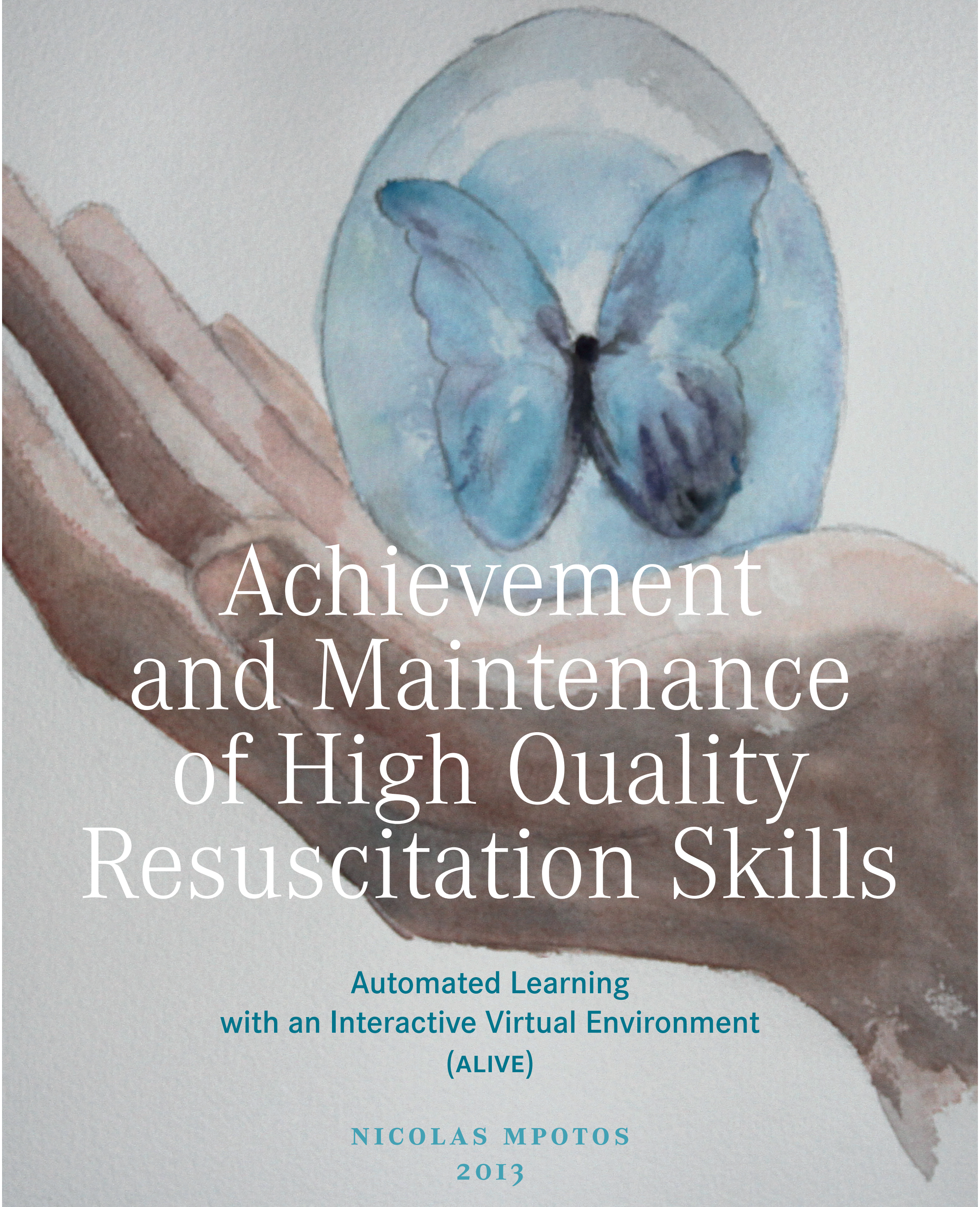

Achievement and Maintenance of High Quality Resuscitation Skills

Automated Learning with an Interactive Virtual Environment (ALIVE)

NICOLAS MPOTOS

2013

UNIVERSITEIT GENT

Ghent University
Faculty of Medicine and Health Sciences

Achievement and Maintenance of High Quality Resuscitation Skills

Automated Learning with an Interactive Virtual Environment (ALIVE)

This thesis is submitted as fulfilment of the requirements for the degree of
DOCTOR IN MEDICAL SCIENCES

25 NOVEMBER 2013

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Achievement and Maintenance of High Quality Resuscitation Skills

Automated Learning with an Interactive Virtual Environment

(ALIVE)

Academisch proefschrift

ter verkrijging van de graad van Doctor in de Medische Wetenschappen
aan de Universiteit Gent,
op gezag van de rector Prof. Dr. Anne De Paepe,
in het openbaar te verdedigen
ten overstaan van de promotiecommissie
van de faculteit Geneeskunde en Gezondheidswetenschappen

op 25 november 2013

in de Aula van de Universiteit Gent

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Abbreviations

ALIVE	Automated Learning with an Interactive Virtual Environment
ALS	Advanced Life Support
CPR	Cardiopulmonary Resuscitation
ERC	European Resuscitation Council
EMS	Emergency Medical Services
OHCA	Out-of-hospital cardiac arrest

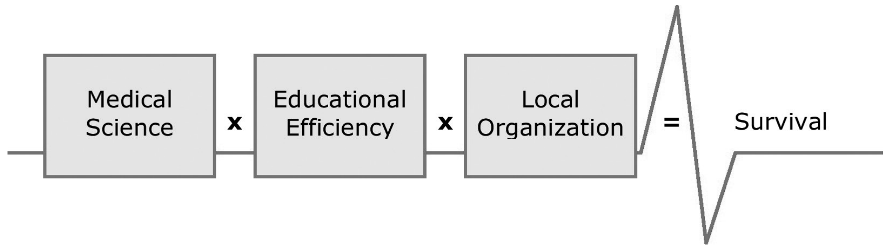
Introduction

Incidence of cardiac arrest and determinants of survival

Every year, around 350 000 Europeans suffer an out-of-hospital cardiac arrest (OHCA) and cardiovascular disease remains responsible for 41% of all deaths in Europe (1, 2). OHCA can occur anywhere, for example in the street, at work, or while exercising or doing other strenuous activity. The vast majority of OHCA cases happen at home. Currently, less than 10% of all these patients survive (3). Bystander cardiopulmonary resuscitation (CPR) by lay people increases survival 2-3 times (4-7). Unfortunately, less than 20% of cardiac arrest victims receive this vital help in time to save their life (4-7). Bystander CPR rates vary widely across Europe, with Andalusia in Spain as low as 12%, Germany 15%, through to very high rates in the Netherlands (61%) and Sweden (59%) (7). The actual survival rate varies with the setting, with some countries (generally those in Eastern Europe) having survival as low as 6%, whereas countries with an excellent record in bystander CPR such as the Netherlands and Norway have survival rates as high as 40%.

This massive difference in survival reflects the way in which the different elements of the so-called 'Utstein Formula of Survival' are implemented in a country. The 'Utstein Formula of Survival' underscores that survival after cardiac arrest depends on medical science, education and local implementation (8).

Figure 1 *The Utstein Formula of Survival*



Medical science provides evidence-based data for the best way to deliver chest compressions and ventilations, the optimal energy and electrical waveform for defibrillation, and the most effective drugs to restore or maintain blood circulation. The European Resuscitation Council (ERC) regularly publishes updated guidelines advising healthcare providers on best practice (9). According to the latest ERC 2010 Guidelines all rescuers, trained or not, should provide chest compressions to victims of cardiac arrest. A strong emphasis on delivering high quality chest compressions remains essential. The aim should be to push to a depth of at least 5 cm at a rate of at least 100 compressions per minute, allowing full chest recoil and minimising interruptions in chest compressions. Trained rescuers should also provide ventilations with a compression-ventilation ratio of 30:2 (10). And although compression depth is an important component of cardiopulmonary resuscitation and should be measured routinely, the most effective depth is currently unknown (11).

Education refers to providing lay rescuers and professional healthcare providers with the skills they need to provide effective resuscitation and make life-saving decisions. Effective and efficient resuscitation education is one of the essential elements in the translation of guidelines into clinical practice.

Local implementation refers to the local dispatch and Emergency Medical System (EMS), the facilities in the receiving hospital and the local level of education.

Survival from cardiac arrest will only increase by improving our scientific understanding of the cardiac arrest resuscitation complex, by improving development and training of evidence based guidelines, and by improving implementation of these guidelines in all steps of the clinical practice of emergency cardiovascular care.

If we could improve rates of bystander CPR in Europe to the levels seen in these best-performing nations, then around 100 000 lives could be saved each year across Europe (12). To put these numbers in perspective, the estimate of 350 000 OHCA deaths is equivalent to 1000 deaths per day every day of the year across Europe. By comparison, 28 000 people die across Europe each year in road accidents (13).

Instructor-led training versus alternative methods: review of evidence

Several studies have implicated the existing educational programmes for teaching CPR skills as a prime target for interventions to improve survival after cardiac arrest (14-17). The most important reason being that prompt initiation of quality CPR (= chest compressions and rescue breaths) is live-saving and can double or even triple survival rates (4-7). Despite this knowledge only a minority of victims receive bystander CPR because not enough members of the community have (properly) learned the CPR techniques, and when faced with a victim of cardiac arrest many are not prepared to use the techniques effectively (18-21).

The current CPR training programmes, which are still largely based on instructor-led training, result in varying and often poor rates of skill acquisition (22-25), leading to universally poor skill performance. Apart from the skill acquisition, substantial skill decay within three to six months after training has also been established as a major issue (22-32).

The ERC 2005 Guidelines already focused on improving the quality of CPR, which is an important determinant of outcome following cardiac arrest (30, 33-39). However, when Perkins et al. investigated the effect of these guidelines on the resuscitation skills of doctors and nurses by measuring their resuscitation performance following an Advanced Life Support course, they found that the quality of CPR performance was still sub-optimal (40). Delays in starting CPR, shallow compression depth, excessive interruptions in chest compressions and prolonged pre-shock pauses were the major concerns.

In an attempt to remediate the shortcomings of instructor-led training, alternative training methods such as self-instruction using videos or digital versatile discs (DVD's) with or without a manikin (41-43), the use of automated voice feedback (44, 45), computers (46) and micro-simulation (47) have been developed to try to improve CPR quality.

Video self-instruction means practicing on a manikin while watching a video tape without an instructor or textbook. The focus is on the primary skills of CPR such as compressions and ventilations. Video self-instruction eliminates course content not related to the performance of CPR and has the advantage of rewinding or pausing if necessary. Eisenburger et al. concluded that the duration to acquire skills differed between students and that individual practice coached by video had advantages over instructor-led courses (48). Video self-instruction is a method able to train both younger and older adults in

CPR (49). It takes less time to achieve a certain level of CPR performance than a traditional course (50) and it results in superior CPR performance compared with traditional training (41).

Another educational method is *the automated voice advisory manikin system*. The voice advisory manikin is a CPR training manikin modified to interface with a computer that has voice advisory software installed. It uses sensors from the manikin to measure performance accurately and it provides real-time voice feedback on compression depth and rate, ratio of chest compressions to ventilations, hand position, ventilation volume and insufflation rate. Continuous corrective voice feedback has been shown to improve performance of CPR skills even when compared to one-on-one standardized instructor-led training (51, 52). Wik et al. suggested that the voice advisory manikin is an effective training tool, minimizing the risk of mistakes going uncorrected and never deviating from the CPR guidelines and limits programmed into the system (51). Audio and visual feedback have been used in (refresher) training and resulted in improved retention of chest compression skills compared to instructor feedback (53). Video self-instruction produced retention performance at least as good as traditional training (54).

Studies have repeatedly shown, however, that even these newer methods lack efficacy and lead to poor skill acquisition with the quality of skills decreasing rapidly after training (23, 55).

Improving training quality: we still need better

In conclusion the existing instructor-led training, considered as the standard, and the alternative methods such as self-instruction using videos or DVD's, automated voice feedback, computers and micro-simulation result in variable and often poor skill acquisition and retention.

A number of explanations exist: cardiac arrest events occur infrequently from the perspective of any given rescuer, and rescuers are trained infrequently, with as result that they do not always feel comfortable with their abilities during cardiac arrest care (56). Clearly, better programs to improve training efficacy and retention are desirable with the expectation that this would translate into better CPR performed during actual resuscitation attempts and according to the Utstein formula ultimately translate into better survival rates (56). Performing CPR requires, however, the execution of highly time-sensitive psychomotor actions of underestimated complexity. Current methods to teach CPR are mostly based on a single training session, not adapted to individual learners and they do not contain strategies for long-term skill mastery. According to the latest ERC 2010 guidelines, CPR training should be tailored to the needs of different types of learners and learning styles to ensure adequate acquisition and retention of skills (25). Furthermore, educational interventions need to be evaluated to ensure that they achieve the desired educational outcomes. International guidelines already emphasized the importance of simplification of CPR instruction to focus on competence in the small set of skills most strongly associated with the victim's survival (57).

Variables affecting skill acquisition and retention are many and difficult to isolate. Factors that negatively affect retention include insufficient hands-on practice, inconsistent teaching, unrelated course content, complex instruction, delays between instruction and skills practice, lack of supervision, poor instructor feedback and instructor incompetence. Factors that positively affect skills acquisition and retention include hands-on practice, instruction simplicity, multi-media presentations and debriefing (feedback and feedforward) (58-60). Providing feedback on a trainees' skill level is also known to have a powerful impact on acquisition and retention of skills (61-62).

Retention of skills should be confirmed through assessment and not be assumed to persist for pre-established time intervals. The use of frequent assessments will identify individuals who require retraining to maintain their skills (44, 63-66). Considering the very large number of people who should be trained annually, ranging from health care providers to first responders at work, teachers, youth workers, firemen, safety staff and in the end every active member of the community, there is a real need to develop an alternative educational approach that is effective, efficient and as such requires limited training time and is consequently cost-effective.

Research objectives

The aim of the current PhD thesis is to develop an alternative and more effective educational approach consisting of Automated Learning with an Interactive Virtual Environment (ALIVE). In 2009, during the process of evaluation of the science, the International Liaison Committee on Resuscitation (ILCOR) identified a number of important knowledge gaps on CPR education (67). The following knowledge gaps will be addressed in this PhD thesis:

- Standardization in research methods
- Potential for tailoring preparation and training to individual learning styles
- Modalities to increase knowledge/skill retention
- Optimal method for learning and retention of knowledge/skills
- Optimal format and duration of self-instruction
- Optimal format for refresher training when the need is identified
- Economy and logistics of shorter intervals for update/retraining
- Effect of type of measurement/assessment

In contrast with the current educational strategies using a single CPR training session, ALIVE aims at training participants to a predefined skill level, targeting the needs of each type of learner and establishing the basis for a life-long learning path. The approach should be effective and efficient, requiring limited training time and being cost-effective. Improving effectiveness and efficiency might result in better training quality and local implementation.

The different research objectives to achieve this goal, together with the research designs, and research techniques are summarised in Table 1.

Table 1: *Overview of the research goals, research designs, and research techniques*

Chapter	Research objective	Research goals	Research design	Research techniques
1	RO 1	Does training in a computerised self-learning station using a combination of video instruction followed by voice feedback result in at least equal CPR skill acquisition as compared to instructor-led training?	Randomised controlled trial in third year pharmacy students (n=120)	· Multiple logistic regression analysis · Non-inferiority analysis · McNemar test
2	RO 2	a) What is the learning efficacy of video training and the additional impact of subsequent voice feedback exercises on the acquisition of CPR skills in a self-learning station? b) What is the predictive value for success of potential covariables such as gender, height and weight in relation to the resuscitation outcome parameters?	Interventional study in third year pharmacy students (n=125)	Confidence intervals (CI) for the differences between proportions
3	RO 3	How to retrain CPR skills in a self-learning station: using video, voice feedback or both?	Randomised controlled trial in third year medicine students (n=192)	· Generalised estimating equations (GEE) analysis · Fisher Exact tests
4	RO 4	Does overtraining of compression depth result in better retention of compression depth?	Randomised controlled trial in third year medicine students (n=190)	· Multiple logistic regression analysis · Mann-Whitney test
5	RO 5	Assessing basic life support skills without an instructor: is it possible?	Interventional study and survey in third year medicine students (n=184)	Principal components analysis (PCA)
6	RO 6	Do short self-learning sessions followed by automated assessment with debriefing lead to a high level CPR acquisition?	Interventional study in students in pharmacy and educational sciences (n=404)	Confidence intervals (CI) for the differences between proportions
7	RO 7	Can automated testing with feedback followed by optional training in a mobile self-learning station rapidly retrain CPR quality to a predefined level?	Interventional study in emergency nurses (n=44)	Confidence intervals (CI) for the differences between proportions

RO = Research Objective

As mentioned previously hands-on practice, instruction simplicity, multi-media presentations and debriefing/feedback all affect effectiveness. The main research goal was to study if incorporating these four factors in an automated learning strategy is effective to acquire and maintain CPR skills (research objectives 6 and 7). To achieve this, one of the first objectives was to determine if self-learning using multi-media (video and computer exercises with concurrent voice feedback) is equal to instructor-led teaching (RO 1). In addition the differential impact of the multi-media training components on skills acquisition and retraining should be established (RO 2 and 3) together with the specific impact of voice feedback prompts (overtraining) on compression depth (RO 4). Secondly, in order to assess the learning objectives and adapt the training to each participants' individual needs, an automated assessment strategy for the core CPR skills should be developed (RO 5).

Adult learning: acquisition of practical resuscitation skills

The development and retention of practical skills that improve an individual's performance are of great importance in many areas of professional life. Once a skill has been learnt, appropriate application and correct performance become the key issues. This is particularly important in the field of resuscitation where the ability of lay people and healthcare professionals to learn an retain resuscitation skills may influence the outcomes of patients who suffer cardiopulmonary arrest (8). Adult learning is defined as 'the entire range of formal, non-formal and informal learning activities which are undertaken by adults after a break since leaving initial education and training, and which results in the acquisition of new knowledge and skills' (68). Adult learners usually come from varying backgrounds and each have their own strengths, weaknesses, anxieties and aspirations. Therefore, it is important to recognise the uniqueness of each participant and work with him or her to achieve the learning objectives. Previous knowledge, experience and established attitudes will influence the way adults learn because adults apply their existing knowledge in the process of acquiring new skills (69). Adults have reached a stage of independence through the process of maturation and are capable of self-direction and taking responsibility for their own actions (70). They are accustomed to setting their own goals and deciding how they will achieve them (70). The learning of practical skills is influenced by the retention of factual knowledge, the performance of the skill itself and by the attitude of the learner (71). The interaction between the learner and the teaching environment is important in achieving a behavioural change in their practice and mastery of a skill (72). The motivation to learn is essential if education is to be successful (73, 74). Facilitating the process of learning by increasing the motivation of candidates is a complex procedure, but is crucial to the education of adults. We can influence motivation in many ways, by attention to the learning environment, providing material appropriate to the candidate's needs, ensuring that instruction is carried out to the highest standards, and by applying the principles of adult learning (72).

Knowles summarized six key principles to direct the teaching and learning principles to be adopted when setting up learning environments with adults (70):

1. ***Need to know.*** Adults need to know why they need to learn something before learning it (why-what and how).
2. ***Learner self-concept (self-direction).*** Since adults are mature, they prefer self-direction. It is better to engage them in a process of inquiry, analysis and decision-making, rather than to transmit knowledge.
3. ***Learners experience.*** Adults bring in a lot of personal experiences that represent a rich resource of learning. They learn better when they link what is to be learned to their earlier experiences.
4. ***Readiness to learn (life-tasks).*** Adults typically become ready to learn when they experience a need to cope with a real-life situation or perform a task.
5. ***Orientation to learning (problem-centered).*** Adults are competency-based learners. They easily learn a skill or acquire knowledge when they can apply it in immediate circumstances. Education is a process of increasing competency levels to achieve their full potential.
6. ***Motivation to learn (internal).*** The motivation for adult learners is internal rather than external.

Adults learn with a more immediate perspective than children. New material should be presented in discrete stages (participation, identification, internalisation and dissemination) with the intention of leading to a natural progression in the acquisition of knowledge and competence (75). In the past, however, the "see one, do one, teach one" approach was adopted but is now generally discredited in educational circles. The poor acquisition and retention of resuscitation skills by learners demonstrated in many studies has been attributed to ineffective teaching that neglects the above ideas about teaching and learning with adults in mind. In the context of the present CPR research, an educational strategy has been developed that considers evidence-based teaching and learning strategies in general (61) and the nature of involving adult learners more specifically. We label this strategy as the ALIVE educational strategy.

ALIVE educational strategy

The ALIVE educational strategy is based on sound educational principles. In the process of skill acquisition a staged approach will be used. The first three stages will use a video learning-while-watching technique, the fourth stage will use computer exercises with concurrent voice feedback and at the fifth or final stage the candidate will be assessed while performing the skill independently.

STAGE 1:
REAL SPEED DEMONSTRATION

At the first stage a video will be used, showing an instructor who demonstrates the skill as they would normally practise it. In order for it to appear realistic the demonstration is performed at normal speed; it allows the learner a unique 'fly on the wall' insight into the performance of the skill. No commentary or explanation is given, other than any verbalisation that accompanies the skill. The demonstration provides the learner with strong visual images, creating an 'advance organiser' upon which new learning can subsequently be structured. This advance organiser model is intended to help the learner apply new information in the context of existing images and knowledge, thereby facilitating the acquisition of the skill.

STAGE 2:
REPEAT DEMONSTRATION WITH DIALOGUE INFORMING THE LEARNER OF THE RATIONALE FOR ACTIONS

During this stage there is a transfer of facts and ideas from the virtual teacher to the learner. The mind has two main functions: processing information and storing information. Stage 1 has provided a strong visual image of how the skill should be performed. In stage 2 the virtual instructor is able to slow down the whole performance of the skill, providing the basis for actions and indicating the evidence base for the skill where appropriate. At this stage, the provision of meaningful feedback is important in the acquisition of psychomotor skills. There is further opportunity at this stage to reinforce important principles and facilitate the integration of new cognitive and psychomotor learning.

STAGE 3:

REPEAT DEMONSTRATION GUIDED BY THE VIRTUAL INSTRUCTOR TOGETHER WITH PRACTICE

During this third stage the learner practices the skill while watching the instructor perform it simultaneously. Strong visual reminders will help the candidate recall the skill under the stressful conditions of actual practice. At this stage the responsibility for the performed skill is moved firmly away from the instructor towards the learner. The emphasis is on allowing the cognitive understanding (knowledge) to guide the psychomotor activity (performance of the skill). There are three domains that have to be taken into account: cognitive, affective and psychomotor, and attention to all three is necessary for the transition of theory into practice. This stage of the instructional process facilitates the integration of all three.

STAGE 4:

REPEATED PRACTICE BY THE LEARNER WITH CONCURRENT FEEDBACK

This stage completes the teaching and learning process. It completes the transference of ability from the virtual instructor to the candidate, and helps establish the abilities of learners in the particular skill. However, this will only be achieved if the environment allows the learner to gain confidence in performing the skill. Therefore, positive reinforcement of the skill practice is provided through concurrent voice feedback. Additional corrective voice feedback, based on the current Resuscitation Guidelines is also provided in order to achieve the learning objectives.

STAGE 5:

COMPETENCE EVALUATION

For virtually all newly learnt skills, a single practise will be insufficient. By means of testing a candidates' competences, the achievement of the learning objective is determined. Subsequent feedback and feedforward should encourage the candidate to continue to practice in order to gain further confidence and competence. The rationale is motivated by the simulation-based education literature emphasising that debriefing, including feedback and feedforward, is the key phase where most of the learning takes place (56, 61, 76-78). Further training and testing to achieve gradually higher pass levels using additional multiple short training sessions is in line with the principles of Mastery Learning (61). Since the retention of both knowledge and psychomotor skills declines markedly with time and is reduced significantly after three to six months, repetition of the fifth and/or fourth stage over time is strongly recommended in order to regain the initially acquired confidence and competence.

ALIVE technical components and development

Investigating and developing a novel educational self-learning approach requires the use of adapted software and hardware. To investigate the research objectives discussed in this PhD thesis significant software development and adaptation was required. To gain understanding in the different manuscripts the knowledge of the required software modifications is essential. As the basis for our technological development the two major commercially available self-learning methods were used: the Mini Anne™ Self Directed Learning CPR video (Laerdal, Norway) and the Resusci Anne (RA) Skills Station™ (Laerdal, Norway). As discussed previously, these methods still lack efficacy and lead to equally suboptimal skill acquisition and rapid skill decay as compared to instructor-led training (23, 55). However, they offer advantages related to self-learning such as flexibility, one-to-one teaching and increased hands-on time.

INITIAL SKILL ACQUISITION

The RA Skills Station™ consists of a computer running RA Skills Station software™ version 2.0 connected to an “RA torso” manikin (Laerdal, Norway). This system allows retraining of CPR skills through computer exercises while performance is measured and registered. The software uses concurrent voice feedback messages such as: “compress deeper”, “compress faster”, “release pressure between compressions” and “a little less air”. Corrective feedback is triggered by CPR performance outside the accepted limits. When CPR is performed correctly, positive feedback is provided (e.g. “you’re doing fine”). Since the RA Skills Station™ was originally developed for refresher training, we needed to adapt it to teach initial skill acquisition. A step-by-step explanation and demonstration (Mini Anne™ video) was therefore introduced. The Mini Anne™ video consists of a DVD showing a virtual instructor demonstrating the core CPR skills in a staged approach, while the trainee is practising-while-watching. The Mini Anne™ video was edited by adding an introduction sequence (explaining the concept of the video and demonstrating the use of a face shield) and by removing repetitive sequences. The resulting video (duration 20 min) contained instruction and demonstration on the core CPR skills including compression, ventilation and combined CPR exercises. To embed the Mini Anne™ video in the Resusci Anne Skills Station™ software, Laerdal Medical provided us with a modified version of their commercial software. After these modifications, the self-learning station was able to show the edited Mini Anne™ video and allow subsequent computer exercises with concurrent voice feedback.

AUTOMATED SKILLS ASSESSMENT

CPR testing methods require the presence of an instructor, making testing time-consuming with a risk of instructor bias, which is not in line with the philosophy of a self-learning station. Automated testing grounds the scalability of formative assessment and certification procedures without instructor involvement. We designed an interactive user interface with Flash™ (Adobe Systems Inc., USA) to guide the students through a testing procedure without the presence of an instructor, allowing them to perform CPR skills on a commercially available “Resusci Anne torso” manikin (Laerdal, Norway), while their performance was automatically registered by the existing software (RA Skills Station™ software version 2.0, Laerdal, Norway) running on a computer. To embed the newly developed Flash™-based user interface in the RA Skills Station™ software, Laerdal Medical provided us with a modified version of their commercial software. Laerdal was not further involved in the development of the interactive Flash™ video and the concept of removing the instructor from the testing procedure which was developed at Ghent University.

MULTIPLE TRAINING SESSIONS WITH AUTOMATED ASSESSMENT AND FEEDBACK

With the previously described software developments the RA Skills Station allowed initial skill acquisition, skill retraining and automated testing. However, although the testing procedure was automated, there was still no instant feedback on the test result communicated to the student. To allow automated analysis of the test data followed by an on-screen test result a new software program was developed by our research group. This software program was called ALIVE. The software was designed in order to be used in three different ways: for initial skills acquisition, for skills retraining or as an automated testing station. After login and registration of basic demographical data, the ALIVE software asked the student to perform a baseline test after which he could learn CPR or refresh his skills if necessary. The use of the RA Skills Station at this stage was still required in order to capture CPR performance, provide concurrent voice feedback and store the obtained data as an xml file. After each test, the ALIVE software analysed the data stored in the xml file, calculated a result and provided real-time feedback and feed-forward. These test results were stored together with the feedback in an individual portfolio. This further development allowed us to train participants to a predefined bench, using multiple short training sessions with automated assessment and feedback.

Conflict of interest statement

We received an unrestricted grant from the Laerdal Foundation. Laerdal (Stavanger, Norway) provided the manikin, the face shields and the RA Skills Station^{TM} licenses for the study. The required software modifications to the RA Skills Station were provided with the help of Laerdal Sophus programmers (Laerdal, Sweden). Laerdal has taken no part in designing the studies, analysing the data or writing the manuscripts.

Chapter 1

Combining video instruction followed by voice feedback in a self-learning station for acquisition of Basic Life Support skills: a randomised non-inferiority trial.

RESUSCITATION 2011;82:896-901

Contents lists available at ScienceDirect

Resuscitation

journal homepage: www.elsevier.com/locate/resuscitation

Simulation and education

Combining video instruction followed by voice feedback in a self-learning station for acquisition of Basic Life Support skills: A randomised non-inferiority trial☆

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ARTICLE INFO

Article history:
Received 24 August 2010
Received in revised form 26 January 2011
Accepted 14 February 2011

Keywords:
Basic Life Support
Cardiopulmonary resuscitation
Instructor
Non-inferiority
Self-directed learning
Training

ABSTRACT

Introduction: Current computerised self-learning (SL) stations for Basic Life Support (BLS) are an alternative to instructor-led (IL) refresher training but are not intended for initial skill acquisition. We developed a SL station for initial skill acquisition and evaluated its efficacy.
Methods: In a non-inferiority trial, 120 pharmacy students were randomised to IL small group training or individual training in a SL station. In the IL group, instructors demonstrated the skills and provided feedback. In the SL group a shortened Mini Anne™ video, to acquire the skills, was followed by Resusci Anne Skills Station™ software (both Laerdal, Norway) with voice feedback for further refinement. Testing was performed individually, respecting a seven week interval after training for every student.
Results: One hundred and seventeen participants were assessed (three drop-outs). The proportion of students achieving a mean compression depth 40–50 mm was 24/56 (43%) IL vs. 31/61 (51%) SL and 39/56 (70%) IL vs. 48/61 (79%) SL for a mean compression depth ≥40 mm. Compression rate 80–120/min was achieved in 49/56 (88%) IL vs. 57/61 (93%) SL and any incomplete release (≥5 mm) was observed in 31/56 (55%) IL and 35/61 (57%) SL. Adequate mean ventilation volume (400–1000 ml) was achieved in 29/56 (52%) IL vs. 36/61 (59%) SL. Non-inferiority was confirmed for depth and although inconclusive, other areas came close to demonstrate it.
Conclusions: Compression skills acquired in a SL station combining video-instruction with training using voice feedback were not inferior to IL training.

