). If trainees are stuck at a particular step of the ALS procedure, they can also use the help menu to get the list of tasks which are appropriate at that moment.

Finally, at the end of any scenario, a debriefing screen allows trainees to review the appropriate and inappropriate tasks they performed.

2.1.3 Implementation details

We developed EMSAVE using NeoAxis,[30] a 3D game engine programmable in C#. The serious game is a standalone application that can be run in full screen or windowed mode on Windows desktop and laptop PCs.

Knowledge about ALS procedures in the scenarios is represented with the ConcurTaskTrees (CTT)[31] task modeling formalism, augmented with an XML-based knowledge representation we defined to represent additional information (e.g., patient states, trainees' errors, and dialogs). In this way, ALS instructors can edit the knowledge in the scenarios by using a visual tool, without the intervention of computer programmers.

CTT is particularly suited to analyze and structure training procedures, since it allows instructors to hierarchically organize tasks, and specify relations among them by means of temporal operators such as sequential enabling (for tasks that should be performed in a predefined order), order independence (for groups of tasks that can be performed in any order), and choice (for alternative tasks). In particular, hierarchical organization supports the reuse of groups of tasks in different scenarios, thus reducing the effort required to extend the set of training scenarios. Once the correct procedure is modeled, it is used by the serious game to monitor procedure execution, comparing the tasks chosen by trainees with appropriate ones in the CTT.[32]

2.2 Preliminary studies

A preliminary prototype of EMSAVE was tested in a pilot study on 12 nurses of the local emergency medical service to evaluate its usability as well as perceived usefulness and possible acceptance as a training tool.[33] More precisely, the pilot study focused on technical aspects such as navigation in the 3D virtual environment (found simple and quick to learn by, respectively, 10 and 11 nurses), task selection (found quick to learn by 11 nurses), graphics and sound (appreciated by 11 nurses). Moreover, we asked nurses if they thought the serious game could increase their knowledge and skills (11 agreed) and could integrate well with traditional training methods (all agreed), as well as if they felt involved in the experience (11 agreed) and were willing to use the serious game (11 agreed).

The pilot study was followed by an iterative prototyping phase which included several informal evaluations with ALS providers and instructors. All the collected suggestions and comments contributed to greatly improve the prototype, leading to the serious game described in Section 2.1 and evaluated in this paper.

2.3 Present study

The present study focused on a retraining course and included a retention test three months later. Three cardiac arrest scenarios requiring trainees to correctly perform different ALS procedures were developed in two different virtual environments: a living room (Figure 1a) and a train station (Figure 1b). ALS instructors in our team (TP, a medical doctor certified by the American Heart Association, and DP, a registered nurse certified by the European Resuscitation Council) wrote the training scenarios and refined them with other five ALS experts (EC, a medical doctor and director of an emergency medical service, as well as two doctors and two registered nurses external to the team). The ALS retraining course lasted half a day and was organized jointly with the hospital training center of the Santa Maria della Misericordia University Hospital in Udine, Italy.

2.3.1 Participant recruitment and setting

Participants were recruited on a voluntary basis, and received 6 CME credits for attending the course. The course was advertised: a) on the hospital website, in the training center page that lists all upcoming courses available to healthcare professionals; b) in a monthly hospital bulletin; c) on a leaflet sent to all the hospital departments dealing with emergencies or critical patients in the Friuli Venezia Giulia region of Italy (a total of 14 hospitals); d) by directly informing the head nurses of these departments via e-mail or phone. Since the course was meant for refreshing ALS knowledge and skills in already trained ALS providers, we admitted only participants who had already followed an ALS training course. In particular, we required them to be trained according to the 2005 guidelines, since the 2010 guidelines had been released only a few months earlier.

Four retraining sessions took place in May 2011 with 10 participants per session, in a classroom of the University of Udine. Each participant used an individual PC with earphones.

2.3.2 Procedure

During the retraining course, participants went through 7 steps:

1. They were administered an initial questionnaire concerning demographics (age, gender), computer use (items 1 to 5 in Table 1), and ALS (items 6 to 11 in Table 1).
2. To assess their baseline ALS knowledge and skills, they took a multiple-choice ALS test with 38 questions (*pre-test*). The ALS test, available as supplementary material of this paper, was created by the ALS instructors in our team, who also wrote the training scenarios, and was checked by an external ALS instructor (a registered nurse, certified by the European Resuscitation Council). The ALS test was specifically designed to asses knowledge and decision-making skills that could be refreshed by playing the training scenarios. For example, questions dealt with symptoms manifested by virtual patients during the scenarios, diagnoses trainees should make after checking them, treatments to perform and when they are recommended. Correct answers to the ALS test were not revealed to participants after the test, since we were going to use the same ALS test to evaluate retention. Step 1 and 2 were allotted a total of 30 minutes.
3. Software designers and developers FB (PhD in Computer Science) and ACV (PhD student in Computer Science at the time of the study) provided a 15-minute tutorial on how to move, perform tasks and obtain help from the 3D serious game.

