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The impact of a perceptual and adaptive learning module on transoesophageal echocardiography interpretation by anaesthesiology residents

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Abstract

Background: The role of transoesophageal echocardiography (TOE) in anaesthetic practice is expanding. We evaluated the effect of a TOE perceptual and adaptive learning module (PALM) on first-yr anaesthesiology residents' performance, in diagnosing cardiac pathology by TOE.

Methods: First-yr residents were assigned to a group ($n=12$) that used a TOE PALM or a control group that did not ($n=12$). Both groups received a TOE pretest that measured their accuracy and response times. The PALM group completed the PALM and a posttest within 30 min and a delayed test six months later. The control group received a delayed test six months after their pretest. Accuracy and fluency (accurate responses within 10 s) were measured.

Results: The PALM group had statistically significant improvements for both accuracy and fluency ($P<0.0001$) in diagnosing cardiac pathology by TOE. After six months, the PALM group's performance remained significantly higher than their pretest values for accuracy ($P=0.0002$, $d=2.7$) and fluency ($P<0.0001$, $d=2.3$).

Conclusions: In this pilot study, exposure to a PALM significantly improved accuracy and fluency in diagnosing TOE cardiac pathology, in a group of first-year anaesthesiology residents. PALMs can significantly improve learning and pattern recognition in medical education.

Key words: echocardiography; education; medical; pattern recognition; visual; transoesophageal

Transoesophageal echocardiography (TOE) is an integral tool in the management of cardiac surgical patients, with utility in other settings as well. A basic perioperative TOE cardiac examination can provide anaesthesiologists with information to both diagnose causes of haemodynamic instability and monitor the effectiveness of therapeutic interventions.[1] Practice guidelines recommend that TOE be used during episodes of unexplained persistent hypotension or hypoxaemia.[2] Simulators have gained popularity as tools for teaching echocardiography to medical trainees, and use of TOE simulators has been associated with improved image acquisition and identification proficiency compared with traditional learning methods.[3–5] Despite the

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Editor's key points

- The effects of a perceptual and adaptive learning module (PALM) on acquisition and retention of transoesophageal echocardiography (TOE) skills were tested in anaesthesia trainees.
- Use of a PALM improved both accuracy and fluency in diagnosing cardiac pathology by TOE.
- PALMs are a useful tool for teaching TOE, and may be applicable to other diagnostic modalities involving pattern recognition.

expanding focus, formal TOE education seems to be lacking from many anaesthesiology residency programmes, with only 38% of 108 surveyed USA anaesthesiology programmes offering a dedicated TOE rotation for residents.[6]

Perceptual and adaptive learning modules (PALMs) present an alternative route for training TOE interpretation. PALMs are intelligent, online tools created to enhance the development of pattern recognition, such as that involved in interpreting TOEs.[7] [8] Pattern recognition relies on perceptual learning which, in turn, underlies enhancement of information extraction from the environment as a result of deliberate practice. Perceptual learning is characterized by a discovery process (distinguishing relevant features from irrelevant variation) and the development of fluency (or "automaticity") in recognition.[8] The principles underlying perceptual learning apply to high-level complex tasks, such as those involved in medical pattern recognition.[9] With PALMs, learners sequentially observe a series of unique items (e.g. images, videoclips) and classify them into appropriate groups (e.g. diagnoses), each group consisting of a large number of unique, but related, items. An algorithm uses response accuracy and delay to sequence and space exemplars from each category with learners receiving feedback after each trial. Perceptual learning represents an important element of diagnostic reasoning,[10] and training approaches directed at perceptual learning have been shown to improve several clinical interpretation skills.[11–13] Recent studies have demonstrated the effectiveness of PALMs in training recognition of histopathologic processes[14] and dermatologic lesions.[15]

We evaluated the effect of online TOE PALM training on the accuracy and fluency in diagnosing basic cardiac pathology by postgraduate yr-one (PGY-1) anaesthesiology residents compared with PGY-1 anaesthesiology residents who received no PALM training.

Methods

The study was approved by the University of California Los Angeles (UCLA) Institutional Review Board (#11-002361). Verbal informed consent was obtained from all residents. No internal or external sources of funding were used. This prospective, cohort study included 24 anaesthesiology residents enrolled in their PGY-1 yr at UCLA. No residents were excluded from the analysis. The study extended over a period of eight months.