1. Introduction

For initial acquisition of Basic Life Support (BLS) skills, the European Resuscitation Council (ERC) Guidelines 2005 recommend training in small instructor-led (IL) groups with hands-on practice.[1] Recent studies indicate that training with a video or an interactive CD can be an alternative to traditional IL courses.[2–8]

The Mini Anne™ Self Directed Learning CPR program (Laerdal, Norway) is an effective method using a video to acquire the core skills of CPR.[5,9] It uses a "practice-while-watching" technique with learners practising CPR on a personal manikin (Mini Anne™) while watching the skills being demonstrated on a video. On the other hand, the Resusci Anne (RA) Skills Station™ (Laerdal, Norway) has been shown a feasible strategy for BLS refresher training.[10–14] The RA Skills Station™ provides self-directed BLS skill training with concurrent voice feedback during training. In addition it enables automatic recording and storage of performance data.

The goal of the current study was to develop a self-learning (SL) station for initial skill acquisition. Because the RA Skills Station™ is designed for refresher training only, a modification to enable initial skill acquisition was required. We therefore combined a Mini Anne™ approach with the RA Skills Station™ sequentially in one SL session and compared this new SL method with IL training. Given the available evidence underpinning the efficacy of IL small group training, we adopted a non-inferiority research design.[1,15] We hypothesized that training in a computerised SL station would result in at least equal BLS skill mastery as compared to IL training.

2. Research methods

2.1. Participants

The Ethics Committee of Ghent University Hospital approved the study. During the academic year 2009–2010, after obtaining informed consent, 120 third year pharmacy students were randomly assigned to IL group training (maximum six students) or individual training in a SL station using an online Research Randomizer software tool (http://www.randomizer.org/). No exclusion criteria were applied before randomisation and no stratification was performed. Participation in the study was voluntary and the students were informed that non-participation would not influence their grades.

☆ A Spanish translated version of the abstract of this article appears as Appendix in the final online version at doi:10.1016/j.resuscitation.2011.02.024.
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doi:10.1016/j.resuscitation.2011.02.024

2.2. Research procedure

At Ghent University, CPR training is a mandatory part of the pharmacy student's curriculum, and consists of a lecture followed by an IL training session. To introduce SL in the curriculum, we intended to change the practical IL part of the course to computer-guided learning, while keeping the lecture (90 min) to provide background on the techniques of BLS and to motivate students for the practical training. After the lecture, a SL station was made available in a small room secured with a badge reader, accessible 24 h a day and seven days a week. During a 12-week study period each student could exercise for 1 h with the option to attend a second time.

Since the RA Skills Station™ was originally developed for refresher training, we needed to adapt it to teach initial skill acquisition. A step-by-step explanation and demonstration (Mini Anne™), in line with cognitive instructional design guidelines, was therefore introduced.[16,17] As such, the SL station included one computer showing an edited Mini Anne™ video and a second computer running RA Skills Station software™ version 2.0 connected to an "RA torso" manikin (Laerdal, Norway). The Mini Anne™ video was edited by adding an introduction sequence (explaining the concept of the video and demonstrating the use of a face shield) and by removing repetitive sequences. The resulting video (duration 20 min) contained instruction and demonstration on the core CPR skills including compression, ventilation and combined CPR exercises.

After entering the room, participants first followed the edited Mini Anne™ video, while practising on the RA manikin using a face shield. After completion, they were directed to login on the second computer providing visual and voice instructions during further training on the manikin. The Skills Station™ exercises were presented in three parts: compressions, ventilations and full CPR. During the exercises, the computer provided concurrent voice feedback.

The computer registered performance of chest compression depth, rate, incomplete release and ventilation volume. The manikin's feedback as well as evaluation limits for compression rate and incomplete release was used as set by the manufacturer: rate 90–115/min, incomplete release ≥5 mm. For the feedback of CPR, cycles of 27–35 compressions and 1–4 ventilations were considered acceptable. For compression depth, our previous experiences with the SL station had shown that voice feedback using compression depth margins according to the guidelines induced learners to avoid deep compressions, leading to superficial compressions during retention testing.[18] We therefore applied an upper limit of 55 mm before the voice prompt "compressions to deep" was activated. The IL group was taught compression depth as usual, because we wanted this to serve as a true control without changing our standard way of teaching. For ventilation volume we selected a range of 400–1000 ml, because the chest of the manikin visibly rises after insufflation of 400 ml. The upper limit of 1000 ml was arbitrarily chosen.

Participants could repeat exercises but they were not obliged to take all exercises or to spend a minimum of time per exercise. After every exercise a score (automatically calculated by the Skills Station™ software, according to the limits), accompanied by specific feedback was communicated on-screen to the participant. To pass the compression exercise 90 compressions were required with minimum 70% correct, for the ventilation exercise 12 ventilations were required with minimum 70% correct. For the combined CPR exercise 3 cycles of CPR were required with a minimum of 90 compressions (of which 70% correct) and a minimum of 6 ventilations (of which 70% correct).

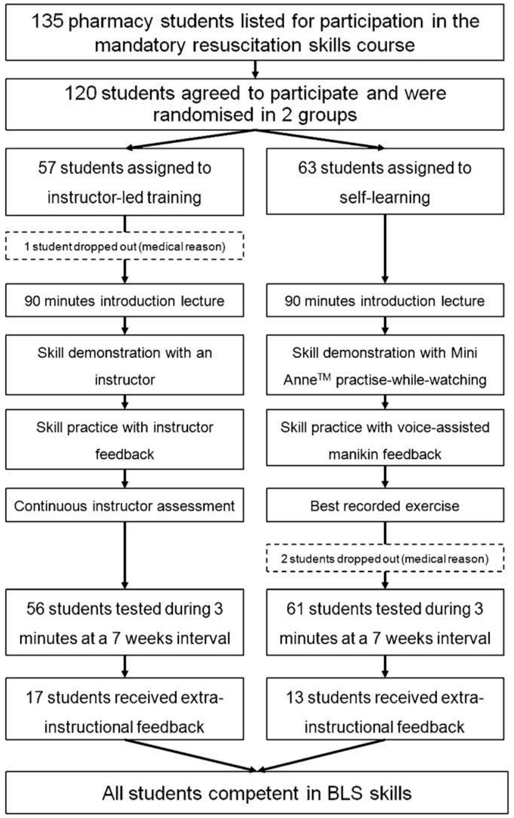

Fig. 1. Participants flow chart.

In the IL group, students attended a traditional BLS course where an ERC-certified BLS instructor trained them on a manikin in groups with a maximum of six participants. Each group session lasted no more than 90 min. The introduction to CPR was similar to the content of the Mini Anne™ video used in the SL condition, followed by exercising on a "RA torso" manikin (Laerdal, Norway) without indicator lights, metronome or voice feedback. Individual instructor feedback was given, focussing on correct compression and ventilation techniques according to the ERC guidelines. Continuous performance assessment was carried out by the instructors with further practice and sufficient individual manikin exposure until every student was judged to be adequately trained (i.e. competent to perform BLS). No test was taken at the end of the course. The participant flow chart is shown in Fig. 1.

Respecting a seven week interval after initial training for every student, testing was done individually in a room with a RA manikin connected to a laptop computer equipped with the same RA Skills Station™ software as during SL training, but with feedback disabled. An ERC BLS instructor welcomed the student and informed him that the test would consist of resuscitating a victim (i.e. the manikin) who just collapsed. No further information was given, except for the condition of the manikin, which was communicated after each appropriate assessment by the rescuer. The test protocol was consistent with the Utstein objective of "demonstrable lifesaving CPR on a manikin in a simulated scenario after the training course" and was similar to that used in other studies.[2–4,19] Participants were then given 3 min to perform CPR skills (without concurrent feedback). Skills were registered by the RA Skills Station™ software capturing data on compression depth and rate, on incomplete release and ventilation volume.[20] The instructor scored the participants overall performance as competent or not yet competent. After testing, "not yet competent" students were given extra-instructional feedback by the instructor with further practice in order to ensure skill mastery (i.e. "competent") in all students at the end of the study (Fig. 1).

2.3. Objectives and outcome measures

The trial was designed to determine whether the individual SL training method for initial skills acquisition was as effective (i.e. non-inferior) as conventional IL training. Four quality indicators related to BLS mastery were defined: compression depth, compression rate, incomplete release and ventilation volume.

Proportions in relation to the quality indicators were used as outcome measures to assess differences in BLS mastery: proportion of participants with mean compression depth 40–50 mm, proportion of participants with mean compression depth ≥40 mm, proportion of participants with mean compression rate 80–120/min, proportion of participants with any incomplete release (≥5 mm) and proportion of participants with mean ventilation volume 400–1000 ml.

For the outcome measures, the null hypothesis (H_0) stated that SL training was inferior to IL training measured seven weeks after training. To establish non-inferiority the upper limit of the 90% confidence interval (CI) needed to fall below the predefined non-inferiority margin. Comparing proportions, a difference of 10% was defined as non-inferior. Previous results from our research group reported a success rate for IL training of 56% for mean compression depth 40–50 mm, 62% for mean compression depth ≥40 mm, 70% for mean compression rate 80–120/min and 75% for mean ventilation volume 400–1000 ml.[21] A 46–50% rate of incomplete release is reported in literature.[22–24] This means that the 90% CI for the odds ratio for IL vs. SL training should not exceed 1.49 for compression depth 40–50 mm; 1.51 for compression depth ≥40 mm, 1.56 for mean compression rate 80–120/min and 1.62 for mean ventilation volume 400–1000 ml. For incomplete release, the lower limit of the 90% CI for the odds ratio should not fall below 0.67. In addition, for the SL group, performance at the end of training and seven weeks later was compared.

2.4. Statistical methods

Differences in odds between both training conditions (IL and SL) for proportional BLS quality indicators were analysed by multiple logistic regression analysis, correcting for gender, height, weight and previous BLS training.[21,25] Non-inferiority criteria for the odds ratio for proportional BLS quality indicators were evaluated based on two-sided 90% CI instead of 95% CI for the purpose of a 1-sided test.[15] Performance at the end of training and after seven weeks in the SL group was compared using a McNemar test. Values are presented as counts (proportions) or means with standard deviation. Statistical analyses were performed using PASW® statistics 18 for Windows (SPSS Inc. Chicago, USA).

Table 1
Characteristics of students randomised to instructor-led (IL) or self-learning (SL) groups. Values represented as means (SD) or counts (proportions).

	IL (n = 57)	SL (n = 63)
Age (years)	21 (2)	21 (1)
Females	50 (88%)	44 (70%)
Height (cm)	170 (7)	173 (8)
Weight (kg)	61 (9)	64 (10)
Previous BLS training	9 (16%)	12 (19%)
Time since last training (months)	48 (31)	64 (30)

3. Results

3.1. Recruitment and baseline data

One hundred and twenty of 135 eligible students agreed to participate in the study and gave informed consent. The IL and the SL group respectively consisted of 88% and 70% female students and mean age was 21 years in both groups (Table 1). Twenty-one students, nine IL and 12 SL, reported previous BLS training. After randomisation, 56 students were trained in the IL condition (one student fell ill) and 63 in the SL condition. After seven weeks 56 IL and 61 SL students (two were ill) were tested (Fig. 1). After the retention test 17 IL and 13 SL students received extra instructional feedback and practice in order to become competent at the end of the course (Fig. 1).

3.2. Comparison of BLS quality between the two groups

After correction for gender, height, weight and previous BLS training, the adjusted two-sided 90% CI for the odds ratio of good mean compression depth 40–50 mm was (0.37–1.32) and therefore below the non-inferiority margin of 1.49, establishing non-inferiority (Table 2). Further, the adjusted proportion of students achieving a mean compression depth ≥40 mm was 9% higher in the IL condition. The odds ratio for good mean compression depth ≥40 mm was 0.73 and the corresponding 90% CI for the odds ratio (0.35–1.51) had the non-inferiority margin of 1.51 as its upper bound. The two-sided 90% CI for the odds ratio of good mean compression rate 80–120/min was (0.17–1.57) and therefore included the non-inferiority margin of 1.56. For incomplete release, with the lower bound of the 90% CI for the odds ratio (0.52–1.84) falling below the non-inferiority margin of 0.67 there was insufficient evidence to establish non-inferiority. The adjusted odds ratio for good mean ventilation volume 400–1000 ml was 0.85, in favour of the SL condition, and the upper bound of the corresponding 90% CI for the odds ratio (0.44–1.62) equalled the non-inferiority margin of 1.62.

3.3. Differences between end of training and retention data for SL group

In the SL station, the proportion of participants achieving a mean compression depth of 40–50 mm was 50/61 (82%) at the end of training and 31/61 (51%) after seven weeks (P < 0.001). For a depth ≥40 mm, this was 60/61 (98%) and 48/61 (79%), respectively (P = 0.002).

The proportion of participants achieving a mean compression rate 80–120/min was 61/61 (100%) at the end of training and 57/61 (93%) at seven weeks (P = 0.13). The proportions of participants with any incomplete release were similar after training 37/61 (61%) and at seven weeks 35/61 (57%) (P = 0.84). The proportion of participants with a ventilation volume 400–1000 ml was 60/61 (98%) and 36/61 (59%), respectively (P < 0.001). At the end of SL training, one student did not achieve adequate depth and another one did not achieve adequate ventilation volume. These two participants returned for a second training session.

Table 2
Results seven weeks after training.

	IL (n = 56)	SL (n = 61)						
	Number of participants (%)	Number of participants (%)	Non inferiority margin[a]	Unadjusted odds ratio (90% CI)	Result	Adjusted[b] odds ratio (90% CI)	Result	P-value
Mean compression depth 40–50 mm	24 (43)	31 (51)	1.49	0.73 (0.39;1.34)	Non inferior	0.70 (0.37;1.32)	Non inferior	0.35
Mean compression depth ≥40 mm	39 (70)	48 (79)	1.51	0.62 (0.31;1.25)	Non inferior	0.73 (0.35;1.51)	Inconcl.	0.48
Mean compression rate 80–120/min	49 (88)	57 (93)	1.56	0.49 (0.17;1.45)	Non inferior	0.51 (0.17;1.57)	Inconcl.	0.33
Any incomplete release ≥5 mm	31 (55)	35 (57)	0.67	0.92 (0.50;1.70)	Inconcl.	0.97 (0.52;1.84)	Inconcl.	0.94
Mean ventilation volume 400–1000 ml	29 (52)	36 (59)	1.62	0.75 (0.40;1.38)	Non inferior	0.85 (0.44;1.62)	Inconcl.	0.67

Inconcl. = inconclusive.
[a] To establish non-inferiority the upper limit of the 90% CI needed to fall below the predefined non-inferiority margin, for any incomplete release the lower limit of the 90% confidence interval for the odds ratio should not fall below 0.67.
[b] Adjusted for gender, height, weight and previous BLS training.

4. Discussion

We developed a novel approach to acquire BLS skills in a SL station by combining a practice-while-watching technique with exercises using concurrent individualised feedback. The results demonstrate non-inferiority for the proportion of students reaching a compression depth between 40 and 50 mm. For the other proportions, formally, the test results were inconclusive but came very close to demonstrate it.

The concept of this method is that new skills are demonstrated by a virtual instructor while the student practises individually, followed by refinement of skills by concurrent voice feedback and textual feedback after every exercise, while performance is constantly registered. With a 98% success rate for compression and ventilation skills at the end of training (with voice feedback enabled), this new training method proved highly effective in a population with 17% previous BLS training. This also explains the fact that only two non-successful participants of the SL group had to return for a second training session.

Kardong-Edgren et al. are the only who studied training with voice feedback in combination with another learning method.[26] They compared a self-directed e-learning course for cognitive learning (the American Heart Association's HeartCode™ program) followed by psychomotor skills refinement, using a voice assisted manikin (Laerdal, Norway) with IL training in nursing students with previous BLS training. They reported that, immediately after training, 53% of all students' compressions had adequate depth (38–51 mm) and 46% of all bag-valve-mask ventilations had adequate volume (500–800 ml). Comparing their results with our data is difficult for two reasons. Our results at the end of training in the SL group were obtained with voice guidance and their population had a higher percentage of previously trained participants (92% vs. 17% in our sample).

Using only the Mini Anne™ video self-instruction method, Nielsen et al. reported adequate compression depth (40–50 mm) after 3.5–4 months in 30% and 78% (≥40 mm) of nursing students.[27] Their results may have been influenced by a pre-test which may have induced a learning effect.[28,29] Our higher percentage (51%) of students achieving depth 40–50 mm may be due to a shorter retention interval.[4] Another difference is that, in the Nielsen study, the Mini Anne™ was used during group-training with facilitators present which may also have resulted in an improved learning outcome due to instructor and peer facilitation. Facilitation by instructors and peers was also present in the study by Einspruch et al. who compared a traditional IL BLS course with a 20 min video self-instruction program used in three self-training groups (self-training alone, self-training with instructor facilitation, and self-training with peer facilitation).[4] The three self-learning groups were reported together, leading to proportions of adults (between the ages of 40 and 50 years and without CPR training for the past five years) achieving compressions with adequate depth (≥38 mm) of 38% during initial performance and 48% in a two-month retention test.[4] For self-training alone and considering compressions of ≥40 mm as adequate, our data shows better acquisition (98%) and retention (79%) at seven weeks. Perhaps our results at retention could even be underestimated in comparison to other studies that used a lower limit of 38 mm for adequate compression depth.[4–6,10–13,19,26]

Einspruch et al. additionally reported proportions of participants achieving adequate ventilations (≥700 ml) of 61% immediately after training and 41% after 2 months.[4] Our data show better acquisition (98%) and retention (59%) at seven weeks for good mean ventilation, but we used a lower margin of 400 ml.

Improved performance of our SL group at retention testing could be explained by the refinement of skills using concurrent voice feedback.[10,26] An alternative explanation for our good results might be age-related differences in attention span and memory capacity.[30] The mean age of the participants in the present study was 21 years, potentially resulting in better acquisition of skills, although Braslow et al. found that participants over 40 year performed compressions comparable to younger participants.[3] Finally, our study population consisted of pharmacy students who may have more motivation than the general population.

Taking into account ERC 2005 guidelines, the proportion of students achieving complete release, adequate mean compression depth and mean ventilation volume after seven weeks remained unsatisfactory in both conditions. This confirms previous research documenting poor retention of skills after both IL and self-directed or voice assisted manikin learning.[2,9,11,31] As an alternative to evaluate the student's compressions as adequate, all compressions $\geq$40 mm were considered as adequate (therefore including compressions of more than 50 mm). This analysis seems justified because deeper compression depths are in line with ILCOR 2005 treatment recommendations stating that it is reasonable for lay rescuers and healthcare providers to compress the sternum by "at least 4–5 cm".[32] Additionally, the ERC 2010 guidelines now recommend a compression depth of "at least 5 cm".[33]

Of the SL group 98% had a depth $\geq$40 mm after initial learning. After seven weeks this was 70% for IL vs. 79% for SL. The unsuccessful students needed extra-instructional feedback in order to become competent (Fig. 1). Therefore, we conclude that a single training session (IL or SL) was insufficient to retain BLS skills. Repetitive training and testing may be essential to consolidate new skills.[31]

Participants were not tested immediately after training because our standard course for pharmacy students used continuous assessment and not end-of-course assessment. Therefore decline in skills could not be analysed in the IL group. Pre-training testing (to control for potential BLS mastery differences before the intervention) and testing at the end of training (to assess the effect of the intervention) should be encouraged in future studies. However, testing on its own, may induce a learning effect and better retention.[27–29,31] A post hoc power analysis resulted in a power of 0.31 for compression depth 40–50 mm, 0.32 for compression depth $\geq$40 mm, 0.34 for rate 80–120/min, 0.29 for any incomplete release ($\geq$5 mm) and 0.36 for ventilation volume 400–1000 ml. We therefore cannot rule out a Type-II error as the reason for some results being statistically inconclusive. We have studied skills after seven weeks and therefore conclusions on longer-term retention cannot be drawn. Also the use of a lecture before training limits the generalizability of the results. ERC 2010 guidelines are encouraging short video/computer self-instruction courses, with minimal or no instructor coaching, combined with hands-on practice as an effective alternative to instructor-led BLS courses, but several knowledge gaps need to be addressed.[34] This includes the contribution of each self-learning component (Mini Anne video, RA Skills Station) and additional mediating variables that play a role in learning performance (time on task, self-efficacy, cognitive load and quality and quantity of feedback).

5. Conclusions

Based on the proportion of students achieving adequate compression depth, skills acquired in a SL station combining video-instruction with training using voice feedback were not inferior to IL training. This study provides evidence supporting the use of a SL station for initial BLS skill acquisition.

Conflict of interest statement

Laerdal Medical (Stavanger, Norway) supported the study by providing the manikin, the face shields and the RA Skills Station™ software for the duration of the study. Laerdal Medical has taken no part in designing the study, analysing data or writing of the manuscript. The authors have received a grant from the Laerdal Foundation to conduct further research in this area.

Acknowledgements

We are grateful to the management of Ghent University Hospital, to the IT department for computer support, to Charlotte Vankeirsbilck and Lien Yde for administrative support, and to all the students who participated in the study.

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Chapter 2

Acquiring basic life support skills in a self-learning station: video alone is not enough.

EUR J EMERG MED 2013;20:315-21

Acquiring basic life support skills in a self-learning station: video alone is not enough

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Objectives To develop a self-learning station combining a video with computer exercises to learn cardiopulmonary resuscitation (CPR) to novices, and to assess the efficacy of these two components on CPR acquisition.

Methods One hundred and twenty-five pharmacy students were trained using learning-while-watching video instructions followed by exercises with voice feedback. The proportion of students with adequate CPR skills (≥ 70% compressions with depth ≥ 50 mm, ≥ 70% compressions with complete release < 5 mm, a compression rate between 100 and 120/min, ≥ 70% ventilations with a volume between 400 and 1000 ml) was measured at baseline, after video training and after subsequent voice-feedback training.

Results Complete datasets were obtained for 104 students. After video training, the 70% cut-off for compression depth was achieved in 29/104 students, for complete release in 75/104, for ventilation volume in 44/104. Mean compression rate 100–120/min was adequate in 77/104 students. Compared with baseline results, only rate (29/104 vs. 77/104) and ventilation volume (6/104 vs. 44/104) improved. After subsequent training with voice feedback the proportions were: compression depth 88/104, compression rate 77/104, ventilation volume 74/104 and complete release 90/104. Compared with the skill level after video training only compression rate did not further improve. A score combining the three compression skills resulted in the following success rates: 6/104 (baseline), 15/104 (after the video), 59/104 (after voice feedback).

Conclusion Although in a self-learning station video training can introduce CPR skills to novices, additional voice-feedback exercises were needed to achieve acceptable CPR quality. *European Journal of Emergency Medicine* 20:315–321 © 2013 Wolters Kluwer Health | Lippincott Williams & Wilkins.

European Journal of Emergency Medicine 2013, 20:315–321

Keywords: basic life support, cardiopulmonary resuscitation, computer-assisted instruction, education, self-learning

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Received 26 April 2012 **Accepted** 18 July 2012

Introduction

International cardiopulmonary resuscitation (CPR) guidelines encourage short video/computer self-learning courses, with minimal or no instructor coaching [1]. Various CPR self-learning programmes have been compared with instructor-led courses for training lay people and healthcare providers [2–14]. Despite intensive efforts, general mastery of CPR skills after instructor-led courses and alternative self-learning programmes remain disappointingly poor, establishing the need for the development of more effective training strategies [1,15–18]. As self-learning stations for CPR were initially designed for refreshing skills, we developed a self-learning station combining a Mini Anne practice-while-watching video followed by voice-feedback exercises (Resusci Anne Skills Station) to teach CPR to novices [2].

In a previous study, we showed that such a combined instructional strategy is noninferior to instructor-led training for initial CPR skill acquisition in a self-learning station [2]. Although this combined instructional self-learning strategy is still not superior for (re)training skills, it can be a valuable time-efficient alternative [2,19]. Knowledge gaps, however, remain about the impact of each training component on skill acquisition in lay people.

In the present study, we analysed the learning efficacy of the video-training component and the additional impact of subsequent voice-feedback exercises on the acquisition of CPR skills. As, according to the literature, male sex is associated with better quality of CPR, we additionally investigated the predictive value for success of potential covariables such as sex, height and weight in relation to the target outcomes [20,21].

Materials and methods

At Ghent University CPR training is a mandatory part of the pharmacy student's curriculum. A self-learning station, as described previously, was made available in a small room secured with a badge reader, accessible 24 h a day, 7 days a week [2]. During a 5-week study period each student was directed to practice CPR for up to 1 h.

0969-9546 © 2013 Wolters Kluwer Health | Lippincott Williams & Wilkins

DOI: 10.1097/MEJ.0b013e328358490a

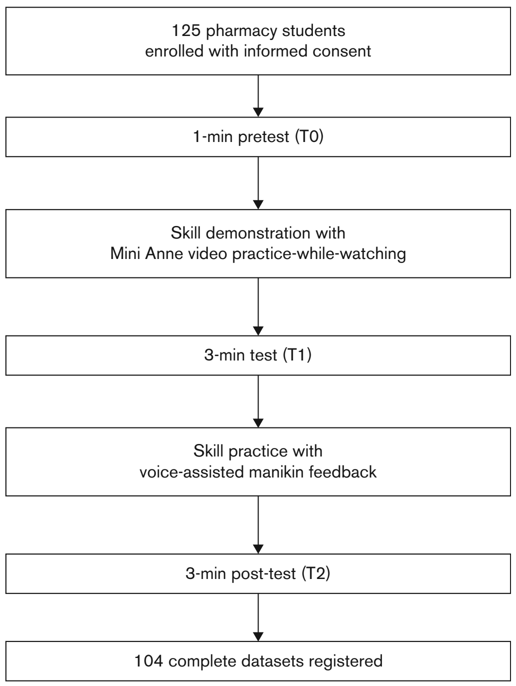
The students were informed that nonparticipation in the study would not influence their grades and the Ethics Committee of Ghent University Hospital approved the study. Students' characteristics (age, sex, height and weight) were registered before the training.

At the beginning of the training, an introduction video showed the use of the face shield and mentioned that its use was mandatory for hygienic reasons during the whole training. After this, to establish baseline skill level an automated pretest (T0) was taken, asking the students to try to resuscitate a cardiac arrest victim (Resusci Anne torso manikin, Laerdal, Norway) during a 1-min period. After the test, the students were trained in CPR using a combined learning strategy consisting of a practice-while-watching video (Mini Anne, Laerdal, Norway) followed by computer exercises with concurrent voice feedback (Resusci Anne Skills Station, Laerdal, Norway) [2]. Practising and testing were done on a full size manikin torso lying on the floor and using a face shield, whereas performance of chest compression depth, compression rate, complete release and ventilation volume was registered automatically. Feedback limits during training in the Skills Station were set by the investigators as follows: for compressions at a depth of at least 50 mm (the physical upper compression limit of the manikin is 6 cm); for rate at 100–120/min; for ventilation at 400–1000 ml (because the chest of the manikin visibly rises after insufflation of at least 400 ml); for complete release at less than 5 mm.

To establish the impact of each training component, an automated 3-min test (without any feedback) was introduced after the practice-while-watching video (T1), as well as after the voice-feedback exercises (T2; Fig. 1).

Students who did not achieve the expected competency level after the last test were invited for additional instructor-facilitated training in the self-learning station.

Fig. 1



Participant flow chart.

Objectives and outcome measures

The primary aim of the study was to establish the impact of video learning and the additional impact of subsequent voice-feedback exercises on four CPR quality indicators related to CPR mastery: compression depth, compression rate, complete release and ventilation volume.

Outcome measures included achievement of a mean compression depth of at least 50 mm, a compression rate 100–120/min, a complete release (< 5 mm) during all compressions and a mean ventilation volume 400–1000 ml. In addition, we also analysed how many students were able to achieve 70% or more compressions with a depth of at least 50 mm, 70% or more compressions with complete release and 70% or more ventilations with a volume 400–1000 ml. Because separate compression quality indicators do not allow an overall pass or fail assessment in a self-learning station, we calculated a score combining compression depth, release and rate. To be able to provide effective CPR, we expected lay rescuers to achieve at least 70% of all compressions with correct depth and release as well as a rate between 100 and 120/min. As the 70% threshold value was chosen arbitrarily, we additionally explored the effect of other threshold values (50, 60, 80, 90 and 100%) on the outcomes.

Statistical methods

Regarding the proportional CPR quality indicators of both groups, performances at different stages of the training (T0, T1, T2) were compared. To analyse the learning efficacy of the video, the results of the 1-min pretest (T0) were compared with the results from the first minute of the test after the video (T1). For the additional impact of the voice feedback, the results from the first minute of the test after the video exercise (T1) were compared with the results from the first minute of the test after the voice-feedback exercises (T2).

Confidence intervals (CI) are reported for the differences between proportions. Confidence intervals were chosen because they integrate sample size, effect difference and near significance of the findings all at once without the limitations imposed by a single P value. For sex, CIs were based on two-sample tests for equality of proportions with continuity correction using software package R

(The R Foundation for Statistical Computing, Vienna, Austria). For time, Wilson score CI for the difference between two correlated proportions were calculated using software package R (version 2.14.1; The R Foundation for Statistical Computing) [22].

