EEG in Critical Care-
From patterns to decision:
Translating EEG into Clinical Action

Kanokwan Boonyapisit, MD.

Department of Medicine

Siriraj Hospital

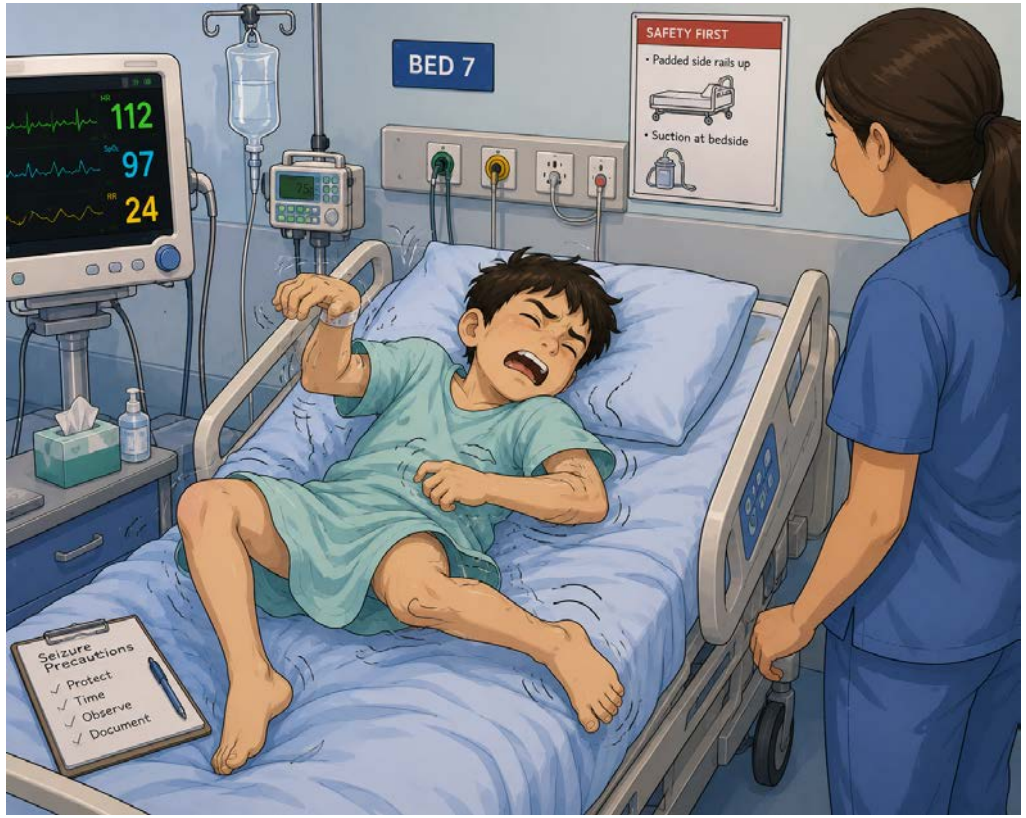
Mahidol University
Faculty of Medicine Siriraj Hospital

SI-NEURO

Use of EEG in the inpatient settings

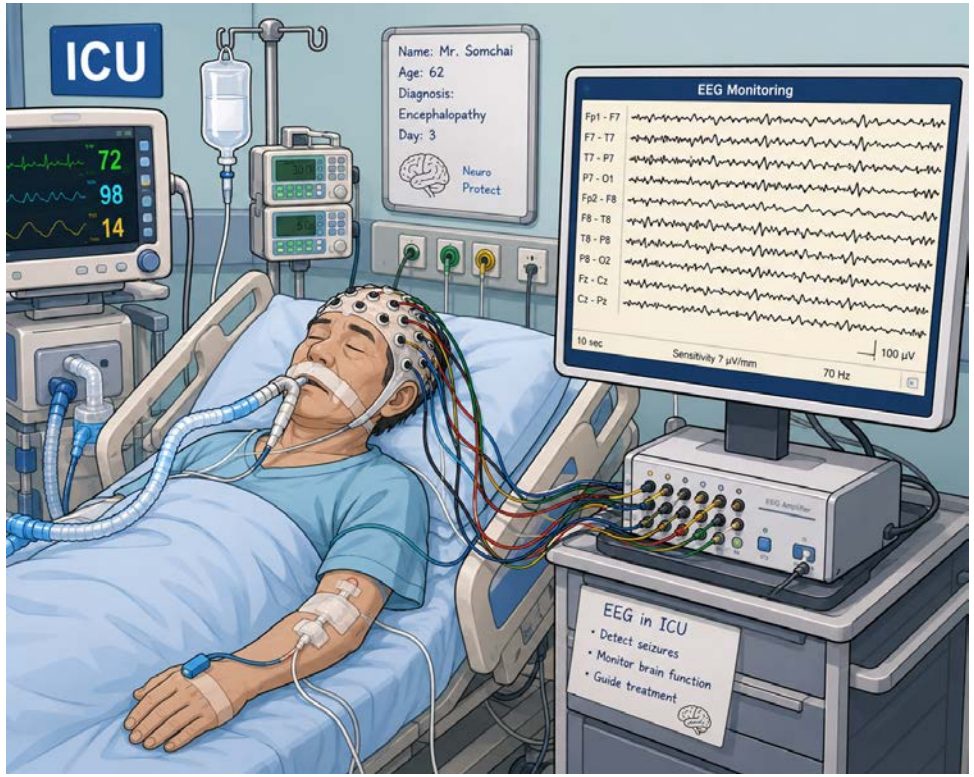
Use of EEG in the inpatient settings

- 1. Assist in the diagnosis of transient episodes



Use of EEG in the inpatient settings

- 2. For the diagnosis of nonconvulsive seizures in patients with alteration of consciousness in the ICU

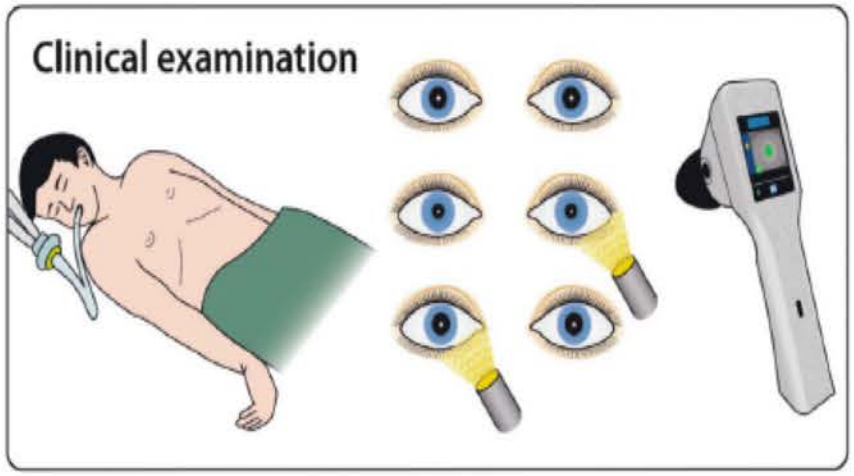


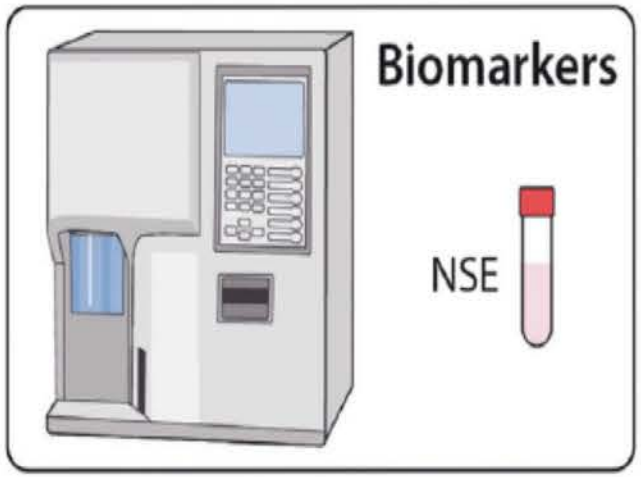
Use of EEG in the inpatient settings

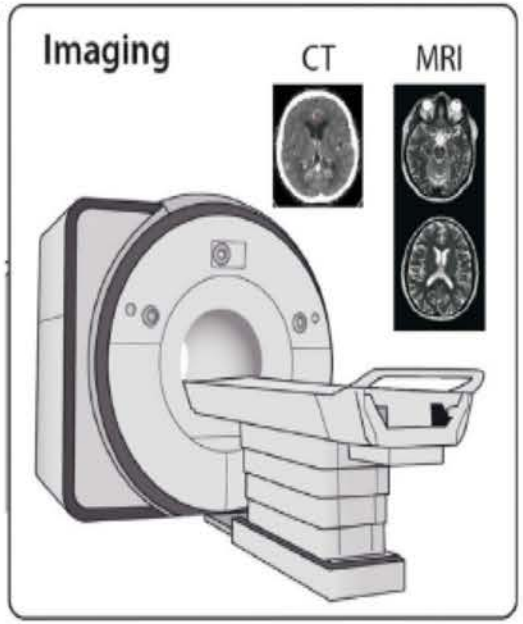
- 3. For management of status epilepticus eg. guide in medication titration

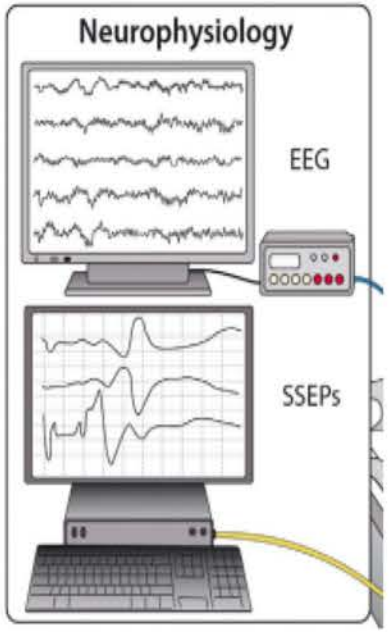
Use of EEG in the inpatient settings

- 4. Use together with multimodal methods to determine prognosis in post cardiac arrest patients









EEG interpretation in the inpatient settings

What do you need to know before EEG reading?

