Quantitative EEG

J. Chris Sackellares, M.D.

Malcom Randall VA Medical Center

Gainesville, Florida

Introduction

Clinical interpretation of EEG is based on visual inspection of multichannel EEG traces by an experienced electroencephalographer. Because this process is time consuming, availability of qualified electroencephalographers is the limiting factor in applying the diagnostic power of the EEG, particularly in the EMU and ICU.

Quantitative EEG methods have been developed to assist clinicians in interpreting EEG. There have been major advances in development of quantitative procedures to analyze EEG. However, validation procedures and performance evaluations of quantitative methods are required before the full “potential” of these techniques will be realized.

Definitions

Quantitative EEG (QEEG) – mathematical processing of digitally recorded EEG to highlight specific waveform components, transform the EEG into a format or domain that elucidates relevant information, or associate numerical results with the EEG data for subsequent review and comparison.

Signal analysis

Automated event detection

Monitoring and trending EEG

Source analysis

(Adapted from Nuwer. Neurology 1997; 49:227-292

Posted on American Academy of Neurology Web site)

Signal analysis -transforms

Quantitative measurement of specific EEG properties or a transformation of the raw EEG signal into numerical parameters other than the traditional amplitude versus time.

EEG is typically displayed as amplitude (voltage) versus time (seconds) for each channel derived from selected pairs. This is referred to as the "time domain".

Common signal transformations are:

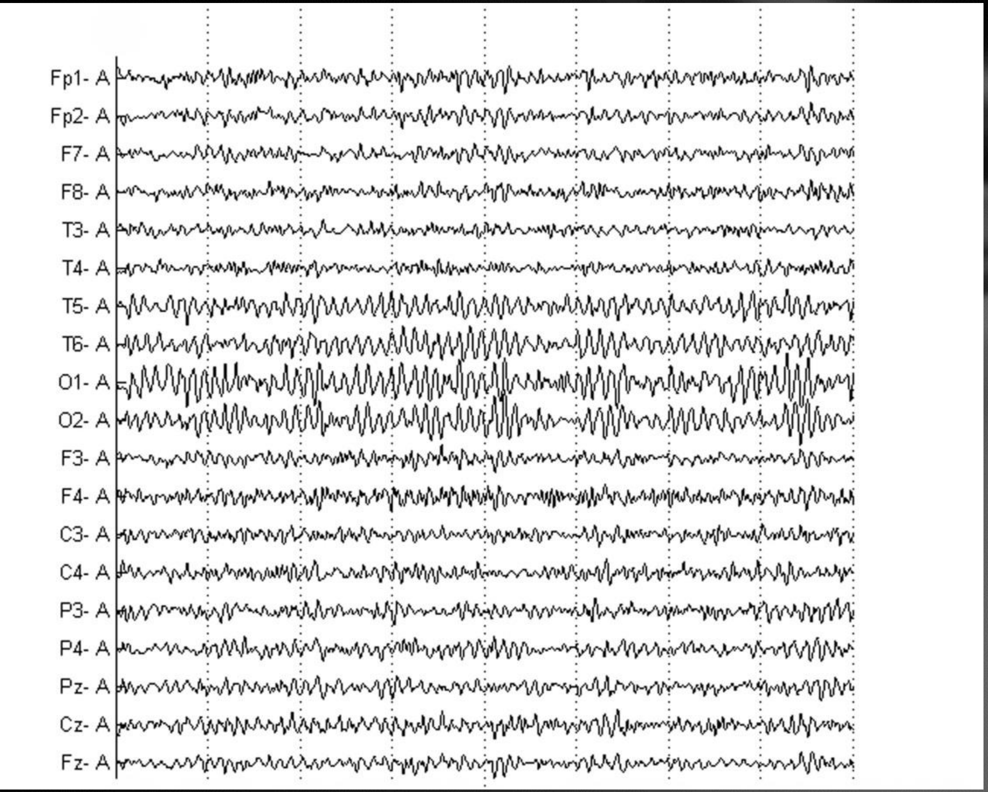
- Fourier transform (power spectrum) – transforms the signal from the time domain to the frequency domain (power (voltage squared versus frequency (cycles per second)
- Time-frequency transform – three dimensional transform graphing power versus frequency versus time
- Wavelet analysis
- Measures of Rhythmicity/predictability/order

EEG – time domain

The EEG is typically displayed as multiple traces (channels) organized by anatomical location of electrodes.