Results

Recruitment and baseline data

During the academic year 2010–2011, 125 pharmacy students gave informed consent and were trained in a self-learning station. In the test procedures, a technical failure occurred during data registration of 21 students, resulting in incomplete datasets. There was no systematic variation to which subjects data were lost. Complete datasets were obtained from 104 students (Fig. 1). Student characteristics are described in Table 1. Fourteen students received previous training, of which two students received training within the last 6 months. Additional analysis initially excluding these two students and thereafter excluding all students with previous training did not show any significant differences in the results (data not shown).

Impact of the practice-while-watching video and voice-feedback exercises

As shown in Table 2 the video only had a significant impact on compression rate and ventilation skills. The proportion of students with adequate compression depth and complete release did not differ before and after the video (Table 2).

After subsequent training with voice feedback a significant improvement was observed for all compression and ventilation outcome measures, except for compression rate (Table 2).

Interaction effects of student characteristics

For the student characteristics, significant interactions with CPR quality indicators could be observed for sex, height and weight. Being taller or weighing more was in favour of deeper compression depth at T0 and related to sex (men being on average 13 cm taller and 13 kg heavier than women). No additional interactions were observed for height and weight. In relation to sex no significant interactions were found with respect to compression rate and mean ventilation volume 400–1000 ml. For compression depth, female students performed worse than male students at T0 and at T1 (Table 3). In both genders, the proportion of students with adequate depth did not improve significantly after the video training (T1). However, this proportion increased significantly after the voice-feedback exercises in both male and female students, and resulted in no significant differences between male (89%) and female students (88%) at T2 [−1% (−14%, 15%)]. The same was observed for at least 70% of all compressions of at least 50 mm (Table 3).

For the variables describing complete release significant interactions between sex were found at T0, as well as at T1 for the variable '≥ 70% of compressions with complete release'. In contrast to compression depth, the proportion of women who succeeded was larger than the proportion of men (Table 3). Again all significant interaction effects due to sex disappeared after the voice-feedback exercises (T2) and for the variable '≥ 70% of compressions with complete release'. This was because of the fact that significantly more men achieved at least 70% complete release [from 41 to 81%: +41% (16%, 56%)], whereas no significant increase was observed for women [from 83 to 88%: +5% (−4%, 15%); Table 3].

Combined assessment score for compression skills

On the basis of the combination of percentage compressions with a depth of at least 50 mm, percentage compressions with complete release and compression rate between 100 and 120/min, a 'pass 70' score resulted in a 57% overall success rate. The proportions of students achieving a composite pass score using different thresholds are shown in Table 4. Ventilation skills were, however, not included in the combined score.

Discussion

We analysed the learning efficacy of a practice-while-watching video and the additional impact of subsequent training with voice-feedback exercises on CPR skills acquisition in a self-learning station. The goal of the present trial was to assess the impact of each individual component and not to demonstrate superiority of the training method as such. To assess the quality of CPR performance, reporting proportions of successful students provides more information than reporting improvements of (group) mean values. We, therefore, analysed and reported the proportion of successful participants for each important CPR component against a predefined pass level. To allow comparison with other studies, mean values were also reported in the manuscript.

With regard to the 14 students with previous training, we investigated their impact on the results by removing them from the dataset, which did not change the results. We, therefore, believe that including these 14 students in the analysis was justified.

The integration of a video-based approach in our combined learning strategy builds on the reported benefits of interactive video instruction on general performance of CPR [3–14,23]. Four studies assessing the efficacy of video training only report group means or mean percentages [3–6], five studies report (mean) proportions of compression and ventilations [7–11] and three studies report proportions of participants achieving a specific target [12–14]. A systematic review by Mäkinen *et al.* [24] in 2007 concluded that explicit comparable outcomes are needed to assess the quality of CPR. All studies show a general improvement in attitude towards CPR and an improvement in skills compared with traditional learning, although in most cases performance

Table 1 Characteristics of students (n=104)

	Males (n=27)	Females (n=77)
Age (years)	21 (1)	21 (1)
Height (cm)	182 (7)	169 (5)
Weight (kg)	74 (9)	61 (8)
Previous BLS training	4 (15%)	10 (13%)
Time since last training (months) (n=14)	31 (81)	42 (35)

Values represented as means (SD) or counts (proportions).
BLS, basic life support.

Table 2 Results of 1 min cardiopulmonary resuscitation at baseline, after video training and after voice-feedback training (n=104)

	Number of participants n/N (%) [95% CI]			Number of participants n/N (%) [95% CI]	
	Pretest (T0)	Test after video exercise (T1)	Difference T0–T1 (%) [95% CI]	Test after voice-feedback exercise (T2)	Difference T1–T2 (%) [95% CI]
Mean compression depth ≥ 50 mm	30/104 (29%) [21%, 38%]	36/104 (35%) [26%, 44%]	6% [−2%, 14%]	92/104 (89%) [81%, 93%]	54% [42%, 63%]
≥ 70% of compressions ≥ 50 mm	26/104 (25%) [18%, 34%]	29/104 (28%) [20%, 37%]	3% [−5%, 11%]	88/104 (85%) [77%, 90%]	57% [45%, 66%]
Compression rate 100–120/min	29/104 (28%) [20%, 37%]	77/104 (74%) [65%, 82%]	46% [33%, 57%]	77/104 (74%) [65%, 82%]	0% [−11%, 11%]
Mean ventilation volume 400–1000 ml	8/104 (8%) [4%, 14%]	44/104 (42%) [33%, 52%]	34% [24%, 45%]	74/104 (71%) [62%, 79%]	29% [16%, 41%]
≥ 70% of ventilations 400–1000 ml	6/104 (6%) [3%, 12%]	44/104 (42%) [33%, 52%]	36% [26%, 46%]	74/104 (71%) [62%, 79%]	29% [16%, 41%]
All compressions with complete release <5 mm	44/104 (42%) [33%, 52%]	40/104 (39%) [30%, 48%]	−3% [−16%, 8%]	58/104 (56%) [65%, 46%]	17% [5%, 29%]
≥ 70% of compressions with complete release <5 mm	74/104 (71%) [62%, 79%]	75/104 (72%) [63%, 80%]	−1% [−9%, 7%]	90/104 (87%) [79%, 92%]	15% [5%, 24%]

CI, confidence interval.

Table 3 Mean compression depth and complete release by sex and time of evaluation (n=104)

	Number of participants n/N (%) [95% CI]					
	Pretest (T0)	Test after video exercise (T1)	Test after voice-feedback exercise (T2)	Pretest (T0)	Test after video exercise (T1)	Test after voice-feedback exercise (T2)
	Mean compression depth ≥ 50 mm			≥ 70% of all compressions ≥ 50 mm		
Probability success males	15/27 (56%) [37%, 72%]	15/27 (56%) [37%, 72%]	24/27 (89%) [72%, 96%]	13/27 (48%) [31%, 66%]	14/27 (52%) [34%, 69%]	24/17 (89%) [72%, 96%]
Probability success females	15/77 (19%) [12%, 30%]	21/77 (27%) [19%, 38%]	68/77 (88%) [79%, 94%]	13/77 (17%) [10%, 27%]	15/77 (20%) [12%, 30%]	64/77 (83%) [73%, 90%]
	All compressions with complete release			≥ 70% of compressions with complete release		
Probability success males	6/27 (22%) [11%, 41%]	9/27 (33%) [19%, 52%]	15/27 (56%) [37%, 72%]	11/27 (41%) [25%, 59%]	11/27 (41%) [25%, 59%]	22/27 (82%) [41%]
Probability success females	38/77 (49%) [39%, 60%]	31/77 (40%) [30%, 51%]	43/77 (56%) [45%, 66%]	63/77 (82%) [72%, 89%]	64/77 (83%) [73%, 90%]	68/77 (88%) [79%, 94%]

Items marked in grey show that differences in skills between genders disappeared after additional voice-feedback training.
CI, confidence interval.

of CPR skills was not adequate. Saraç and Ok [25] reported that video self-instruction even resulted in weaker CPR performance compared with instructor-led training. Bobrow *et al.* [5] analysed the influence of watching an ultra-brief video, a brief video and a brief video combined with psychomotor skill practice in lay people and found that all video groups successfully achieved a median chest compression rate within the target (90–100/min). Median compression depth did not differ between video groups (ultra-brief video: 41 mm; brief video: 42 mm; brief video with practice: 48 mm) and was significantly greater compared with the control group (30 mm). Moreover, addition of practice-while-watching did not improve performance. In the Bobrow study, median group values were reported (using ERC 2005 guidelines), which does not indicate the proportions of successful students or the number of correct compressions. In our study the practice-while-watching video only had a positive impact on the proportion of successful students with good compression rate and good mean ventilation volume 400–1000 ml, although the absolute proportion for the latter was still low (42%). Considerable improvement in compression rate during the practice-while-watching video training can be explained by the continuous presence of a metronome sound. Jäntti *et al.* [26] reported that metronome guidance used during manikin CPR corrected chest compression rate in experienced rescuers, but did not affect chest compression depth or rescuer fatigue. Chung *et al.* [27] observed that the average compression depth was significantly lower in metronome-guided CPR with the rate set at 100/min. In our study metronome-guided practice-while-watching was not associated with improved compression depth. This could mean that watching someone performing compressions on a video does not provide sufficient information regarding the required depth and release.

Subsequent training with voice feedback resulted in significant improvement of all CPR quality indicators, except compression rate, in the majority of students. With 85% of the students delivering at least 70% of their compressions of at least 50 mm, 87% delivering at least 70% of all their compressions with complete release and 74% achieving a compression rate between 100 and 120/min, this combined learning approach proved very effective and confirms previous results obtained for initial CPR skills acquisition in a self-learning station [2]. The acquisition of ventilation skills, which is generally poor, was shown to be satisfactory in 71% of the students achieving a good mean ventilation volume and having at least 70% of all ventilations between 400 and 1000 ml.

The significant improvement of the quality indicators after the subsequent voice-feedback exercises is attributed to voice prompting [28–31]. An earlier study of voice-assisted manikin feedback found that subjects receiving voice feedback during a 3-min period of CPR not only performed better, but also maintained that level of performance in the second period without the feedback [30]. The generally good performance at the end of the current study may also be partly attributed to the fact that repeated testing, even within a same training session, may induce a learning effect and better retention of skills [32–34]. An alternative explanation for good performance in our young population might be an age-related advantage in attention span and memory capacity [35].

With regard to sex, previous manikin studies demonstrated that female rescuers achieved fewer compressions with adequate depth [20,21,36]. Our study however, showed that after voice-feedback exercises female rescuers can 'catch up' with male rescuers regarding compression depth. These findings could be attributed to the fact that women have relatively less muscle strength, resulting in more shallow compressions and more complete release at the start compared with men [37,38]. After voice feedback, training women achieved deeper compressions and men achieved more complete release. Therefore, voice-feedback exercises appear to be a good strategy to further train and improve both male and female students that lack adequate skills mastery at the start and after video training. In view of community CPR training programs this finding is important with regard to the choice of the training method.

Table 4 suggests that a 70% threshold value for a combined score could be an achievable target to train and assess students in the future. A higher threshold (e.g. 80%) might be difficult to achieve as 50% of the students would be judged incompetent after a single short training. Lowering the threshold (e.g. to 60%) would result in loss of quality in CPR mastery without a great increase in the percentage of successful students (+ 7%). Although an overall success rate of almost 60% of the students achieving at least 70% success

Table 4 Proportion of participants achieving a composite PASS score using different thresholds (n=104)

	Number of participants (%)		
	Pretest (T0)	Test after video exercise (T1)	Test after voice-feedback exercise (T2)
Pass 100	2 (2)	4 (4)	18 (17)
Pass 90	4 (4)	11 (11)	44 (42)
Pass 80	5 (5)	13 (13)	52 (50)
Pass 70[a]	6 (6)	15 (14)	59 (57)
Pass 60	6 (6)	18 (17)	67 (64)
Pass 50	9 (8)	19 (18)	68 (65)

[a]Pass 70: $\geq$ 70% of all compressions $\geq$ 50 mm and $\geq$ 70% of all compressions with complete release and compression rate between 100 and 120/min.

for compression depth and release as well as a rate between 100 and 120/min may not seem very high, we believe it is a promising result for lay rescuers after a 1-h training in a self-learning station. It has to be emphasized that these results were obtained within a very brief time span and that students were not trained to achieve the combined score. We currently cannot compare this result with data from other studies because reporting a combined pass/fail score based on proportions is new. Clearly a single short training in a self-learning station is not sufficient for all learners, and future research should determine how to train students to a predefined pass level and provide further training to the remaining unsuccessful students. As compression depth, release and rate are the quality indicators most likely to influence the outcome of resuscitation, ventilation skills were not included in the combined score. However, when training professional rescuers, ventilation skills mastery should be included in the assessment.

Limitations

We conducted a prospective observational study without a control group. The generally young age in our population of pharmacy students limits the generalizability of the results. As we expected most lay students do not know how to perform CPR, a methodological choice of a 1-min test at T0 was made. To allow comparison only the first minute of T1 and T2 could be analysed. Future research, however, should be performed with tests of equal duration (e.g. 2 min). The duration of the flexible voice-feedback exercises should be measured to allow comparison between students.

Conclusion

Although in a self-learning station video training may be useful to introduce new skills, additional voice-feedback exercises are needed to achieve acceptable CPR quality. Furthermore voice-feedback exercises are able to remove pretraining differences between genders. A self-learning station building on this 1-h combined teaching strategy may be a valuable alternative to an instructor-led course.

Acknowledgements

We are grateful to the management of Ghent University Hospital, to the IT department for computer support, to Charlotte Vankeirsbilck and Lien Yde for administrative support and to all the students who participated in the study. The Flash module was programmed by Uniweb bvba (Strombeek-Bever, Belgium) and was embedded in the existing Resusci Anne Skills Station software with the help of Laerdal Sophus programmers (Laerdal, Sweden).

Conflicts of interest

Laerdal (Stavanger, Norway) provided the manikin, the face shields and the Resusci Anne Skills Station licenses for the study. Laerdal has taken no part in designing the study, analysing the data or in writing or revising the manuscript. The authors received an unrestricted grant from the Laerdal Foundation.

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Chapter 3

Retraining basic life support skills using video, voice feedback or both: a randomised controlled trial.

RESUSCITATION 2013;84:72-7

Contents lists available at SciVerse ScienceDirect

Resuscitation

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Simulation and education

Retraining basic life support skills using video, voice feedback or both: A randomised controlled trial☆

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ARTICLE INFO

Article history:
Received 14 February 2012
Received in revised form 16 July 2012
Accepted 9 August 2012

Keywords:
Basic life support
Cardiopulmonary resuscitation
Compression depth
Self-learning
Skill retention

ABSTRACT

Introduction: The optimal strategy to retrain basic life support (BLS) skills on a manikin is unknown. We analysed the differential impact of a video (video group, VG), voice feedback (VFG), or a serial combination of both (combined group, CG) on BLS skills in a self-learning (SL) environment.

Methods: Two hundred and thirteen medicine students were randomly assigned to a VG, a VFG and a CG. The VG refreshed the skills with a practice-while-watching video (abbreviated Mini Anne™ video, Laerdal, Norway) and a manikin, the VFG with a computer-guided manikin (Resusci Anne Skills Station™, Laerdal, Norway) and the CG with a serial combination of both. Each student performed two sequences of 60 compressions, 12 ventilations and three complete cycles of BLS (30:2). The proportions of students achieving adequate skills were analysed using generalised estimating equations analysis, taking into account pre-test results and training strategy.

Results: Complete datasets were obtained from 192 students (60 VG, 69 VFG and 63 CG). Before and after training, ≥70% of compressions with depth ≥50 mm were achieved by 14/60 (23%) vs. 16/60 (27%) VG, 24/69 (35%) vs. 50/69 (73%) VFG and 19/63 (30%) vs. 41/63 (65%) CG ($P < 0.001$). Compression rate 100–120/min was present in 27/60 (45%) vs. 52/60 (87%) VG, 28/69 (41%) vs. 44/69 (64%) VFG and 27/63 (43%) vs. 42/63 (67%) CG ($P = 0.05$). Achievement of ≥70% ventilations with a volume 400–1000 ml was present in 29/60 (49%) vs. 32/60 (53%) VG, 32/69 (46%) vs. 52/69 (75%) VFG and 25/63 (40%) vs. 51/63 (81%) CG ($P = 0.001$). There was no between-groups difference for complete release.

Conclusions: Voice feedback and a sequential combination of video and voice feedback are both effective strategies to refresh BLS skills in a SL station. Video training alone only improved compression rate. None of the three strategies resulted in an improvement of complete release.

1. Introduction

The European Resuscitation Council (ERC) 2010 Guidelines recommend a compression depth of at least 50 mm, followed by complete release, at a rate of at least 100/min with minimal interruptions, in order to provide adequate circulation.[1] Most studies, however, show that cardiopulmonary resuscitation (CPR) skills decay within three to 6 months after initial training.[2–11] This results in highly variable and often poor basic life support (BLS) quality, even when performed by trained healthcare providers, including hospital-based nurses and physicians.[12–15] The need for efficient retraining of BLS skills is obvious, but the optimal format for self-instructional refresher training is still one of the knowledge gaps to be addressed.[10,11]

A sequential combination of a practice-while-watching video (Mini-Anne™, Laerdal, Norway) followed by training with voice feedback exercises appears to be an effective strategy to train and retrain BLS skills in a self-learning (SL) station.[16,17] However, the differential impact of each component in this combined learning strategy is unknown. We hypothesised that retraining BLS skills with the combination of a learning-while-watching video followed by further practice with voice feedback would result in a higher proportion of students with adequate BLS skills compared to either strategy alone.

☆ A Spanish translated version of the summary of this article appears as Appendix in the final online version at http://dx.doi.org/10.1016/j.resuscitation.2012.08.320.

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http://dx.doi.org/10.1016/j.resuscitation.2012.08.320

2. Research methods

2.1. Participants

The study was approved by the Ethics Committee of Ghent University Hospital. During the academic year 2010–2011, 214 of 216 eligible third year medicine students agreed to participate. The students were told that different educational strategies for refresher training in a SL station would be applied and evaluated. As BLS training was a mandatory part of the medicine student's curriculum, all students had followed an initial instructor-led BLS course during their first year and a refresher course in their second year; 1 year prior to the present study. Participation in the study was on a voluntary base and non-participation did not influence student grades.

2.2. Research procedure

A SL station was made available in a small room secured with a badge reader, accessible 24 h a day, 7 days a week.[16,17] After signing informed consent all students scheduled an appointment in Google Agenda (30 min slot) for participation in the study. Practising and testing was done on a full size torso disposed on the floor, using a face shield for the ventilations. Performance of chest compression depth, complete release, compression rate and ventilation volume was registered automatically during training. After entering the room, the students were guided by the computer to start the exercise by clicking on the start icon on the desktop. The computer automatically assigned the students randomly to one of three refresher-training strategies: a video group (VG), a voice feedback group (VFG) or a serial combination of both (combined group, CG). After login, a purposely developed Flash™ user interface (Adobe Systems Inc., USA) guided the students through the refresher course. To each group, a similar introduction video explaining the use of the face shield was shown. Next, and in order to establish baseline skills, students were invited to perform a 2 min pre-test as described previously.[17] After the pre-test, each group watched the same 1-min priming video. The video was based on the Mini-Anne™ video (Laerdal, Norway), shortened to 1 min, showing an instructor demonstrating 30:2 CPR on a manikin. During compressions, a text message was displayed emphasising the new 2010 compression depth guidelines of ≥5 cm. After watching this priming video, each student followed two consecutive training sequences according to his/her randomisation condition: with practice-while-watching videos (Mini-Anne™, Laerdal, Norway) for the VG, with voice-feedback exercises (Skills Station™, Laerdal, Norway) for the VFG, or with a combination of both in the CG condition (Fig. 1).

In order to guarantee equal hands-on time in all groups, compliance to the study protocol was required. For this purpose a flow chart was disposed next to the manikin. The flow chart mentioned that a first and a second exercise sequence would have to be performed with either a practice-while-watching video or computer voice-feedback. The students did, however, not know in advance to which training (video, voice feedback or a combination of both) they would be allocated by the computer. Participants were required to perform both sequences completely. For each of the two sequences the order and number of exercises was predefined and detailed as follows: 60 compressions, 12 ventilations and three full CPR cycles. Because the experimental software could not automatically control the sequence and the number of exercises, protocol violation occurred during the first week of the study. We therefore introduced a non-obstructive observer who ensured that the study protocol was respected without providing any kind of feedback. In this way, treatment allocation was guaranteed.

In the VG, participants performed both training sequences with a practice-while-watching video. To adhere to the study protocol a Mini-Anne™ video (Laerdal, Norway) was edited in order to first show an instructor demonstrating with commentary 60 compressions, 12 ventilations and three cycles of 30 compressions and two ventilations. After this demonstration the same amount of compressions, ventilations and combined CPR was repeated, allowing practice-while-watching. In the VFG, participants performed both training sequences with computer-guided voice feedback prompts. The software used messages such as: "compress deeper", "compress faster", "release pressure between compressions" and "a little less air".[19] Corrective feedback was triggered by CPR performance outside the accepted limits. When CPR was performed correctly, positive feedback was provided (e.g. "you're doing fine"). The feedback limits of the Skills Station™ (Laerdal, Norway) were set as follows: compression depth ≥50 mm; complete release <5 mm; rate 100–120/min and ventilations between 400 and 1000 ml (because the chest of the manikin visibly rises after insufflation of at least 400 ml). The CG participants started their first training sequence with the edited Mini-Anne™ video, and performed their second training sequence with the voice-feedback exercises. After training, a 5 min pause was introduced to allow the students to take a rest, after which all students performed a 2 min post-test. Students not achieving a mean compression depth ≥50 mm during this 2 min post-test, were scheduled for remedial training based on the strategy that – depending on the present study result – would show to be the most effective. Remedial training was performed within 1 month after the post-test.

2.3. Outcome measures

The primary aim of the study was to establish the differential impact of two single or combined learning strategies (video and voice feedback) in regard to four BLS quality indicators: compression depth, complete release, compression rate and ventilation volume.

Proportions of participants with mean compression depth ≥50 mm, with complete release (<5 mm) in all compressions, with compression rate 100–120/min and with mean ventilation volume 400–1000 ml were used as outcome measures to assess impact on BLS mastery. In a previous study with the Resusci Anne Skills Station™ (Laerdal, Norway) we used a 70% threshold during training to assess mastery of each skill.[17] In order to allow comparison between the studies we decided – a priori – to analyse how many students were able to achieve 70% or more compressions with a depth ≥50 mm, 70% or more compressions with complete release and 70% or more ventilations with a volume 400–1000 ml. To investigate overall skills mastery, a combined PASS score for compressions skills and for all skills was calculated.

2.4. Statistical methods

To analyse the learning efficacy of the three strategies, the results of the pre-test and the results of the post-test for the dichotomous BLS quality indicators were compared using generalised estimating equations (GEE) analysis with logit link function. Results for the BLS quality parameters in the pre- and post tests are reported as counts and proportions for each learning strategy, together with their GEE based *P*-values for improvement. In addition, post-test results were compared between learning strategies using GEE analysis and Fisher Exact tests.

P-Values <0.05 were considered significant. In case of multiple comparisons, a Bonferroni correction ($\alpha = 0.05/3$) was applied,

Table 1
Students' characteristics (n = 213). Values represented as means (SD) or counts (proportions).

	Video group (n = 68)	Voice feedback group (n = 77)	Combined group (n = 68)
Age (years)	21 (1.0)	20 (0.9)	21 (1.1)
Male, n (%)	23 (34)	33 (43)	30 (44)
Length (cm)	173 (8.6)	174 (9.9)	174 (8.4)
Weight (cm)	64 (9.7)	68 (12.6)	66 (11.6)

implying P-values <0.016 to be significant. Furthermore, in the students who did not achieve a mean compression depth ≥50 mm, BLS skill mastery improvement after retraining was analysed using the McNemar test. All statistical analyses were performed using IBM SPSS Statistics version 19 (SPSS Inc., IBM, Chicago, IL, USA).

3. Results

3.1. Recruitment and baseline data

Two hundred and fourteen students signed an informed consent and agreed to participate in the study. One student could not participate because of a medical reason. Student's characteristics are summarised in Table 1.

Prior to the involvement of the non-obstructive observer, the study protocol was violated by 10 students: five students exceeded the training time, three students did not respect the exercise sequence and two students did not complete the exercise sequence. In 11 students, incomplete data were obtained due to a technical problem. Complete datasets were obtained for 60 students of the VG, 69 students of the VFG and 63 of the CG. A total of 192 datasets was analysed (Fig. 1).

3.2. Learning efficacy of the three retraining strategies

Table 2 shows the results for BLS quality parameters in both pre- and post tests, together with the GEE based P-value of improvement for each learning strategy. Taking into account pre-test results and training strategy, the learning efficacy of the VFG and CG was superior to the VG for compression depth and ventilation skills but not for complete release and compression rate (P-values for time vs. group interaction). Compression rate, however, improved significantly in all three learning strategies. The null hypothesis (no difference in learning efficacy between groups) could therefore be rejected for all variables except for complete release (Table 2).

Before the video (VG), 45% of the students achieved a compression rate between 100 and 120/min and after training 87% achieved the target compression rate (P < 0.001). All other variables showed no significant improvement after training with video (Table 2). Both training in the VFG and CG resulted in a significant improvement of the proportion of successful students at the post-test for all variables with the exception of complete release (Table 2).

In addition, the results of the 2 min post-test of the three groups were compared. Table 3 shows a significant difference in groups with regard to mean compression depth ≥50 mm, ≥70% of compressions ≥50 mm, compression rate, mean ventilation volume between 400 and 1000 ml, ≥70% of ventilations between 400 and 1000 ml, and ≥70% of compressions with complete release (P < 0.05).

VG compared to VFG and to CG showed significant differences in proportions for all variables, except for complete release. When VFG was compared to CG, no significant difference in proportions could be demonstrated for any of the variables (Table 3). Using combined PASS scores, the VG had no overall learning effect between the pre- and post-test compared to the VFG and the CG (Table 2). However, when comparing the combined PASS scores at the end of training, the differences between the learning strategies disappeared (Table 3).

3.3. Remedial training of the students with <50 mm mean compression depth

All students who did not achieve a mean compression depth ≥50 mm were retrained with a single voice-feedback exercise of 3 CPR cycles (30:2). This strategy resulted in a significant improvement of all variables, except for compression rate and complete release (Table 4).

4. Discussion

Our results demonstrate that medicine students, retrained with voice feedback or with the serial combination of video and voice feedback, showed a significant improvement in mean compression depth, compression rate and mean ventilation volume. Students retrained with video only showed significant improvement in compression rate. None of the three alternative retraining strategies resulted in a significant improvement in complete release. A

Table 2
Summary of success rate evolution in each research condition for the different BLS skills and results of the GEE analysis (P-value time vs. group interaction[a]). Results for each individual BLS skill parameters are reported for the pre- and post tests and are shown as counts (proportions) for each learning strategy, together with their GEE based P-values for improvement.[b]

	Time vs. group interaction	Video group n = 60			Voice feedback group n = 69			Combined group n = 63		
	P-Value[a]	Pre-test	Post-test	P-Value[b]	Pre-test	Post-test	P-Value[b]	Pre-test	Post-test	P-Value[b]
Mean compression depth ≥50 mm	<0.001	15 (25%)	17 (28%)	0.41	28 (41%)	53 (77%)	<0.001	20 (32%)	44 (70%)	<0.001
≥70% of compressions ≥50 mm	<0.001	14 (23%)	16 (27%)	0.48	24 (35%)	50 (73%)	<0.001	19 (30%)	41 (65%)	<0.001
All compressions with complete release <5 mm	0.75	6 (10%)	8 (13%)	0.48	8 (12%)	11 (16%)	0.37	8 (13%)	8 (13%)	1
≥70% of compressions with complete release <5 mm	0.29	25 (42%)	26 (43%)	0.78	29 (42%)	39 (57%)	0.015	39 (62%)	46 (73%)	0.12
Compression rate 100–120/min	0.05	27 (45%)	52 (87%)	<0.001	28 (41%)	44 (64%)	0.001	27 (43%)	42 (67%)	0.002
Mean ventilation volume between 400 and 1000 ml	<0.001	39 (66%)	36 (60%)	0.34	41 (59%)	60 (87%)	<0.001	34 (54%)	52 (83%)	<0.001
≥70% of ventilations between 400 and 1000 ml	0.001	29 (49%)	32 (53%)	0.53	32 (46%)	52 (75%)	<0.001	25 (40%)	51 (81%)	<0.001
Compression variables PASS 70[c]	0.271	5 (8%)	9 (15%)	0.042	5 (7%)	17 (25%)	0.003	5 (8%)	17 (27%)	0.006
All criteria PASS 70[d]	0.16	3 (5%)	5 (8%)	0.319	3 (4%)	13 (19%)	0.002	2 (3%)	15 (24%)	0.005

[c] Pass 70 compression variables: ≥70% of all compressions ≥50 mm and ≥70% of all compressions with complete release and compression rate between 100 and 120/min.
[d] Pass 70 all criteria: ≥70% of all compressions ≥50 mm and ≥70% of all compressions with complete release and compression rate between 100 and 120/min and ≥70% of all ventilations between 400 and 1000 ml.

