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Knowledge and skills acquisition in medical students

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Document Version
Publisher's PDF, also known as Version of record

Publication date:
2018

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):
Cecilio Fernandes, D. (2018). *Knowledge and skills acquisition in medical students: exploring aspects of the curriculum*. [Thesis fully internal (DIV), University of Groningen]. University of Groningen.

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THE EFFECT OF EXPERT AND AUGMENTED FEEDBACK ON THE ACQUISITION AND RETENTION OF A COMPLEX MEDICAL SKILL

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Submitted to Instructional Science

ABSTRACT

Introduction

Many medical skills are complex, since declarative (biomedical) knowledge needs to be integrated with perceptual-motor and perceptual-cognitive skills. Feedback helps learners by guiding their actions and integrating learners' knowledge and skills, but it is unclear how to support the integration of declarative knowledge with skills. We therefore investigated the effect of expert and augmented feedback on acquisition and retention of a complex medical skill (acquiring a transthoracic echocardiogram) in a simulator study.

Methods

36 medical undergraduate students were randomly assigned to one of three sources of feedback: Expert (EF), Augmented visual (HS), and Expert plus Help Screen (EF+HS). Participants practiced until proficiency. The outcome measures included a knowledge and practical test, quality of and time needed to obtain the images at acquisition and after 11 days (retention test). The knowledge test was divided into three topics: names of the images, manipulation of the probe, and anatomy of the heart. The practical test consisted of obtaining the images, of which the quality was rated in a 5-point scale.

Results

Immediately after the training, the students in the EF group were faster than the two other groups in obtaining the images. However, this difference was absent in the retention test. In the retention test, the EF+HS group scored significantly higher on image quality than the other groups.

Conclusion

Our results demonstrate the superior effect of augmented combined with expert feedback during skill acquisition on retention of a complex medical task. Experts seemed to reduce learners' cognitive load during practice and therefore helped integrating declarative knowledge with the skills themselves.

INTRODUCTION

Many medical skills are complex because they require integrating medical knowledge with perceptual and motor skills. Mastering a medical skill requires the learner not only to acquire the necessary medical knowledge and knowledge of the procedure itself, but also to acquire the necessary perceptual-motor skills, while all these different components need to be integrated to result in coherent task performance. Without instruction and feedback, learning such a complex skill may be challenging for the student, or even impossible. Instruction from an expert supports the learner by helping them to integrate the necessary knowledge and skills, while feedback helps learners by guiding their actions and correcting them when necessary. Although much is already known about feedback in relatively simple perceptual-motor skills, less is known about feedback in skills that are more complex and require a large amount of background knowledge.

While instruction and training are very important in medical training, students also learn skills by observation or by imitation in the clinical setting.[1] However, the clinical environment is saturated with relevant and irrelevant information so the medical student may find it difficult to recognize which information is relevant. The role of the teacher is to guide students to recognize the relevant information, to acquire the motor skills, and to formulate a diagnose based on all the relevant information.

We will first give a short overview of what is known about the effectiveness of feedback in skill acquisition, before applying this to the complex medical skill we were interested in: making an transthoracic echocardiogram (TTE). TTE is a noninvasive technique, which uses an ultrasound probe placed on the patient’s chest to create moving images of the heart that are displayed on a monitor.

FEEDBACK IN SKILL ACQUISITION

Mastering a skill involves learners to automatize the required actions, which requires more than practicing: it also requires learners to know whether they are performing the skill correctly by remembering the instructions to perform it. Trying to remember the instructions may lead to errors, as students can forget them.[2] The cognitive demand and amount of errors will decrease as learners automatize the skill.[3]

Skill acquisition is supported by two types of knowledge: declarative and procedural knowledge.[3,4] Declarative knowledge refers to knowledge about facts or events (“knowing what”) and can be consciously inspected. Procedural knowledge refers to “knowing how”, and cannot be consciously inspected. Declarative knowledge decays over time, which means that it is possible to forget this knowledge when it is not used often enough, whereas procedural knowledge is not subject to decay.[3,5] Learning a new skill starts with receiving instructions, which are in the declarative format.[5] While practicing a skill, declarative knowledge is slowly transformed into procedural knowledge, a process known as proceduralization; and the skill can be called to have become automatized.[3,6]