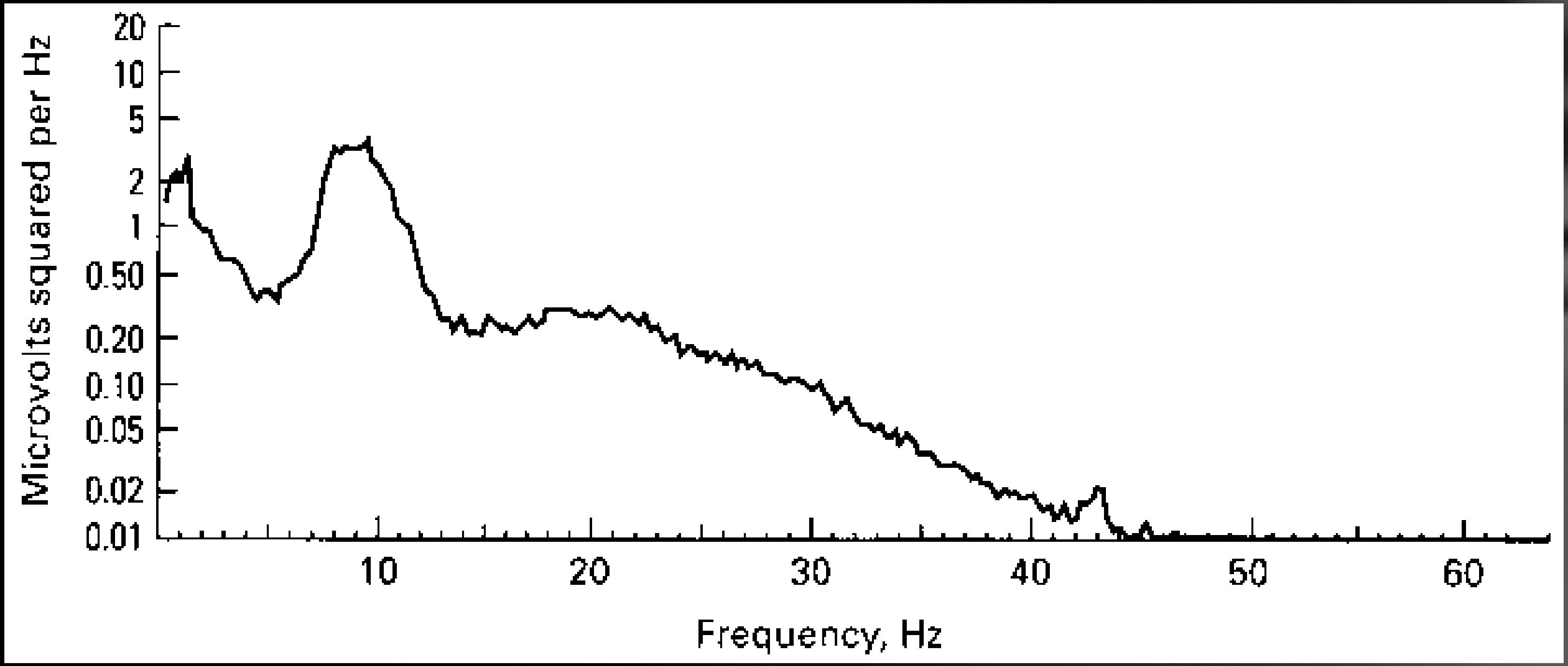
Each channel displays the potential difference (voltage) between an electrode pair as a function of time

Analysis depends on visual inspection by experts



EEG- frequency domain (spectrogram)

Power versus frequency



Signal analysis – some monovariant properties

Properties of individual EEG channels or groups of channels (e.g. left hemisphere derivations or right hemisphere derivations provide quantitative measures that can be compared among locations or over time:

Spectral Power (signal modeled as a combination of sines and cosines)

