Position Article

The issue of electrocardiography interpretation competence revisited

La cuestión de la competencia en la interpretación del electrocardiograma revisitada

Raimundo Carmona Puerta[1,2*] https://orcid.org/0000-0003-2246-1089

Elizabeth Lorenzo Martínez[1,3] https://orcid.org/0000-0001-8293-5392

[1]Universidad Católica del Cibao. La Vega, República Dominicana.

[2]Vicerrectoría de Investigación y Asuntos Académicos de Posgrado. La Vega, República Dominicana.

[3]Escuela de Medicina, Facultad de Ciencias de la Salud. La Vega, República Dominicana.

[*]Autor para la correspondencia: endotelio1975@gmail.com

ABSTRACT

Introduction: The lack of electrocardiography interpretation competence affects medical students worldwide. Instructors need to understand how the skill of interpreting the electrocardiogram develops.

Objective: To analyse key processes for the development of electrocardiography competencies.

Methods: A comprehensive search of citations published in MEDLINE, Scopus, Web of Science, SciELO, ScienceDirect, and the Cochrane Library was conducted from August 2024 to November 2024. The search terms included: curriculum, ECG competence, ECG learning, electrocardiography, fast-and-slow thinking and medical students. A total of 180 articles were identified, with 56 included in the review based on the quality of results and relevance to the topic.

Results: Multiple studies demonstrate a lack of electrocardiography competencies among undergraduate and postgraduate students. Certification in electrocardiography is essential for the development of this skill. Training programs should avoid content overload and prioritize students' ability to identify significant emergency and non-emergency electrocardiographic alterations. Experienced physicians primarily rely on pattern recognition to interpret an electrocardiogram, while novices engage in systematic analysis. Forgetting can diminish already acquired competencies in electrocardiography, making the establishment of memory traces crucial for mitigating this issue. Repeated exposure to electrocardiogram tracings is indispensable.

Conclusions: Internationally, it is recognized that electrocardiography competence is limited. The processes of developing and maintaining this skill are complex. Faculty should understand these processes to introduce improvements in the curricular design of medical degree programs and other related fields.

Keywords: curriculum; ECG competence; ECG learning; electrocardiography; fast-and-slow thinking; medical students.

RESUMEN

Introducción: El déficit de competencia en electrocardiografía afecta a estudiantes de medicina en todo el mundo. Los docentes necesitan conocer cómo se desarrolla la habilidad de interpretar el electrocardiograma.

Objetivo: Analizar procesos clave para el desarrollo de competencias en electrocardiografía.

Métodos: Se realizó una búsqueda exhaustiva de citas publicadas en MEDLINE, Scopus, Web of Science, SciELO, ScienceDirect y la Biblioteca Cochrane desde agosto 2024 hasta noviembre 2024. Los términos de búsqueda incluyeron: aprendizaje en electrocardiografía, competencia en electrocardiografía, curriculum, electrocardiografía, estudiantes de medicina y pensamiento rápido y lento. Se identificaron 180 artículos, solo 56 se incluyeron en la revisión por su calidad.

Resultados: Múltiples estudios demuestran déficit de competencias en electrocardiografía entre estudiantes de grado y postgrado. La certificación en electrocardiografía es esencial para desarrollar esta habilidad. Los programas de formación deben evitar sobrecarga de contenido y priorizar que los estudiantes identifiquen las principales alteraciones electrocardiográficas de emergencia y no emergencias. Para interpretar un electrocardiograma los médicos mas

experimentados se basan principalmente en el reconocimiento de patrones mientras los novicios realizan un análisis sistemático. El olvido reduce competencias ya alcanzadas en electrocardiografía, por lo que establecer huellas mnemónicas es clave para su mitigación. La exposición repetida a trazos de electrocardiograma es indispensable.

Conclusiones: A nivel internacional se reconoce que la competencia en electrocardiografía es limitada. Los procesos de desarrollo y mantenimiento de esta habilidad son complejos. Los docentes deben conocerlos para introducir mejoras en los diseños curriculares de la carrera de medicina y otras con intereses comunes.

Palabras clave: aprendizaje en electrocardiografía; competencia en electrocardiografía; curriculum; electrocardiografía; estudiantes de medicina; pensamiento rápido y lento.

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Introduction

The electrocardiogram (ECG) is the graphic recording of electrical signals coming from the heart. These signals translate the occurrence of certain physiological processes and are susceptible to alteration when the heart becomes ill. Following the stethoscope, the ECG is the most commonly used diagnostic tool in cardiology practice. It allows the identification of the normal rhythm, sino-atrial rhythms, atrial arrhythmias, junctional rhythms, ventricular rhythms, conduction disturbances, chamber enlargement, ischaemia and abnormal repolarization which are considered training priorities topics for medical students.[1]

It should be highlighted that unlike other diagnostic tools used in cardiology such as imaging modalities with which it is possible to visualize the structure and function of the heart the ECG uses electrical signals and vectors, which translate to an abstract graphical representation of impulse propagation and/or pathology. With the improvement of ECG algorithms and the introduction of artificial intelligence it is perceived that the students and practitioners have become lazy to analyze the ECG. It is even difficult to find great ECG masters and the young talents who would be their relief, have become echocardiographers, cardiac electrophysiologists, nuclear cardiologists, preventative cardiologists, and cardiac

catheter experts.[2] There is a need to rescue the golden age of ECG and this starts from the first teaching contact in medical school. The aim of this review is to analyze key processes for the development of ECG competencies.

