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

Article Type: Original Article

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 compression skills mastery in most participants.

Methods
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 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 100-120/min within a two month period. Automated feedback was provided and failed participants had to retrain within 2 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.

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.
Ghent, 2 January 2013

Dear Editor,

Please find attached our revised research manuscript "Efficiency of short individualised CPR self-learning sessions with automated assessment and feedback." by Nicolas Mpotos, Bram De Wever, Nick Cleymans, Joris Raemaekers, Martin Valcke and Koenraad G. Monsieurs.

We hope this manuscript is now suitable for publication in Resuscitation.

With best wishes,
On behalf of all co-authors,

Dr. Nicolas Mpotos, corresponding author

Ghent University Hospital
Emergency Department
De Pintelaan 185
B-9000 Ghent
Belgium
Detailed answers to the reviewers

Dear editor, prof Perkins, dr Lippert,

Thank you for reviewing our manuscript and giving such constructive feedback.

1/ Editor comments

We removed all SL abbreviations from the abstract.

We adapted the sentence in line 33 as follows: We developed an individualised self-learning cycle comporting training and automated assessment with feedback.

To illustrate the flow of the individual learning cycle we have added an additional figure to the manuscript (Fig. 1).

2/ Reviewer 1: dr. F. Lippert

1. The title is rather long. I suggest deleting the term: "a novel approach to CPR mastery". Other research groups also claim to introduce novel approaches in different settings; however, time will show whether it is novel or forgotten. I suggest that you use the title Efficiency of short individualised self-learning sessions with automated assessment, feedback and training

Thank you for this suggestion. We have now adapted our title to: “Efficiency of short individualised CPR self-learning sessions with automated assessment and feedback.”
2. The purpose of the study and the hypothesis tested in this study could be stated more clearly than it is at the moment. In the abstract it is now directly stated. It is said that "We developed and individualised self-learning cycle". In the introduction the authors state a hypothesis and finally the authors state that they "investigated the number of training sessions participants required to achieve compression skills acquisition according to a predefined pass level." I suggest that the purpose is more clearly presented especially in the abstract.

_We adapted the abstract in line 33 as follows:_ We developed a strategy of short CPR self-learning sessions followed by automated assessment with feedback and investigated its efficiency to achieve compression skills mastery in most participants.

_The introduction was adapted as follows in line 86:_ Therefore, we investigated the efficiency of a strategy comporting additional short training sessions to achieve compression skills according to a predefined pass level.

3. Line 38, and line 108, it says: ..followed by computer exercises.". This is not right. The authors probably mean practical exercises facilitated by a computer?

_Correct. We changed this into “excercises with computer voice feedback”._

4. Line 85-87, it says: "we investigated the number of training sessions participants required to achieve compression skills acquisition ." The word "acquisition" is superfluous.

_Thank you, we removed the word “acquisition”._
5. Line 90, it says: "Research Methods" It should be "Methods" according to the manuscript guidance for Resuscitation

Adapted.

6. Line 104, it says: "since they were lay students who were expected to perform poorly". I suggest that you delete this sentence. It is great that the authors did this baseline testing and it is also relevant that no feedback was given. However, any assumption on their performance is irrelevant. Would you give feedback if they were more experienced, no I assume.

Thank you, we agree with you and adapted the sentence as follows: Before initial training we assessed all participants baseline compressions and ventilations skills, however, no feedback on the test result was provided at this stage.

7. Line 260 it says: "we will investigate this future". Besides the missing word "in" I believe that such kind of statement should not be included in a publication. Let us wait and see your future study and I am looking forward to that.

Thank you, we removed this part of the sentence.

8. The study population consists of students so it is young and probably people who learn easily and not representative of the general lay population. I believe this should be more clearly stated or and with references to results from publications with similar test persons.

Thank you for pointing this out. We adapted the limitation section as follows in line 251: The mean age of the students in the present study was 20 years, potentially
resulting in better acquisition of skills. However, Braslow et al. found that participants over 40 year performed compressions comparable to younger participants. Although our population consisted of young motivated lay students, which might not represent the general population, this study demonstrates the feasibility and the high success rate of automated learning as a way to acquire good CPR skills.