4. Participants played a cardiac arrest scenario to familiarize with the serious game, its controls and interface (30 minutes). During this familiarization scenario, which was not subject to evaluation, participants could ask experimenters for assistance or further explanations about how to use EMSAVE at any time.
5. Participants played two retraining scenarios during which they could not ask experimenters for assistance and could rely only on EMSAVE help if they made any error. Both scenarios concerned a critical patient whose condition worsened, resulting in a cardiac arrest, but the causes were very different (respectively, anaphylactic shock and ventricular tachycardia deteriorating into a pulseless tachyarrhythmia) requiring participants to handle them in distinct ways. The 3D virtual environment was also different: a living room for the first scenario and a train station for the second. In both scenarios, participants had to reach the patient and perform the necessary tasks to handle the emergency, interacting with a virtual teammate and, when appropriate, with a patient's relative. A total of 1 hour (about twice the average time required by an experienced EMSAVE user to complete the two scenarios) was allotted for this step.
6. The ALS test was administered again, this time as a *post-test* to assess possible improvements.
7. Participants were administered a final questionnaire concerning possible retraining frequency with the serious game (item 1 in Table 3), perceived validity, effectiveness, willingness to use, usability, engagement, and overall appreciation, measured as level of agreement to 12 statements (2 to 13 in Table 3) on a 5-value Likert scale. Step 6 and 7 were allotted 30 minutes.

While playing scenarios, participants wore earphones to listen to serious game dialogs and sounds individually and without disturbing the others. Moreover, during the whole course, they were asked not to talk to each other about scenarios and questions. They could not use books, Internet, or any other resource to answer the questions. Experimenters explained them that the results were going to be used only to evaluate the serious game, and that their performance would have been reported anonymously.

Three months after the retraining course, retention was assessed via e-mail with the same ALS test. Again, participants were invited to answer questions on their own, without any help.

2.3.3 Statistical analysis

After checking that its assumptions were met, a one-way analysis of variance (ANOVA) for repeated measures, followed by a post-hoc Bonferroni test, was used to compare the results of the ALS test in the three conditions (pre-test, post-test and retention test).

2.3.4 Ethics

Since the study concerned a training service (not a medical therapy) and involved no risk of harm, formal ethical approval was not required by Italian regulations. As mentioned in Section 2.3.1, participants enrolled in the retraining course on a voluntary basis. They were informed that information collected by means of the questionnaires and the ALS test were going to be used for a research study to evaluate the serious game, not their performance, and the results would have been reported anonymously. Participants were told they could skip questions without providing an explanation. The retention test was again performed on a voluntary basis, so participants could opt out.

3. RESULTS

3.1 Participants

Forty ALS providers enrolled in the study, 25 (62.5%) female and 15 (37.5%) male. Age ranged from 24 to 49 years, the median was 36, and the mean was 35.5 (SD=6.4).

As shown in Table 1, all participants used computers. In particular, 86% of participants used them for more than 5 years. About one third of participants used computers a few times a week and about two thirds every day.

1. Do you use computers?				
Yes	No			
40	0			
2. How long have you been using computers?				
Less than a year	1-2 years	2-5 years	5-10 years	More than 10 years
2	0	5	15	18
3. How often do you use computers?				
Once a month or less	A few times a month	A few times a week	Every day for 1 to 3 hours	Every day for more than 3 hours
0	2	12	23	3
4. For which activities do you mainly use computers? (Check all that you perform regularly)				
Applications related to my profession	Office applications, email, and Internet	Multimedia applications	Video games	Other: ___________
28	32	17	6	2 (Databases)
5. Do you use 3D video games or other 3D applications?				
Yes	No			
5	35			
6. Which department do you work for?				
ER	EMS	ICU	Cardiology	Other:________
16	12	11	0	1 (Anesthesia)
7. How often are you involved in the ALS team in your department?				

Never	Rarely	Sometimes	Often	Always
2	3	7	17	11
8. How would you rate your ALS knowledge and skill level?				
Very poor	Poor	Sufficient	Good	Very good
0	1	24	15	0
9. Have you ever attended an ALS retraining course?				
Yes	No			
9	31			
10. How often do you think you should attend an ALS retraining course?				
Once every 5 years or less	Once every 1-2 years	Once every 6 months	Once a month	Once a week or more
0	23	14	3	0
11. I feel the need to refresh ALS procedures				
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
0	3	0	26	11

Table 1: The 11 items of the initial questionnaire with the obtained frequencies.

Most participants regularly used applications for office, Internet, and e-mail as well as applications related to their profession. Less than half used multimedia applications regularly and only 15% video games. Even less participants used 3D video games or other 3D applications. In particular, cross tabulation for video game and 3D application use (Table 2) shows that only 5% of participants played 3D video games, 10% played non-3D video games, and 7.5% used non-game 3D applications. The remaining participants did not regularly use any kind of video game or 3D application. Therefore, most participants were probably not used to the kind of experience we proposed.