Basic Concepts

To standardize the reading of this article, we adopted the definitions of key terms according to previous works by Viljoen *et al.*[3]

ECG analysis: refers to the detailed examination of an ECG tracing, which requires the measurement of intervals and the evaluation of the rhythm and each waveform.

ECG interpretation: refers to the conclusion reached after careful ECG analysis, that is, making a diagnosis of an arrhythmia, ischaemia and so on.

ECG competence: refers to the ability to accurately analyse and interpret the ECG.

ECG knowledge: refers to the understanding of ECG concepts, for example, knowing that transmural ischaemia or pericarditis can cause ST-segment elevation.

Gaps in ECG interpretation. Identifying the problem

Several studies reveal that the deficit of skills in interpreting ECG is a worldwide problem that affects healthcare professionals of all academic levels.[4] Exceptionally, there are investigations that reflect the opposite. Although almost all medical school curricula include teaching electrocardiography, newly graduated doctors lack the necessary competence in this subject. Some attributes of prominent studies on the topic are summarized in Table 1.

Table 1 - Summary of relevant characteristics of selected studies on ECG competence

Study	Year of publication	Country	Academic degree	ECG diagnoses with more interpretation errors
Kopeć G *et al.*[5]	2015	Poland	Undergraduate: medicine students	Emergencies: atrial fibrillation, A-V block III, VT, VF. Common ECG abnormalities: LVH, RVH, Ischemia, Inferior wall infarction

Vishnevsky *et al.*[6]	2022	Israel	Undergraduate: medicine students	Long QT, LBBB, SVT and pacemaker rhythm
Getachew *et al.*[7]	2020	Ethiopia	Undergraduate: medicine students	Pulseless electrical activity, LVH and A-V block III.
Jablonover *et al.*[8]	2014	United States	Graduate medical students	
Mabuza *et al.*[9]	2020	South Africa	Generalist practitioners	Heart rate calculation, heart rhythm, acute antero-septal myocardial infarction, AF and acute inferior myocardial infarction
Kayar *et al.*[10]	2023	Turkey	General pediatricians and pediatric residents	Sinus bradycardia, A-V block II (Mobitz type 1), blocked supraventricular extrasystoles, supraventricular extrasystoles with aberration, Brugada syndrome
Ebrahim *et al.*[11]	2020	Kuwait	General pediatricians, pediatric cardiologists and other subspecialties	RBBB, 2:1 A-V conduction and AT
Rakab *et al.*[12]	2023	Eight middle eastern countries: Syria, Yemen, Egypt, Jordan, Sudan, Iraq, Algeria and Qatar	Specialists in Internal Medicine and Emergency medicine	Acute myocardial infarction, pathological Q-wave
Collins *et al.*[13]	2008	England	Junior Psychiatry doctors	LBBB, inferior myocardial infarction and paced ventricular rhythm
Lundberg *et al.*[14]	2013	United States	Graduating Physician Assistant Students	LAFB, Long QT, Pericarditis, LBBB, RBBB, Wolff-Parkinson-White
Alalwan *et al.*[15]	2023	Saudi Arabia	Paramedic students	Pathological Q-wave, ventricular extrasystoles, acute myocardial infarction, AF, A-V block III and VT

Aljohani *et al.*[16]	2022	Saudi Arabia	Critical care nurses	VF, AF, atrial flutter and A-V block III
Yaqoob *et al.*[17]	2023	Pakistan	Registered nursing	AT, ventricular extrasystoles, VT, pathological Q-wave, A-V block III and AF
Bdair [18]	2022	Saudi Arabia	Nursing students	?
Amini *et al.*[19]	2022	Iran		Normal ECG, acute myocardial infarction, pathological Q-wave, AT, ventricular extrasystoles and AF

Source: Consulted studies.

Abbreviations: AT: atrial tachycardia; A-V: atrioventricular; AF: atrial fibrillation; VF: ventricular fibrillation

Medical students

The ability to recognize emergency signs in ECG and cardiac anomalies among undergraduates from all Polish medical schools was low in a study.[5] Multivariable analysis showed that being in clinical years (OR: 2.45 [1.35-4.46]) and self-learning (OR: 2.44 [1.46–4.08]) determined competence in ECG interpretation. The authors concluded that there are qualitative and quantitative differences in ECG teaching in medical faculties. A low competence in ECG interpretation was revealed when surveying 341 medical students at the Hebrew University of Jerusalem, Israel in 2019.[6] The overall percentage and by year of those who passed an ECG exam was low (third year: 17.5%, fourth year: 10.8%, fifth year: 15.1%, sixth year: 45.1%, overall: 23.5%). A research carried out on medical interns at Addis Ababa University and Haramaya University, Ethiopia, showed low competence in ECG interpretations.[7] In 88% of items evaluated, the percentage of correct answers ranged between 2.5 – 43.1%, the worst results were obtained for pulseless electrical activity, left ventricular hypertrophy and third degree atrioventricular block.

Graduate medical students and general practitioners

The limited ability to accurately interpret ECG abnormalities in graduate medical students at the George Washington University School of Medicine was exposed after completion of a 22-item ECG assessment.[8] When evaluating the competence in a sample of South African generalist practitioners in ECG interpretation, poor

results were found.[9] Correct heart rate calculation was achieved by 14/83 (16.9%), ECG rhythm by 7/83 (8.4%), acute antero-septal myocardial infarction by 29/83 (34.9%), atrial fibrillation by 19/83 (22.9%) and acute inferior myocardial infarction by 22/83 (26.5%) of the generalist practitioners.

