Letter to the editor

Epileptic Disord 2022; 24 (5): 979-982

Epileptic Disorders

Competency-based EEG education: a list of "must-know" EEG findings for adult and child neurology residents

Fábio A. Nascimento[1,2], Jin Jing[1], Roy Strowd[3], Irfan S. Sheikh[1], Dan Weber[4], Jay R. Gavvala[5], Atul Maheshwari[5], Adriana Tanner[6], Marcus Ng[7], K. P. Vinayan[8], Saurabh R. Sinha[9], Elza M. Yacubian[10], Vikram R. Rao[11], M. Scott Perry[12], Nathan B. Fountain[13], Ioannis Karakis[14], Elaine Wirrell[15], Fang Yuan[16], Daniel Friedman[17], Hatice Tankisi[18,19], Stefan Rampp[20], Rebecca Fasano[14], Jo M. Wilmshurst[21], Cormac O'Donovan[3], Donald Schomer[22], Peter W. Kaplan[23], Michael R. Sperling[24], Selim Benbadis[25], M. Brandon Westover[1], Sándor Beniczky[18,19]

[1] Department of Neurology, Massachusetts General Hospital, Harvard Medical School, Boston, MA, USA
[2] Department of Neurology, Washington University School of Medicine, St. Louis, MO, USA
[3] Department of Neurology, Wake Forest University School of Medicine, Winston-Salem, NC, USA
[4] Department of Neurology, Saint Louis University, Saint Louis, MO, USA
[5] Department of Neurology, Baylor College of Medicine, Houston, TX, USA
[6] Mercy Health, Grand Rapids, MI, USA
[7] Section of Neurology, University of Manitoba, Winnipeg, MB, Canada
[8] Department of Pediatric Neurology and Advanced Center for Epilepsy, Amrita Institute of Medical Sciences, Cochin, Kerala, India
[9] Department of Neurology, University of Pennsylvania Perelman School of Medicine, Philadeplhia, PA, USA
[10] Department of Neurology and Neurosurgery, Universidade Federal de São Paulo, São Paulo, Brazil
[11] Department of Neurology and Weill Institute for Neurosciences, University of California, San Francisco, California, USA
[12] Jane and John Justin Neurosciences Center, Cook Children's Health Care System, Fort Worth, TX, USA
[13] Department of Neurology, University of Virginia, Charlottesville, VA, USA
[14] Department of Neurology, Emory University School of Medicine, Atlanta, GA, USA
[15] Department of Neurology, Mayo Clinic, Rochester, MN, USA
[16] Department of Neurocritical Care, The Second Affiliated Hospital of Guangzhou University of Chinese Medicine, China
[17] Department of Neurology, New York University Grossman School of Medicine, New York, NY, USA
[18] Member of the European Reference Network EpiCARE, Department of Clinical Neurophysiology, Aarhus University Hospital, Aarhus Denmark
[19] Member of the European Reference Network EpiCARE, Department of Clinical Neurophysiology, Danish Epilepsy Center, Dianalund, Denmark

doi:10.1684/epd.2022.1476

The competency-based model has been guiding medical education on an international level over the last decades [1]. This model is learner-centered and has mastery of specific knowledge and skills as its unit of progression [2]. In the realm of electroencephalography (EEG), there have been continued efforts to ensure that residents have the competence to accurately and reliably interpret EEGs by the time they complete residency training. Achieving this goal is imperative, especially in countries where EEGs are typically read by neurologists without clinical neurophysiology or epilepsy fellowship training [3, 4], due to the deleterious consequences of EEG misinterpretation and epilepsy misdiagnosis [3]. In an attempt to define minimum EEG competency milestones, we herein propose a prioritized list of routine EEG findings that all adult and child neurology residents should be able to identify and interpret on completion of training.

Resident EEG education is guided by well-formulated milestones proposed by organizations such as the Accreditation Council for Graduate Medical Education (ACGME) [5] and International League Against Epilepsy (ILAE) [6]. These milestones, however, are not meant to be used to determine whether a trainee is competent to graduate; additionally, the milestones do not specify particular EEG findings that should be mastered by trainees. For example, the ACGME EEG Level 3 milestone encapsulates recognition of "common EEG abnormalities"; these "abnormalities", nonetheless, are not specified. We surveyed a group of EEG/epilepsy experts to delineate a list of routine EEG findings rated by their clinical yield for adult and child neurology resident education.