	Use of 3D applications		
Use of video games	No	Yes	**Total**
No	31	3	**34**
Yes	4	2	**6**
Total	**35**	**5**	**40**

Table 2: Cross tabulation for video game (question 4) and 3D application (question 5) use.

Considering working departments, 70% of participants worked in the emergency area. Among the remaining participants, all but one worked in Intensive Care Units. Only 5% of participants never worked in a team who had to provide ALS, while 70% worked often or always in ALS teams.

No participant rated his/her ALS knowledge and skills as very poor or very good. One participant rated it as poor and less than 40% rated it as good. The remaining 60% rated their ALS knowledge and skills as sufficient. The need to refresh ALS procedures was felt by more than 90% of participants, yet less than 25% of participants ever attended an ALS retraining course, despite the perceived need of attending it at least once every 1-2 years (more than 40% at least once every 6 months).

3.2 EMSAVE ratings

The final questionnaire administered at the end of the retraining course was completed by all 40 participants. Table 3 reports the questionnaire items and the frequencies of answers. Considering frequency of training with the 3D serious game, 75% of participants thought they should use it for training at least once every 6 months (15% even once a week or more). There was a large agreement on all the positive statements about EMSAVE and the training experience: all but one participants considered EMSAVE as a valid ALS self-training tool and more than 75% of them thought it increased their confidence in ALS procedures.

	Once every 5 years or less	Once every 1-2 years	Once every 6 months	Once a month	Once a week or more	
1. How often do you think the 3D serious game should be used for training?	0	4	19	11	6	
	1. Strongly disagree	2. Disagree	3. Neither agree nor disagree	4. Agree	5. Strongly agree	Median
2. I think the 3D serious game is a valid self-training tool to refresh and keep ALS knowledge and skills up to date	0	0	1	23	16	4
3. After completing the simulated scenarios, I feel more confident about ALS procedures	0	0	9	25	6	4
4. The proposed scenarios are realistic	0	0	8	27	5	4
5. The proposed scenarios match the ones proposed by instructors during ALS courses	0	0	1	33	6	4
6. I think that in the future 3D serious games will become a widespread	0	1	2	24	13	4

retraining tool						
7. I would gladly use the 3D serious game for retraining if it were available in my department	0	0	1	17	22	5
8. I would gladly use the 3D serious game for retraining if it were available on my home computer	0	1	1	18	20	4.5
9. I would like one hour of my work every month to be devoted to retraining with the 3D serious game	0	0	6	16	18	4
10. It was easy to refresh procedures using the 3D serious game	0	4	11	22	3	4
11. Performing procedures with the 3D serious game was engaging	0	0	4	23	13	4
12. Overall, I am satisfied by the 3D serious game for retraining	0	0	1	21	18	4
13. I positively value the training experience I had in this course	0	0	0	19	21	5

Table 3: The 13 items of the final questionnaire with the obtained frequencies.

The proposed scenarios were considered realistic by 80% of participants and all but one participant agreed that the proposed scenarios matched those proposed by instructors during ALS courses. A vast majority of participants thought that 3D serious games will become a widespread retraining tool. All but one participant were willing to use the 3D serious game for their retraining if it were available in their work department and all but two if it were available at their home. Most participants would also like to devote one work hour each month to retrain with EMSAVE.

More than half of the participants thought that refreshing procedures with the 3D serious game was easy. Cross tabulation with video game and 3D application use (Table 4) shows that all the participants who disagreed did not play video games regularly and 75% of them also did not use 3D applications. However, it is interesting to note that 21 of the 31 participants who did not play video games regularly and did never use any 3D application agreed on serious game ease of use.

	Use of video games				
	No		Yes		
	Use of 3D applications		Use of 3D applications		
Ease of use	No	Yes	No	Yes	**Total**
1. Strongly disagree					
2. Disagree	3	1			**4**
3. Neither agree nor disagree	7	1	3		**11**
4. Agree	19	1	1	1	**22**
5. Strongly agree	2			1	**3**
Total	**31**	**3**	**4**	**2**	**40**

Table 4: Cross tabulation of ease of use (item 10 in Table 3) with video game (item 4 in Table 1) and 3D application (item 5 in Table 1) use.

A vast majority of participants thought that performing procedures with the serious game was engaging. Overall, the 3D serious game experience was considerably appreciated: all but one participant were satisfied by the 3D serious game and all of them positively valued the training experience.

3.3 ALS test results

As described in Section 2.3.2, the ALS test was administered three times: before and after using the 3D serious game, and three months later. All 39 participants contacted three months later accepted to fill the ALS test (one participant could not be contacted because she had passed away). The statistical analysis reported in this section thus concerns the 39 participants who completed all three ALS tests.

Answers to the pre-test showed that ALS knowledge and skills could be improved: correct answers were 916 out of 1482 (38 questions x 39 participants), with a mean of 23.5 correct answers per participant (SD=4.3). In the post-test, correct answers were 1104, that is 21% more than the pre-test, with a mean of 28.3 per participant (SD=3.7). Finally, in the retention test, correct answers were 1028, that is 7% less than the post-test, but still 12% more than the pre-test, with a mean of 26.4 correct answers per participant (SD=3.6).

