Quantitative EEG: Overview and seizure detection

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Quantitative EEG: Why?

- Continuous EEG monitoring → large quantities of data
  - 24 hours of EEG data at 15 seconds / page → 5760 pages of EEG in 24 hours
  - One continuous EEG every day for a year → 2.1 million pages of EEG

- Quantitative EEG ("trend analysis") = large amounts of EEG data → condensed form

Quantitative EEG: Theory

- EEG normally transitions between different states
  - Wakefulness
  - Drowsiness
  - Sleep
- Each state→ expected range of frequencies and voltages
  - Pediatric and adult patients → different “normals”
  - Medications, skull integrity influence EEG

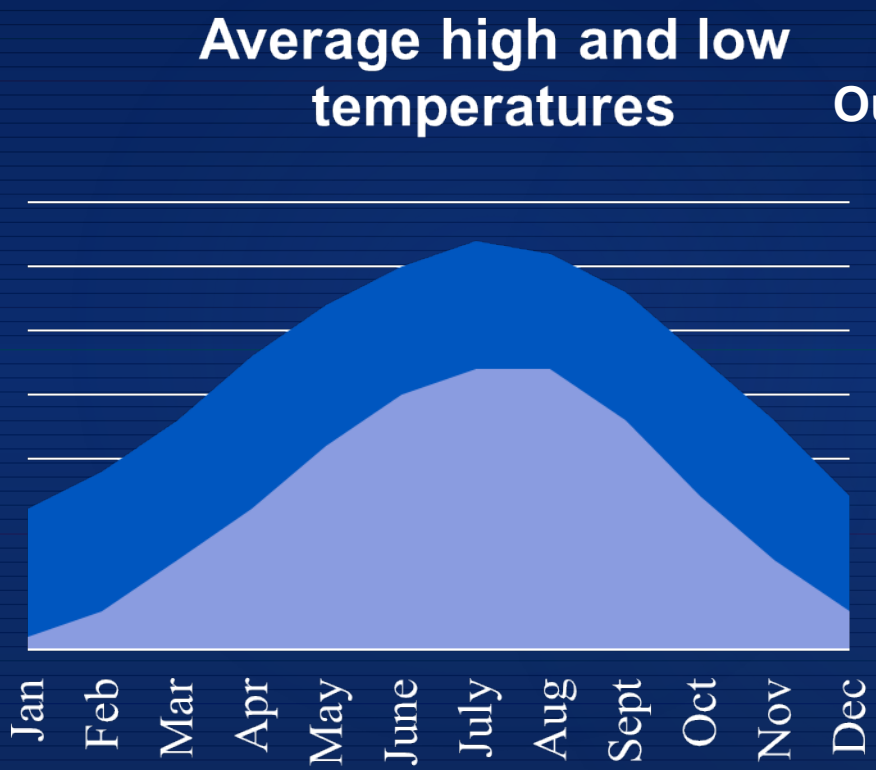
Quantitative EEG: Theory

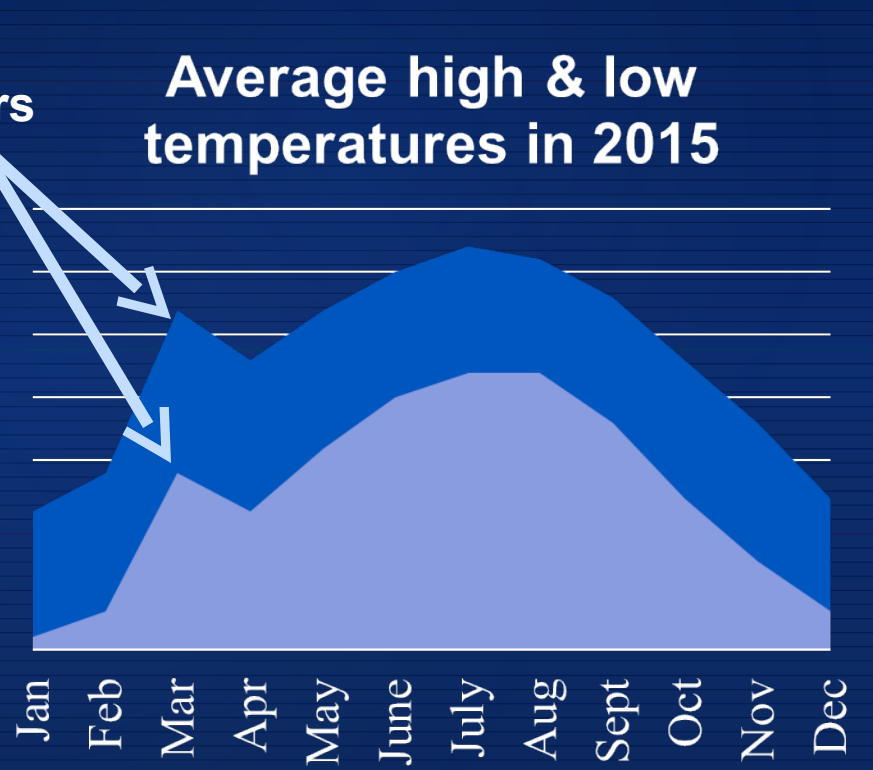
- When unexpected frequencies and voltages are present → concern for abnormality
  - Ischemia (discussed later by Dr. Herman)
  - Other types of structural brain injury (i.e., hemorrhage, infection, etc.)
  - **Seizures**
- Quantitative EEG → more rapid identification of EEG regions of concern

An analogy: temperature

Jan low	Jan. high	Feb low	Feb high	Mar low	Mar high	April low	April high	May low	May high	June low	Jun high
11.7	20.6	7.2	25.0	17.2	30.0	18.3	28.3	22.8	26.7	19.4	30.0
5.6	13.9	11.7	24.4	13.9	26.1	15.0	25.0	20.6	26.6	19.4	30.3
5.0	13.9	14.4	24.4	10.0	22.8	8.9	22.8	18.9	26.8	19.4	30.6
2.2	11.7	11.1	20.0	12.2	22.2	7.8	25.6	17.2	27.2	19.4	30.7
-1.1	7.2	2.2	12.2	8.3	23.3	10.0	21.1	12.2	27.3	20.0	30.6
-1.7	12.2	0.0	13.3	11.1	25.0	5.0	20.0	9.4	27.2	20.0	30.5
6.7	18.3	2.8	7.8	9.4	26.7	15.0	24.4	11.7	27.1	20.0	30.8
8.3	15.0	0.0	16.7	13.3	31.1	12.2	25.0	17.8	27.8	20.0	30.6
9.4	15.0	2.2	8.9	17.2	25.0	8.3	21.7	17.8	27.7	20.0	31.1
5.6	18.9	-1.1	6.7	21.1	23.9	5.0	16.1	20.0	27.8	20.6	31.0
0.0	11.7	-3.3	13.9	21.2	27.8	7.8	23.3	17.2	27.9	20.6	31.1
-1.1	15.0	2.8	13.3	20.6	27.2	15.0	22.2	19.4	28.2	20.6	31.3
0.6	13.3	0.0	10.6	23.3	28.3	14.4	22.2	20.0	28.3	20.6	31.1
-0.6	17.8	-2.2	6.7	23.4	30.0	11.7	21.1	16.7	28.4	21.1	31.0
7.2	18.9	3.9	17.8	22.8	30.6	9.4	16.1	14.4	28.3	21.1	31.1
9.4	20.0	8.3	20.6	23.3	30.0	10.0	24.4	15.0	28.1	21.1	31.7
3.3	12.2	6.1	18.3	21.1	29.4	8.9	23.9	19.4	28.9	21.1	31.5
1.1	11.7	4.4	16.1	21.7	29.4	6.1	27.2	20.6	29.0	21.1	31.7
-4.4	7.2	1.1	15.6	20.6	30.0	11.1	30.6	19.4	28.9	21.1	31.4
-5.0	10.6	5.0	22.2	15.0	23.3	12.8	28.3	19.4	29.1	21.7	31.7
2.8	13.9	12.2	25.6	12.2	22.8	15.6	28.3	21.1	28.9	21.7	32
2.8	10.6	14.4	25.0	9.4	26.1	18.3	27.8	16.1	29.4	21.7	31.5
0.6	4.4	13.3	23.9	13.9	30.0	15.0	27.2	13.9	29.5	21.7	32.2
-1.7	11.7	12.8	25.0	16.1	31.7	12.8	25.0	13.3	29.2	21.7	32.5
-2.2	16.7	6.1	15.0	22.8	31.7	12.8	26.1	18.3	29.4	21.7	32.2
3.9	20.0	0.0	14.4	22.2	27.2	14.4	28.3	20.0	29.4	22.2	32.1
8.3	20.6	1.1	16.1	23.3	28.3	18.3	30.6	17.8	29.4	22.2	32.2
7.8	11.7	2.8	20.6	22.8	33.9	20.0	30.5	20.0	30.0	22.2	32.6
4.4	17.8	8.3	23.9	15.6	28.3	19.4	32.8	21.7	30.0	22.2	32.2
1.1	18.9	-17.8	-17.8	15.6	28.3	18.3	28.9	21.1	30.0	22.2	32.3
2.8	20.0	-17.8	-17.8	18.9	31.7	-17.8	-17.8	21.1	30.0	-17.8	-17.8