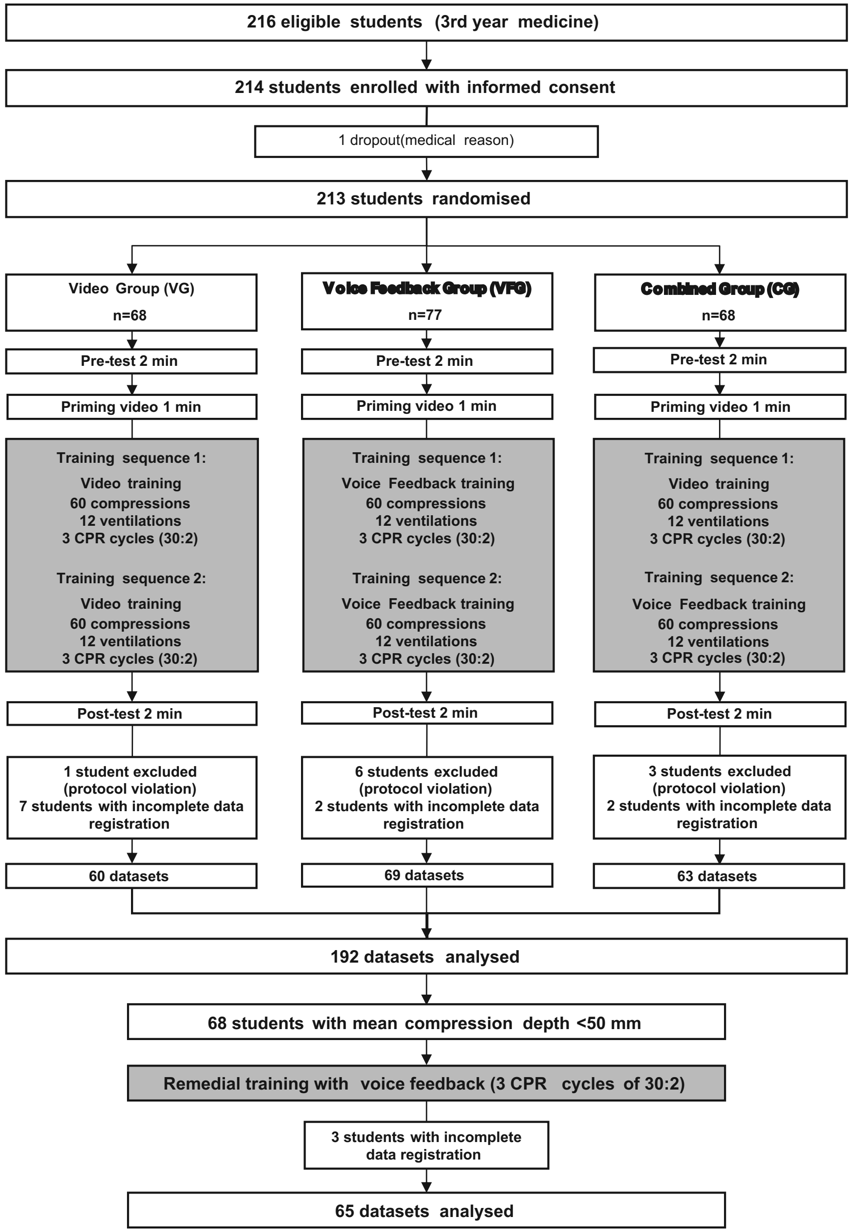

Fig. 1. Participant flow chart.

significant difference in resuscitation performance between VFG/CG and VG was found; indicating that both voice feedback based retraining and a combination of video and voice feedback retraining are superior.

A benefit of video training and voice feedback training compared to – traditional – instructor-led training was demonstrated in previous studies.[16,18–24] In a SL station, a serial combination of video training and voice feedback training proved to be equal to instructor-led training for initial skill acquisition.[16] Braslow et al. found that CPR performance after video training was superior compared to traditional training with an instructor.[18–20] Braslow et al. rated video trained participants competent in 80% of the time, compared to traditionally trained participants, who were competent in only 45%.[18] Todd et al. judged 81% video trained participants

Table 3
Counts (proportions) for post test of dichotomous BLS quality parameters per learning strategy. Comparison is based on Fisher Exact tests[a] and GEE analysis.[b] For pair wise comparisons, P-values <0.016 are considered statistically significant after applying the Bonferonni correction.

	Video group (VG) n = 60	Voice-feedback group (VFG) n = 69	Combined group n = 63	P-Value[a]	P VG–VFG[b]	P VG–CG[b]	P VFG–CG[b]
Mean compression depth ≥50 mm	17 (28%)	53 (77%)	44 (70%)	<0.001	<0.001	<0.001	0.37
≥70% of compressions ≥50 mm	16 (27%)	50 (73%)	41 (65%)	<0.001	<0.001	<0.001	0.36
All compressions with complete release <5 mm	8 (13%)	11 (16%)	8 (13%)	0.87	0.68	0.92	0.60
≥70% of compressions with complete release <5 mm	26 (43%)	39 (57%)	46 (73%)	0.004	0.14	0.001	0.05
Compression rate 100–120/min	52 (87%)	44 (64%)	42 (67%)	0.006	0.004	0.011	0.73
Mean ventilation volume between 400 and 1000 ml	36 (60%)	60 (87%)	52 (83%)	0.001	0.001	0.007	0.48
≥70% of ventilations between 400and 1000 ml	32 (53%)	52 (75%)	51 (81%)	0.002	0.01	0.001	0.44
Compression variables PASS 70[c]	9 (15%)	17 (25%)	17 (27%)	0.234	0.177	0.108	0.003
All criteria PASS 70[d]	5 (8%)	13 (19%)	15 (24%)	0.062	0.094	0.026	0.486

[c] Pass 70 compression variables: ≥70% of all compressions ≥50 mm and ≥70% of all compressions with complete release and compression rate between 100 and 120/min.
[d] Pass 70 all criteria: ≥70% of all compressions ≥50 mm and ≥70% of all compressions with complete release and compression rate between 100 and 120/min and ≥70% of all ventilations between 400 and 1000 ml.

Table 4
Results of a short voice feedback remedial training for students with <50 mm mean compression depth (n = 65).

	Before remedial training n = 65	After remedial training n = 65	McNemar P-value
Mean compression depth ≥50 mm	43 (66%)	63 (97%)	<0.001
≥70% of compressions ≥50 mm	40 (62%)	61 (94%)	<0.001
All compressions with complete release <5 mm	13 (20%)	14 (22%)	1
≥70% of compressions with complete release <5 mm	43 (66%)	47 (72%)	0.42
Compression rate 100–120/min	45 (69%)	51 (79%)	0.35
Mean ventilation volume between 400 and 1000 ml	42 (65%)	60 (92%)	<0.001
≥70% of ventilations between 400 and 1000 ml	36 (55%)	56 (86%)	<0.001

competent in their performance of CPR, compared to 57% of traditionally trained participants.[19] Batcheller et al. rated 63% of the video trained subjects competent compared to 6% of the traditionally trained participants.[20] Jones et al. found similar results for all CPR variables comparing a self-instructional video group with an instructor-led group, except for compression depth which was significantly better for the instructor-led group.[24] In contrast with these studies, we found that video training did not improve resuscitation skills, with the exception of compression rate. This can be explained in two ways. Firstly, our evaluation criteria – building on the proportion of successful students – were more rigid compared to previous studies that were rather based on the analysis of group means or rating scores. Secondly, as demonstrated by Akhtar et al., the video format and content may be an important determinant of the efficacy of the learning process.[25] This underscores the importance of validating every new training method.

The strikingly positive improvement in compression rate with video training may be explained by the fact that in the practice-while-watching video a rhythmical beat at 100/min supported the students (metronome guidance) to pursue and attain a compression rate in line with the resuscitation guidelines. Jäntti et al. reported earlier that metronome guidance used when performing CPR, helped to correct chest compression rate in experienced rescuers, but did not affect chest compression depth or rescuer fatigue.[26] Chung et al. observed that the average compression depth was significantly lower in metronome-guided CPR with the rate set at 100/min.[27] A similar observation was made in the current study where metronome-guided practice-while-watching was not associated with improvement in compression depth.

An obvious reason why video training may not result in skills mastery is the absence of concurrent feedback. A systematic review concluded that the use of CPR feedback/prompt devices during training can be a valuable strategy to improve CPR skill acquisition and retention.[28] In a training setting, Wik et al. showed that concurrent voice feedback improved performance of CPR skills.[21] Hostler et al. noticed a benefit of voice feedback on insufflation volume and compression depth compared with instructor training.[22] During real resuscitation events, Fischer et al. demonstrated more compressions with correct hand position, complete decompression and compression rates closer to the recommended guidelines using automated external defibrillators with voice feedback.[23] Compression depth, however, did not meet the guidelines and decreased in the voice feedback group compared to the control group. This was explained by the fact that in the control group participants were told to push "as hard as they could". Hostler et al. found that real-time feedback during CPR resulted in performance closer to the guidelines, but feedback did not improve survival.[29]

In the present study none of the training methods improved complete release. Watching a video might not be the ideal method to learn to release pressure between compressions. In the Laerdal Skills Station™ software, the different voice feedback instructions are prioritised to avoid overwhelming the student. Incomplete release will therefore only be corrected if all other BLS skills have been executed adequately. Other possible explanations for poor performance regarding complete release – independent of the learning strategy – are related to the relatively short exercises, and/or the deeper compression depth or the higher compression rate required by the ERC 2010 Guidelines. When students try to achieve a deeper compression depth, they may be less likely to release pressure between compressions, resulting in more incomplete release.

Our results suggest inferior improvement and inferior CPR performance with a video retraining strategy, questioning the contribution of video in the combined learning strategy. Therefore a single voice-feedback exercise of 3 CPR cycles (30:2) was used for remedial training of the unsuccessful students. This short additional training was highly effective to improve compression and ventilation skills. It is possible that some students might benefit from multiple short refreshers instead of one longer exercise, resulting in significantly shorter overall training time.[30,31] Our pre-test results indicate poor skill retention. These findings are

similar to the poor retention reported after other traditional 4–5 h instructor-led training courses.[31–36] This highlights the need for more frequent assessment and retraining.

To avoid bias due to different training exposure, care was taken to control equal training time in the three study groups. To ensure that the participants followed the exercise sequences allocated to them, we involved a non-obstructive observer. This is in contrast with the philosophy of a SL station, allowing flexible and individualised training and can be considered as a study limitation. Some data were lost because of technical problems. Also, the study was not blinded because the students experienced what condition they were allocated to. However, the students were not aware of the potential differential impact of alternative training conditions. We therefore believe this had no impact on their motivation and involvement. The combined success rates reported in Tables 2 and 3 may not seem very high. It has to be stressed, however, that the primary objective of the trial was to investigate the impact of each training component and not to train all students against a pre-defined PASS level. Clearly a single short training session is insufficient to achieve such a combined PASS score in all students. Further research is needed to investigate how a pre-defined combined PASS score can be achieved by every student.

5. Conclusions

Voice feedback and a sequential combination of video and voice feedback are both effective strategies to refresh BLS skills in a SL station. Video training alone did only improve compression rate. None of the three strategies resulted in an improvement of complete release.

Conflict of interest statement

Laerdal (Stavanger, Norway) provided the manikin, the face shields and the Resusci Anne Skills Station™ licenses for the study. Laerdal has taken no part in neither designing the study, analysing data nor writing of the manuscript. The authors have received a grant from the Laerdal Foundation.

Acknowledgements

We are grateful to the management of Ghent University Hospital, to the IT department for computer support, to Charlotte Vankeirsbilck for administrative support and to all the students who participated in the study. The Flash™ module was programmed by Uniweb bvba (Strombeek-Bever, Belgium) and was embedded in the existing Resusci Anne Skills Station™ software with the help of Laerdal Sophus programmers (Laerdal, Sweden).

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Chapter 4

Training to deeper compression depth reduces shallow compressions after six months in a manikin model.

RESUSCITATION 2011;82:1323-7

Contents lists available at ScienceDirect

Resuscitation

journal homepage: www.elsevier.com/locate/resuscitation

Simulation and education

Training to deeper compression depth reduces shallow compressions after six months in a manikin model☆

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ARTICLE INFO

Article history:
Received 23 January 2011
Received in revised form 16 April 2011
Accepted 1 June 2011

Keywords:
Basic life support
Cardiopulmonary resuscitation
Compression depth
Self-learning
Skill retention

ABSTRACT

Introduction: Studies show that students, trained to perform compressions between 40 and 50 mm deep, often do not achieve sufficient depth at retention testing. We hypothesized that training to achieve depths >50 mm would decrease the proportion of students with depth <40 mm after 6 months, compared to students trained to a depth interval of 40–50 mm.
Methods: A basic life support (BLS) self-learning station was attended by 190 third year medicine students. They were first offered the possibility to refresh their skills, following the instructions of a 15 min abbreviated Mini Anne™ video (Laerdal, Norway) using a full size torso and a face shield. This was followed by further training using Resusci Anne Skills Station™ software (Laerdal, Norway). Voice feedback was provided according to randomisation to a standard group (SG) 40–50 mm and a deeper group (DG) >50 mm. Quality of compressions was tested after 6 months.
Results: The SG and DG groups consisted of 90 (67% female) and 100 (58% female) participants respectively. At the end of training, all students reached the target depth without overlap between groups. After 6 months, the proportion of students achieving a depth <40 mm was 26/89 (29%) in the SG vs. 12/89 (14%) in the DG (P = 0.01). The proportion of students with a depth >50 mm was 5/89 (6%) for the SG and 44/89 (49%) in the DG (P < 0.001).
Conclusions: The educational strategy to train students to a deeper depth, reduced shallow compressions 6 months after training.

1. Introduction

The European Resuscitation Council (ERC) 2005 Guidelines recommended training to a compression depth of 40–50 mm followed by complete decompression at a rate of 100/min.[1] Already within 3–6 months after training, however, shallow compressions are a major problem.[2–6] This is confirmed by clinical studies demonstrating poor basic life support (BLS) quality, even when performed by trained healthcare providers including nurses and physicians.[7–9] The reason why rescuers deliver shallow compressions is unclear. A possible contributing factor may be the initial learning process, traditionally focussing on achieving compressions within a narrow depth interval and on the avoidance of compressions that are "too deep". Deeper chest compressions, however, have been associated with a higher rate of defibrillation success and better short term survival compared to shallow compressions.[10,11] We hypothesized that training to a depth of >50 mm in a self-learning (SL) station would result in less shallow compressions at retention testing after 6 months, compared to training following the ERC 2005 guidelines (40–50 mm).

2. Research methods

2.1. Participants

The study was approved by the Ethics Committee of Ghent University Hospital. During the academic year 2009–2010, after obtaining their informed consent, 190 third year medicine students were randomly assigned to a standard group (SG: 40–50 mm depth) and a deeper group (DG: >50 mm depth). Students were told that different educational strategies would be applied, but they were not informed about the different compression depths and no exclusion criteria were introduced before randomisation. As BLS training was a mandatory part of the medicine student's curriculum, all students had followed an initial BLS course in their first year and a refresher course in their second year (1 year before the study). Participation in the study was on a voluntary base, non-participation did not influence students' grades.

☆ A Spanish translated version of the abstract of this article appears as Appendix in the final online version at doi:10.1016/j.resuscitation.2011.06.004.
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doi:10.1016/j.resuscitation.2011.06.004

2.2. Research procedure

A SL station was made available in a small room, secured with a badge reader, accessible 24 h a day, 7 days a week. During an 8 weeks study period each student was invited to exercise BLS for up to 1 h.

The SL station consisted of a computer connected to a "Resusci Anne torso" manikin (maximum compression depth 60 mm) and running Resusci Anne Skills Station™ software (Laerdal, Norway). This software was adapted by integrating a Mini Anne™ video before the existing program. The Mini Anne™ video was edited by adding an introduction sequence (explaining the concept of the video and the use of a face shield) and by shortening the existing sequences demonstrating the core CPR skills including compression, ventilation and combined CPR. The length of the introduction video was 15 min.

After entering the room, participants were guided to start the Resusci Anne Skills Station™ software on the computer. Using a batch file, the computer automatically randomised the students into the SG or the DG. Students were then asked to login after which they were first invited to follow the Mini Anne™ "practice-while-watching" video. Practising was done on the full size torso with a face shield while listening and looking at the video instructions. Performance was registered automatically during "practice-while-watching", enabling the calculation of an average baseline skill level for this exercise. Students could rewind and forward the Mini Anne™ video at their convenience. The next step consisted of training on the manikin with voice feedback. The Skills Station™ exercises were presented in three parts: the first part centred on ventilations, the next part focused on compressions and in the final part the students had to perform full CPR. During the exercises, the computer provided on-line constructive voice feedback and registered chest compression depth, rate, ventilation volume and incomplete release. Feedback limits for compressions were set at depth 40–50 mm (SG) or 50–100 mm (DG); rate 90–115/min; ventilation limits were 400–1000 ml (because the chest of the manikin visibly rises after insufflation of 400 ml); incomplete release ≥5 mm. Since the exact upper compression limit of the manikin was unknown when the study was designed, we used a "safe" upper limit of 100 mm, to reflect the absence of an upper limit in the DG. For compression rate a range of 90–115 was the default setting of the software, which we left unchanged. It was our aim to train using a narrow window, and to allow more flexibility during assessment (80–120/min), according to the 2005 guidelines.

Participants could repeat exercises, they were not obliged to do all exercises or to spend a minimum of time per exercise. After every exercise, a score (automatically calculated by the Skills Station™ software, according to the limits), accompanied by specific feedback was communicated on-screen to the participant. To pass the voice assisted compression exercise, 90 compressions were required with minimum 70% correct, for the ventilation exercise 12 ventilations were required with minimum 70% correct. For the combined CPR exercise 3 cycles of one-person CPR were required with a minimum of 90 compressions (of which 70% correct) and a minimum of 6 ventilations (of which 70% correct).

After 6 months, all students were invited by email to attend the SL station for a test, with individual appointments every 15 min. To enable individual testing without an instructor, we designed an interactive user interface with Flash™ (Adobe Systems Inc., USA). The Flash™ software presented a scenario in which a victim had just collapsed in the room, without breathing and circulation, and an ambulance was called. The student was asked to resuscitate the victim. This resulted in the students performing BLS on a manikin during 3 min, while their performance was automatically registered.

Table 1
Characteristics of students randomised to standard group (SG) or deeper group (DG). Values represented as means (SD) or counts (proportions).

	SG (n = 90)	DG (n = 100)
Age (years)	21 (1)	21 (3)
Females	60 (67%)	58 (58%)
Height (cm)	173 (9)	175 (9)
Weight (kg)	66 (11)	66 (12)

2.3. Objectives and outcome measures

The goal of the study was to test if training to a compression depth >50 mm would result in a decrease in the proportion of participants achieving an unsatisfactory mean compression depth <40 mm after 6 months.

As dependent variables, four quality indicators related to BLS mastery were used: adequate compression depth was defined as 40–50 mm, incomplete release as ≥5 mm, adequate compression rate as 80–120/min and adequate ventilation volume as 400–1000 ml. Proportions in relation to meeting specific quality indicators were used as outcome measures to study potential differences in BLS mastery: proportion of participants with mean compression depth <40 mm, 40–50 mm, >50 mm; proportion of participants with any incomplete release (≥5 mm); proportion of participants with mean compression rate 80–120/min and proportion of participants with mean ventilation volume 400–1000 ml.

2.4. Statistical methods

Differences in odds between both training conditions (SG and DG) for proportional BLS quality indicators were analysed by applying multiple logistic regression analysis, correcting for gender, height, and weight. The difference in mean compression depth at the end of training and after 6 months was compared in both groups using the Mann–Whitney test. All statistical analyses were performed using PASW® statistics 18 for Windows (SPSS Inc., Chicago, USA).

3. Results

3.1. Recruitment and baseline data

All eligible students (190) signed an informed consent and agreed to participate in the study. After randomisation, 90 students were trained in the SG and 100 in the DG. The SG and the DG group respectively consisted of 67% and 58% female students and the mean age was 21 years in both groups (Table 1). After 6 months, 90 SG and 94 DG students were tested (six drop-outs: three students stopped studying medicine, one student was ill and two did not show up for testing for unknown reasons) (Fig. 1).

During testing, one SG student did only carry out part of the activities and due to a technical failure five datasets in the DG were incomplete (Fig. 1). Complete datasets were obtained for the remaining 178 students.

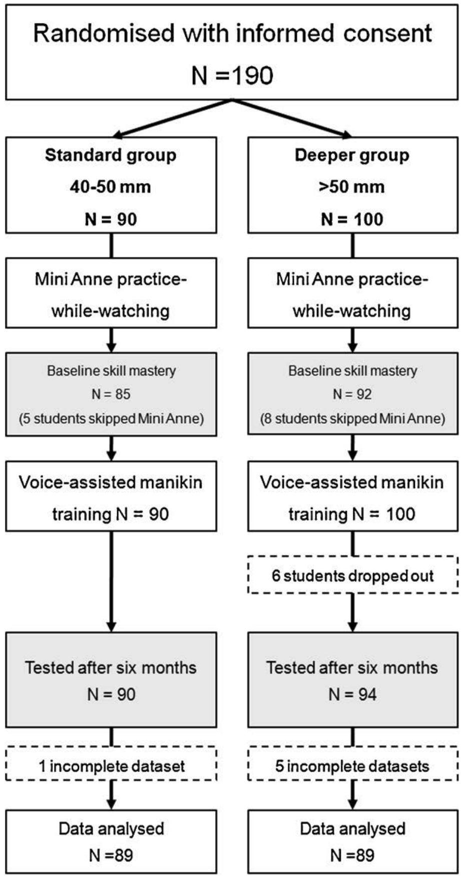

Fig. 1. Participant flow chart.

3.2. Performance during training

Five SG and 8 DG students skipped the practice-while-watching video. Of the remaining students, the proportion achieving an average compression depth 40–50 mm during the video introduction was 28/85 (33%) in the SG and 28/92 (30%) in the DG (Table 2). At the end of the training session with voice feedback, the students in each research group reached the target depth. The median compression depths were significantly different: 44 mm (IQR 4.3; range 41–48)

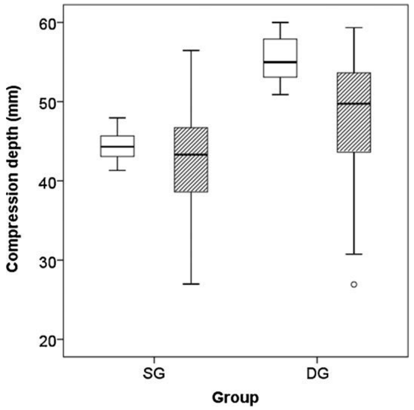

Fig. 2. Median compression depth during training (blank) and after 6 months (shaded) for the standard group (SG) and the deeper group (DG).

and 55 mm (IQR 4.7; range 51–60) in the SG and DG respectively (Fig. 2).

3.3. Performance after 6 months

The proportion of students with a depth <40 mm was significantly lower in the DG, compared to the SG (P = 0.01), and the proportion of students achieving compressions >50 mm was significantly higher in the DG setting (P < 0.001) (Table 3). Median compression depth was 43 mm (IQR 8; range 27–57) in the SG and 50 mm (IQR 10; range 27–57) in the DG. The median difference in mean compression depth between training and the 6 months test was −1 mm (IQR 7.6) for the SG and −6 mm for the DG (IQR 8.8) (P < 0.001).

The majority of participants were able to maintain adequate chest compression rate in both groups and there was no difference in the proportion of participants with adequate ventilation volume and any incomplete release (Table 3). Further analysis showed that 50% of all the students had incomplete release in less than 10% of all compressions.

4. Discussion

Our results demonstrate that students trained to compress >50 mm had less shallow compressions and compressed significantly deeper after 6 months, compared to a group trained to a depth interval of 40–50 mm.

Deeper compression depths are in line with the new ERC 2010 guidelines.[12] Therefore, the group trained to compress >50 mm illustrates the results that can be achieved by a SL station using

Table 2
Results during practice-while-watching introduction.

	SG (n = 85) Number of participants (%)	DG (n = 92) Number of participants (%)	Unadjusted odds ratio (95% CI)	Adjusted[a] odds ratio (95% CI)	P-value
Mean compression depth, <40 mm	52 (61)	58 (63)	0.92 (0.50; 1.70)	0.84 (0.44; 1.60)	0.60
Mean compression depth, 40–50 mm	28 (33)	28 (30)	1.12 (0.60; 2.12)	1.20 (0.62; 2.33)	0.59
Mean compression depth, >50 mm	5 (6)	6 (7)	0.90 (0.26; 3.05)	1.04 (0.30; 3.62)	0.96
Mean compression rate, 80–120/min	78 (92)	80 (87)	1.67 (0.63; 4.47)	1.47 (0.54; 4.02)	0.46
Mean ventilation volume, 400–1000 ml	64 (75)	64 (70)	1.33 (0.69; 2.59)	1.37 (0.70; 2.68)	0.35
Any incomplete release, >5 mm	82 (97)	81 (90)	3.04 (0.79; 11.62)	3.00 (0.78; 11.53)	0.11

[a] Adjusted for gender, height, weight.

Table 3
Results 6 months after training.

	SG (n = 89) Number of participants (%)	DG (n = 89) Number of participants (%)	Unadjusted odds ratio (95% CI)	Adjusted[a] odds ratio (95% CI)	P-value
Mean compression depth, <40 mm	26 (29)	12 (14)	2.65 (1.24; 5.67)	2.67 (1.24; 5.73)	0.01
Mean compression depth, 40–50 mm	58 (65)	33 (37)	3.18 (1.72; 5.86)	3.34 (1.77; 6.30)	<0.001
Mean compression depth, >50 mm	5 (6)	44 (49)	0.06 (0.02; 0.16)	0.05 (0.02; 0.15)	<0.001
Mean compression rate 80–120/min	84 (94)	78 (88)	2.37 (0.79; 7.13)	2.25 (0.74; 6.85)	0.16
Mean ventilation volume, 400–1000 ml	69 (78)	60 (67)	1.67 (0.86; 3.25)	1.63 (0.82; 3.21)	0.16
Any incomplete release, >5 mm	67 (75)	62 (70)	1.33 (0.69; 2.57)	1.44 (0.71; 2.90)	0.31

[a] Adjusted for gender, height, weight.

voice feedback according to ERC 2010 guidelines. Since the manikin was not able to record compressions of more than 60 mm we cannot exclude that this training strategy may lead to compressions deeper than 60 mm. However, the harms and benefits of deeper compressions are unknown and the ILCOR Consensus on Science states that there is insufficient evidence to recommend a specific upper compression limit.[13] The American Heart Association 2010 guidelines therefore do not mention an upper compression limit.[14]

With 49% of participants achieving >50 mm at 6 months retention testing, a significant decay in compression depth was also present in this deeper compression group. We also observed that the median decay in the DG was significantly larger compared to the SG. We believe this could be explained by the fact that compressing deeper requires greater effort, resulting in a relatively larger decay at retention testing. The decay in compression depth seems to be independent of the teaching method.[3–6] Repetitive training and testing may be needed to improve decay in skill quality.[15,16]To assess base line performance before training with voice feedback, we have used mean compression depth measured during the whole Mini Anne video practice-while-watching exercise. This may have underestimated the performance level immediately before the voice feedback exercises, since skills may have improved by the end of the Mini Anne training. Nevertheless, performance registered during the Mini Anne video was poor, especially in a population of medicine students that had already followed a traditional BLS course twice. The excellent performance during training with voice feedback follows previous studies on the effectiveness of this approach.[17–19]

The fully automated SL station proved very effective to train participants to a predefined target compression depth range. Furthermore, an interactive Flash module, embedded in commercially available software (RA Skills Station™ software) allowed students to be guided accurately through the testing procedure, without instructor involvement. A limitation of our study is that the results were obtained within a training context based on a SL station combining a Mini Anne™ video followed by voice feedback, as described previously.[20] The results are therefore not generalizable to other teaching strategies. The contribution of each training component (interactive Flash™ embedding the Mini Anne video, RA Skills Station™, feedback) was not assessed separately. We are addressing this in further studies. Future research is needed to determine which instructional strategy is most effective for refresher training and to investigate the effect of recurrent training and testing on the consolidation and retention of BLS skills.

5. Conclusions

Compression depth in previously trained medicine students was mostly shallow during video assisted refreshment. During further training with voice feedback, a SG (40–50 mm) and a DG (>50 mm) attained significantly different compression depths. Follow-up after 6 months showed a reduction of shallow compressions in the DG. This may be an important educational strategy to improve compression depth and skill retention.

Conflict of interest

Laerdal (Stavanger, Norway) provided the manikin, the face shields and the RA Skills Station™ licenses for the duration of the study. Laerdal has taken no part in neither designing the study, analysing data nor writing of the manuscript. The authors have received a grant from the Laerdal Foundation to conduct research in this area.

Acknowledgements

We are grateful to the management of Ghent University Hospital, to the IT department for computer support, to Charlotte Vankeirsbilck for administrative support, to Lisa Malfait for the intro video and to all the students who participated in the study. The Flash™ module was programmed by Uniweb bvba (Strombeek-Bever, Belgium) and was embedded in the existing RA Skills Station™ software with the help of Laerdal Sophus programmers (Laerdal, Sweden).

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.resuscitation.2011.06.004.

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Chapter 5

Assessing Basic Life Support skills without an instructor: is it possible ?

BMC MED EDUC 2012;12:58-66

BMC Medical Education

TECHNICAL ADVANCE Open Access

Assessing basic life support skills without an instructor: is it possible?

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Abstract

Background: Current methods to assess Basic Life Support skills (BLS; chest compressions and ventilations) require the presence of an instructor. This is time-consuming and comports instructor bias. Since BLS skills testing is a routine activity, it is potentially suitable for automation. We developed a fully automated BLS testing station without instructor by using innovative software linked to a training manikin. The goal of our study was to investigate the feasibility of adequate testing (effectiveness) within the shortest period of time (efficiency).