The authors (FN, JJ, MBW, SB) designed an online survey (*see supplementary material*) in which a comprehensive set of adult and pediatric routine EEG findings were listed under four major sections: normal findings, artifacts, normal variants, and abnormal findings. Neonatal EEG findings were not included. EEG/epilepsy experts were asked to rate each EEG finding on a 5-point Likert rating scale (1 = "not

[20] Department of Neurosurgery, University Hospital Erlangen, Erlangen, Germany and Department of Neurosurgery, University Hospital Halle (Saale), Germany
[21] Department of Pediatric Neurology, Red Cross War Memorial Children's Hospital, Neuroscience Institute, University of Cape Town, Cape Town, South Africa
[22] Department of Neurology, Beth Israel Deaconess Medical Center, Boston, MA, USA
[23] Department of Neurology, Johns Hopkins University, Baltimore, MD, USA
[24] Department of Neurology, Thomas Jefferson University, Philadelphia, PA, USA
[25] Member of the European Reference Network EpiCARE, Department of Neurology, University of South Florida, Tampa, FL, USA

Received June 15, 2022; Accepted June 22, 2022

• **Correspondence:**
Fábio Augusto Nascimento e Silva
Campus Box 8111, 660 South Euclid Avenue. St. Louis, MO, 63110, USA
<nascimento.fabio.a@gmail.com>
<fabion@wustl.edu>

at all important", 5 = "extremely important") based on the importance for adult and child neurology residents to learn this finding during residency training. We applied different weights to each answer corresponding to its respective point per the 5-point Likert rating scale (*e.g.*, a weight of 5 for 5 points on the Likert scale = "extremely important"), and generated a single weighted mean for each finding. Further, we asked experts for their rationale in rating each EEG finding. Data collection was performed from April to May 2022. All data is available upon request.
Twenty-six EEG/epilepsy experts completed the survey from the following countries: the USA (*n*=19), Denmark (*n*=2), Canada (*n*=1), Germany (*n*=1), Brazil (*n*=1), China (*n*=1), and India (*n*=1). All experts practice either in an academic setting (*n*=24/26; 92%) or combined academic-private setting (*n*=2/26; 8%). The mean number of years reading EEGs (including during clinical neurophysiology or epilepsy fellowship training) among experts was 20 years (range: 2-47 years). EEG findings and their respective weighted mean scores are shown in *table 1*.
Experts rated EEG findings based on whether their misinterpretation would lead to unnecessary treatments (*n*=24/26; 92%), additional unnecessary tests (*n*=23/26; 88%), or epilepsy misdiagnoses (*n*=22/26; 85%). Free text responses were evaluated and included rating the relative importance of EEG findings depending on the prevalence of the findings in clinical practice (*n*=1/26), their presence in previous examinations assessing EEG competency after residency graduation (*n*=1/26), and the expert's previous learning experience while a resident (*n*=1/26). One expert stated that "if a neurologist has to interpret EEG after graduation, additional training is essential" whereas another expert noted that "all topics need to be known by an EEG specialist [reader] including a neurology resident".
Despite neurology residents' high motivation to learn EEG [7, 8], both their level of confidence in interpreting EEG independently [7-10] and their objective knowledge of EEG [8] are far from optimal. In a survey of USA adult neurology residencies, program directors reported that this educational gap is a result of insufficient EEG exposure and ineffective didactics [11]. We believe that a key factor contributing to these education barriers arises from a lack of objective, well-defined EEG competencies expected of graduating residents including the absence of a recognized list of "must-know" EEG findings. Our study provides such a list which includes an inventory of routine EEG findings generated based upon opinions of a large group of multinational EEG/epilepsy experts who practice academic epileptology.
We believe that this resource addresses several challenges associated with trainee EEG education. First, our list of "must-know" routine EEG findings may be used in combination with broader milestones (such as those proposed by the ACGME [5] and ILAE [6]) to help residency programs create consistent, specific, attainable EEG learning milestones. These benchmarks may be used to develop milestone-based curricula and, ultimately, a roadmap for resident EEG training. Moreover, these milestones may be used as assessment standards; in other words, to evaluate residents' EEG competence longitudinally throughout residency training.
Second, this resource may be helpful in prioritizing EEG findings that must be learned during residency training. Similarly, by using the above-mentioned milestone-based assessment standards, programs may adjust quality and quantity of resident EEG exposure to achieve the level of proficiency in EEG required by completion of residency training. This aspect may be especially beneficial given the pervasive problem of insufficient EEG exposure, a well-known barrier to resident EEG education [11]. Survey data from USA adult neurology program directors showed that residents are required to undergo an average of 1.7 one-month EEG rotations to graduate (range: 0-4), and these trainees typically read zero to 30 EEGs per rotation [11]. Given this relatively small amount of dedicated EEG learning time, we believe that residents should focus on those EEG findings that have the greatest clinical yield – those findings that, if misread, might result in unnecessary treatments, tests, or epilepsy misdiagnoses. Residency programs could create educational libraries containing anonymized examples of high-yield EEG findings to ensure that residents are exposed to all of these essential EEG findings during their training. Lastly, using a comparable list of EEG findings to teach residents and assess their competency might serve research purposes, allowing a more valid comparison of trainee