Feedback during skill acquisition has been found useful for a number of reasons.[7] Firstly, it prevents the proceduralization of wrong knowledge by providing guidance to the learners on how to perform the actions of a task, so that learners can adapt their actions accordingly.[7] Feedback also decreases learners' cognitive demand of retrieving the declarative knowledge by giving learners' the correct knowledge, especially in complex skills.[8] Feedback also guides learners' attention to the relevant aspects of the task,[8] and keeps learners motivated by rewarding a correct action or punishing an incorrect action.[7]

However, for complex skills such as TTE that require both declarative (biomedical) and procedural knowledge (skills), there are still some aspects of feedback that remain unclear, most notably those associated with how to best support the integration of declarative knowledge with skills, and promote skill retention.

The optimal amount of feedback needed is related to the complexity of the skill.[8] Complex skills require more declarative knowledge than simple skills. Tasks that heavily rely on declarative knowledge are more cognitively demanding for the learner, since retrieving declarative knowledge is costly to the cognitive system. The more complex the skill is, the more time, practice and feedback it takes to master it. However, more feedback is not always better, as studies have shown that too much feedback *during* training may actually hamper performance later after a period of non-use.[9,10,11] Students who received constant feedback during training (concurrent feedback) performed worse in a retention test than those who received feedback only on the outcome (terminal feedback)[12,13] and than those who received gradually diminishing concurrent feedback.[14] The idea is that the feedback may become incorporated into the memories of the movements, and that when the feedback is removed, performance will consequently suffer.[9] The explanation may lie on how declarative and procedural knowledge interact. When acquiring a skill, students' procedural knowledge is general and as they progress this knowledge becomes highly specified.[2] When students receive constant concurrent feedback, their production rules will include the feedback itself, and, then later, when the feedback is removed, students will not be able to retrieve the production rule. To avoid that learners become dependent on feedback, it has therefore been proposed that the amount of feedback should decrease as the level of mastery increases.[8,15] This would also support students' learning which aspects of the tasks are relevant for the skills.

However, there are still aspects of feedback that remain unclear for complex skills (such as TTE) that require both declarative (biomedical) and procedural knowledge (skills). It is not clear how to best support the *integration* of declarative knowledge with procedural knowledge, or how to promote skill retention over time. The advance in TTE simulators however offers a good opportunity to investigate the effect of feedback on acquisition and retention of such complex skills. We therefore performed a simulator experiment to assess the effect of different types of feedback on skill retention. However, before describing our experiment we will first describe what is known about feedback on the specific skills necessary for TTE.

TRANSTHORACIC ECHOCARDIOGRAM (TTE)

Performing a TTE relies on biomedical knowledge on anatomy, physiology and pathology of the heart, and understanding the relation between moving the probe and the image on the monitor; students need to acquire the perceptual-motor skills for probe manipulation and the perceptual-cognitive skills for mentally transforming 2D TTE images into a 3D representation of the heart.

Perceptual-motor skills

Perceptual-motor skills refer to the ability to integrate motor actions with observed changes in the environment. For a TTE, this refers to being able to move the probe in such a way that the required image is shown on the monitor.

Many studies have examined the effect of the attentional focus in motor skills. It has been found that focusing feedback on external information rather than on the actual movement itself is more effective for learning: for example, instructions to students to focus on the target of the dart rather than on the movement of their arm increased target accuracy.[16] This advantage of attentional focus on external information is quite consistent and has been found in many other motor skills, including golf,[17] volleyball,[18] basketball,[19] and soccer.[18]

Another beneficial effect in motor skill training is the use of added external feedback, for example adding a display that will provide feedback regarding the learners' movement. Such so-called augmented feedback seems to improve motor learning.[14,20] For example, Kovacs, Buchana and Shea[21] demonstrated that the use of augmented visual feedback decreased the number of errors and time necessary to acquire a bimanual coordination task, although there was a drop in performance later when the feedback was removed. In a later study, Kovacs and Shea[14] investigated whether gradually decreasing the frequency of feedback over time would prevent this deterioration in performance, and indeed found that slowly reducing the frequency of the augmented feedback resulted in effective performance after acquisition and on a later retention test (without feedback). Snodgrass et al.[20] examined whether augmented visual feedback enabled students to manually apply forces during a cervical spine mobilization similar to the forces applied by experts. This was found to be true: both in the acquisition and in the retention test, students who had received augmented visual feedback applied forces that were similar to those of experts, while the control group did not. It has been hypothesized that the beneficial effect of concurrent feedback during skill acquisition lies in the fact that this feedback reduces the cognitive demands and avoids cognitive overload in the learner, especially in complex tasks.[22]