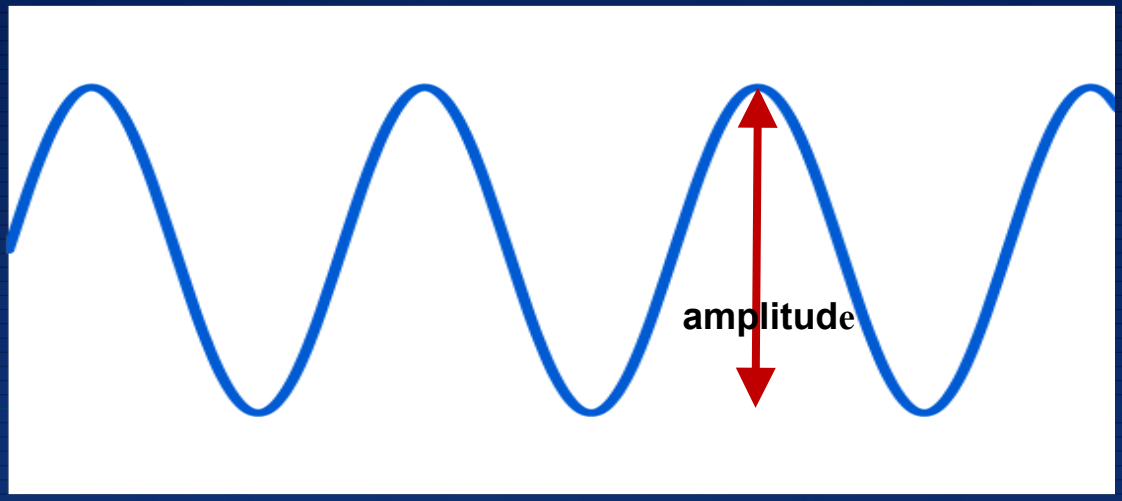
An analogy: temperature

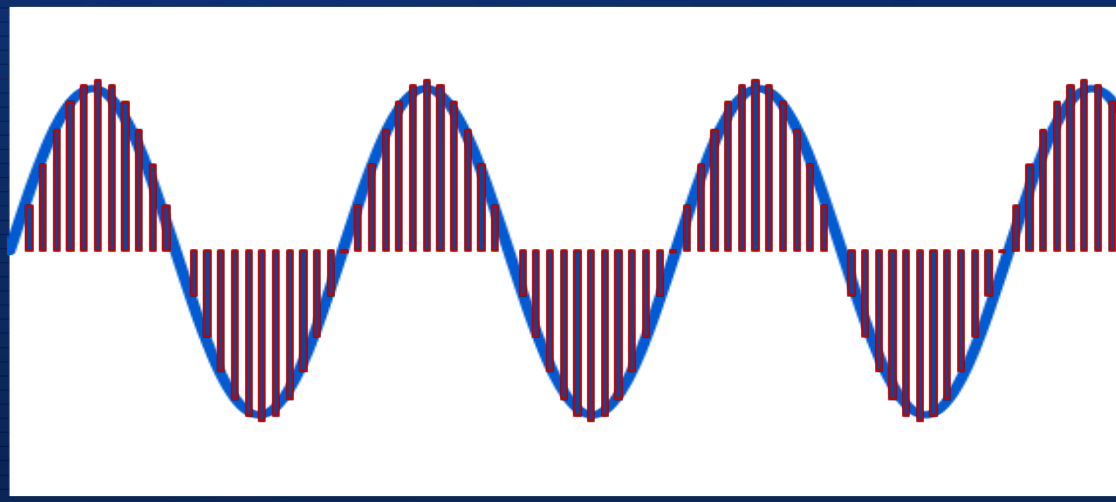




QEEG Principles

- Amplitude: voltage difference from peak to peak
- Power: Integral (area under the curve) of waveform
  - Expressed in units of μV^2

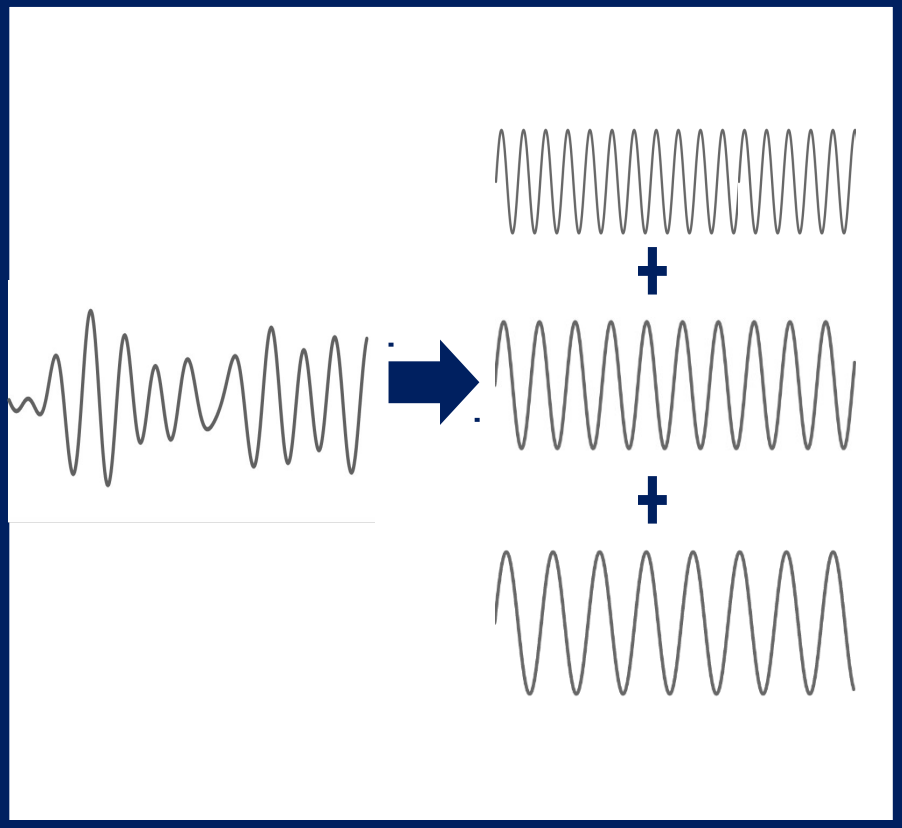


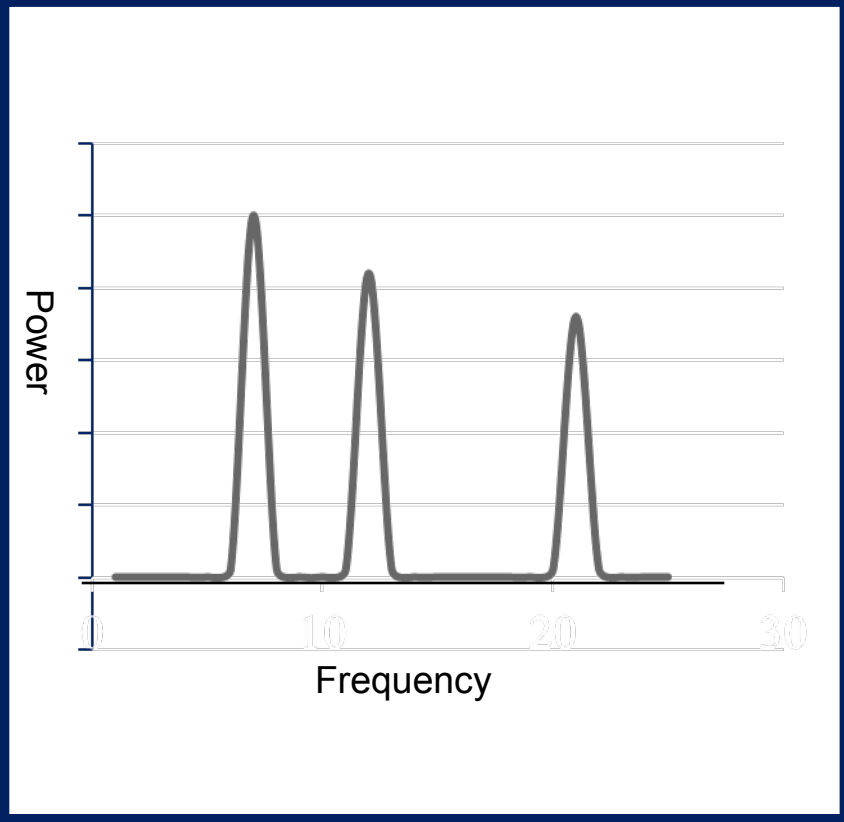


QEEG: Principles

- EEG is broken into brief time segments (epochs) – usually 30 seconds to 2 minutes
- QEEG software performs a Fast Fourier Transformation (FFT) on underlying EEG

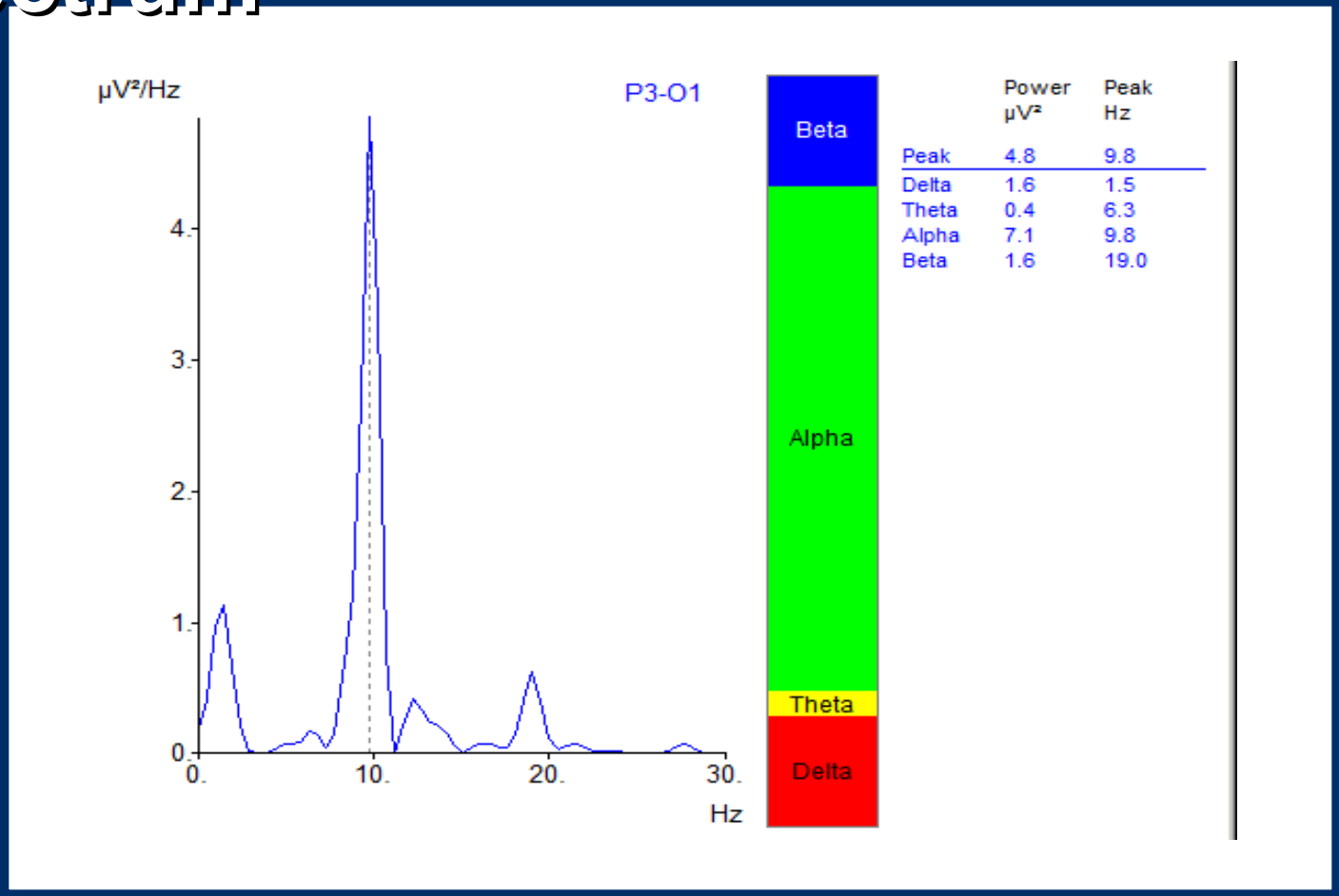
Fast Fourier Transformation





- EEG is broken down into component waveforms
- Power and frequency for component waveforms are analyzed for the epoch
- This analysis is manipulated to generate the final QEEG trend

