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NEUROCRITICAL CARE SOCIETY

REVIEW ARTICLE

Structure and Outcomes of Educational Programs for Training Non-electroencephalographers in Performing and Screening Adult EEG: A Systematic Review

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Abstract

Objective: To qualitatively and quantitatively summarize curricula, teaching methods, and effectiveness of educational programs for training bedside care providers (non-experts) in the performance and screening of adult electroencephalography (EEG) for nonconvulsive seizures and other patterns.

Methods: PRISMA methodological standards were followed. MEDLINE, EMBASE, Cochrane, CINAHL, WOS, Scopus, and MedEdPORTAL databases were searched from inception until February 26, 2020 with no restrictions. Abstract and full-text review was completed in duplicate. Studies were included if they were original research; involved non-experts performing, troubleshooting, or screening adult EEG; and provided qualitative descriptions of curricula and teaching methods and/or quantitative assessment of non-experts (vs gold standard EEG performance by neurodiagnostic technologists or interpretation by neurophysiologists). Data were extracted in duplicate. A content analysis and a meta-narrative review were performed.

Results: Of 2430 abstracts, 35 studies were included. Sensitivity and specificity of seizure identification varied from 38 to 100% and 65 to 100% for raw EEG; 40 to 93% and 38 to 95% for quantitative EEG, and 95 to 100% and 65 to 85% for sonified EEG, respectively. Non-expert performance of EEG resulted in statistically significant reduced delay (86 min, $p<0.0001$; 196 min, $p<0.0001$; 667 min, $p<0.005$) in EEG completion and changes in management in approximately 40% of patients. Non-experts who were trained included physicians, nurses, neurodiagnostic technicians, and medical students. Numerous teaching methods were utilized and often combined, with instructional and hands-on training being most common.

Conclusions: Several different bedside providers can be educated to perform and screen adult EEG, particularly for the purpose of diagnosing nonconvulsive seizures. While further rigorous research is warranted, this review demonstrates several potential bridges by which EEG may be integrated into the care of critically ill patients.

Keywords: Electroencephalography, Seizure, Education, Critical care, Intensive care unit

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Background

Guidelines recommend continuous electroencephalography (EEG) monitoring of select critically ill patients [1–4]. Continuous EEG can assist with detection and management of nonconvulsive seizures (NCSZs), ischemia, and elevated intracranial pressure as well as

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prognostication. Most centers, however, utilize EEG to identify NCSZs [5] that occur in approximately 10% of comatose patients [2] and have been associated with neurophysiologic disturbances, morbidity, and mortality [6–12].

Guidelines recommend frequent review of continuous EEG by neurodiagnostic technologists (NDTs) for technical quality and neurophysiologists for interpretation and clinical correlation [3]. At most centers, tracings are only reviewed remotely by neurophysiologists a few times per day [5]. In addition, bedside personnel generally do not have specific proficiencies in EEG application, troubleshooting, or interpretation. To ensure treatments are delivered in a timely manner, strategies are needed to better integrate EEG information into patient care and "bridge the gap" between bedside care providers and neurophysiologists [13]. Several simplified technologies such as electrode caps [14], abbreviated montages [15–18], and user-friendly EEG machines [19–21] have been designed to facilitate timely application of EEG by bedside healthcare professionals. Transformation of raw EEG data into more intelligible modalities such as sonified [20–23] and quantitative EEG [24] may also assist bedside care providers in detecting clinically relevant events such as NCSZs.

The accuracy of bedside care provider screening of continuous EEG for NCSZs is likely influenced by various inherent EEG and electrographic seizure characteristics. Despite these inherent factors, we hypothesize that bedside care providers can be trained to accurately perform and screen EEG in a manner that positively impacts patient care. Understanding the influence of modifiable factors such as the modality of EEG, type of bedside care provider, and the educational curriculum and teaching methods utilized to train them may aid healthcare teams in developing EEG training strategies and improving upon how EEG is integrated into the care of critically ill patients. The aim of this systematic review was twofold: first, to qualitatively summarize the curricula and teaching methods of educational programs for training non-neurophysiologists (hereafter referred to as non-experts) in the performance and screening of adult EEG and second, to quantitatively summarize the effectiveness of these educational interventions including diagnostic accuracy of non-expert screening of EEG for electrographic seizures as an indicator of NCSZs.

Methods

This systematic review was conducted according to established methodological standards and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [25–27]. The study protocol was registered in PROSPERO (https://www.crd.york.ac.uk/PROSPERO/registration number CRD42019126639).

Search Strategy

In consultation with a librarian, a search strategy was developed (Appendix 1). Search terms included EEG, education, seizures, epilepsy, interpretation, and all related synonyms. No restrictions were placed on the date of publication or the language. The search was executed on February 26, 2020, and included seven biographical databases (MEDLINE, EMBASE, Cochrane, CINAHL, WOS, Scopus, and MedEdPORTAL). Reference lists of all included articles were manually searched to identify additional studies. References were exported and managed using EndNote X7 [28].

Study Selection

All titles and abstracts were independently screened in duplicate by three blinded reviewers (JK, KMF, and AA) to identify potentially relevant studies. When corresponding author information was available, attempts were made to obtain more detailed information for selected studies only published in abstract form. Potentially relevant full-text articles and studies available only in abstract form were subsequently independently reviewed in duplicate by the same three blinded reviewers, who applied the inclusion and exclusion criteria. Disagreements were resolved by discussion or consensus with a fourth reviewer (CJ). Studies were included if they were original research; involved non-experts performing, troubleshooting, or screening any format of adult (>16 years old) EEG as part of the study; and provided qualitative descriptions of curricula and teaching methods and/or quantitative assessment of non-experts (vs gold standard EEG performance by NDTs or interpretation by neurophysiologists). Drawing from meta-synthesis methods, we purposely broadened our scope to ensure data adequacy and included studies conducted both within and outside the intensive care unit (ICU) with the assumption that some educational components in one setting could potentially be extrapolated to others [26, 27]. However, studies assessing non-expert interpretation of EEG during electroconvulsive therapy were deemed beyond the scope of this review and therefore excluded. We also limited our selection to studies involving only adult (>16 years old) EEGs, given the differences between neonatal, infant, pediatric, and adult EEGs that could affect the required knowledge, skills, and therefore curricula required for non-experts [29].

Study Quality and Risk of Bias Assessment

Three blinded reviewers (JK, KMF, and AA) independently assessed the quality of included studies using the

Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS2) tool [30]. This tool was chosen on the basis that the quantitative component of the review focusing on the effectiveness of educational programs was often reported as a measure of non-experts' ability to diagnose EEG patterns. Each study was assessed for risk of bias and applicability within four domains: patient/EEG selection, index test (non-experts' performance or screening of EEG), reference standard (NDT performance or neurophysiologist interpretation of EEG), and flow/timing of the index test in relation to the reference standard. Applicability was assessed within the broad scope of EEG education, as well as from an ICU perspective. Concerns regarding risk of bias and applicability were graded as high or low. If the study contained insufficient information about a specific domain or if it was not designed as a diagnostic accuracy study, it was graded as unclear or not applicable, respectively.

Data Synthesis

All data from included articles were independently extracted and agreed upon in duplicate by three authors (JK, KMF, and AA) using a standard Microsoft Excel [31] data form created by the study team. Appendix 1 provides a list of all extracted data. A content analysis and a meta-narrative review detailing the entire body of literature as well as a subset specific to ICU EEGs and personnel were conducted [26, 27]. Due to contextual and methodological heterogeneity, as well as limited availability of raw data, a meta-analysis was not possible. However, we did summarize the diagnostic accuracy of non-experts in identifying electrographic seizures, as the most clinically relevant quantitative outcome.

Results

Results of the Search

A total of 2430 unique studies were identified (Fig. 1). After applying inclusion and exclusion criteria, 35 studies remained.

Description of Studies

Appendix 2 presents the characteristics of the 35 included studies. We were able to obtain data for three of the six included studies published only in abstract form [32–34]. The overall number of publications on the topic of EEG education has increased since the first publication by Pauri in 1992 [35]. Since 2000, the number of publications has exponentially increased, which has largely been driven by those within the ICU and acute care settings (Fig. 2).

Fifteen studies were performed in an ICU setting, utilizing EEGs of ICU patients [18, 20, 21, 36–47]. Another nine studies were completed in acute care settings including with emergency medical services, the emergency room, and/or inpatient wards (sometimes including ICU) [14–17, 19, 22, 32, 48, 49]. Two studies were completed within seizure monitoring units [23, 35], and seven involved both inpatient and outpatient settings [33, 50–55].

Two ICU and acute care studies limited patients to those with hypoxemic ischemic brain injury [36, 37]. Otherwise, the diagnosis of patients within the ICU and acute care settings when specified varied widely within studies.