Perceptual-cognitive skills

Perceptual-cognitive skills refer to the ability to integrate relevant information from the environment with the necessary knowledge to decide on the next action.[23] For the TTE, this refers to understanding the dynamic image on the screen and relate that to heart anatomy and pathology, and decide whether there is enough evidence already to formulate a diagnosis.

In making a TTE, spatial cognition is also important. Spatial skills refer to the ability to mentally understand and manipulate an object in 3D.[24] For the TTE, the spatial component involves understanding how a 2D image of the heart relates to the 3D structure of the heart, and being able to mentally transform and manipulate a 2D image into a 3D representation. Furthermore, doctors need to understand the 3D relation between the heart and other organs such as the lungs. Because the TTE provides a dynamic image of a beating heart, the student should also understand how the image changes over time.

CURRENT STUDY

Although there is literature on feedback in either perceptual-cognitive or perceptual-motor skills, it remains unclear how we can best guide learning a complex skill that needs *integrating* declarative *knowledge* (biomedical knowledge such as anatomy) with perceptual-cognitive and perceptual-motor *skills*. So, for example, studies on motor skill acquisition suggest that reducing the frequency of augmented visual feedback during acquisition increases learners' performance in acquiring and retaining perceptual-motor tasks, but other than for TTE, these tasks typically require little declarative knowledge. Thus, expert feedback may be necessary to support learners to integrate the declarative knowledge with perceptual-cognitive and perceptual-motor skills.

Also, many studies focus on acquisition rather than on retention of complex skills. So, studies may indicate the beneficial effect of multiple sources of feedback because it may reduce students' cognitive load during acquisition,[8,10,25] but, studies on the effect of multiple sources of feedback on the retention of either complex skills[22] or medical skills[10] are lacking.

Therefore, to study the effect of augmented (visual) and expert feedback on the acquisition and retention of a complex medical skill that integrates declarative knowledge with perceptual-cognitive and perceptual-motor skills, we conducted a randomized experiment that included three different feedback conditions: (1) feedback provided by an expert, (2) augmented visual feedback provided by the help screen, and (3) feedback provided by both an expert and a help screen.

The first group received feedback from an expert in TTE. Expert feedback should support students to focus on relevant aspects of the tasks, and support learners to integrate their declarative knowledge (biomedical knowledge) with perceptual-cognitive and perceptual-motor skills.

The second group received augmented visual feedback. We expected that the visual augmented feedback of the simulator would support participants to acquire the perceptual-motor and perceptual-cognitive skills. The visual feedback provides information regarding the accuracy of the probe movements, helping learners' proceduralization by showing how accurate the movements are. The visual feedback also reminds students what the images should look like, helping them to recall the correct declarative knowledge. The augmented visual feedback, however, does not help students to integrate their cognitive and perceptual-motor skills.

The third group received feedback from the expert and the same help-screen. In this group, the visual feedback provided by the help-screen offers information regarding the accuracy of the students' movements. The expert feedback guides students' attention to relevant aspects of the tasks. It should also help participants to integrate their knowledge with the cognitive skills and perceptual-motor skills.

Since expert feedback supports the integration of declarative knowledge with perceptual-cognitive and perceptual-motor skills, we hypothesized that, during skill acquisition, learners who are guided by experts would obtain the TTE images faster than those who were only guided by augmented visual feedback. Because the literature suggests that adding augmented visual feedback may reduce the cognitive overload during the acquisition of the TTE, we speculated that participants who received feedback from multiple sources would obtain the images with better quality than those who were only guided by expert feedback.