Methods: As part of a randomised controlled trial investigating different compression depth training strategies, 184 medicine students received an individual appointment for a retention test six months after training. An interactive Flash^{TM} (Adobe Systems Inc., USA) user interface was developed, to guide the students through the testing procedure after login, while Skills Station^{TM} software (Laerdal Medical, Norway) automatically recorded compressions and ventilations and their duration ("time on task"). In a subgroup of 29 students the room entrance and exit time was registered to assess efficiency. To obtain a qualitative insight of the effectiveness, student's perceptions about the instructional organisation and about the usability of the fully automated testing station were surveyed.

Results: During testing there was incomplete data registration in two students and one student performed compressions only. The average time on task for the remaining 181 students was three minutes (SD 0.5). In the subgroup, the average overall time spent in the testing station was 7.5 minutes (SD 1.4). Mean scores were 5.3/6 (SD 0.5, range 4.0-6.0) for instructional organisation and 5.0/6 (SD 0.61, range 3.1-6.0) for usability. Students highly appreciated the automated testing procedure.

Conclusions: Our automated testing station was an effective and efficient method to assess BLS skills in medicine students. Instructional organisation and usability were judged to be very good. This method enables future formative assessment and certification procedures to be carried out without instructor involvement.

Trial registration: B67020097543

Keywords: Automated testing, Basic Life Support, Cardiopulmonary resuscitation, Self-directed learning

Background

Delivery of high quality chest compressions is the Basic Life Support (BLS) skill most likely to improve survival [1-5]. To ensure trainees reliably achieve the learning objectives, educational interventions should be evaluated through assessment [6]. Since BLS skills mastery rapidly decays and should not be assumed to persist for pre-defined time periods, regular skill assessment should be established to determine the need for refresher training [6]. Current BLS testing methods require the presence of an instructor, making testing time-consuming with a risk of instructor bias [7]. Acquiring objective data from recording manikins provides more accurate information about skills mastery than instructor judgement. However, current manikin-based solutions still require an instructor to organise testing, to manage the candidates, to present a scenario (when required) and to operate the manikin and the computer.

The goal of our study was to investigate the feasibility of adequate testing (effectiveness) within the shortest

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period of time (efficiency), using an automated testing procedure without an instructor.

To determine the effectiveness of the testing procedure, we surveyed the participants' perceptions regarding the key elements in the instructional setting of the automated testing station (goals, instructions, assessment and feedback) and elements related to the setup. In the literature, the latter is labelled as "usability" [8].

Efficiency was measured by a research collaborator who registered the overall time spent in the testing station in a subgroup of students

Methods

During the academic year 2009–2010, as part of a randomised controlled trial investigating different compression depth training strategies in a self-learning (SL) station, 184 third year medicine students had to be assessed six months after initial training [9]. In order to facilitate the assessment procedure, our objective was to develop a fully automated testing method without instructor and to evaluate if such a method would be able to achieve adequate testing (effectiveness) within the shortest period of time (efficiency). The Ethics Committee of Ghent University Hospital approved the study on 8 December 2009 (trial registration B67020097543). Participation in the study was voluntary, non-participation did not influence student grades. All students had received instructor-led (IL) training and testing during the first and second year of medicine.

The actual testing results are reported in the randomised controlled trial by Mpotos and colleagues [9]. To ensure BLS competency of every student in accordance to the resuscitation guidelines a refresher training was provided in the following year.

Research procedure

We designed an interactive user interface with Flash^{TM} (Adobe Systems Inc., USA) to guide the students through the testing procedure without the presence of an instructor, allowing them to perform BLS skills on a commercially available "Resusci Anne torso" manikin (Laerdal Medical, Norway) during three minutes, while their performance was automatically registered by existing software (Resusci Anne Skills Station^{TM} software version 2.0,

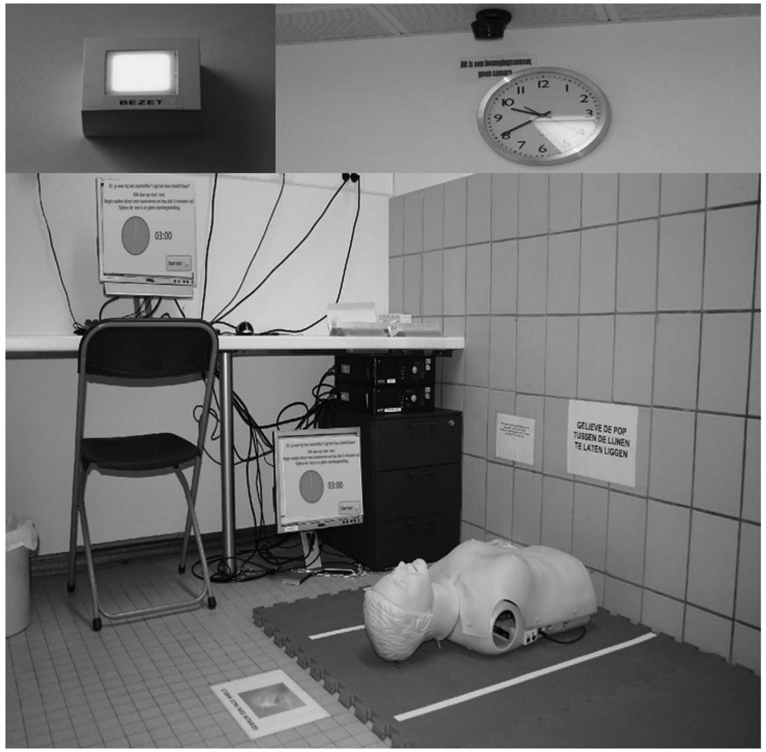

Figure 1 Testing room equipped with a computer and manikin. Left upper corner: indicator light outside the room. Right upper corner: clock and infrared sensor to detect presence of a student.

Laerdal Medical, Norway) running on a computer. To embed the newly developed Flash^{TM}-based user interface in the Resusci Anne Skills Station^{TM} software, Laerdal Medical provided us with a modified version of their commercial software. Laerdal Medical was not further involved in the development of the interactive Flash^{TM} video and the concept of removing the instructor from the testing procedure which was developed at Ghent University.The computer and the manikin were placed in a small room, accessible 24 hours a day, and seven days a week. The room was equipped with an infrared detector connected to an indicator light placed on the outside, notifying when the testing station was in use [Figure 1]. After entering the room and logging in to the computer, a short video message showed an instructor with the following message in the participants' native language: "Welcome to the resuscitation self-learning station [Figure 2a]. You will be asked to perform a test in relation to your previously acquired resuscitation skills. The test consists of performing BLS for three minutes. For reasons of hygiene the use of a face shield while ventilating the manikin is mandatory. When you feel ready to begin, click the "start test" button. The test cannot be interrupted and will automatically stop after 3 minutes".

After this introduction, a text message was displayed asking the student to take a face shield and place it on the manikin. By clicking "continue", the next screen informed the student that a victim had just collapsed in the room, that there was no breathing and circulation and that an ambulance was called. The student was asked to kneel down next to the victim and to resuscitate the victim. The same screen showed an analogue clock and a digital countdown timer of three minutes [Figure 2b]. By clicking "continue", the next screen asked the student to confirm that he was sitting next to the manikin and that the face shield was properly placed on the manikin's face. The student was asked to click the "start test" button displayed on the screen and to perform BLS for three minutes [Figure 2c]. Because during training in the SL station six months before the test, students had received automated voice feedback from the manikin, we stressed that the test would be without voice assistance. The Resusci Anne Skills Station^{TM} automatically registered the data picked up by sensors in the manikin. The amount of time spent performing compressions and ventilations was also registered and will be referred to as "time on task". For our test, a time on task of three minutes was required. Exactly after three minutes, the clock and numeric countdown turned red and an audio warning signal was played. This was immediately followed by a video message from the instructor to announce the end of the test, also asking the student to clean the manikin and to leave the room [Figure 2d]. The program then automatically returned to the login screen and performance results were stored as xml files in a database. Students did not receive feedback about their performance at the end of the test.

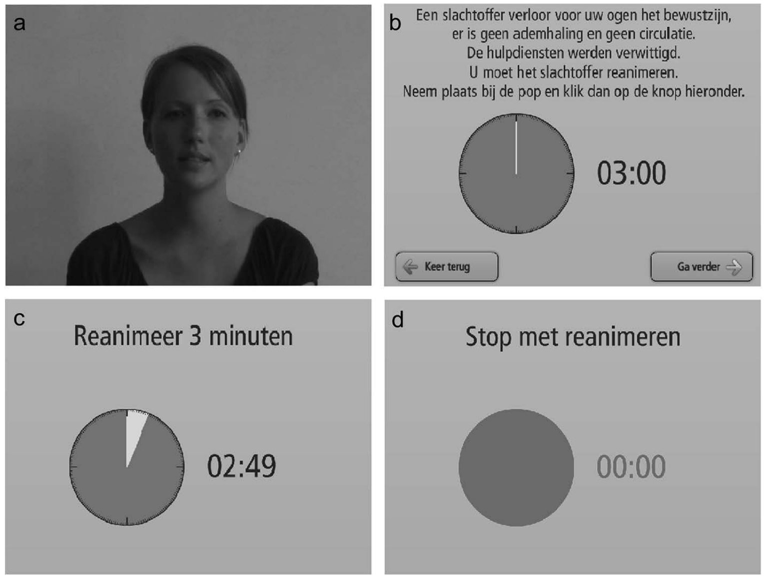

Figure 2 Screenshots of the Flash module. Translation of the text is described in the methods section.

Typical information stored in the xml files is illustrated in Table 1. Settings/limits for the different BLS parameters could be modified in a configuration file that was part of the Skills Station^{TM} software.

To measure the overall time spent in the testing station (assessment of the efficiency) a research collaborator manually logged the room entrance and exit times during two halve days, resulting in data of a subgroup of 29 students. Six months after completion of the test, all students were asked to complete an online questionnaire regarding their perceptions about being tested in the fully automated testing station (assessment of the effectiveness). In total, 20 items on a six point Likert scale (strongly agree, certainly agree, agree, somewhat agree, hardly agree, strongly disagree) were presented [Figure 3].

Statistical methods

Results are reported as means with standard deviations. With respect to the questionnaire, descriptive results (based on percentages) are graphically represented.

Table 1 Information stored in the xml files

• program version
• date
• login name
• scenario type
• total number of compression
• average compression depth
• number registered with incomplete release (≥5 mm)
• number registered with hand position too low/too high up/too far to the right/too far too the left
• number registered with incorrect hand placement
• number registered with average, adequate, insufficient and excessive rate, time-outs, total number of ventilations
• number of ventilations registered with average, adequate, insufficient and excessive volume
• average minute volume
• number of ventilations registered with insufficient relaxation
• average inspiration time
• number of ventilations registered with adequate, too short, too long inspiration time
• average ventilation flow rate
• number of ventilations registered with adequate, too short, too long duration
• number of ventilations registered with airway closed
• number of cycles registered with too few compressions/ventilations, too many compressions/ventilations, enough compressions/ventilations
• total hands off time
• number of cycles registered with correct, too long, much too long, average hands off time
• total cycles counted

Students' responses to the questionnaire were analysed through principal components analysis (PCA) [10]. Since independence of the components was not assumed, an oblique rotation (promax) was used instead of an orthogonal rotation. In order to determine the number of components, parallel analysis (PA) was used. PA is a statistically based method to decide upon the number of components, focusing on the number of components that account for more variance than the components derived from random data, and is more appropriate than using screen plots or the values-greater-than-one rule [11]. Individual loadings of 0.40 or larger were used to identify components. Extracted components were examined and labelled based on the items loading on the specific component. Cronbach's α was calculated to determine the internal consistency of the items within each component. All statistical analyses were performed using PASW® statistics 18 for Windows (SPSS Inc. Chicago, USA). For the parallel analysis, the SPSS syntax of O'Connor was used [11].

Results

One hundred and eighty-four students were tested. During testing there was a technical failure (incomplete data registration) in two students and one student performed compressions only. Complete data sets were obtained for the remaining 181 students. According to the automatic time registration of the system, average time on task was three minutes (SD 0.5). Manual timing of the entrance and exit time in the subgroup of 29 students showed an average time of 7.5 minutes (SD 1.4) spent in the testing station.

The questionnaire was completed by 174/184 students (response rate of 94 %). The descriptive results are shown in Figure 3. None of the 20 items received a "strongly disagree" score and only five items (16, 17, 10, 18, and 9) received a "hardly agree" score from a small number of students. Furthermore the graph shows that for the upper 15 questions, more than 80 % of the students either strongly or certainly agreed and that for items 13, 17, and 10 more than 70 % of the students either strongly or certainly agreed. In response to item 18, asking students whether they preferred the automated testing station to an IL test, 55 % of the students either strongly or certainly agreed, 25 % agreed, 15 % somewhat agreed, and 5 % hardly agreed.

Principal component analysis

We first checked if the data of the 20-item perception questionnaire was suitable for PCA. The Kaiser-Meyer-Olkin value was 0.896, which is above the recommended value of 0.6, and the Bartlett's Test of Sphericity was significant ($P < 0.001$). Parallel analysis indicated that a two-component structure should be retained. The results of

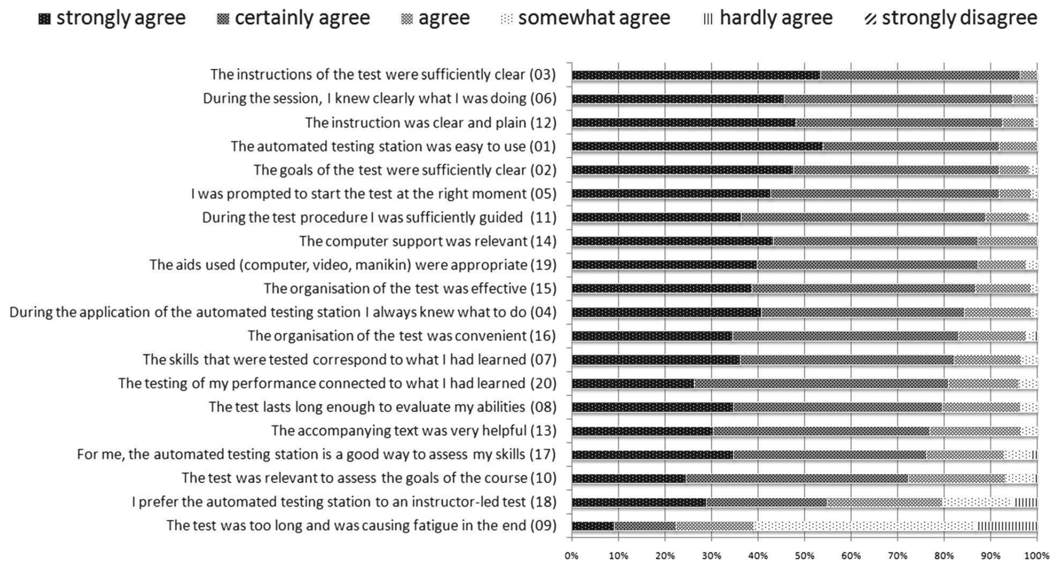

Figure 3 Descriptive results of the questionnaire.

the PCA with promax rotation showed that 50.2 % of the total variance was explained by the two components (respectively 40.6 and 9.6 %). The pattern matrix is presented in Table 2 and shows that 12 items load on the first component, which could be labelled as "instructional organisation", and seven items load on the second component, which can be considered as "usability". One item (item nine) was reversed for the PCA, but did not reflect a significant loading (<0.4). Cronbach's α was 0.92 for the first component and 0.82 for the second component; both larger than 0.80, which is generally seen as a threshold for good internal consistency. Mean scores were 5.3/6 (SD 0.5, range 4.0-6.0) for the first component, indicating that students on average "certainly agreed" to "strongly agreed" about the instructional organisation, and 5.0/6 (SD 0.61, range 3.1-6.0) for the second component, indicating that students on average "certainly agreed" about the usability [Table 2].

Discussion

We have developed a fully automated testing station to assess BLS skills. An interactive Flash^{TM} module, embedded in commercially available software (Resusci Anne Skills Station^{TM} software), allowed guiding students accurately through the testing procedure without instructor involvement. Although the software contained a timer to indicate the duration of the test, this does not automatically imply that rescuers performed BLS during the full three minutes. By recording the actual time-on-task, we could confirm that average test duration was three minutes. An automated testing station can be used to assess large groups of trainees (i.e. for certificative testing). On a 14 hour per day base, considering an average time of 7.5 minutes per student, eight students could be tested in one hour and in total 112 subjects could be tested in a day. Achieving this number with an instructor would be far more labour- and time-intensive.

Testing stations could also present an added value as an integral part of training, since testing has been shown to yield a powerful effect on retention which may be essential to consolidate newly acquired skills [12]. Adding a test as a final activity in a BLS course seems to have a stronger long-term learning impact as compared to spending an equal amount of time practising the same skills [13-15]. At a theoretical level, the training of continuous retrieval processes seems to account for the "testing effect". Also, requiring learners to elaborate while retrieving earlier knowledge during testing, has been found to affect long term learning [12,14,15]. Though these assumptions explain the testing effect in relation to declarative knowledge acquisition, the theoretical assumptions also fit the beneficial impact on the acquisition of skills, and tests also invoke retrieval and elaboration of procedural knowledge [14].

The SWOT analysis in Table 3 describes strengths and weaknesses that might affect the achievement of this objective. The automated testing station can also be used in the context of research where there is a need for pre- and post testing of BLS mastery after experimental interventions (i.e. formative testing). The student's responses

Table 2 Pattern matrix of the principal components analysis (promax rotation)

Item	Variable	Component 1 Organisation	Component 2 Usability
12	The instruction was clear and plain.	**0.83**	0.02
3	The instructions of the test were sufficiently clear.	**0.78**	0.01
4	During the application of the automated testing station I always knew what to do.	**0.78**	0.05
14	The computer support was relevant.	**0.77**	−0.03
15	The organisation of the test was effective.	**0.76**	−0.06
5	I was prompted to start the test at the right moment.	**0.75**	0.01
2	The goals of the test were sufficiently clear.	**0.71**	−0.03
6	During the session, I knew clearly what I was doing.	**0.71**	0.09
1	The automated testing station was easy to use.	**0.71**	−0.04
16	The organisation of the test was convenient.	**0.69**	0.05
11	During the test procedure I was sufficiently guided.	**0.61**	0.10
13	The accompanying text was very helpful.	**0.57**	−0.09
10	The test was relevant to assess the goals of the course.	−0.18	**0.88**
17	To me, the automated testing station is a good way to assess my skills.	−0.03	**0.85**
18	I prefer the automated testing station to an instructor-led test.	−0.16	**0.77**
20	The testing of my performance connected to what I had learned.	−0.02	**0.76**
19	The aids used (computer, video, manikin) were appropriate.	0.33	**0.52**
7	The skills that were tested correspond to what I had learned.	0.22	**0.48**
8	The test lasted long enough to evaluate my abilities.	0.10	**0.45**
9	The test was too long and was causing fatigue in the end (R).	0.23	−0.10

Note: Values >0.40 are highlighted for ease of interpretation. Item 9 was reversed (R) for the principal components analysis.

to the perception questionnaire indicate that students are positive about the automated testing station. In this respect, the results show that 80 % of the students agreed, certainly agreed or strongly agreed that they prefer an automated testing station to an IL test (item 18). With respect to item nine, the scores were not in line with the other items. Almost 40 % of the students agreed, certainly agreed or strongly agreed that "the test was too long and was causing fatigue in the end". There may be two reasons for atypical scoring of this item. First, it is the only negatively formulated item in the questionnaire, and students may have overlooked this. Second, it combines two statements, namely "the test was too long" and "the test was causing fatigue in the end". We also notice the atypical behaviour of this item in the PCA, since it does not reach the threshold loading (higher than 0.4) on the components.

The PCA resulted in a two-component structure, with one component focusing on the quality of instructional organisation (goals, instructions, assessment and feedback) and the other component focusing on usability. Average scores indicated that students certainly to strongly agreed that the instructional organisation was appropriate and students certainly agreed that the approach was usable. The results of this questionnaire are important for two reasons. First, they show that the automated testing station is functioning properly and is adequately organised. Second, they show that students were positive about the usability of the testing station.

As suggested by Kromann and colleagues, future studies should investigate the intrinsic testing effect and the extrinsic learning effect of formative testing, informing the participant about performance and guiding him towards further skills improvement and mastery [14,15]. These studies could incorporate automated skills testing as a formative assessment procedure in an adaptive learning cycle with repetitive testing [16].

Limitations

A number of limitations have to be stressed. When discussing the quality of this specific assessment setting, two aspects have to be distinguished. The first aspect is the quality of the assessment process. The second aspect is the quality of the measurement of the performance indicators. This is guaranteed by the intrinsic quality of the manikin sensors and by the use of existing registration software. Maintenance protocols and timely replacement of sensors, valves and springs are imperative to guarantee measurement reliability and validity. In the context of the present study, the students were familiar

Table 3 SWOT analysis of automated BLS skills testing

Strengths	Weaknesses
• Accessible (24 h/24 h)	• Need for human supervision to supply disposables (wipes and lungs)
• Automated	• Frequent manikin maintenance
• Standardised	• Technical failures (manikin, hardware or software bug, computer problems
• Objective (no instructor bias)	• Hygiene concerns
• Able to achieve adequate testing (effectiveness)	
• within the shortest period of time (efficiency)	
Opportunities	**Threats**
• Formative testing of large groups	• Dependency of computer and internet technology
• Certification procedures	• Monopoly of technology and commercial exploitation
• Pre- and post testing in educational interventions	
Acceptance by internet generation	

with training in a SL station and that may have improved the usability of the testing station. However, the automated testing situation and the specific Flash™ module were completely new to the students. Presenting the usability questionnaire six months after testing may have introduced a bias. Further research is needed to confirm these results in terms of non-inferiority compared to IL testing and usability in other student populations.

The software prototype we used only focussed on testing the technical CPR components. Future developments could embed interactive components allowing the trainee to dial a phone number or assessing cardiac arrest by performing the right actions on-screen.

Conclusions

Automated testing is an effective and efficient method for assessing BLS skills in medicine students and has the potential to innovate traditional resuscitation training. It grounds the scalability of formative assessment and certification procedures without instructor involvement.

Competing interests

Laerdal Medical (Stavanger, Norway) provided technical support by creating the possibility to replace the existing introduction video of their commercial software package with an interactive Flash™ video. Laerdal Medical also provided the face shields and the RA Skills Station licenses for the duration of the study. The authors have received a grant from the Laerdal Foundation to conduct research in this area. However, Laerdal has taken no part in the design of the study, the analysis of the data or the writing of the current manuscript.

Acknowledgements

We are grateful to the management of Ghent University Hospital, to the IT department for computer support, to Charlotte Vankeirsbilck for administrative support and to all the students who participated in the study. We thank Lisa Malfait for her participation in the intro video and for her informed consent to use any image related to this video. The programming of the Flash™ module was done by Uniweb bvba (Strombeek-Bever, Belgium).

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Authors' contributions

NM, MV and KM conceived the study, designed the trial, and obtained research funding. NM and KM supervised the conduct of the trial and data collection. NM, MV and KM undertook recruitment of students and managed the data, including quality control. BDW provided statistical advice on study design and analysed the data. NM drafted the manuscript, and all authors contributed substantially to its revision. KM takes responsibility for the paper as a whole. All authors read and approved the final manuscript.

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Received: 18 December 2011 Accepted: 23 July 2012
Published: 23 July 2012

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doi:10.1186/1472-6920-12-58
Cite this article as: Mpotos et al.: Assessing basic life support skills without an instructor: is it possible?. *BMC Medical Education* 2012 **12**:58.

Chapter 6

Efficiency of short individualised CPR self-learning sessions with automated assessment and feedback.

RESUSCITATION 2013;84:1267-73

Contents lists available at SciVerse ScienceDirect

Resuscitation

journal homepage: www.elsevier.com/locate/resuscitation

Simulation and education

Efficiency of short individualised CPR self-learning sessions with automated assessment and feedback☆

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ARTICLE INFO

Article history:
Received 7 November 2012
Received in revised form 29 January 2013
Accepted 26 February 2013

Keywords:
Assessment
Basic life support
Cardiopulmonary resuscitation
Feedback
Retention
Self-learning

ABSTRACT

Introduction: Regular assessments are recommended to identify individuals requiring additional resuscitation training. We developed a strategy of short CPR self-learning sessions followed by automated assessment with feedback and investigated its efficiency to achieve a pre-defined level of compression skills.

Methods: Four hundred and four students in pharmacy and educational sciences participated. Initial training (max. 40 min) consisted of a 15 min learning-while-watching video followed by manikin exercises with computer voice feedback. At baseline and after training, performance was measured using an automated test. To be judged competent participants had to achieve ≥70% compressions with depth ≥50 mm and ≥70% compressions with complete release (<5 mm) and a compression rate between 100 and 120 min^{-1} within a two month period. Automated feedback was provided and failed participants had to retrain within two weeks. Retraining (max. 20 min and max. three times) was done with voice feedback exercises. Before retraining, the previous test result was displayed together with feedforward. After five months all participants were invited for a retention test.

Results: After one to four sessions, 99% (401/404) of all participants achieved competency. After five months 48% (137/288) of the students participating in the retention test was still competent. The percentage competent participants was 80% (230/288) for compression depth, 97% (279/288) for complete release and 60% (172/288) for mean rate.

Conclusions: One or multiple short self-learning sessions were highly efficient to successfully train 99% of participants. After five months, retention of compression depth and complete release was very high. However, only 48% still achieved a 70% combined score for compression skills, highlighting the importance of regular assessment and retraining.

1. Introduction

According to the European Resuscitation Council (ERC) 2010 guidelines, cardiopulmonary resuscitation (CPR) training should be tailored to the needs of different types of learners to ensure acquisition and retention of skills.[1] CPR skills are, however, poorly acquired and retention deteriorates in as little as three to six months.[1] The use of frequent assessments can identify those individuals requiring refresher training to help maintain their knowledge and skills.[2–7] Providing feedback on a trainee's skill level is also known to have great impact on acquisition and retention of skills.[8–11]

Previous research demonstrated that for training in a self-learning (SL) station, a combined instructional strategy consisting of a Mini Anne™ video (Laerdal, Norway) followed by refinement with voice feedback exercises in the Resusci Anne Skills Station™ (Laerdal, Norway) was non-inferior for acquisition of chest compression skills compared to instructor-led (IL) training.[12] Video alone showed not to be sufficient to acquire CPR skills.[13] To retrain CPR skills in a SL station adequately, voice feedback exercises appeared to be more effective than a video.[14]

To report clinical competence the proportion of successful participants should be assessed against a predefined pass level.[15] In 1995 the Royal College of General Practitioners already suggested

☆ A Spanish translated version of the abstract of this article appears as Appendix in the final online version at http://dx.doi.org/10.1016/j.resuscitation.2013.02.020.

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http://dx.doi.org/10.1016/j.resuscitation.2013.02.020

a 70% level for adequate chest compressions as a lower limit for effective circulatory support.[16] Our previous research explored the possibility to implement such a 70% level in a combined score for compression skills based on 70% compression with correct depth, 70% compressions with complete release and with correct compression rate.[13,14] The choice for a 70% cut-off value for a combined assessment score is, however, at this stage not based on clear-cut empirical evidence. Since no specific CPR related research is available to propose a benchmark, we build on general principles as derived from Mastery Learning research indicating that a high attainment level has to be pursued before moving to the next learning goal and that formative assessment should be adopted to give immediate feedback to foster the high attainment level of the goals being pursued. In this context, Hattie reports that Mastery Learning approaches result in high effect sizes when considering the impact on learning performance (ES = .58).[9] The development of an automated testing method in combination with such a combined assessment score now allows the introduction of automated feedback and feedforward on the test result.[17]

However, a lack of knowledge remains about the optimal learning strategy for each individual to acquire and maintain a sufficient CPR skill level. We hypothesised that for some people multiple training sessions incorporating testing and feedback/feedforward would be necessary to achieve competency, while others can reach a similar level of skill acquisition with only a single successful training session. Therefore, we investigated the efficiency of a strategy comprising additional short CPR self-learning sessions followed by automated assessment and feedback to achieve a pre-defined level of compression skills. In addition, the retention after five months was assessed.

2. Methods

The study was approved by the Ethics Committee of Ghent University Hospital. Our study population comprised 428 of 431 eligible students (pharmacy and educational sciences) giving informed consent. During a two month study period a SL station, as described previously, was made available in a small room accessible 24 h a day and seven days a week.[12–14] In Google Calendar participants had to book a first training session (limited to a maximum of 40 min) and up to three additional sessions (with a maximum of 20 min each) in case of failure on the automated test following each training session.

Practising and testing was done on a full size torso and using a face shield (Laerdal, Norway), while performance of chest compression depth, complete release, compression rate and ventilation volume was registered. An automated test asked the participant to resuscitate (30:2 CPR) a victim of cardiac arrest during 2 min.[17] Before initial training we assessed all participants' baseline compressions and ventilations skills, however, no test result and no feedback was provided at this stage. After the baseline test, all participants were trained in 30:2 CPR (compressions and ventilations) using a combined learning strategy consisting of a 15 min learning-while-watching video (Mini Anne™) followed by a manikin exercise with concurrent computer voice feedback (Resusci Anne Skills Station™).[14] During the voice feedback exercises the limits of the Skills Station™ were set as follows: compressions depth ≥ 50 mm; complete release < 5 mm; compression rate 100–120 min^{-1} and ventilation volume between 400 and 1000 ml (because the chest of the manikin visibly rises after insufflation of 400 ml).[13,14]

After initial training (T1), a new automated 2 min test was taken to assess compression and ventilation skills. To allow calculation of a meaningful test result we defined that a minimum of 120 compressions over 2 min had to be recorded. In case this was not achieved, a message was displayed asking the student to perform a new test. In the pre-test, no test result and feedback was provided. Since compression depth is one of the most important determinants of survival, the methodological choice was made to only give assessment feedback on compression skills.[16,18] To be considered competent all participants had to achieve a 70% combined score for compression skills consisting of ≥70% compressions with a depth ≥50 mm and ≥70% compressions with complete release and a mean rate between 100 and 120 min^{-1}.[14] At this stage an instant result for the compression skills was provided to the student (feedback) accompanied by feedforward (how to improve) if the student was not successful (Fig. 1).