Residents and specialists

The accuracy level of pediatricians in ECG evaluation is low as concluded by Kayar *et al*.[10] after surveying a group of doctors, 160 of whom were pediatric residents and 82 were pediatricians. Another study carried out in general (n = 71) and subspecialty (n = 54) pediatricians also concluded that their skill and level of accuracy at interpretation is suboptimal, including cardiologists.[11] The electrocardiographic interpretation abilities of resident doctors at internal medicine (n = 530) and emergency medicine departments (n = 100) in eight Arabic countries was recently examined.[12] 50.5% of the participants scored above 7.5/10 on the ECG interpretation scale, which was interpreted by the authors as adequate.[12] This conclusion could be questionable because only half of the participants performed well in a test that can be decisive in saving a life. In junior psychiatry doctors from three London hospitals, a reasonable level of competence was found to identify ECGs as normal or abnormal, but much less precision in making exact ECG diagnoses.[13]

Other health professionals

In the evaluation of ECG prior to graduation of 51 students belonging to the class of 2011 of medical assistant at the George Washington University School of Medicine and Health Sciences, the need to improve training in ECG interpretation skills was demonstrated.[14] The average score after interpreting 22 ECGs was 50.7%. Proficiency in ECG interpretation among Saudi Arabian paramedic students at Prince Sultan College of Emergency Medical Services at King Saud University was good, with 64.2% of 137 students scoring > 7.5 points.[20] Factors such as grade point average (>3.5) and enrollment in cardiology and advanced cardiac life support courses were found to be significantly associated with competency ($p<0.001$). Another Saudi study that evaluated the competence of paramedics in ECG interpretation yielded opposite results. Less than half of the participants (n = 231) responded correctly when asked to identify 12 ECG strips.[15] In 255 critical care nurses from 4 hospitals in the Al-Madinah Region in Saudi Arabia evaluated to determine the level of competence in ECG interpretation, it was observed that this was low.[16] Yakoob *et al*.[17] applied a questionnaire composed of 12 validated

items to 120 registered nurses working in the critical care units of Dow University Hospital, Karachi concluded that the ECG interpretation competence level of nurses was suboptimal, only a third reached or exceeded the minimum score (≥ 9 out of 12) to be considered competent in the subject. The overall ECG interpretation competence among Saudi undergraduate nursing students showed to be limited in a quasi-experimental pre–post-test design, although it was proved that after enrolling in an educational program the evaluation scores improved significantly (pre-test: 4.16 ± 1.88 vs post-test: 7.43 ± 2.38; $p < 0.001$).[18] The opposite occurred in another research carried out at the National Heart Institute, Kuala Lumpur, Malaysia, in which 93.7% (n = 255) and 88.2% (n = 255) of the nurses had good ECG interpretation knowledge and good practice on ECG, respectively.[21] The level of knowledge and practices regarding ECG interpretation on cardiac arrhythmia among registered nurses (n = 105) working in critical care units of Perak, Malaysia, is good, according to a recent study.[22]

Studies with combined samples

Rahimpour *et al*.[23] compared ECG interpretation competence among emergency nurses (n = 105) and emergency medical service personnel (n = 65) applying a questionnaire that had a maximum score of 10. Results showed a mean score of 6.65 ± 2.16 for emergency nurses and 4.87 ± 1.81 for emergency medical service personnel ($p < 0.05$), highlighting the need for continued education in both comparison groups, although one had better competence than the other. A meta-analysis that included studies in which the accuracy of ECG interpretation across all training levels was evaluated determined that the median accuracy was 54% (interquartile range, 40%-66%; n = 62 studies) on pretraining assessments and 67% (interquartile range, 55%-77%; n = 47 studies) on post training assessments.[4] The ECG interpretation competence in a sample of medical students, nurses and other health professionals affiliated with an Iranian university was evaluated using the questionnaire developed by Coll-Badell *et al*.[24] receiving an overall score of 5.13 ± 2.25, a value less than 7.5 required to declare good competence.[19]

Certification in electrocardiography

Competence in ECG interpretation is a fundamental pillar of undergraduate and postgraduate clinical training.[25] In most countries, the certification of this skill is not strictly regulated. Kashou *et al*.[26] believe that once competency standards

are established, they would help establish objective expectations for all physicians in training and practicing medical professionals. In addition, it would assist medical educators in setting expectations in curriculum development in their respective medical professions and students in the design of translatable educational objectives. Ajmal and Marcus[27] mentioned in their review article that the ECG interpreter (the physician) should have to be certified in cardiology or have to pass an examination that includes ECGs representing a wide variety of abnormalities. It would also be desirable to certify other non-medical professionals who provide health care.

According to Ericsson's[28] work, it takes at least 10,000 hours of deliberate practice to acquire expertise in any field. There are some ECG proficiency standards, mainly established by various medical societies, but none constitute a gold standard that acts as a universal model. Some are based on the number of ECGs reported during a training program while others make a judgment on interpretation skills based on a proficiency test. The American College of Cardiology (ACC) and the American Heart Association (AHA) have stated that most physicians only become competent after reading at least 500 tracings under the supervision of an expert electrocardiographer.[29] Interpretation of 3000 - 3500 ECGs over a period of 36 months is considered adequate to acquire competence in physicians enrolled in cardiovascular disease training programs.[30] It is expected that this knowledge will be acquired in the first 12 months of training and in the remaining time it will be developed and perfected. However, there is no research to support the number of ECGs that must be analyzed to achieve proficiency in electrocardiography.