METHODS

Participants

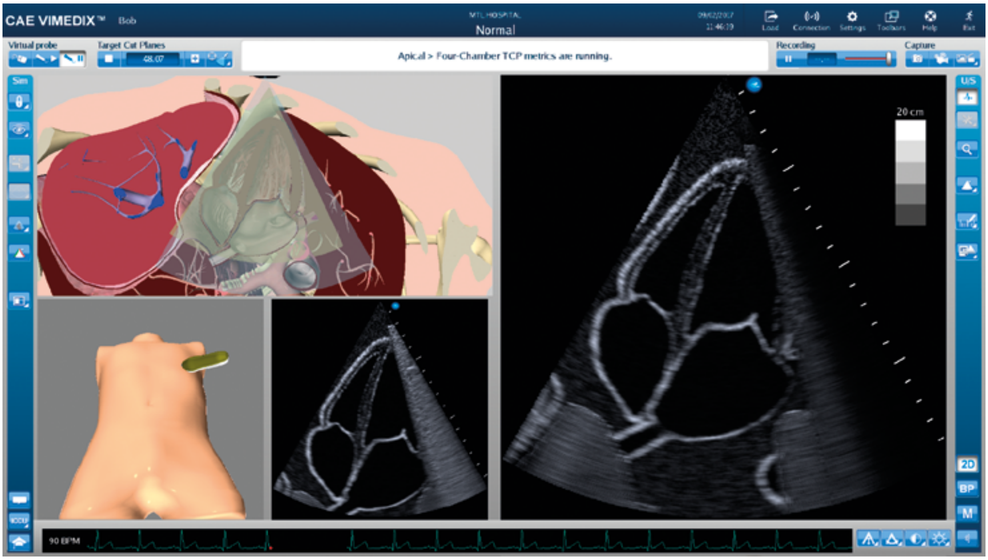
Participants were 39 medical students in their second, third, fourth, and sixth years of medical school (i.e., in the preclinical (year 1-3) and clinical (year 4-6) phase of undergraduate medical training). They were randomized to one of three groups.

TTE simulator

In this study, the CAE VIMEDIX™ ultrasound simulator was used. The simulator consists of a life-size mannequin torso with soft skin, and accurate and palpable anatomical parts, a TTE transducer, and a computer with monitor. Users have the choice of selecting multiple images simultaneously, which are the standard two-dimensional echo image, a three-dimension augmented reality model of the human body, and live feedback (Figure 1). The latter offers the users feedback about the cut-plane and the intended placing of the probe.

Procedure and design

This study was conducted at the Wenckebach Skills Center of the University Medical Center Groningen. Undergraduate medical students were recruited by e-mail, in which they received instructions about the planning, the timing, and the advantages/disadvantages of voluntarily participating in this experiment. They were all informed that participation



Apical > Four-Chamber TCP metrics are running.

Figure 1. Screenshots of the CAE VIMEDIX Ultrasound Simulator software. Reprinted from Product & Services: VIMEDIX, CAE Healthcare, Retrieved March 20, 2017, from https://caehealthcare.com/ultrasound-simulation/vimedix.

was voluntary; they could opt out at any moment without any consequences. All data were processed confidentially. All participants signed an informed consent form, and the experiment was performed in accordance to Dutch Law regulations. At the end of the experiment participants received a gift voucher worth € 10,00.

This experiment was divided into two parts: a training session and a retention test after 11 days.

The training session consisted of two to three hours of training, depending on how fast the participant learned to make the images. At the start of the experiment, participants were given written information on the acoustic windows and views of the heart that they would learn. Then, participants watched a video that explained the anatomy of the heart and showed how to manipulate the probe to obtain the images. Next, we provided a second set of written material explaining how to place and manipulate the probe. They watched the same video one more time, but this time they could stop it, and fast-forward or go back to repeat until they felt confident enough to take the knowledge test. They could also study all the material provided while watching the video. To ensure that students had acquired all the necessary knowledge to perform the TTE, they were asked to take a knowledge test on the computer. In this test, they had to answer all questions correctly. If they made a mistake, they received feedback on their answers and had to repeat the test until they were able to answer all questions correctly twice in a row.

The EF Group practiced on the simulator with the assistance of an expert cardiologist. The HS Group practiced on the simulator with the assistance of the help screens that were available on the simulator. The EF+HS Group practiced on the simulator with the assistance of both an expert cardiologist and the help screens. All students were instructed to obtain the best images possible without any time restriction. After practicing on the simulator, students took a practical test, in which they had to obtain all images correctly twice in a row. If an image was not correct, students could practice on that image and repeat the test for that image until they were able to obtain the image correctly twice in a row. During the test all the simulator's help screens were disabled.

