Whole Brain Training using EEG Connectivity and Asymmetry

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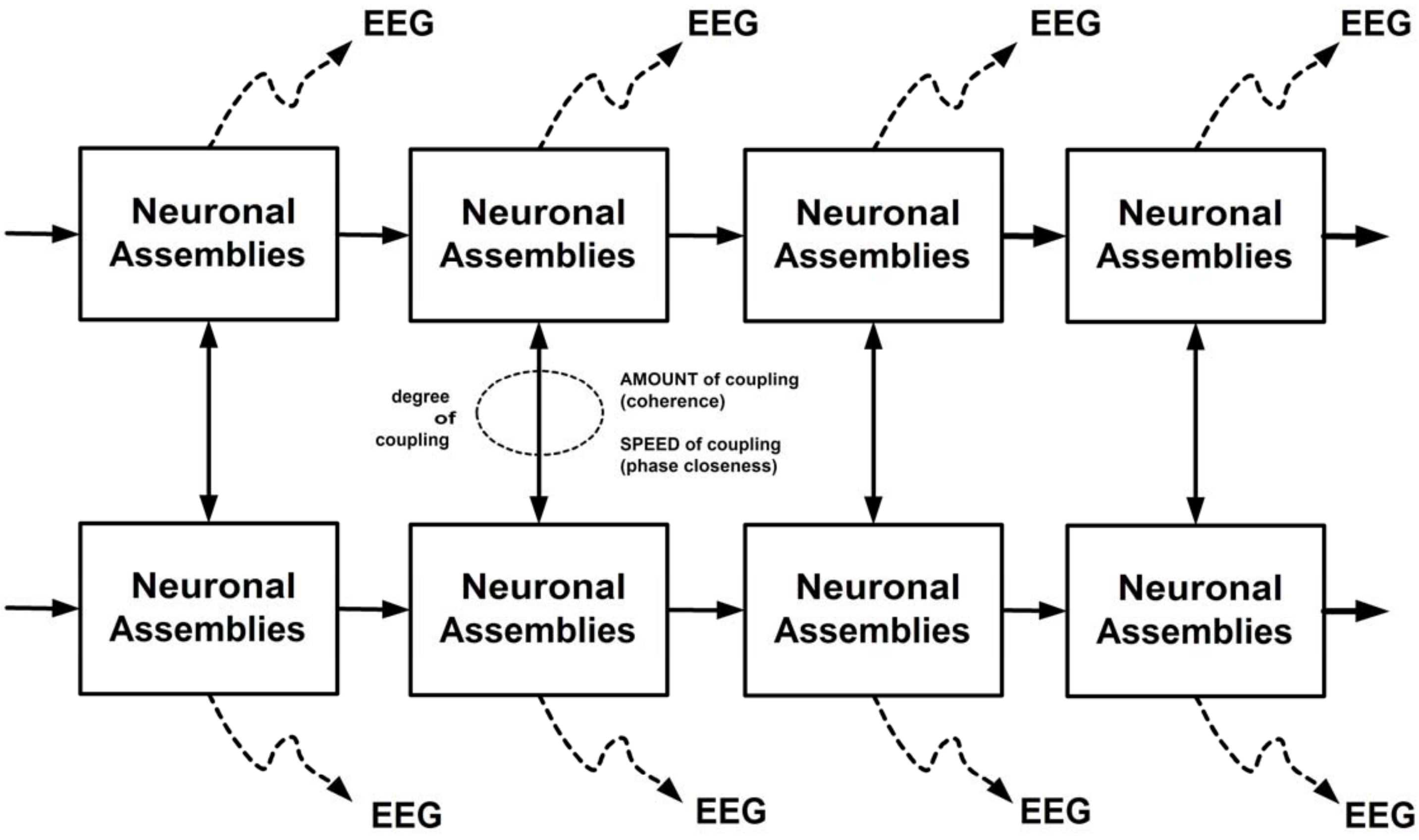
The Purpose of Connectivity Training