Intervention: After graduation from medical school, all anaesthesiology residents at UCLA are first enrolled in a yr-long, medicine-based training curriculum, designed to prepare them for future training in anaesthesiology. In the final three months of this PGY-1 curriculum, they participate in a standardized didactic programme that includes introductory lectures in basic anaesthetic topics. Although they receive the same lectures, the residents are divided into three groups because of scheduling concerns. For the purposes of the present study, two of the three groups from Spring, 2014 were assigned to an experimental PALM group (N = 12) that utilized a TOE PALM, and the remaining group from 2014 and one group from 2015 were assigned to a control group (N = 12) before the start of the study. The allocation of residents to either PALM or control group was solely based on which rotation they were previously assigned (i.e. samples of convenience). All groups received a primer lecture (by B.T.R.), either in person or online, on the basics of TOE, including an example videoclip of each of the diagnoses and views (categories) in the PALM. Both groups then received a TOE pretest that measured accuracy and response time (RT). The PALM group completed the TOE PALM immediately after the pretest and a posttest immediately after the PALM. Both groups completed a delayed test about six months after their pretest [170 (43) days for the PALM group and 179 (68) days for the control group].

Reference data: Pretest data were collected for more senior residents (clinical anaesthesiology-1 [CA-1] and clinical anaesthesiology-2 [CA-2]), cardiac anaesthesiology faculty, and rotating fourth-yr medical students (MS4), on a voluntary basis, in order to provide a context for the performances of the study groups. All of the faculty members actively practice TOE during cardiac surgical procedures and are board certified in Advanced Perioperative Transesophageal Echocardiography by the National Board of Echocardiography (USA).

PALM overview: We developed a PALM that demonstrated basic cardiac diagnoses in short video loops as viewed using TOE. Specifically, the TOE PALM asks subjects to identify images according to the six diagnoses listed in column 2 of Table 1, all of which were listed as answer choices on every trial. PALM trials consisted of unique examples of each diagnosis shown in one of three distinct views of the heart specified in column 1 of Table 1. The combination of pathology and orientation in which it could be demonstrated produced the 10 total presentations ("categories") that needed to be mastered listed in column 3 of Table 1.

Videoclips: A total of 223 unique TOE videoclips were used in the study. 179 videoclips were used in the PALM and 44 videoclips were used in the associated pretests, posttests, and

Table 1 The TOE views, the diagnoses into which videoclip presentations were to be classified, and the 10 categories resulting from the combinations of views and diagnoses that were presented in the TOE PALM. MO4C, midoesophageal 4 chamber; TGMPSA, transgastric midpapillary short axis; MOLA, midoesophageal long axis; LV, left ventricular; RV, right ventricular

Views	Diagnoses	PALM categories
MO4C	Aortic Stenosis	Aortic Stenosis MOLA
TGMPSA	Hypovolaemia	Hypovolemia TGMPSA
MOLA	LV Dysfunction	LV Dysfunction MOLA
	Normal Function	LV Dysfunction TGMPSA
	Pericardial Effusion	Normal Function MO4C
	RV Dysfunction	Normal Function MOLA
		Normal Function TGMPSA
		Pericardial Effusion MO4C
		Pericardial Effusion TGMPSA
		RV Dysfunction MO4C

delayed tests (see below). The videoclips were constructed from 161 videos recorded from intraoperative TOE examinations, during cardiac surgery at the UCLA Medical Center and displayed as short, 800x600 pixel, mp4 segments that were looped. All of the views in the videoclips were standard two-dimensional (2D) views presented according to the guidelines for performing a comprehensive TOE examination published by the American Society of Echocardiography and the Society of Cardiovascular Anesthesiologists.[16] In addition to 2D views, the Aortic Stenosis MOLA and Normal Function MOLA categories also contained coloured Doppler views. The videoclips chosen for both the PALM and tests demonstrated easily-recognizable diagnoses (i.e. large pericardial effusions, severe ventricular dysfunction).

Timing: Response time (RT) was calculated from the beginning of video presentation to the time of answer selection. We set the target RT for each trial at 10 s because faculty members who completed the PALM had an average accurate RT of 9.3 s. This time represented physical RT (i.e. the total time needed to make the diagnosis, find the correct answer among the possible choices, move the pointer to it, and click). The PALM had a maximum time allowance of 20 s for each trial.

Feedback and progression: Feedback indicating whether the answer choice was correct or incorrect and denoting the correct diagnosis was provided after each trial. As the PALM was designed to adapt to the performance of subjects, it continuously monitored accuracy and RT and modified the order sequence of subsequent trials based on these values. Successive exemplars from a given category (i.e. diagnosis) were always separated by at least four trials from other categories. In order to promote directed learning, the PALM retired (removed) diagnoses from the learning set if accurate answers were provided within the target RT. Simply trying to go fast was not a beneficial strategy as retirement of a category required three *consecutive* accurate answers, each within the target RT, and this fact was explained to the trainees.