Essential competencies and curricular design in ECG training

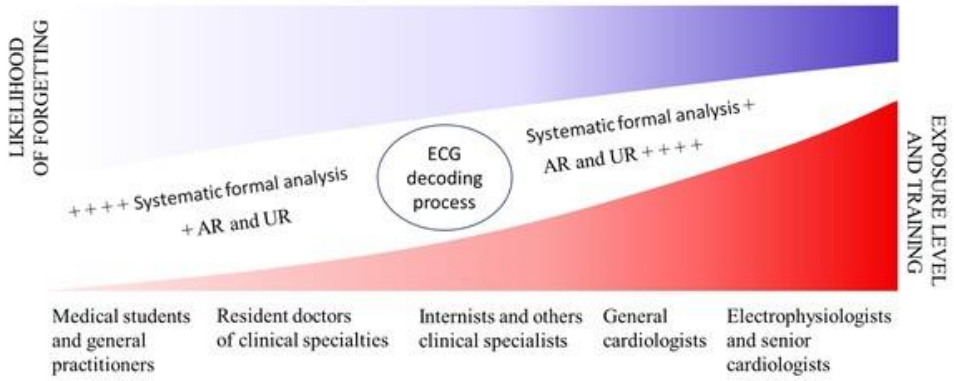
A classification that organizes the competencies that must be achieved during the training for undergraduate and postgraduate trainees was proposed by Antiperovitch *et al*.[31] with the support of researchers and educators from the International Society of Electrocardiology and the International Society of Holter and Noninvasive Electrocardiology. The different patterns are classified into four classes (A-D) based on emergency/nonemergency and common/uncommon criteria. A panel of experts from eight South African medical schools agreed that the topics to be included in undergraduate ECG courses should be: normal ECG, sinus rhythm, sinus arrhythmia, sinus tachycardia and bradycardia, atrial fibrillation and flutter, monomorphic and polymorphic ventricular tachycardia, torsades de pointes, ventricular fibrillation, bundle branch blocks, atrioventricular blocks, left and right ventricular hypertrophy, myocardial infarction with and without ST segment elevation, and pericarditis.[1] Other expert panel made up of

16 emergency medicine residency program directors from Canada evaluated a list of potentially important adult ECG diagnoses/findings with the aim of reaching consensus on the topics that should be taken into account when determining competence in ECG reading.[32] The authors of the study explained that although several of these diagnoses may not be observed during the training period, an individual student could use the list of diagnoses and/or findings to measure their learning and undertake a self-study that will contribute to improvement in those areas where him perceive deficiencies.

Bouza-Jiménez *et al*.[33] proposed a new curricular design that contains a didactic sequencing of the clinical electrocardiography content in each year or cycle of the curriculum. The process would be sequenced in four stages, preparatory, training, systematization, and consolidation, covering all years of the course. The early linkage of the medical student with the clinical area is advantageous for ECG learning as demonstrated by the application of a new curriculum design in Egyptian universities.[34] A large proportion of students responded in a survey that they would recommend this new design to future medical students (87.0 %), increased self-confidence in ECG interpretation (82.2 %), satisfaction with the method (82.2 %) and increased motivation for self-learning (70.9 %).

Processes involved in ECG analysis and interpretation

The way physicians approach ECG reading seems to respond to a dual-process system model based on pattern recognition and through a more formal systematic analysis.[35] Experience facilitates the fluid movement from one system to the other, which allows mitigating possible errors derived from one of the two processes. More experienced and academically advanced physicians employ unconscious and automatic reasoning more effectively than less experienced physicians (fig. 1), allowing them to make diagnoses within seconds, and resort to conscious analytical thinking when confronted with patterns that they cannot diagnose at the outset or fail to identify a very specific feature twice.[36] The concept of two main systems of thought was profoundly developed by psychologist Daniel Kahneman,[37] who was awarded the 2002 Nobel Prize in Economic Sciences. System 1 is fast, automatic, frequent, emotional, stereotypic, and unconscious, while System 2 is slow, effortful, infrequent, logical, calculating, and conscious. The predominance of System 1 (pattern recognition) in the clinician's cognitive processes is overwhelmingly significant.[38]



Note: The two main analysis resources that an electrocardiogram interpreter has to decode it and the magnitude with which they are used depending on the degree of training achieved are also shown. Crosses express lesser (+) or greater use (++++).

Abbreviations: AR: Automatic reasoning; ECG: Electrocardiogram; UR: Unconscious reasoning.

Fig. 1 - Level of exposure to the electrocardiogram and its forgetfulness in relation to the degree of training achieved.

Currently, the classical idea that both systems of thinking are exclusive (exclusivity feature) for certain responses is a subject of debate.[39,40] It has not yet been determined which of the two thinking systems weighs more in achieving expertise in electrocardiography. However, Ark *et al.*[41] demonstrated that receiving combined instruction on ECG features, and similarities (familiarity with ECG patterns) results in higher diagnostic performance than using these methods separately in novice diagnosticians. Other studies also support that instructing novice diagnosticians to employ a combined approach to clinical reasoning when diagnosing ECGs leads to greater diagnostic accuracy.[42] From May's perspective, the combined reasoning approaches, from the earliest stages, are more successful than one approach alone.[43] The direction of reasoning also matters in electrocardiography. Experiments conducted by Norman *et al.* [44] found that diagnostic accuracy is higher (61.9% vs. 49.4%) when using a backward-driven reasoning system (hypothesis testing) compared to a forward-driven reasoning system (hypothesis generation through data). Backward-driven reasoning involves first making a diagnosis and then identifying the characteristics that support it, whereas forward-driven reasoning entails collecting and synthesizing data, applying a given set of rules, and subsequently issuing a diagnosis.