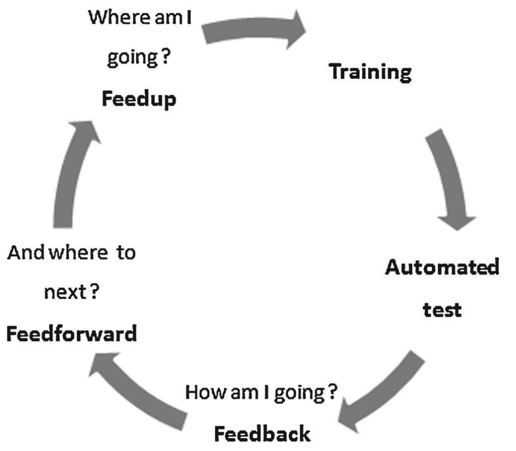

Fig. 1. Individual learning cycle incorporating feedup, training, automated testing and feedback/feedforward.

According to the training algorithm, participants not achieving a 70% combined score for compression skills after the initial 40 min training had to attend further training within two weeks (Fig. 2). When the student logged in for his next training session, he received the feedback of his last test together with feedforward on how to improve during the following voice feedback exercises (=feedup). Participants could then practice 30:2 CPR (with a maximum of 20 min) until they felt competent to perform a new test. A maximum of three additional training sessions (T2, T3, T4) was allowed. Participants who were still unsuccessful after the third additional training session were offered IL remedial training. All participants who achieved the 70% combined score for compression skills without IL remedial training were invited for a retention test five months after their last test.

2.1. Objectives and outcome measures

The primary aim of the study was to investigate the efficiency of short individualised CPR self-learning sessions with automated assessment and feedback in order to meet a predefined CPR mastery level. In addition skill retention after five months was assessed. The outcome measure was the achievement of a combined score for compression skills consisting of ≥70% compressions with depth ≥50 mm, ≥70% compressions with complete release (<5 mm) and a mean compression rate between 100 and 120 min^{-1}. Additionally we looked at each individual compression skill, at how many participants achieved ≥70% ventilations with a volume 400–1000 ml, and how many participants achieved higher thresholds than the predefined 70%.

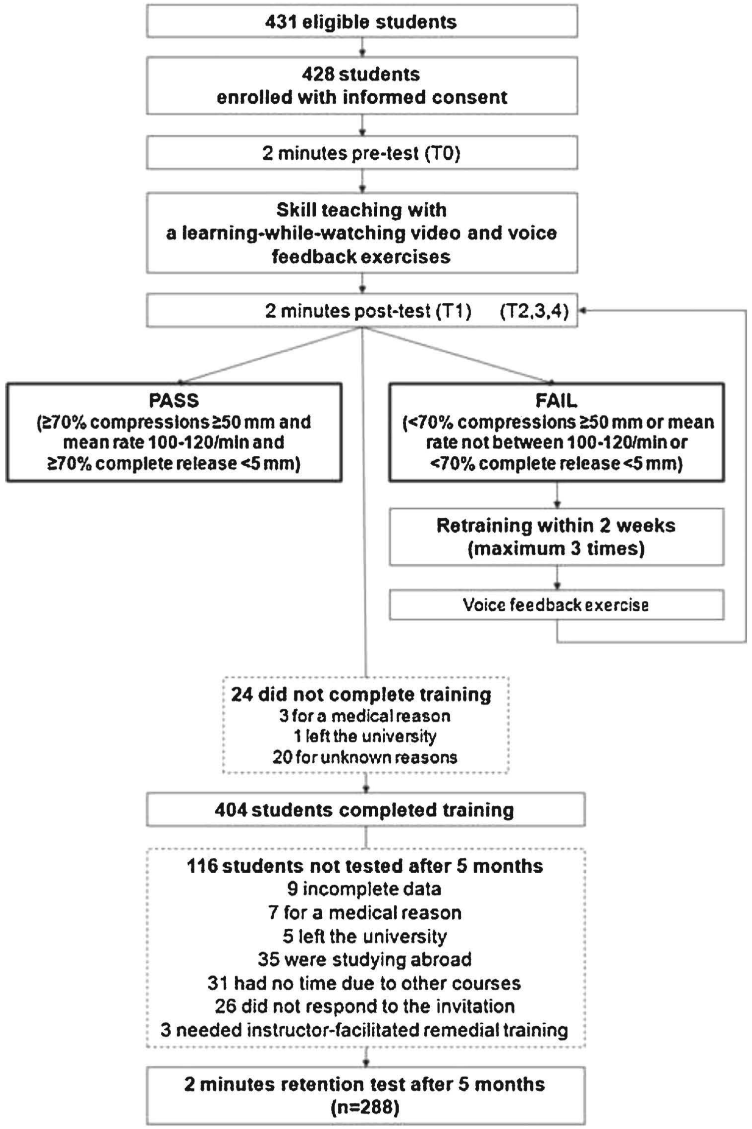

Fig. 2. Participants flow chart.

2.2. Statistical methods

The proportion of participants achieving a 70% threshold at different stages of the training (T1, T2, T3, T4) were compared for the combined compression skills score, the different compression skills and in addition the ventilation skills. To analyse skill decay, the results at the end of training were compared with the results obtained after five months. Confidence intervals (CI) are reported for the differences between proportions using PASW® statistics 18 for Windows (SPSS Inc. Chicago, USA).

3. Results

During the academic year 2011–2012, 404 participants (155 pharmacy students and 249 educational sciences' students) completed the training (Fig. 2). This group of 404 students consisted of 87% females and the mean age was 20 years (SD 2.5). One hundred and two participants (25%) had followed a CPR course in the past, with a mean time of 27 months ago (SD 26).

Of all participants 307/404 performed a valid pre-test (>120 compressions). The 70% combined assessment score at T0 was achieved by 16/307 and no correlation was found with previous CPR training ($P = 0.7$).

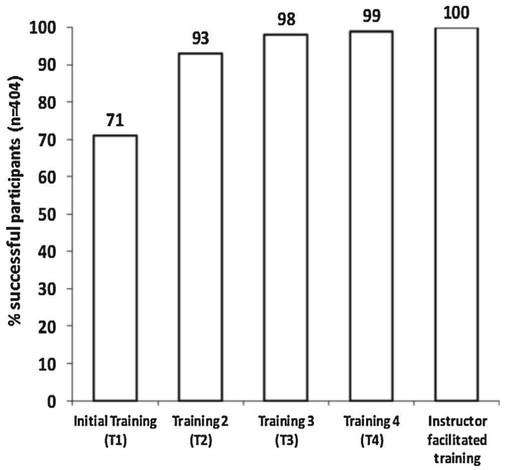

Fig. 3. Success rates after initial training (T1), retraining (T2, T3, T4) and instructor-facilitated training.

3.1. Multiple short training sessions

Twenty-four participants did not complete the training: three for a medical reason, one left the university and 20 interrupted training without giving any reason (Fig. 2). Results (cumulative proportions) for each individual skill after the consecutive training sessions are shown in Table 1. For the 70% combined score for compression skills the cumulative proportion of competent participants after one additional training session was 374/404 (93%), after a second 394/404 (98%) and after a third 401/404 (99%) (Fig. 3).

The three remaining unsuccessful participants were invited for an instructor-facilitated training session. Only one student responded to the invitation and became competent after the training. The other two did not respond to the invitation. The proportion of successful participants achieving a higher score (80, 90 or 100%) than the pre-defined 70% are shown in Fig. 4.

3.2. Skill retention after five months

After five months, retention data were obtained from 288 participants. The reasons for drop-out are listed in Fig. 2. The results for each individual skill and for the 70% combined score for compression skills are shown in Table 2. The largest skill decay was observed for compression rate due to lower (73/288) or higher (43/288) compression rates compared to the 100–120 min^{-1} limits. The proportion of participants who maintained a higher level (80, 90 or 100%) for their skills than the pre-defined 70% is shown in Fig. 4. For each higher threshold the proportion of unsuccessful students after five months was almost the same. Additional analysis showed that skill retention (combined score for compression skills and individual CPR skills) in participants needing multiple training sessions before succeeding did not differ from participants succeeding after the initial training ($P = 0.139$).

4. Discussion

Our results demonstrate that after one or multiple short training sessions followed by assessment and feedback 99% of all participants were able to achieve a predefined 70% combined score for compression skills. Retention testing showed that 48% of the participants still achieved this pass level after five months and as shown in Fig. 4 some of the participants were even able to maintain a higher level than the predefined 70%. Although this combined score for compression skills shows important decay, mostly due to inadequate compression rate, retention for compression depth and complete release was very high.

Assessing the proportion of successful participants against a predefined pass level is recommended to report clinical competence.[15] According to a systematic review on the

Table 1
Cumulative proportions of successful participants after initial training (T1) and after additional training sessions (T2, T3, T4).

	T1	T2	T3	T4
	Number of participants *n/N* (%) [95% CI]	Number of participants *n/N* (%) [95% CI]	Number of participants *n/N* (%) [95% CI]	Number of participants *n/N* (%) [95% CI]
≥70% of compressions ≥ 50 mm	376/404 (93%) [0.91–0.96]	395/404 (98%) [0.96–0.99]	402/404 (100%)	402/404 (100%)
≥70% of compressions with complete release < 5 mm	365/404 (90%) [0.87–0.93]	401/404 (99%) [0.99–1]	403/404 (100%)	404/404 (100%)
Compression rate 100–120 min^{-1}	335/404 (83%) [0.79–0.87]	391/404 (97%) [0.95–0.99]	401/404 (99%) [0.99–1]	404/404 (100%)
≥70% of ventilations between 400 and 1000 ml	296/404 (73%) [0.69–0.78]	317/404 (79%) [0.75–0.83]	318/404 (79%) [0.75–0.83]	318/404 (79%) [0.75–0.83]
70% combined score for compression skills[a]	286/404 (71%) [0.66–0.75]	374/404 (93%) [0.9–0.95]	394/404 (98%) [0.96–0.99]	401/404 (99%) [0.99–1]
70% combined score for ALL skills[b]	208/404 (52%) [0.47–0.56]	277/404 (69%) [0.64–0.73]	291/404 (72%) [0.68–0.76]	297/404 (74%) [0.69–0.78]

[a] 70% combined score for compression skills: ≥70% of all compressions ≥ 50 mm and ≥70% of all compressions with complete release and compression rate between 100 and 120 min^{-1}.
[b] 70% combined score for ALL skills: ≥70% of all compressions ≥ 50 mm and ≥70% of all compressions with complete release and compression rate between 100 and 120 min^{-1} and ≥70% of all ventilations between 400 and 1000 ml.

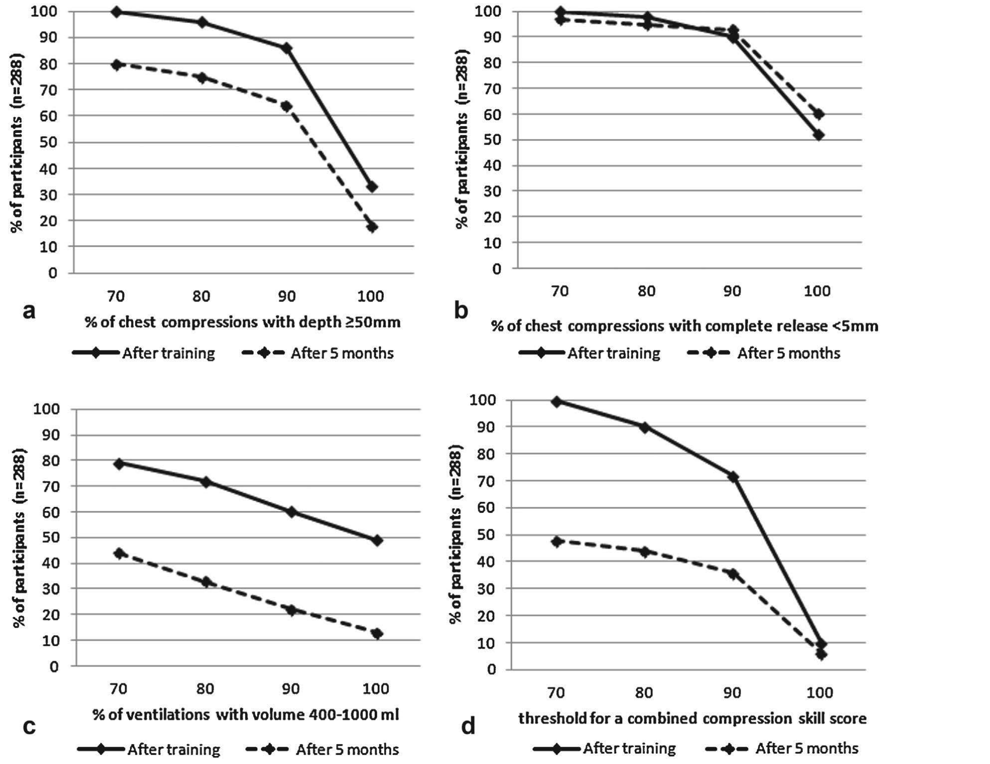

Fig. 4. Proportion of participants achieving a percentage of compressions with depth ≥ 5 cm (a), with complete release < 5 mm (b), ventilations with volume 400–1000 ml (c), and a threshold for a combined score for compression skills (d).

Table 2
Proportions of success at the end of the training and after five months for participants completing the study (n = 288).

	End of training	After five months	
	Number of participants n/N (%) [95% CI]	Number of participants n/N (%) [95% CI]	Difference in proportion % [95% CI]
≥70% of compressions ≥ 50 mm	288/288 (100%)	230/288 (80%) [0.75–0.85]	20% [0.16–0.24]
≥70% of compressions with complete release < 5 mm	288/288 (100%)	279/288 (97%) [0.95–0.99]	3% [0.01–0.05]
Compression rate 100–120 min^{-1}	288/288 (100%)	172/288 (60%) [0.54–0.65]	40% [0.36–0.45]
≥70% of ventilations between 400 and 1000 ml	227/288 (79%) [0.74–0.84]	126/288 (44%) [0.38–0.49]	35% [0.29–0.41]
70% combined score for compression skills[a]	288/288 (100%)	137/288 (48%) [0.42–0.53]	52% [0.48–0.57]
70% combined score for ALL skills[b]	227/288 (79%) [0.74–0.84]	62/288 (22%) [0.17–0.26]	57% [0.52–0.63]

[a] 70% combined score for compression skills: ≥70% of all compressions ≥ 50 mm and ≥70% of all compressions with complete release and compression rate between 100 and 120 min^{-1}.
[b] 70% combined score for ALL skills: ≥70% of all compressions ≥ 50 mm and ≥70% of all compressions with complete release and compression rate between 100 and 120 min^{-1} and ≥70% of all ventilations between 400 and 1000 ml.

methodology of CPR skills assessment by Mäkinen and colleagues, most current studies use varying methods of assessment, have methodological shortcomings and evaluate their teaching strategy poorly.[19,20]

In previous work we started reporting the proportion of successful participants against a predefined 70% pass level for each CPR skill individually, and we explored the feasibility to introduce a combined pass level.[13,14] To participants, achieving a combined pass level is more demanding than achieving a pass level for each individual skill, but a combined score probably reflects the degree of CPR mastery better. To our knowledge the current study is the first to train and assess participants systematically against a predefined combined pass level. Given this approach it is difficult to compare training and retention data with the literature.

Providing feedback on a participant's actual training level after assessment together with feedforward is the most powerful tool for improvement.[9,21–23] By introducing automated assessment followed by feedback and feedforward at the end of each training session we were able to train 99% of the participants to our predefined pass level for compression skills. Since every participant learns in a different way, not immediately succeeding after a first assessment may just indicate that some of them needed more time and practice to achieve the required skill level. After an initial 40 min training session (T1) 71% of the participants achieved the predefined 70% combined score for compression skills and after an additional 20 min training this improved to 93% (T2), demonstrating the feasibility and efficiency of our automated training strategy. We believe that the further improvement at T3 and even the extra 1% at T4 justify the additional training. We adhere in this context to the principles of Mastery Learning that state that continuous formative assessment and feedback should aim at a high attainment level of all students.[9]

Five months after training 52% of the participants was unable to achieve the 70% combined score for compression skills. Inadequate compression rate in 40% accounted as the main reason to explain this decay. A 70% pass level for compression depth and complete release was, however, maintained in 80 and 97% of the participants respectively. Good retention of compression depth and complete release were also observed in the participants achieving higher pass levels (Fig. 4). This is an important finding since it has recently been confirmed that compression depth and release are the skills most influencing survival.[18] Therefore, it might be a feasible strategy to train participants gradually to higher pass levels using additional multiple short training sessions.

Regarding the poor retention of compression rate, we hypothesise that it may be very difficult for some people to remember the rate of 100–120 min^{-1} during CPR, resulting in lower or higher compression rates. Field and colleagues reported a decrease in compression depth by an increase in rate, which was also shown in a recent clinical trial by Monsieurs and colleagues where excessive chest compression rate was also associated with insufficient compression depth.[24,25] A possibility to improve retention of chest compression rate in the absence of a metronome might be to optimise feedback by introducing auditory feedback recalling the correct beat.[23,26] Jäntti and colleagues reported that metronome guidance used during manikin CPR corrected chest compression rate in experienced rescuers and did not affect chest compression depth or rescuer fatigue.[27] Therefore, CPR feedback/prompt devices with a metronome could be used to maintain a correct compression rate.[23,28]

Although all lay participants were trained in ventilations skills with the learning-while-watching video and voice feedback exercises, they were only assessed and given feedback on their compression skills. This choice is partly supported by the ILCOR and ERC 2010 guidelines and by the trial of Stiell and colleagues establishing a strong association between compression depth and survival.[1,18,29] The absence of feedback/feedforward on ventilation skills performance was reflected in the absence of improvement in ventilation mastery after multiple training sessions (Table 1). However, despite the absence of feedback, ventilation performance was adequate in 79% of the participants at the end of training, but a considerable decay was observed after five months. When training professional rescuers, feedback on ventilation skills should be given together with feedback on compression skills, using a combined score including all CPR skills.

Our population consisted of young motivated lay students, which do not represent the general population. Although Braslow et al. found that participants over 40 year performed compressions comparable to younger participants,[30] age-related differences in attention span en memory capacity may influence CPR performance. The impact of age-related differences in our specific learning environment is currently unknown. At five months retention testing the dropout was nearly 25% and the reasons are illustrated in Fig. 2. The high dropout rate is a study limitation as it is possible that dropouts would have the poorest results. This study demonstrates the feasibility and the high success rate of automated learning as a way to acquire good CPR skills. However, we believe that skill decay will always be present, no matter how efficient the learning strategy, and that the use of regular assessments is required to ensure the maintenance of competency. Our automated assessment procedure has already been proven very effective and efficient and could be used for those assessments.[1,17] The addition of automated feedback and feedforward might be sufficient to improve a participant's skill level with every test. It is currently unknown if a strategy of repetitive testing with feedback is as effective as standard retraining with voice feedback exercises.

The current results underscore the potential of novel computer assisted self-learning strategies to achieve high quality resuscitation skills. The ultimate goal is to increase bystander CPR and to improve resuscitation outcome. Therefore, the training strategy should be easily adoptable and affordable.

5. Conclusions

One to maximum four short SL sessions led to compression skills competency in 99% of the participants. After five months, retention of compression depth and complete release was very high. However, only 48% of the participants still achieved a 70% combined score for compression skills, indicating the importance of regular assessment and retraining in almost half of the participants.

Conflict of interest statement

We received an unrestricted grant from the Laerdal Foundation. Laerdal (Stavanger, Norway) provided the manikin, the face shields and the Resusci Anne Skills Station™ licenses for the study. Laerdal has taken no part in designing the study, analysing data or writing of the manuscript.

Acknowledgements

We are grateful to the management of Ghent University Hospital, to Francis Dewandel from the IT department for computer support, to Charlotte Vankeirsbilck for administrative support and to all the students who participated in the study. We are especially grateful to Bram Gadeyne for the software development.

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Chapter 7

Automated testing combined with automated retraining to improve CPR skill level in emergency nurses.

SUBMITTED

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Abstract

OBJECTIVES

To investigate the effect of automated testing and retraining on the cardiopulmonary resuscitation (CPR) competency level of emergency nurses.

METHODS

A software program was developed allowing automated testing followed by computer exercises based on the Resusci Anne Skills Station™ (Laerdal, Norway). Using this system, the CPR competencies of 43 emergency nurses (mean age 37 years, SD 11, 53% female) were assessed. Nurses passed the test if they achieved a combined score consisting of ≥70% compressions with depth ≥50 mm and ≥70% compressions with complete release (<5 mm) and a mean compression rate between 100-120/min and ≥70% bag-valve-mask ventilations between 400-1000 ml. Nurses failing the test received automated feedback and feedforward on how to improve. They could then either practise with computer exercises or take the test again without additional practise. Nurses were expected to demonstrate competency within two months and they were retested 10 months after baseline.

RESULTS

At baseline 35/43 nurses failed the test. Seven of them did not attempt further testing/practise and 7 others did not continue until competency, resulting in 14/43 not competent nurses by the end of the training period. After 10 months 39 nurses were retested. Twenty four nurses failed with as most common reason incomplete release.

CONCLUSION

Automated testing with feedback was effective in detecting nurses needing CPR retraining. Automated training and retesting improved skills to a predefined pass level. Since not all nurses trained until competency, achieving CPR competence remains a significant individual and institutional challenge. Ten months after baseline the combined score showed important decay, highlighting the need for frequent assessments.

Word count abstract: 250

Word count text manuscript: 1560

Key Words: Assessment; Basic Life Support; CPR; Nurses; Self-learning.

INTRODUCTION

Emergency nurses are often involved in the management of cardiac arrest. Lack of cardiopulmonary resuscitation (CPR) skills of nurses and physicians contributes to poor outcome of cardiac arrest victims.[1-5] The retention of compression and ventilation skills rapidly decays and the use of frequent assessments may identify those individuals requiring refresher training.[6-10] Although recommended by the European Resuscitation Council (ERC) and by the American Heart Association (AHA)[11,12] systematic testing of healthcare providers after a course or after a predefined interval is still not current practice.

We have previously developed an automated testing station enabling formative assessment and certification procedures in a time-efficient manner without instructor involvement.[13] It also offers the possibility to provide immediate automated feedback and feedforward about the test result.[14] This technological advance might reduce recertification time and allow focused individualised retraining. In a randomised controlled trial, voice feedback exercises showed to be the most effective strategy to adequately retrain CPR skills in a self-learning station.[15] The purpose of the current study is to investigate the effect of automated testing combined with automated retraining on the cardiopulmonary resuscitation (CPR) competency level of emergency nurses.

RESEARCH METHODS

The Ethics Committee of Groeninge General Hospital (Kortrijk, Belgium) approved the study. From March 2012 until January 2013, 43 of the 51 emergency nurses gave informed consent and participated in the study. Eight months prior to the study all nurses had been trained with the commercially available Resusci Anne Skills Station™ (Laerdal, Norway) computer exercises.

A self-learning station equipped with a manikin linked to a computer was available in a small room secured with a numeric lock, accessible 24 hours a day and seven days a week.[16,17] For the purpose of the study, a software program was developed to allow automated testing with feedback/feedforward (Ghent University, Belgium) combined with automated self-training sessions on a CPR manikin (Resusci Anne Skills Station™, Laerdal, Norway). As such we created short self-learning sessions where the nurses could repetitively test or test-practice-test until they achieved the required predefined pass level. Practising and testing was done on a full size torso disposed on the floor and using a bag-valve-mask device while performance of chest compression depth, complete release, rate and ventilation volume was registered. Each emergency nurse was invited to perform a first automated test (resuscitate a victim of cardiac arrest during 2 minutes) in order to establish baseline CPR skill level (T0; basic life support). To pass the test, nurses had to achieve a 70% combined assessment score consisting of ≥70% compressions with depth ≥50 mm and ≥70% compressions with complete release (<5 mm) and a mean compression rate between 100-120/min and ≥70% ventilations with a volume between 400-1000 ml. The 70% cut-off was arbitrarily chosen in accordance with our previous research.[14,15,18]

After each test an instant result was provided on screen (feedback). Nurses who failed the test also received feedforward on how to improve. They could then choose to perform a new test or first practice. Both could take place immediately or at a different moment, in which case the feedback and feedforward of the last test was recalled at the beginning of the new session (= feedup). Practice was done using full CPR (30 ventilations to two compressions) computer exercises with concurrent voice feedback (Resusci Anne Skills Station™) and followed by a new 2 minutes test.[15] Voice feedback limits during practice with the Skills Station™ computer exercises were set according to the ERC 2010 guidelines: for compressions at depth 50-60 mm; incomplete release ≥5 mm; rate 100-120/min; ventilation limits were 400-1000 ml (because the chest of the manikin visibly rises after insufflation of 400 ml).

All nurses were asked to achieve a pass on the test within a two months period. Ten months after the baseline measurement each nurse was invited to perform a new test (T2). Before performing the new test the result of the last performed test was displayed on screen. Not competent nurses also received feedforward on how to improve. The participants flow chart is shown in Figure 1.

Performances at baseline, following training, and after 10 months were compared. Proportions are reported as counts and percentages. Confidence intervals (CI) are reported for the differences between proportions.

RESULTS

Forty-three emergency nurses participated in the study. Mean age was 37 years (SD 11) and 53% were female. At baseline 35/43 nurses did not achieve the predefined pass level of which seven did not attempt any further training (repeated automated testing or practice with computer exercises). Seven others started to train but did not continue until reaching a pass, resulting in 14/43 nurses not achieving the pass level at the end of the two months period (Fig. 2). Eleven nurses skipped the Skills Station™ computer exercises and succeeded by only performing repetitive tests with feedback. The total mean practice time was 13 minutes (SD 15).

Ten months after baseline 39 nurses were retested (4 nurses dropped out: 1 had retired, 1 had left the hospital and 2 for medical reasons) and 24 did not pass the test (T2). Six of the 14 nurses not achieving a pass at T1 (two had attempted training but four had only performed a baseline test) passed after 10 months (Fig 2).

The proportion of successful nurses improved for all outcome measures after training (T1; Fig. 3 and 4) and was maintained or even improved after 10 months (T2) except for complete release (Fig. 4).

The reason for failing the test at T0 was due to failure of one skill in 22/35 (63%) nurses, two skills in 10/35 (29%), three skills in 2/35 (6%). Only one nurse failed on all four skills. After 10 months (T2) the proportions were respectively 20/24 (83%), 3/24 (12.5%), 1/24 (4%) and 0/24 (0%). The skills most likely to fail at T0 were mean compression rate (16/35), ventilation volume (14/35) and compression depth (13/35). After 10 months most failures were due to incomplete release (12/24) and inadequate mean compression rate (8/24).

Complete release appeared to be the skill with the most decay (15%) whereas the other skills were maintained or even improved. Proportions of successful nurses at baseline (T0), at the end of training (T1) and after 10 months (T2) are reported for the combined assessment score and for each individual skill (Table 1).

DISCUSSION

Numerous studies mention poor retention of CPR skills after training.[1,4,5] Moreover, delivery of CPR below standard has been reported. [19-23] According to Mäkinen and colleagues various methods to assess CPR skills are currently used, often with methodological shortcomings.[24,25] Furthermore, instructors' judgement alone is not sufficient to determine competence.[26] The use of technology enables accurate automated assessment and feedback.[13] Wass and colleagues reported that clinical competence should be assessed against a predefined pass level.[27] A combined assessment score allows more comprehensive reporting of overall CPR quality than reporting each skill separately. However, the relative importance of each individual skill and the exact relationship between skill level after training and real-life CPR performance are currently unknown.

Eight months after a refresher course in a Resusci Anne Skills Station™ (Laerdal, Norway), CPR skills were evaluated with an automated test using the combined assessment score. The proportion of emergency nurses achieving a pass level was low, although the scores on the individual skills were acceptable. Our data show the feasibility to identify nurses needing retraining by means of an automated test. Furthermore, additional practice and/or testing with feedback allowed most nurses to improve their skill level to the predefined level (Table 1 and Fig. 4). The mean time to become competent was 13 minutes, which can be explained by the fact that almost half of the nurses only performed repetitive tests followed by automated feedback/feedforward. Kromann and colleagues reported that testing on its own has a learning effect.[28,29] Furthermore, feedback and feedforward are also powerful tools for improvement.[5,22,30,31] This could explain the improvement of skills in nurses who did not practice with the Skills Station™ computer exercises. We hypothesize that the decay in complete release might be explained by improved compression depth causing more incomplete chest recoil. Despite the fact that some nurses failed the combined assessment score after 10 months, the proportion of successful nurses improved compared to the baseline test. Achieving or maintaining high quality resuscitation skills and competence in every participant is possible but remains a major individual and institutional challenge. In a review on competency assessment Allen and colleagues suggested testing once or twice a year.[32] It is currently unknown whether this should be achieved by a fixed or a flexible interval based on individual progress and skill level.

LIMITATIONS

No details regarding the efficacy of the CPR training prior to the study were available. During the study, some nurses could not be motivated to train until proficiency. Furthermore, the nurses were not familiar with automated assessment which may have negatively influenced the baseline results.

IMPLICATIONS FOR EMERGENCY NURSES

The combination of automated testing and automated training is a technically feasible strategy to effectively improve the CPR competency of emergency nurses. It's success, however, depends highly on the motivation of each individual nurse.