Testing: In order to assess the effectiveness of the PALM, two different versions of a test were developed. The tests were used to measure the ability of residents to identify unseen exemplars of the categories before the PALM (pretest), immediately after the PALM (posttest), and after a delay of six months (delayed test). Each trainee in the experimental group received a different version of the test for their pretest and posttests. For both groups, the delayed test was always the same version that they received as a pretest six months earlier. In order to normalize for possible differences in difficulty between the two versions, 50% of trainees received a given version for each test. Each test version included 22 total videoclips consisting of two unique exemplars from each of the 10 categories and an additional videoclip, with coloured Doppler for both the Aortic Stenosis MOLA and Normal Function MOLA categories. Videoclips with coloured Doppler were included in the tests because some of the exemplars of these two categories in the TOE PALM included coloured Doppler.

Analyses: Two separate outcomes were measured: accuracy (calculated as the percent of responses that were correct) and fluency (calculated as the percent of responses that were both accurate and made within the target RT). Differences between pretest, posttest, and delayed test performance within each group were assessed by correlated (paired), two-tailed Student's *t*-tests, with differences between groups assessed by independent, two-tailed Student's *t*-tests. Statistical significance was accepted as *P* value < 0.05. The Shapiro-Wilk test was used to confirm that the data for each group were normally distributed. Statistical analyses were performed using VassarStats© (http://vassarstats.net/ Last accessed: September 10, 2016). Effect size (Cohen's *d*) was calculated as the difference in means divided by the pooled SD. Thus, the effect size is a measure of the magnitude of the observed difference in means between the two groups expressed as a fraction of the pooled SD.

Results

The TOE PALM itself required 29 (10) min with the entire primer lecture plus pretest/PALM/posttest sequence taking <1 h. Table 2 displays the performance for each group completing the pretest. Accuracy scores increased steadily with increased level of training: Fluency scores were relatively low and uniform, except for that of the faculty. For both measures, faculty performance was statistically significantly better than that of other groups.

The effects of the TOE PALM on PGY-1 performance can be seen in Table 3. Residents who completed the TOE PALM had large statistically significant improvements in both accuracy and fluency in correctly diagnosing cardiac pathology.

At six months, the PALM group's performance remained significantly higher than their pretest values for both accuracy and fluency (Table 3). Although the performance of the control group also increased over this period, the enhanced performance of the PALM group relative to the pretest was statistically significantly superior to that of the control group for both accuracy and fluency (Table 4).

At six months after completion of the TOE PALM, no statistically significant differences were found in the accuracy ($P = 0.31$) and fluency ($P = 0.72$) scores between the PALM group and the cardiac anaesthesiology faculty group (cf., PALM group delayed test data of Table 3 with faculty group pretest data of Table 2). However, sample sizes were too small to determine if the small differences between the two groups were statistically significant.

Discussion

Our results demonstrate that brief exposure to an online PALM, can significantly improve accuracy and fluency in diagnosing cardiac pathology by TOE, in a group of PGY-1 anaesthesiology residents compared with similar residents not completing this PALM. Based on the large effect sizes, performance of the PALM group improved by 4–5 SD between pretest and posttest. The PALM group's performance remained higher by 2–3 SD at the time of the delayed test. In contrast, the increase in control group performance between the pretest and delayed test was only 0.5–1 SD.

Table 2 Pretest performance as a function of training level. MS4, fourth-yr medical student; PGY-1, postgraduate yr-one; CA-1, clinical anaesthesiology-1; CA-2, clinical anaesthesiology-2; SE, standard error; *d*, effect size

Group	N	Accuracy mean % (SE)	Fluency mean % (SE)
MS4	4	31 (10)	15 (5)
PGY-1	24	40 (2)	23 (2)
CA-1	10	45 (6)	22 (3)
CA-2	7	53 (5)	26 (8)
Faculty	4	75 (4) ◊	50 (6) ◊
Faculty *vs.* each other group		◊$P \leq 0.02$; $d \geq 2.1$	◊$P \leq 0.001$; $d \geq 2.4$

Table 3 Comparison of PGY-1 performance as a function of PALM or no PALM (control) intervention. SE, standard error; *d*, effect size

Intervention, performance	Pretest mean % (SE)	Posttest mean % (SE)	Delayed test mean % (SE)	Posttest *vs* Pretest		Delayed test *vs*. pretest	
				P	*d*	P	*d*
PALM Accuracy	38 (2)	79 (3)	67 (4)	< 0.0001	5.4	< 0.0001	2.7
Control Accuracy	43 (4)		53 (6)			> 0.05	.57
PALM Fluency	20 (3)	70 (4)	53 (5)	< 0.0001	4.3	< 0.0001	2.3
Control Fluency	25 (4)		40 (4)			0.03	1.1