Two experienced cardiologists with expertise on TTE participated in this study. They provided feedback similar to real-life training. When the help screens were on, the experts provided feedback similar to real-life training, but they also took advantage of the help screens. For example, when the probe was in the wrong position, the instructor would point to the help screens and give feedback regarding the position of the probe.

At the end of the session, students filled out a short questionnaire, to evaluate the TTE training that they received.

After 11 days, students were invited back for the final test. They performed the same knowledge and practical test as in the training session, and, at the end, filled out questionnaires.

Outcome variables

Knowledge test

The knowledge test consisted of 20 multiple-choice questions and one match-pattern question, which were divided into three blocks: names of the images, manipulation of the probe, and anatomy of the heart. Students took the test on a computer. All questions were automatically scored as correct or incorrect. At the end of each question block, students received feedback per question.

Quality of the images

Students were asked to obtain the following five images on the simulator: Parasternal long- and short-axis view, Apical four-chamber view, and Subcostal four-chamber and Inferior Caval Vein view. The quality of each image was graded independently by two experienced cardiologists who were blinded to the groups and participants. They graded the images on a scale ranging from 0 to 4 points, based on the following criteria:

1. Chambers are not displayed/wrong image.
2. One or more chambers are not displayed/not fully displayed.
3. All chambers are displayed, however, one chamber is incomplete.
4. All chambers are displayed, however, the angle/cross-cut is off.
5. All chambers are displayed with the right angle/cut.

Performance measures

In addition to the quality of the images, the time it took to complete each image was measured during the practical test, using a chronometer. The number of attempts for each block of the knowledge test and for each image was measured as well.

Questionnaire

The questionnaire was answered immediately after final test session. A questionnaire was used to collect extra information about the participants and the experiment. The questionnaire (in appendix) was divided in three parts. The first part contained questions regarding the participants' demographics and how many times they have watched or performed the TTE. The second part contained nine questions on the instructions and the experienced cognitive load of the training, which had to be scored on a Likert scale. The last part contained open questions in which participants could elaborate more on the quality of the training and give suggestions for improving the training session.

Data Analysis

To investigate the influence of the three types of feedback on students' skill acquisition, we conducted an analysis of variance (ANOVA) using *group* as independent variable and *number of students' attempts for the knowledge test*, *number of students' attempts for the practical test*, *time that students took to complete the training*, and *time that students took to complete the practical test after the training session* as dependent variables.

To investigate the influence of the three types of feedback on students' skill retention, we conducted an analysis of covariance (ANCOVA). *Groups* were added as a fixed factor. The scores of the knowledge test, gender, medical year, and how many times students had performed and watched a TTE were added as covariates in the model. To determine which groups differed on the corrected means of the model, we performed post hoc multiple-comparison tests.

To investigate the relationship between the scores in the different blocks of the knowledge test and the TTE performance, we conducted a Pearson correlation analysis between the three block tests and scores on the quality of the images.

We computed the median of the answers to the Likert-scale questions on the questionnaire.

RESULTS

In this experiment, 39 students participated. They were equally divided over the EF, HS, and EF+HS groups. However, six participants crossed over to the group with HS, when both experts were unexpectedly not available due to patient care. Of the 39 participants, 3 did not attend the follow-up session and were excluded from the analysis. Of the remaining 36 students, 10 students were in the EF group, 16 in HS, and 10 in the EF+HS group.

Baseline measurement

Two baseline variables could have affected the experiment, namely whether participants had performed a cardiac ultrasound before and whether they had watched others make a cardiac ultrasound. Since only two participants had performed a TTE previously, an analysis of variance to determine any difference between groups was not possible. The second variable concerned how many times participants had watched someone else perform a TTE. We conducted an analysis of variance and did not find a significant difference between the three experimental groups (F [2, 33] = 0.282 p = 0.756), meaning that all groups had comparable previous experience with echocardiography.