- Age
- State of consciousness

Clinical history
Neuroimaging
Prior EEG findings
Video during the EEG recording

What are on EEG records?

- Normal physiologic rhythm
  - Normal rhythm
  - Normal variants
- Abnormal physiologic rhythm
  - Epileptiform abnormalities
  - Non epileptiform abnormalities
- Artifact:
  - Physiologic artifacts
  - Nonphysiologic artifacts

Steps

- Check
  - Montages
  - Filter
  - Sensitivities
- Describe EEG

Describe

- Normal physiologic rhythm
  - Normal rhythm
  - Normal variants
- Abnormal physiologic rhythm
  - Epileptiform abnormalities
  - Non epileptiform abnormalities
- Artifact:
  - Physiologic artifacts
  - Nonphysiologic artifacts

EEG waveform characteristics

- Frequency: delta (<4 Hz), theta (4-7 Hz), alpha (8-13 Hz), Beta (>13 Hz)
- Voltage
- Waveform
- Occurrence: intermittent, continuous
- Location
- Reactivity
- Interhemispheric coherence: symmetry, synchrony

What are on EEG records?

- Normal physiologic rhythm
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Potential sources of artifact when recording EEG in the ICU

Patient
Eyes and eyelids (eye movement, eyelid flutter, blinking, nystagmus, bobbing, etc.)
Orolingual movements (glossokinetic potential, chewing, etc.)
Muscle activity (myoclonus, micro-shivering, jaw clenching, tremor, etc.)
Cardiovascular activity (EKG, pulse artifact, etc.)
Respiration
Sweat
Patting/rocking (especially in infants)
Continuous EEG setup
Electrodes (instability, electrode pop, unequal impedances)
Wires
Jacks/jackboxes

Gaspard N, Hirsch LJ. Neurology 2013;80 :S26–S42

Potential sources of artifact when recording EEG in the ICU

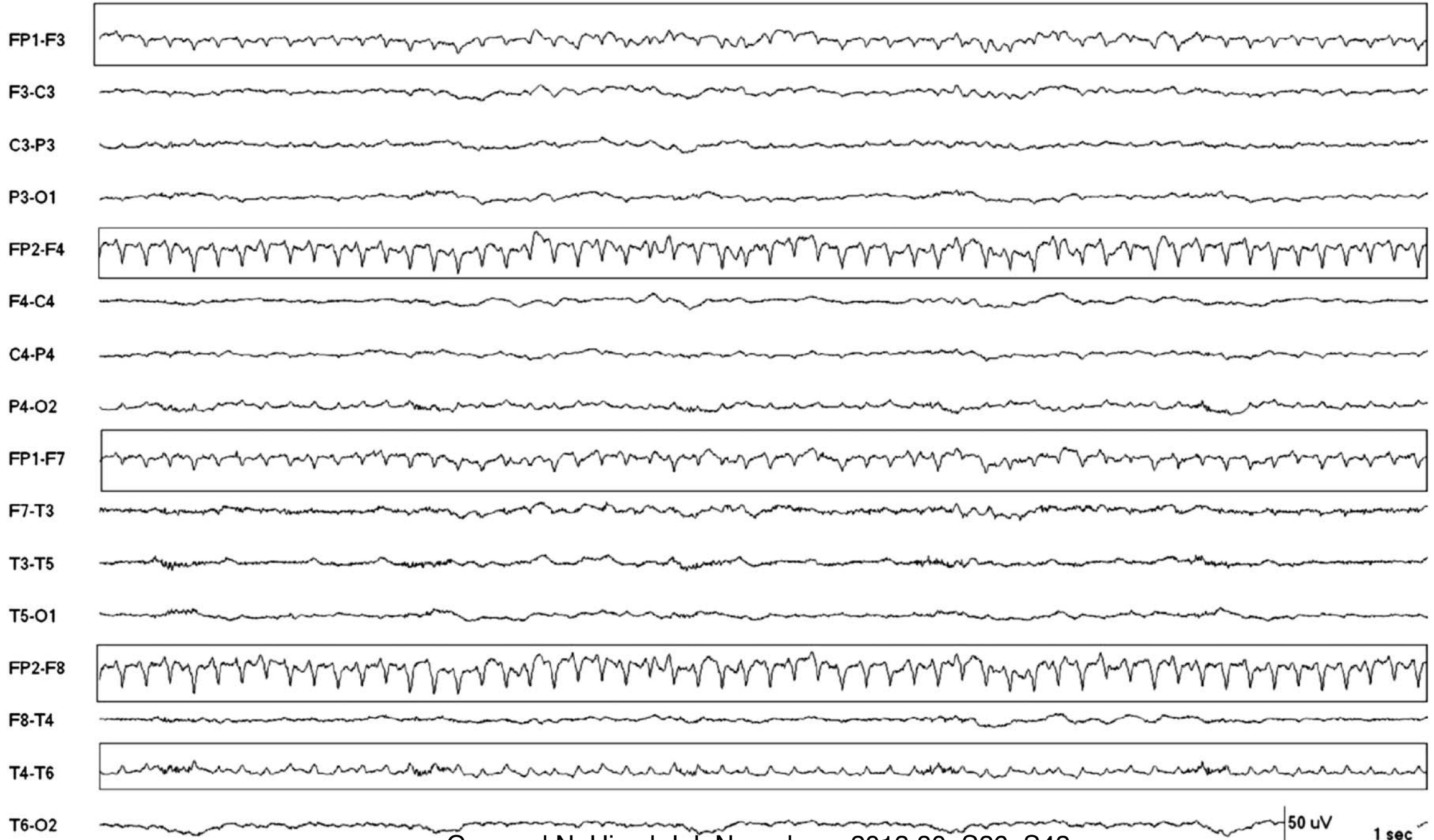
Monitoring and life-support devices
60-Hz noise (or 50-Hz in some countries)
Mechanical ventilation (including water condensation in the ventilation tubing, extracorporeal membrane oxygenation, rapid oscillation ventilators
IV drip
Hemofiltration, hemodialysis
Pacemaker
Implanted ventricular assist device
Oscillating bed
Staff
Chest percussion (for pulmonary care): most common mimic of seizures
Suctioning

Gaspard N, Hirsch LJ. Neurology 2013;80 :S26–S42

Features that may suggest artifacts rather than cerebral activity

Distribution of the activity over multiple electrodes without a physiologic electrical field
Atypical multiple phase reversals
Activity localized to a single electrode
Highly stereotyped or very monomorphic pattern
Periodic pattern with perfect regularity
Evidence from the video recording pointing at the source of the artifact (chewing, toothbrushing, patting, chest percussion, etc.)

Gaspard N, Hirsch LJ. Neurology 2013;80 :S26–S42



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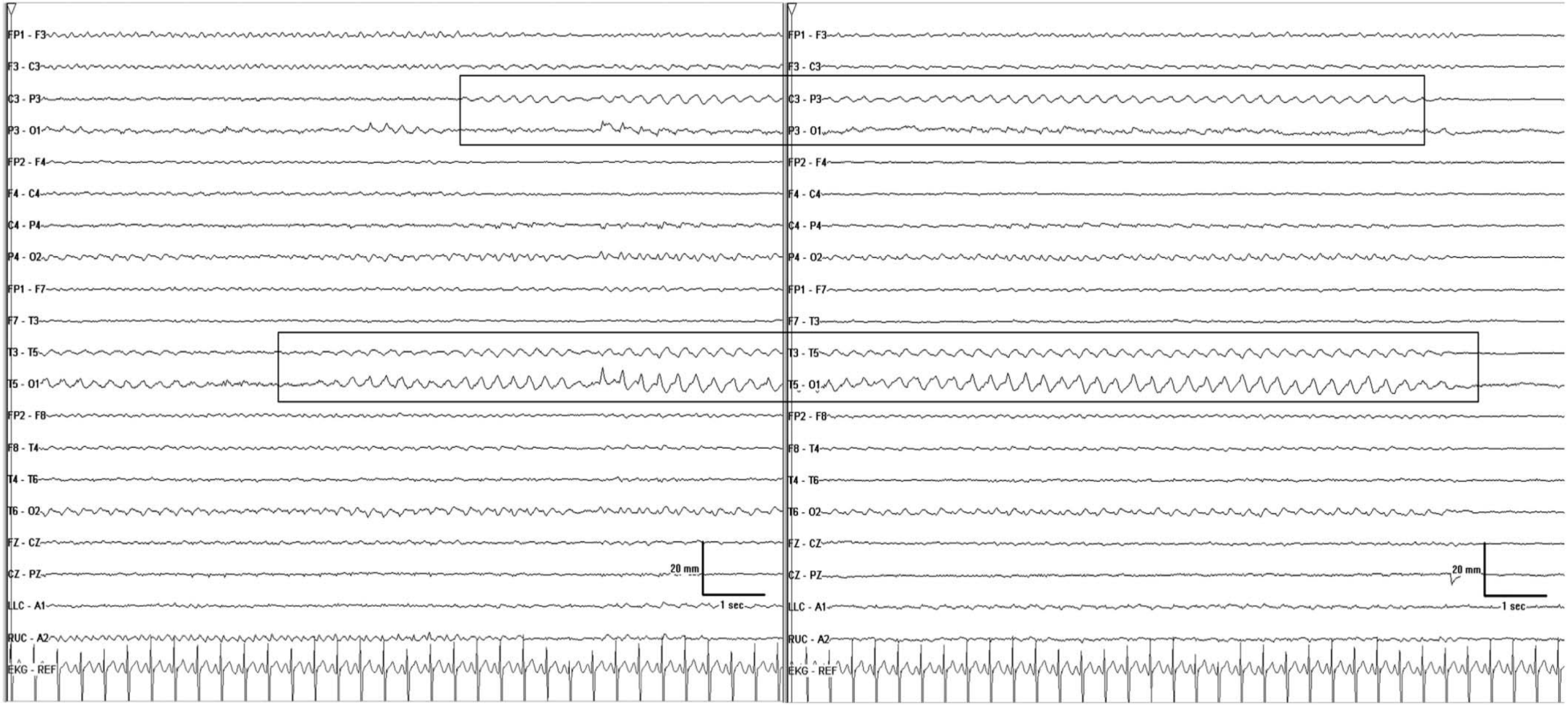