The mean of correct answers in the pre-test, post-test and retention test is shown in Figure 2. ANOVA revealed that these means differed significantly, $F(2, 76) = 39.5$, $p < 0.001$. The effect size was large, $\eta^2 = 0.51$.

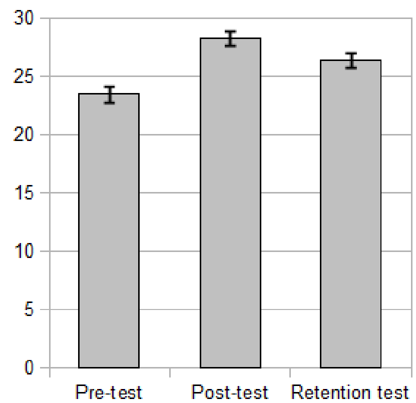

Figure 2: Average number of correct answers in the pre-test, post-test and retention test. Capped vertical bars indicate ± SE.

Post-hoc analysis showed that the difference between the pre-test and post-test means (+4.8 answers) was statistically significant (95%CI +3.4, +6.2, $p < 0.001$). Using EMSAVE thus improved ALS knowledge and skills.

As expected, there was a decrease in ALS knowledge and skills (-1.9 correct answers in the retention test with respect to post-test). This difference was statistically significant (95%CI -0.6, -3.3, $p < 0.01$), confirming that ALS knowledge and skills partially decrease over a three months period.

However, performance in the retention test was better than in the pre-test (+2.9 correct answers) and the difference was statistically significant (95%CI +1.5, +4.2, $p < 0.001$). Part of the ALS knowledge and skills acquired by using EMSAVE were thus retained at three months.

Considering the results of individual questions (Figure 3 and Figure 4), the number of correct answers in the post-test increased in 79% of questions. In particular, in 45% of questions, the number of correct answers increased by 1 to 5, in 13% by 6 to 10, while in 21% by more than 10 with peaks of 21 and 23 for question 12 and 34. In 11% of questions, the result was the same in pre-test and post-test, while in 11% the number of correct answers decreased by 2 to 7.

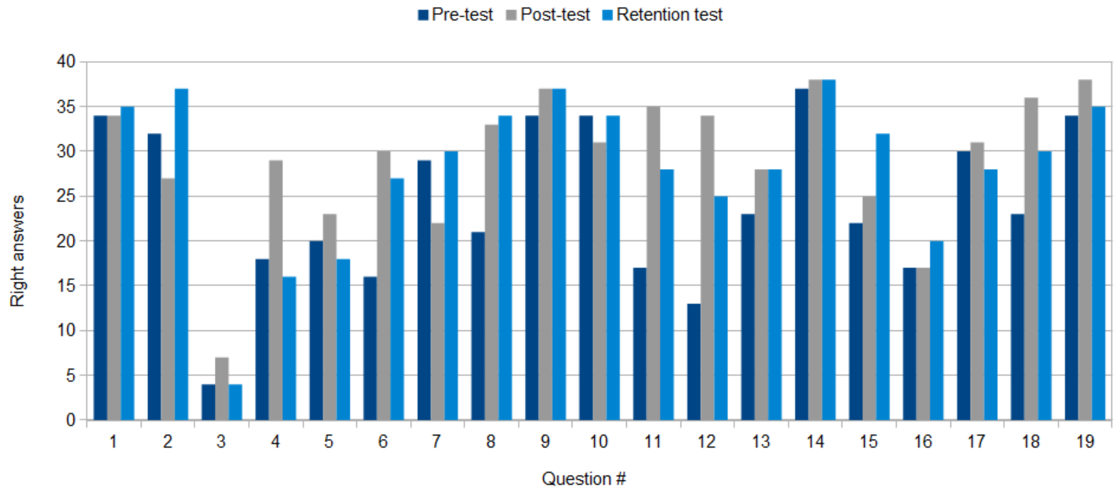

Figure 3: The number of correct answers to questions 1-19 in the pre-test, post-test and retention test (questions and their answers are provided as supplementary material).