Training session

During the training session, participants practiced until they reached proficiency. Thus, all participants achieved the highest score at the knowledge and at the practical test. In Figure 2 the various times it took to reach this level are shown. The number of student attempts at the knowledge test (F [2, 33] = 0.402 p = 0.672) and at the practical test (F [2, 33] = 2.159 p = 0.131) was not significantly different between the groups. However, the time students took to complete the practical test (F [2, 33] = 4.824 p = 0.015) was significantly different between the groups; a Tukey posthoc analysis demonstrated that the EF group was significantly faster than the other two groups (Figure 2).

Retention session

The scores for the quality of the images in the retention session are shown in Figure 3. The analysis of covariance demonstrated a significant difference between groups (F [2, 32] = 3.374 p = 0.049*)*. Post hoc multiple-comparison analyses demonstrated that the EF+HS group scored significantly higher on the practical test than the HS group

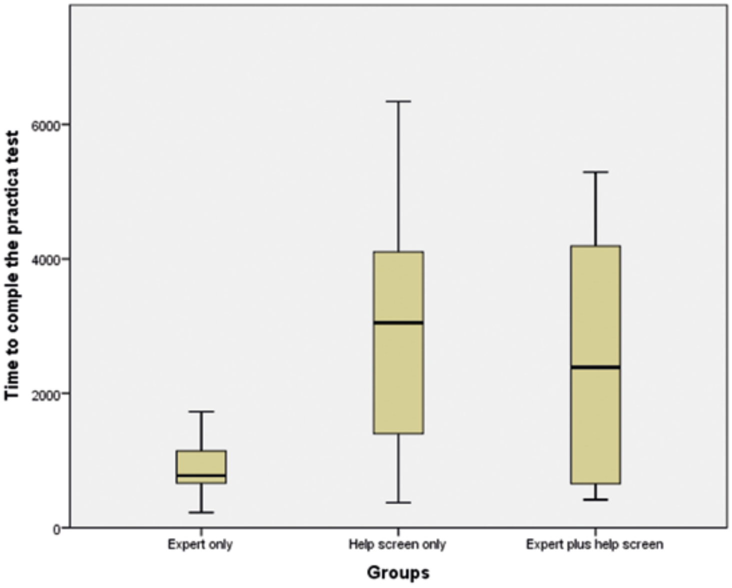


Figure 2. Box plot comparison of time (in seconds) to complete the practical test across groups EF, HS, and EF+HS, immediately after training.

(16.20 vs. 14.00, respectively). The EF group did not show any significant difference when compared to the other two groups (Figure 4).

An analysis of variance demonstrated that there was no difference between the groups in terms of the time students took to complete the final practical test (F [2, 33] = 0.347 p = 0.710).

A Pearson correlation analysis demonstrated that the quality of the image correlated positively with the scores on the knowledge test on names of the images, manipulation of the probe, and anatomy of the heart. (Table 1). Only the knowledge related to manipulation of the probe significantly correlated with the practical test (r = 0.45 p = 0.005). The magnitude of this correlation is considered moderate.

Questionnaire

Overall, students found the instructions used in the training session very clear (median score 4). They perceived the theoretical part of the training as easier than the practical part (median scores 3 and 4, respectively) and indicated that they put a lot of effort into both parts (median score 4, for both parts). The video and the knowledge test were considered the most helpful materials; students stated that both forced them to remember and apply