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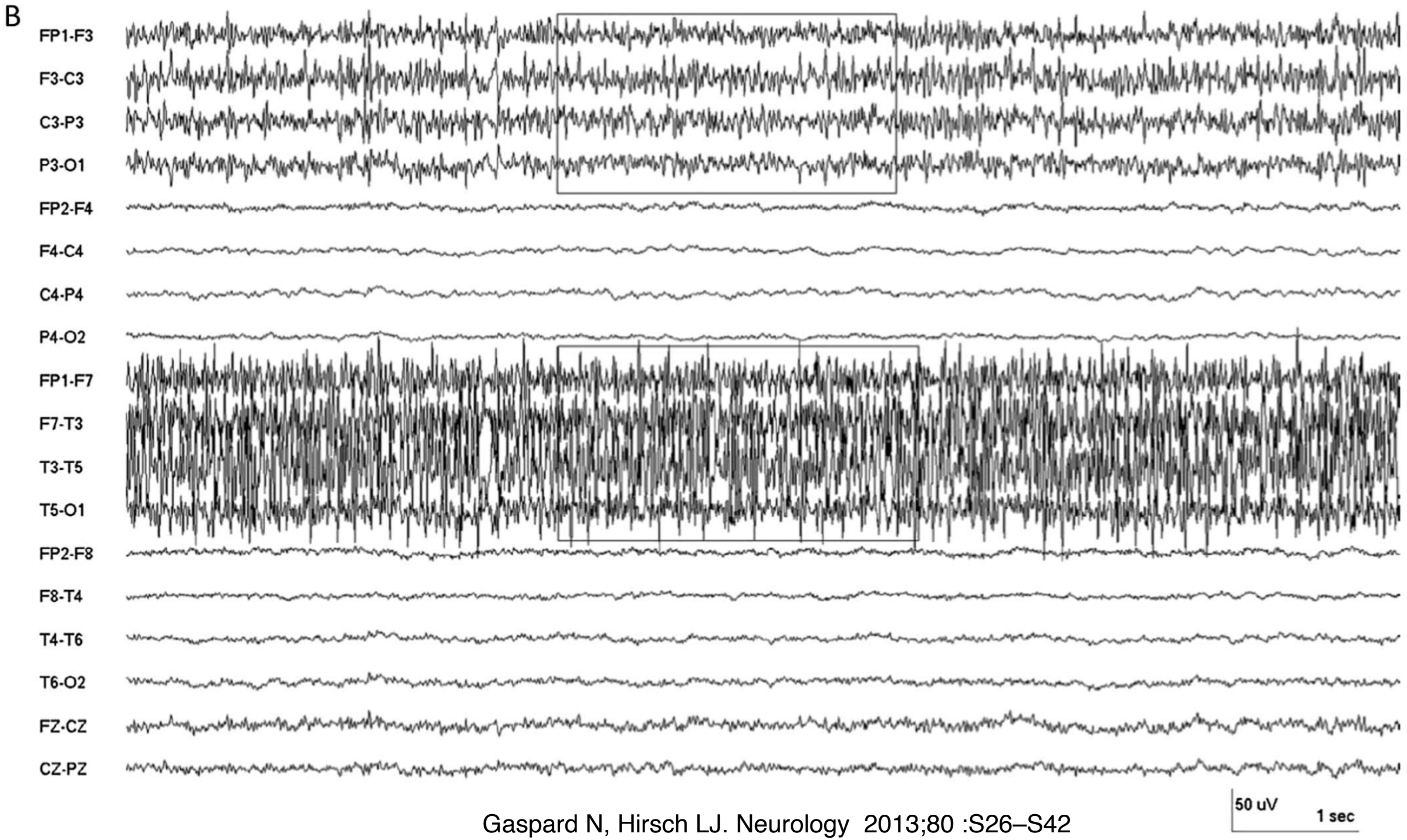

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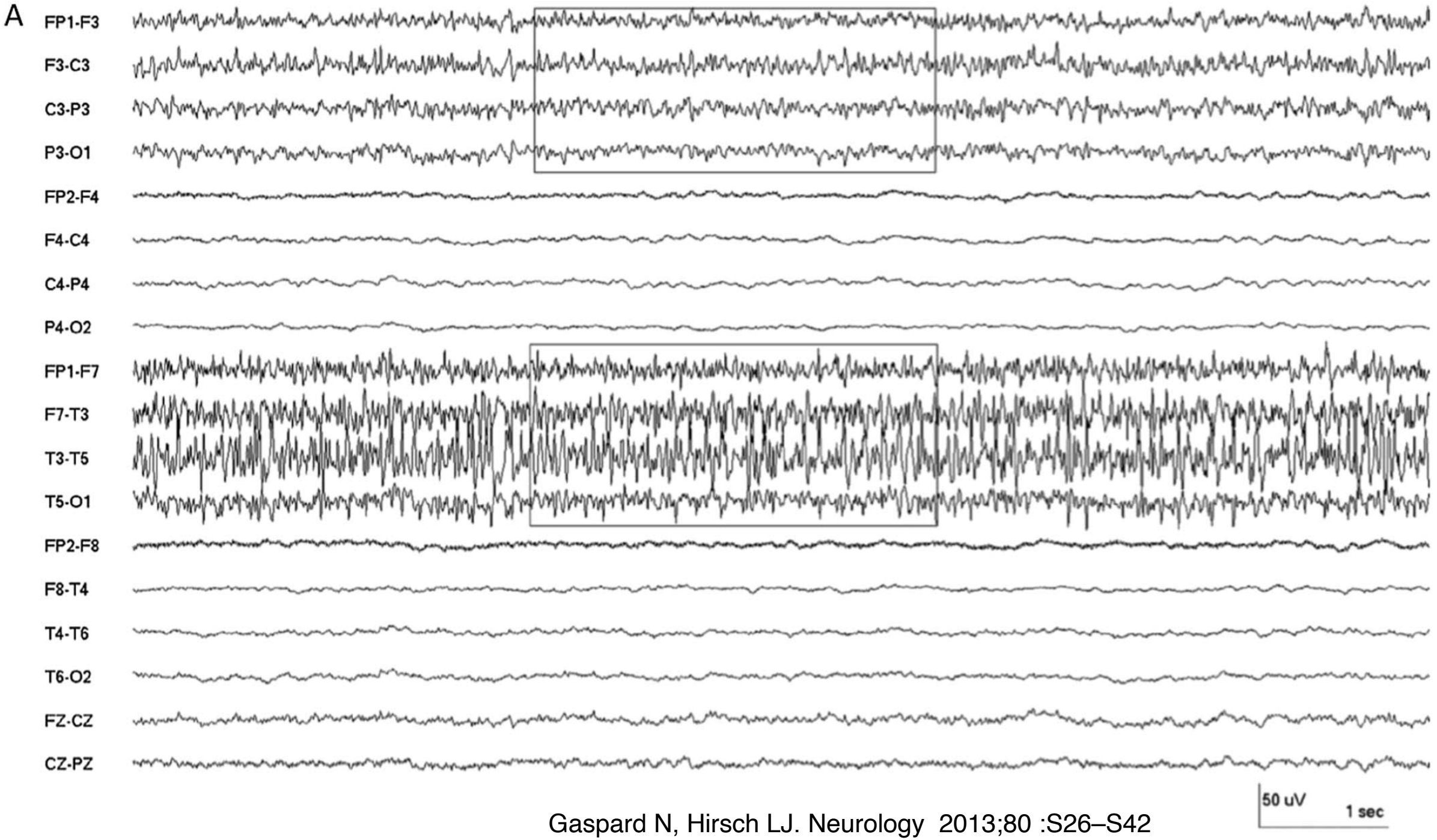


Gaspard N, Hirsch LJ. Neurology 2013;80 :S26–S42

Overview on clinical interpretation of the EEGs in the inpatient settings

Clinical interpretation

	EEG	New terms	Clinical interpretation
1.	Slow PDR		Mild diffused encephalopathy
2.	Intermittent slow, generalized		Mild diffused encephalopathy
3.	FIRDA, OIRDA	GRDA	Diffused encephalopathy, The pr of FIRDA is suggestive of subc abnormalities
4.	Continuous slow, generalized (theta)		Moderately severe diffused encephalopathy
5.	Continuous slow, generalized		Severe diffused encephalopathy
6.	Intermittent slow, focal		Suggestive of focal cortical dys ____ region
7.	Continuous slow, focal (delta)		Suggestive of focal structu ____ region

Find the causes of diffuse encephalopathy

Evaluate for structural lesions

A. EEG Background

Symmetry	Background EEG frequency	PDR	Continuity	Reactivity	State Changes	Cyclic Alternating Pattern of Encephalopathy (CAPE)	Voltage	AP Gradient	Breach effect
Symmetric	**Beta**	**Present** Specify frequency	**Continuous:** <1% **periods of suppression** (<10 µV) or **attenuation** (≥10µV but <50% of background voltage)	**Reactive**	**Present with normal stage N2 sleep transients**	**Present**	**High** ≥150 µV	**Present**	**Present**
Mild asymmetry <50% Voltage OR 0.5-1 Hz Frequency	**Alpha**	**Absent**		**Unreactive**	**Present but with abnormal stage N2 sleep transients**	**Absent**	**Normal** ≥20 to <150 µV	**Absent**	**Absent**
Marked asymmetry ≥50% Voltage OR >1 Hz Frequency	**Theta**	**Unclear**	**Nearly continuous:** 1-9% **periods of suppression attenuation**	**SIRPIDs only**	**Present but without stage N2 sleep transients**	**Unknown/unclear**	**Low** 10 to <20 µV	**Reverse**	**Unclear**
	Delta		**Discontinuous:** 10-49% **periods of suppression** or **attenuation**	**Unclear**	**Absent**		**Suppressed** <10 µV		
			Burst-suppression or **Burst-attenuation:** 50-99% **periods of suppression** or **attenuation**	**Unknown**					
			Suppression: >99% **periods of suppression** or **attenuation**						

If Burst-suppression or Burst-attenuation then specify if:

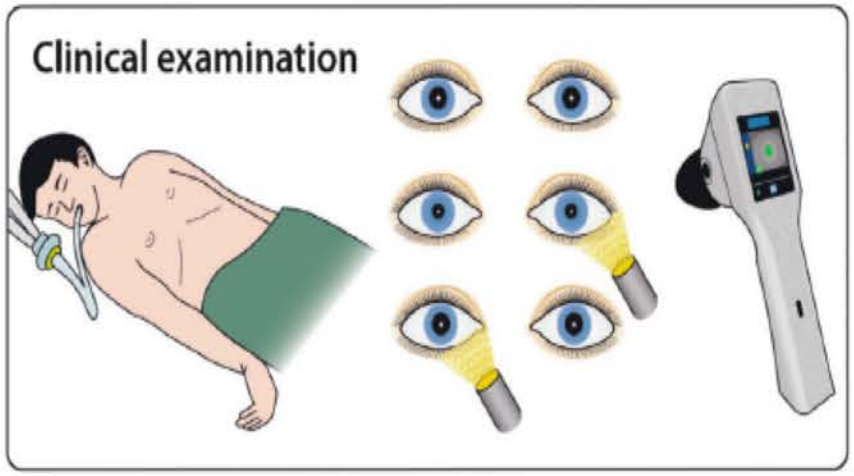
- **Localization of Bursts** (G/ L/ BI/ UI/ Mf)
- **Highly Epileptiform Bursts** (Present or Absent)
- **Identical Bursts** (Present or Absent)

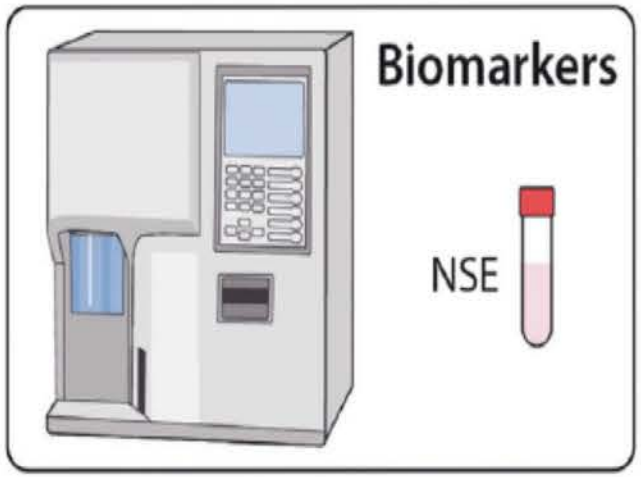
Clinical interpretation

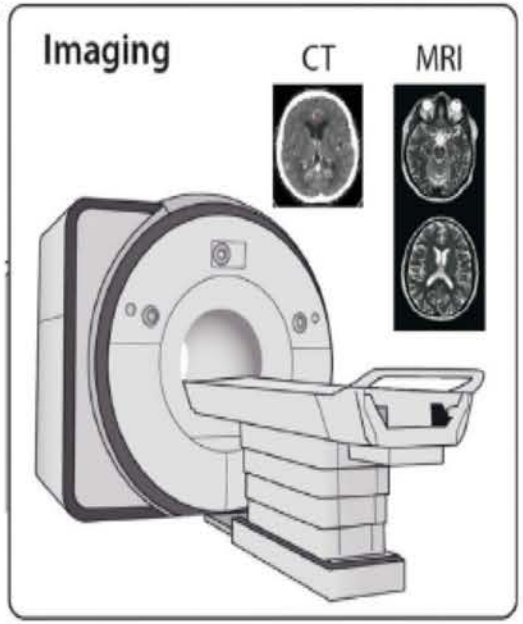
	EEG	Clinical interpretation
8.	Sharp waves, spike, focal	Focal epilepsy arising from ____ region (if patient has history of seizure) Consistent with increased risk of epilepsy (if no history of seizure)
9.	Sharp waves, spike, generalized	Generalized epilepsy (if patient has history of seizure) Consistent with increased risk of epilepsy (if no history of seizure)

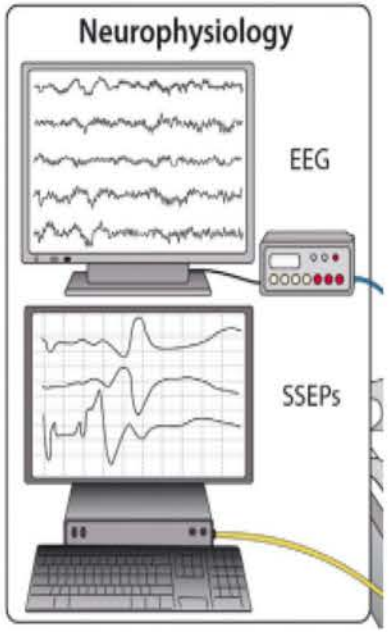
Use of EEG in the inpatient settings

- 4. Use together with multimodal methods to determine prognosis in post cardiac arrest patients







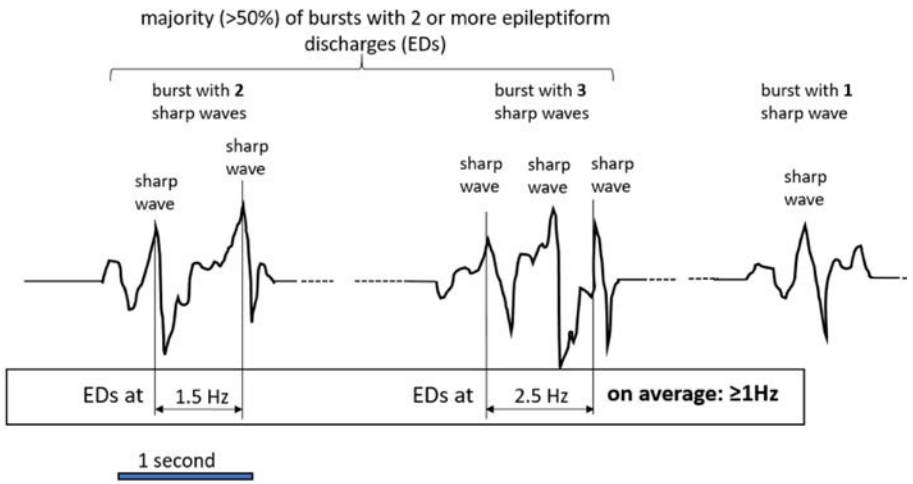


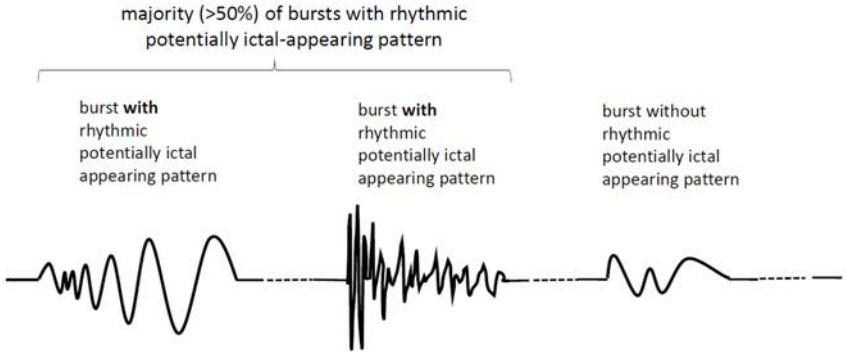
Clinical interpretation

	EEG	Clinical interpretation
10.	Burst suppression	Severe diffused encephalopathy
11.	Diffused background suppression	Severe diffused encephalopathy

HIGHLY EPILEPTIFORM BURSTS

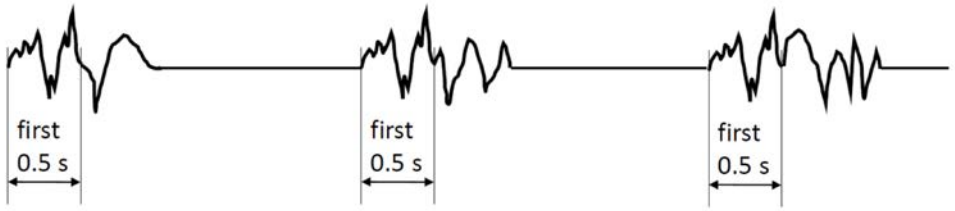
1. Two or more epileptiform discharges (spikes or sharp waves),
2. within the majority (>50%) of bursts, and
3. occur at an average of 1 Hz or faster within a single burst





IDENTICAL BURSTS

Present if the first 0.5 s or longer of each burst is visually similar in all channels in the vast majority (>90%) of bursts.



Localization of Bursts (G/ L/ BI/ UI/ Mf)

Highly Epileptiform Bursts (Present or Absent)

Identical Bursts (Present or Absent)

If Burst-suppression or Burst-attenuation then specify if:

Continuity
Continuous: <1% **periods of suppression** (<10 µV) or **attenuation** (≥10µV but <50% of background voltage)
Nearly continuous: 1-9% **periods of suppression attenuation**
Discontinuous: 10-49% **periods of suppression** or **attenuation**
Burst-suppression or **Burst-attenuation:** 50-99% **periods of suppression** or **attenuation**
Suppression: >99% **periods of suppression** or **attenuation**

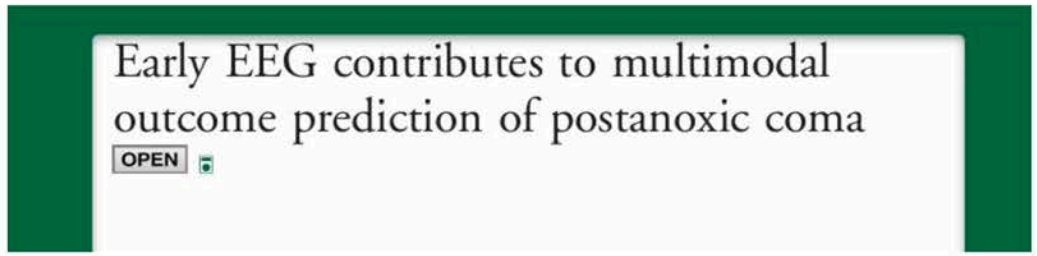
Which EEG Patterns Matter?