Study Quality Assessment

Three studies did not assess diagnostic (and/or pre-/post-test) accuracy and therefore could not be assessed by the QUADAS-2 tool [47, 52, 55]. For the remaining studies, the results of the QUADAS-2 assessment are shown in Fig. 3.

Educational Objectives

ICU and acute care non-experts included ICU physicians and fellows, emergency physicians, neurology residents, nurses, NDTs, and medical students. Non-experts in other studies also included neurosurgery residents. Thirty-three papers reported on training non-experts to screen EEG [14–18, 20–23, 32–47, 49–56], and nine studies reported data on non-experts performing and/or troubleshooting EEGs [14, 16, 17, 19–21, 45, 48, 49] (Table 1).

EEG Screening

Studies training non-experts to screen EEG focused on various modalities. The most common modality was raw EEG (24 studies total, 14 ICU and acute care) [14–18, 22, 23, 32–37, 39, 41, 45–47, 50–55], followed by amplitude integrated EEG (aEEG) (six studies, all ICU and acute care) [37, 38, 41, 43, 44, 49], color and/or density spectral array (CSA, CDSA, DSA) (four studies, all ICU and acute care) [40, 41, 43, 44] and sonified EEG (four studies, three ICU and acute care) [20–23]. Six studies taught non-experts to analyze combinations of modalities, most often containing aEEG (5/6 studies), followed by CSA, CDSA, and/or DSA (3/6 studies), raw EEG (2/6 studies), and rhythmicity spectrograms (2/6 studies) [37, 38, 41–44] (Table 1).

A primary focus of most EEG screening curriculums was electrographic seizure detection that in the majority of studies consisted of NCSZs (32 studies, 22 ICU and acute care) [14–18, 20–23, 32–47, 49–55]. Several studies did broaden their objectives to identification of various EEG patterns including periodic discharges, rhythmic delta activity, slowing, burst suppression, sleep architecture, normal variants and artifacts (13 studies, five ICU

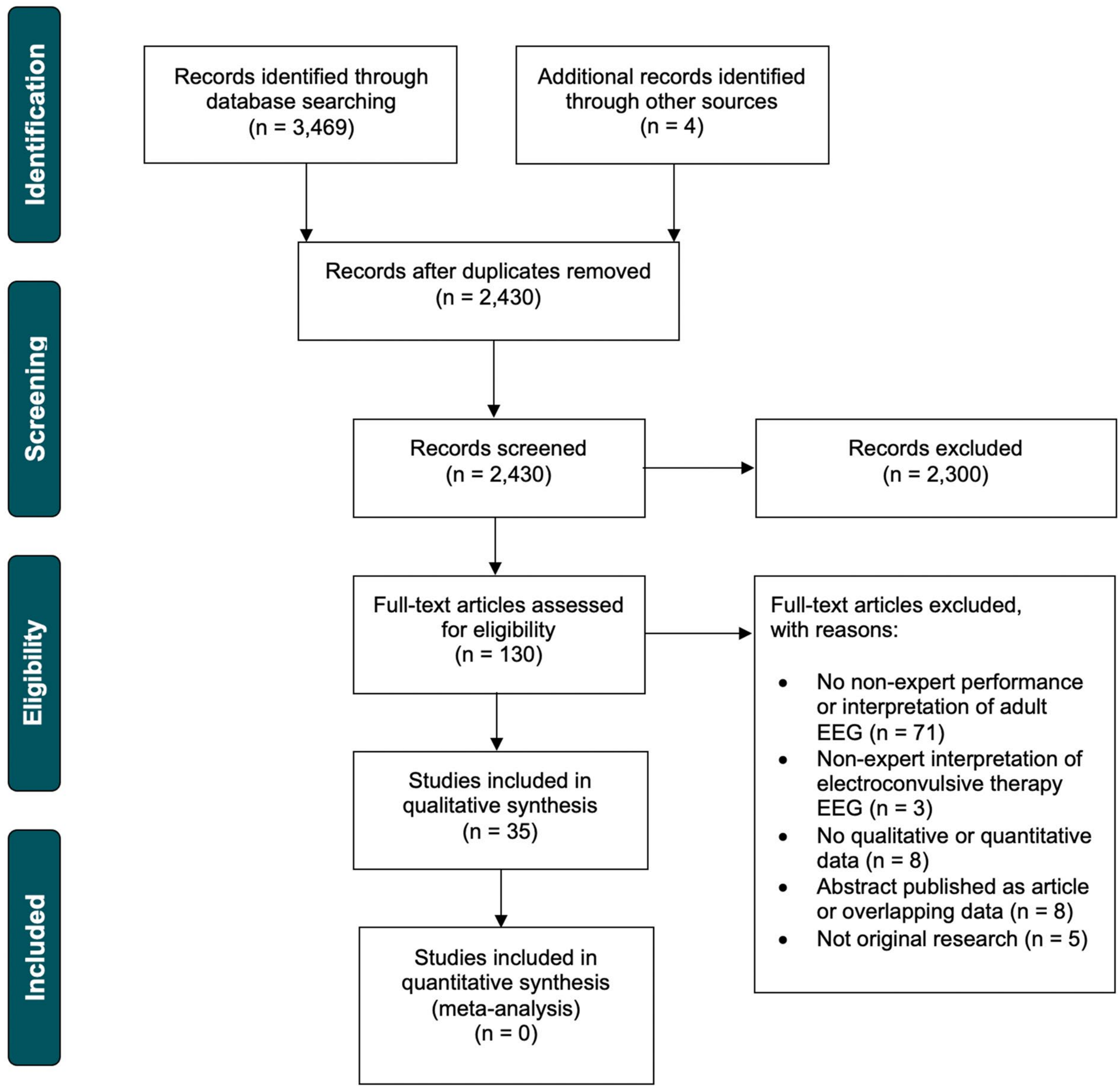

Fig. 1 PRISMA diagram of study selection

and acute care) [22, 32–34, 39, 46, 47, 50–55]. In ICU and acute care settings, this was often done with the intent of minimizing false positives when screening for seizures (Table 1).

EEG Performance

One study involved medical students performing EEGs with a full 21-electrode complement with the assistance of an electrode cap (Hydrodot EzeNet, Hydrodot Inc.) after 20 h of didactic and hands-on training [48]. Seiler and colleagues utilized a portion of their 4-h EEG curriculum toward both didactic and hands-on sessions detailing lead identification and repair, stopping/starting recordings, focusing the EEG camera and annotating [45]. Other studies focused on training non-experts to perform EEGs with abbreviated electrode complements and the assistance of simplified technology such as peel and stick electrodes and electrode caps [14, 16, 17, 19–21, 49] (Table 1).

Educational Methods

Methods of teaching varied (Table 1). The most utilized method was use of an instructional lecture whether delivered live or via video (16 studies, 14 ICU and acute care)

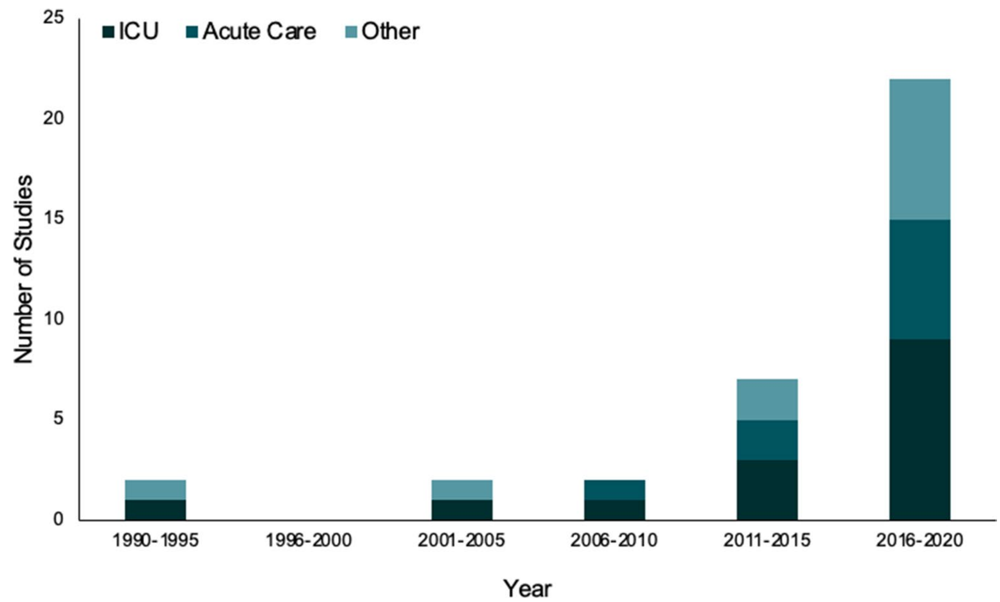

Fig. 2 Publication trend of EEG education studies

[14, 21–23, 37–40, 42, 43, 45–49, 56]. This was followed closely by practice/hands-on learning (17 studies total, 12 ICU and acute care) [14, 17, 19, 23, 32, 37–40, 45, 46, 48–52, 55]. Half of all studies utilized two or more teaching methods and most often combined instructional lectures and practice (17 studies, 13 ICU and acute care) [14, 17, 23, 32, 34, 37–40, 44–49, 52, 55].