Fast Fourier Transformation power spectrum

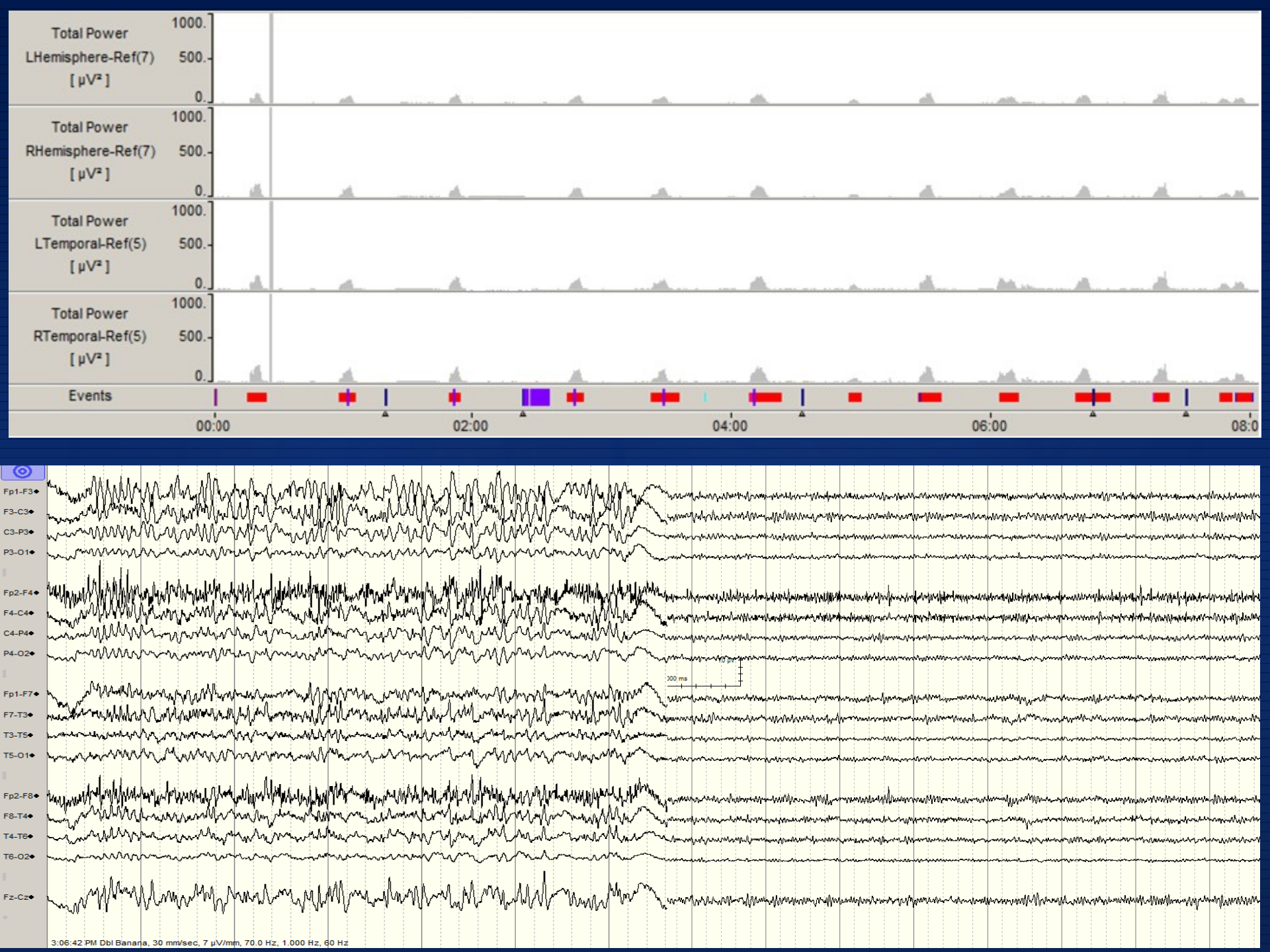


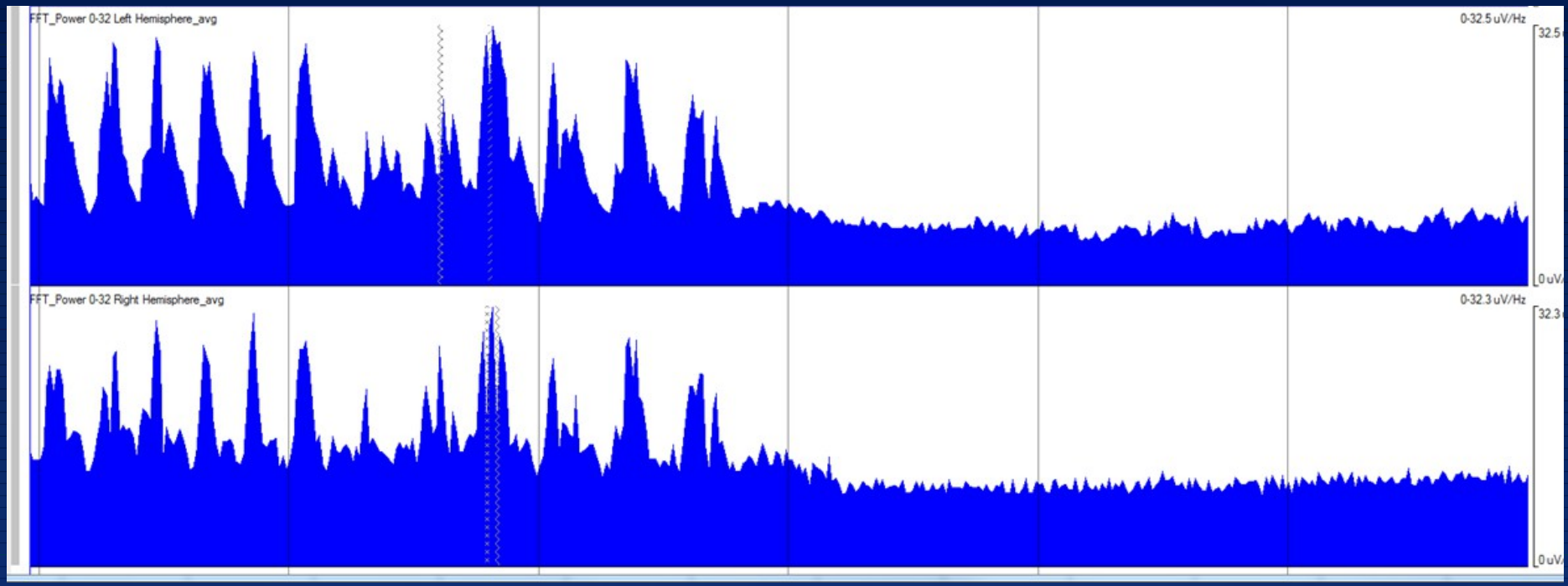
Types of Quantitative EEG

- Multiple different types of trends to detect seizures
  - Amplitude-based
    - Total power
    - Amplitude integrated EEG
    - Envelope trend
  - Asymmetry
  - Rhythmicity
  - Frequency-amplitude based
    - Density spectral array / compressed spectral array
- Most commonly used = combination “panel” with multiple trends over time

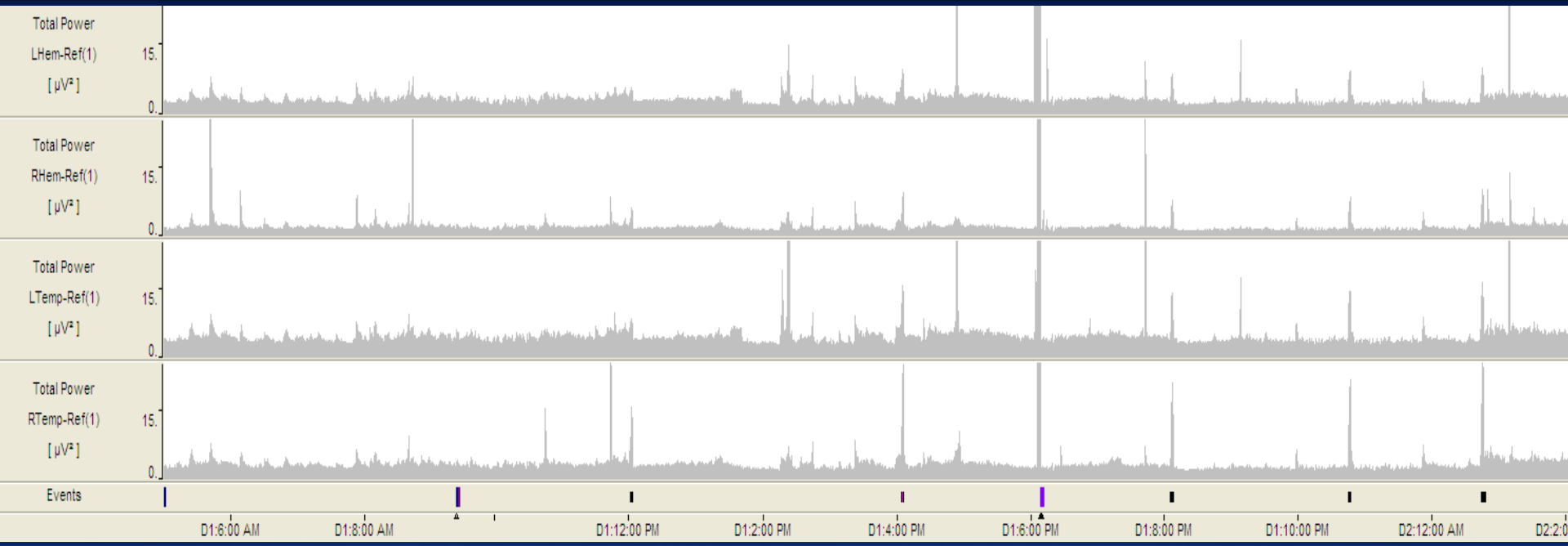
Total power

- Looks at change in the total power in an EEG
- Most accurate at detection of seizures in patients with:
  - High voltage seizures
  - Suppressed interictal background activity
- Very prone to detection of artifacts:
  - Muscle / EMG
  - Chewing
  - Movement
  - Blinking