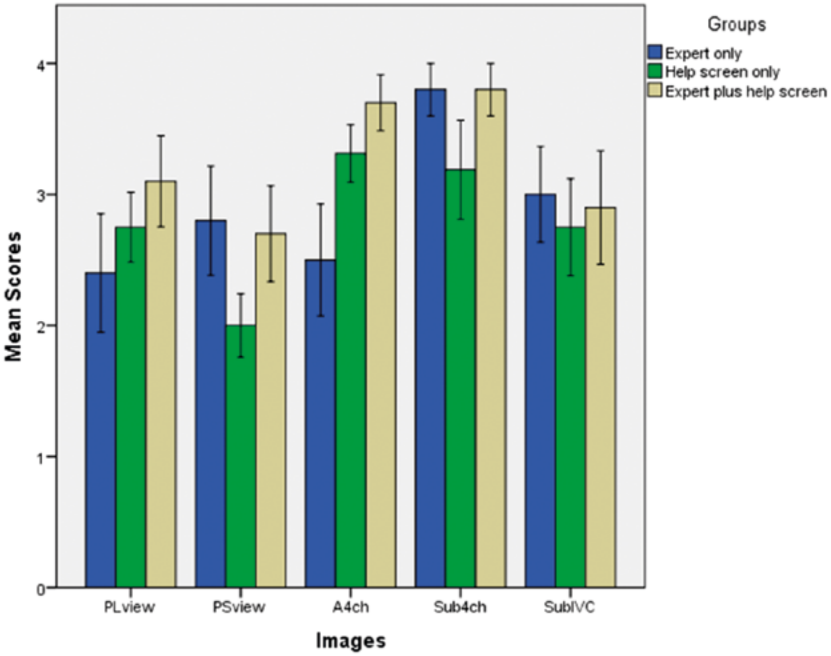


Figure 3. Mean score and Standard error for the quality of the five individual images across groups EF, HS, and EF+HS, after 11 days. PLview = Parasternal Long Axis View; PSview = Parasternal Short Axis View; A4ch = Apical 4 chamber view; Sub4ch = Subcoastal 4 chamber view; SubIVC = Subcoastal Inferior Caval Vein view.

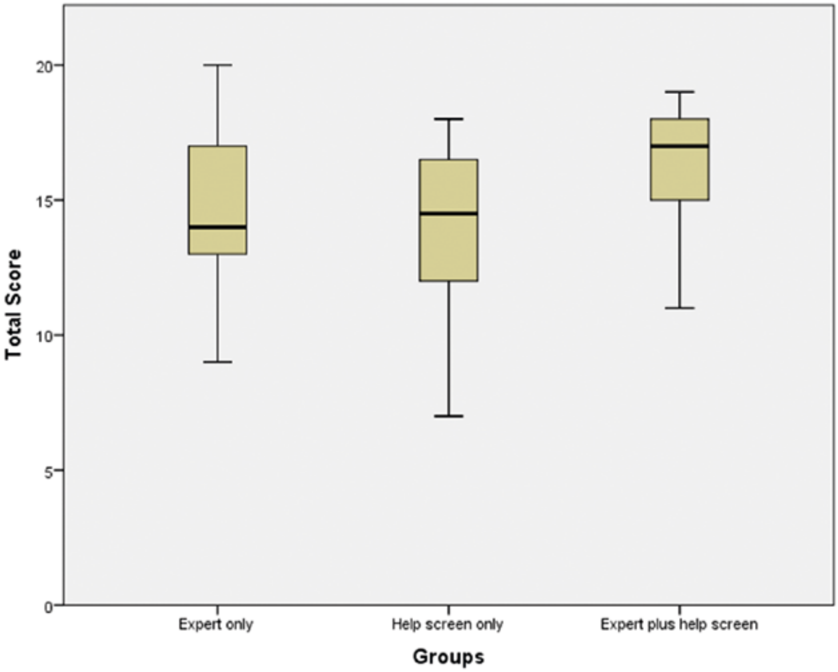


Figure 4. Box plot comparison of the total scores, ranging from 0 to 20 points, in the practical test across groups EF, HS, and EF+HS, in the retention test.

Table 1. Correlations between the quality of the images and the score on the different blocks in the knowledge test.

		Block in knowledge test		
		Name of the Image	Manipulation of the Probe	Structure of the Heart
Quality of images	r	0.21	0.45	0.31
	p	*0.222*	*0.005*	*0.660*

r = Pearson correlation; *p* = significance

what they had studied. Nevertheless, students found it not necessary to be tested twice in a row. The number of help screens, however, was overwhelming for some students. A few students suggested to include more information/practice on how to manipulate the probe and the effect of manipulating the probe to the image. Furthermore, two students suggested spreading the practice over a few days instead of practicing in one session.

DISCUSSION

In this study, we sought to determine the optimal way of guiding students' acquisition and retention of a complex medical skill, transthoracic cardiac ultrasound (TTE), with a focus on feedback. We manipulated the source of feedback students received during their practice on the simulator: feedback was provided by an expert (EF), by a help screen (HS), or by an expert and a help screen (EF+HS).