Hofmeijer et al. Neurology 2015

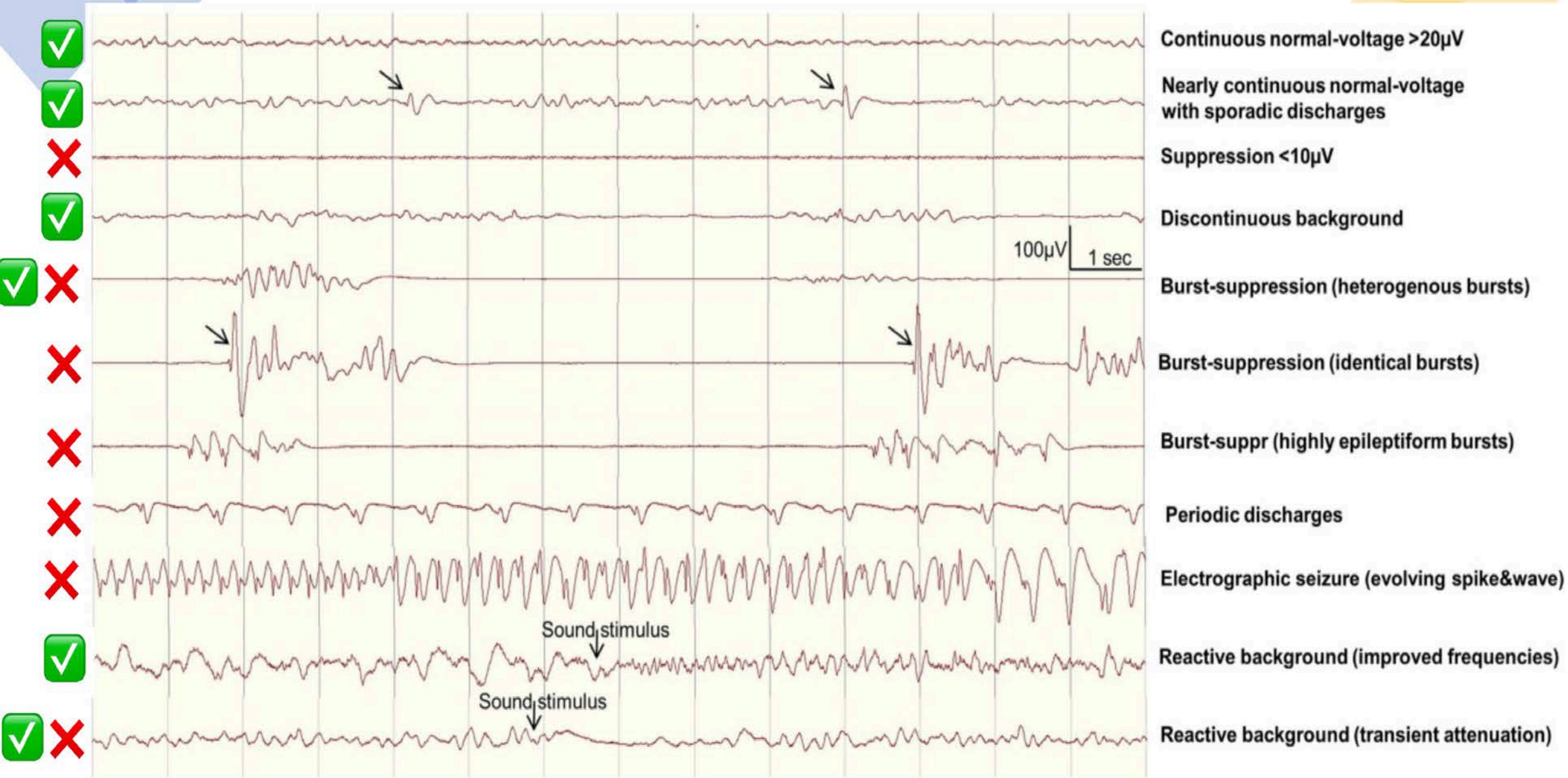
To determine whether early EEG patterns improve outcome prediction after cardiac arrest

Prospective cohort

- 227 comatose post cardiac arrest patients
- Continuous EEG during first 72 h h
- Outcome at 6 months(CPC)



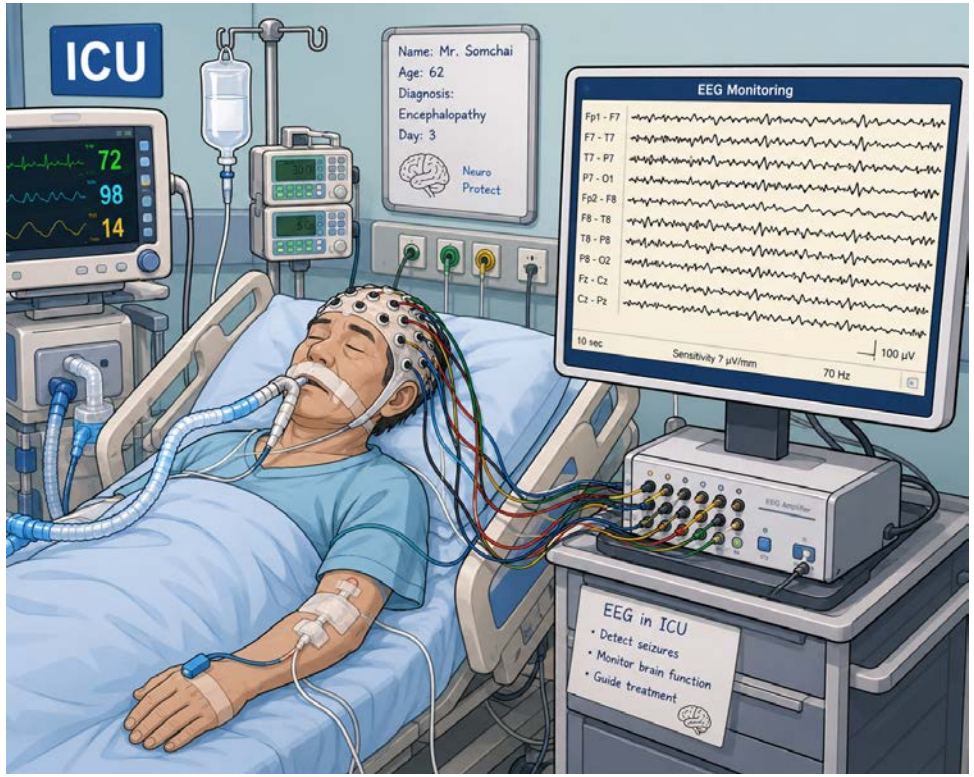
EEG Category	Patterns	Outcome Implication
Highly Unfavorable	Isoelectric EEG Low-voltage EEG Burst suppression with identical bursts	Almost invariably poor outcome
Intermediate ("Gray Zone")	GPDs Evolving seizures Burst suppression without identical bursts	Uncertain prognosis
Favorable	Continuous background (normal or diffusely slowed)	Associated with recovery



Sandroni, C., Cronberg, T. & Hofmeijer, J. Intensive Care Med 2022;48, 1439–42.

Use of EEG in the inpatient settings

- 2. For the diagnosis of nonconvulsive seizures in patients with alteration of consciousness in the ICU



Clinical interpretation

	EEG	New terms	Clinical interpretation
12.	GPEDs	GPD/GPD+	Middle part of status epilepticus Severe diffused encephalopathy eg HIE Suggestive of CJD (if patient had history of rapidly progressive dementia) Suggestive of severe diffused encephalopathy from metabolic causes (if triphasic in morphology)
13.	PLEDs	LPD/LPD+	Suggestive of presence of acute structural lesion with tendencies to create seizures in _____ region
14.	Triphasic waves	GPD triphasic	Suggestive of severe diffused encephalopathy from metabolic causes eg. hepatic encephalopathy, uremic encephalopathy
15.	EEG seizures	Electrographic seizures (Esz) Electrographic SE (ESE) Electroclinical Sz (ECSz) Electroclinical SE (ECSE)	

C. Rhythmic and Periodic Patterns (RPPs)

Main term 1	Main term 2
G *Generalized* *- Optional: Specify frontally, occipitally, or midline predominant; or generalized, not otherwise specified.*	**PD** *Periodic Discharges*
L *Lateralized* *- Optional: Specify unilateral, bilateral asymmetric, or bilateral asynchronous* *- Optional: Specify lobe(s) most involved or hemispheric*	**RDA** *Rhythmic Delta Activity*
BI *Bilateral Independent* *- Optional: Specify symmetric or asymmetric* *- Optional: Specify lobe(s) most involved or hemispheric*	**SW** *Spike and Wave* *OR* *Polyspike and Wave* *OR* *Sharp and Wave*
UI *Unilateral Independent* *- Optional: Specify unilateral, bilateral asymmetric, or bilateral asynchronous for each pattern* *- Optional: Specify lobe(s) most involved*	
Mf *Multifocal* *- Optional: Specify symmetric or asymmetric* *- Optional: Specify lobe(s) most involved or hemispheric*	

Major modifiers

Prevalence	Duration	Frequency	Phases[1]	Sharpness[2]	Voltage (Absolute)	Voltage (Relative)[3]	Stimulus Induced or Stimulus Terminated	Evolution[4]
Continuous ≥90%	**Very long** ≥1 h	**4 Hz**	**>3**	**Spiky** <70 ms	**High** ≥150 µV	**>2**	**SI** *Stimulus Induced*	**Evolving**
Abundant 50-89%	**Long** 10-59 min	**3.5 Hz**	**3**	**Sharp** 70-200 ms	**Medium** 50-149 µV	**≤2**	**ST** *Stimulus Terminated*	**Fluctuating**
Frequent 10-49%	**Intermediate duration** 1-9.9 min	**3 Hz**	**2**	**Sharply contoured** >200 ms	**Low** 20-49 µV		**Spontaneous only**	**Static**
Occasional 1-9%	**Brief** 10-59 s	**2.5 Hz**	**1**	**Blunt** >200 ms	**Very low** <20 µV		**Unknown**	
Rare <1%	**Very brief** <10 s	**2 Hz**						
		1.5 Hz						
		1 Hz						
		0.5 Hz						
		<0.5 Hz						

Minor modifiers

Onset	Triphasic[5]	Lag	Polarity[2]
Sudden ≤3 s	**Yes**	**A-P** *Anterior-Posterior*	**Negative**
Gradual >3 s	**No**	**P-A** *Posterior-Anterior*	**Positive**
		No	**Dipole**
			Unclear