The duration of training was mentioned by 18 studies and varied from a 4-min video to a 4-month EEG/epilepsy residency rotation [21, 51]. The longest duration of training within ICU and acute care studies focused on performing and interpreting EEGs was 20 h and 30 h, respectively [48, 54]. Only two studies mentioned ongoing, regular training of non-experts [14, 46] (Table 1).

Educational Outcomes

Figure 4 demonstrates the sensitivity and specificity of non-experts in identifying electrographic seizures using various EEG modalities. These seizures were NCSZs in all but two studies [23, 35]. The sensitivity and specificity of seizure identification varied from 38 to 100% and 65 to 100% for raw EEG; 95 to 100% and 65 to 85% for sonified EEG, and 40 to 93% and 38 to 95% for quantitative EEG, respectively (Table 1). Appendix 3 demonstrates these same values with the addition of other markers of diagnostic accuracy/agreement. Studies did not provide enough qualitative information to determine reasons for interstudy variability of non-expert sensitivity and specificity for electrographic seizures.

Most studies using pre-/posttest designs showed statistically significant improvement in scores following education with effect size varying based on the unit of measurement: 52% and 12% improvement in sensitivity and specificity for seizures, respectively ($p < 0.0001$) [32], and up to 33% improvement in test scores ($p < 0.001$) [33, 45, 53, 54].

Studies that tracked outcomes of training non-experts to perform EEGs demonstrated a statistically significant reduction in delay (86 min, $p < 0.0001$ [14]; 196 min, $p < 0.0001$ [19]; 667 min, $p < 0.005$ [20]) and setup time (8 min, $p < 0.0001$ [19]) of non-expert vs conventional EEGs. One study found no difference in the quality of non-expert compared to conventional EEG as judged by interpreting experts [19], while another found that 30% of non-expert (vs 5% conventional) EEGs were uninterpretable ($p < 0.0375$) [14]. Three studies demonstrated non-expert performed EEGs appropriately changed management approximately 40% of the time as illustrated in Fig. 5 [20, 21, 48] (Fig. 5; Table 1).

Discussion

This systematic review included 35 studies detailing quantitative and/or qualitative results of education of non-experts in the performance and screening of various EEG modalities. Contextual and methodological heterogeneity as well as limited raw data prohibited a meta-analysis; however, results were examined via a content analysis and meta-narrative process [26, 27]. The results suggest that several different members of the clinical

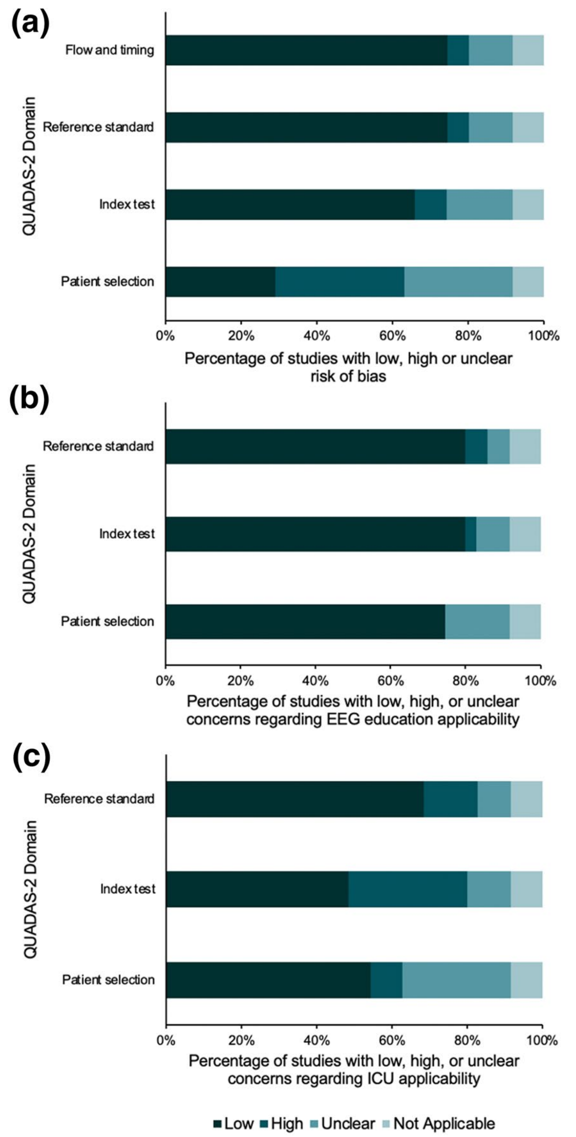

Fig. 3 QUADAS-2 results. Graphs demonstrating percentage of studies with low, high, and unclear risk of bias (**a**), general EEG education applicability concerns (**b**), and ICU applicability concerns (**c**). Risk of bias was deemed low in the majority of domains with the exception of patient selection. Patient/EEG selection was biased in several studies because non-consecutive patients/EEGs that provided good examples of various EEG patterns were purposely chosen. Concern regarding EEG education applicability was low in the majority of studies; however, when assessed in regard application within the ICU, the proportion of studies with high concerns increased across all domains. Concerns regarding ICU applicability of the index test (non-expert performance/screening of EEG) and reference standard (expert performance/interpretation of EEG) increased as several studies involved non-experts' and experts' interpretation of short EEG epochs that did not emulate the amount of EEG required to screen for ICU patients undergoing continuous EEG

team including physicians, fellows, residents, medical students, nurses, and NDTs can be educated to perform and screen EEG, particularly for the purpose of diagnosing NCSZs.

Within the acute care setting, the sensitivity of non-expert screening of sonified EEG for NCSZs was an impressive 95–100% [21, 22]. While promising, these values derive from one study with only seven non-experts that produced a wide confidence interval and another study that involved screening of a relatively small duration of EEG. Both studies had only seven seizures for non-experts to identify and were conducted within the same center. While these values are not externally validated within the acute care setting, the final study assessing non-expert screening of sonified EEG within the seizure monitoring unit of a different center produced a similar sensitivity (90%) [23]. Within the acute care setting, the sensitivities for non-expert screening of quantitative EEG for seizures varied widely from 40 to 93% [37, 38, 40–44, 49]. Specificities of non-expert screening of sonified and quantitative EEG for seizures were 65–85% and 38–95%, respectively [21, 22, 37, 38, 40–44, 49] (Table 1).

False negatives may occur with seizures that are low in amplitude, low in frequency, focal, brief, or have characteristics that prevent them from standing out compared to the EEG background [38]. False positives can arise from artifacts and other EEG patterns. Both may cause significant clinical consequences including ongoing NCSZs, neurophysiologic disturbances, morbidity, mortality, complications, increased length of stay, and additional health care costs [6–12, 20, 57]. While it is ideal and recommended to obtain confirmation of potential NCSZs identified by ICU professionals by a neurophysiologist [3], high false positive rates would cause this approach to be arduous and nonsustainable. Therefore, while techniques of screening for NCSZs require a high sensitivity, an adequate specificity and false positive rate are also advisable. Reported false positive rates for NCSZs within the acute care setting which hypothetically could translate into neurophysiologist notifications ranged from 3.2/hr to 1/10 hr in the studies [38, 40, 44].

Various modalities of quantitative EEG were taught to non-experts, including aEEG, CSA, CDSA, DSA, and rhythmicity spectrogram. These modalities were often used in combinations, making it difficult to determine whether one was superior. However, the studies that only used a single quantitative trend [37, 40, 49] produced the lowest sensitivities and specificities of all quantitative EEG studies, suggesting that combinations of trends may outperform single trends (Fig. 4; Appendix 3).