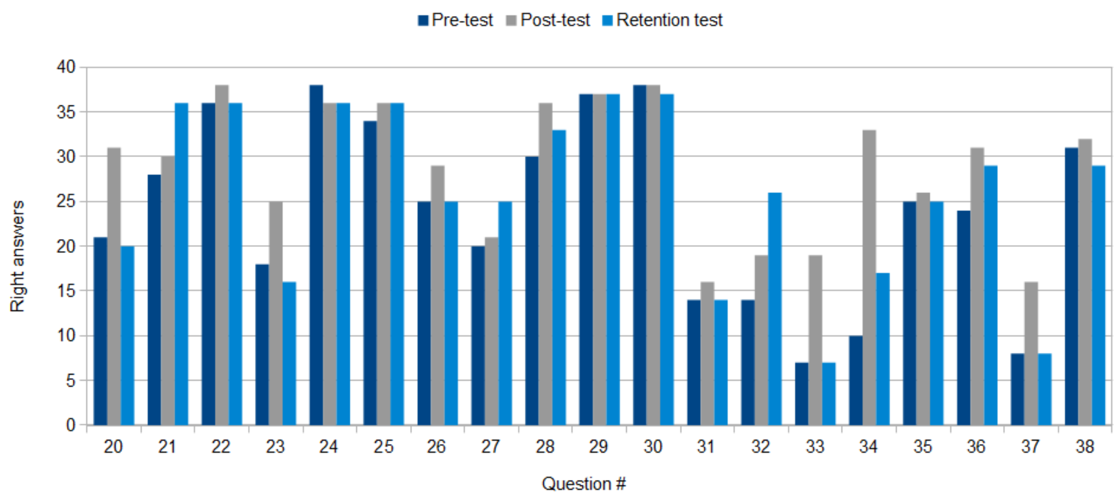

Figure 4: The number of correct answers to questions 20-38 in the pre-test, post-test and retention test (questions and their answers are provided as supplementary material).

Knowledge and skills decrease between post- and retention tests affected 58% of questions. In 34% of questions, the number of correct answers decreased by 1 to 5, in 13% by 6 to 10, while in 11% by more than 10. There was no decrease in 16% of questions, while in 26% of questions there was an increase by 1 to 10.

Finally, comparing pre-test and retention test, the number of correct answers in the retention test increased in 55% of questions. More precisely, in 32% of questions, the number of correct answers increased by 1 to 5, in 10% by 6 to 10, and in 13% by more than 10. In 24% of questions, the result was the same in the pre-test and retention test, while in 21% of questions the number of correct answers decreased by 1 to 2.

4. DISCUSSION

4.1 Need for retraining

As previously reported, several ALS providers in the considered sample had never received ALS retraining despite their perceived need to frequently attend retraining sessions. Such need is further motivated by the results of the pre-test which revealed lack in ALS knowledge and skills (about a third of questions were correctly answered by less than half of participants). In addition, decrease in knowledge and skills in 3 months affected about 60% of questions, highlighting the importance of making retraining widely accessible and appealing for ALS providers.

4.2 Related work

Different computer-based tools were previously proposed in the literature to train healthcare professionals in emergency response, but their evaluation led to conflicting results. For example, the MicroSim in Hospital tool by Laerdal was investigated as a competence booster for ALS retraining, but surprisingly the tool did not impact favorably on skill retention.[34] That study hypothesized that the absence of a significant effect was due to a lack of social interaction about which participants complained, but the results also highlight that participants were not sufficiently motivated to use the tool: 20% of them never used it during the one-year study and only 23/40 completed 12 or more cases as suggested by the evaluation protocol.

Since motivation and engagement are instead a key feature of games, Knight et al. investigated the exploitation of 3D serious games in major incident triage training.[27] A pragmatic controlled trial with 91 trainees showed that participants who trained with a 3D serious game assigned triage tags in eight scenarios better than participants who trained with a card-sorting exercise. Accuracy in following the steps of the triage procedure was also higher in participants who trained with the serious game, while there was no significant difference in time required to complete the triage scenarios.

4.3 Overall interpretation of results

Our study indicates that 3D serious games can be effectively exploited for ALS retraining, since they can improve ALS knowledge and skills after a retraining session. With EMSAVE, the average number of correct answers per participant improved by almost 5 out of 38 questions, and all but one participant improved. More precisely, all participants who rated their ALS knowledge and skills at least as sufficient improved after using the serious game, while the only participant who self-rated his ALS knowledge and skills as poor did not improve. This evidence supports our idea that the serious game is a useful retraining tool and could be effectively employed to refresh, update, and increase knowledge and skills in ALS providers who are already sufficiently trained.

As remarked in Section 4.1, despite the expected decrease in ALS knowledge and skills, there was a significant retention benefit at 3 months (an average increase of almost 3 correct answers per participant with respect to the pre-test). Decrease over time could be further mitigated by low-cost regular retraining sessions with the serious game. Indeed, even if enough resources are allocated to comply with Resuscitation Council guidelines, retraining courses are planned once every two years, while serious games can be used much more frequently, even at home.

Acceptance of more frequent ALS retraining with serious games is supported by data from the final questionnaire: participants proved willing to attend retraining courses often if based on 3D serious games, with 85% willing to devote one hour per month to retrain with

EMSAVE, by using it in their department or at home.

Considering that 3D serious games are a novel tool, not yet routinely used in ALS training, and most participants in our study were not acquainted with video games and 3D applications, the agreement on positive questionnaire statements is very encouraging: all but one participant regarded EMSAVE as a valid retraining tool, which proved to be effective in increasing self-confidence on ALS procedures. The fact that the scenarios were considered realistic and similar to those employed in traditional ALS training contributes to confirm the validity of the serious game. Another indicator of the high level of engagement obtained is the absence of drop out at follow-up, suggesting an overall positive experience. Finally, the perceived easiness of use was a positive result, especially considering participants' lack of experience with 3D applications.