Plus (+) Modifiers
No +
+F *Superimposed fast activity – applies to PD or RDA only* **EDB** (*Extreme Delta Brush): A specific subtype of +F*
+R *Superimposed rhythmic activity – applies to PD only*
+S *Superimposed sharp waves or spikes, or sharply contoured – applies to RDA only*
+FR *If both subtypes apply – applies to PD only*
+FS *If both subtypes apply – applies to RDA only*

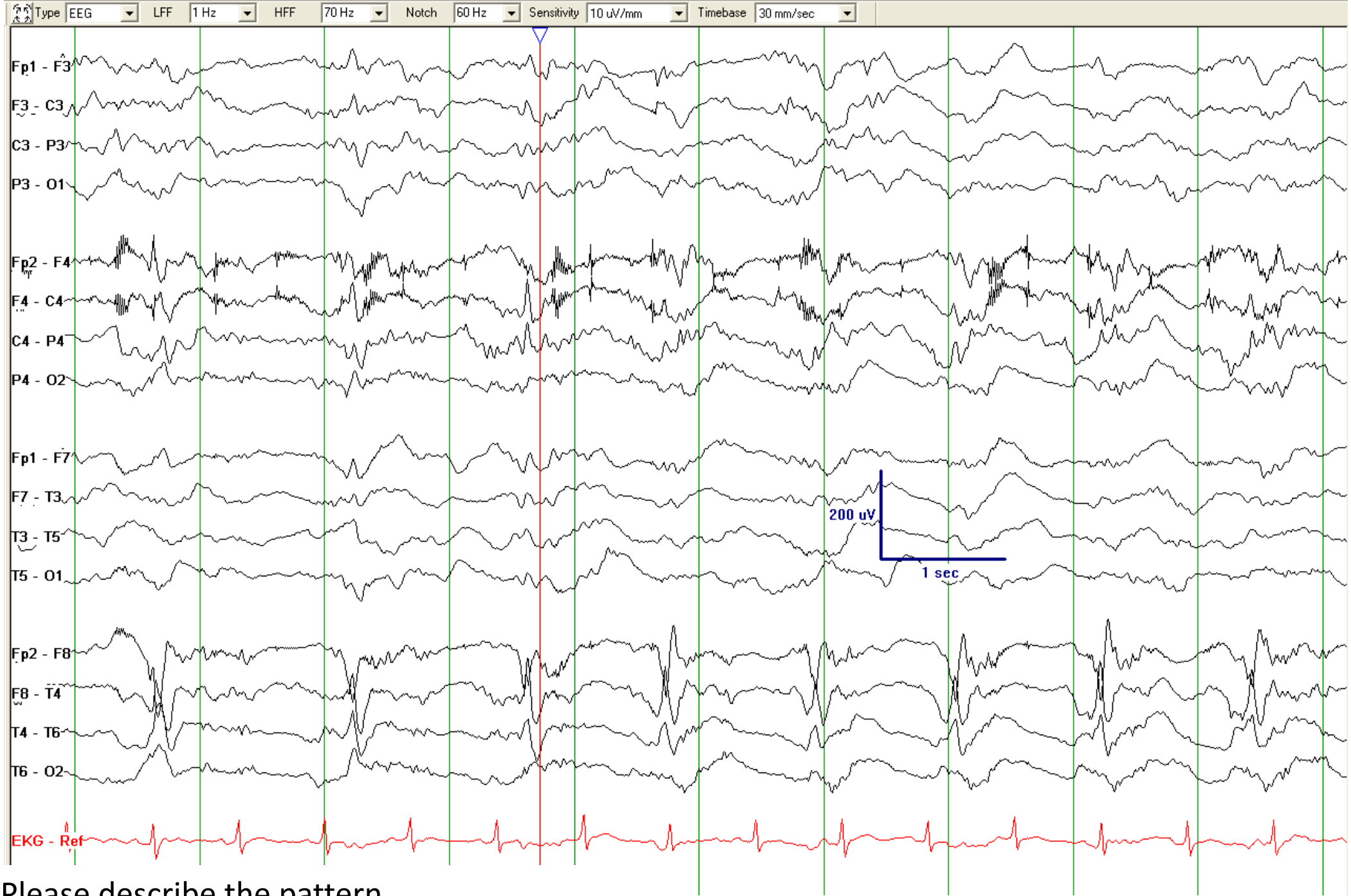
NOTE 1: Phases: Applies to PD and SW only, including the slow wave of the SW complex

NOTE 2: Sharpness and Polarity: Applies to the predominant phase of PD and the spike or sharp component of SW only

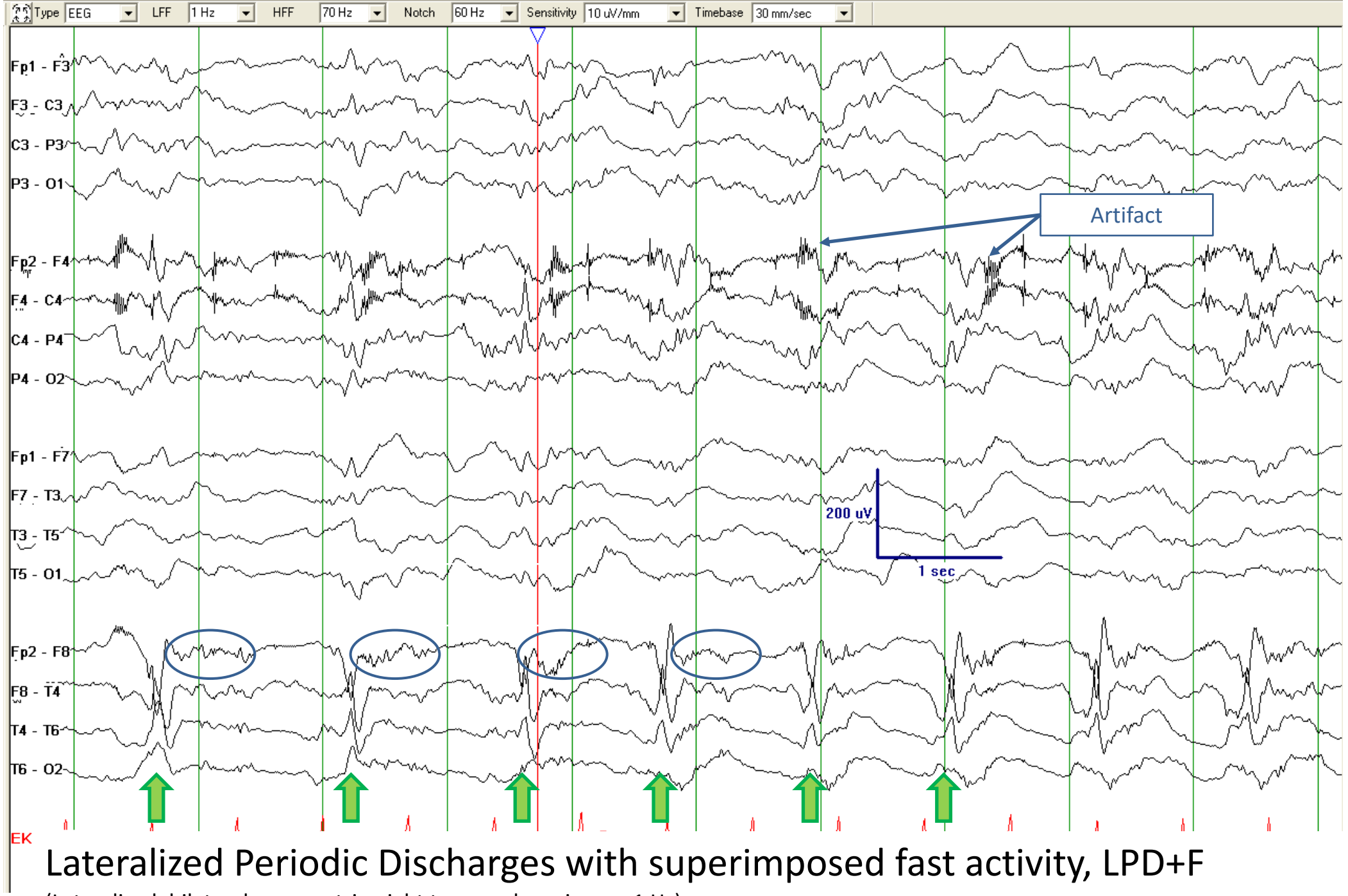
NOTE 3: Relative voltage: Applies to PD only

NOTE 4: Evolution: Refers to frequency, location or morphology

NOTE 5: Triphasic: Applies to PD or SW only



Please describe the pattern



Fast activity:

Lateralized Periodic Discharges with superimposed fast activity, LPD+F

(Lateralized: bilateral asymmetric, right temporal maximum, 1 Hz)

Research

JAMA Neurology | Original Investigation

Assessment of the Validity of the 2HELPS2B Score for Inpatient Seizure Risk Prediction

Aaron F. Struck, MD; Mohammad Tabaeizadeh, MD; Sarah E. Schmitt, MD; Andres Rodriguez Ruiz, MD; Christa B. Swisher, MD; Thanujaa Subramaniam, MD; Christian Hernandez, MD; Safa Kaleem, BS; Hiba A. Haider, MD; Abbas Fodé Cissé, MD; Monica B. Dhakar, MD; Lawrence J. Hirsch, MD; Eric S. Rosenthal, MD; Sahar F. Zafar, MD; Nicholas Gaspard, MD, PhD; M. Brandon Westover, MD, PhD

JAMA Neurol. 2020;77(4):500-507.

Table 1. 2HELPS2B

Risk Factor	Score	% 0	1	2	3	4	5+
Frequency >2 Hz[a]	1						
Independent sporadic epileptiform discharges	1						
LPD/BIPD/LRDA	1						
Plus features (superimposed rhythmic, fast, sharp)[b]	1						
Prior seizure[c]	1						
BIRD	2						
Total Score							
Predicted risk of seizure,[d] 2HELPS2B score		<5	12	27	50	73	88
Actual risk of seizure							
FS[e]		3	12	34	52	71	84
VAL[f]		4	15	34	55	75	93

Abbreviations: BIPD, bilateral independent periodic discharges; BIRD, brief potentially ictal rhythmic discharge; FS, foundational study; LPDs, lateralized periodic discharges; LRDA, lateralized rhythmic delta activity; VAL, validation study cohort.