It is also possible that combining quantitative EEG screening with raw EEG confirmation may improve

Table 1 Qualitative and quantitative summary of EEG education

EEG Education					
Setting	**Acute Care ICU / ER, EMS / Inpatient**				**Inpatient & Outpatient** / **SMU**
Goals and Objectives	**Performance of EEG**		**Interpretation of EEG**		
			Sz ID [14-18, 21-23, 35-38, 49, 56]	**Sz ID and other EEG patterns** [22, 32-34, 39, 46-47, 50-55]	
	Traditional technology fm-EEG [45, 48]	Simplified technology rm-EEG [14, 17, 19-21, 49]	**Raw EEG** [14-18, 22, 32-33, 35-38, 41, 46-47, 50-55]	**Quantitative EEG** aEEG [37-38, 41, 43-44, 49] C/DSA [40-41, 43-44] Rhythmicity [38, 43] Other [41-43]	**Sonified EEG** [20-23]
Education Strategies - Target Learner	MS RNs	ICU/ER aMD Neuro fMD Neuro rMD	ER/ICU aMD, ICU fMD, neuro fMD/rMD RNs MS (not taught qEEG) NDT (not taught sonified)		
- Duration	*4hr*-20hr	*4min*-3hr	30min-30hr	15min-8hr	4min-*4hr*
- Teaching Methods	Didactic lecture (live/video) Hands on practice Written manual		Didactic lectures (live/video), small group sessions, discussions, Self-directed learning, practice with/without expert Written handbooks/manuals, EEG atlases Online and Holberg SCORE EEG platforms, EEG app		
Education Outcomes	Non-expert vs expert EEG Statistically significant reduction (86min, $p<0.0001$; 196min, $p<0.0001$; 667min, $p<0.005$) in time delay to EEG [14, 19-20] Statistically significant reduction (8min, $p<0.0001$) in EEG set up time [19] No difference in EEG quality [19] 25% EEG uninterpretable ($p<0.0375$) [14] Change in Dx work-up in 49% [48] and change in Rx in 40-42% [20-21, 48]		Sz detection 38-100% sensitivity 65-100% specificity [15-16, 18, 22, 32, 35-36] strong agreement between expert/non-expert [39]	Sz detection 40-93% sensitivity 38-95% specificity [37-38, 40, 42-44, 49] FPR 3.2/h - 1/10hr [37, 40, 44] 78% IRA [41]	Sz detection 95-100% sensitivity 65-85% specificity [20-23]

aEEG amplitude-integrated EEG; *C/DSA* color and/or density spectral array; *EMS* emergency medical services; *ER* emergency room; *fm-EEG* full montage (18-channel) EEG; *rm-EEG* reduced (<18-channel) montage EEG; *h* hour; *ICU* Intensive Care Unit; *ID* identification; *aMD* attending physician; *fMD* fellow physician; *rMD* resident physician; *min* minute; *MS* medical student; *NDT* neurodiagnostic technologist; *Neuro* Neurology; *RN* registered nurse; *SMU* seizure monitoring unit; *Sz* seizure; *tech* technologist. *Italicized* values best possible estimate based on provided information

specificity and allow non-experts to rule out artifacts and other patterns that may mimic seizures on quantitative EEG. This would warrant non-expert education of raw EEG interpretation which was shown possible in 14 acute care settings involving nurses, physicians, residents, and medical students reviewing full (18-channel) and abbreviated (2–15-channel) montage EEGs for NCSZs [14–18, 22, 32, 36, 37, 39, 41, 45–47]. Sensitivities and specificities ranged between 75 and 100% and 76 and 100%, respectively, for nurses, residents, and physicians [15, 16, 18, 22, 32, 36].

Research regarding artificial intelligence and machine learning is evolving, as are seizure detection algorithms [58, 59]. These have the potential to facilitate precision medicine within neurocritical care as well as other areas. However, there are multiple challenges related to implementing these techniques including safe implementation of data-driven conclusions [60]. A future area for research should include integration of these tools at the bedside along with non-expert screening of EEG and data-driven conclusions.

To further facilitate timely access to EEG, several technologies have been developed including abbreviated montages [15–18], peel and stick electrodes, electrode caps/bands [14], and simplified EEG machines [19–21]. Many of the included studies demonstrated that nurses, physicians, fellows, and residents can be trained to perform good quality EEGs utilizing such technology resulting in significantly reduced delays in EEG setup time and completion, as well as appropriate modifications (most often de-escalation) to treatment in approximately 40% of patients [14, 16, 17, 19–21, 49] (Fig. 5). Ruling out NCSZs may help avoid medications with unnecessary risks [57]. Yazbeck and colleagues hypothesize that this de-escalation of unnecessary treatment may lead to reduced ICU and hospital length of stay as well as healthcare costs [20]. While access to these additional technologies may not be possible for all, Zehtabchi's research protocol suggests that with a modest investment of time even medical students can be trained to perform high-quality conventional 18-channel EEG [48]. Furthermore, to assist with maintaining good-quality continuous EEG, Seiler et al. demonstrated that nurses could be trained to identify and repair faulty electrodes, set and focus the camera, start/stop recordings for investigations and procedures as well as annotate EEG [45]. Such skills could lessen the times NDTs are required to attend patients undergoing

Study	EEG Details	EEG Hours	Seizure (#)*	Non-Expert (#)	Sensitivity (95%CI)	Specificity (95% CI)
Quantitaive EEG	**# qEEG trend**					
Lybeck [37] 2020	1	284		aMD (5)	0.50 (0.44, 0.65)	0.87 (0.82, 0.90)
Kang [38] 2019	2	174		RN	0.85 (0.71, 0.93)	0.90 (0.82, 0.94)
Herta [42] 2017	6	480		RN (15)	*0.85*	0.89
Amorin [40] 2017	1	80	50%	RN (33)	0.70	0.40
Swisher [43] 2015	4	180	105	NDT (7)	0.80 (0.77, 0.83)	0.80 (0.76, 0.83)
	4	180	105	RN (5)	0.87 (0.83, 0.90)	0.62 (0.56, 0.67)
Dericioglu [44] 2015	2	615	700	RN (1)	0.92	0.94
	2	615	700	RN (1)	0.99	0.95
	2	615	700	fMD (1)	0.92	0.95
	2	615	700	rMD (1)	0.88	0.95
Nitzschke [49] 2011	1	*20*	11	aMD (4)	0.40	0.89
Sonified EEG						
Hobbs [21] 2018		*32*		aMD (2), rMD (5)	1 (0.16, 1)	0.85 (0.68, 0.95)
Parvizi [22] 2018		0.35	7	MS (34)	0.98 (0.96, 1)	0.66 (0.63, 0.69)
		0.35	7	RN (30)	0.95 (0.90, 1)	0.65 (0.61, 0.69)
Khamis [23] 2012			46	other (5)	0.90	
Raw EEG	**# channels**					
Gururangan [15] 2018	18	0.18	7	rMD (20)	0.95	0.8
	8	0.18	7	rMD (20)	0.75	0.9
	18	0.18	7	MS (42)	0.63	0.69
	8	0.18	7	MS (42)	0.38	0.86
Parvizi [22] 2018	18	0.35	7	MS (34)	0.76 (0.69, 0.84)	0.65 (0.63, 0.69)
Manez Miro [16] 2018	8		35 pt	aMD, rMD, fMD	0.92	0.97
You [36] 2017	4	19.5	15%	aMD (3)	1 (0.54, 1)	1 (0.89, 1)
Kromm [32] 2017	18	0.13	5	RN (10)	0.98	0.76
Karakis [18] 2010	18	12.7		rMD (2)	0.95	0.91
	6	12.7		rMD (2)	1	0.94
Pauri [35] 1992	15	461	253	NDT	0.74	

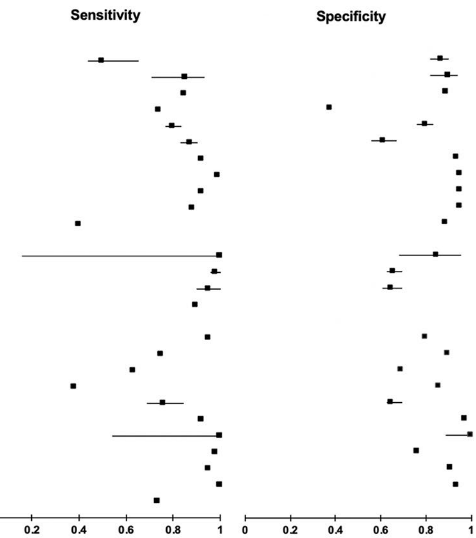

Fig. 4 Sensitivity and specificity of non-experts identifying electrographic seizures. aMD attending physician; CI confidence interval; EEG electro-encephalography; fMD fellow physician; MS medical student; qEEG quantitative electroencephalography; rMD resident physician; and RN nurse. *Number of seizures indicated unless otherwise specified. † fMD were epilepsy fellows. ‡ Sensitivity and specificity for detection of patients with seizures not total seizure count

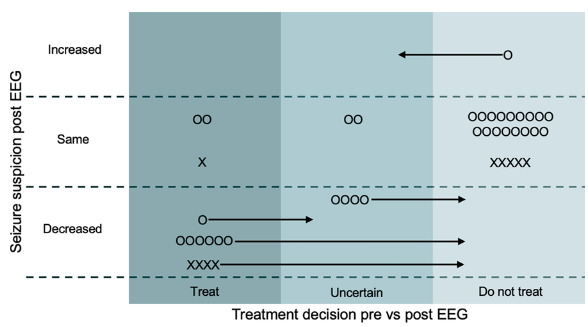

Fig. 5 Change in seizure suspicion and treatment pre- vs post-non-expert EEG. x represents individual patients from Yazbeck et al. [20]; o represents individual patients from Hobbs et al. [21]. Arrows indicate direction of change in treatment decisions (e.g., dosing of sedatives, addition/removal of antiseizure medications) for individual patients. Zetabchi et al. [48] did not report on individual patients but reported that non-expert performed EEG on patients with altered mental status helped establish the diagnosis in 59%, changed the overall work-up or disposition in 49% and changed the treatment plan in 42%

continuous EEG, leaving them with more time to focus on other responsibilities.