Total Power
LHemisphere-Ref(7)
[µV²]
1000.
500.
0.
Total Power
RHemisphere-Ref(7)
[µV²]
1000.
500.
0.
Total Power
LTemporal-Ref(5)
[µV²]
1000.
500.
0.
Total Power
RTemporal-Ref(5)
[µV²]
1000.
500.
0.
Events
00:00
02:00
04:00
06:00
08:0
Fp1-F3
F3-C3
C3-P3
P3-O1
Fp2-F4
F4-C4
C4-P4
P4-O2
Fp1-F7
F7-T3
T3-T5
T5-O1
Fp2-F8
F8-T4
T4-T6
T6-O2
Fz-Cz
100 ms
3:06:42 PM Dbl Banana, 30 mm/sec, 7 µV/mm, 70.0 Hz, 1.000 Hz, 60 Hz



Another representation of total power using different software; here, individual peaks again correspond to seizures



This panel highlights the limitations of total power trends. Each black mark represents a seizure. Although all seizures are associated with an increase in total power, there are many false positives due to muscle artifacts, movement and chewing

Amplitude integrated EEG (aEEG)

- Amplitude integrated EEG:
  - Plots the minimum and maximum amplitudes over time
  - Mathematically manipulated to enhance activity in the alpha and beta range and smooth the overall signal

Amplitude integrated EEG (aEEG)

- Amplitude scale has two portions:
  - Bottom portion from 0 – 10 μV = linear
  - Top portion from 10 – 100 μV = logarithmic
- Can be performed on one channel (common in neonatal ICUs), several channels, or grouped / averaged channels

Amplitude integrated EEG (aEEG): Utility

- Most studies of aEEG come from neonatal population
- Reasonably sensitive when used with raw EEG
  - 76-81% sensitive when 2 channel aEEG used in combination with raw EEG (78% specificity)
- Low sensitivity without concurrent EEG
  - 38-55% sensitive when 1 channel aEEG used without raw EEG

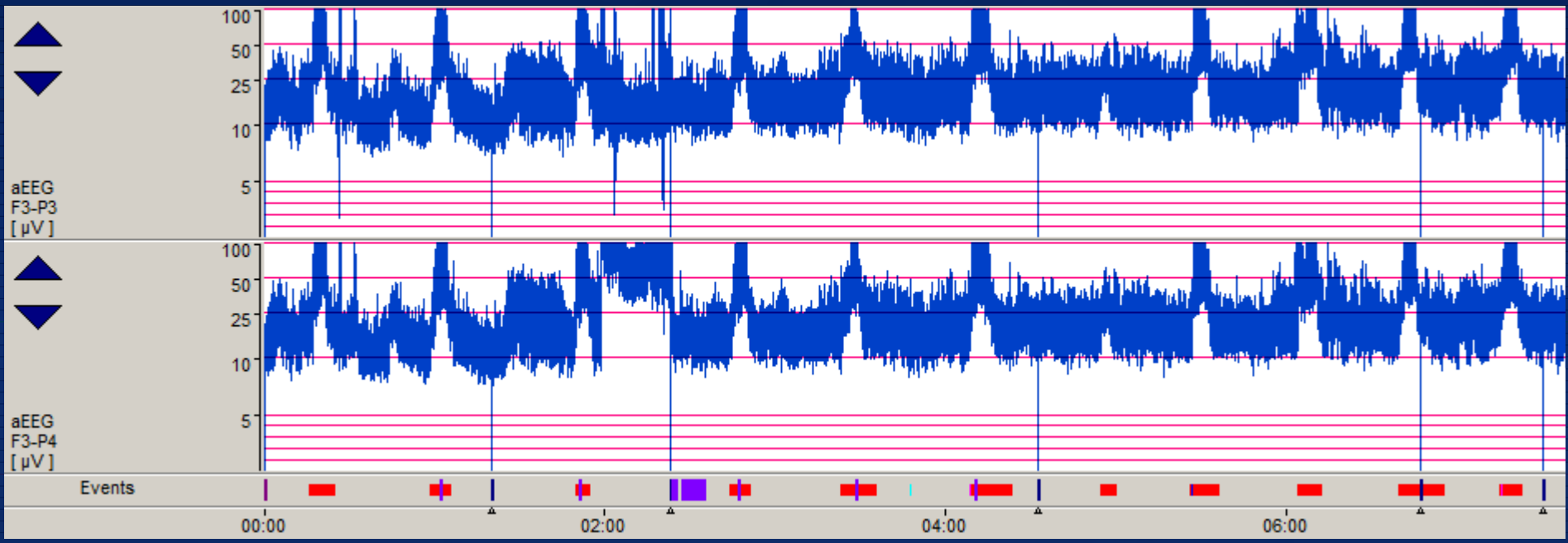
Shah DK et al. *Pediatrics* 2008. Shellhaas RA et al. *Pediatrics* 2007. Toet MC et al. *Pediatrics* 2002. Lawrence R et al. *J Pediatrics* 2009. Rennie JM et al. *Arch Dis Child Fetal Neonatal Ed* 2004. Stewart CP et al. *Neurology* 2010.

Amplitude integrated EEG (aEEG): Utility

- Experience is important to interpretation
  - Neonatalogists without EEG experience detected 12-38% of neonatal seizures
  - Experienced electrophysiologists detected 76-81% of seizures

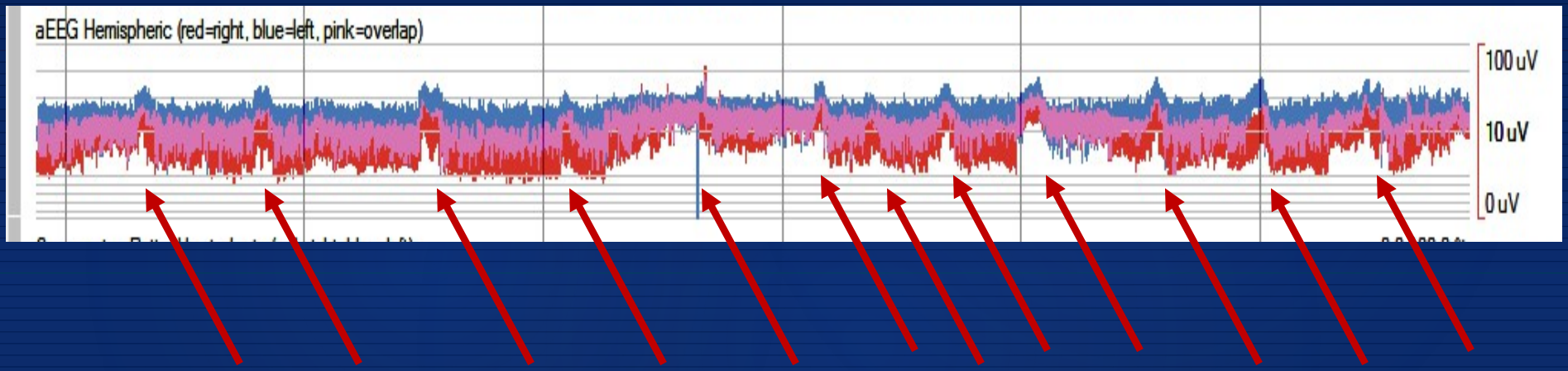
Shah DK et al. *Pediatrics* 2008. Shellhaas RA et al. *Pediatrics* 2007. Toet MC et al. *Pediatrics* 2002. Lawrence R et al. *J Pediatrics* 2009. Rennie JM et al. *Arch Dis Child Fetal Neonatal Ed* 2004. Stewart CP et al. *Neurology* 2010.

