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How can we improve teaching of ECG interpretation skills?

Findings from a prospective randomised trial

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Abstract

Background: There is an ongoing debate on how ECG interpretation should be taught during undergraduate medical training. This study addressed the impact of teaching format, examination consequences and student motivation on skills retention.

Methods: A total of 493 fourth-year medical students participated in a six-group, partially randomised trial. Students received three levels of teaching intensity: self-directed learning (2 groups), lectures (2 groups) or small-group peer-teaching (2 groups). On each level of teaching intensity, end-of-course written examinations (ECG exit exam) were summative in one group and formative in the other. Learning outcome was assessed in a retention test two months later.

Results: Retention test scores were predicted by summative assessments (adjusted beta 4.08; 95% CI 1.39-6.78) but not by the type of teaching. Overall performance levels and motivation did not predict performance decrease or skills retention.

Conclusions: Summative assessments increase medium-term retention of ECG interpretation skills, irrespective of instructional format.

Key words: medical education, assessment, teaching, electrocardiogram, forgetting, decrease, learning

Introduction

Electrocardiogram (ECG) interpretation is an important clinical skill as it allows rapid diagnosis of potentially life-threatening diseases [1]. According to the European Society of Cardiology's guideline for the management of acute myocardial infarction [2], the time taken between the first medical contact and the recording of the first ECG is a good index of the quality of care and should not exceed 10 minutes. In addition to swiftness, accuracy of the diagnosis derived from an ECG tracing is key to patient outcome [3]. Given that cardiovascular disease is highly prevalent [4], physicians of any specialty need to be familiar with the basic principles of ECG interpretation and must be capable of identifying important diagnoses. However, concerns have been raised that in many countries physicians lack these basic skills [5, 6]. One potential reason for this may be a failure of medical education to equip physicians with the knowledge and skills required to interpret an ECG. In fact, a recent survey among German medical school graduates revealed that 60% felt inadequately prepared for post-graduate training. Specifically, student replies indicated deficits in the ability to read an ECG [7]. Similar findings have been reported for graduates in New Zealand [8].

Numerous studies have addressed the question of how best to teach ECG interpretation skills [9-12]. A recent review of these studies [13] concluded that based on the available evidence, 'no single method or format of teaching is most effective in delivering ECG interpretation skills'. The authors noted that in most studies, learning outcome was assessed either shortly after or immediately after teaching and called for more research on the impact of teaching interventions on medium- and long-term skills retention.

Recent research [14] indicated that the consequences of a final exam (i.e. whether it generates a grade and can be failed ('summative') or just provides some feedback ('formative')) might outweigh any effect of teaching interventions carefully tailored to help students learn how to read an ECG. However, in that study students were aware of exam consequences, and it may be hypothesised that students taking a formative exam could have scored higher but did not feel incentivised to put much effort into the exam as they could not fail it. In addition, this study only assessed short-term learning outcome.

The primary aim of this study was to examine the effect of teaching intensity (peer teaching, lectures or self-directed learning, SDL) and examination consequences (summative versus formative) on medium-term retention of ECG interpretation skills (two months after the end of teaching). In addition, we aimed at identifying predictors of the change in student performance levels between the end of the teaching module and the retention test. We hypothesised summative exams to have a significant effect on skill retention but expected more intensive teaching to be associated with a lesser degree of performance decline towards the retention test.

Methods

Study design

This is a follow-up study of an earlier trial on the effect of teaching interventions and exam consequences on short-term learning outcome regarding ECG interpretation skills. Details on the design of this six-group (3x2), partially randomised and single-blinded trial can be found elsewhere [14]. In brief, four consecutive cohorts of fourth-year medical students enrolled in a six-week cardio-respiratory module at Göttingen Medical School were included in the trial. All students were provided with a written guide to ECG interpretation and were invited to attend three introductory lectures during which **electrophysiological principles and the basics of ECG interpretation** were discussed. Following this, students were either asked to work through the written ECG guide and practice their interpretation skills on the 40 tracings provided therein (reference condition: SDL), or they were randomised to either receive eight lectures on specific diagnoses or participate in eight small-group teaching sessions facilitated by more advanced medical students ('peer teachers') who had received specific teacher training [15]. The content addressed (i.e. the ECG tracings discussed during sessions) was identical on all three levels of teaching intensity. While students in the SDL condition did not receive any additional formal instruction, students attending lectures were shown how to interpret the 40 ECG tracings contained in the written guide (five ECGs per session, **organized**

in sections on stable coronary artery disease, acute myocardial infarction, ventricular hypertrophy, bundle branch blocks, bradycardia, tachycardia, miscellaneous findings and a summary section). Students allocated to small-group teaching were asked to discuss the same tracings and arrive at their own findings, supported by their respective peer teacher. Tracings in the written guide were not accompanied by information on the clinical context in order to avoid cueing effects. Correct ECG interpretations were available to all students in an online repository.