4.4 Discussion on individual questions

The results on individual questions, reported in Section 3.3 and illustrated in Figure 3, showed that using EMSAVE increased the number of correct answers between pre-test and post-test in about 80% of questions, and in more than 20% of them the increase was of more than 10 correct answers. The questions on which EMSAVE was most effective concerned therapeutic hypothermia (+18 correct answers in question 11 and +23 in question 34): a considerable number of participants were not familiar with this recent therapy, and EMSAVE error explanations described its importance in the context of the scenarios to ALS providers who omitted it. A specific error explanation provided by the serious game was also useful to explain why in a specific scenario ALS providers should administer adrenaline intramuscularly and not subcutaneously (+12 correct answers in question 8). EMSAVE was also greatly effective to illustrate task order (+11 correct answers in question 4, +14 in question 6, +21 in question 12, +13 in question 18).

EMSAVE had no effect (i.e., the number of correct answers in pre-test and post-test was the same) on 4 of the 38 questions. However, it is important to note that two of these questions were answered correctly by all but one (question 30) or two (question 29) participants, so there was very little room for improvement.

We investigated why in 4 questions EMSAVE led to a slight decrease in the number of correct answers in post-test with respect to pre-test. Question 2 (-5 correct answers) was about oxygen usage, whose recommended order and conditions changed in the latest ALS guidelines (illustrated by EMSAVE), which differ from previous participants' experience. The ventricular tachycardia scenario recommended to delay oxygen application, and some participants generalized this new recommendation to other situations, while in case of oral swelling the oxygen should be immediately provided, as suggested also by previous recommendations and as explained by EMSAVE in the anaphylactic shock scenario. After the course, some participants asked ALS instructors for more explanations about delayed application of oxygen in the ventricular tachycardia scenario: this might have contributed to increase correct answers in the retention test (+10 with respect to post-test and +5 with respect to pre-test).

A decrease (-7 correct answers) was also found in question 7: in this case, the correct answer was the one saying that all the others were correct. Some participants might have focused their attention on a particular aspect depicted by the serious game, so in the post-test they chose that aspect instead of the answer which included all aspects. A similar issue (i.e., the correct answer said that two of the previous answers were right) might have mislead a few participants (-3 correct answers) also in question 10. In question 24, the decrease was very small (-2 correct answers in the post-test, question correctly answered by all but one participant in the pre-test).

Finally, considering retention, the large increase in ALS knowledge and skills in questions 6, 8, 11, and 12 was substantially maintained after 3 months, and partly maintained in questions 18 and 34. In addition, ALS knowledge and skills was fully retained in several questions (i.e., 9, 13, 14, 25) where the increase between pre-test and post-test was lower. In questions 2, 7, and 10, for which there was a decrease between pre-test and post-test, the number of correct answers in the retention test was the same or greater than in the pre-test: as mentioned above, some participants might have clarified doubts after the course.

4.5 Limitations

The extremely positive feedback received by participants may have been influenced by the voluntary adhesion to educational resources, which is a well-known source of bias.[35] Retention was evaluated by e-mail and thus not in the same conditions of the pre-test and post-test. Although participants gained no advantages by correctly answering the retention test and experimenters invited them to answer it without external help, we could not check that all participants behaved as instructed. On the other hand, we cannot guarantee that due attention was devoted to the test or that the test was taken in an environment that supported the same focus as the classroom.

As described before, EMSAVE was designed to refresh ALS knowledge and decision-making skills. This study focused on these aspects, and the positive results cannot be generalized to practical skills such as chest compression. However, from the perspective of a whole ALS retraining program, EMSAVE can be complemented by other computer-based systems that specifically focus on practical skills such as iCPR.[36]

AUTHORS' CONTRIBUTIONS

EC and LC conceived and obtained funding for the research project that includes the described study. FB, LC and ACV designed the 3D serious game used in the study, and FB and ACV developed it. All authors contributed to the design and the organization of the study. DP and TP handled recruitment of participants. FB, ACV, DP and TP supervised the conduct of the study and data collection. FB and LC analyzed the data. FB, LC, TP, and ACV drafted the manuscript, and all authors contributed to its revision.

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CONFLICT OF INTEREST STATEMENT

No author has conflicts of interest.

SUMMARY TABLE

What was already known on the topic

- Advanced Life Support (ALS) knowledge and skills usually decrease long before ALS providers have the opportunity to attend a retraining course, calling attention to new approaches for making frequent retraining accessible and appealing.
- Computer-based training systems, especially those exploiting realistic 3D graphics, offer several features that make them possibly suitable for frequent retraining, but their evaluation in the medical domain led to conflicting results.
- In addition to the benefits of computer-based training systems, 3D serious games can motivate and engage learners by adding gaming elements to the simulation and proved effective for triage training in the medical domain.

What this study added to our knowledge

- 3D serious games can be effectively used in the medical domain for ALS retraining, to refresh, update and increase knowledge and decision-making skills.
- By using a 3D serious game for ALS retraining, participants were able to gain ALS knowledge and decision-making skills. Moreover, despite the well-known decrease over time in ALS knowledge and skills, there was a significant retention benefit at 3 months.
- The proposed training approach positively engaged participants, who also reported willingness to frequently retrain with the 3D serious game.

