Making Coherence Coherent

Brain Connectivity
Assessment and Training

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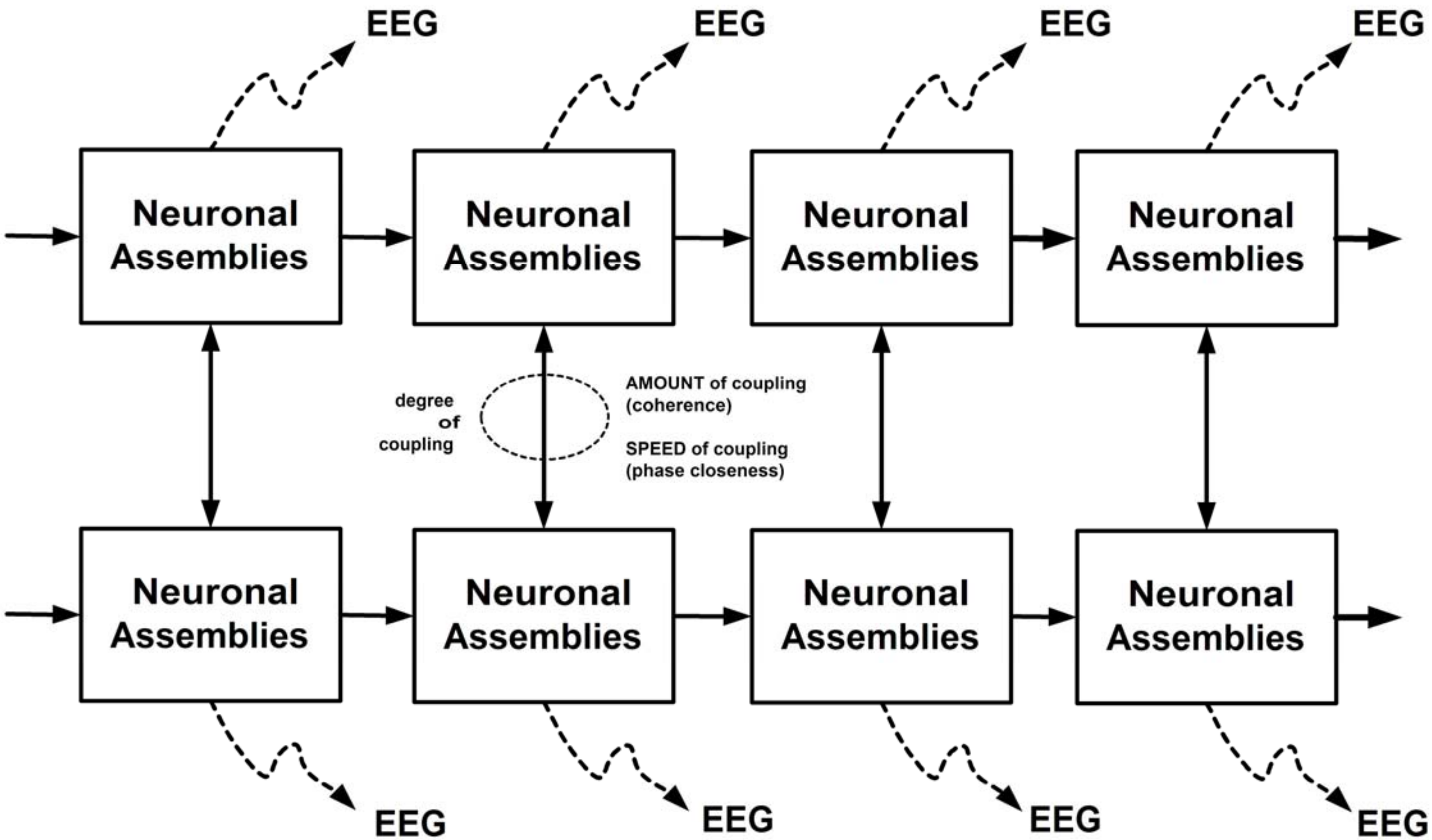
The Purpose of Connectivity Training

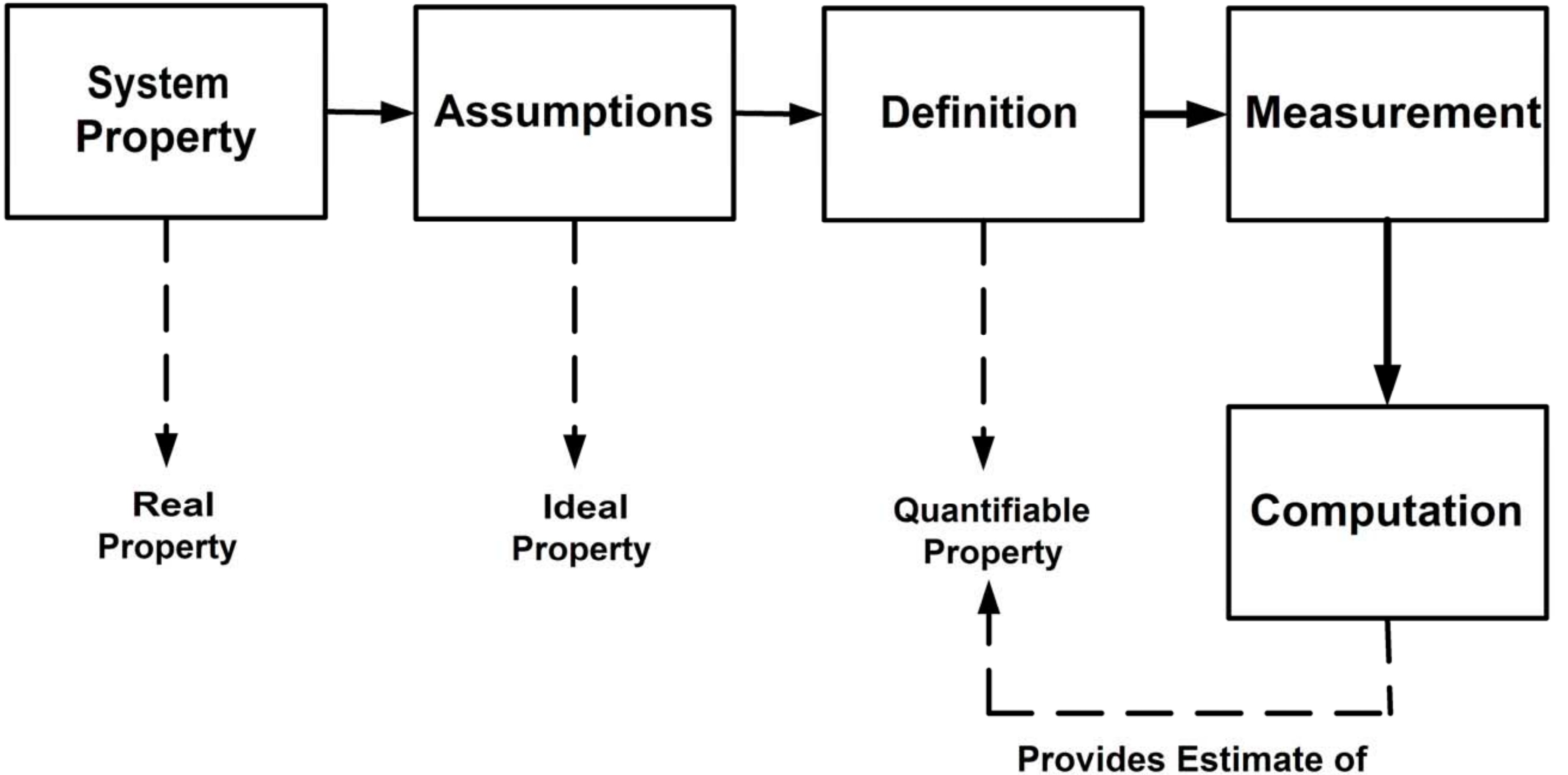
- To reflect whole brain function
- Show relationship between two sites
- Reflect amount of information shared
- Reflect speed of information sharing
- Real-time recording or postprocessed
- Useful for assessing brain function
- Useful for training brain connectivity
- Takes us beyond amplitude training

Generalized Connectivity Model



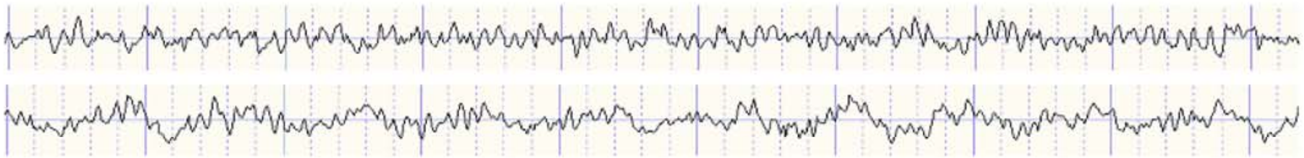
Generalized Model for EEG Generation

System Identification and Parameter Estimation



Coherence Estimation in Real Time

Given two EEG signals in real time,



To compute Coherence Estimates for real-time training, we can:

Perform Transforms on "chunks" using 0.5 - 2.0 second sample windows (may overlap) → **Perform Calculations on resulting data** → **Coherence Estimate**

-or-

Filter signals to produce filtered versions of original signals (1-3 cycle delay) → **Perform Calculations on resulting waveforms: envelope detection, peak detection, cross-correlation, etc. (1-2 cycle delay)** → **Coherence Estimate**

-or-

Use Quadrature Methods to extract and compute cross-terms directly (1-3 cycle delay) → **Coherence Estimate**

Connectivity Measures

- Many ways to measure connectivity
- Always asking “how similar are the signals?”
- Relative Phase sensitive or insensitive
- Absolute phase sensitive or insensitive
- Amplitude sensitive or insensitive
- Measurement across time or across frequency
- Source of raw data
  - Waveform
  - FFT
  - Digital Filter (IIR or FIR) or Quadrature Filter