The professionals visualized the ECG images depending on the level reached. Using eye-tracking metrics techniques in medical professionals with different levels of experience (medical students, technicians, nurses, fellows, consultants) it was found that consulting cardiologists had the lowest fixation count per participant

(fellows: 2135 vs. consultants: 1385, the value is the median), fixation count per lead for each ECG (fellows: 9.12 vs. consultants: 6.57, the value is the median) and ECG lead revisitation per participant (fellows: 2.55 vs. consultants: 2.01, the value is the median).[45] These data help to understand how medical expertise for ECG interpretation relates to the acquired visual expertise strategies.

Memory traces are key to preserving the ability to interpret the ECG

The establishment of memory traces is considered key in ECG learning and maintenance of competence. The forgetting curve for ECG interpretation in medical students declines sharply in the short term (2-4 weeks) and then remains stable in the medium (10-12 weeks) and long term (18-20 weeks).[46] Many programs and teaching methods that are reported as successful in the literature fail in daily practice because of decreased knowledge retention. Hence, one of the main objectives of the teaching and learning process is to reduce forgetfulness. Researchers from the University of Colorado, USA, managed to mitigate the forgetting curve in medical students, maintaining its competence in ECG interpretation with the implementation of a curricular innovation based on spaced repetition and retrieval practice using ECG quizzes.[47] In the study by Raupach *et al*.[48] carried out on medical students, the summative assessments increased the medium-term ECG interpretation skills retention but the motivation and overall performance levels were not associated with performance decrease or skills retention. In addition, an educational/work environment where there is high exposure to ECG is required, as the ability to interpret ECG is only acquired, maintained, and expanded by interpreting more and more ECGs. A student who passes an ECG curriculum program and does not visualize tracings on a continuous basis is doomed to failure in that area. Humans are prone to fail in observation when exposed to unusual targets.[49] This applies mainly to the visual identification of certain targets when they are rare, but if a target has a high frequency of presentation and the interpreter has little exposure to it its identification will result in high failure rates. This has been called by researchers the low-prevalence effect.[50] A study that analyzed whether providing case vignettes contributes to ECG diagnostic accuracy demonstrated only a marginal benefit with this strategy, but all participants were more likely to make a correct ECG diagnosis if they reported having seen the condition during prior clinical training, which supports what was previously mentioned.[51] Vishnevsky *et al*.[6] in their study conducted on Hebrew medical students concluded that competency and confidence in ECG interpretation seem to be significantly improved by increased and repetitive

exposure to ECG. ACC/AHA recommends a minimum of 100 ECG interpretations per year to maintain competency.[29] The American College of Physiacians does not give a number of ECGs, instead recommending that physicians who infrequently interpret ECGs should consider periodic self-study or continuing medical education to ensure that their skills remain current.[52]

ECG exposure is mandatory to overcome forgetfulness

Several scientific evidence show that those professionals who attend training programs with high rates of ECG exposure obtain the best results in proficiency tests. This was demonstrated in a study in which higher educational level was an independent predictor of ECG interpretation competence among healthcare professionals and students.[19] Emergency care providers with higher qualifications (involving more study time, practice and in-depth training) were more proficient in ECG pattern identification compared to those with lower qualifications according to a recent study.[15] A Turkish study among pediatric physicians found that the variables that were related to increased ECG interpretive ability were age, increased experience after graduating from medical school, increased seniority during residency, and increased of self-confidence in the interpretation of the ECG.[10] Even those who attended an ECG course after graduating scored higher on ECG knowledge than those who did not. When asked to identify 30 12-lead ECGs with common urgent and nonurgent findings to 1206 healthcare professionals, cardiology fellows-in-training demonstrated superior performance across all metrics examined (percentage of correctly identified ECG findings), interpretation time per ECG, and self- reported confidence compared to primary care physicians, resident physicians, medical students, advanced practice providers nurses and allied health professionals.[53] The retention of ECG competence significantly decreased six months after receiving instruction based on either lectures or blended learning (lectures supplemented with the use of a web application) in two cohorts of fourth-year medical students from the University of Cape Town, South Africa, demonstrating that competence declines without ongoing teaching and testing.[54] In relative terms, the decrease in competency based on the decline in scores six months after clinical clerkship was very similar between both methods (blended lecture: 23.3% vs. lecture only: 24.9%).

Training year was the only variable significantly associated with ECG interpretation in a multi-center online cross-sectional study conducted in arabic resident doctors.[12] A meta-analysis showed that cardiologists achieve the highest scores in tests that assess the accuracy of ECG interpretation compared to doctors at all

training levels.[4] The level of ECG exposure is strongly related to the type of curriculum completed. Those who acquire basic level skills are exposed to a low density of traces and the opposite is true for those who train in prolonged cardiovascular programs (fig. 1). Experience and skill make up a more complex variable called expertise. Those professionals with high ECG expertise have been exposed to thousands of tracings throughout their career. ACC/AHA consider that the recognition of ECG patterns is only learned through repeated exposure to the patterns since it is necessary to visually recognize the many diagnostic variants that exist.[29] However, although clinical exposure is essential for gaining experience in ECG analysis and interpretation,[29,55] experiential learning alone does not ensure ECG competence unless it is supplemented by structured teaching.[56]

Conclusions

Limited competence in electrocardiography interpretation is a common denominator among medical students and young physicians worldwide. The problem is also found in other healthcare professionals. Increased exposure to ECGs is a critical goal to develop and then maintain this skill. ECG pattern recognition varies with experience. While more experienced and highly trained physicians primarily use automatic pattern recognition, those with less experience and training rely more on preset criteria and algorithms. Continuous ECG exposure is required to mitigate the forgetting curve. Certification and recertification in ECG interpretation should be a goal to be achieved by the regulatory authorities of medical privileges in all countries. Understanding the intricate processes involved in ECG learning is essential for the development of improved programs and teaching methods in this field.