Education of non-expert clinical team members may help better integrate continuous EEG data into patient management, particularly in regard to timely detection and management of NCSZs that could potentially reduce neurophysiologic disturbances, mortality, and morbidity of affected patients [1, 2, 4, 6–12]. With such an approach, critical care and neurology teams could expand and intensify their continuous EEG programs through relatively inexpensive means. It is likely that much of the existing literature stems from these overarching goals given the increase in publications on this subject (Fig. 2) since formative papers were published regarding the incidence and impact of NCSZs in critically ill patients [6, 61].

The use of EEG is also expanding beyond that of NCSZ detection and management and includes ischemia monitoring [62], detection of cortical spreading depressions [63], noninvasive intracranial pressure monitoring [64], and neuro-prognostication [65–68]. No studies within this review focused on teaching bedside healthcare workers elements important for these domains and may prove to be an area for future research. It is also possible that similar teaching methods may prove useful in training bedside non-experts to utilize and interpret other multimodal neuromonitoring modalities.

This systematic review has many strengths. It used established systematic review methodology and a pre-registered protocol. We searched seven large online databases, without restrictions on language or date of publication. We also screened all reference lists of selected studies. Furthermore, the processes of title/abstract screening, full-text selection, and quality rating were performed in duplicate by three independent and blinded reviewers. Our review also has limitations. While we did search MedEdPORTAL, we may have missed grey literature and therefore studies may have been missed. We included six studies only published in abstract form in our analysis but were only able to obtain full data for three. Given the heterogeneity of studies (even within the ICU and acute care setting) as well as limited raw data, a meta-analysis was not possible. We therefore relied heavily on content analysis and meta-narrative approaches; however, some included studies provided minimal qualitative descriptions, thereby limiting this approach as well. Lastly, very few studies evaluated non-experts pre- and post-educational interventions which further limits our ability to quantitatively summarize the effectiveness of educational interventions on improving diagnostic accuracy for screening of seizures. Regardless, to our knowledge, this is the first systematic review of this important and evolving topic.

Continuing medical education for healthcare professionals is a necessity and has several potential advantages including improved patient care and outcomes, improved job satisfaction and staff retention, reduced healthcare costs, improved organizational reputations, and potentially less medical malpractice lawsuits [69, 70]. This review demonstrates that a variety of teaching methods can be utilized to train an assortment of healthcare workers in the performance and screening of EEG. To enhance the success, applicability and reproducibility of future curricula and research in this area several factors need to be addressed. Formalized curriculum development [71] and research [72] following proposed methods should be completed. Considerations should be made of learning theories [73], and curriculums, such as many studies herein, should utilize interactive formats and combined teaching methods, as these have shown previously to have greater effects than those using a didactic format and single interventions, respectively [69]. Teams need to reflect upon barriers to continuing medical education [74–76] and strategically address these through accessible (e.g., online) and versatile curricula. Lastly, the effectiveness of training needs to be measured both pre- and post-implementation, on multiple levels, including learner satisfaction, learning curves, competence and performance as well as organizational results such as patient outcomes, length of stay, and healthcare costs [69, 70, 76, 77].

Conclusion

Several different bedside providers can be educated to perform and screen adult EEG particularly for the purpose of diagnosing NCSZs. Numerous teaching methods have been utilized and often combined, with hands-on/practice and instructional techniques the most common. EEG performed by non-experts results in reduced delays in EEG setup times and completion, as well as changes in management for many patients. Sensitivity and specificity of non-experts' detection of NCSZs vary widely, and the current literature is limited in providing explanations for this. While further rigorous research is warranted, this review demonstrates several potential bridges by which EEG may be integrated into the care of patients.

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Author contributions
Julie Kromm contributed to conception and design of project, acquisition and interpretation of data, drafting and critically revising manuscript for intellectual content and has approved the final version of manuscript. Kirsten Fiest contributed to conception and design of project, acquisition of data, critically revising manuscript for intellectual content and has approved the final version of manuscript. Ayham Alkhachroum contributed to acquisition and interpretation of data, critically revising manuscript for intellectual content and has approved the final version of manuscript. Colin Josephson contributed to conception and design of project, acquisition of data, critically revising manuscript for intellectual content and has approved the final version of manuscript. Andreas Kramer contributed to conception and design of project, critically revising manuscript for intellectual content and has approved the final version of manuscript. Nathalie Jette contributed to conception and design of project, critically revising manuscript for intellectual content and has approved the final version of manuscript.

Conflict of interests
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Ethics approval
As a systematic review, this work did not require ethics approval.

Appendix 1: Search Strategy and List of Data Extracted From Studies

MEDLINE Search Strategy

1	exp electroencephalography/
2	electroencephalogra*.mp
3	EEG*.mp
4	Spectral array*.mp
5	(brain adj1 activit*).mp
6	brain wave*.mp

7	brainwave*.mp
8	electrocorticograph*.mp
9	ECOG*.mp
10	Alpha rhythm*.mp
11	Beta rhythm*.mp
12	Delta rhythm*.mp
13	Gamma rhythm*.mp
14	Theta rhythm*.mp
15	or/1–14
16	exp Education/
17	educat*.mp
18	teach*.mp
19	train*.mp
20	instruct*.mp
21	workshop*.mp
22	or/16–21
23	15 and 22
24	exp Electroencephalography/ed [Education]
25	23 or 24
26	exp Epilepsy/
27	exp Seizures/
28	epilep*.mp
29	seizure*.mp
30	convulsion*.mp
31	or/26–30
32	interpret*.mp
33	exp Diagnosis/
34	diagnos*.mp
35	di.fs
36	or/32–35
37	adolescent/
38	exp Adult/
39	adolescen*.mp
40	teen*.mp
41	youth*.mp
42	adult*.mp
43	aged.mp
44	elderly.mp
45	senior*.mp
46	or/37–45
47	15 and 25 and 31 and 36 and 46
48	remove duplicates from 47

EMBASE Search Strategy

1	exp electroencephalogram/
2	exp electrocorticography/
3	electroencephalogra*.mp
4	EEG*.mp
5	Spectral array*.mp
6	(brain adj1 activit*).mp
7	brain wave*.mp
8	brainwave*.mp
9	electrocorticograph*.mp
10	ECOG*.mp
11	Alpha rhythm*.mp
12	Beta rhythm*.mp
13	Delta rhythm*.mp
14	Gamma rhythm*.mp
15	Theta rhythm*.mp
16	or/1–15
17	exp Education/
18	educat*.mp
19	teach*.mp
20	train*.mp
21	instruct*.mp
22	workshop*.mp
23	or/17–22
24	exp "seizure, epilepsy and convulsion"/
25	epilep*.mp
26	seizure*.mp
27	convulsion*.mp
28	or/24–27
29	interpret*.mp
30	exp Diagnosis/
31	diagnos*.mp
32	di.fs
33	or/29–32
34	exp adolescent/
35	exp adult/
36	adolescen*.mp
37	teen*.mp
38	youth*.mp
39	adult*.mp
40	aged.mp
41	elderly.mp
42	senior*.mp
43	or/34–42
44	16 and 23 and 28 and 33 and 43
45	remove duplicates from 44

Cochrane Search Strategy

1	electroencephalogra*.mp
2	EEG*.mp
3	Spectral array*.mp
4	(brain adj1 activit*).mp
5	brain wave*.mp
6	brainwave*.mp

7	electrocorticograph*.mp
8	ECOG*.mp
9	Alpha rhythm*.mp
10	Beta rhythm*.mp
11	Delta rhythm*.mp
12	Gamma rhythm*.mp
13	Theta rhythm*.mp
14	or/1–13
15	educat*.mp
16	teach*.mp
17	train*.mp
18	instruct*.mp
19	workshop*.mp
20	or/15–19
21	epilep*.mp
22	seizure*.mp
23	convulsion*.mp
24	or/21–23
25	interpret*.mp
26	diagnos*.mp
27	25 or 26
28	adolescen*.mp
29	teen*.mp
30	youth*.mp
31	adult*.mp
32	aged.mp
33	elderly.mp
34	senior*.mp
35	or/28–34
36	14 and 20 and 24 and 27 and 35