JAMA Neurol. 2020;77(4):500-507.

Table 2. Seizure Risk Based on 1-Hour Screening EEG

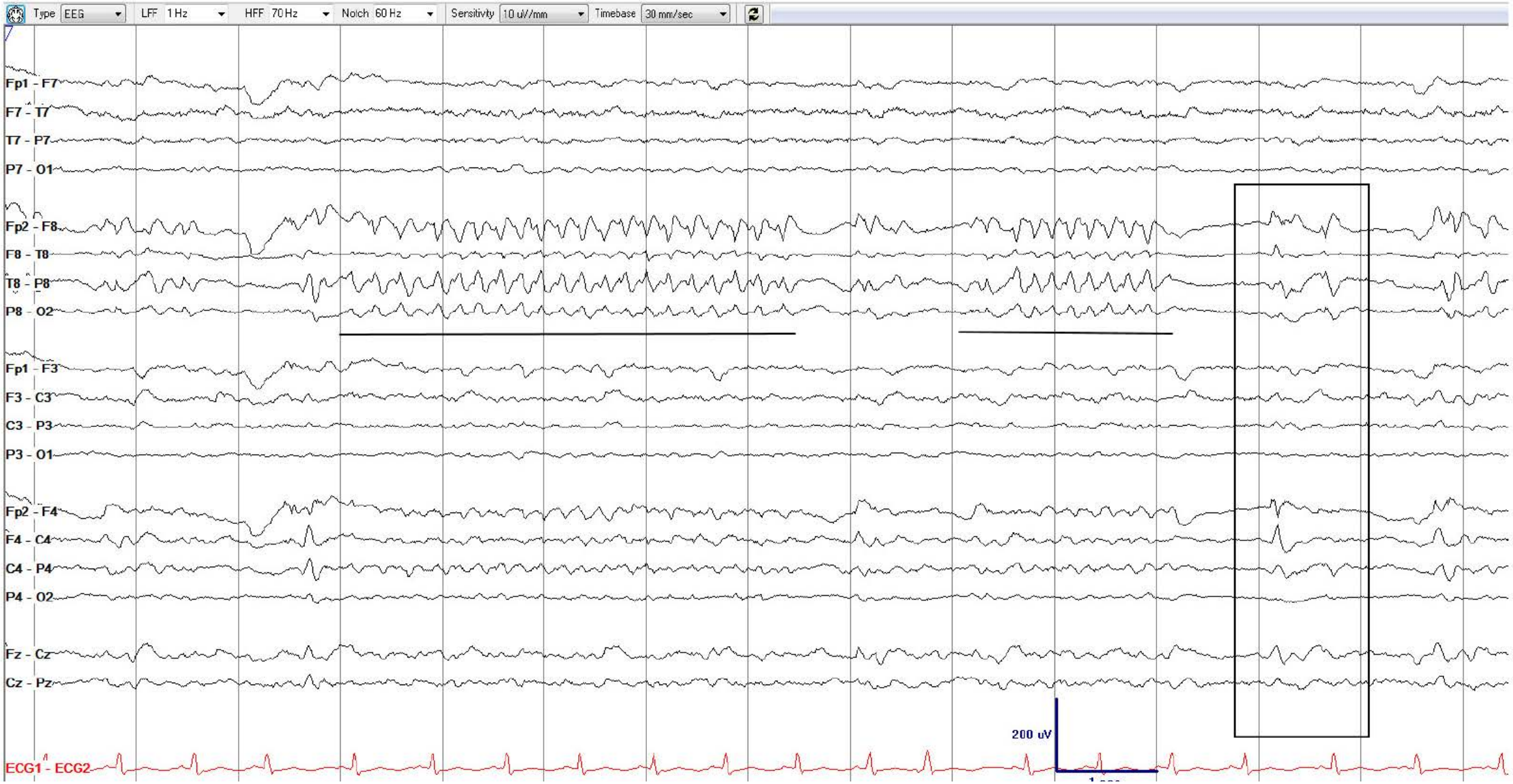
Seizure Risk Group	No. (% of Cohort)	Overall Seizure Risk, %	False-Negative Rate,[a] %	Recommend Duration of EEG Monitoring
Low risk:[b] 2HELPS2B score = 0	594 (40)	3.1	3.1	1 h (Length of screening EEG)
Medium risk:[c] 2HELPS2B score = 1	597 (40)	12.0	4.0	12 h
High risk:[d] 2HELPS2B score, ≥2	310 (21)	26.6	3.1	At least 24 h

JAMA Neurol. 2020;77(4):500-507.

Clinical interpretation

	New terms	Clinical interpretation
16.	**BRIEF POTENTIALLY ICTAL RHYTHMIC DISCHARGES (BIRDs)**	Focal or generalized rhythmic activity >4 Hz (at least 6 waves at a regular rate) lasting ≥0.5 to <10 s*, that has at least one of the following features a. Evolution ("evolving BIRDs", a form of definite BIRDs) b. Similar morphology and location as interictal epileptiform discharges or seizures in the same patient (definite BIRDs) c. Sharply contoured but without (a) or (b) (possible BIRDs)

* not consistent with a known normal pattern or benign variant,
not part of burst-suppression or burst-attenuation, without a definite clinical correlate



Brief Potentially Ictal Rhythmic Discharges, similar to sporadic epileptiform discharges = DEFINITE BIRDs

(Right anterior-mid temporal maximum, 5 Hz, sharply contoured, rhythmic activity, lasting 4.5 and 2 seconds (underlined). This activity has a similar **location and morphology** as the sporadic epileptiform discharges (box), making this a definite BIRD.

Clinical interpretation

	EEG	New terms	Clinical interpretation
12.	GPEDs	GPD/GPD+	-Middle part of status epile -Severe diffused encepl -Suggestive of CJD (if rapidly progressive de -Suggestive of severe encephalopathy from triphasic in morpholo
13.	PLEDs	LPD/LPD+	Suggestive of pr lesion with te icles to c _____ region
14.	Triphasic waves	GPD triphasic	Suggestive of severe diffused encephalopathy from metabolic causes eg. hepatic encephalopathy, uremic encephalopathy
15.	EEG seizures	Electrographic seizures (Esz) Electrographic SE (ESE) Electroclinical Sz (ECSz) Electroclinical SE (ECSE)	

- Evaluate for structural lesions or causes
- Monitor for seizures
- Decide about cEEG

ELECTROGRAPHIC AND ELECTROCLINICAL SEIZURES

D. Electrographic and Electroclinical Seizures

Electrographic Seizure (ESz)

Either:

A) Epileptiform discharges averaging >2.5 Hz for ≥10 s (>25 discharges in 10 s), OR

B) Any pattern with definite evolution and lasting ≥10 s

Electroclinical Seizure (ECSz)

Any EEG pattern with either:

A) Definite clinical correlate time-locked to the pattern (of any duration), OR

B) EEG *and* clinical improvement with a parenteral anti-seizure medication

Electrographic Status Epilepticus (ESE)

An electrographic seizure for either:

A) ≥10 continuous minutes, OR

B) A total duration of ≥20% of any 60-minute period of recording.

Electroclinical Status Epilepticus (ECSE)

An electroclinical seizure for either

A) ≥10 continuous minutes, OR

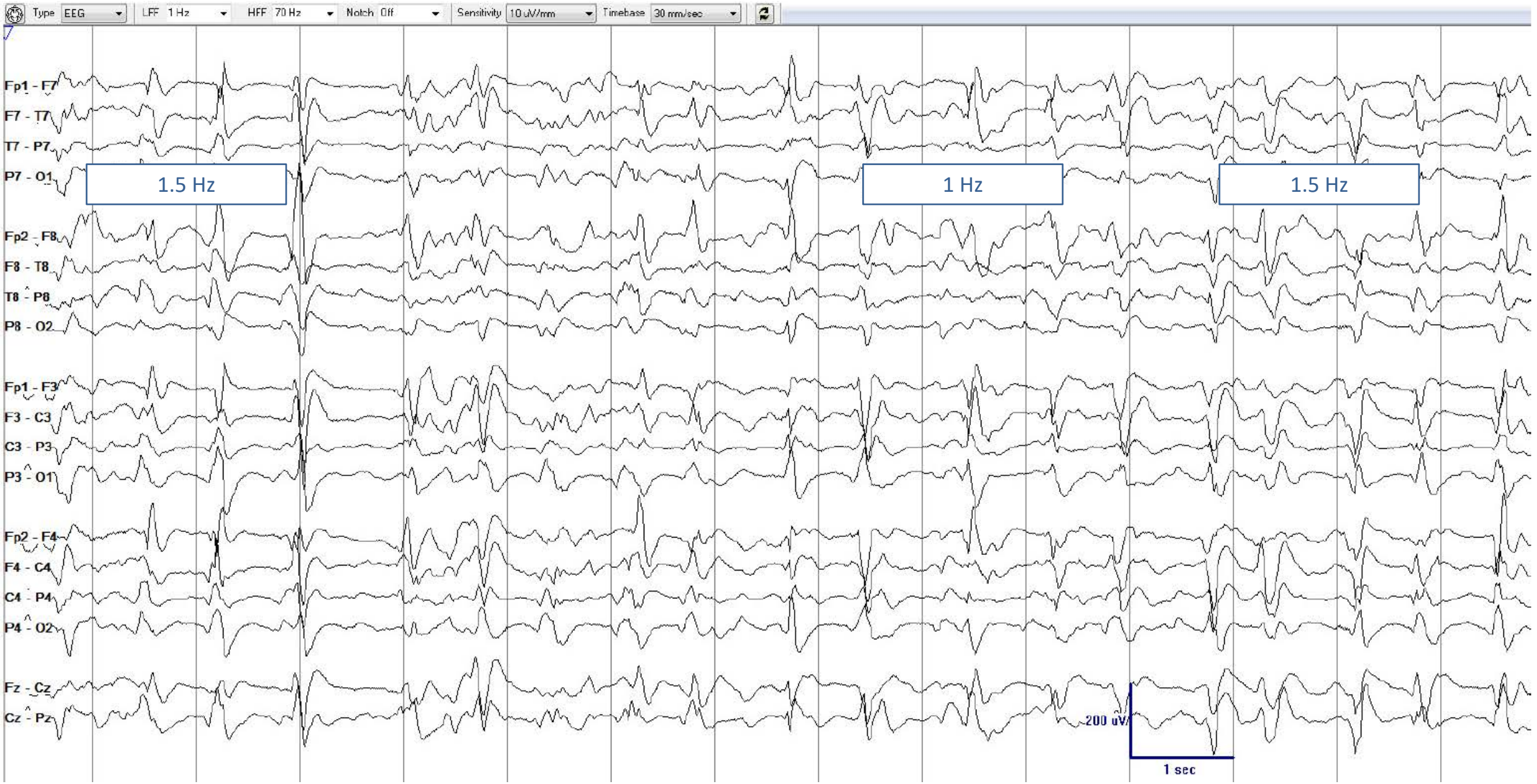
B) A total duration of ≥20% of any 60-minute period of recording, OR

C) ≥5 continuous minutes if the seizure is convulsive (i.e., with bilateral tonic-clonic motor activity).