Initial performance levels were assessed in a written ECG exam held on the first day of the module (entry exam). During the last week of the cardio-respiratory module, students sat an ECG exit exam that was either summative (first and third cohort) or formative (second and fourth cohort; see [14] for details). Summative exams generated credit points relevant for students' overall marks at the end of undergraduate medical education while, following a formative exam, students were merely provided with the total score they had achieved. The study was partially randomised as we were unable to randomise exit exam consequences within cohorts, i.e. exam consequences were manipulated for entire cohorts, and students were aware of the nature of the exit exam (summative vs. formative). Thus, randomisation of three levels of teaching format within cohorts and the allocation of two different exams between cohorts resulted in a total of (2 x 3) six study groups. Only one-half of the final cohort (summer 2010) was included due to the other half being invited to participate in a different study in which exit ECG performance was incentivised financially. Since this was expected to impact on exam performance, these students were excluded from the present analysis.

Medium-term retention of ECG interpretation skills was assessed in an unannounced retention test that occurred eight weeks after the end of the cardio-respiratory module. Participation in the retention test was incentivised by giving all students (regardless of teaching intensity during the module or examination consequences in the ECG exit exam) the opportunity to score two bonus credit points for general medicine if they achieved half of all available raw points.

Assessment tools

Tracings of ECGs with medically important findings were used for the three ECG assessments. The entry exam, exit exam and retention test consisted of three, five and two tracings, respectively. Students were asked to provide a full written interpretation of rhythm, rate, axis, conduction times, signs of hypertrophy and ST segment abnormalities. Their entries were compared to correct interpretations provided by expert electrocardiographers, and a total of 10 raw points was available for each tracing. In order to avoid cueing, different tracings were used for each exam, but the same exams were used in all four student cohorts. The main findings in the entry exam were a normal ECG, an AV block I° with right bundle branch block and a STEMI. Main findings of the ECGs presented in the exit exam were Mobitz II° AV block, STEMI, atrial fibrillation, left ventricular hypertrophy and QT prolongation. Tracings used in the retention test featured tachyarrhythmia with left bundle branch block and acute right heart strain, both of which require urgent medical attention. None of these tracings were available to students or teachers (lecturers / peer teachers), and ECGs used for assessments were not included in the written ECG guide. Two raters blinded to student identity independently scored exams, and inter-rater agreement was high (weighted kappa >0.9 for all three exams).

In order to adjust our analysis for general performance levels, we also obtained student scores achieved in a summative end-of-module (EOM) exam. This examination consisted of 69 multiple choice questions on cardio-respiratory disease; ECG interpretation was not covered in EOM exams.

Student enrolment, data collection and analysis

Four weeks before the start of the module, medical students were informed about the study by e-mail. On the first day of the module, all students were asked to provide written consent to participate in the study. Consenting students were then asked to provide basic demo-

graphic information (age and sex) on a paper questionnaire. In addition, students were invited to self-rate a number of statements regarding their learning behaviour and previous ECG interpretation training on six-point scales (see **Table 1** for the exact wording of these statements). Following this, students were asked to complete the ECG entry exam.

Descriptive analyses of demographic variables, student self-ratings and scores in all ECG exams as well as the EOM exam were conducted separately for each of the six study groups, and differences between groups were assessed by χ^2 tests and analysis of variance or t tests, as appropriate. Student ratings on six-point scales were dichotomized by collapsing the two most positive options and the remaining four options into positive and neutral/negative categories, respectively.