CONCLUSIONS

Automated testing with feedback was effective in detecting nurses needing CPR retraining. Additional practice and/or retesting improved skills to a predefined pass level. Since not all nurses trained until competency, achieving CPR competence remains a significant individual and institutional challenge. Ten months after baseline the combined score showed important decay, highlighting the need for frequent assessments.

ACKNOWLEDGEMENTS

We are grateful to the management of Groeninge General Hospital (Kortrijk, Belgium) and to all the emergency nurses who participated in the study. We are especially grateful to Bram Gadeyne for the software development.

FUNDING

Laerdal Medical (Stavanger, Norway) provided the manikin and the Resusci Anne Skills Station™ licenses for the study. Laerdal has taken no part in neither designing the study, developing the software, analysing data nor writing of the manuscript.

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LEGEND TO THE FIGURES AND TABLES

Figure 1: Study design

Figure 2: Evolution of PASS/FAIL ratio at baseline (T0), at the end of the training (T1) and after 10 months (T2)

Figure 3: Mean compression rate at baseline (T0), at the end of the training (T1) and after 10 months (T2)

Figure 4: Cumulative proportion of participants achieving a minimal percentage of compressions with depth ≥5 cm (a), with complete release <5 mm (b), ventilations with volume 400-1000 ml (c), a threshold for a combined assessment score (d)

Table 1: Proportions of success at baseline (n=43), at the end of the training (n=43) and after 10 months (n=39).

Figure 1 *Study design*

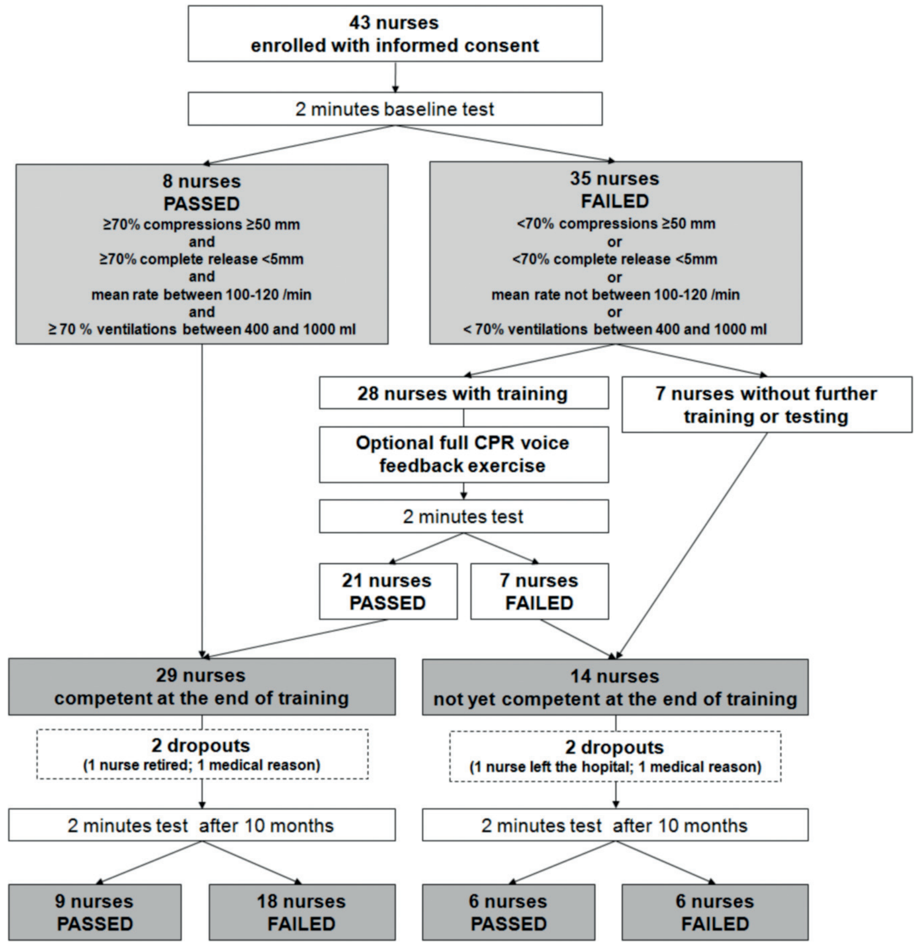

Figure 2 *Evolution of PASS/FAIL ratio at baseline (T0), at the end of the training (T1) and after 10 months (T2)*

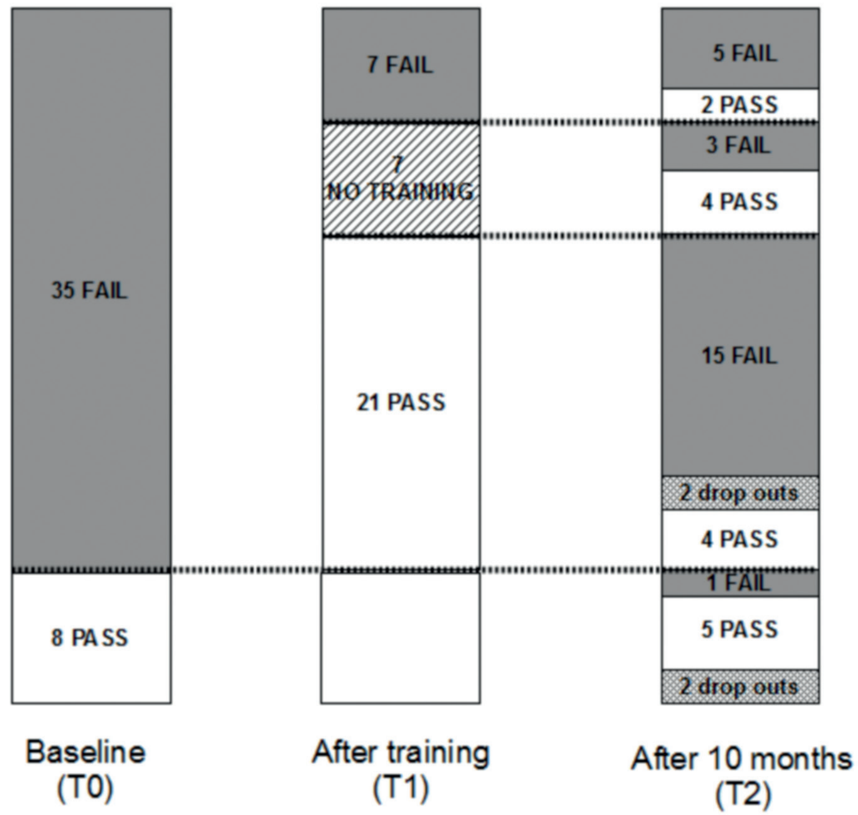

Figure 3 *Mean compression rate at baseline (T0), at the end of the training (T1) and after 10 months (T2)*

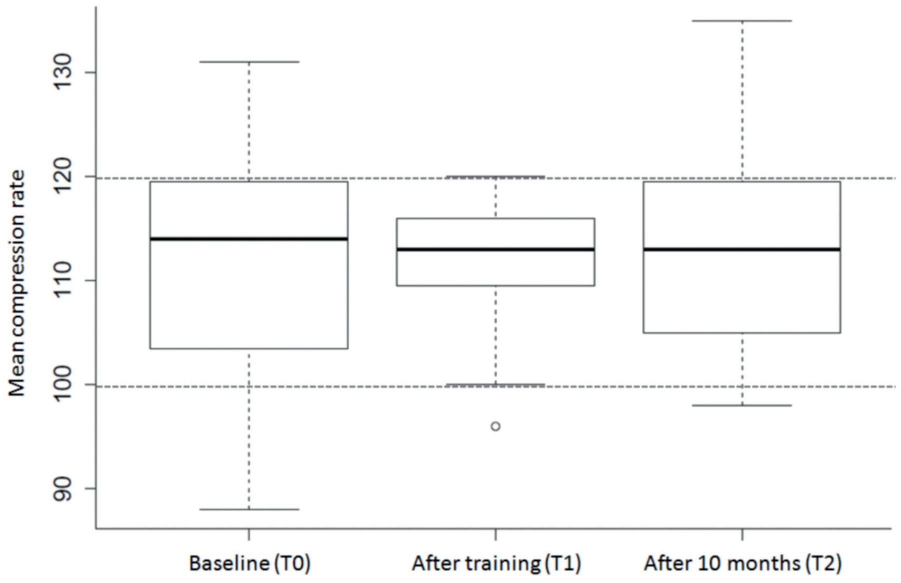

Figure 4 *Cumulative proportion of participants achieving a minimal percentage of compressions with depth ≥5 cm (a), with complete release <5 mm (b), ventilations with volume 400-1000 ml (c), a threshold for a combined assessment score (d)*

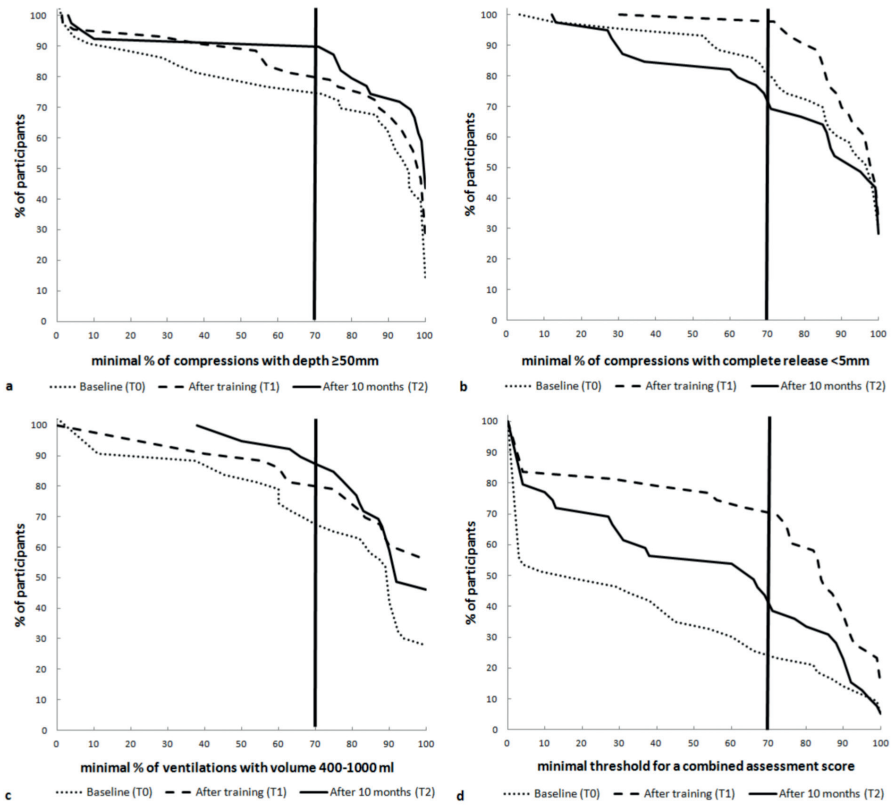

Table 1 *Proportions of success at baseline (n=43), at the end of the training (n=43) and after 10 months (n=39)*

	Baseline (T0)	End of training (T1)		After 10 months (T2)	
	Number of participants n/N (%)	Number of participants n/N (%)	Difference in proportion (T0-T1) % [95% CI]	Number of participants n/N (%)	Difference in proportion (T1-T2) % [95% CI]
70% combined score [a]	8/43 (19)	29/43 (67)	48% [0.33 - 0.63]	15/39 (39)	28% [0.14 - 0.42]
≤70% compressions ≤50 mm	30/43 (70)	31/43 (72)	2% [-0.02 - 0.06]	34/39 (87)	15% [0.04 - 0.26]
≤70% compressions with complete release <5 mm	34/43 (79)	36/43 (84)	5% [-0.02 - 0.12]	27/39 (69)	15% [0.04 - 0.26]
Compression rate 100-120/min	27/43 (63)	35/43 (81)	18% [0.07 - 0.30]	31/39 (80)	1% [-0.02 - 0.04]
≤70% ventilations between 400-1000 ml	29/43 (67)	32/43 (74)	7% [-0.01 - 0.15]	35/39 (90)	16% [0.05 - 0.28]

Chapter 8

General discussion

Introduction

The aim of this PhD thesis was to develop a novel educational approach: Automated Learning with an Interactive Virtual Environment (ALIVE). The main research goal was to study if such an automated learning strategy incorporating more hands-on practice, instructional simplicity, multi-media presentations and individualised debriefing/feedback is effective to acquire and maintain high quality CPR skills.

In order to answer this question, seven research objectives were formulated in the introduction. In this final chapter, the results of the previously presented studies are summarised and discussed along these seven research objectives. Moreover, limitations of the presented studies are discussed and approached as directions for future research. Implications for further research, teaching practice and educational policy are outlined.

8.2 Research objectives

8.2.1 RESEARCH OBJECTIVE 1

ANALYSIS OF NON-INFERIORITY OF COMPUTERISED SELF-LEARNING USING A COMBINATION OF VIDEO INSTRUCTION FOLLOWED BY VOICE FEEDBACK COMPARED TO INSTRUCTOR-LED TRAINING

In Chapter 1 we developed a novel approach to acquire CPR skills in a self-learning station by combining a practice-while-watching technique with exercises using concurrent individualised voice feedback. The concept of this method is the demonstration of new skills by a virtual instructor (video) while the student practices individually. This first practice is followed by refinement of skills using computer exercises with concurrent voice feedback and textual feedback after every exercise, while performance is constantly registered.

In the initial development of the learning strategy we hypothesized that training in a computerised self-learning station might result in at least equal CPR skill mastery as compared to instructor-led training. A previous trial from our research group investigating efficacy of retraining CPR skills with a self-learning station (RA Skills Station with voice feedback exercises) compared to instructor-led training was not able to demonstrate superiority (79). The choice of a superiority design is however not fit to demonstrate equality. Given the available evidence underpinning the efficacy of instructor-led small group training, we adopted a non-inferiority research design (79-81).

The results (adjusted for gender, height, weight and previous CPR training) demonstrated non-inferiority for the proportion of students reaching a compression depth between 40 and 50 mm. For the other skills, formally, the test results for the adjusted odds ratio were inconclusive but came very close to demonstrate non-inferiority. When unadjusted all other odds ratios, except for incomplete release, demonstrated non-inferiority.

LIMITATIONS

- The sample size was based on the number of available students and a post hoc power analysis resulted in a power of 0.31 for compression depth 40-50 mm, 0.32 for compression depth ≥40 mm, 0.34 for rate 80-120/min, 0.29 for any incomplete release (≥5 mm) and 0.36 for ventilation volume 400-1000 ml. We therefore cannot rule out a type II error as the reason for some of the adjusted odds ratios being statistically inconclusive. In a superiority trial the null hypothesis is that treatments are equally effective and the alternative hypothesis is that they differ. A type I error is falsely finding a treatment effect when there is none, and a type II error is failing to detect a treatment effect when one truly exists. In non-inferiority trials, the null and alternative hypotheses are reversed; a type I error is the erroneous acceptance of an inferior new treatment, whereas a type II error is the erroneous rejection of a truly non-inferior treatment.
- The outcome parameters used in the trial were based on the proportion of students achieving an adequate “mean” skill level. However, to assess the quality of CPR performance, reporting proportions of successful students against a predefined bench provides more information than reporting improvements of (group) mean values.
- To assess the effect of the training intervention in the self-learning group, data with concurrent voice feedback were used instead of a formal pre- and post-test after training. This is in part explained by the fact that the technical development of the self-learning station did not include an automated testing component at that time. Pre-training testing (to control for potential CPR mastery differences before the intervention) and testing at the end of training (to assess the effect of the intervention) should be encouraged to increase the research quality.
- Due to the rigid academic calendar, retention of skills could only be assessed after seven weeks and therefore conclusions on longer-term retention could not be drawn.

8.2.2 RESEARCH OBJECTIVE 2a

ANALYSIS OF THE LEARNING EFFICACY OF VIDEO TRAINING AND THE ADDITIONAL IMPACT OF SUBSEQUENT VOICE FEEDBACK EXERCISES ON THE ACQUISITION OF CPR SKILLS IN A SELF-LEARNING STATION

In Chapter 2 we focused on the individual teaching components of the combined self-learning strategy as discussed in Chapter 1: video learning-while-watching and computer exercises with concurrent voice feedback.

To analyse the learning efficacy of the video, the results of the 1 minute pre-test (T0) were compared with the results from the first minute of the test after the video (T1). For the additional impact of the voice feedback, the results from the first minute of the test after the video exercise (T1) were compared with the results from the first minute of the test after the voice feedback exercises (T2). As discussed previously, reporting proportions of successful students against a predefined bench provides more information than reporting improvements of (group) mean values to assess the quality of CPR performance. We therefore analysed and reported the proportion of successful participants for each important CPR component against a predefined pass level. However, to allow comparison with other studies, mean values were also reported in the manuscript.

Despite the fact that several studies and the International Liaison Committee for Resuscitation (ILCOR) encourage short video self-instruction courses, the impact of video learning-while-watching on skills acquisition was not significant, except for good compression rate and good mean ventilation volume 400-1000 ml. The improvement in compression rate during the practice-while-watching video training can be explained by the continuous presence of a metronome sound. Jäntti et al. (82) reported that metronome guidance used during manikin CPR corrected chest compression rate in experienced rescuers, but did not affect chest compression depth or rescuer fatigue. Chung et al. (83) observed that the average compression depth was significantly lower in metronome-guided CPR with the rate set at 100/min. In our study metronome-guided practice-while-watching was associated with insufficient compression depth. This could mean that watching someone performing compressions on a video does not provide sufficient information regarding the required depth and release. Learning-while-watching might be useful for the introduction of new skills, but they should be refined with additional training, for instance with computer exercises using concurrent voice feedback. Providing feedback on the actual training level is important for psychomotor skill acquisition (61, 84). This might explain why concurrent voice feedback during the computer exercises was able to improve the participant's performance significantly.

Chapter 2 also explored the possibility of introducing a combined assessment score, which would probably better reflect the degree of CPR skills mastery. An overall success rate of almost 60% of the students achieving at least 70% success for good compression depth and release as well as a rate between 100 and 120/min was observed. It has to be emphasized that these results were obtained within a very brief time span (1 hour training in a self-learning station) and that students were not trained to a predefined level. We currently cannot compare this result with data from other studies because reporting a combined assessment score based on proportions of adequate skills is new. Clearly a single short training in a self-learning station is not sufficient for all learners, and future research should determine how to train students to a predefined level and provide further training to the remaining unsuccessful students.

LIMITATIONS

- We conducted a prospective observational study without a control group and the overall young age in our population of pharmacy students limits the generalizability of the results. With regard to the limitation discussed in Chapter 1, pre-training testing (to control for potential CPR mastery differences before the intervention) was introduced. Since we expected that most lay students would not know how to perform CPR, a methodological choice of a 1 minute pre-test was made. To allow comparison with the 3 minutes test after the video (T1) and voice feedback exercises (T2), only the first minute of T1 and T2 was analysed. Future research, however, should be performed with tests of equal duration (e.g. 2 minutes). In addition, introducing a pre-test in participants who are entirely new to the skills resulted in a large amount of participants skipping the test. Differences in training time using the voice feedback exercises were not measured. Although these differences are inherent to this new self-learning method, they might introduce a bias since the duration of the training session is also a major determinant of CPR quality. To counter this, a study design should guarantee equal hands-on time in all participants, which is particularly difficult and in contrast with the philosophy of a self-learning strategy.
- As discussed previously in Chapter 1, reporting proportions of successful students against a predefined bench provides more information than reporting improvements of (group) mean values when assessing the quality of CPR performance. We therefore reported the proportion of adequate skills against a predefined 70% level but also reported the proportion of students achieving an adequate "mean" skill level to allow comparison with other studies.
- As compression depth, release and rate are the quality indicators most likely to influence the outcome of resuscitation, ventilation skills were not included in the combined score. However, when training professional rescuers, ventilation skills mastery should be included in the assessment.

8.2.2 RESEARCH OBJECTIVE 2b

ANALYSIS OF THE PREDICTIVE VALUE FOR SUCCESS OF POTENTIAL COVARIABLES SUCH AS GENDER, HEIGHT AND WEIGHT IN RELATION TO THE RESUSCITATION OUTCOME PARAMETERS

With regard to gender, previous manikin studies demonstrated that female rescuers achieved fewer compressions with adequate depth (85-87). In Chapter 1 we adjusted our results for potential covariables such as gender, height and weight. In Chapter 2 we analysed if these covariables had a predicted value for success. Significant interactions with CPR quality indicators could be observed for gender, height and weight. Being taller or weighing more was in favour of deeper compression depth at the pre-test and related to gender (men being on average 13 cm taller and 13 kg heavier than women). No additional interactions with the other variables (compression release, compression rate and ventilation volume) were observed for height and weight. In relation to gender no significant interactions were found with respect to compression rate and mean ventilation volume 400-1000 ml. For compression depth, female students performed worse than male students at the pre-test and after the video exercise. In both genders, the proportion of students with adequate mean depth did not improve significantly after the video training. However, this proportion increased significantly after the voice feedback exercises in both male and female students, and resulted in no significant differences between male (89%) and female students (88%) after the computer exercises. The same was observed for ≥70% compressions ≥50 mm.

Our results showed that after voice feedback exercises female rescuers can 'catch up' with male rescuers regarding compression depth. These findings could be attributed to the fact that women have relatively less muscle strength, resulting in more shallow compressions and more complete release at the start compared with men (88, 89). After the voice feedback exercises, women achieved deeper compressions and men achieved more complete release. Therefore, voice feedback exercises appear to be a good strategy to further train and improve both male and female students that lack adequate skills mastery at the start and after video training. In view of community CPR training programs this finding is important with regard to the choice of the training method.

LIMITATIONS

- The overall young age in our population of pharmacy students together with the small sample size limits the generalizability of the results.

8.2.3 RESEARCH OBJECTIVE 3

ANALYSIS OF THE IMPACT OF VIDEO, VOICE FEEDBACK OR BOTH ON RETRAINING OF CPR SKILLS IN A SELF-LEARNING STATION

In Chapter 3 we compared the effectiveness of three new self-learning modalities for refreshing CPR skills in third year medical students: practice-while-watching video (Mini Anne, Laerdal, Norway), automated voice feedback/prompt system and a combination of both. The video was edited to show an instructor demonstrating three cycles of CPR followed by the same sequence of practice-while-watching. The automated voice feedback/prompt system used a computer-guided manikin with automated verbal instructions and feedback to guide trainees to provide high quality CPR with appropriate chest compression depth, rate, with complete release and appropriate ventilation volume. Trainees received real-time corrective feedback when their performance failed to meet preset criteria for high quality CPR.

Our results showed that the video method did not improve any CPR performance except the compression rate. This emphasises the importance of validating new videos rather than assuming that they will be effective in any training environment or learners (90). By contrast, both voice feedback training and combined video and voice feedback training produced similar levels of improvement in performance of chest compression depth, rate, and ventilation volume except complete release. Comparing these three self-learning modalities, the difference of skill retraining (refresher effect) was due to the presence of voice feedback training. An additional video did not add value (no difference between voice feedback group versus combined group).

We need to look into the key differences between the two multi-media modalities (video and computer exercises with voice feedback) compared in this study more closely. The video group received visual and tactile sensory input without any feedback to their student's performance. The voice feedback group had auditory and tactile sensory input as well as real-time feedback. Was the voice feedback group more effective because the auditory input was more potent than visual input? Or was it the feedback that made the significant difference? Recent educational literature supports that deliberate practice with frequent feedback is important for psychomotor skill acquisition (84). Many other simulation-based education literature also emphasizes that providing feedback on a trainees' skill level has a powerful impact on acquisition and retention of skills and that debriefing is the key phase where most of the learning takes place (61, 62, 76). However, a different study design would be needed to tease out which feedback component made a substantial difference in training effect.

LIMITATIONS

- The results may have been influenced by the pre-test and priming video which may have induced a learning effect. In addition to this the trainees were third year medical students who had received at least two previous CPR training sessions in their first and second year. They had, however, limited clinical experience. Finally, the duration of the training session, a major determinant of CPR quality, may have subjected the students to fatigue leading to suboptimal CPR quality although the duration of CPR was not extensive (6 cycles).
- To avoid bias due to different training duration, care was taken to control equal training time in the three study groups. To ensure that the participants followed the exercise sequences allocated to them, we involved a non-obstructive observer. This is in contrast with the philosophy of a self-learning station, allowing flexible and individualised training and can be considered as a study limitation. Some data were lost because of technical problems. Also, the study was not blinded because the students experienced what condition they were allocated to. However, the students were not aware of the potential differential impact of alternative training conditions. We therefore believe this had no impact on their motivation and involvement.
- The success rates for a combined assessment score reported in Chapter 3 may not seem very high. It has to be stressed, however, that the primary objective of the trial was to investigate the impact of each training component and not to train all students against a predefined PASS level. Clearly a single short training session is insufficient to achieve a high combined PASS score in all students. Further research is needed to investigate how a predefined combined PASS level can be achieved by every student.

8.2.4 RESEARCH OBJECTIVE 4

ANALYSIS OF THE IMPACT OF OVERTRAINING ON THE RETENTION OF COMPRESSION DEPTH

In Chapter 4 we investigated the impact of overtraining compression depth on CPR skill retention six months after initial training. The rationale was in part motivated by the observation that the majority of chest compressions delivered by rescuers following the 2005 guidelines were too shallow. The computerised self-learning station provided an opportunity to train participants to a specific target depth. Medical student participants (n= 180) were randomised to training with CPR feedback targeting compressions of 40-50 mm versus >50 mm. At follow-up assessment the proportion of students achieving a depth <40 mm was 29% in the standard group versus 14% in the deep compression group ($P = 0.01$). Compressions above 50 mm were achieved by 6% in the standard group compared to 49% in the deep group ($P < 0.001$).

In this chapter, using different limits for concurrent voice feedback, we were able to train two groups of students to a predefined 40-50 mm or >50 mm compression depth range respectively, without any overlap. This underscores the high precision and impact of the voice feedback prompts on psychomotor skills development.

LIMITATIONS

- A limitation is that the results were obtained within a training context based on a self-learning station combining a Mini Anne™ video followed by voice feedback, as described in Chapter 1. The results are therefore not generalizable to other teaching strategies. The contribution of each training component (interactive Flash™ embedding the Mini Anne™ video, RA Skills Station™, feedback) was not assessed separately. Future research is needed to investigate the effect of recurrent training and testing on the consolidation and retention of CPR skills.

8.2.5 RESEARCH OBJECTIVE 5

ANALYSIS OF THE FEASIBILITY AND EFFICACY OF ASSESSING BASIC LIFE SUPPORT SKILLS WITHOUT AN INSTRUCTOR

Current methods to assess CPR skills (chest compressions and ventilations) require the presence of an instructor. This is time-consuming and comports instructor bias. Since CPR skills testing is a routine activity, it is potentially suitable for automation. In Chapter 5 we developed a fully automated CPR testing station without instructor by using innovative software linked to a training manikin. The main objective was to investigate the feasibility of adequate testing (effectiveness) within the shortest period of time (efficiency).

As part of a randomised controlled trial investigating different compression depth training strategies (Chapter 3), 184 medicine students received an individual appointment for a retention test six months after training. An interactive Flash™ (Adobe Systems Inc., USA) user interface was developed, to guide the students through the testing procedure after login, while Skills Station™ software (Laerdal, Norway) automatically recorded compressions and ventilations and their duration (“time on task”).

The average time on task for all 181 students was three minutes (SD 0.5). In a subgroup of 29 students the room entrance and exit time was registered to assess efficiency. The average overall time spent in the testing station was 7.5 minutes (SD 1.4). To obtain a qualitative insight of the effectiveness, student's perceptions about the instructional organisation and about the usability of the fully automated testing station were surveyed. Mean scores were 5.3/6 (SD 0.5, range 4.0-6.0) for instructional organisation and 5.0/6 (SD 0.61, range 3.1-6.0) for usability. Students highly appreciated the automated testing procedure.

The development of automated testing showed to be an effective and efficient method to assess CPR skills and the method enabled formative assessment and certification procedures to be carried out without instructor involvement.

LIMITATIONS

- When discussing the quality of this specific assessment setting, two aspects have to be distinguished. The first aspect is the quality of the assessment process. The second aspect is the quality of the measurement of the performance indicators, which is guaranteed by the intrinsic quality of the manikin sensors and by the use of existing registration software. Maintenance protocols and timely replacement of sensors, valves and springs are imperative to guarantee measurement reliability and validity.
- In the context of the present study, the students were familiar with training in a self-learning station and which may have improved the usability of the testing station. However, the automated testing situation and the specific Flash™ module were completely new to the students.
- The software prototype we used only focused on testing the technical CPR components. Future developments could embed interactive components allowing the trainee to dial a phone number or assessing cardiac arrest by performing the right actions on-screen.

8.2.6 RESEARCH OBJECTIVE 6

ANALYSIS OF THE IMPACT OF SHORT SELF-LEARNING SESSIONS FOLLOWED BY AUTOMATED ASSESSMENT WITH DEBRIEFING ON CPR SKILLS ACQUISITION AND RETENTION

The research objectives discussed in the previous chapters established which training strategy should be used to train and retrain CPR skills in a self-learning station. As discussed in Chapters 2 and 3 a single training session is clearly not enough to train every participant to a predefined level. Automated assessment offers the possibility to detect participants requiring additional training. Moreover, it allows the introduction of instant feedback and feedforward on the test result. The rationale is motivated by the simulation-based education literature emphasising that debriefing, including feedback and feedforward, is the key phase where most of the learning takes place (56, 61, 76-78). Our automated learning strategy already comported hands-on practice, instruction simplicity and the use of multi-media. Implementation of the debriefing concept (feedback and feedforward) after automated assessment was the final step in the integration of the four components into our automated educational strategy. In Chapter 6 we analysed if short self-learning sessions followed by automated assessment (against a predefined level and with debriefing) led to a high level CPR acquisition in lay people.