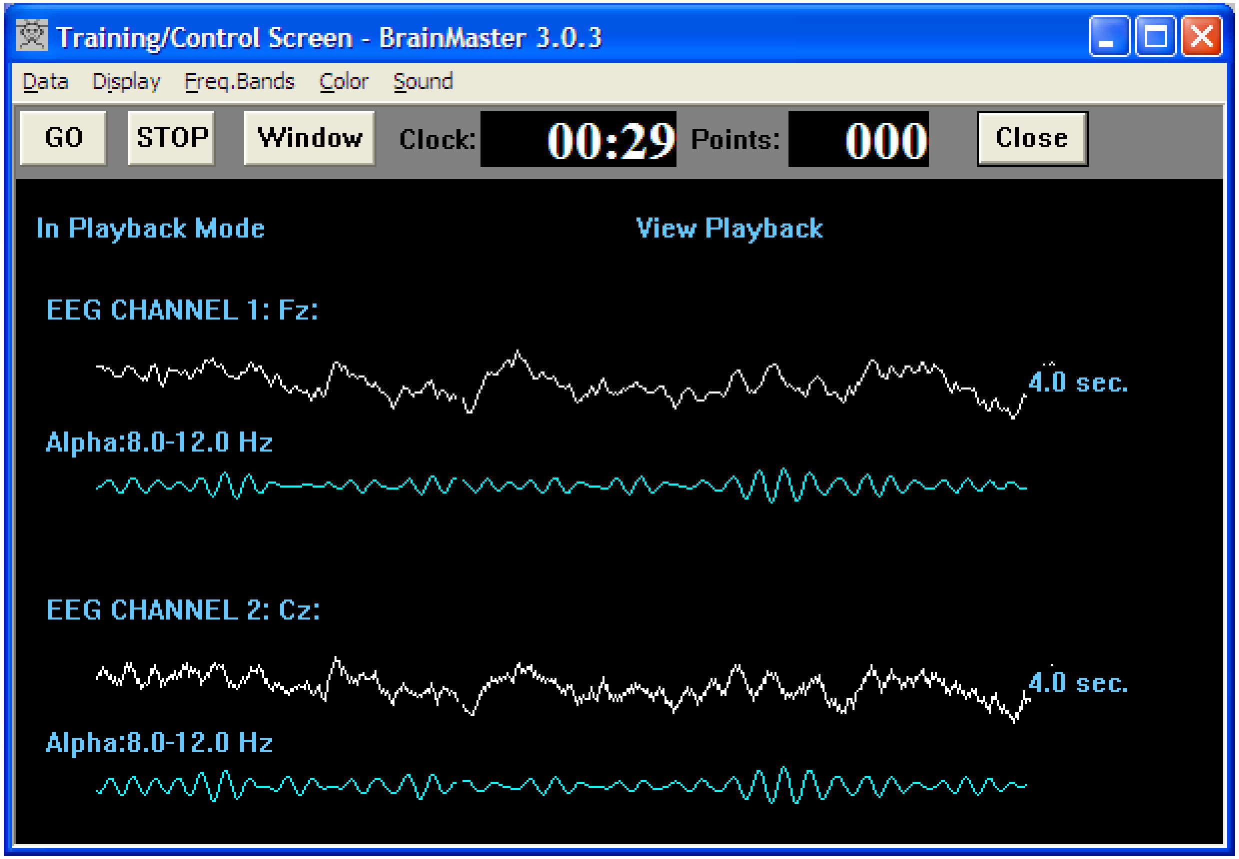
Connectivity Measures - Summary

- Pure Coherence (is relative phase stable?)
  - joint energy / sum of self-energy
- Synchrony Metric (do phase and amplitude match?)
  - Joint energy / sum of self-energy
- Spectral Correlation Coefficient (FFT amplitudes same?)
  - Correlation (f) between amplitude spectra
- Comodulation (do components wax & wane together?)
  - Correlation (t) between amplitude time-series
- Phase (is relative timing stable or same?)
  - Arctan of ratio of quadrature components
- Sum & Difference Channels (arithmetic comparison)
  - Simply add or subtract raw waveforms

Classical or “pure” Coherence

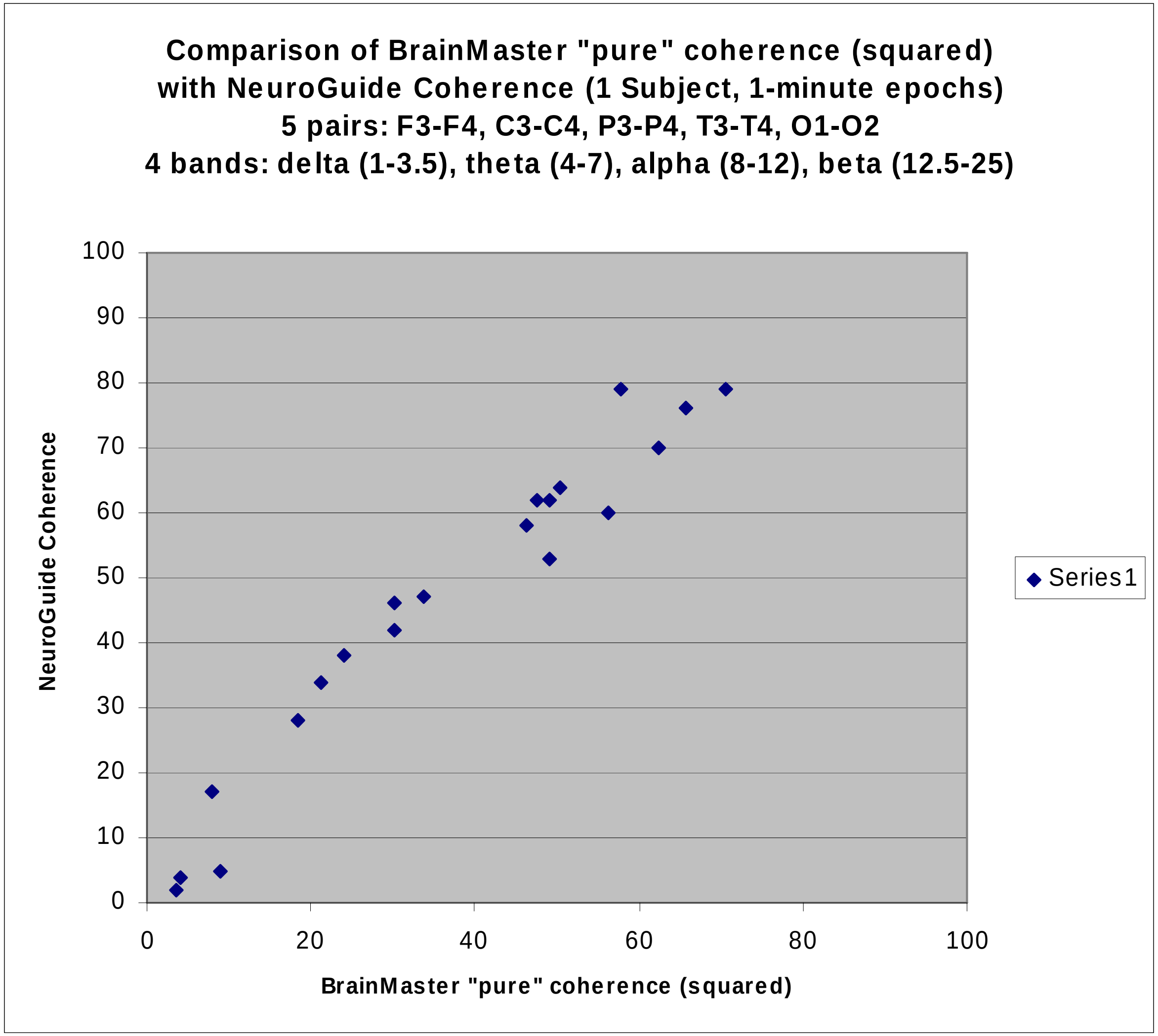
- Measure of phase stability between two signals – gets “inside” signals
- Wants them to be at the same frequency
- Doesn’t care about absolute phase separation
- Doesn’t care about relative amplitude
- Measures of amount of shared information
- Useful when sites have different timing
- Can use FFT or Quadrature filters to calculate

Pure Coherence



- How stable is the phase relationship between the waveforms on the two channels?

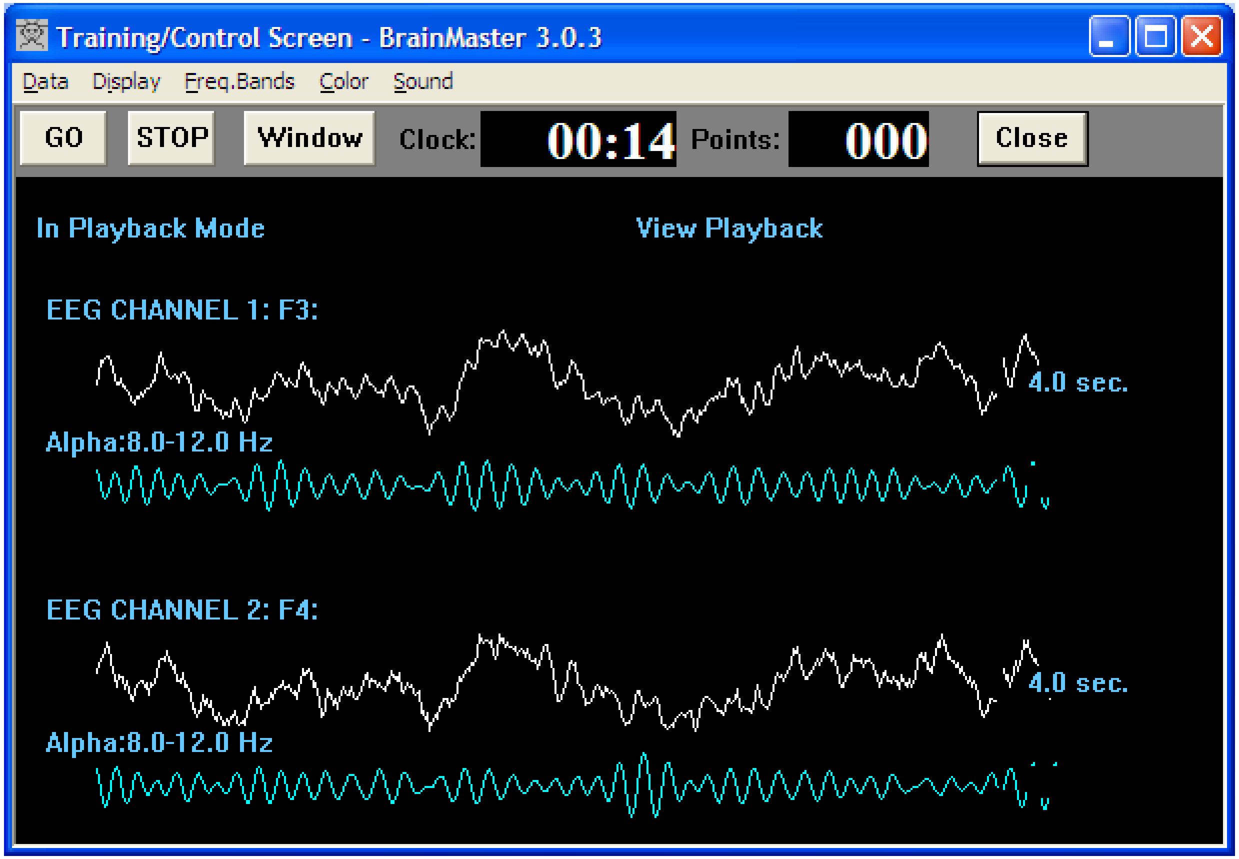
Pure Coherence: BMr-NG Concordance



"Training" Coherence/Similarity (BrainMaster)