The primary outcome for this study was the percent score achieved in the ECG retention test as this outcome is most relevant for clinical practice. Secondary outcomes included the decrease (i.e., difference) in percent scores between the ECG exit exam and the ECG retention test as well as the proportional retention. The latter was calculated as (ECG retention test percent score / ECG exit exam percent score * 100). Multiple linear regression analyses including sex, age, performance levels, and baseline self-ratings of motivation, interest and learning styles were used to identify predictors of primary and secondary outcomes. Formative exams and the lowest level of teaching intensity (SDL) were used as reference for these analyses, and results are given as beta coefficients and 95% confidence intervals (CI). The main effects of teaching intensity and examination consequences as well as a potential interaction between the two (with regard to primary and secondary outcomes) were assessed in an ANOVA. Statistical analysis was performed using SPSS 21.0 (Armonk, NY: IBM Corp.). Data are presented as mean \pm standard deviation or percentages (n), as appropriate. Significance levels were set to $p < 0.05$. This study was approved by the local Ethics Committee (Ethik-Kommission der Medizinischen Fakultät der Georg-August-Universität Göttingen; application numbers 23/2/09, 18/8/09 and 1/3/10).

Results

A total of 565 students were eligible for study participation, and 564 provided written consent to participate. Only students with complete data on all three ECG exams ($n = 493$) were included in the final analysis, and their characteristics are given in **Table 1**. The final study sample differs from that in our earlier trial [14] in that a total of 41 students did not take the retention test. Students in the six groups differed significantly with regard to performance in the ECG entry exam as well as the EOM exam, previous ECG training and expectations towards ECG teaching, hence the need to adjust for these variables in the linear regression analyses.

The overall percent scores achieved in the ECG entry, exit and retention exam were $25.6 \pm 13.2\%$, $72.9 \pm 17.0\%$ and $53.1 \pm 16.8\%$, respectively. Changes in performance levels between the three assessment points are displayed by group in **Figure 1**. An ANOVA assessing the effects of teaching intensity and examination consequences on percent scores achieved in the retention test and controlling for performance in the ECG entry exam yielded a significant effect of examination consequences ($\eta^2 = 0.038$; $p < 0.001$) but no significant effect of teaching format ($\eta^2 = 0.008$; $p = 0.140$). There was no interaction between examination consequences and teaching intensity ($\eta^2 = 0.001$; $p = 0.711$). With regard to the secondary outcomes, a similar ANOVA with the decrease in performance levels observed between the ECG exit exam and the retention test as the dependent variable showed a significant effect of examination consequences ($\eta^2 = 0.148$; $p < 0.001$) but neither for teaching intensity ($\eta^2 = 0.002$; $p = 0.649$) nor for the interaction between the two ($\eta^2 = 0.001$; $p = 0.774$). The same pattern of results emerged for the secondary outcome of proportional retention (exam consequences: $\eta^2 = 0.067$; $p < 0.001$; teaching intensity: $\eta^2 = 0.0002$; $p < 0.944$; interaction: $\eta^2 = 0.0002$; $p < 0.955$).

Results of the multiple linear regression analyses are presented in **Table 2**. The effect of a summative ECG exit exam on retention exam performance (column 1) remained after including all the baseline characteristics in the model (beta coefficient 4.08; 95% CI 1.39-6.78). Other significant predictors of performance in the retention test were a positive anticipation of ECG teaching, higher scores in the ECG entry exam as well as performance on the EOM exam. Conversely, a summative ECG exit exam was also a strong predictor of the decrease in performance levels observed between the ECG exit exam and the retention test (column 2). None of the other variables significantly predicted this decrease in performance levels. Finally, proportional retention (column 3) was significantly lower in students who had taken a summative ECG exit exam and in students who had expected to be taught how to interpret an ECG in classroom sessions.

Discussion

In this study, we found a significant effect of summative exams on medium-term retention of ECG interpretation skills. Contrary to our expectations, more intensive teaching was not associated with improved outcome in the retention test. These effects remained after adjusting for relevant baseline predictors including motivation to learn and general performance levels. The medium- relative to the short-term effect of summative assessments was attenuated, which was illustrated by the greater proportional decline in performance among those who had taken a summative exam. The overall decline in performance between the exit exam and the retention test was substantial and independent of student characteristics.