CINAHL Search Strategy

S1	(MH "Electroencephalography")
S2	electroencephalogra*
S3	EEG*
S4	Spectral array*
S5	(MH "Brain Waves")
S6	brain N1 activit*
S7	brain wave*
S8	brainwave*
S9	electrocorticograph*
S10	ECOG*
S11	Alpha rhythm*
S12	Beta rhythm*
S13	Delta rhythm*
S14	Gamma rhythm*
S15	Theta rhythm*
S16	S1 OR S2 OR S3 OR S4 OR S5 OR S6 OR S7 OR S8 OR S9 OR S10 OR S11 OR S12 OR S13 OR S14 OR S15
S17	(MH "Education + ")
S18	educat*
S19	teach*
S20	train*
S21	instruct*
S22	workshop*
S23	S17 OR S18 OR S19 OR S20 OR S21 OR S22
S24	S16 AND S23
S25	(MH "Electroencephalography/ED")
S26	(MH "Electroneurodiagnostic Technologists/ED")
S27	S24 OR S25 OR S26
S28	exp Epilepsy/
S29	exp Seizures/
S30	epilep*
S31	seizure*
S32	convulsion*
S33	S28 OR S29 OR S30 OR S31 OR S32
S34	interpret*
S35	(MH "Diagnosis + ")
S36	diagnos*
S37	S34 OR S35 OR S36
S38	(MH "Adult + ")
S39	(MH "Adolescence + ")
S40	adolescen*
S41	teen*
S42	youth*
S43	adult*
S44	aged
S45	elderly
S46	senior*
S47	S38 OR S39 OR S40 OR S41 OR S42 OR S43 OR S44 OR S45 OR S46
S58	S16 AND S27 AND S33 AND S37 AND S47

Web of Science Search Strategy

TOPIC: (Electroencephalogra* OR EEG* OR spectral array* OR brain activit* OR brain electric activit* OR brain wave* OR brainwave* OR electrocorticograph* OR ECOG* OR Alpha rhythm* OR Beta rhythm* OR Delta rhythm* OR Gamma rhythm* OR Theta rhythm*)

AND

TOPIC: (educat* OR teach* OR train* OR instruct* OR workshop*)

AND

TOPIC: (epilep* OR seizure* OR convulsion*)

AND

TOPIC: (interpret* OR diagnos*)

AND

TOPIC: (adolescen* OR teen* OR youth* OR adult* OR aged OR elderly OR senior*)

SCOPUS Search Strategy

(TITLE-ABS-KEY (electroencephalogra* OR eeg* OR "spectral array" OR "spectral arrays" OR "brain activity" OR "brain activities" OR "brain electric activity" OR "brain electric activities" OR "brain wave" OR "brain waves" OR brainwave OR brainwaves OR electrocorticograph*)
AND
TITLE-ABS-KEY (educat* OR teach* OR train* OR instruct* OR workshop*)
AND
TITLE-ABS-KEY (epilep* OR seizure* OR convulsion*)
AND
TITLE-ABS-KEY (interpret* OR diagnos*)

MedEdPORTAL Search Strategy

ANYWHERE: (EEG)
OR
ANYWHERE: (Seizure)
OR
ANYWHERE (Epilepsy)

Data Extracted from Studies

The following data were extracted when possible:

- Study information
  - Author
  - Year
  - Country
- Non-expert information
  - Number of non-experts
  - Demographics
    - Age
    - Sex
    - Healthcare profession
      - Nurse
      - Neurodiagnostic technologist
      - Medical student
      - Resident (specialty noted)
      - Fellow (specialty noted)
      - Attending physician (specialty noted)
      - Years of experience in current profession
- EEG Curriculum information
  - Learning Theories
  - Objectives
  - Content
  - Teaching methods
  - Duration
  - Resources provided to learners
  - Learner feedback regarding curriculum
- EEG information
  - Method of selection
  - Number
  - Duration
  - Type of EEG
    - Raw EEG defined as montaged EEG (number of channels noted)
    - Sonified EEG
    - Quantitative EEG—specific trends noted including:
      - Amplitude integrated EEG
      - Color spectral array
      - Color density spectral array
      - Density spectral array
      - Rhythmicity spectrogram
      - Asymmetry spectrogram
      - Seizure/pattern indicators
      - Other
  - Demographics of patients whose EEGs were performed/reviewed by non-experts
    - Age
    - Diagnosis
    - Location including
      - Intensive Care Unit
      - Emergency room
      - Hospital ward
      - Seizure monitoring unit
      - Outpatient setting

    - Other
- EEG patterns (criteria used and numbers of) to be identified by non-experts
    - Electrographic seizures
    - Periodic discharges
    - Rhythmic delta activity
    - Slowing
    - Burst suppression
    - Artifacts
    - Normal patterns
    - Other
- Details of gold standard comparison
    - EEG performance/interpreted by neurodiagnostic technologist/neurophysiologist
    - Type of EEG performed/interpreted noted including
        - Raw EEG defined as montaged EEG (number of channels noted)
        - Sonified EEG
        - Quantitative EEG—specific trends noted similar to above
- Non-expert quantitative outcomes
    - Time required to review EEG and comparisons to gold standard
    - Time required to perform EEG and comparisons to gold standard
    - Diagnostic accuracy (for any of the above noted patterns)
        - True positives
        - True negatives
        - False positives
        - False negatives
        - Sensitivity
        - Specificity
        - Kappa values
        - Interrater agreement
        - Percent agreement
        - Pre-curriculum test results
        - Post-curriculum test results
        - Other
    - Measures of changes in patient management

Appendix 2: Summary of EEG education studies

Author Location (year)	Patient Number & Diagnoses†	Non-expert Number & Position††	EEG Type‡	Qualitative Education Description‡‡		Tracing Number & Duration*	Quantitative Education Outcomes**
INTENSIVE CARE UNIT							
Lybeck [37] Sweden (2020)	37 HIBI	5 ICU aMD	Raw EEG 2 channel aEEG	Objective Methods	identification of Sz on raw and aEEG lectures, case-based discussion, interpretation of EEG with expert assistance, practice assignment with vodcast detailing answers/approach 1-day course	71 284hr	Sz detection (including experts) 50% sensitivity (95% CI, 44-65%) 87% specificity (95% CI, 82-90%) Kappa 0.43 (non-experts and experts)
Yazbeck [20] USA (2019)	10 AMS	RN 3 ICU aMD	Raw EEG 8 channel Sonified EEG	Objective	operating (RNs) and interpreting (MDs) sonified Ceribell EEG	10	Less delay with non-expert EEG vs conventional EEG 5.0 +/- 2.4min vs 11.2 +/-3.6hr (p<0.005) Change in Rx decisions in 40% of patients
Kang [38] USA (2019)	20 TBI AIS ICH encephalitis epilepsy	RN	aEEG Rhythmicity spectrogram	Objective Methods	identification of Sz on qEEG lecture, bedside examples of current patients Sz for reference 15min	20 174hr	Sz detection 85.1% sensitivity (95% CI, 71.1-93.3%) 89.8% specificity (95% CI, 82.2-94.2%) FPR 1/10hr Best at identifying >1min and hemispheric Sz
Ding [39] Canada (2019)		16 Neuro rMD	Raw EEG clips 18 channel	Objective Content Methods	understand and apply ACNS critical care EEG terminology ACNS critical care EEG patterns lecture, self-study including reading and training slides/practice 2hr	37	Sz detection Percent Agreement (with experts) 86.4% Kappa (non-experts) 0.82
Hobbs [21] USA (2018)	34 TBI SAH AIS ICH encephalitis	2 ICU aMD 5 Neuro fMD	Sonified EEG	Objective Content Methods	identification of Sz with sonified EEG application, use and interpretation of Ceribell EEG video 4min	35 *32hr*	Median time delay to Ceribell vs conventional EEG 23min vs 145min Sz detection vs expert interpretation of 8 channel raw EEG 100% sensitivity (95% CI, 16-100%) 85% specificity (95% CI, 68-95%) Changes in Rx decisions occurred in 40% of patients → significant net 27% reduction (p=0.01) in unnecessary Rx
You [36] Korea (2017)	39 HIBI	3 ER aMD	Raw EEG 4 channel			39 19.5hr	Sz detection 100% sensitivity (95% CI, 54.1-100%) 100% specificity (95% CI, 89.4-100%)
Amorim [40] USA (2017)	30 TBI SAH AIS ICH encephalitis tox-metabolic epilepsy	33 RN	CSA	Objective Content Methods	identification of Sz on CDSA EEG theory, CDSA theory and interpretation small group didactic session, practice and discussion 40min	30 80hr	Sz (50% prevalence) detection 73.8% sensitivity 37.6% specificity FPR 3.2/hr
Citerio [41] Italy (2017)		ICU aMD	Raw EEG 6 channel DSA aEEG BS rate	Objective Methods	qEEG interpretation online course	1740hr	Sz detection vs expert interpretation 6 channel raw and qEEG. 80.2% of EEGs with Sz identified
Herta [42] Austria (2017)		15 RN 3 Other	NeuroTrend qEEG	Objective Content Methods	identify EEG patterns on NeuroTrend qEEG NeuroTrend software, EEG patterns (PD, SW, rhythmic activity) lecture 1hr	20 480hr	Sz detection / localization *84.5%* sensitivity 88.7% specificity 78.0% / 92.3% IRA
Swisher [43] USA (2015)	45 TBI AIS ICH HIBI epilepsy	7 NDT 5 RN	aEEG clips CDSA clips Rhythmicity spectrogram clips Asymmetry clips	Objective Content Methods	identification of Sz on qEEG. science of qEEG and premise of Sz detection lecture 15min	180 180hr	Sz (105) detection by NDT / RN 79.7% / 87.1% sensitivity 79.8% / 61.6% specificity
Dericioglu [44] Turkey (2015)	20 AIS ICH HIBI encephalitis tox-metabolic epilepsy	1 ICU fMD 1 Neuro rMD 2 RNs	aEEG DSA	Objective Content Methods	identification of Sz on aEEG and CDSA theoretical knowledge and aEEG/CDSA examples small group and individual learning 5-6hr	20 615hr	Sz (700) detection 93% sensitivity 95% specificity FPR 1 Sz/6hr
Seiler [45] USA (2012)		47 RN	Raw EEG	Objective Content Methods	logistics and interpretation of cEEG prevalence of Sz in ICU, EEG basics, electrographic Sz, EEG troubleshooting lecture, small group sessions and practice, bedside manual/checklist 4hr		Pre/post knowledge/skill testing questions Immediate post: mean 18.5 (range, 14-20) Comparison with pre t = -15.093, df = 46, p<0.001 30-day delayed post: mean 17.3 (range, 12-20) Comparison with pre t = -12.42, df = 44, p<0.001