In the test immediately after the training session, all participants were required to be able to acquire all images correctly twice in a row, so quality of images across the conditions cannot be compared. What we did find was that EF participants were faster than the two other groups in obtaining the TTE images. This finding contradicts our hypothesis and the literature. Hatala et al.[10] conducted a meta-analysis to investigate the effectiveness of feedback for simulation based medical education. The meta-analysis revealed a moderate advantage of expert feedback to simulator feedback, and showed that an extra source of feedback leads to a performance improvement in the short term (i.e., during acquisition). The explanation for our contradictory finding may lie in the type of tasks investigated: the literature regarding medical skill acquisition mostly focuses on procedural (perceptual-motor) skills, while in our study, the TTE requires the integration of declarative knowledge with perceptual-cognitive and perceptual-motor skills.

In the retention test after 11 days, there were no group differences in time needed to acquire the images. In terms of quality of the images, participants from all groups already showed a decay in their knowledge and a decrease in their TTE performance levels, even though all participants had perfect scores immediately after the training. Interestingly, the EF+HS group acquired the best quality images of all groups. We think that this may be caused by the reduction of cognitive load during the practice session, as suggested by Hatala et al.[10] Experts guide learners by helping them to use and interpret the help screen, without the metacognitive load associated with using help screens by themselves. We believe that in the expert (EF and EF+HS) condition, experts helped students focus their attention on important parts of the task. Students in the HS group had to rely on previously given instructions only; they were actually seen to explicitly recall all instructions. We believe this cognitive load may have hampered the automation of the motor actions, because these students needed to actively remember the relationship between the help screen and the image. This resulted in a poor retention later when compared to the EF+HS group. Furthermore, students in the HS group may have focused their attention on the motor actions, but not on the relationship between the anatomy and the images, which is one of the most difficult aspects of the TTE.[26] Studies on perceptual-motor skills have shown that learners who focus on their own movements may perform worse than students who focus on the effects of their movements (for a review, see Wulf et al.[27]).

Summarizing then, it appears that although expert feedback may reduce the training time for the acquisition of a complex medical skill, expert feedback alone may not be optimal for skill retention. The addition of augmented visual feedback to expert feedback seems to promote learners' skill retention. Whether this also holds after more practice sessions, or over longer retention intervals, remains to be seen, however.

The reason we studied TTE in this experiment was that it is a complex medical skill that requires the integration of declarative (biomedical) knowledge, perceptual-cognitive and perceptual-motor skills. Our assumption that this integration of knowledge and skills is indeed necessary for TTE is supported by the positive correlation between the score on the declarative test on probe manipulation and the quality of the images: participants with better memory for probe manipulation also acquired better quality images.

From a practical perspective, the training of TTE skills often focusses on the acquisition rather than on the retention. Since the acquisition and retention of a the TTE skills appear to be affected by the source of feedback, TTE training may have to combine expert feedback with augmented visual feedback to improve learners' retention. Improving learners' TTE retention will decrease the number of training sessions, because learners' will be able to remember their knowledge and skills.

A limitation of the present study may lie in the fact that we did not control for practice time on the simulator. However, we believe this also to be a positive aspect of our study. Assuming a competency-based stance, we decided that it would be more useful to ensure similar levels of performance rather than of practice time, which also enabled a more reliable comparison of skill decay over time. Many educators will also be familiar with the fact that students may vary considerably in the time needed to acquire a skill, and this is also what we found in this study: although we did not specifically measure practice and learning time, students did show considerable differences in time needed to master the TTE skills: sessions ranged from 60 to 120 minutes.

Another possible limitation lies in the short time between the training and retention session since in practice, medical skills have to be retained over many months. However, 11 days proved to be enough to show a drop in learners' knowledge and skills. Maybe our participants were not able to automatize their skills in one training session to be able to retain their skills for more than a week. This indicates that repeat training sessions are necessary (even within 11 days for TTE) for students to acquire and retain their skills over time.

CONCLUSION

In accordance with prior suggestions from the literature, our results demonstrate the superior combined effect of augmented feedback combined with expert guidance and feedback during skill acquisition on retention of a complex medical task. Experts seemed to be especially useful for learners in that they reduced the cognitive load during practice and therefore helped integrating declarative knowledge with the skills themselves.

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