Bibliographic References

1. Viljoen CA, Millar RS, Manning K, Burch VC. Determining electrocardiography training priorities for medical students using a modified Delphi method. BMC Med Educ. 2020;20(1):431. DOI: https://doi.org/10.1186/s12909-020-02354-4

2. Hurst JW. Where have all the teachers of electrocardiography gone? J Electrocardiol. 2006;39(1):112. DOI: https://doi.org/https://doi.org/10.1016/j.jelectrocard.2005.10.016

3. Viljoen CA, Scott Millar R, Engel ME, Shelton M, Burch V. Is computer-assisted instruction more effective than other educational methods in achieving ECG competence among medical students and residents? Protocol for a systematic review and meta-analysis. BMJ Open. 2017;7(12):e018811. DOI: https://doi.org/10.1136/bmjopen-2017-018811

4. Cook DA, Oh S-Y, Pusic MV. Accuracy of physicians' electrocardiogram interpretations: A systematic review and meta-analysis. JAMA Inter Med. 2020;180(11):1461-71. DOI: https://doi.org/10.1001/jamainternmed.2020.3989

5. Kopeć G, Magoń W, Hołda M, Podolec P. Competency in ECG interpretation among medical students. Med Sci Monit. 2015;21:3386-94. DOI: https://doi.org/10.12659/MSM.895129

6. Vishnevsky G, Cohen T, Elitzur Y, Reis S. Competency and confidence in ECG interpretation among medical students. Int J Med Sci Educ. 2022;13:315-21. DOI: https://doi.org/10.5116/ijme.6372.2a55

7. Getachew M, Beyene T, Kebede S. Electrocardiography interpretation competency of medical interns: Experience from two Ethiopian medical schools. Emerg Med Int. 2020;2020:7695638. DOI: https://doi.org/10.1155/2020/7695638

8. Jablonover RS, Lundberg E, Zhang Y, Stagnaro-Green A. Competency in electrocardiogram interpretation among graduating medical students. Teach Learn Med. 2014;26(3):279-84. DOI: https://doi.org/10.1080/10401334.2014.918882

9. Mabuza LH, Mntla PS. Generalist practitioners' self-rating and competence in electrocardiogram interpretation in South Africa. Afr J Prim Health Care Fam Med. 2020;12(1):e1-e7. DOI: https://doi.org/10.4102/PHCFM.V12I1.2421

10. Kayar O, Sayıcı İU, Yoldaş T, Özgür S. Pediatric electrocardiography interpretation: Where we are now? Turk Pediatri Ars. 2023;58(6):612-7. DOI: https://doi.org/10.5152/TurkArchPediatr.2023.23075

11. Ebrahim M, Alseid R, Aleinati R, Tuzcu V. Electrocardiogram interpretation among pediatricians: Assessing knowledge, attitudes, and practice. Ann Pediatr Cardiol. 2020;13(3):205-11. DOI: https://doi.org/10.4103/apc.APC_18_20

12. Rakab A, Swed S, Alibrahim H, Bohsas H, Abouainain Y, Abbas KS, *et al*. Assessment of the competence in electrocardiographic interpretation among Arabic resident doctors at the emergency medicine and internal medicine

departments: A multi-center online cross-sectional study. 2023;10:1140806. DOI: https://doi.org/10.3389/fmed.2023.1140806

13. Collins N, Mandal U, Pendlebury G, Drife J. Junior psychiatrists' electrocardiogram interpretation skills. Psychiatri Bull. 2008;32(9):353-5. DOI: https://doi.org/10.1192/pb.bp.107.018960

14. Lundberg EL, Stagnaro-Green A, Zhang Y, LeLacheur S, Jablonover R. Assessment of competency in electrocardiogram interpretation of graduating physician assistant students. J Physician Assist Educ. 2013;24(4):15-8. DOI: https://doi.org/10.1097/01367895-201324040-00003

15. Alalwan MA, Alshammari T, Alawjan H, Alkhayat H, Alsaleh A, Alamri I, *et al*. Electrocardiographic interpretation by emergency medical services professionals in Saudi Arabia: A cross sectional study. PLoS ONE. 2023;18(10):e0292868. DOI: https://doi.org/10.1371/journal.pone.0292868

16. Aljohani MS. Competency in ECG interpretation and arrhythmias management among critical care nurses in Saudi Arabia: A cross sectional study. Healthcare. 2022;10(12):2576. DOI: https://doi.org/10.3390/healthcare10122576

17. Yaqoob M, Ali A, Siddiqui F, Rehan M. 12-Leads electrocardiogram interpretation competency among nurses working in critical care areas at Dow University Hospital, Karachi. J Liaquat Univ Med Health Sci. 2023;22(3):174-8. DOI: https://doi.org/10.22442/jlumhs.2023.00975