- Total power in all frequency bands
- Power in specific frequency bands (e.g. delta power)

Entropy (randomness)

Approximate entropy (estimate of entropy)

Information (randomness)

Lyapunov exponent (measure of order versus disorder; rate of information change

Wavelets (signal modeled wavelet functions

Matching pursuit (wavelet based method useful for detecting transients)

Pattern match regularity statistic (measure of signal regularity)

Signal analysis – bivariant properties

Measures often used to compare signals in electrode pairs

- Correlation (time domain)*
- Coherence (frequency domain – from the power spectra)*
- Mutual information (based on Shannon's information theory)
- Phase delay (useful for evaluating phase relationship in nonlinear data)
- Similarity index
- T-index (mean/standard deviation)

Network Analysis

Based on graph theory

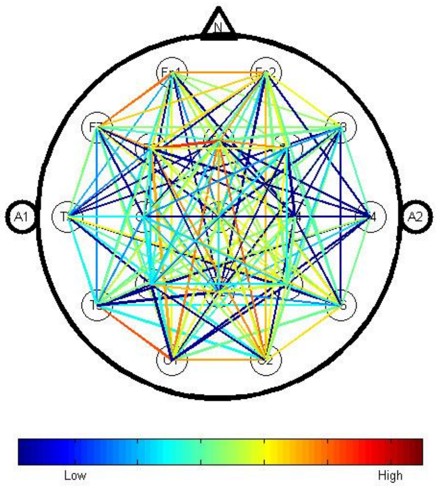
Each electrode is a “node” and connections between electrodes are edges

“Connectivity” between all electrode pairs is measured, using one of the bi-variant measures (e.g. coherence).

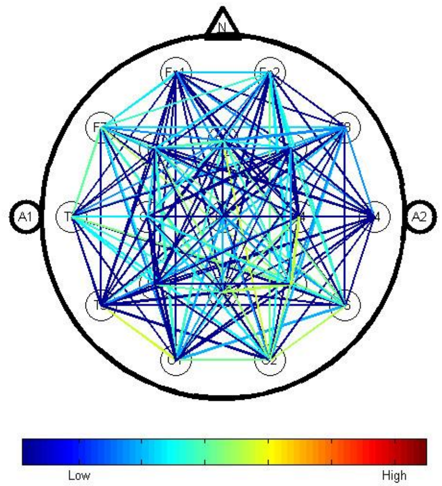
Networks are generated using connectivity thresholds to identify significant connections between nodes

Local and Global graph properties (e.g. local efficiency and global efficiency) are computed

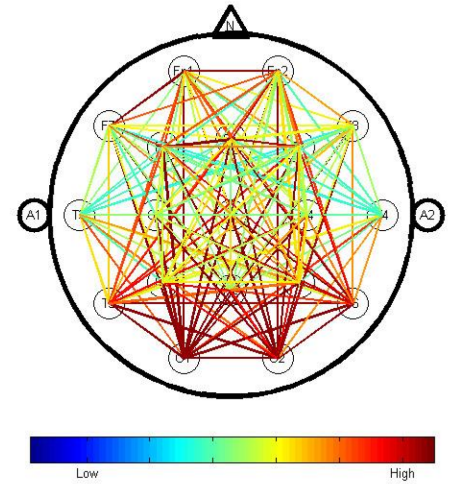
Networks derived from bivariate measures – normal EEG