Karakis [18] USA (2010)		2 Neuro rMD	Raw EEG clips 18 channel 6 channel (hairline)			38 12.7hr	Sz detection with 18 channel /6 channel hairline montage EEG 95% / 100% sensitivity 91% / 94% specificity
Young [46] Canada (2005)	55 TBI SAH AIS ICH DVST CNS tumor tox-metabolic	RN	Raw EEG 18 channel	Objective Methods	raw cEEG interpretation Jordan et. al program and weekly EEG reading with expert		
Jordan [47] USA (1993)		RN	Raw EEG 18 channel	Objective Methods	raw cEEG interpretation instructional video, EEG handbook, ICU EEG reference manual 8+hr		
ACUTE CARE (includes ICU, ER and/or hospital ward)							
McKay [14] USA (2019)	20 ICH HIBI tox-metabolic meningitis myoclonus epilepsy	12 Neuro rMD	Raw EEG 20 channel	Objective Content Methods	perform and interpret EEGs using electrode cap EEG electrode cap and computer information instructional training sessions (1hr) and residency EEG/epilepsy rotations	20	Less delay (median) with non-expert EEG median vs conventional EEG 22.5min vs 104.5min p<0.0001 EEG quality 70% non-expert EEG interpretable vs 95% conventional EEGs (p<0.0375) Sz (3 patients) detection 2 false negatives 1 true positive
Parvizi [22] USA (2018)	84 AMS	34 MS 30 RN	Raw EEG clips 18 channel Sonified EEG clips	Objective Content Methods	identification of Sz and other patterns on raw and sonified EEG. review of Sz and other EEG patterns video 4min	84	Sz (7) detection on sonified EEG MS 98% sensitivity (95% CI, 96-100%) 66% specificity (95% CI, 63-69%) RN 95% sensitivity (95% CI, 90-100%) 65% specificity (95% CI, 61-69%) Sz (7) detection on raw EEG MS 76% sensitivity (95% CI, 69-84%) 65% specificity (95% CI, 58-73%)
Gururangan [15] USA (2018)	AMS	20 Neuro rMD 42 MS	Raw EEG 18 channel 8 channel			88	Sz (7) detection on 18 / 8 channel raw EEG Neuro rMD 95% / 75% sensitivity 80% / 90% specificity MS 63% / 38% sensitivity 69% / 86% specificity
Manez Miro [16] Spain (2018)	129 HIBI myoclonus tox-metabolic epilepsy	Neuro aMD Neuro rMD NeurofMD†††	Raw EEG 8 channel			135	Non-convulsive status epilepticus (35 pt) vs final discharge diagnosis 92.1% sensitivity 97.2% specificity
Kromm [32] Canada (2017)		14 RN	Raw EEG clips 18 channel	Objective Content Methods Assess	interpret raw EEG and identify Sz neuroanatomy, Sz and EEG theory, EEG patterns: normal, slowing, Sz, IIC, artifacts. Kern's approach - spiral curriculum with 15 interactive online tutorials and associated practice modules providing instant feedback average 7hr survey and in-person feedback on curriculum	15	Pre / post Sz detection of 10 RN who completed entire study 46% / 98% sensitivity (p<0.0001) 64% / 76% specificity (p<0.0001) Most common EEG patterns to generate false positives: burst suppression (specificity 14%) inter-ictal SW (specificity 21%) FIRDA (specificity 43%) Lateralized PD (specificity 50%)
Ladino [19] Canada (2016)	19 AIS ICH encephalitis tox-metabolic epilepsy	2 Neuro fMD	Raw EEG StatNet device 18 channel	Objective Content Methods	train non-expert to perform StatNet EEG application of electrodes, machine operation hands on training 3hr	19 9.5hr	StatNet / routine EEG 22.42 / 217.74 min mean delay (p<0.0001) 9.98 / 17.88 min mean set up time (p<0.0001) No difference in EEG quality
Zehtabchi [48] USA (2014)	149 AMS	MS	Raw EEG	Objective Methods	perform conventional 18 channel EEG using micro-EEG (wireless EEG device) lecture and supervised practice 20hr		Change in Dx work-up 49% (95% CI, 38-60%) Change in Rx 42% (95% CI, 31-54%)
Nitzschke [49] Germany (2011)	56 AMS	12 EMS aMD 4 ICU aMD	Raw EEG clips 1 channel aEEG	Objective Methods	train ER aMDs to perform single channel EEG and ICU aMDs to identify Sz on aEEG brief lecture on performing EEG followed by hands on training and a 30 aEEG practice session 2+hr	56 *20hr*	Sz (11) detection vs expert interpreting single channel raw EEG 40% sensitivity (range, 40-60%) 89% specificity (range, 87-93%)

Bubrick [17] USA (2010)	39 AMS	Neuro rMD	Raw EEG 6 channel (BTH)	Objective	perform BTH EEG and identify epileptiform	39 3min-3hr each	Epileptiform patterns (16) detection vs expert interpreting BTH 6 channel raw EEG 0 false positive 1 false negative
				Content	patterns anatomic landmarks, electrode placement, EEG machine operations		
				Methods	hands on session and written manual		
INPATIENT and OUTPATIENT							
Eldoen [50] (2018)		NDT	Raw EEG	Objective	Interpretation and reporting of EEG	100	EEG findings/conclusions 10 false positive 1 false negative
				Methods	Holberg SCORE EEG education platform		
Dericiolgu [51] Turkey (2018)		11 Neuro rMD	Raw EEG clips	Objective	EEG interpretation	30	Skill testing questions 28-60% correct, not affected by duration (3 vs 4mth) of training nor time from training
				Methods	clinical rotation during residency training (3-4mth)		
Benson [33] USA (2018)		15 Neuro rMD	Raw EEG clips 18 channel	Objective	recognition of EEG patters		Pre/post skill testing questions Pre score 73.8% (SD 19) Immediate post score 89.3% (SD 11, p=0.0038)
				Content	55 EEG atlas including normal and variants, slowing, epileptiform patterns, artifacts		
				Methods	app 30min		
Moeller [55] USA/Canada (2017)		21 Neuro rMD	Raw EEG	Objective	understand and apply basic aspects of EEG interpretation		
				Content	EEG theory/logistics, normal awake/asleep EEG, abnormal EEG patterns, artifacts		
				Methods	Flipped classroom approach involving 10 online videos to be watched prior to EEG/epilepsy rotation		
Clary [52] USA (2017)		Neuro rMD		Objective	redesign of EMU/epilepsy		
				Content	emphasize EEG reading and Sz management		
				Methods	supervised EEG reading and patient management combined with structured independent educational activities		
Weber [54] USA (2016)		20 Neuro rMD	Raw EEG clips	Objective	identify normal and abnormal EEG patterns		Pre/post skill testing questions 42.7% (95% CI, 36.9-48.5%) 75.4% (95% CI, 70.7-80.2%) p<0.001
				Content	normal EEG and variants, stimulation procedures, slowing, Sz, PD, electrocerebral silence, artifacts 20 interactive teaching modules		
				Methods	16-30hrs		
Leira [53] USA (2004)		15 Neuro rMD 3 NSx rMD 3 ICU fMD 26 RN 3 NDT	Raw EEG clips	Objective	identify epileptiform discharges		Pre/post skill testing questions (p=0.002) All 61.3% / 66.9% Neuro rMD 75.3% / 80 % NSx rMD 58.3% / 61.1% ICU fMD 48.6 %/ 52.8% NDT 94.4% / 93% NICU RN 50.7% / 55.9% MICU RN 46.5% / 58.3% Ward RN 55.7% / 63%
				Content	EEG basics, normal EEG, artifacts, epileptiform discharges		
				Methods	computer based PowerPoint lecture		
SEIZURE MONITORING UNIT							
Khamis [23] Australia (2012)	10 epilepsy	5 "auditory participants"	Sonified EEG	Objective	identify Sz on sonified EEG.	30	Sz (46) detection 89.6% sensitivity 0.0065/hr FPR
				Content	sonified EEG software, characteristics of Sz and other EEG abnormalities		
				Methods	lecture, discussion, practice 4+hr		
Pauri [35] USA (1992)	12 epilepsy	NDT	Raw EEG 15 channel			12 461hr	Sz (253) detection vs expert interpreting 15 channel raw EEG 73.5% sensitivity
OTHER							
Hughes [56] USA (2018)		Neuro aMD		Objective	improve knowledge of the use and interpretation of EEG for Sz detection		Pre/post-test knowledge testing questions Significant p<0.05 improvements observed in several categories and 28% of neurologists reported an increase in confidence.
				Methods	vodcast 30min		
Barratt [34] USA (2015)	epilepsy sleep disorder	200 MS	Raw EEG clips	Objective	understand basics of sleep disorders and the use of EEG in their diagnosis and management		Individual/Group readiness assurance test scores 89% (range 40-100%) 99.8% (range 96-100%)
				Content	indications for EEG and polysomnography, normal awake/asleep EEG, abnormal EEG patterns, artifacts, clinical features and management of sleep disorders		
				Methods	comprehensive image-rich reading assignment followed by individual and team readiness assurance tests prior to team based learning activities		