- Similarity measure using Quad filters
- Measure of phase and amplitude match between two signals – gets "inside" signals
- Wants them to have zero phase separation
- Wants them to have same amplitude
- Useful for synchrony training
- Random signals will have low coherence

Training Coherence (Similarity)

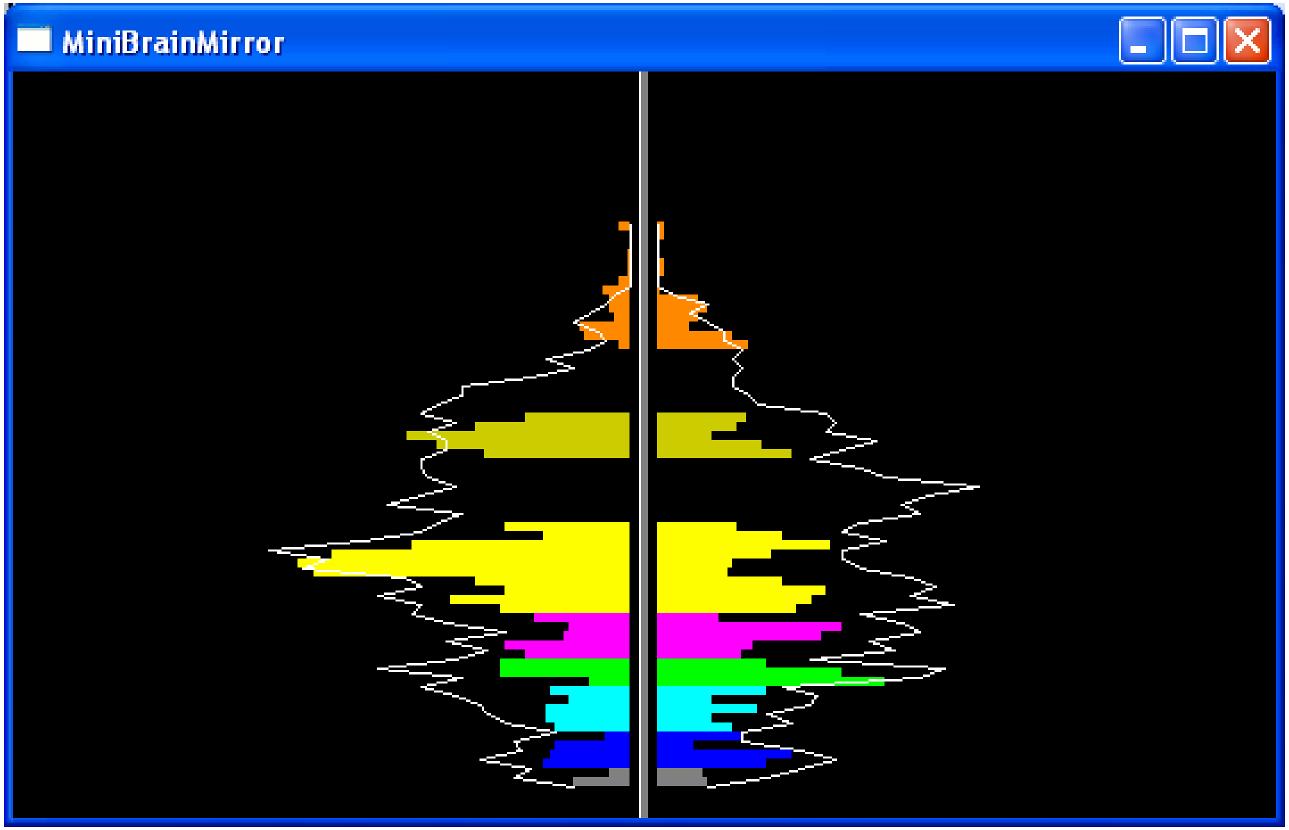


- Are the two channels consistently in phase and of the same size?

Spectral Correlation Coefficient (Lexicor)

- Measure of amplitude similarity in spectral energy – uses FFT amplitude data
- Wants two signals to have similar power spectral shape
- Completely ignores phase relationship
- Meaningful for a single epoch
- Random signals may have large correlation if spectra are similar

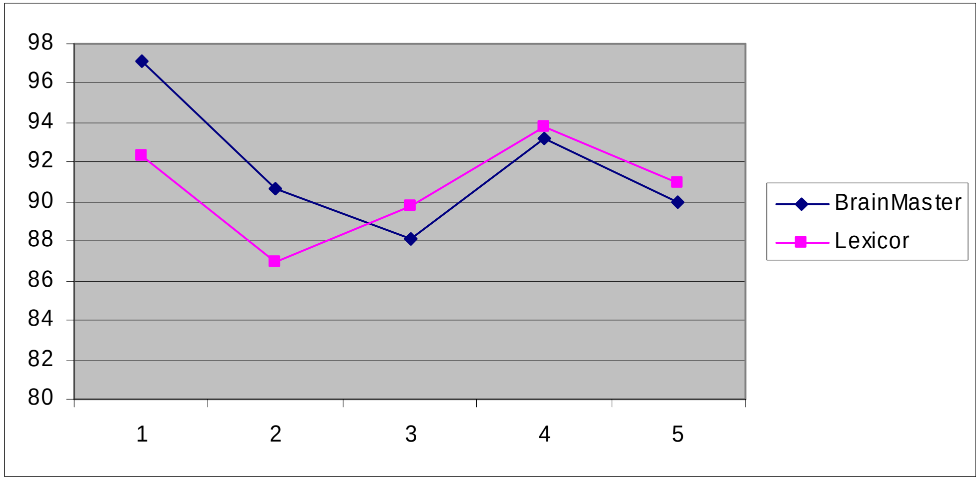
Spectral Correlation Coefficient (SCC/"Lexicor")

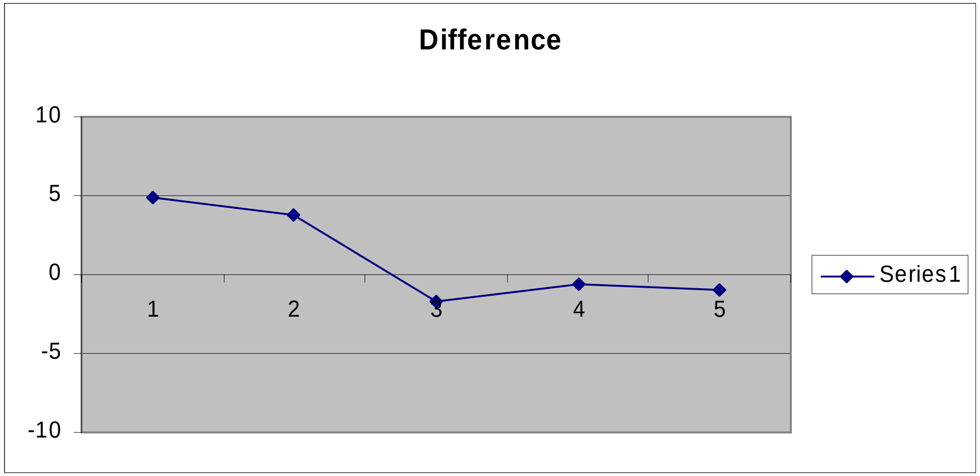


- How similar (symmetrical) is the shape of the spectral amplitude of the two channels in a particular band?

SCC: BMr – Lexicor Concordance

(G, B, A, T, D; as of 1/12/07)

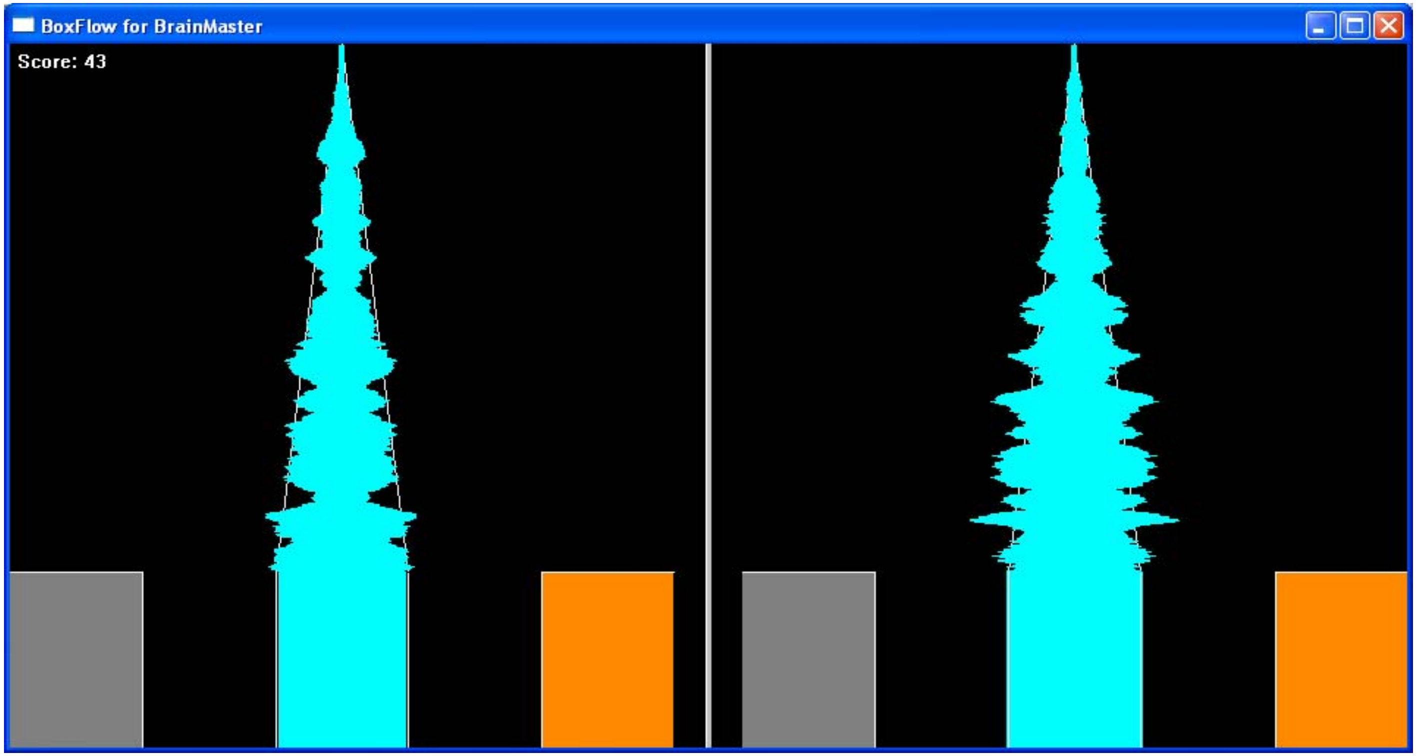




Comodulation (Sterman/Kaiser)