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SUPPLEMENTARY MATERIAL: ALS TEST

Correct answers are highlighted in *italics*.

8. Which of the following signs is particularly alarming during anaphylaxis?
    1. Skin rush
    2. Itch
    3. Palpebral edema
    4. *Voice change*

9. In case of anaphylaxis with oral swelling, oxygen should be administered
    1. *Immediately in A*
    2. Only after monitoring SpO2
    3. Not necessarily at 100%
    4. Only if signs of bronchospasm are present

10. Pump-volume-rate: which is the main problem during anaphylaxis?
    1. Pump
    2. *Pump and volume*
    3. Volume
    4. All three issues coexist

11. After evaluating A/B, in a peri-arrest patient with anaphylaxis, which is the first action that follows?
    1. *Obtain high bore venous access*
    2. Adrenaline 0.5 mg IM
    3. Adrenaline 1 mg subcutaneous
    4. Salbutamol 5 mg aerosol if bronchospasm is present

12. Evaluation of circulation during anaphylactic shock:
    1. Takes place after evaluating the airways
    2. Includes only vital signs
    3. *Includes pulse, heart rate, arterial pressure, refilling time and skin temperature*
    4. Is limited to arterial pressure only

13. In C, in the peri-arrest patient with suspected anaphylaxis, after obtaining a large bore peripheral access you should prioritize administration of:
    1. Adrenaline 0.5 mg IV
    2. Metilprednisolone 500 mg IV
    3. *Fluids*
    4. Chlorpheniramine 10 mg IV

14. Fluid administration during anaphylactic shock:

1. Should start as soon as possible and may require large amounts that can exceed 3000 ml
2. Colloids are relatively contraindicated
3. Should be stopped if the patients has signs of pulmonary congestion
4. *All the above*

15. In the peri-arrest patient with anaphylactic shock, adrenaline should be administered:
    1. Subcutaneously
    2. Via aerosol
    3. *Intramuscularly*
    4. IV even by non-experienced personnel

16. In a patient with anaphylactic shock, ventricular fibrillation:
    1. *Is characterized by high-frequency chaotic waveforms*
    2. May show signs of atrial activity in lead II
    3. A pulse may be present, especially if the patient has relative hypovolemia
    4. Benefits from chest compressions with mechanical chest compressors

17. Treatment of a patient in cardiac arrest due to anaphylactic shock, includes:
    1. Rapid infusion of fluids and administration of adrenaline
    2. Administration of hydrocortisone and chlorpheniramine
    3. Increased energy requirements for defibrillation
    4. *Answers a and b are both true*

18. Therapeutic hypothermia after cardiac arrest from anaphylactic shock
    1. Is not indicated
    2. *Is indicated if the patient is unconscious after ROSC*
    3. Is contraindicated due to anaphylactic induced vasodilation
    4. There is no evidence whatsoever that it is effective in this special circumstance

19. In case of cardiac arrest in a monitored patient, first of all you need to:
    1. *Confirm cardiac arrest*
    2. Begin chest compressions
    3. Verify cable connections and change ECG lead
    4. Rapidly establish airway

20. SAMPLE and head-to-toe physical examination can allow one to:
    1. *Understand the cause of arrest/peri-arrest*
    2. Establish timing of pharmacological therapy
    3. Establish if we can administer adrenaline
    4. Understand if symptoms are related to the disease

21. If the patient becomes confused while you are asking about his/her medical history:

1. You should repeat the questions to help the patient understand them better
2. You will rely on medical records available in the emergency department
3. *Relatives are a valuable alternative to acquire the patient's past medical history*
4. You should rely only on the patient in order to avoid litigation

22. The dose of adrenaline for anaphylactic shock:

1. Is 0.5 mg IV
2. *Is 0.5 mg IM*
3. Is 1 mg IM
4. May be administered IV in a 1 mg dose but only by experienced personnel

23. Airway management in case of obstructive edema should be provided by:

1. Supraglottic devices such as laryngeal tube, laryngeal mask, etc
2. Repeatedly attempting to intubate since it is the only way to overcome the obstruction
3. An oropharyngeal cannula, but only in the spontaneously breathing patient
4. *A single intubation attempt and, in case of failure, an airway adjunct such as the rhinopharyngeal cannula*

24. Tracheal intubation in a patient with signs of impending obstructive airways:

1. Can be postponed, intubation has not been demonstrated to improve outcome in cardiac arrest patients
2. Is not a priority
3. Is difficult and risky, if you are not an airway expert seek for an alternative such as the oropharyngeal cannula
4. *Is a priority*

25. If a patient with anaphylaxis is hypotensive after restoration of spontaneous circulation, you can:

1. *Further load the patient with fluids*
2. Infuse catecholamines
3. Wait, this a common feature immediately after resuscitation
4. Repeat adrenaline 1 mg IV