18. Bdair IA. Electrocardiogram interpretation competency among undergraduate nursing students: A quasi-experimental study. Nurs Forum. 2022;57(6):1273-80. DOI: https://doi.org/10.1111/nuf.12790

19. Amini K, Mirzaei A, Hosseini M, Zandian H, Azizpour I, Haghi Y. Assessment of electrocardiogram interpretation competency among healthcare professionals and students of Ardabil University of Medical Sciences: a multidisciplinary study. BMC Medical Educ. 2022;22(1):448. DOI: https://doi.org/10.1186/s12909-022-03518-0

20. Mobrad A. Electrocardiogram interpretation competency among paramedic students. J Multidiscip Healthc. 2020;13:823-8. DOI: https://doi.org/10.2147/JMDH.S273132

21. Jamahari NA, Binti Sh Abdullah SS, Hussain A, Liang F. Knowledge and practice on electrocardiogram interpretation among nurses at national heart institute. J Health Transl Med. 2023;26(Suppl. 2):446-51. DOI: https://doi.org/10.22452/jummec.sp2023no2.50

22. Ros SC, Isa R, Fauzi R, Isa SN, Wan Mansor WA. Critical care nurses' competency in electrocardiogram interpretation: A cross-sectional study. Malays J Med Health Sci. 2022;18:124-31. DOI: https://doi.org/10.47836/mjmhs18.s15.17

23. Rahimpour M, Shahbazi S, Ghafourifard M, Gilani N, Breen C. Electrocardiogram interpretation competency among emergency nurses and emergency medical service (EMS) personnel: A cross-sectional and comparative descriptive study. Nurs Open. 2021;8(4):1712-9. DOI: https://doi.org/10.1002/nop2.809

24. Coll-Badell M, Jiménez-Herrera MF, Llaurado-Serra M. Emergency nurse competence in electrocardiographic interpretation in Spain: A cross-sectional study. J Emerg Nurs. 2017;43(6):560-70. DOI: https://doi.org/10.1016/j.jen.2017.06.001

25. Breen CJ, Kelly GP, Kernohan WG. ECG interpretation skill acquisition: A review of learning, teaching and assessment. J Electrocardiol. 2022;73:125-8. DOI: https://doi.org/10.1016/j.jelectrocard.2019.03.010

26. Kashou A, May A, DeSimone C, Noseworthy P. The essential skill of ECG interpretation: How do we define and improve competency? Postgrad Med J. 2020;96(1133):125-7. DOI: https://doi.org/10.1136/postgradmedj-2019-137191

27. Ajmal M, Marcus F. Standardization in performing and interpreting electrocardiograms. Am J Med. 2021;134(4):430-4. DOI: https://doi.org/10.1016/j.amjmed.2020.10.042

28. Ericsson KA, Krampe RT, Tesch-Römer C. The role of deliberate practice in the acquisition of expert performance. Psychol Rev. 1993;100(3):363-406. DOI: https://doi.org/10.1037/0033-295X.100.3.363

29. Kadish AH, Buxton AE, Kennedy HL, Knight BP, Mason JW, Schuger CD, *et al*. ACC/AHA clinical competence statement on electrocardiography and ambulatory electrocardiography. Circulation. 2001;104(25):3169-78. DOI: https://doi.org/doi:10.1161/circ.104.25.3169

30. Balady GJ, Bufalino VJ, Gulati M, Kuvin JT, Mendes LA, Schuller JL. COCATS 4 Task Force 3: Training in electrocardiography, ambulatory electrocardiography, and exercise testing. J Am Coll Cardiol. 2015;65(17):1763-77. DOI: https://doi.org/https://doi.org/10.1016/j.jacc.2015.03.021

31. Antiperovitch P, Zareba W, Steinberg JS, Bacharova L, Tereshchenko LG, Farre J, *et al*. Proposed in-training electrocardiogram interpretation competencies for undergraduate and postgraduate trainees. J Hosp Med. 2018;13(3):185-93. DOI: https://doi.org/10.12788/jhm.2876

32. Patocka C, Turner J, Wiseman J. What adult electrocardiogram (ECG) diagnoses and/or findings do residents in emergency medicine need to know? CEJM. 2015;17(6):601-8. DOI: https://doi.org/10.1017/cem.2014.58

33. Bouza-Jiménez Y, Milián-Vázquez PM, López-Rodríguez-del-Rey MM, Acosta-Figueredo E. El proceso de enseñanza aprendizaje de la electrocardiografía en la carrera de medicina. Medisur. 2020;18(4):591-604.

34. Seif AA, Eldamanhoury HM, Darahim K, Boulos DNK, Bahaa N, Ciraj AM, *et al*. EE-6S: an integrated approach for introducing early clinical exposure in the new Egyptian medical curriculum. Adv Physiol Educ. 2021;45(1):109-20. DOI: https://doi.org/10.1152/ADVAN.00166.2020

35. Davies A, Mueller J, Horseman L, Splendiani B, Hill E, Vigo M, *et al*. How do healthcare practitioners read electrocardiograms? A dual-process model of electrocardiogram interpretation. Br J Card Nurs. 2019;14(10):1-19. DOI: https://doi.org/10.12968/bjca.2019.0073

36. Wu W, Hall AK, Braund H, Bell CR, Szulewski A. The development of visual expertise in ECG interpretation: An eye-tracking augmented re situ interview approach. Teach Learn Med. 2021;33(3):258-69. DOI: https://doi.org/10.1080/10401334.2020.1844009