- Measures similarity in amplitudes across time – classically uses FFT amplitude data
- Correlation between envelopes of two signals
- Completely ignores phase relationship
- Must be considered across time epoch
- Reflects how similarly signals wax and wane together
- Can be computed using digital filters
- Random signals will have low comodulation

Comodulation (SKIL)

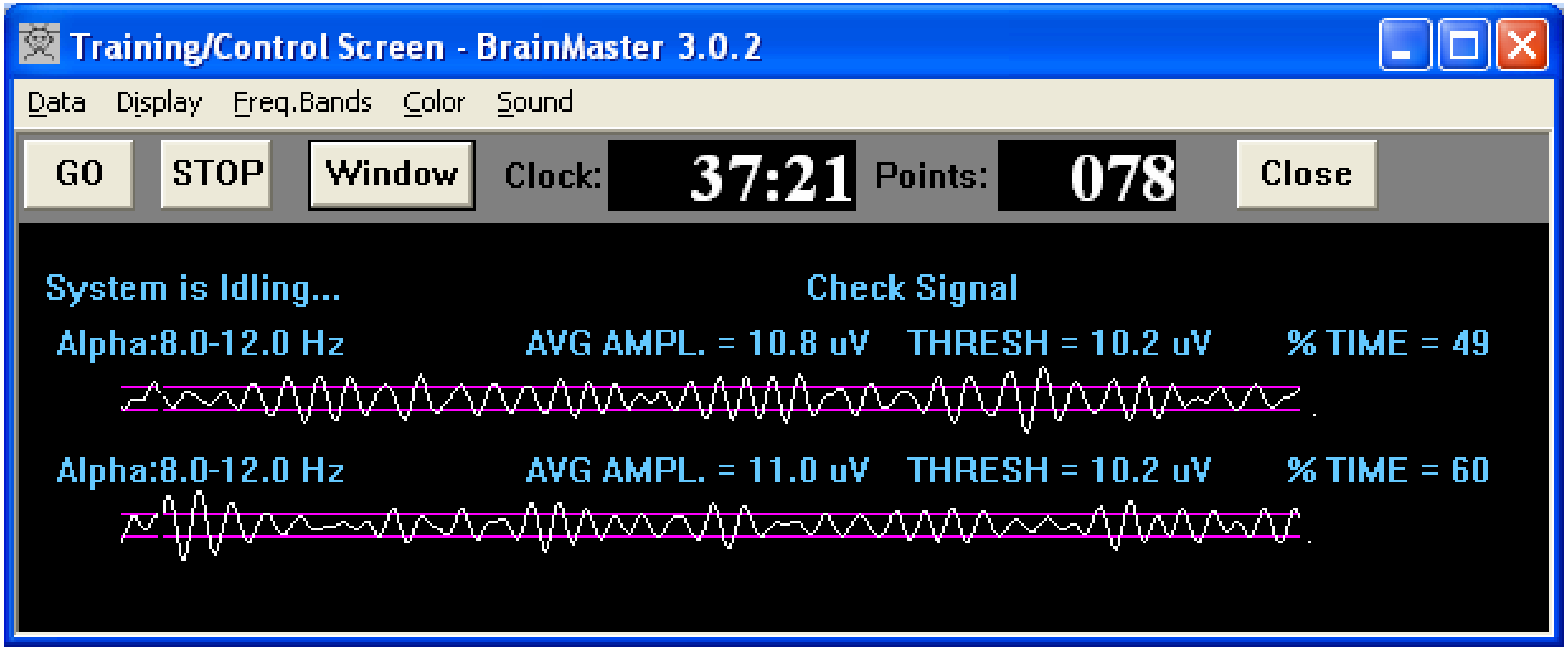


- How similar is the waxing and waning of the amplitudes in the two channels over time?

Phase measurement

- Various methods to compute
- Attempts to extract phase relationship using mathematical technique
- Stability and “wraparound” issues
- FFT or Quad Digital Filters
- Reflects how well signals line up in time
- Measure of speed of information sharing
- Useful for synchrony training

Phase



- Exactly how do the peaks and valleys line up? (What is their phase separation at any instant?)

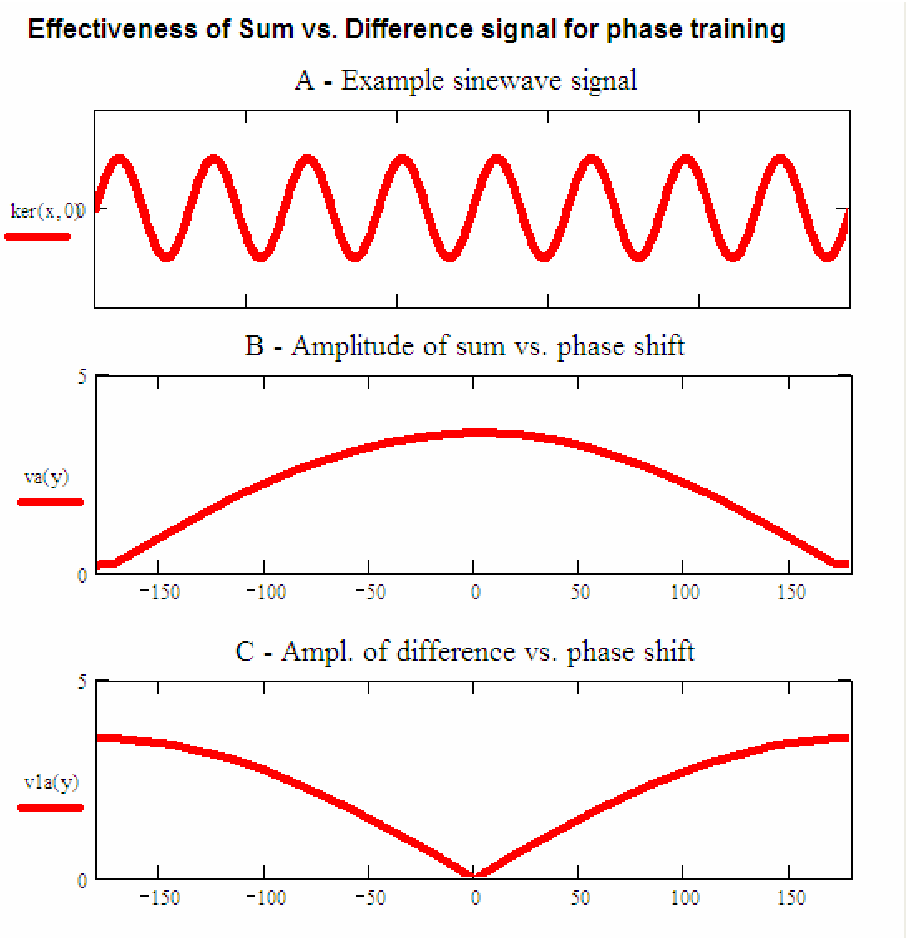
Sum-channel

- Adds two signals together in time domain
- Gets “inside” signals
- Peaks and valleys reinforce in time
- Very sensitive to phase relationship
- Wants signals to be in phase
- Largest when both signals are large
- Useful for synchrony training
- Can uptrain coherence with sum-channel mode
- Random signals: sum & difference will look the same