26. Immediately after ROSC

1. Assess circulation and consciousness
2. *Assess circulation, breathing and consciousness*
3. Assess EtCO2
4. Asses circulation, vital parameters, and arterial blood gas

27. In a patient with acute coronary syndrome you should administer oxygen:

1. As soon as possible

2. *After assessing B if patient has an SpO2 < 92%*
3. After assessing ABCDE
4. Should not be administered in acute coronary syndromes because it promotes vasoconstriction

28. Tachycardia in an unstable patient should:
    1. Be treated to reduce vital signs instability
    2. Not be treated, tachycardia does not compromise patient stability
    3. Be electrically cardioverted as treatment of choice
    4. *Answers a and c are both true*

29. Sedation for electrical cardioversion:
    1. Should be preferably avoided if the patient is hypotensive
    2. *Should be performed in any case, carefully choosing the sedative agent*
    3. In urgent settings can be performed without informing the patient
    4. Is not a priority if the patient is unstable

30. In the peri-arrest settings, ventricular tachycardia:
    1. Should be treated like a shockable rhythm
    2. Should be treated with a 360 J shock using a biphasic defibrillator
    3. Is treated as first choice with pharmacological therapy
    4. *None of the above*

31. Treatment of ventricular fibrillation in patients with acute coronary syndrome:
    1. Depends on whether there is pulse
    2. Requires the ‘sync’ option to be selected before attempting to shock
    3. Is based on chest compressions
    4. *Requires early defibrillation*

32. In treating ventricular tachycardia with pulse:
    1. The treatment is not different from ventricular fibrillation
    2. Once the shock is delivered immediately start chest compressions
    3. Administer adrenaline every 3-5 min
    4. *None of the above is true*

33. In a peri-arrest situation, due to ventricular tachycardia:
    1. If hypotensive, consider volume depletion
    2. Tachycardia compensates hypovolemia
    3. *Should be treated with electrical cardioversion as treatment of choice*
    4. Answers a and b are both true

34. When evaluating breathing:
    1. If breathing looks normal it is not necessary to assess B, administer high flow O2

2. Ask the patient if he/she is breathing well, monitor SpO2 because if it is >92% there is no need to supplement O2
3. *You should apply a systematic approach in all patients*
4. An arterial blood gas is part of the evaluation

35. Therapeutic hypothermia for unconscious patients with acute coronary syndrome complicated by cardiac arrest:
1. Is contraindicated
2. Should be performed after coronary angiography
3. *Improves outcome and should be administrated as soon as possible*
4. May induce coronary vasoconstriction, worsening myocardial ischemia

36. Treatment of pulseless ventricular tachycardia:
1. Depends on patient conditions
2. Depends on the experience of medical personnel
3. Depends whether the patient presents adverse signs
4. *In any case cannot be postponed*

37. The choice of energy for synchronized electrical cardioversion:
1. Is chosen by the operator according to his/her experience
2. *Should be increased in case of refractory ventricular tachycardia*
3. Depends on the adverse signs of the patient
4. Depends on the patient's initial blood pressure

38. Airway management during cardiac arrest:
1. If performed early improves outcome
2. Even if not performed by experienced personnel is the gold standard
3. *May be postponed since there are other priorities*
4. Is useful for drug administration

39. Inferior STEMI presents with:
1. ST elevation in V1, V2 and AVL
2. ST elevation in V3, V4, V5, and AVF
3. *ST elevation in DII, DIII, and AVF*
4. ST elevation in DI, DII, and AVF

40. In patients with inferior MI:
1. *Treat hypotension with fluids*
2. Hypotension is common because it depends on volume status
3. Hypotension should be treated with inotropes
4. Hypotension is common, fluid loading is contraindicated since it might lead to pulmonary edema

41. Therapeutic hypothermia following inferior MI complicated by ventricular fibrillation:

1. Is contraindicated if the patient is hypotensive
2. *Should be started, administering cold fluids (<10°C)*
3. Should be started after hospital admission
4. If coronary angiography is indicated, hypothermia should not be started since it might precipitate ventricular arrhythmia and re-arrest

42. Pump-volume-rate: severe hypotension in a patient with ventricular tachycardia is related to:

1. Pump
2. *Rate and pump*
3. Volume
4. Rate and volume

43. Ventricular tachycardia with pulse in a patient with severe adverse signs

1. *Should be promptly treated by synchronized electrical cardioversion*
2. Should be promptly treated with amiodarone 300 mg IV and electrical cardioversion
3. Should be promptly treated with lidocaine 100 mg, if amiodarone is not available, and electrical cardioversion
4. Should be promptly defibrillated

44. If after electrical cardioversion the patient goes in ventricular fibrillation:

1. Administer amiodarone 300 mg IV
2. Administer adrenaline 1 mg IV
3. *Confirm cardiac arrest*
4. Immediately defibrillate the patient

45. If the patient maintains a normal respiratory activity, but the ECG displays a defibrillating rhythm

1. It is likely to be pulseless ventricular tachycardia
2. It is likely to be ventricular fibrillation
3. It is likely to be gasping
4. *None of the above*