Correlation network

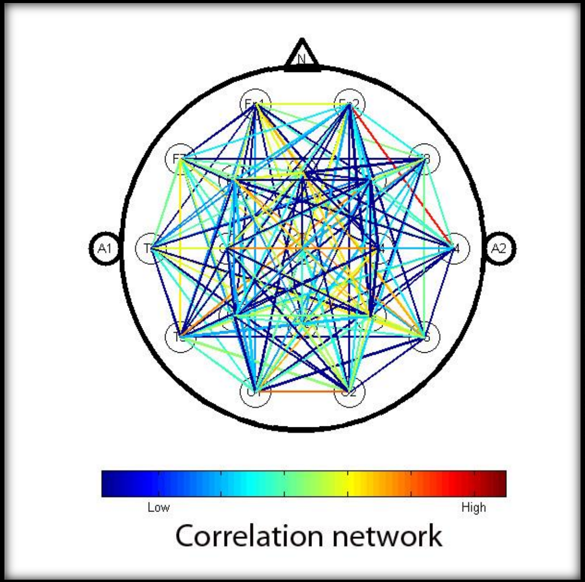


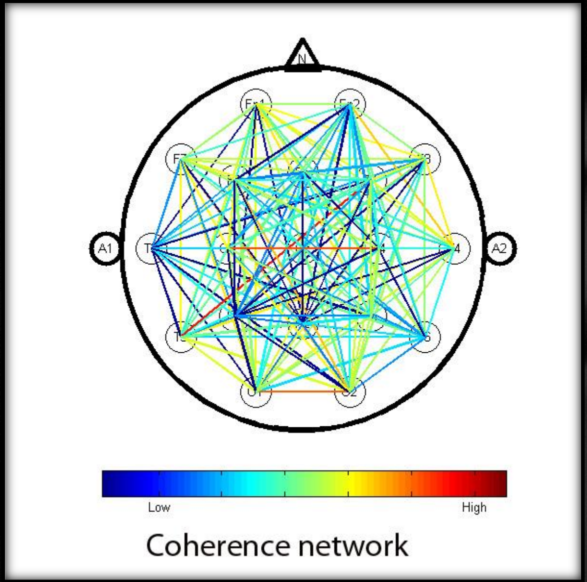
Coherence network

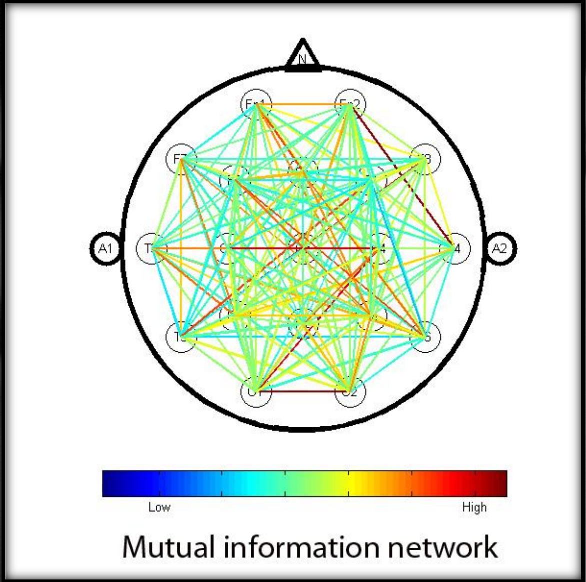


Mutual information network

Networks derived from bivariate measures – diffusely slow EEG







Automated event detector

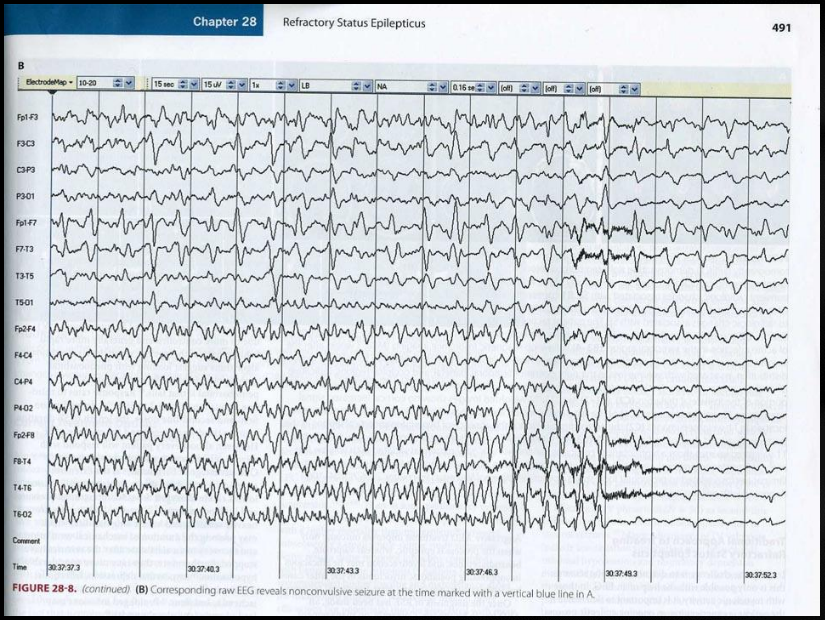
Algorithm that uses spatial and temporal EEG signal characteristics over time to detect transient events of interest, such as:

Epileptiform transients

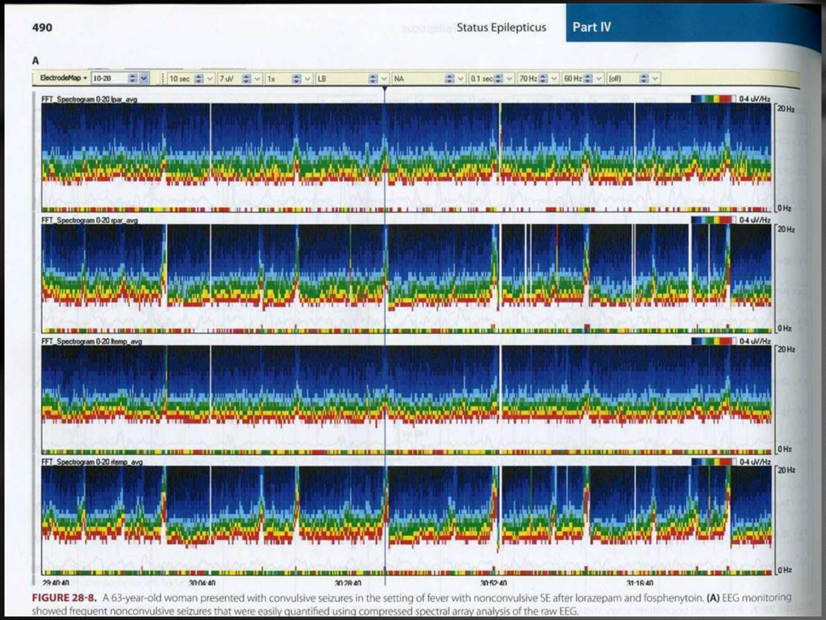
- Interictal epileptiform transients
  - spikes
  - sharp waves
  - spike and wave complexes
  - periodic lateralized epileptiform discharges
  - generalized periodic epileptiform discharges
- Electrographic seizures
- Diffuse, focal or lateralized background changes (e.g. due to ischemia)

Trending – compressed spectral array

Original EEG signal showing seizure



Power spectrum over

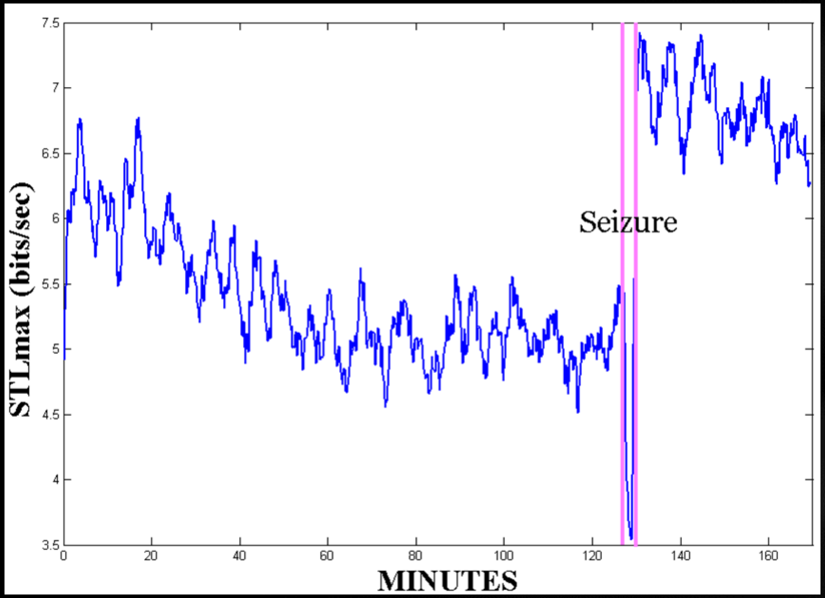


Reprinted from Sirven JI and Stern JM, *Atlas of Video-EEG Monitoring*, McGraw Hill, N.Y., 2011