Possible ECSE: An RPP that qualifies for the IIC (below) that is present for ≥10 continuous minutes or for a total duration of ≥20% of any 60-minute period of recording, which shows EEG improvement with a parenteral anti-seizure medication ***BUT*** without clinical improvement.

Clinical interpretation

	New terms	Clinical interpretation
12.	**ICTAL-INTERICTAL CONTINUUM (IIC)**	A pattern on the IIC is a pattern that does not qualify as definite seizure, but there is a reasonable chance that it may be contributing to impaired alertness, causing other clinical symptoms, and/or contributing to neuronal injury. Such patterns include: 1. Any PD or SW pattern that averages >1.0 Hz and <2.5 Hz over 10 s (>10 and < 25 discharges in 10 sec); or 2. Any PD or SW pattern that averages >0.5 Hz and <1 Hz over 10 s (>5 and <10 discharges in 10 sec), and has a plus modifier or fluctuation; or 3. Any lateralized RDA averaging >1 Hz for at least 10 s (at least 10 waves in 10 s) with a plus modifier or fluctuation AND 4. Does not qualify as an ESz or ESE.



Generalized Periodic discharges with fluctuating frequency: fluctuating GPDs (IIC)

(fluctuating between 1 Hz → 1.5 → 1 → 1.5 Hz: now qualifying as a pattern on the Ictal-Interictal-Continuum [IIC])

Part 2 of 3

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Epilepsia™

RESEARCH ARTICLE

Diagnosing nonconvulsive status epilepticus: Defining electroencephalographic and clinical response to diagnostic intravenous antiseizure medication trials

Markus Leitinger[1,2] | Nicolas Gaspard[3,4] | Lawrence J. Hirsch[5] | Sándor Beniczky[6,7,8] | Peter W. Kaplan[9] | Khalil Husari[9] | Eugen Trinka[1,2,10]

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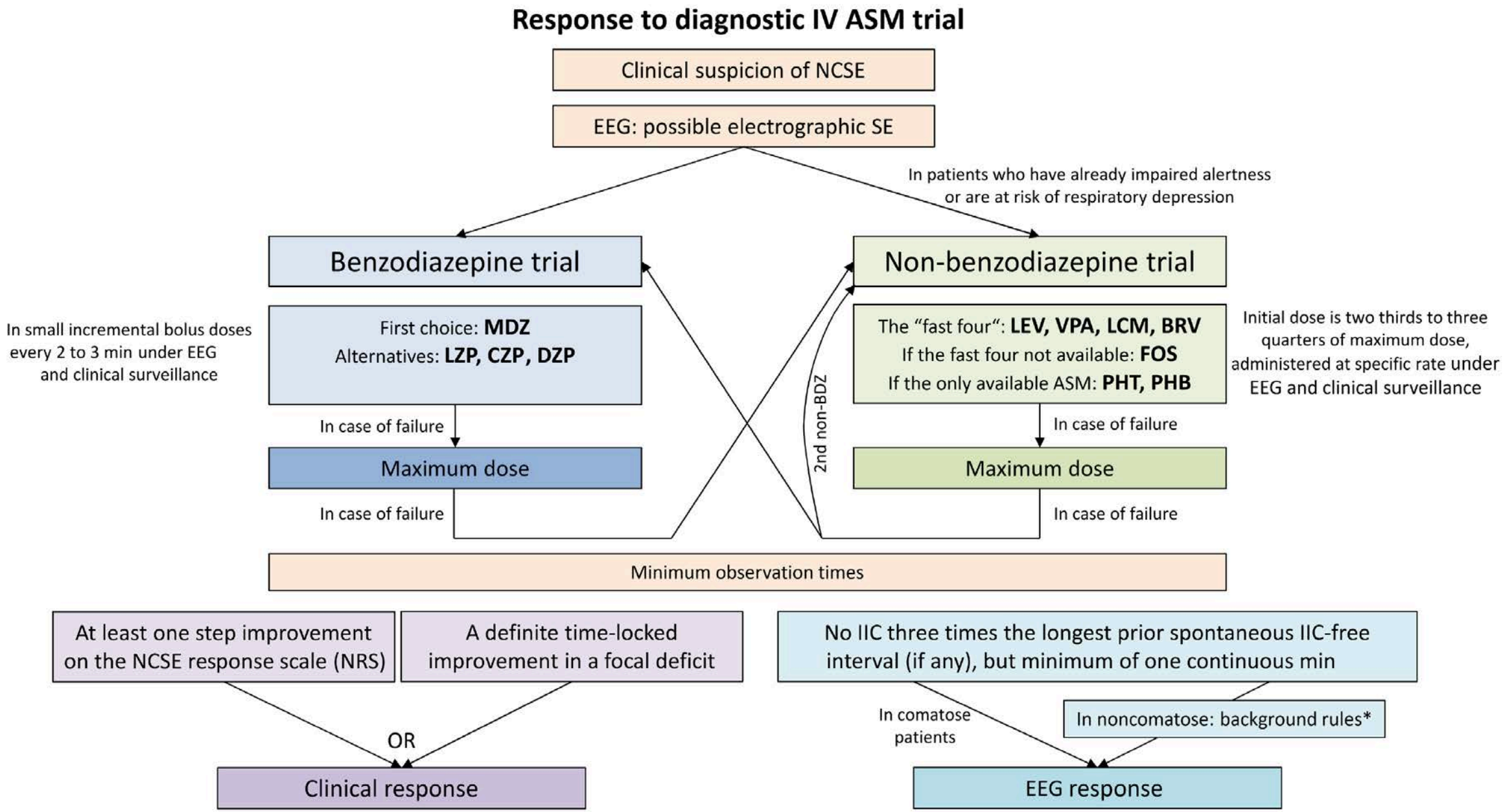
Objective: The Salzburg criteria for nonconvulsive status epilepticus (NCSE) and the American Clinical Neurophysiology Society (ACNS) Standardized Critical Care EEG Terminology 2021 include a diagnostic trial with intravenous (IV) antiseizure medications (ASMs) to assess electroencephalographic (EEG) and clinical response as a diagnostic criterion for definite NCSE and possible NCSE.
However, how to perform this diagnostic test and assessing the EEG and clinical responses have not been operationally defined.
Methods: We performed a Delphi process involving six experts to standardize the diagnostic administration of IV ASM and propose operational criteria for EEG and clinical response.



Overview of the diagnostic IV ASM trial recommendations.

TABLE 4 The NRS for measurement of clinical improvement in response to intravenous antiseizure medication.

Level 10: Normal
Level 9: Speaks or writes words with clear sense, oriented to person, year, and city or region, but behavior or performance different than normal
Level 8: Speaks or writes words with clear sense, but disoriented to person, year, and city or region
Level 7: Speaks or writes words or syllables, incomprehensible or confused
Level 6: Follows commands (verbally or by demonstration) (e.g., open/close eyes, raise arms, say "1, 2, 3″)
Level 5: Directed gaze to examiner (or responsive vertical eye movement in locked-in syndrome), does not follow any commands (neither verbal nor by demonstration)
Level 4: Opens eyes spontaneously or to verbal stimulus or to light touch (no directed gaze), does not follow any commands
Level 3: Opens eyes to (strong) tactile stimulus (right or left shoulder, nose), does not follow commands (neither verbal nor by demonstration)
Level 2: Localizes to/wards off painful stimuli
Level 1: No purposeful response to painful stimuli

Note: For scoring, use the highest level achieved before and after medication. At least one-step improvement on the NRS or a definite time-locked improvement in a focal deficit poses a positive response to treatment.

Abbreviation: NRS, nonconvulsive status epilepticus response scale.

Some common errors related to interpreting intensive care unit EEG

Misinterpreting artifact as seizures
Assuming there is a clear dichotomy between ictal and interictal EEG patterns in encephalopathic patients (there is not)
Underdiagnosing nonconvulsive seizures/status epilepticus on EEG
Believing that because some patterns *can* be ictal at times implies that they are always, often, or usually ictal
Assuming a comatose patient in nonconvulsive status will wake up immediately if successfully treated

Gaspard N, Hirsch LJ. Neurology 2013;80 :S26–S42

Some common errors related to interpreting intensive care unit EEG

Assuming a comatose patient in nonconvulsive status will wake up immediately if successfully treated

Corollary error: If they don't improve clinically, concluding it was not nonconvulsive status epilepticus (it still could be, just not proven)

Related error: Concluding that if an EEG pattern resolves with an antiepileptic drug, that proves it was nonconvulsive status (might have been, but need clinical improvement to prove it)

Also related error: When doing a diagnostic benzodiazepine treatment trial, using too high of a dose (and putting the patient into deep sleep/coma)

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Some common errors related to interpreting intensive care unit EEG

Concluding that if a pattern is induced or exacerbated by alerting or stimulation, it is not "ictal" (it still can be)

Interpreting quantitative EEG, especially amplitude-integrated EEG, without the raw EEG or without an electroencephalographer

Assuming that a negative scalp EEG rules out seizure (it does not)

Overuse of filters (especially the high-frequency and notch filters)

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Questions?