Amplitude integrated EEG (aEEG)



Example of amplitude integrated EEG in patient with seizures: during seizures the amplitude increases, creating a small peak

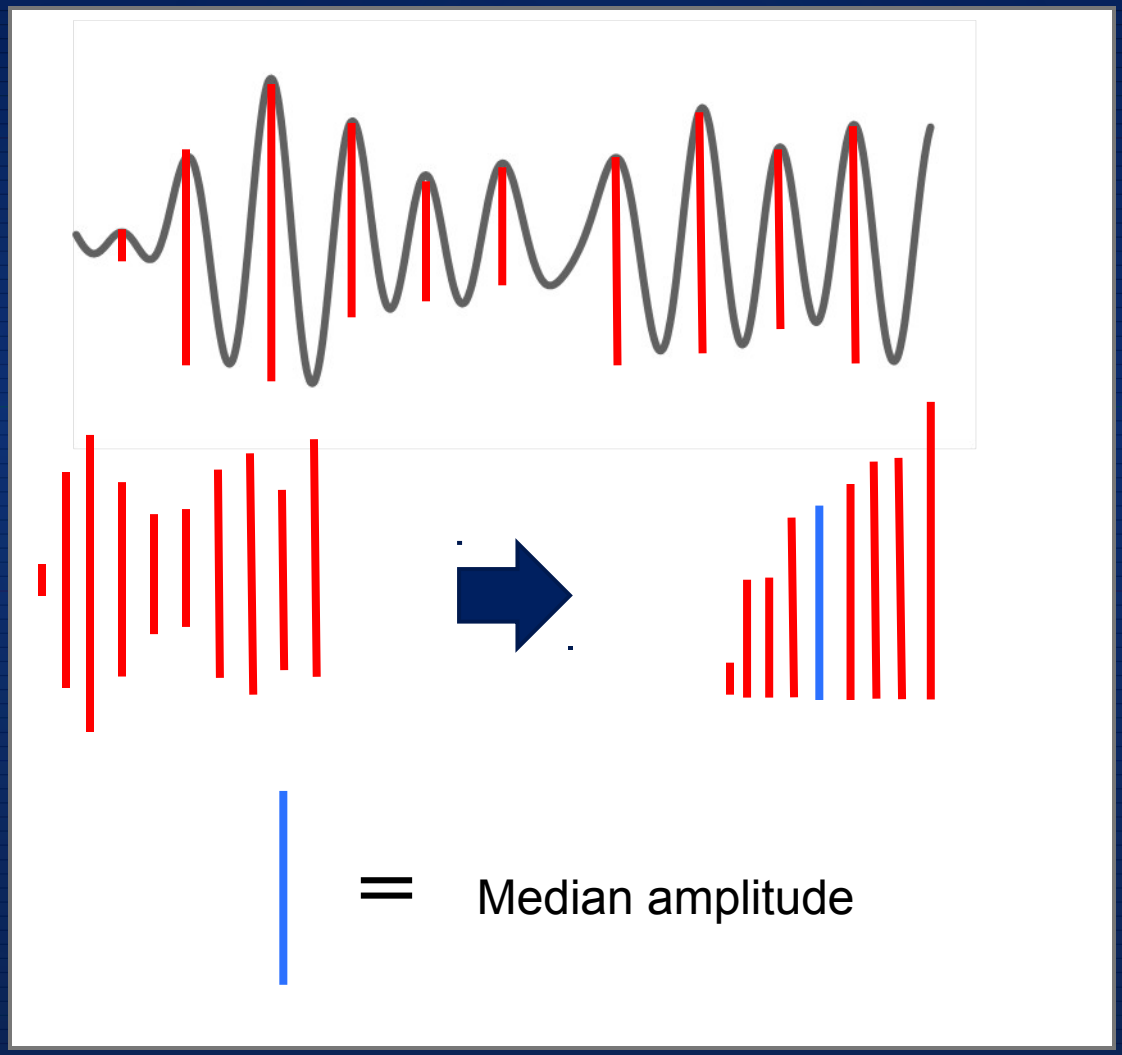
Amplitude integrated EEG (aEEG)

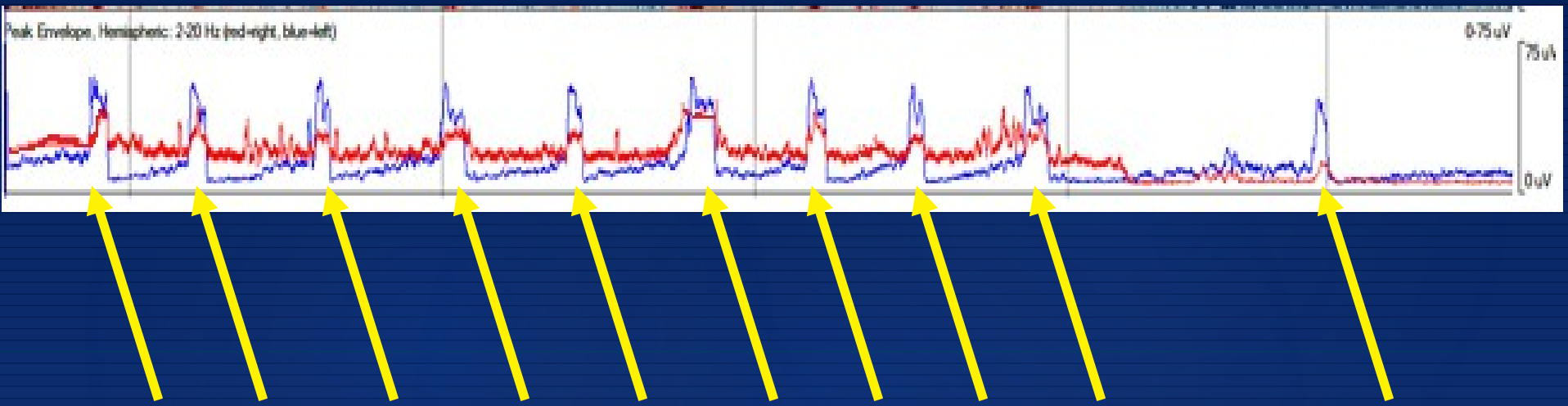


In this type of display of aEEG, the left and right hemispheres are displayed concurrently, with red = right hemisphere, blue = left hemisphere and pink = overlap. In this example, higher amplitude activity is seen in the left hemisphere. Seizures are associated with peaks in activity (red arrows)

Envelope / peak envelope

- Looks at the peak-to-peak amplitude of the waveforms in an epoch
- Determines the median amplitude for that epoch
- Helpful for removing signal due to artifacts

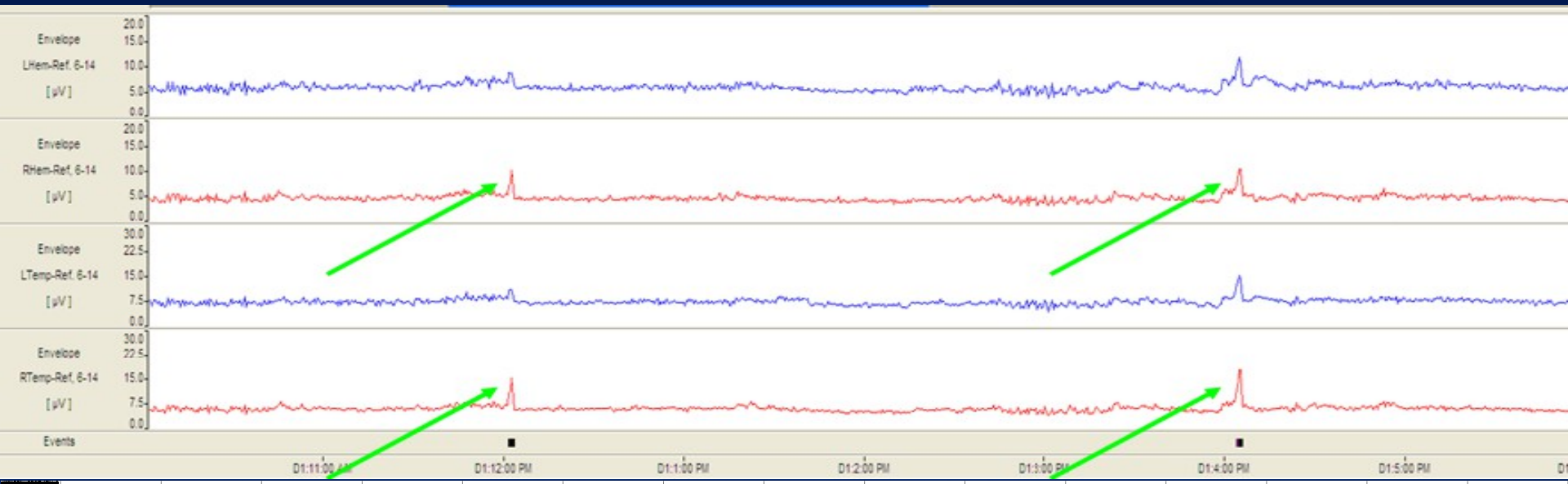




Peak envelope: Yellow arrows correspond to seizures. Left and right hemisphere are displayed together (red=right, left = blue)

Note that blue peaks are higher than red peaks, which suggests that higher amplitude seizure activity is present in left hemisphere.

In this seizure trend, seizures are seen as peaks (green arrow)



Issues with envelope trend

- If an epoch is saturated with artifacts (EMG, movement, chewing), median amplitude will be still elevated→ false positives

- One study looked at sensitivity of envelope trend in neonatal seizures:
  - Sensitivity= 88% of prolonged seizures, 40% of brief seizures, 20% of slowly evolving seizures
  - “Less than 2 false positives per hour”

Abend NS et al. *Epilepsia* 2008.