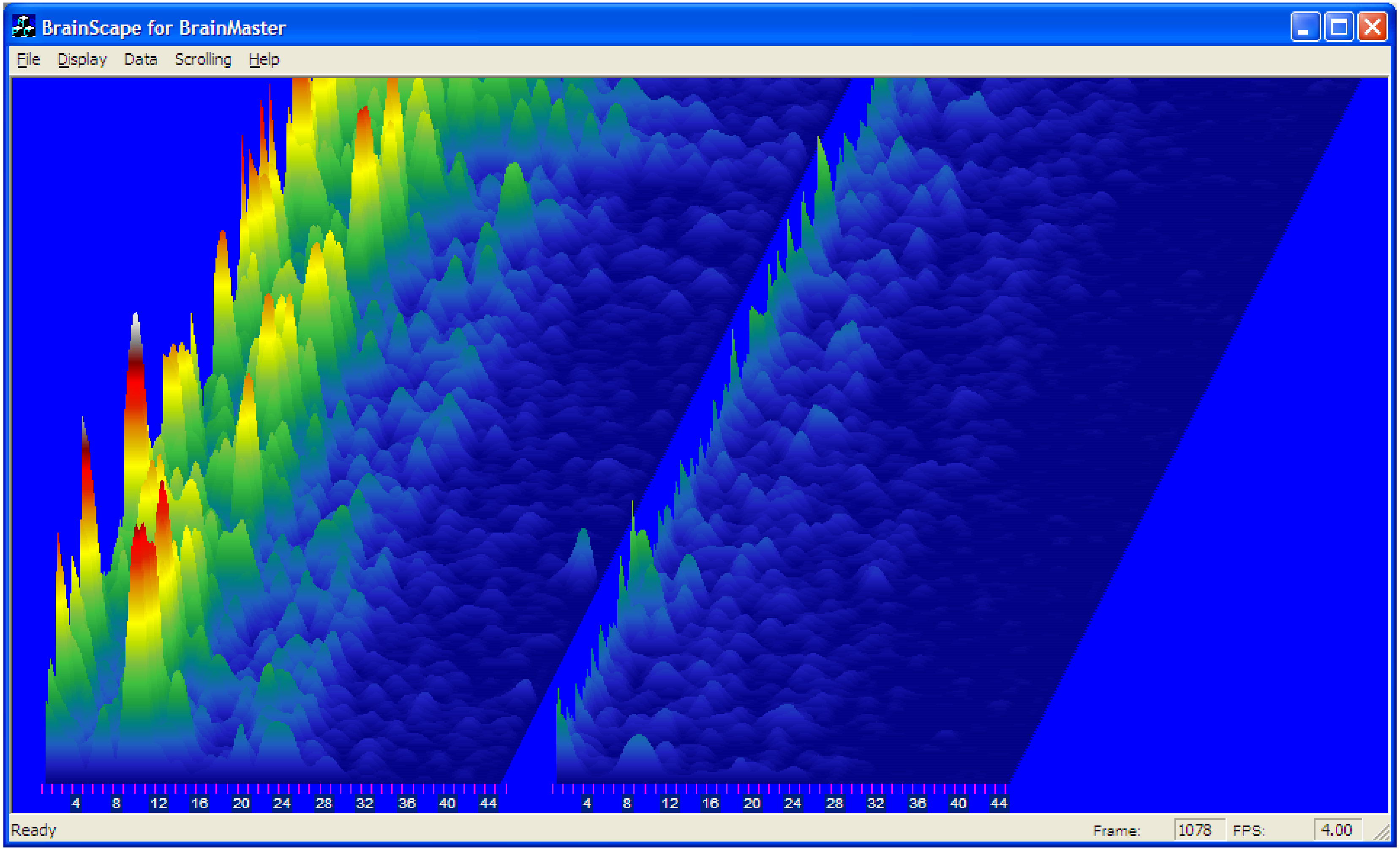
Difference-channel

- Same as bipolar montage
- Similar signals will cancel
- Emphasizes differences
- Useful for coherence downtraining
- Cannot uptrain coherence with bipolar
- Random (uncorrelated) signals: sum & difference signals will look the same

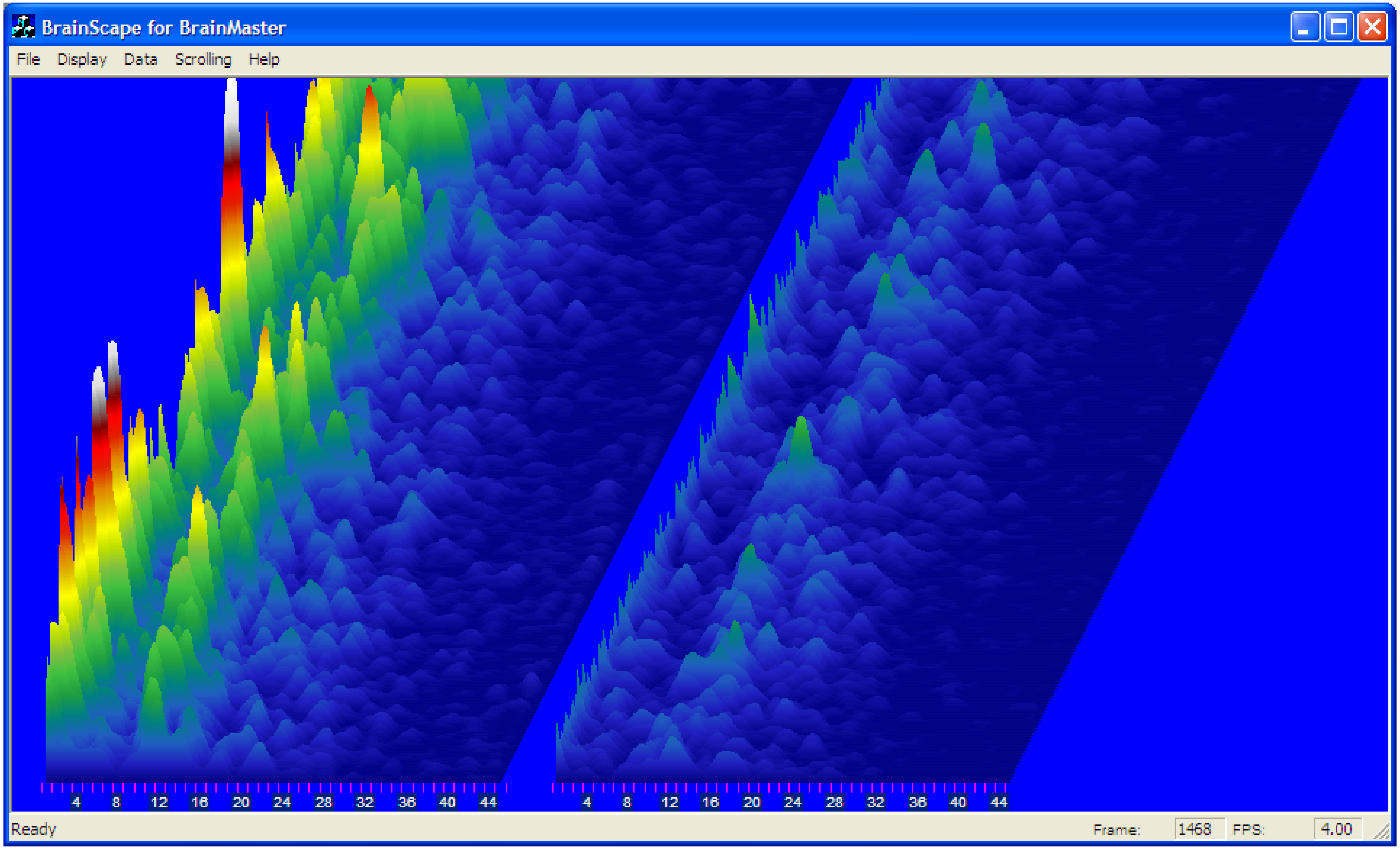
Channel Sum & Difference



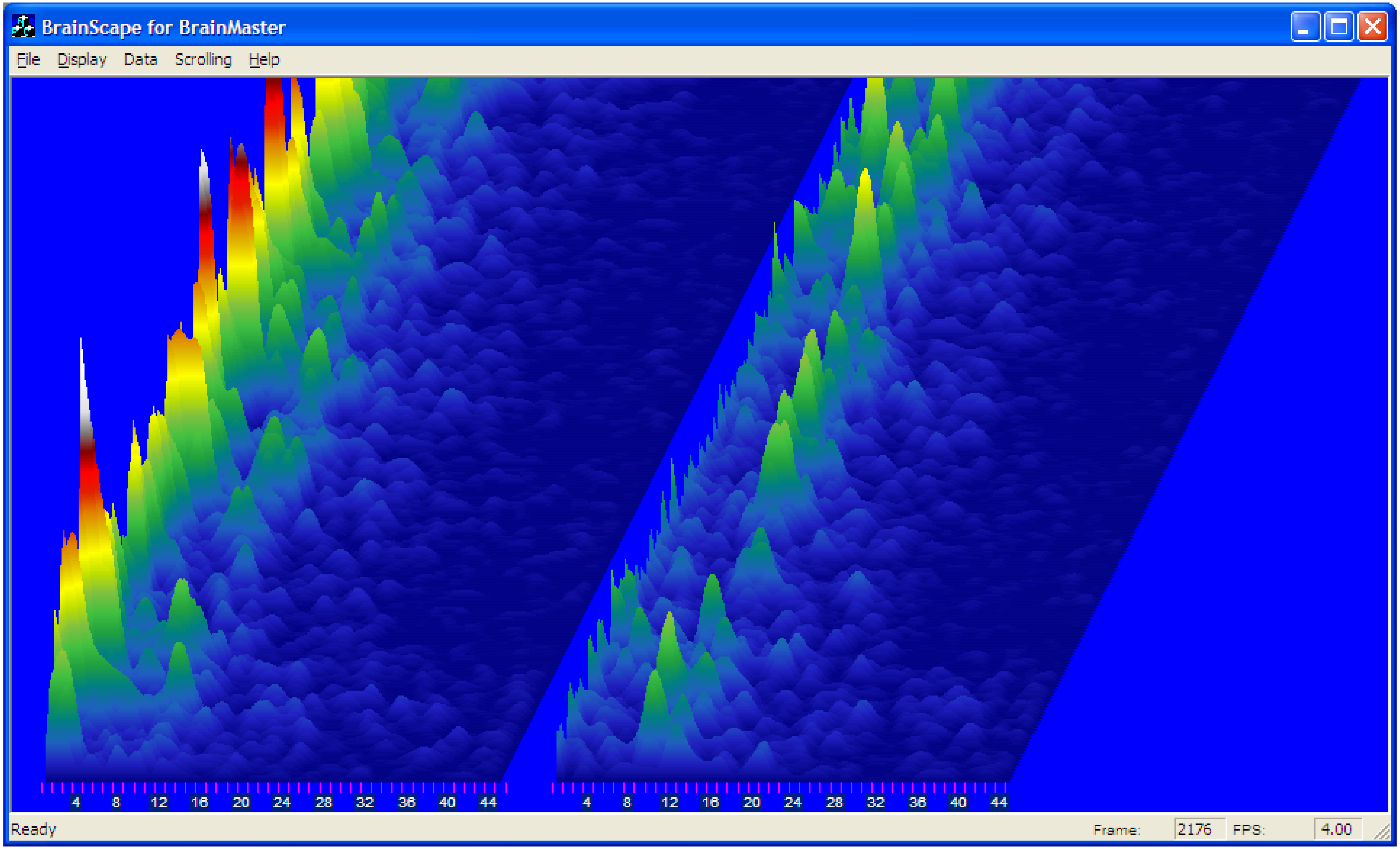
Channel Recombination – BrainScape JTFA F3 & F4