9. Why did you not give feedback on ventilations? I would like a comment on that.

In accordance to literature ventilation skills are difficult to acquire and reported performance is often poor. Since compression depth is one of the most important determinants of survival, the methodological choice was made to only give feedback on compression skills. Looking retrospectively at our data, we must agree that the assumption of poor ventilation acquisition in our training strategy was incorrect. A certain amount of the students were able to achieve adequate ventilation skills and we hypothesize that feedback after testing might have been able to let the other students achieve proficiency.

10. The dropout was nearly 25% for the 5 months retention testing. It is a weakness of the results that the dropout is so high and one might suspect that those who did not respond or claimed not to have time for this might be the those with poorest results.

This is a correct and pertinent observation. Working with students comports the difficulty that it is quite impossible to oblige them to come back for retention testing, unless it is in view of formal curriculum assessment.

We added this limitation as follows in line 256: At 5 months retention testing the dropout was nearly 25% and reasons are illustrated in Figure 1. It is a limitation that
The dropout is so high and one might suspect that those who did not respond or claimed not to have time for this might be the ones with the poorest results.

11. I miss some final comments on the clinical impact and thoughts of the potential financial impact of this learning approach. Please add some comments.

We added the following comments in line 267: The current results are quite helpful for better CPR skill training and retraining for both lay person and healthcare providers. The findings underscore the opportunity to use novel training strategies for performance improvement in resuscitation and achievement of high quality resuscitation skills in less time and with more hands-on practice compared to traditional instructor-led teaching. It is necessary to enhance resuscitation training for all citizens, starting in schools and institutes, 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.

12. Figure 1. I suggest that you add the terms T0, T1, T2/T3 into the figure in order to clarify the flow of the study.

Adapted.

13. Figure 1. There is a misspelling in the line "7 for a medical reason".

Corrected.

14. Figure 2. The legend says "Success rates for initial training (T0), retraining (T1,T2,T3) and rescue training". There is confusion between terminology in the
legend and in the figure. It seems that results for T0 (baseline?) is missing. I would like to see results for baseline, i.e. the pre-test prior to learning. I also suggest that you add the results of the 5 month retention training into the figure.

There was indeed a confusion in the terminology. We corrected the legend title as follows: Success rates after initial training (T1), retraining (T2, T3, T4) and instructor facilitated training.

Pre-test results were not mentioned in the figure since no students managed to achieve the combined score for compression skills. In addition, the majority of students skipped the pre-test since they did not know how to perform CPR. It will be impossible to mention results at retention in figure 2 since the numbers of students are different after training (404) and at retention (288).

15. Figure 2 it says “rescue” training. The word rescue is confusing. Does it mean CPR training or does it mean final training. I suggest deleting the word rescue or instead saying CPR.

Adapted.

16. Table 1, 2 and 3. These are very complex tables with a lot of data. It is actually very difficult to comprehend. I suggest that you either reduce the information available by choosing the most important ones or even better that you illustrate this as bars or lines -like figure 3. It does not seem necessary to give the confidence intervals with 3 decimals throughout the entire table.

Thank you. We simplified the lay-out of Table 1 by removing the differences in proportions, which can easily be calculated. Confidence intervals were reported with 2
decimals where possible. Table 3 was removed from the manuscript since it is redundant with the data in figure 3.
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.
Efficiency of short individualised CPR self-learning sessions with automated assessment and feedback.

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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 compression skills mastery in most participants.

Methods

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 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 100-120/min within a two month period. Automated feedback was provided and failed participants had to retrain within 2 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.

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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.

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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.
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. However, CPR skills are poorly acquired and retention deteriorates in as little as three to six months. The use of frequent assessments can identify those individuals requiring refresher training to help maintain their knowledge and skills. Providing feedback on a trainee's skill level is also known to have great impact on acquisition and retention of skills.

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. Video alone showed not to be sufficient to acquire CPR skills. To retrain CPR skills in a SL station adequately, voice feedback exercises appeared to be more effective than a video.

To report clinical competence the proportion of successful participants should be assessed against a predefined pass level. In 1995 the Royal College of General Practitioners already suggested a 70% level for adequate chest compressions as a lower limit for effective circulatory support. 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. 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.
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 comporting additional short training sessions to achieve compression skills according to a predefined pass level. In addition, the retention after five months was assessed.

**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 hours a day and seven days a week. In Google Calendar participants had to book a first training session (limited to a maximum of 40 minutes) and up to three additional sessions (with a maximum of 20 minutes 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 two minutes. Before initial training we assessed all participants baseline compressions and ventilations skills, however, no feedback on the test result 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 minutes learning-while-watching video (Mini Anne™) followed by an exercise with concurrent computer voice feedback (Resusci Anne Skills Station™). 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 and ventilation volume between 400-1000 ml (because the chest of the manikin visibly rises after insufflation of 400 ml).  