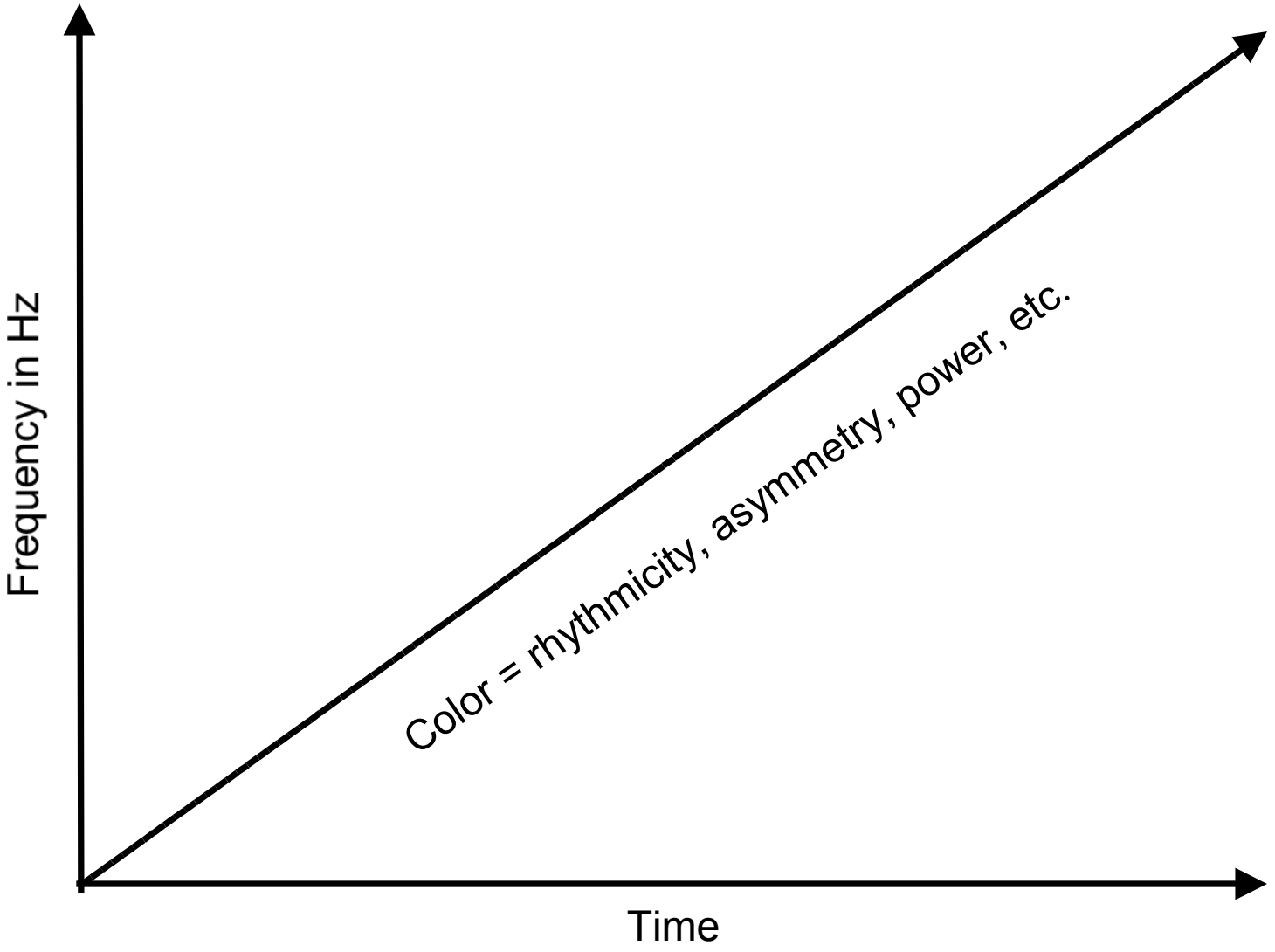
Issues with envelope trend

- Another study evaluated sensitivity of envelope trend in adults:
  - Reasonable sensitivity for experienced users (87%)
  - Poor sensitivity for inexperienced users (47%)
  - Predictors for missed seizures:
    - Low seizure amplitude
    - Frequent artifacts
    - High amplitude background
    - Trend toward missing shorter duration seizures

Akman CI et al. *Epilepsy Research* 2011.

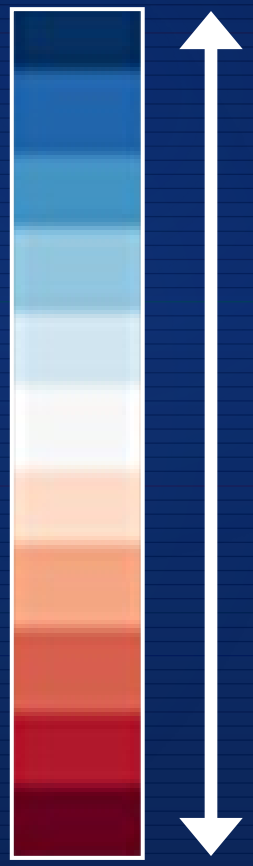
Spectrograms

- Spectrogram: Allows simultaneous display of multiple pieces of information at once
- Vertical axis: Frequency
- Horizontal axis: Time
- Z-axis = color (on a defined scale): represents a value at a particular frequency
- Different color scales may be used for different measures. Examples:
  - Asymmetry: red-white-blue scale
  - Rhythmicity: yellow-blue scale
  - Power: modified “rainbow”


Frequency in Hz
Color = rhythmicity, asymmetry, power, etc.
Time

Asymmetry spectrogram

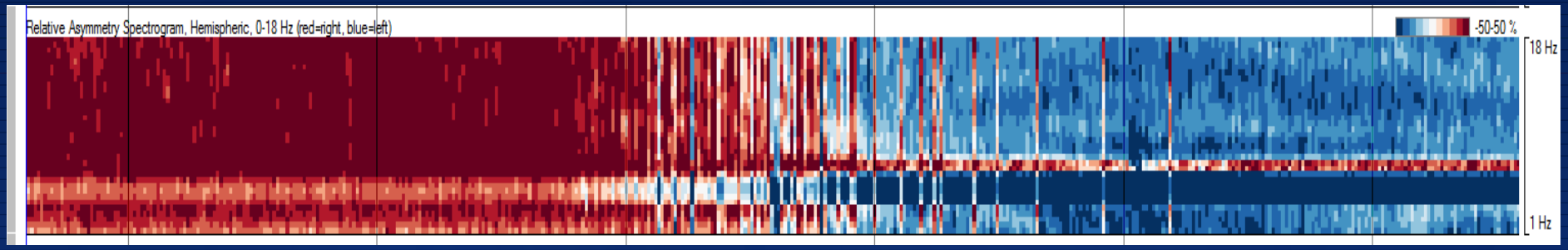
- Shows asymmetry at each frequency from 1 to 18 Hz over time
- The relative power is plotted on a red-white-blue spectrum (right)



More power right hemisphere

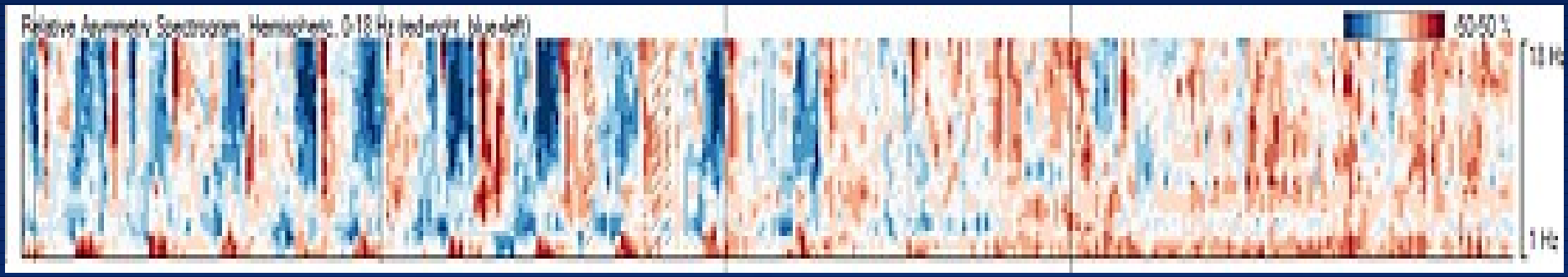
More power left hemisphere

Asymmetry spectrogram



This is an asymmetry spectrogram from an individual who is continually seizing out of the right hemisphere during the early portion of the spectrogram; this produces a dense red bar on the left. After seizure activity stops, activity in the right hemisphere is diffusely attenuated, which causes the spectrogram to appear blue.

Asymmetry spectrogram

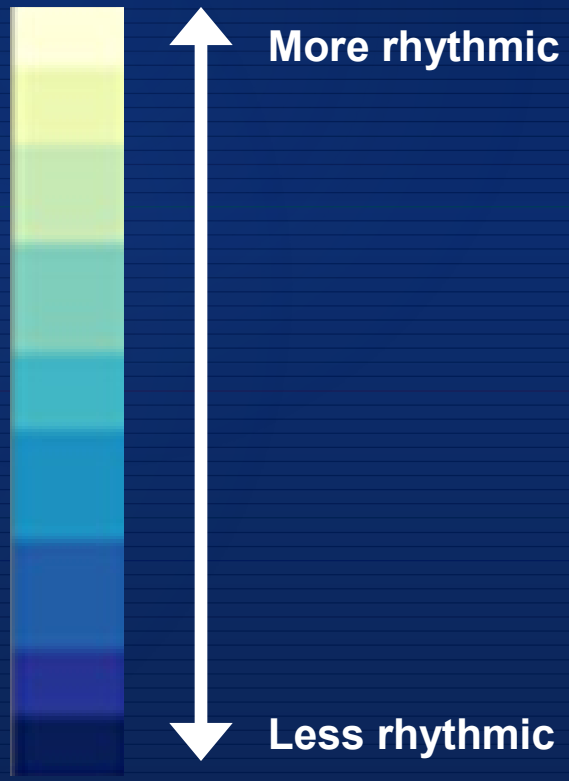


This is an asymmetry spectrogram from an individual with multiple discrete left hemispheric seizures. Seizures are associated with an increase in left hemispheric power primarily at faster frequencies (7-18 Hz) → stripes of blue at the top of the spectrogram during seizures

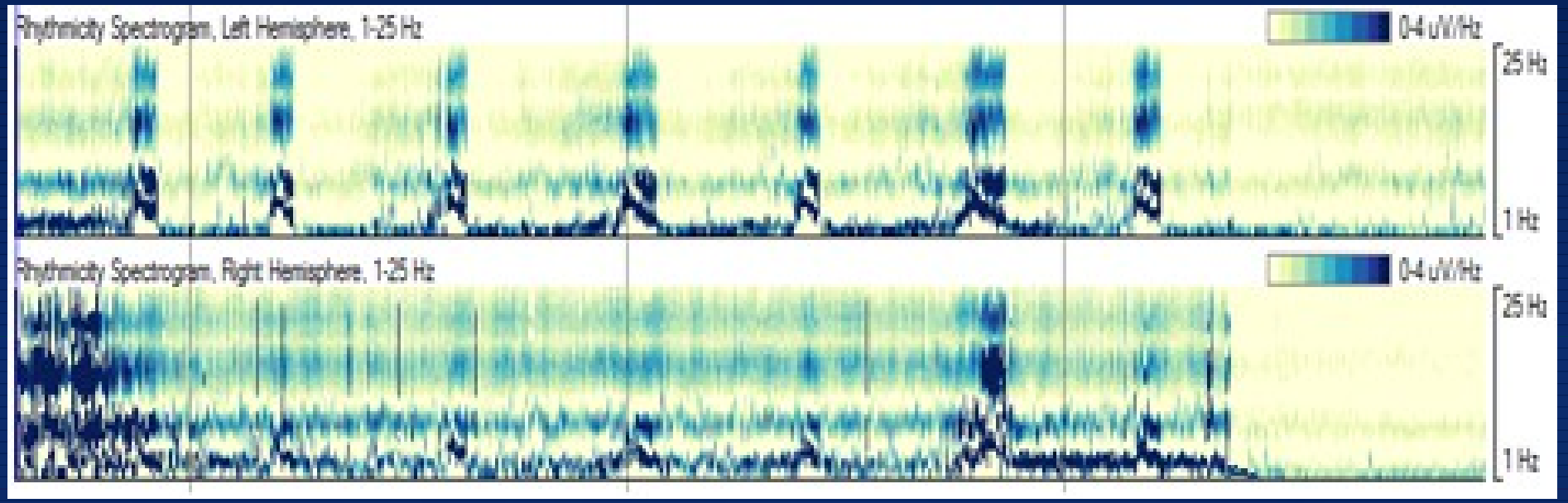
After seizure activity stops, there is relative slowing and attenuation over the left hemisphere, which causes the spectrogram to appear red