Table 1. Survey data outlining routine EEG findings per major category (normal findings, artifacts, normal variants, and abnormal findings) and their respective weighted mean scores based on EEG/epilepsy expert scoring (1 = "not at all important", 5 = "extremely important").

Normal findings	Artifacts	Normal variants	Abnormal findings
• Awake, adult PDR (4.77) • Awake, pediatric PDR (4.58) • Drowsiness, slowing of PDR (4.58) • Stage 2 sleep, sleep spindles (4.46) • Stage 2 sleep, K complexes (4.42) • Drowsiness, diffuse irregular delta-theta slowing of background (4.42) • Stage 1/2 sleep, vertex waves (4.42) • Drowsiness, slow roving lateral eye movements (4.23) • Stage 1/2 sleep, POSTS (4.23) • Stage 3 sleep, diffuse irregular delta slowing (4.19) • Rapid eye movement (REM) sleep, erratic eye movements (3.85) • Rapid eye movement (REM) sleep, sawtooth waves (3.12)	• EKG (4.58) • Eye blinks (4.54) • Electrode pop (4.46) • Myogenic (4.42) • Eye fluttering (4.38) • Lateral eye movements (4.31) • 60-/50-Hz artifact (4.23) • Pulse (4.15) • Lateral rectus spikes (4.12) • Chewing/bruxism (4.04) • Sweat (3.92) • Glossokinetic (3.77) • Nystagmus (3.65) • Respiration/ breathing (3.62)	• Wickets (4.35) • Hyperventilation-induced slowing (4.19) • Small sharp spikes (4.19) • Breach (4.12) • Rhythmic mid-temporal theta of drowsiness (4.08) • Hypnopompic hypersynchrony (3.92) • Hypnagogic hypersynchrony (3.92) • Photic driving (3.85) • Mu rhythm (3.81) • Posterior slow waves of youth (3.81) • Photomyogenic response (3.81) • Lambda waves (3.73) • Temporal slowing of the elderly (3.69) • Slow alpha variant (3.50) • 6 Hz phantom spikes (3.50) • Frontal arousal rhythm (3.42) • 14-and-6 Hz positive spikes (3.42) • Increased frontal beta activity (3.38) • Subclinical rhythmic electrographic discharges in adults (3.35) • Fast alpha variant (3.31) • Midline central theta (Ciganek rhythm) (3.23) • Occipital needle-like spikes of blindness (3.08) • Slow fused transient (2.96) • Fronto-central rhythm (texting rhythm) (2.73)	• Generalized epileptiform discharge, 3 Hz (4.81) • Generalized epileptiform discharge, 3-5 Hz, polyspike (4.77) • Focal seizure (4.77) • Focal epileptiform discharge, spike (4.73) • Focal epileptiform discharge, sharp (4.73) • Generalized seizure, absence (4.73) • Generalized epileptiform discharge, <2.5 Hz (4.69) • Focal epileptiform polyspike (4.65) • Generalized seizure, tonic (4.62) • Infantile spasm (4.35) • Hypsarrhythmia (4.35) • Focal irregular/polymorphic slowing (4.27) • Focal regular/rhythmic slowing (4.23) • Diffuse irregular/polymorphic slowing (4.15) • Diffuse regular/rhythmic slowing (4.15) • Abnormal PDR, slow for age (4.00) • Abnormal PDR, asymmetric (4.00) • Asymmetric sleep spindles (3.73)