A striking finding of this study was the rapid decline in ECG interpretation skills observed in this large cohort of students. Within eight weeks upon the end of the cardio-respiratory module, the proportion of points scored dropped from almost three-quarters to just over 50%. Apart from the fact that failure to identify a tachyarrhythmia or acute right heart strain may put patients at risk, this finding might also explain why previous studies have consistently shown ECG interpretation skills of junior doctors to be suboptimal [8]. The rate of performance de-

cline observed in this study is comparable to that found in other studies. The percentage of knowledge reproduced in a retention test two to four months after teaching in relation to performance in a post-test taken directly after teaching typically ranges from 60% to 70% [16, 17]. Similar results have been reported for the retention of practical skills. In one study, students taking a retention test six weeks after receiving simulator training on the clinical management of chest pain and shortness of breath scored between 70% and 80% of the points they had achieved in a post-training directly after teaching [18]. Similarly, six-month retention rates of 64% have been reported for telephone referral skills [19]. In our study, proportional retention at two months ranged from 70% (any teaching followed by a summative assessment) to 83% (any teaching followed by a formative assessment). As a lack of reinforcement has been suggested as one potential cause for the rapid decay of medical knowledge and skills [20], interventions on the curricular level are most likely to help improve the situation.

Implications for teaching

The findings of this study extend our earlier report of summative assessments being substantially more effective drivers of student learning than state-of-the-art instructional methods that are grounded in theory [14]. This does not question the principle of aligning teaching methods to the desired learning outcome [21]. However, even the most innovative approach to teaching is unlikely to take full effect if only implemented once throughout a six-year curriculum. Repeated training reduces the rate at which skills are lost [22, 23] but its implementation can be challenging given the growing body of information to be covered in undergraduate medical education. However, even ongoing training may not be sufficient unless coupled with appropriate exams. According to current recommendations, these should be spread out across the curriculum longitudinally [24]. Inevitably, this entails the necessity for medical schools to prioritise learning objectives that will be considered essential for graduates and are therefore selected to be included in repeated assessments. ECG interpretation should clearly be prioritised here as all physicians need to be capable of a basic initial assessment indicating whether a life-threatening condition is present or not.

Strengths and limitations

To our knowledge, this is the first study to compare different levels of teaching intensity and different types of examination consequences regarding their effects on medium-term retention of ECG interpretation skills. The large sample size, the partially randomised design of the study, and the fact that our analyses were adjusted for differences between the six student groups strengthen the validity of our results. However, the generalisability of our findings is limited by the inclusion of only two original ECG tracings in the retention test. While using more tracings would have increased the power to detect significant effects, it might also have reduced student motivation to participate in the unannounced test. Our finding of a significant medium-term effect of summative vs. formative assessments even in this limited sample of test items reinforces the importance of summative assessments for student learning outcome. The marginal difference in ECG retention test performance between students engaging in SDL and students receiving more intensive teaching might be explained by the fact that all three teaching formats required students to engage with the material. Lastly, various ways to calculate retention and decrement of performance have been described. We decided to define decline as the absolute difference in percent scores as this method is widely used [25, 26]. However, analysing our data using alternative formulae and adjusting for performance in the entry exam [27] did not substantially alter our results (data not shown). Finally, as Fent and colleagues [13] recently pointed out, studies are needed that will show how training during undergraduate medical education translates into clinical behaviours and, eventually, improved patient outcome.

Conclusions

This study demonstrated a significant effect of summative assessments on medium-term retention of ECG interpretation skills. Compared to self-directed learning, more intensive teaching did not increase performance levels in the retention test. The substantial decline in performance observed over an 8-week period was independent of overall performance lev-

els. These findings have implications for the design of ECG teaching and assessment interventions.

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Conflicts of interest

None

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Figure legend

Figure 1: Student performance in three written ECG exams.

Error bars indicate errors of the mean. SDL, self-directed learning.

Tables

Table 1: Student characteristics, self-ratings and scores in the ECG entry exam as well as the **end-of-module multiple choice** exam the six study groups. Data are presented as mean (SD) \pm standard deviation or % (n) as appropriate. PT, peer teaching; SDL, self-directed learning; ECG, electrocardiogram. **F/ χ^2 and p values refer to differences between the six study groups.**