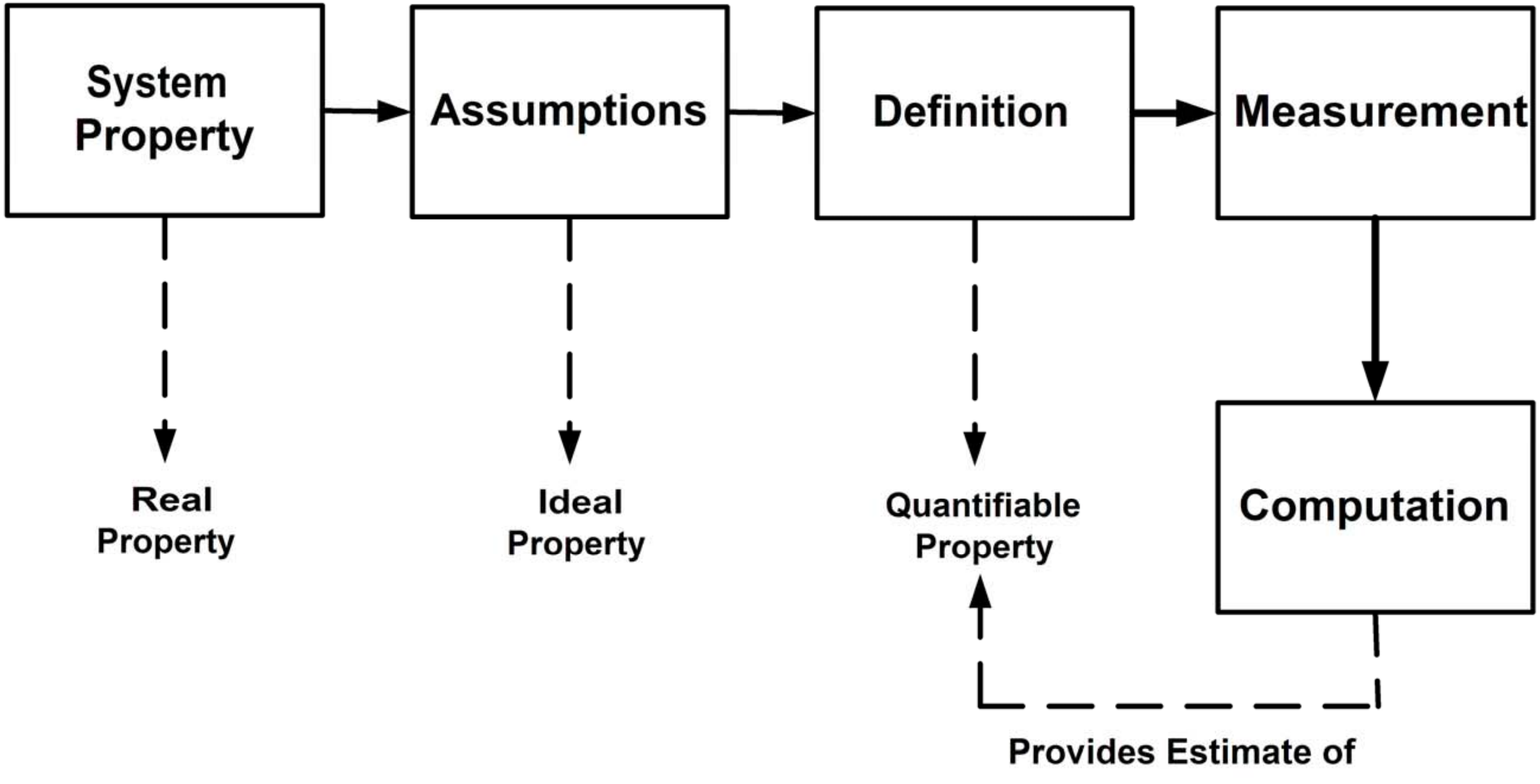
- To reflect whole brain function
- Show relationship between two sites
- Reflect amount of information shared
- Reflect speed of information sharing
- Real-time recording or postprocessed
- Useful for assessing brain function
- Useful for training brain connectivity
- Takes us beyond amplitude training