Table 4 Comparison of maintenance of learning for experimental compared with control PGY-1's. Δ (Delayed—Pretest); SE, standard error; *d*, effect size

Performance	N	Δ (Delayed–Pretest) Mean % (SE)		P	*d*
		PALM	Control		
Accuracy	12	28 (5)	10 (5)	0.02	.97
Fluency	12	33 (5)	15 (6)	0.03	.95

Perceptual and adaptive learning techniques possess broad applicability and represent an emerging frontier in medical education. Within the field of anaesthesiology, TOE is only one exemplar for the power of these approaches. PALMs could be used to improve interpretation of commonly encountered waveforms such as ECGs, EEGs, pulmonary artery catheter waveforms, and central venous catheter waveforms. PALMs have been shown to be effective in histopathology[14] and dermatology,[15] and could be designed to accelerate pattern recognition of abnormalities visualized on a variety of imaging modalities, including plain film radiography, transthoracic echocardiography, computed tomography, and magnetic resonance imaging. Finally training of identification of coagulation abnormalities on thromboelastography or thromboelastometry tracings, acid-base disturbances on arterial blood gas analysis, and respiratory pathology on capnography, flow-volume loops, or airway pressure patterns could all be accelerated with the use of PALMs.

One of the unique features of the PALM is the use of response time in both determining the sequence of categories from which to display exemplars and for determining mastery of each category. As discussed in the Methods section, choosing an answer quickly *per se* did not accelerate (and, in fact, delayed) category retirement. Rather, sequential accurate responses made with short response times (i.e. "fluently") were used as an indicator of the level of mastery. In a study comparing an adaptive learning system based on accuracy alone compared with an adaptive learning system using response times, participants trained using the system that incorporated response times, exhibited substantial enhancements in learning efficiency at both immediate and delayed time points.[17]

The PALM continuously monitors the speed and accuracy of responses and alters the sequencing of successive questions based on these variables. A sequencing algorithm assigns a reappearance priority score to each question and dictates short reappearance times for missed or slowly-answered questions.[7] This use of an Adaptive Response Time Based Sequencing (ARTS) algorithm, has been found to produce greater learning achievement than fixed or random presentation of learning trials, during immediate and delayed retention tests.[18] The PALM also has the ability to retire correctly-answered categories from the sequence after certain learning criteria are met. Problem retirement allows the subject to focus on questions where improvement is needed, and the requirement of a sequence of correct trials within a response time criterion ensures that learning and automaticity have occurred.[7]

Limitations of this study include its single-centre design and lack of background subject characteristic collection. The results on differences between the experimental and control groups after a six-month interval were confounded by ongoing TOE exposure that may have occurred between the pretest and the delayed test (as suggested by the improvement in performance of the control group over this time period). We did not specifically assess for the presence of continued TOE exposure after the pretest as the study was designed to evaluate the effectiveness of a brief educational intervention relative to the "standard of care" (i.e. the normal teaching that occurs during the end of the PGY-1 yr and the beginning of the CA-1 yr). During this time, both the control and experimental groups received the usual education, which includes occasional exposure to echocardiography and informal lectures by faculty members. None of the faculty involved in any aspect of resident education knew which residents were assigned to which group. Even with these additional inputs, differences between the two groups were statistically significant with large effect sizes. Although the study had a small sample size, the effect of the PALM was sufficiently large that statistically significant differences between groups were observed, indicating that power was sufficient.[19] Finally, the time from pretest to delayed test was both slightly longer and had a somewhat larger SD in the control group compared with the PALM group, and this could have been responsible for some of the differences observed in the pretest to delayed test results for the two groups. Future studies will correct this timing disparity.

Based on the results of this pilot study, TOE PALM should be used as a tool for teaching TOE to novices. Perceptual learning instruments such as PALMs present a valuable adjunct to traditional medical training practices. Not only do they provide a more effective means to address pattern recognition than current pedagogical methods, but they can accelerate the time needed to master procedures that presently require experience on actual patients or expensive, physical simulators.

Authors' contributions

Study design/planning: B.T.R., S.K., A.D.
Study conduct: B.T.R., S.K. P.J.K. A.D..
Data analysis: S.K., Writing paper: B.T.R..
Revising paper: all authors.

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Declaration of interest

P.J.K. is the President of Insight Learning Technology Inc. and the author of patents on adaptive and perceptual learning technologies.

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