Rhythmicity spectrogram

- Rhythmicicity spectrogram: measure srhythmicity at different frequencies (1-24 Hz)
- Low rhythmicity = yellow, high rhythmicity = dark blue (see scale at right)

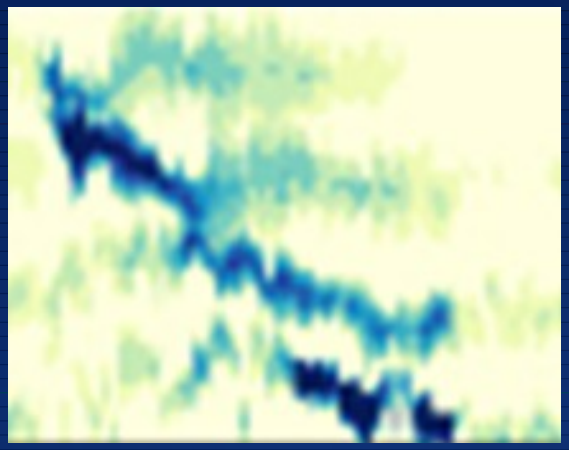


Rhythmicity spectrogram



This spectrogram shows multiple left sided seizures, each of which is associated with an increase in rhythmicity. Each seizure appears as a dark blue band.

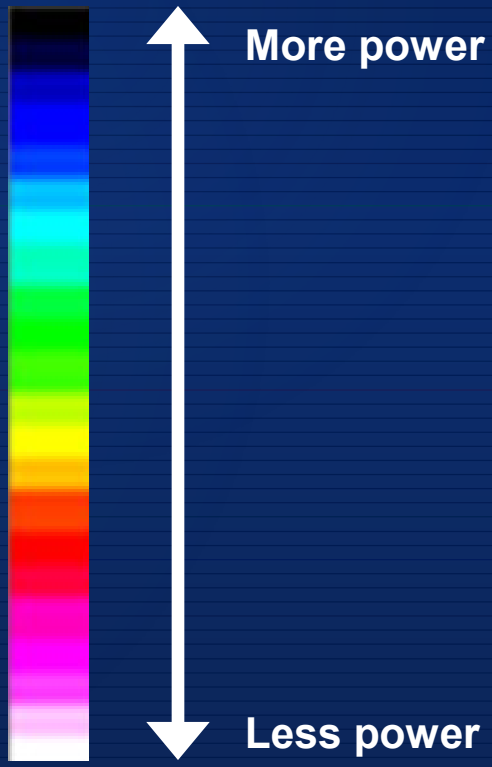
Rhythmicity spectrogram



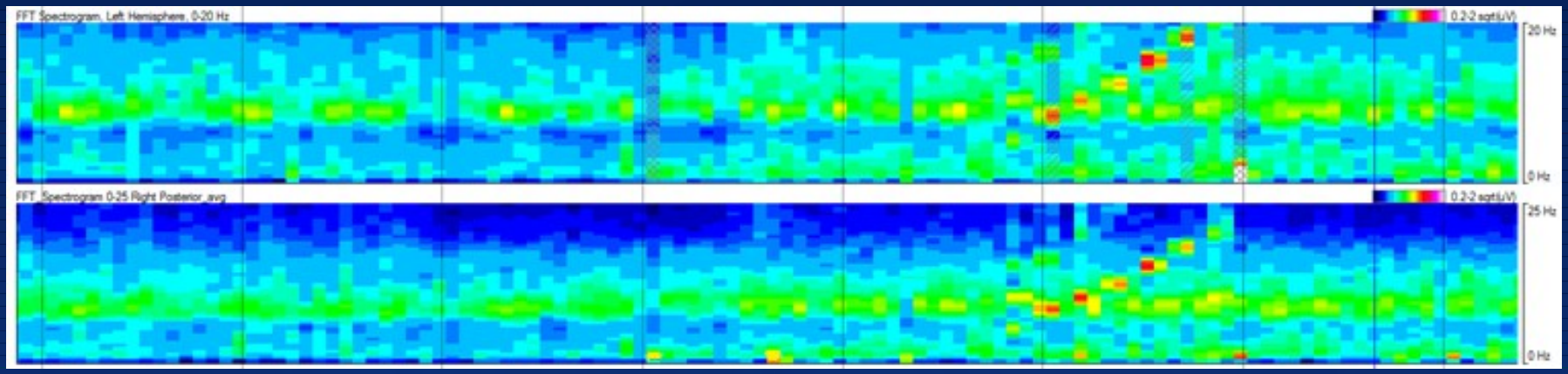
Many seizures often appear as a diagonal line or triangle-shaped lines on the rhythmicity spectrogram, because the seizures begin at faster or increasing frequencies and then gradually slow over the course of the seizure

Color spectrogram

- Also known as “color spectral array”, “color density spectral array,” “density spectral array,” “compressed spectral array” or “power spectrogram”
- Displays the power at frequencies from 1 – 20Hz using a modified rainbow color spectrum
  - White = highest power
  - Pink = very high power
  - Red = high power
  - Yellow = medium power
  - Blue = low power
  - Black = lowest power



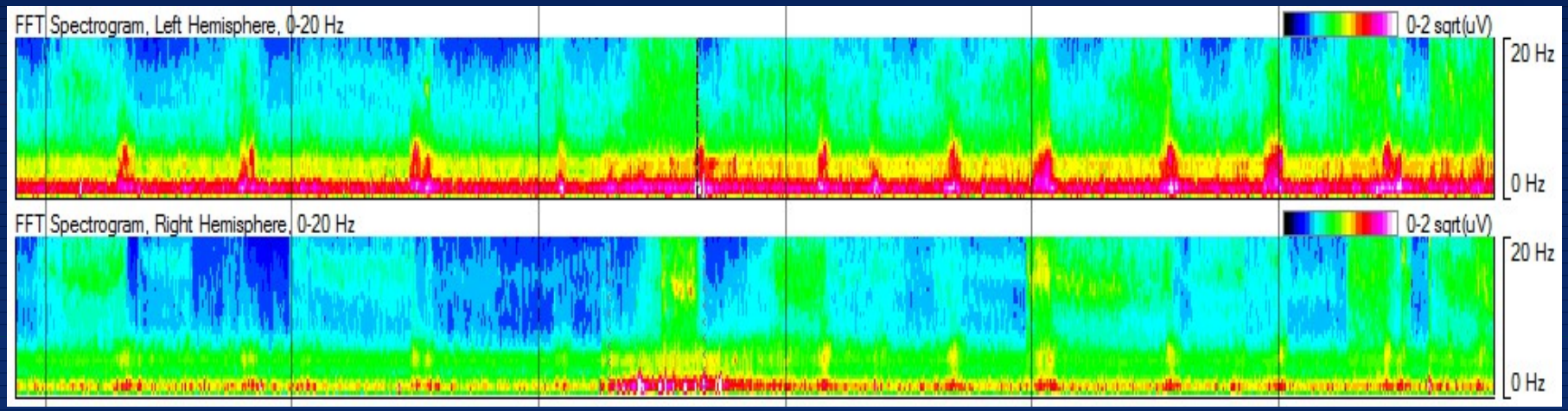
Color spectrogram



Color spectral array during stepped photic stimulation

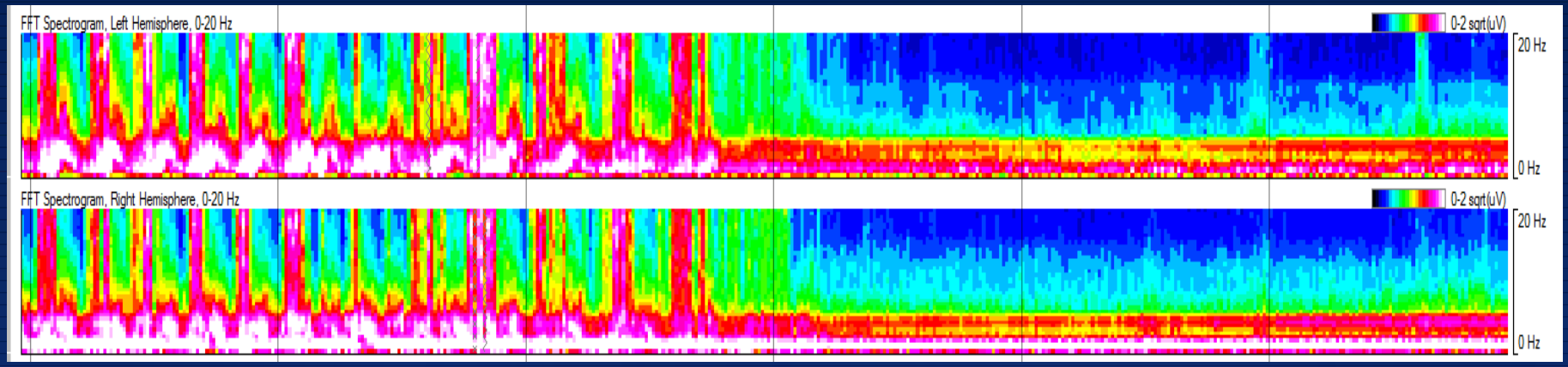
Stimulation at different frequencies produces photic driving, with an increase in power in that frequency band