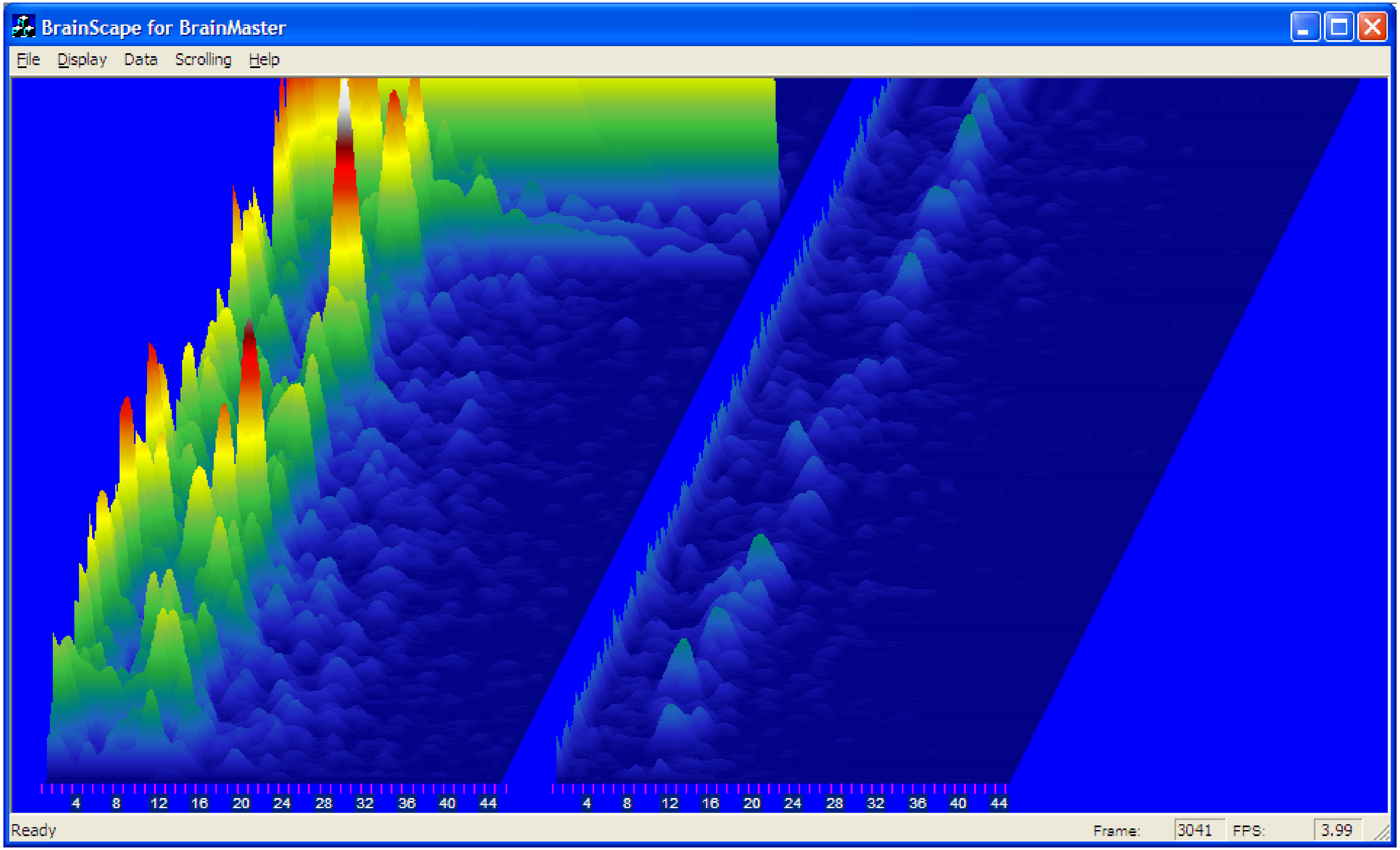
Channel Recombination – BrainScape JTFA C3 and C4



Channel Recombination – BrainScape JTFA T3 and T4



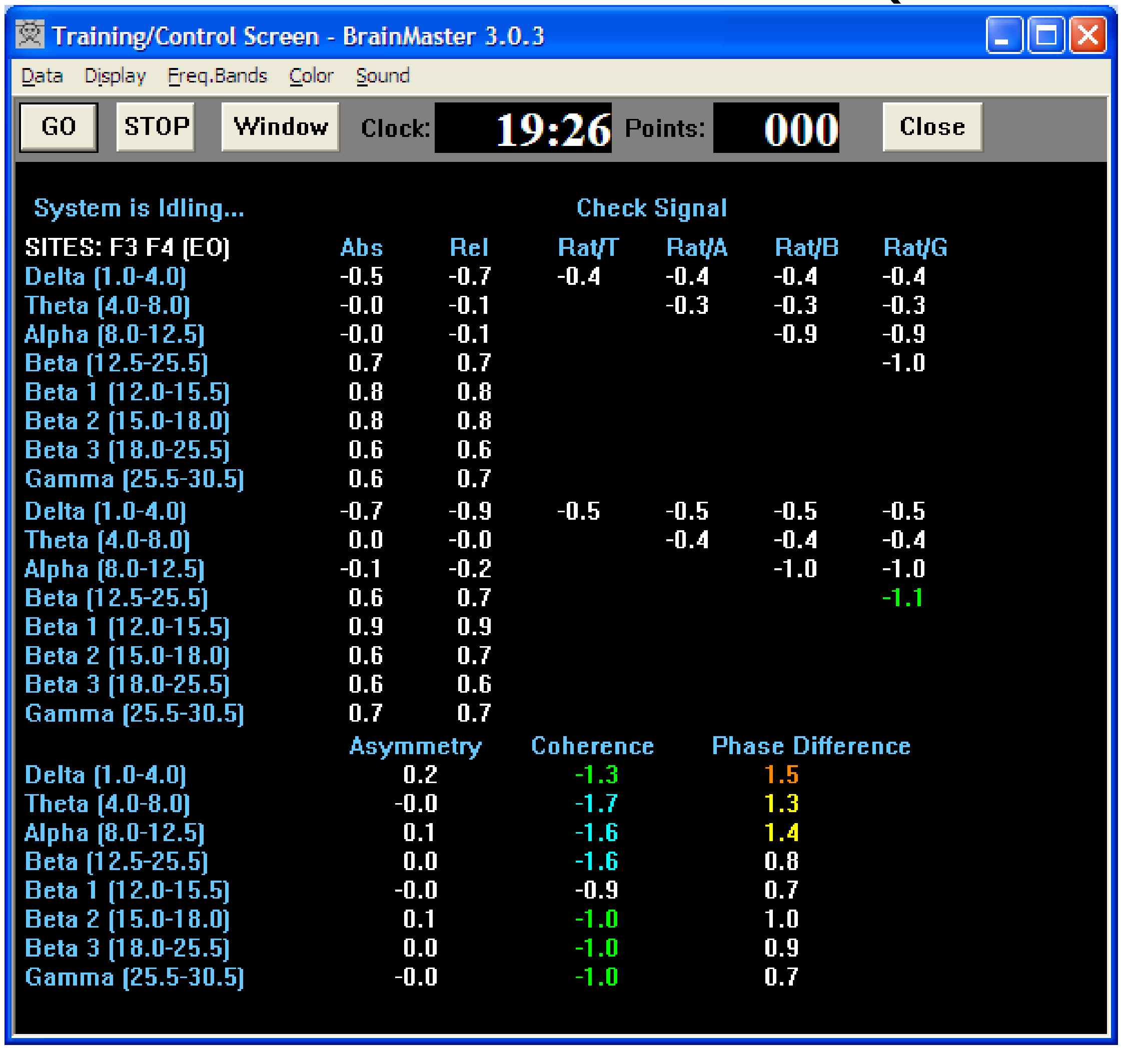
Channel Recombination – BrainScape JTFA O1 and O2



Z-Scores Available

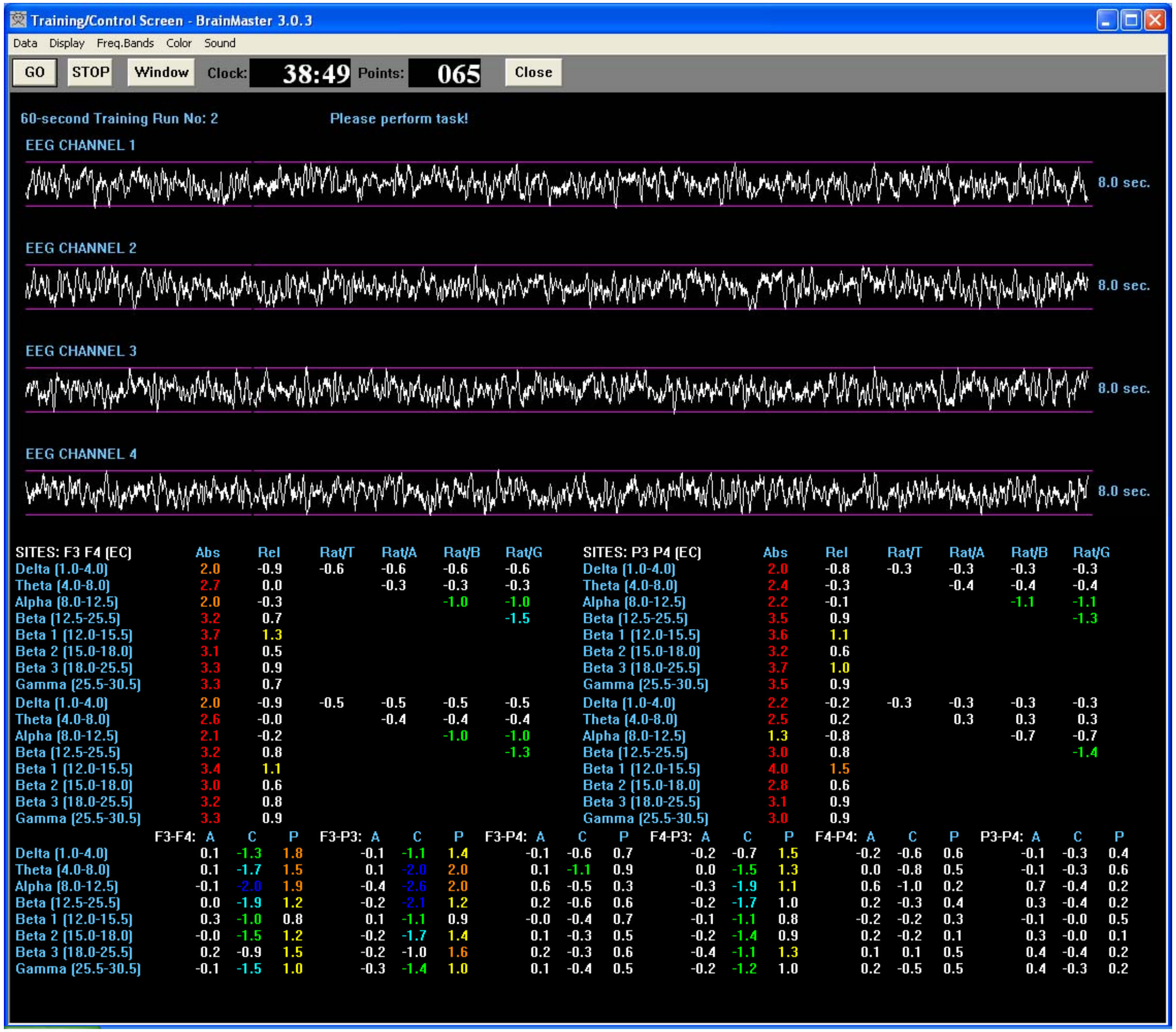
- Absolute Power (8 bands)
- Relative Power (8 bands)
- Power Ratios (10 ratios)
- Asymmetry (8 bands)
- Coherence (8 bands)
- Phase (8 bands)
- Based on database of >600 subjects
- Based on age, eyes open/closed