37. Kahneman D. Thinking, fast and slow. New York: Farrar, Straus and Giroux; 2011.

38. Norman G, Young M, Brooks L. Non-analytical models of clinical reasoning: the role of experience. Med Educ. 2007;41(12):1140-5. DOI: https://doi.org/10.1111/j.1365-2923.2007.02914.x

39. Low J, Butterfill SA, Michael J. A view from mindreading on fast-and-slow thinking. Behav Brain Sci. 2023;46:e130. DOI: https://doi.org/10.1017/s0140525x22002898

40. Stanovich KE, Toplak ME. A good architecture for fast and slow thinking, but exclusivity is exclusively in the past. Behav Brain Sci. 2023;46:e142. DOI: https://doi.org/10.1017/s0140525x22002904

41. Ark TK, Brooks LR, Eva KW. Giving learners the best of both worlds: do clinical teachers need to guard against teaching pattern recognition to novices? Acad Med. 2006;81(4):405-9. DOI: https://doi.org/10.1097/00001888-200604000-00017

42. Eva KW, Hatala RM, Leblanc VR, Brooks LR. Teaching from the clinical reasoning literature: combined reasoning strategies help novice diagnosticians overcome

misleading information. Med Educ. 2007;41(12):1152-8. DOI: https://doi.org/10.1111/j.1365-2923.2007.02923.x

43. May SA. Clinical reasoning and case-based decision making: the fundamental challenge to veterinary educators. Journal of veterinary medical education. 2013;40(3):200-9. DOI: https://doi.org/10.3138/jvme.0113-008R

44. Norman GR, Brooks LR, Colle CL, Hatala RM. The benefit of diagnostic hypotheses in clinical reasoning: Experimental study of an instructional intervention for forward and backward reasoning. Cogn Instr. 1999;17(4):433-48. DOI: https://doi.org/10.1207/S1532690XCI1704_3

45. Tahri Sqalli M, Al-Thani D, Elshazly MB, Al-Hijji M, Alahmadi A, Sqalli Houssaini Y. Understanding cardiology practitioners' interpretations of electrocardiograms: An eye-tracking study. JMIR Hum Factors. 2022;9(1):e34058. DOI: https://doi.org/10.2196/34058

46. Rolskov Bojsen S, Räder SBEW, Holst AG, Kayser L, Ringsted C, Hastrup Svendsen J, *et al*. The acquisition and retention of ECG interpretation skills after a standardized web-based ECG tutorial–a randomised study. BMC Med Educ. 2015;15(1):36. DOI: https://doi.org/10.1186/s12909-015-0319-0

47. Cunningham JM, Johnson M, Kincaid T, Christensen W, Baker J, Turbyfill W, *et al*. The spacing effect: Improving electrocardiogram interpretation. Clin Teach. 2023:e13626. DOI: https://doi.org/10.1111/tct.13626

48. Raupach T, Harendza S, Anders S, Schuelper N, Brown J. How can we improve teaching of ECG interpretation skills? Findings from a prospective randomised trial. J Electrocardiol. 2016;49(1):7-12. DOI: https://doi.org/10.1016/j.jelectrocard.2015.10.004

49. Wolfe JM, Horowitz TS, Van Wert MJ, Kenner NM, Place SS, Kibbi N. Low target prevalence is a stubborn source of errors in visual search tasks. J Exp Psychol Gen. 2007;136(4):623-38. DOI: https://doi.org/10.1037/0096-3445.136.4.623

50. Taylor JET, Hilchey MD, Weidler BJ, Pratt J. Eliminating the low-prevalence effect in visual search with a remarkably simple strategy. Psychol Sci. 2022;33(5):716-24. DOI: https://doi.org/10.1177/09567976211048485

51. Viljoen CA, Millar RS, Manning K, Hoevelmann J, Burch VC. Clinically contextualised ECG interpretation: the impact of prior clinical exposure and case vignettes on ECG diagnostic accuracy. BMC Med Educ. 2021;21(1):417. DOI: https://doi.org/10.1186/s12909-021-02854-x

52. Salerno SM, Alguire PC, Waxman HS. Training and competency evaluation for interpretation of 12-lead electrocardiograms: recommendations from the American College of Physicians. Ann Intern Med. 2003;138(9):747-50. DOI: https://doi.org/10.7326/0003-4819-138-9-200305060-00012

53. Kashou AH, Noseworthy PA, Beckman TJ, Anavekar NS, Cullen MW, Angstman KB, *et al*. ECG interpretation proficiency of healthcare professionals. Curr Probl Cardiol. 2023;48(10):101924. DOI: https://doi.org/10.1016/j.cpcardiol.2023.101924

54. Viljoen CA, Millar RS, Manning K, Burch VC. Effectiveness of blended learning versus lectures alone on ECG analysis and interpretation by medical students. BMC Med Educ. 2020;20(1):488. DOI: https://doi.org/10.1186/s12909-020-02403-y

55. Alinier G, Gordon R, Harwood C, Hunt WB. 12-lead ECG training: the way forward. Nurse Educ Today. 2006;26(1):87-92. DOI: https://doi.org/10.1016/j.nedt.2005.08.004

56. Devitt P, Worthley S, Palmer E, Cehic D. Evaluation of a computer based package on electrocardiography. Aust N Z J Med. 1998;28(4):432-5. DOI: https://doi.org/10.1111/j.1445-5994.1998.tb02076.x

Conflicts of interest

The authors declare no conflicts of interest.