†Patient Diagnoses: AIS acute ischemic stroke; AMS altered mental status; CNS central nervous system; DVST dural venous sinus thrombosis; HIBI hypoxemic ischemic brain injury; ICH intracerebral hemorrhage; SAH subarachnoid hemorrhage; TBI traumatic brain injury; tox-metabolic toxic-metabolic encephalopathy.
††Non-expert Positions: ER emergency room; EMS emergency medical services; ICU intensive care unit; aMD attending physician; fMD fellow physician; rMD resident physician; MICU Medical Intensive Care Unit; MS medical student; NDT neurodiagnostic technologist; Neuro Neurology; NICU Neurologic Intensive Care Unit; NSx Neurosurgery; RN nurse
†††fMD in study included epilepsy fellows
‡EEG Type: Clip indicates epochs of relevant EEG utilized, not full EEG recording. If not otherwise indicated full 18 plus channel EEG utilized. aEEG amplitude integrated EEG; BS rate burst suppression rate; BTH below the hairline montage; CSA color spectral array; CDSA color density spectral array; DSA density spectral array; qEEG quantitative EEG
‡‡Qualitative Education Description: ACNS American Clinical Neurophysiology Society; EMU epilepsy monitoring unit; FIRDA Frontal Intermittent Rhythmic Delta Activity; PD periodic discharges; SW spike/sharp wave; Sz seizure
*Tracing Number and Duration: unless otherwise specified total EEG numbers and duration. *Italicized* values estimates based on total number of EEG tracings and mean duration of each tracing. hr hours; min minutes
**Quantitative Education Outcomes: All outcomes reported in reference to gold standard of expert neurophysiologist reviewing 18 plus channel EEG unless otherwise specified. (#) indicates number of true positive seizures unless otherwise specified. *Italicized* values best estimates based on study data. CI confidence interval; FPR false positive rate; IRA interrater agreement

Appendix 3: Sensitivity, Specificity, and Other Markers of Accuracy/Agreement of Non-Experts Identifying Electrographic Seizures

Author (year)	Non-expert† Number & Position	EEG Type‡	EEG Number & Duration‡‡	Sensitivity* (95%CI)	Specificity* (95% CI)	Other**
QUANTITATIVE EEG (+/- Raw EEG)						
Lybeck [37] (2020)	5 ICU aMD	Raw EEG (2 channel) aEEG	71 / 284hr	0.50 (0.44, 0.65)	0.87 (0.82, 0.90)	k 0.43 (ICU aMDs and experts)
Kang [38] (2019)	RN	aEEG Rhythmicity spectrogram	20 / 174hr	0.85 (0.71, 0.93)	0.90 (0.82, 0.94)	FPR 1/10hr RNs better at diagnosing hemispheric and >1min Sz
Citerio [41] (2017)	ICU aMD	Raw EEG (6 channel) DSA aEEG BS rate	1740hr			80.2% of EEGs with Sz identified
Herta [42] (2017)	15 RN 3 other	NeuroTrend qEEG	20 / 480h	*0.85*	0.89	Sz detection 78.0% IRA Sz localization 92.3% IRA
Amorin [40] (2017)	33 RN	CSA	30 / 80hr	0.74	0.38	FPR 3.2/hr
Swisher [43] (2015)	7 NDT 5 RN	qEEG panel clips aEEG CDSA Rhythmicity spectrogram Asymmetry spectrogram	180 / 180hr	NDTs 0.80 (0.77, 0.83) RNs 0.87 (0.83, 0.90)	NDTs 0.80 (0.76, 0.83) RNs 61.6 (56.4, 66.5)	
Dericioglu [44] (2015)	1 ICU fMD 1 Neuro rMD 2 RN	aEEG CDSA	20 / 615hr	ALL 0.93 fMD 0.92 rMD 0.88 RN1 0.92 RN2 0.99	ALL 0.95 fMD 0.95 rMD 0.95 RN1 0.94 RN2 0.95	FPR 1/6hr
Nitzschke [49] (2011)	4 ICU aMD	aEEG	56 / *20hr*	0.40 (range 0.40, 0.60)	0.89 (range 0.87, 0.93)	
SONIFIED EEG (+/- Raw EEG)						
Hobbs [21] (2018)	2 ICU aMD 5 Neuro rMD	Sonified EEG (8 channel)	35 / *32hr*	1 (0.16, 1)	0.85 (0.68, 095)	Changes in Rx in 40% of patients → significant 27% reduction (p=0.01) in unnecessary Rx
Parvizi [22] (2018)	34 MS 30 RN	Sonified EEG clips	84	MS 0.98 (0.95, 1) RN 0.95 (0.90, 1)	MS 0.66 (0.63, 069) RN 0.65 (0.61, 0.69)	
Khamis [23] (2012)	5 "auditory participants"	Sonified EEG	30	0.90		FPR 0.0065/h
RAW EEG						
Ding [39] (2019)	16 Neuro rMD	Raw EEG clips	37			PA% (vs experts) 86.4% k (non-experts) 0.82
Gururangan [15] (2018)	20 Neuro rMD 42 MS	Raw EEG Raw EEG (8 channel)	44 /0.18hr 44 / 0.18hr	Neuro rMD 0.95 / MS 0.63 Neuro rMD 0.75 / MS 0.38	Neuro rMD 0.80 / MS 0.69 Neuro rMD 0.90 / MS 0.86	
Parvizi [22] (2018)	34 MS	Raw EEG clips	0.35hr	0.76 (0.69, 0.84)	0.65 (0.63, 069)	
Manez Miro [16] (2018)	Neuro aMD Neuro rMD Neuro fMD††	Raw EEG (8 channel)	135	0.92‡	0.97‡	
You [36] (2017)	3 ER aMDs	Raw EEG (4 channel)	39 / 19.5hr	1 (0.54, 1)	1 (0.89, 1)	
Kromm [32] (2017)	10 RNs	Raw EEG clips	15 / 0.13hr	0.98	0.76	
Karakis [18] (2010)	2 Neuro rMD	Raw EEG Raw EEG (6 channel)	38 / 12.7hr	0.95 1	0.91 0.94	
Pauri [35] (1992)	NDTs	Raw EEG (15 channel)	15 / 461hr	0.74		

†Non-expert Number and Positions: ER emergency room; ICU intensive care unit; aMD attending physician; fMD fellow physician; rMD resident physician; MS medical student; NDT neurodiagnostic technologist; Neuro Neurology; RN nurse
††fMD in study included epilepsy fellows
‡EEG Type: Clip indicates epochs of relevant EEG utilized. If not otherwise indicated full 18 plus channel EEG utilized. aEEG amplitude integrated EEG; BS rate burst suppression rate; CSA color spectral array; CDSA color density spectral array; DSA density spectral array
‡‡EEG Number and Duration: total EEG numbers and duration. *Italicized* values estimates based on total number of EEG tracings and mean duration of each tracing. hr hour
*Sensitivity and Specificity: unless otherwise indicated (#) indicates 95% CI (confidence interval). *Italicized* values best estimates based on study data.
**Other: indicates other diagnostic accuracy indicators. FPR false positive rate; IRA interrater agreement; k Kappa; min minute; PA% Percent Agreement; Rx treatment; Sz seizure

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