Number of students	81	77	68	70	136	61	ANOVA / χ^2 test
Teaching format	lectures	PT	lectures	PT	SDL	SDL	
Examination consequences	summative	summative	formative	formative	summative	formative	
Age [years]	23.9 \pm 2.5	24.1 \pm 2.7	24.0 \pm 1.8	24.1 \pm 2.5	24.3 \pm 2.6	24.6 \pm 2.7	F = 0.669 p = 0.647
Percent score achieved in the ECG entry exam	26.8 \pm 14.1	27.7 \pm 12.9	22.7 \pm 11.9	22.3 \pm 12.0	27.0 \pm 13.3	25.1 \pm 13.5	F = 2.447 p = 0.033
Percent score in the end-of-module multiple choice exam	80.3 \pm 8.2	80.3 \pm 7.8	75.2 \pm 7.5	77.2 \pm 7.2	80.7 \pm 8.9	77.4 \pm 10.0	F = 5.813 p < 0.001
Female sex, % (n)	59.3 (48)	59.7 (46)	60.3 (41)	57.1 (40)	56.6 (77)	63.9 (39)	χ^2 = 1.100 p = 0.954
"I need some external pressure in order to be motivated to learn.", % (n) agreement	44.4 (36)	39.0 (30)	39.7 (27)	42.9 (30)	33.1 (45)	31.1 (19)	χ^2 = 4.854 p = 0.434
"Preferably, I learn those things that will be tested in exams.", % (n) agreement	61.7 (50)	50.6 (39)	60.3 (41)	54.3 (38)	52.2 (71)	47.5 (29)	χ^2 = 4.563 p = 0.472
"I am looking forward to learning something about ECG interpretation in this module.", % (n) agreement	93.8 (76)	92.2 (71)	89.7 (61)	88.6 (62)	86.8 (118)	88.5 (54)	χ^2 = 3.459 p = 0.602
"I have read a book on ECG interpretation before.", % (n) agreement	33.3 (27)	26.0 (20)	11.8 (8)	17.1 (12)	19.9 (27)	14.8 (9)	χ^2 = 14.291 p = 0.014
"I have already learned some bits and pieces about the ECG prior to this module.", % (n) agreement	8.6 (7)	7.8 (6)	2.9 (2)	8.6 (6)	2.9 (4)	4.9 (3)	χ^2 = 5.983 p = 0.308
"I expect to be taught all the relevant facts and skills about ECG interpretation during the classroom teaching sessions.", % (n) agreement	74.1 (60)	85.7 (66)	82.4 (56)	92.9 (65)	89.0 (121)	90.2 (55)	χ^2 = 14.743 p = 0.012

Table 2: Predictors of performance on the primary and secondary outcomes. Results were derived from an adjusted linear regression analysis and are presented as **beta values (95% confidence intervals)** indicating the change in the dependent variable to be expected upon a change of 1 unit in each predictor variable. For dichotomous predictor variables, the reference condition is given in parentheses. ECG, electrocardiogram; EOM, end-of-module.

Predictor variables	Adjusted beta (95% confidence interval)		
	Primary outcome	Secondary outcomes	
	Percent score in the retention test	Decrease from exit exam to retention test	Proportional retention
Summative exam (vs. formative exam)	4.08 (1.39-6.78)	13.20 (10.40-16.01)	-15.29 (-20.11-[-10.47])
Lectures (vs. self-directed learning)	-0.41 (-3.57-2.74)	-0.54 (-3.82-2.75)	-1.29 (-6.93-4.35)
Peer teaching (vs. self-directed learning)	2.40 (-0.71-5.51)	-0.56 (-3.80-2.68)	0.34 (-5.21-5.90)
Age [years]	-0.36 (-0.90-0.17)	0.14 (-0.42-0.69)	-0.18 (-1.14-0.77)
Percent score achieved in the ECG entry exam	0.29 (0.18-0.40)	-0.06 (-0.17-0.06)	0.05 (-0.14-0.25)
Percent score in the EOM exam	0.66 (0.50-0.82)	-0.04 (-0.21-0.13)	0.14 (-0.15-0.44)
Female gender (vs. male gender)	0.44 (-2.17-3.06)	2.02 (-0.70-4.74)	-2.31 (-6.97-2.36)
Requirement of external pressure to learn	-0.13 (-2.82-2.57)	-1.83 (-4.63-0.97)	1.90 (-2.91-6.71)
Preference to learn content that will be tested in exams	-2.06 (-4.67-0.56)	0.46 (-2.26-3.17)	-1.85 (-6.52-2.81)
Motivation to learn something about ECG interpretation	4.70 (0.50-8.90)	-2.48 (-6.86-1.89)	4.83 (-2.68-12.33)
Previous study of an ECG book	1.13 (-2.22-4.47)	-0.90 (-4.39-2.58)	3.68 (-2.29-9.66)
Previous ECG training	-1.31 (-7.13-4.50)	0.43 (-5.62-6.49)	-1.53 (-11.91-8.86)
Expectation to be taught ECG interpretation during classroom teaching sessions	-2.68 (-6.39-1.04)	3.49 (-0.37-7.35)	-6.83 (-13.46-[-0.21])

Figure