Trending to assist in event detection

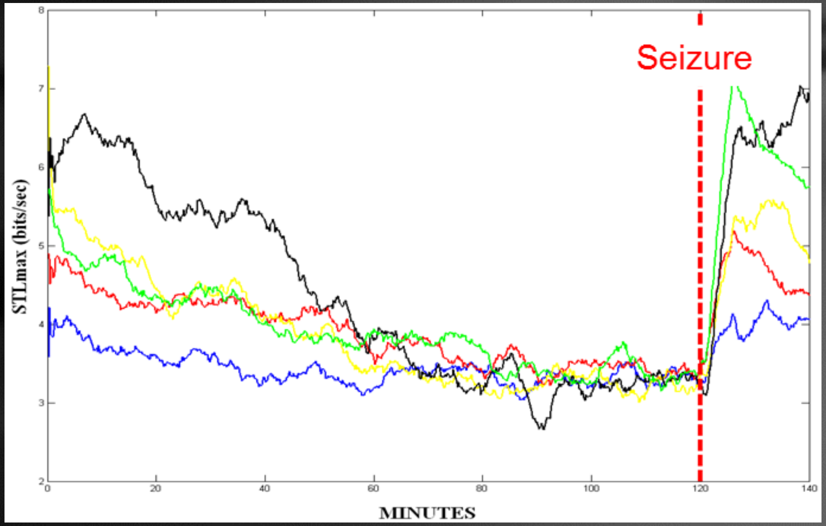
Signal metrics (STLmax) from one channel over time

Temporal trending



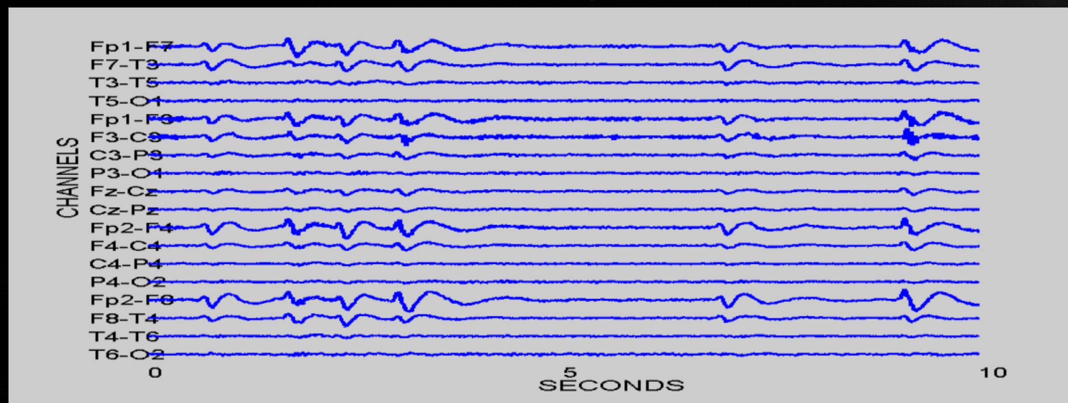
Signal metrics (STLmax) from multiple channels over time

Spatiotemporal trending



Seizure Detection Algorithm

EEG signal



Signal characteristic analysis for each EEG channel

Signal Frequency

Signal Amplitude

Signal stationarity

Spatio - temporal Pattern Recognition

Artifact Rejection

Seizure Detection

Summary

The term Quantitative EEG is often used narrowly to describe EEG signal analysis which describes the power spectral properties of the signal derived from each of multiple electrode sites and compares these values to normative values.

Quantitative EEG in a broader senses provides objective quantitative values for various signal properties which can be used to visual background abnormalities and to detect transients such as interictal epileptiform transients and seizures.

Application of advanced signal processing methods and network analysis provide tools for research into the pathophysiology of neurological disorders and have resulted into the development of diagnostic tools that are particularly useful in long-term monitoring in the EMU and in the ICU.