Four hundred and four students in pharmacy and educational sciences participated. Initial training (max. 40 minutes) consisted of a 15 minutes learning-while-watching video followed by computer exercises with voice feedback. At baseline and after training, performance was measured using an automated test. To be judged competent participants had to achieve ≥70% compressions with depth ≥50 mm and ≥70% compressions with complete release (<5 mm) and a compression rate between 100-120/min within a two months period. Automated feedback was provided and failed participants had to retrain within two weeks. Retraining (max. 20 minutes and max. three times) was done with voice feedback exercises. Before retraining, the previous test result was displayed together with feedforward. After five months all participants were invited for a retention test.

By introducing automated assessment followed by feedback and feedforward at the end of each training session we were able to train 99% of the participants to our predefined pass level for compression skills. Since every participant learns in a different way, not immediately succeeding after a first assessment may just indicate that some of them needed more time and practice to achieve the required skill level. After the first training session 71% of the participants achieved the predefined 70% combined score for compression skills and after an additional 20 minutes training this improved to 93%, demonstrating the feasibility and efficiency of our automated training strategy. Almost all participants (99%) achieved the predefined 70% combined score for compression skills and some even achieved higher levels (80, 90, 100%).

Five months after training 52% of the participants was unable to achieve the 70% combined score for compression skills, indicating the importance of regular assessment and retraining in almost half of the participants. Inadequate compression rate in 40% accounted as the main reason to explain this decay. A 70% pass level for compression depth and complete release was, however, maintained in 80% and 97% of the participants respectively. Good retention of compression depth and complete release were also observed in the participants achieving higher pass levels. This is an important finding since it has recently been confirmed that compression depth and release are the skills most influencing survival, although the optimal depth and required compression quality is still unknown (11).

From an educational perspective it might be a feasible strategy to train participants gradually to higher pass levels using additional multiple short training sessions, which is in line with the principles of Mastery Learning (61). However, the relative importance of each individual skill and the exact relationship between skills level after training and real-life CPR performance are currently unknown. Regarding the poor retention of compression rate, we hypothesise that it may be very difficult to some people to remember the rate of 100-120/min during CPR, resulting in lower or higher compression rates.

LIMITATIONS

- Our population consisted of young motivated lay students, which might not represent the general population. Although all lay participants were trained in ventilations skills with the learning-while-watching video and voice feedback exercises, they were only assessed and given feedback on their compression skills. This choice is partly supported by the ILCOR and ERC 2010 guidelines and by the trial of Stiell and colleagues establishing a strong association between compression depth and survival (11, 39, 91).
- After the test, the absence of debriefing (feedback/feedforward) on ventilation skills performance was reflected in the absence of improvement in ventilation mastery after multiple training sessions. However, despite the absence of feedback, ventilation performance was adequate in 79% of the participants at the end of training, but a considerable decay was observed after five months. When training professional rescuers, feedback on ventilation skills should be given together with feedback on compression skills, using a combined score including all CPR skills.

8.2.7 RESEARCH OBJECTIVE 7

ANALYSIS OF THE FEASIBILITY TO RAPIDLY RETRAIN CPR SKILLS TO A PREDEFINED LEVEL USING AUTOMATED TESTING WITH FEEDBACK AND OPTIONAL TRAINING IN A MOBILE SELF-LEARNING STATION

As Chapter 6 discussed the acquisition of CPR skills in lay people, Chapter 7 analysed if short individualised self-learning sessions followed by automated assessment (against a predefined bench and with feedback) are effective to retrain CPR skills in professional rescuers. Professional rescuers such as emergency nurses are often involved in the management of cardiac arrest. Lack of cardiopulmonary resuscitation (CPR) skills especially in professional rescuers, contributing to poor outcome of cardiac arrest victims, is a major concern (40, 56, 92-94).

Forty-four emergency nurses (55% females, mean age 37 years, SD 11) participated. They had been trained eight months earlier using the commercially available RA Skills Station™ (Laerdal, Norway). A novel automated two minutes test measured CPR performance and provided instant feedback. Nurses were considered competent if they achieved a 70% combined score consisting of ≥70% compressions with depth ≥50 mm and ≥70% compressions with complete release (<5 mm) and a mean compression rate between 100-120/min and ≥70% bag-valve-mask ventilations between 400-1000 ml. Not competent nurses received additional feedforward on how to improve. During a two months period they could train with voice feedback exercises (RA Skills Station™, Laerdal, Norway) or immediately perform a new test. At baseline, 8/44 (18%) tested competent. From the 36 not competent nurses, 7 (19%) did not attempt training. From the remaining 29 nurses, 21 (72%) achieved proficiency, of which 11 (52%) skipped the voice feedback exercises and only performed repetitive tests. Total mean practice time was 13 minutes (SD 15).

The majority of not competent nurses were retrained to a predefined 70% level within a mean time of 13 minutes, which is shorter than most refresher courses actually available. However, not all nurses attempted training or trained until proficiency, indicating that achieving proficiency remains a major individual and institutional challenge.

LIMITATIONS

- No details regarding success after the previous training in the Laerdal Skills Station were available. Furthermore, the lack of familiarity of the nurses with the automated assessment procedure may have contributed to the poor baseline result.
- Since training was not mandatory, some participants did not train until proficiency, which limits the generalizability of our results.

8.3 Limitations

8.3.1 LIMITATIONS RELATED TO THE SCOPE OF OUR STUDIES

Since international guidelines emphasize the simplification of CPR instruction in order to focus on competence in the small set of skills most strongly associated with the victim's survival, our automated learning strategy focused on mastery of core technical CPR skills. This limits the generalizability of the method with regard to acquisition or maintenance of procedural skills such as assessing the victims' consciousness or calling an ambulance. Since various types of e-learning applications are already available to instruct these procedural skills this was, however, not within the scope of the present dissertation. A future development might consist in integrating such applications into the ALIVE strategy.

In Chapter 6 the study design included assessment of retention after five months. This builds on the rationale that most CPR skills decay within three to six months. It might however be interesting to study retention of participants on the longer term. Due to the rigid academic calendar or individual constraints such as motivation it was already difficult to schedule a single retention assessment. The possibility for future competence management through a bi-annual certificate-oriented assessment might help countering this problem.

This dissertation did not examine potential motivational variables or self-efficacy that might have an impact on the learning efficacy.

8.3.2 LIMITATIONS RELATED TO THE STUDY SAMPLE

Conducting research with students comports a limitation with regard to the rather small sample sizes. Enrolling larger student populations is a challenging task, which was in part achieved in Chapter 6. Chapter 1, 2 and 6 involved lay students and Chapter 3 and 4 involved third year medicine students whereas Chapter 7 was conducted with emergency nurses. With the exception for Chapter 7, all other trials used a young and motivated population consisting of university students, limiting the generalizability of the results.
The different trials did not take into account individual differences between participants such as fatigue, physical fitness, time of training. With regard to the increased hands-on time required from the participants, inter-individual differences may have played a role in the way skills were acquired.

8.3.3 MANIKIN STUDIES

To establish the efficacy of an educational strategy we need to conduct proper research. Unlike introducing a new drug, there are no requirements for educational strategies to undergo trials in humans before being adopted. What, then, should be the minimum evidence to label an educational strategy as effective and fit for purpose? Many researchers have addressed this question by finding an alternative solution: manikin studies. There is certainly an important place for manikin studies in education in resuscitation. Common arguments supporting these studies are: manikins provide an unchanging environment from one participant to another and the set-up remains constant between attempts, allowing the generation of more reliable comparative data. However, many of the above arguments are also the very reasons that make these studies unsuitable for extrapolation to human populations, which are diverse, relatively unpredictable and clinically challenging.

8.3.4 METHODOLOGICAL LIMITATIONS

In this dissertation, two major groups of proportional outcome variables were addressed. In Chapters 1 and 4 we initially focused on the proportion of students achieving adequate means (depth, release, ventilation volume). However, to assess the quality of CPR performance, reporting proportions of successful students provides more information than reporting improvements of (group) mean values. Furthermore, to report clinical competence the proportion of successful participants should be assessed against a predefined pass level (95). According to a systematic review on the methodology of CPR skills assessment by Mäkinen and colleagues, most current studies use varying methods of assessment, have methodological shortcomings and evaluate their teaching strategy poorly (91). In a first attempt to use a more rigorous research methodology we started reporting the proportion of successful participants against a predefined 70% pass level for each CPR skill individually, and we explored the feasibility to introduce a combined pass level (Chapters 2 and 3). The use of a combined assessment score (Chapters 6 and 7), requiring the achievement of a 70% predefined level is innovative. To participants, achieving such a combined pass level is more demanding than achieving a pass level for each individual skill, but we believe that it better reflects overall CPR quality than evaluating and reporting each skill separately (96). For compression quality it is also possible to assess each individual compression. A compression is then assessed as adequate when correct compression depth, correct compression frequency and complete release are achieved. This kind of assessment strategy was, however, not investigated.

Another limitation inherent to our new self-learning method is the difference in duration of the training session between participants. This limits the interpretation of the results as discussed in Chapters 1 and 2. To counter this, the study design used in Chapter 3 guaranteed equal hands-on time in all participants. This is, however, in contrast with the philosophy of training flexibility of a self-learning strategy. In order to measure skill decay after participants had been trained using different hands-on times, another solution to the problem was elaborated in Chapter 6. The outcome measure was to train all participants to a minimal predefined bench using a combined assessment score. By doing so, retention of skills could be evaluated by assessing the proportion of successful participants against the same predefined bench.

8.4 Implications and future perspectives

8.4.1 IMPLICATIONS FOR EMPIRICAL RESEARCH

Building on the main research findings, the following implications for empirical research can be formulated. First the efficacy of the integrated ALIVE strategy (Chapters 5 and 6) should be investigated in a larger and more heterogeneous population. By doing so it would be interesting to see if a randomised controlled trial comparing traditional instructor-led training with this new automated learning strategy might be able to confirm non-inferiority or even demonstrate superiority. Second, with rigorous study methodology and the standardized performance measures, we will continue our journey to search for the 'best' CPR skill training methodology.

The current ALIVE strategy focused on individual learning. Given the proven benefits of peer-learning it might be worthwhile to investigate the efficacy of a blended learning programme incorporating automated learning and peer facilitation.

Our novel automated learning strategy might not only be useful to acquire and maintain resuscitation skills, but might also apply to a lot of other technical and non-technical skills. Non-technical skills could for instance be acquired and maintained by incorporating e-learning facilities in the ALIVE software. It would be worthwhile to investigate and further develop these possibilities, which may be of benefit to the whole community.

8.4.2 IMPLICATIONS FOR TEACHING PRACTICE

In this dissertation we demonstrated the feasibility and the high success rate of automated learning as a way to acquire good CPR skills. However, we believe that skill decay will always be present, no matter how efficient the learning strategy, and that the use of regular assessments is required to ensure the maintenance of competency. Our automated assessment procedure has been proven very effective and efficient and could be used for those assessments. Since no specific CPR related research is available to propose a benchmark, we build on general principles as derived from Mastery Learning research indicating that a high attainment level has to be pursued before moving to the next learning goal and that formative assessment should be adopted to give immediate feedback to foster the high attainment level of the goals being pursued. From this educational perspective it might also be a feasible strategy to further train participants gradually to higher pass levels using additional multiple short training sessions. Hattie reports that such Mastery Learning approaches result in high effect sizes when considering the impact on learning performance (effect size = .58) (61). As such, the ALIVE learning strategy provides the basis for a life-long CPR learning path.

The presence of automated feedback and feedforward (= debriefing) after the assessment might be sufficient to improve a participant's skill level with every test. It is, however, currently unknown if a strategy of repetitive testing with debriefing is as effective as standard retraining with computer exercises using concurrent voice feedback. This research is currently ongoing. Hypothesizing that the learning effect of repetitive testing with debriefing would be equal to a longer training with computer exercises using concurrent voice feedback, this would demonstrate that debriefing is as powerful as concurrent voice feedback. Furthermore it would offer the possibility to introduce a new feature in the ALIVE strategy: learning-while-gaming. In such a concept each assessment would be equal to gaming and by gradually increasing the bench, participants would be trained while gaming until a level of proficiency. The major difference with currently available applications is related to the real-time data registration and performance feedback. Such a strategy might be the way to reach every schoolchild and lay person and this technological development is currently ongoing.

With regard to differences in gender, our results showed that after voice feedback exercises female rescuers can 'catch up' with male rescuers regarding compression depth. Therefore, voice feedback exercises appear to be a good strategy to further train and improve both male and female students that lack adequate skills mastery at the start and after video training. In view of community CPR training programs this finding is important with regard to the choice of the training method.

8.4.3 IMPLICATIONS FOR EDUCATIONAL POLICY

It is necessary to enhance resuscitation training for all citizens, starting in schools, targeting medical students, teachers and nurses for training, to in turn become adept performers in resuscitation. Since the current learning strategies clearly lack efficacy and efficiency, the ALIVE learning strategy with its concept of training people to a predefined level offers a unique alternative. Furthermore, with skills deteriorating in as little as three to six months, the European Resuscitation Council and the American Heart Association recommend the use of frequent assessments to identify people requiring additional training (25, 57). Considerable barriers such as lack of personnel, finding time in the busy work schedules, prevent these regular assessments to take place (97).

We demonstrated that it is possible to identify individuals requiring additional training by means of an automated test, and given the rapid decay in skills we strongly encourage the implementation of CPR competency assessments once or twice a year (98).

In order to establish the cost-effectiveness of implementing a mobile ALIVE self-learning system (on the ward) at Ghent University Hospital (Ghent, Belgium), we constructed an activity based costing (ABC) model to compare the current instructor-led training program with ALIVE. In the model, 800 nurses would be tested and retrained on the ward with a mobile training system. The instructional costs taken into account for ALIVE are those related to the current research context at Ghent University Hospital and are not generelizable to a broader context. The main outcome measures were the instructional cost per nurse per year and the total difference in cost for Ghent University Hospital per year.

During a one year pilot project, a mobile ALIVE station will be used to test and retrain 800 nurses on the ward.

The costs included in the ABC model were:

- working hours lost for nurses while in training
- working hours lost for instructors while providing training
- difference in training material costs (manikin, computer program, development costs of ALIVE)

The duration of the ALIVE test was obtained from previous studies. Extrapolating these data resulted in an estimated overall success rate of 98% reached after 27 minutes, with a mean time of 13 minutes to succeed. The estimated 2% nurses unable to succeed through the ALIVE system, would need additional instructor-led training, which was included in the ALIVE cost per nurse. The current ALIVE development cost was also included in the ABC model. Instructor-led retraining resulted in a yearly cost per nurse of 74 euro compared to 13 euro for ALIVE. For the hospital, this resulted in a total saving of 48 383 euro (based on 800 nurses).

This results in a highly cost-effective assessment and retraining strategy compared to traditional instructor-led training. Furthermore, since the general costs were calculated for 800 nurses, expanding the number of trainees would further reduce the training cost. Reducing training costs offers the possibility to train a larger number of staff and on a more frequent basis.

In light of the ongoing expansion of hospital accreditation, keeping track of individual competences is a requirement. In order to achieve that, a training strategy should be easily adoptable and affordable. The ALIVE strategy offers the opportunity to create a life-long learning path by keeping track of each participant's results into a portfolio. Future software developments will provide to possibility to generate individual certificates and in addition it will also enable the possibility to perform (anonymous) benchmarking between different groups of individuals or institutions.

On the longer term we might even consider uploading individual performance data from real-life interventions into the portfolio. This would create a unique opportunity to measure the effects of an educational intervention on the clinical practice.

Chapter 9

Conclusion

To conclude this thesis, we return to the initial objective defined when setting up our research: to improve CPR learning efficacy and implementation. We developed a new learning strategy providing the base for further research. Automated Learning with an Interactive Virtual Environment (ALIVE) provides an efficient and effective alternative to the current teaching methods. By providing sufficient hands-on time, incorporating multimedia and debriefing/feedback, this educational strategy allows participants to develop and maintain a high predefined level of resuscitation skills. The key difference of ALIVE compared to the other single session training strategies is that people are trained until a predefined competence level has been achieved.

The current findings underscore the opportunity to use novel training strategies for performance improvement in resuscitation and to achieve high quality resuscitation skills in less time and with more hands-on practice compared to traditional teaching methods. It is necessary to enhance resuscitation training for all citizens, starting in schools, targeting medical students, teachers and nurses for training, to in turn become adept performers in resuscitation. In order to do that, the training should be easily adoptable and efficient without vast increase for educational personnel needs or training costs. This dissertation highlights the current and future opportunities for new CPR training and retraining for better performance and patient outcome.

We hope that other researchers will adopt our ALIVE strategy and continue to refine the models developed and tested thus far. We expect this will encourage further development and future practices and ultimately benefit all victims of cardiac arrest.

Chapter 10

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98. ***Allen JA, Currey J, Considine J.*** Annual resuscitation competency assessments: a review of the evidence. Aust Crit Care 2013;26:12-7.

Chapter 11

Curriculum Vitae

Personal information

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Qualifications and career

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1997-2005	Medical Degree, magna cum laude Ghent University, Belgium
2005-2006	Traineeship in Anaesthesiology Department of Anaesthesiology, UZ Gent
2006	Brevet Acute Geneeskunde
2006-2008	Master in Occupational Medicine, magna cum laude Ghent University, Belgium
2006-2009	Emergency physician (brevet acute geneeskunde) AZ Nikolaas, St. Niklaas, Belgium
2009-2014	Traineeship Emergency Medicine Department of Emergency Medicine, UZ Gent
2008	ERC Generic Instructor Trainer
2010	ERC Advanced Life Support Course Director
2013	Vice Chairman of the Belgian Resuscitation Council
2013	European Young Investigator of the year

Publication List

INTERNATIONAL PEER REVIEWED JOURNALS

1. ***Mpotos N***, Lemoyne S, Calle PA, Deschepper E, Valcke MA, Monsieurs KG. Combining video instruction followed by voice feedback in a self-learning station for acquisition of Basic Life Support skills: a randomised non-inferiority trial. Resuscitation 2011;82:896-901.
2. Monsieurs KG, ***Mpotos N***. CPR training and subsequent performance in real life: The missing link. Resuscitation 2011;82:503-4. (Editorial)
3. ***Mpotos N***, Lemoyne S, Wyler B, Deschepper E, Herregods L, Calle PA, Valcke MA, Monsieurs KG. Training to deeper compression depth reduces shallow compressions after six months in a manikin model. Resuscitation 2011;82:1323-7.
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6. ***Mpotos N***, De Wever B, Calle PA, Valcke MA, Peersman W, Monsieurs KG. Acquiring basic life support skills in a self-learning station: video alone is not enough. Eur J Emerg Med 2013;20:315-21.
7. ***Mpotos N***, De Wever B, Valcke MA, Monsieurs KG. Assessing Basic Life Support Skills without an Instructor: Is it possible? BMC Med Educ 2012;12:58-66.
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11. Monsieurs KG, ***Mpotos N***. Motion detection technology to measure chest compressions on a manikin: Does it work and does it improve quality? Resuscitation 2013;84:411-2. (Editorial)
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ABSTRACTS

1. ***Mpotos N***, Lemoyne S, Calle P, Monsieurs K. Acquisition of Basic Life Support skills in a fully computerised self-learning station. Oral presentation at Belgian society for disaster and emergency medicine symposium (Besedim) 2010, Brussels, January 16, 2010. Acta Clinica Belgica 2010;65:2 (abstract).
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7. De Ridder M, ***Mpotos N***. New legislation and guidance for first aid at work in Belgium. Oral presentation by M. De Ridder at the 30th international congress on occupational health (ICOH). Cancun, Mexico, March 18-23, 2012.
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12. ***Mpotos N***, De Wever B, Cleymans N, Raemaekers J, Valcke M, Monsieurs KG. Retention of Basic Life Support skills after multiple short training sessions followed by assessment and feedback in a self-learning station. Oral presentation at Resuscitation 2012, Vienna, October 18-21, 2012. Resuscitation 2012;83(S1):e22 (abstract).
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15. ***Mpotos N,*** Cleymans N, Raemaekers J, De Wever B, Loeys T, Herregods L, Valcke M, Monsieurs KG. Automated assessments with feedback for improving CPR skills: a randomised non-inferiority trial. Poster presentation at Resuscitation 2013, Krakow, Poland 26 October 2013.
16. ***Mpotos N.*** Achievement and maintenance of high quality resuscitation skills: Automated Learning with an Interactive Virtual Environment (ALIVE). Oral presentation for the Young Investigator Competition at Resuscitation 2013, Krakow, Poland 26 October 2013.

PRESENTATIONS (INVITED SPEAKER)

1. ***Mpotos N***. (2008) Aanbevelingen voor een basisprogramma voor bedrijfseerste-hulp. Seminaries voor Arbeidsgeneeskunde 5 november 2008, Ghent, Belgium.
2. ***Mpotos N***. (2011) De nieuwe reanimatierichtlijnen: tussen droom en daad. Symposium spoed en intensieve zorgen van het Nationaal Verbond van Katholieke Vlaamse Verpleegkundigen en Vroedvrouwen (NVKVV) 28 maart 2011, Ostend, Belgium.
3. ***Mpotos N***. (2011) Basisprogramma voor de opleiding hulpverlener. Symposium Federale overheidsdienst FOD WASO “het nieuwe KB EHBO” 4 april 2011, Brussels, Belgium.
4. ***Mpotos N***. (2011) Basisprogramma voor de opleiding hulpverlener. Symposium PreBes Oost-Vlaanderen “het nieuwe KB bedrijfseerstehulp (EHBO)” Ghent, Belgium.
5. ***Mpotos N***. Teaching compression depth of “at least 5 cm”. European Resuscitation Council (ERC) congress, Vienna, October 18-21, 2012.
6. ***Mpotos N***. CPR in schools: are children our future? Sympomed congress, Brussels, November 17, 2012.
7. ***Mpotos N***. Maintaining cardiopulmonary resuscitation quality in emergency nurses: an individual and institutional challenge. Katholieke Hogeschool (KATHO) symposium, Kortrijk, February 28, 2012.
8. ***Mpotos N***. Resuscitation education: where and how can we improve? Nederlandse Reanimatie Raad (NRR) congress, Nieuwegein, March 6, 2012.
9. ***Mpotos N.*** Improving CPR quality: CPR feedback / prompt devices. Symposium of the European Resuscitation Council, Krakow, Poland 25 October 2013.

AWARDS AND GRANTS

1. 2010: Laerdal Foundation educational grant.
2. 15/01/2011: ***Best abstract price***: Reducing superficial compression depth by training to a deeper depth: a randomised controlled trial. Oral presentation at Belgian society for disaster and emergency medicine symposium (Besedim) 2011, Brussels.
3. 19/11/2011: ***Best clinical paper price***: Training to deeper compression depth reduces shallow compressions after six months in a manikin model. Resuscitation 2011;82:1323-7. Annual congress of the Belgian society for Anaesthesiology and Resuscitation.
4. 26/10/2013: ***Winner of the European Young Investigator Competition:*** Achievement and Maintenance of High Quality Resuscitation Skills: Automated Learning with an Interactive Virtual Environment (ALIVE). Defended at the Symposium of the European Resuscitation Council in Krakow, Poland.

PROMOTORSHIP

1. Prehospitaal stabilisatie van de wervelzuil. De huidige technieken nader bekeken: efficiëntie vs effectiviteit. BanaBa thesis, Sam Manaerts. Artesis Hogeschool Antwerpen 2013.
2. Ontwikkelen van een geïndividualiseerd leertraject voor reanimatie in een zelfleer-station aan de hand van geautomatiseerd testen gevolgd door feedback. Master thesis Nick Cleymans en Joris Raemaekers. Universiteit Gent 2013.

REVIEWER CERTIFICATE

1. Resuscitation (editorial board member)
2. European Journal of Emergency Medicine
3. Nurse Education Today
4. Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine
5. International Journal of General Medicine

Chapter 12

Acknowledgements

Doctoreren… voor sommigen klinkt het chique en voor anderen dan weer alsof ze het in Keulen horen donderen. Persoonlijk denk ik dat het eerder een combinatie is van onvoorwaardelijke gedrevenheid met een gezonde dosis gekheid, nodig om het traject af te leggen.

Zoals vaak in een mensenleven begint alles bij ontmoetingen die een belangrijke verandering in je leven met zich meebrengen.

In eerste plaats wens ik mijn ouders te bedanken (zonder wiens ontmoeting ik er niet was geweest) om me onvoorwaardelijk alle kansen te hebben gegeven om uit te groeien tot wie ik ben. Mijn familie, broer, schoonzus die geregeld voor de nodige afwisseling zorgden. Kleine Emilie, voor jou schoof parrain met plezier zijn computer aan de kant, al trok jij die snel genoeg weer naar je toe om samen naar Piet Piraat te kijken.

Aan em. prof. dr. Linda Versichelen en prof. dr. Eric Mortier heb ik in de 2^{e} kandidatuur geneeskunde mijn eerste stappen in de wereld van de reanimatie te danken. Gedurende de volgende 7 jaren kreeg ik de kans om me verder in het lesgeven te bekwamen, mede onder de begeleiding van dr. Marc Coppens. Toen ik jaren later een begeleider zocht voor mijn ManaMa thesis rond opleiding bedrijfseerstehulp kwam ik terecht bij prof. dr. Koen Monsieurs. Het werden twee vruchtbare jaren waarbij Koen me met raad en daad bijstond. Onze inspanningen werden bekroond met een eerste nationaal artikel en publicatie van onze aanbevelingen in een Koninklijk Besluit. Daarnaast waren we beiden ook actief binnen de Europese Reanimatie Raad en kon ik dankzij hem mijn onderwijservaring op Europees niveau uitbreiden. Zo stilaan begon de onderwijskundige ervaring zich te vertalen in een wetenschappelijke belangstelling.

Toen ik in 2009 onder de vleugels van prof. dr. Walter Buylaert mijn opleiding urgentiegeneeskunde aanvatte, kregen ook de wetenschappelijke plannen stilaan hun definitieve vorm. In de jaren die volgden, kwamen de ideeën vaak sneller dan de middelen om ze te verwerken. Toen ik al even snel als Koen mijn mails beantwoordde, mijn tijd vaker met hem aan de telefoon spendeerde dan met mijn vrienden, besefte ik dat ik het virus te pakken had.

Op dat ogenblik kwam een ander belangrijke persoon mijn leven binnengewandeld en ook zij bracht belangrijke veranderingen in mijn leven. Liefste Lisa, bedankt om mijn zonnetje en intussen mijn vrouw te zijn. Het was vaak niet makkelijk voor jou, want naast de vele uren en nachten die ik in het ziekenhuis doorbracht zat ik in mijn vrije tijd dan nog eens aan de computer of telefoon op de meest onmogelijke momenten. Meestal op die momenten waar jij liever iets anders had gepland. In het begin was al dat gedoe voor jou Chinees, maar al snel merkte je hoe gepassioneerd ik was in wat ik deed. Toen

ik er dan nog eens gedurende een jaar de volledige verbouwingen van ons nestje bijnam werd de beproeving des te groter. Jouw oneindige geduld en grenzeloze liefde waren op dat moment voor mij de grootste steun.

Beste Koen, jouw enthousiasme voor het wetenschappelijk onderzoek en je drang naar perfectie is onnavolgbaar. Bedankt voor alle kansen, de goede verstandhouding en vriendschap alsook de vele gesprekken die niet altijd betrekking hadden tot het proefschrift maar zeker hun positieve invloed hadden. Beste Martin, ook jij was als copromotor van onschatbare waarde. Je deelde met passie jouw onderwijskundige en wereldervaring met ons. Een belangrijk woord van dank ben ik eveneens verschuldigd aan al mijn co-auteurs en in het bijzonder aan Sabine Lemoyne, Paul Calle en Bram De Wever.

Benedikt, Sean, Philippe, Jim en Ansy als vrienden van het eerste uur waren jullie er steeds om de goede en minder goede momenten te delen. Bene, sinds onze opleiding zijn we onafscheidelijke vrienden en ook al verhuisde je naar Brussel om er je opleiding en doctoraat te beëindigen, het contact bleef steeds. Ik kon de vele feestjes niet altijd bijwonen, maar we hielden elkaar steeds telefonisch op de hoogte.

Voor de technische, administratieve en logistieke ondersteuning tijdens de vele projecten kon ik rekenen op de hulp van Francis Dewandel, Alain Kalmar, Dominic Parewijck, Charlotte Vankeirsbilck alsook Elfi Verstraeten en haar collega's. Dank aan de masterstudenten Lien, Nick en Joris die me bijstonden en met wie ik mijn ervaring kon delen. Bram Gadeyne, toen je ons aanvankelijk enkel uit de nood kwam helpen, werd ook jij noodgedwongen gebeten door het reanimatievirus. Bedankt voor de vele uren vrije tijd die je spendeerde om de software te ontwikkelen en de vele aanpassingen te doen! Zonder dit was het niet gelukt.

Dank aan mijn diensthoofd prof. dr. Walter Buylaert alsook mijn stafleden Peter, Sabine, Patrick en Said voor de opportuniteiten. Ook mijn collega's en jaargenoten wens ik te bedanken voor de vele leuke momenten op de werkvloer. Catheline, David, Kristof, Roel, Tine, Bernard en Stefanie: het was vaak zwaar, hectisch en druk maar de teamspirit en de hechte groepsband hielden de balans in evenwicht.

Gavin and Cees: many thanks for the judicious advices and clear ideas you brought into the draft of this PhD thesis!

ILLUSTRATION COVER

“ALIVE – Our hands can save lives”

Aquarel 50-70cm, Nicolas Mpotos 2013

ISBN 9789090279602

D/2013/13.267/2

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