After initial training (T1), a new automated two minutes test was taken to assess compression and ventilation skills. Since compression depth is one of the most important determinants of survival, the methodological choice was made to only give feedback on compression skills. 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 100-120/min. 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). According to the training algorithm, participants not achieving a 70% combined score for compression skills after the initial 40 minutes 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 minutes) 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.

**Objectives and outcome measures**

The primary aim of the study was to establish the number of training sessions needed to train all participants to a predefined pass 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 100-120/min. 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%.

**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 5 months. Confidence intervals (CI) are reported for the differences between proportions using PASW® statistics 18 for Windows (SPSS Inc. Chicago, USA).

**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).

**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 successful
participants achieving a higher score (80, 90 or 100%) than the pre-defined 70% are
shown in Fig. 4.

**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 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 ($P = 0.139$).

**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 Table 3 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. 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. 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. 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.\textsuperscript{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 minutes 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.

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.\textsuperscript{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 to some people to remember the rate of 100-120/min 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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{27} Therefore, CPR feedback/prompt devices with a metronome could be used to maintain a correct compression rate.\textsuperscript{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.\textsuperscript{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.

The mean age of the students in the present study was 20 years, potentially resulting in better acquisition of skills. However, Braslow et al. found that participants over 40 year performed compressions comparable to younger participants.\textsuperscript{30} Although our population consisted of young motivated lay students, which might not represent the general
population, this study demonstrates the feasibility and the high success rate of automated learning as a way to acquire good CPR skills. At 5 months retention testing the dropout was nearly 25% and reasons are illustrated in Figure 2. It is a limitation that the dropout is so high and one might suspect that those who did not respond or claimed not to have time for this might be the ones with the poorest results.

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.\textsuperscript{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 are quite helpful for better CPR skill training and retraining for both lay person and healthcare providers. The findings underscore the opportunity to use novel training strategies for performance improvement in resuscitation and achievement of high quality resuscitation skills in less time and with more hands-on practice compared to traditional instructor-led teaching. It is necessary to enhance resuscitation training for all citizens, starting in schools and institutes, 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.
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.

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.
References


20. Mpotos N, Valcke MA, Vander Vleuten C, Monsieurs KG. Studies claiming efficacy of CPR training interventions: which skills should be assessed and how should data be reported to allow comparison? Resuscitation 2012, doi 10.1016/j.resuscitation.2012.05. (letter to the editor).


Legend to the figures

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

Fig. 2: Participants flow chart

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

Fig. 4: Proportion of participants achieving a percentage of compressions with depth \( \geq 5 \) cm (a), with complete release <5 mm (b), ventilations with volume 400-1000 ml (c), a threshold for a combined score for compression skills (d)
Table 1: Cumulative proportions of successful participants after initial training (T1) and after additional training sessions (T2, T3, T4).

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

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 100-120/min.

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 100-120/min and ≥70% of all ventilations between 400-1000 ml.
Table 2: Proportions of success at the end of the training and after 5 months for participants completing the study (n=288).

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

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 100-120/min.

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 100-120/min and ≥70% of all ventilations between 400-1000 ml.
Figure 1

Where am I going?

Feedup

And where to next?

Feedforward

How am I going?

Feedback

Training

Automated test
Figure 2

431 eligible students

428 students enrolled with informed consent

2 minutes pre-test (T0)

Skill teaching with a learning-while-watching video and voice feedback exercises

2 minutes post-test (T1) (T2, T3, T4)

PASS
(≥70% compressions ≥50 mm and mean rate 100-120/min and ≥70% complete release <5 mm)

FAIL
(<70% compressions ≥50 mm or mean rate not between 100-120/min or <70% complete release <5 mm)

Retraining within 2 weeks (maximum 3 times)

Voice feedback exercise

24 did not complete training
3 for a medical reason
1 left the university
20 for unknown reasons

404 students completed training

116 students not tested after 5 months
9 incomplete data
7 for a medical reason
5 left the university
35 were studying abroad
31 had no time due to other courses
26 did not respond to the invitation
3 needed instructor-facilitated remedial training

2 minutes retention test after 5 months (n=288)