Live Z Scores – 2 channels (76 targets)



26 x 2 + 24 = 76

Live Z Scores – 4 channels (248 targets)



26 x 4 + 24 x 6 = 248

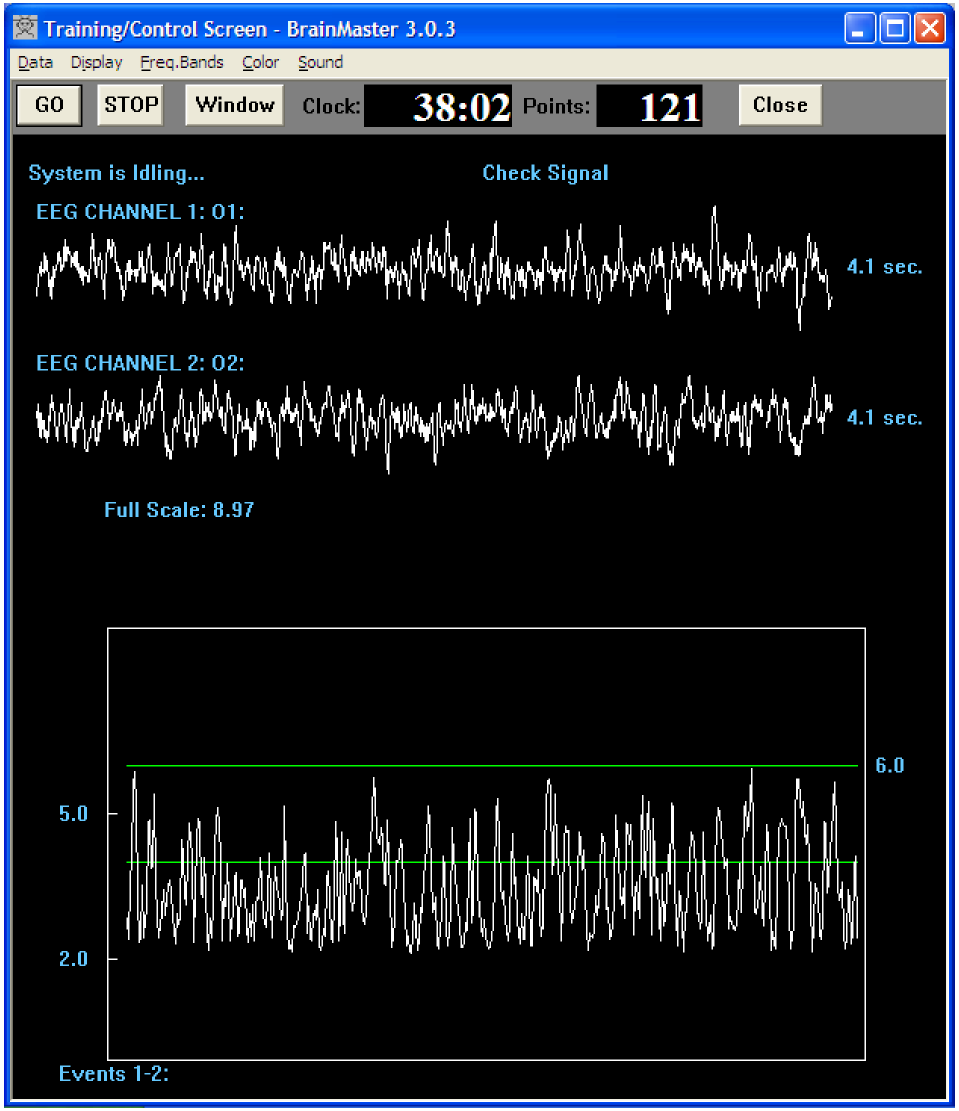
Z-Score Targeting Options

- Train Z Score(s) up or down
  - Simple directional training
- Train Z Score(s) using Rng()
  - Set size and location of target(s)
- Train Z Score(s) using PercentZOK()
  - Set Width of Z Window via. PercentZOK(range)
  - Set Percent Floor as a threshold

Range Function

- Rng(VAR, RANGE, CENTER)
- = 1 if VAR is within RANGE of CENTER
- = 0 else
- Rng(BCOH, 10, 30)
  - 1 if Beta coherence is within +/-10 of 30
- Rng(ZCOB, 2, 0)
  - 1 if Beta coherence z score is within +/-2 of 0

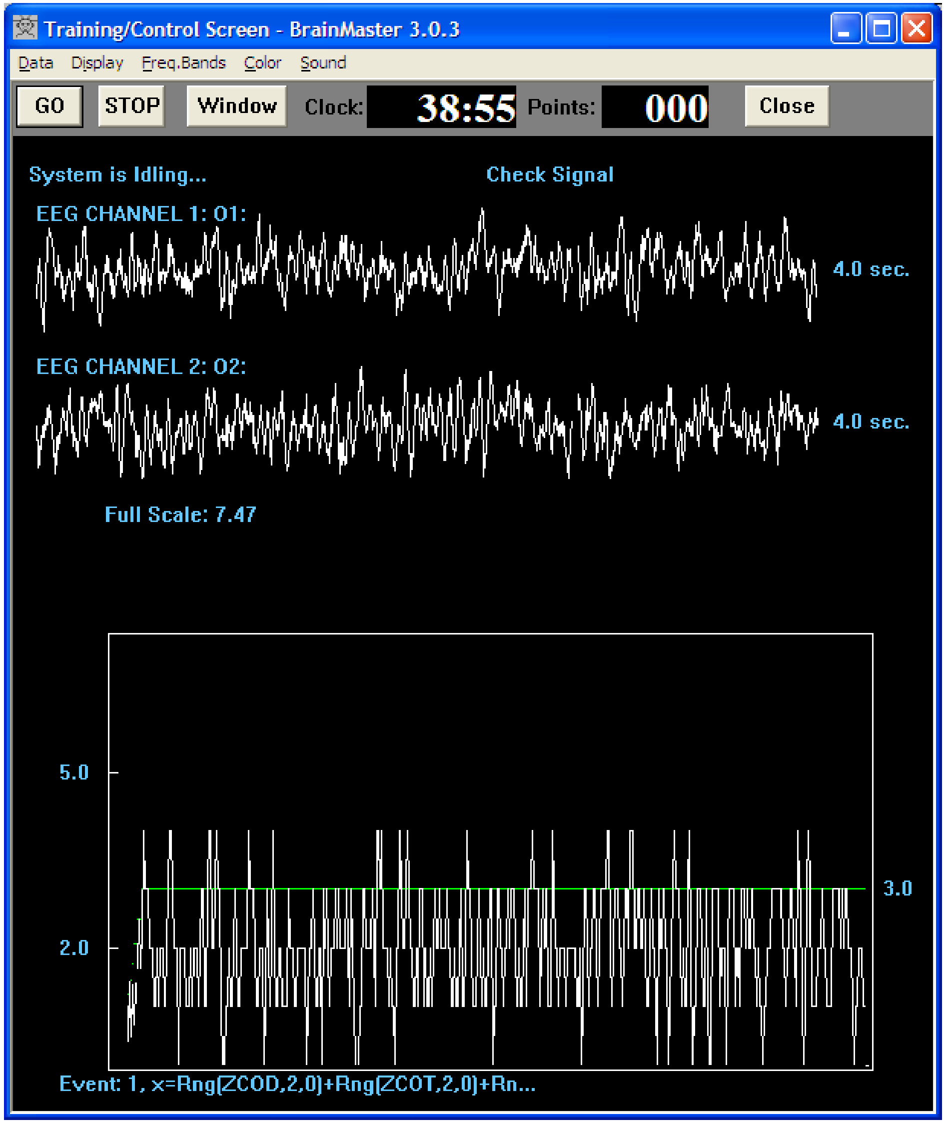
Z-score Coherence Range Training
(feedback when z score is in desired range)



Range training with multiple ranges

- X = Rng(ZCOD, 2,0) + Rng(ZCOT, 2, 0), + Rng(ZCOA, 2, 0) + Rng(ZCOB, 2. 0)
- = 0 if no coherences are in range
- = 1 if 1 coherence is in range
- = 2 if 2 coherences are in range
- = 3 if 3 coherences are in range
- = 4 if all 4 coherences are in range
- Creates new training variable, target > 3