PDR: posterior dominant rhythm; POSTS: positive occipital sharp transients of sleep.

data from different institutions and different countries.

We hope that this list of routine EEG findings has the potential to make the adult and child neurology resident EEG learning process more objective and standardized, which - as a result - may be educationally beneficial to both teachers and trainees. ■

Supplementary material.

Supplementary data accompanying the manuscript are available at www.epilepticdisorders.com. e-Survey utilized in the study.

Disclosures.

F. Nascimento is an Associate Editor of Epileptic Disorders. R. Strowd serves as a consultant for Monteris Medical Inc., and receives an editorial stipend as Section Editor of the Resident and Fellow Section of Neurology. R. Strowd has received research grant support from the American Academy of Neurology, American Society of Clinical Oncology, Southeastern Brain Tumor Foundation, and Jazz Pharmaceuticals and has received royalties from Elsevier, Kaplan, and Lecturio. D. Weber is a speaker for SK Life Sciences. S. Sinha serves on the Board of the American Board of Clinical Neurophysiology. S. Beniczky is Editor-in-Chief of Epileptic Disorders. All other authors report no disclosures relevant to this manuscript.

References

1. McGaghie WC, Miller GE, Sajid AW, Telder TV. Competency-based curriculum development in medical education: an introduction. *Public Health Pap* 1978; 68: 11-91.

2. Sullivan RL. *The competency-based approach to training. Strategy Paper No 1*. Baltimore, Maryland: JHPIEGO Corporation, 1995.

3. Benbadis SR. Errors in EEG and the misdiagnosis of epilepsy: importance, causes, consequences, and proposed remedies. *Epilepsy Behav* 2007; 11: 257-62.

4. Adornato BT, Drogan O, Thoresen P, Coleman M, Henderson VW, Henry KA, *et al*. The practice of neurology, 2000-2010: report of the AAN member subcommittee. *Neurology* 2011; 77: 1921-8.

5. The Accreditation Council for Graduate Medical Education. *Neurology milestones*. ACGME, 2021. www.acgme.org/globalassets/pdfs/milestones/neurologymilestones.pdf

6. Blumcke I, Arzimanoglou A, Beniczky S, Wiebe S. Roadmap for a competency-based educational curriculum in epileptology: report of the Epilepsy Education Task Force of the International League Against Epilepsy. *Epileptic Disord*. 2019; 21: 129-40.

7. Daniello KM, Weber DJ. Education research: the current state of neurophysiology education in selected neurology residency programs. *Neurology* 2018; 90: 708-11.

8. Nascimento FA, Maheshwari A, Chu J, Gavvala JR. EEG education in neurology residency: background knowledge and focal challenges. *Epileptic Disord* 2020; 22: 769-74.

9. Mahajan A, Cahill C, Sharf E, Gupta S, Ahrens S, Joe E, *et al*. Neurology residency training in 2017: a survey of preparation, perspectives, and plans. *Neurology* 2019; 92: 76-83.

10. Lourenco ES, Kowacs DP, Gavvala JR, Kowacs PA, Nascimento FA. EEG education in Brazil: a national survey of adult neurology residents. *Arq Neuropsiquiatr* 2022; 80: 43-7.

11. Nascimento FA, Gavvala JR. Education research: neurology resident EEG education: a survey of US neurology residency program directors. *Neurology* 2021; 96: 821-82.