Color spectrogram



Here, left sided seizures are associated with increased power at 3-5 Hz → red-pink peaks corresponding to seizures

Color spectrogram

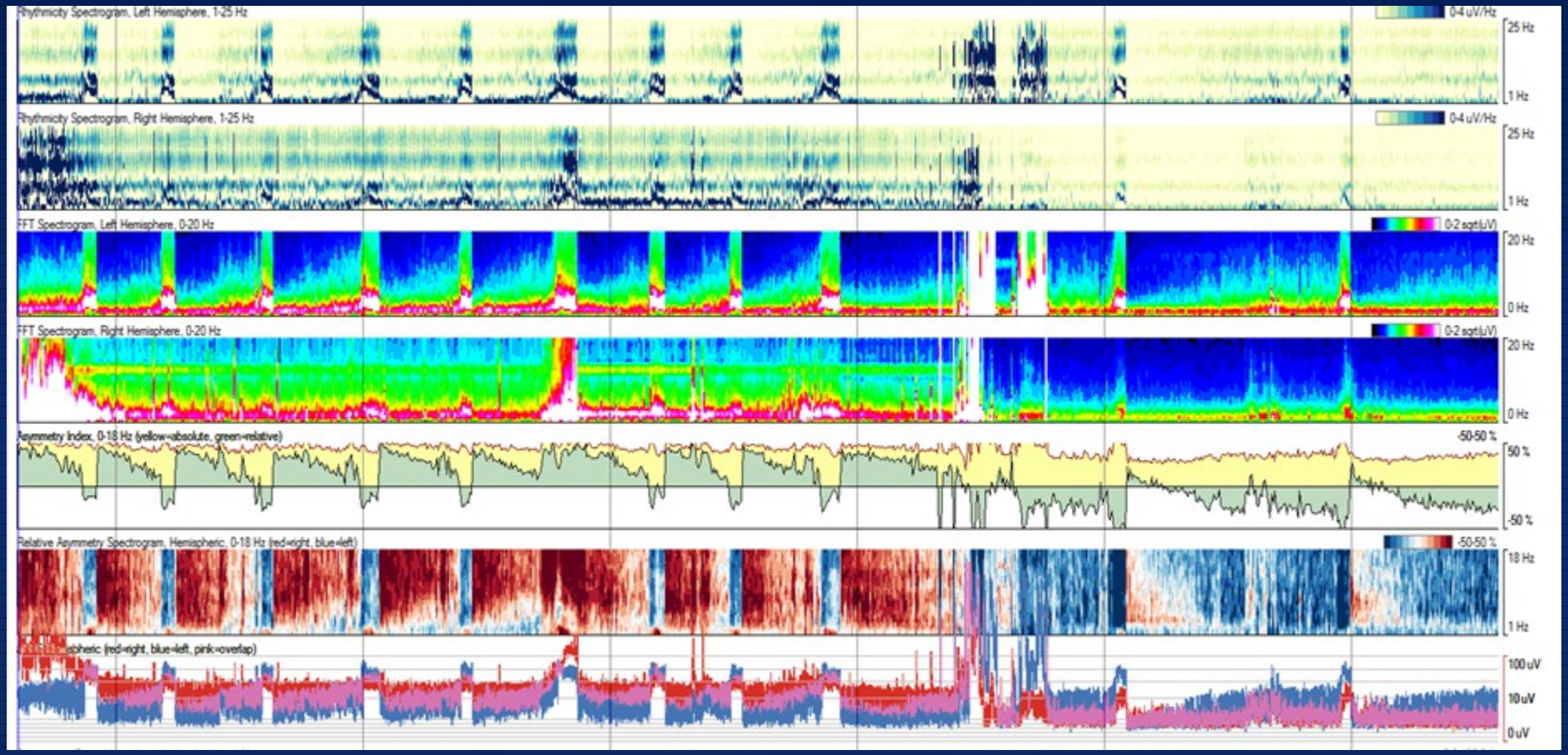


In this spectrogram, seizures are seen as stripes of pink and white (left side)

QEEG: Practical use

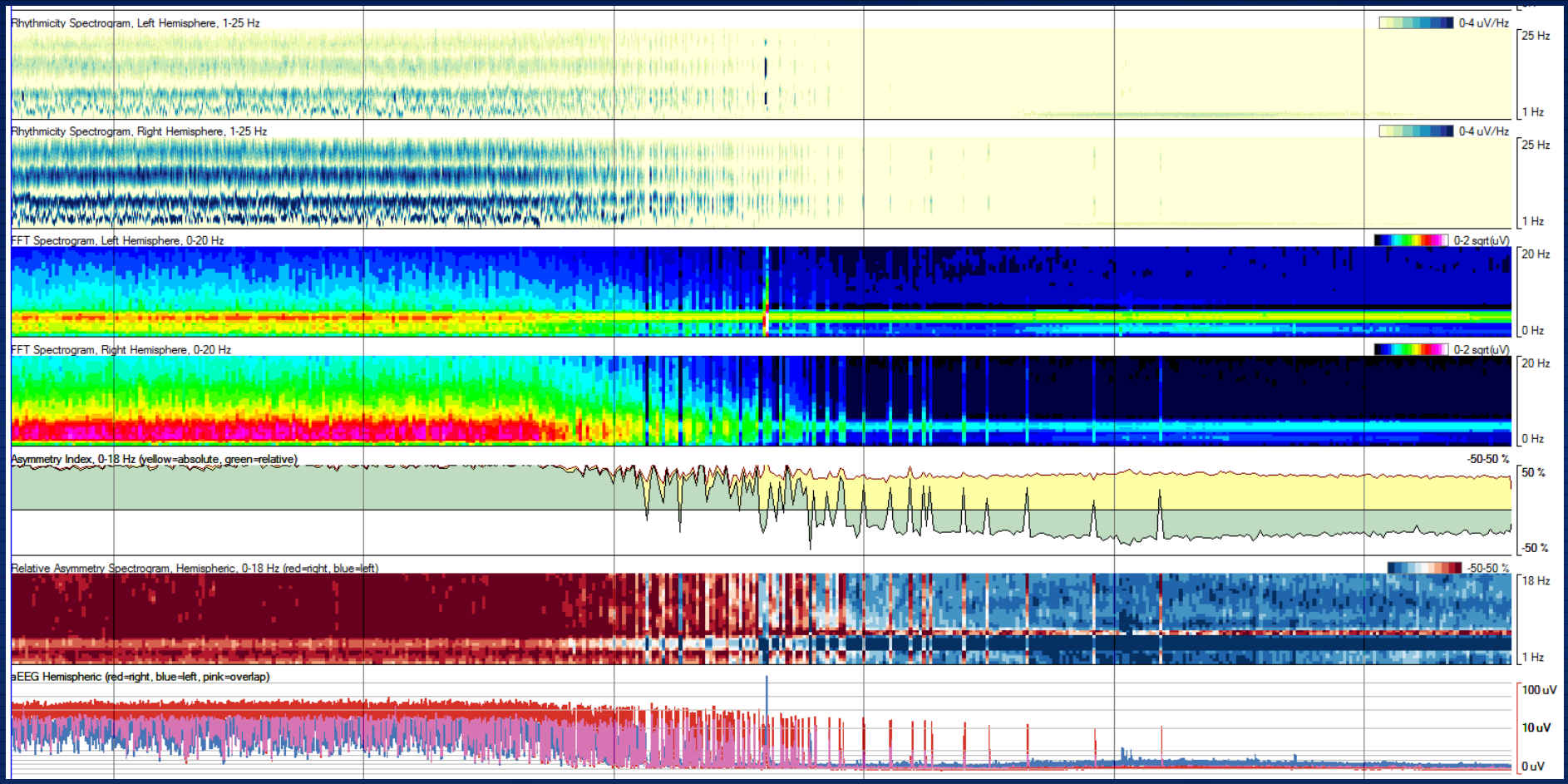
- In clinical practice, most intensive care units use multiple simultaneous trends for seizure identification
- Physicians and health care workers without experience reading EEG can be trained to review QEEG panels, although sensitivity is lower
  - Intensivists
  - Neonatologists
  - Nurses
  - Neurologists without neurophysiology experience

QEEG Panel



This panel shows rhythmicity spectrogram, color spectrogram, asymmetry index, asymmetry spectrogram and aEEG. These trends highlight this patient's (frequent) seizures

QEEG Panel



This panel shows a patient who initially has a prolonged right-sided seizure that subsequently resolves, followed by diffuse slowing and attenuation

QEEG: Practical use

- Sensitivity and specificity may be reasonable for screening EEGs
  - Sensitivity of envelope trend + color spectrogram in adults
    - Combined trends: 100% with experienced users, 79% for inexperienced users
    - Spectrogram alone = 48% sensitive (regardless of experience)
  - Sensitivity of color spectrogram in identifying seizures in children: 83 – 92%
    - Improved specificity with experienced readers

Stewart CP et al. *Neurology* 2010.
Pensirikul A et al. *J Clin Neurophysiol* 2013.
Akman CI et al. *Epilepsy Research* 2011.

QEEG: Practical use

- Recent study examined use of QEEG panel +/- raw EEG with experienced users
  - Their panel:
    - Envelope trend
    - Rhythmicity spectrogram
    - Color spectrogram
    - Asymmetry spectrogram
    - Amplitude integrated EEG
  - Studied 6 hour epochs of EEG, asked to mark seizure onset and end

Hader HA et al. *Neurology* 2016.

QEEG: Practical use

- Mean sensitivity for QEEG only: 51-67% with 1 false positives per hour
- Mean sensitivity for QEEG + raw EEG: 63-68% with 0.5 false positives per hour
- Lower sensitivities with:
  - Low frequency seizures
  - Low amplitude seizures
  - Epochs with rhythmic or periodic patterns
- QEEG → shortened review times (6 minutes alone, 14.5 minutes with raw EEG vs 19 minutes with raw EEG alone)

Hader HA et al. *Neurology* 2016.

QEEG: conclusions

- Quantitative EEG can help reduce an incredibly large amount of data to a more manageable amount of data
- Quantitative EEG is helpful as a screening tool when looking for seizures
- More information is needed to determine the optimal way to use quantitative EEG for seizure identification