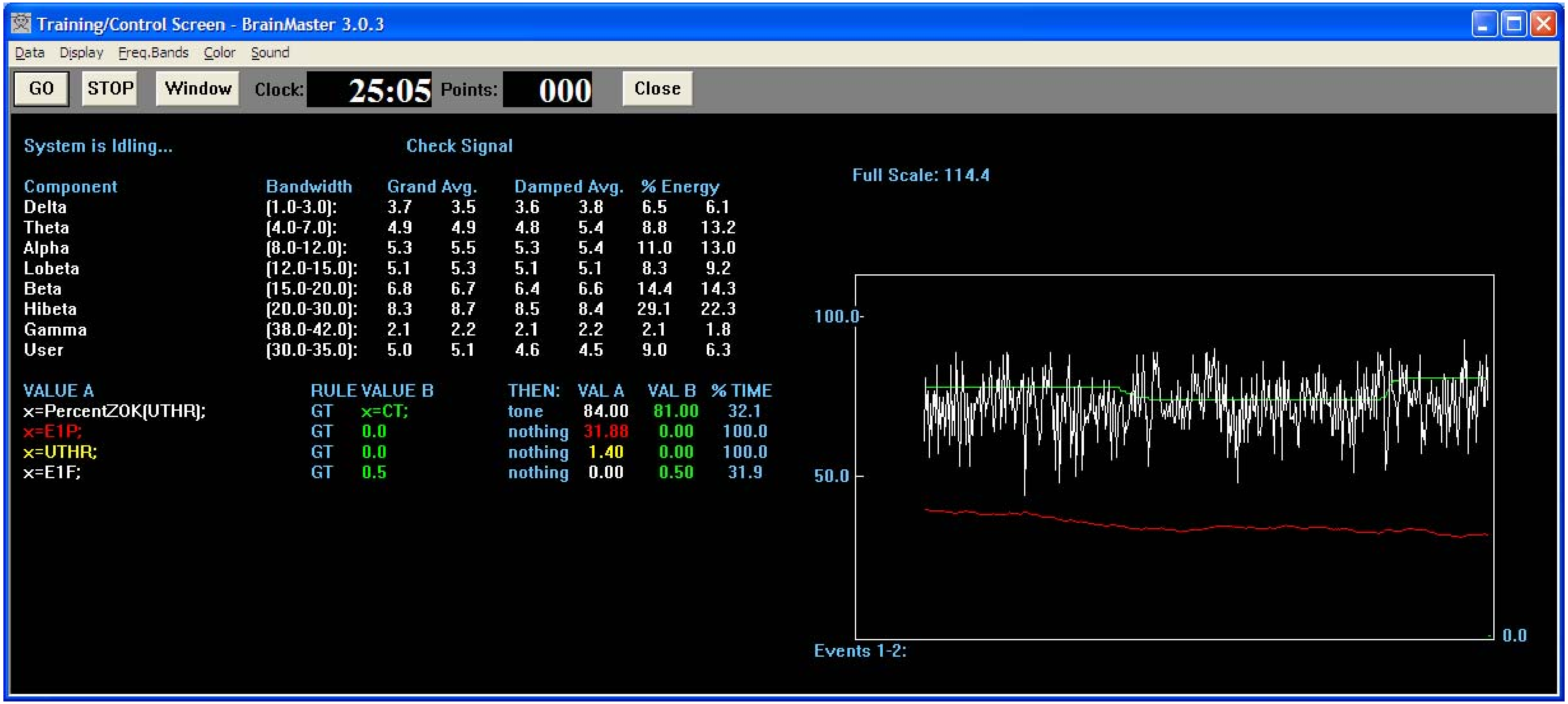
Coherence ranges training with Z Scores (4 coherences in range)



PercentZOK() function

- PercentZOK(RANGE)
  - – Gives percent of Z Scores within RANGE of 0
  - – 1 channel: 24 Z Scores total
  - – 2 channels: 76 Z Scores total
  - – 4 channels: 248 Z Scores total
- Value = 0 to 100

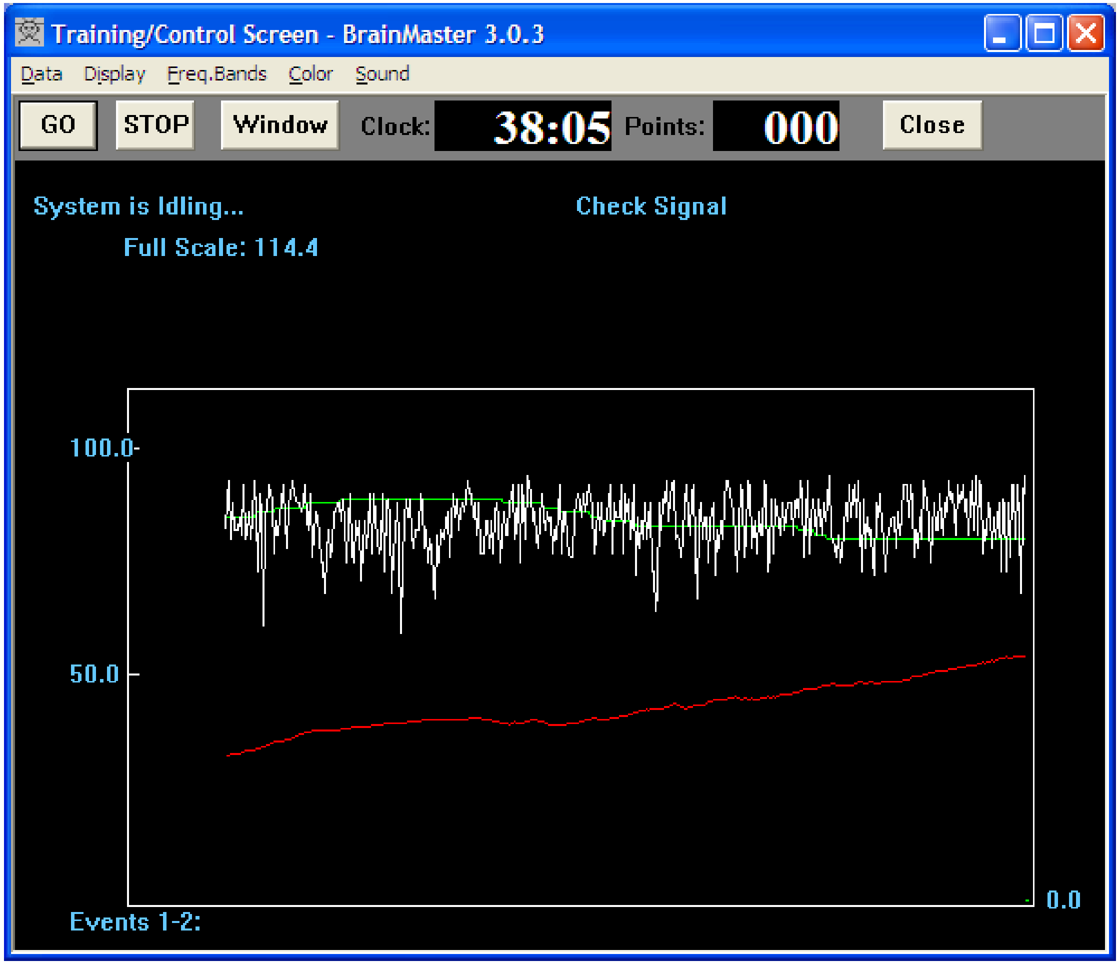
Z Score training using percent Z's in target range



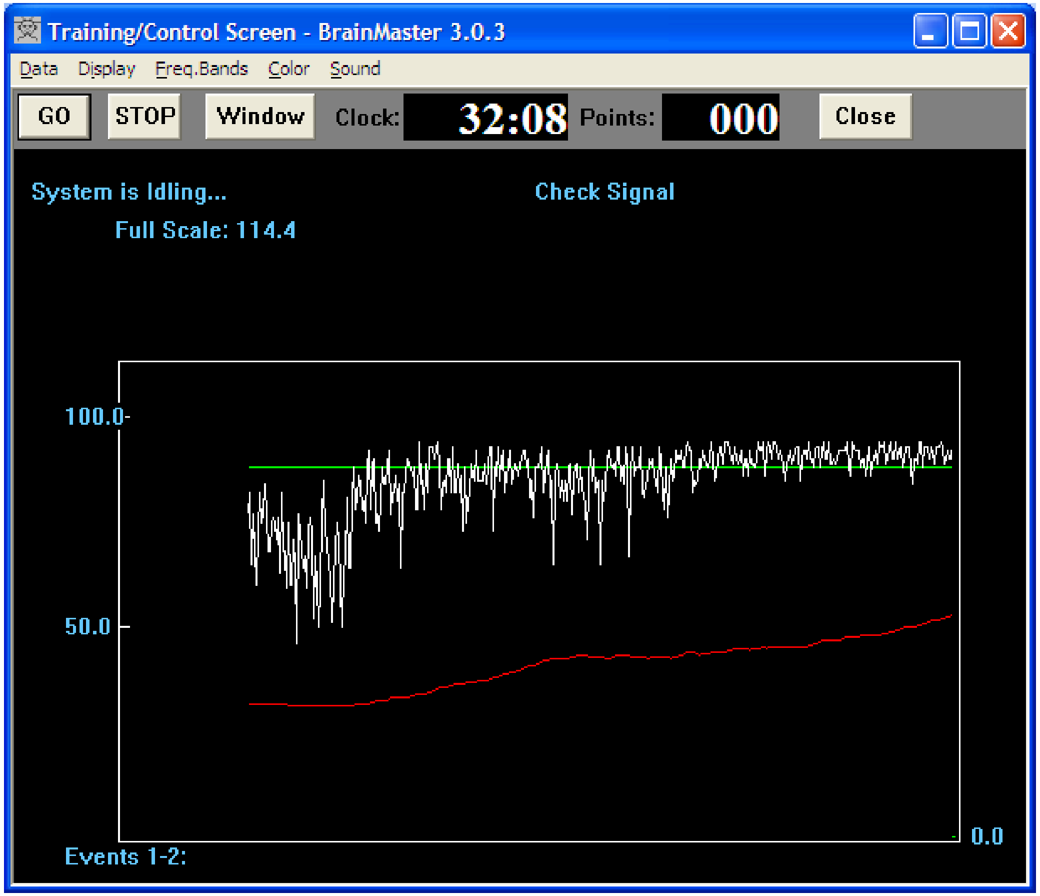
Size of range window (UTHR - currently 1.4 standard deviations)
Threshold % for Reward (CT: between 70% and 80%)
%Z Scores in range (between 50 and 90%)
% Time criterion is met (between 30% and 40%)

Effect of changing %Z threshold

Threshold down -> percent time meeting criteria increases



Effect of widening Z target window window wider -> higher % achievable



Summary

- Wide range of methods available
- All have strengths and weaknesses
- Important to understand basis of each metric and its application to NF
- All have value
- Importance of normative data to interpret