Generalized Connectivity Model



Generalized Model for EEG Generation

System Identification and Parameter Estimation



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

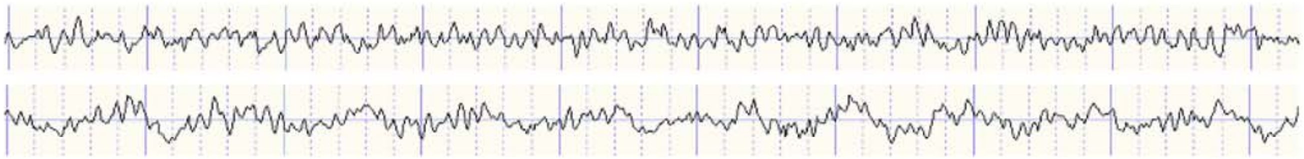
- Pure Coherence (is relative phase stable?)
  - joint energy / product of self-energy
- Synchrony Metric (do phase and amplitude match?)
  - Joint energy (real parts)/ sum of self-energy
- Spectral Correlation Coefficient (FFT amplitudes same?)
  - Correlation (f) between amplitude spectra
- Comodulation (do components wax & wane together?)
  - Correlation (t) between amplitude time-series
- Asymmetry
  - Relative amplitude between two sites
- 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

Coherence Estimation in Real Time

Given two EEG signals in real time,



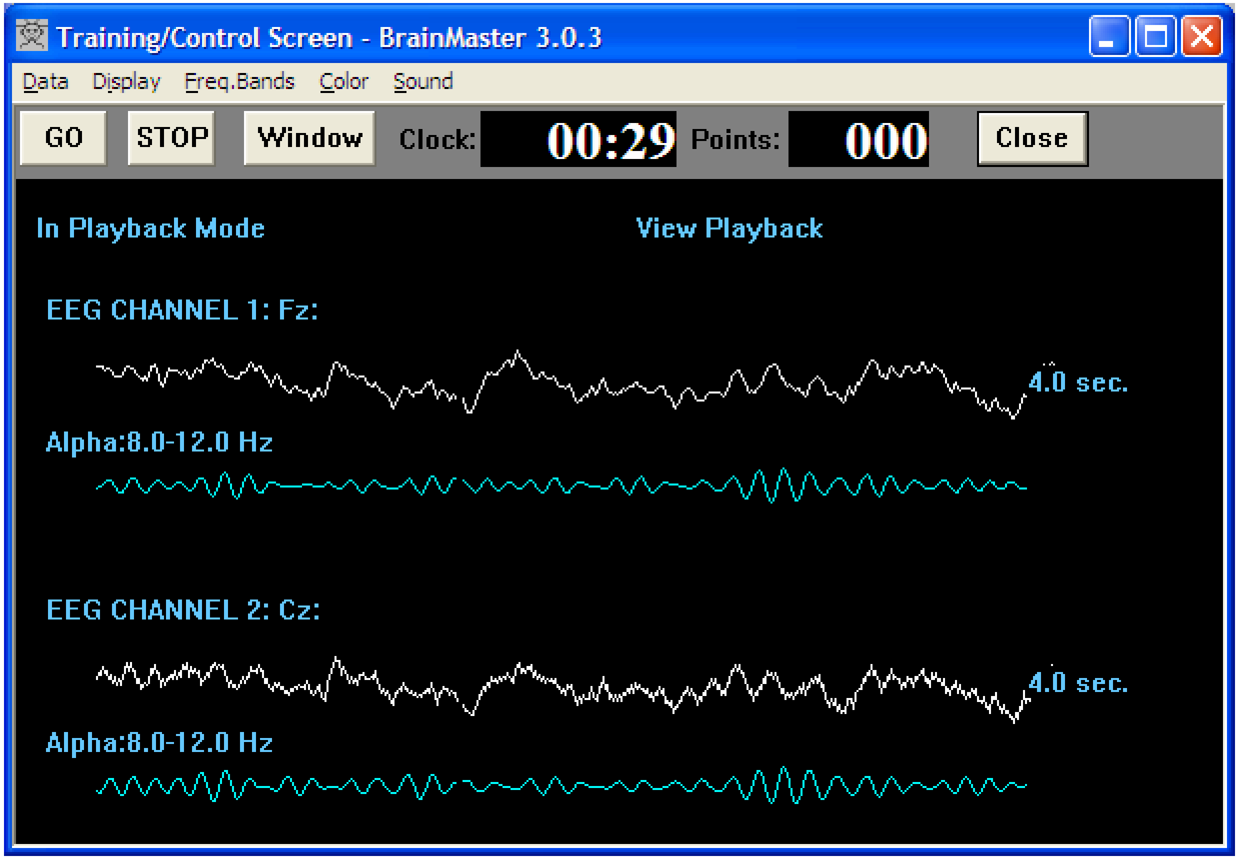
To compute Coherence Estimates for real-time training, we can:

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**

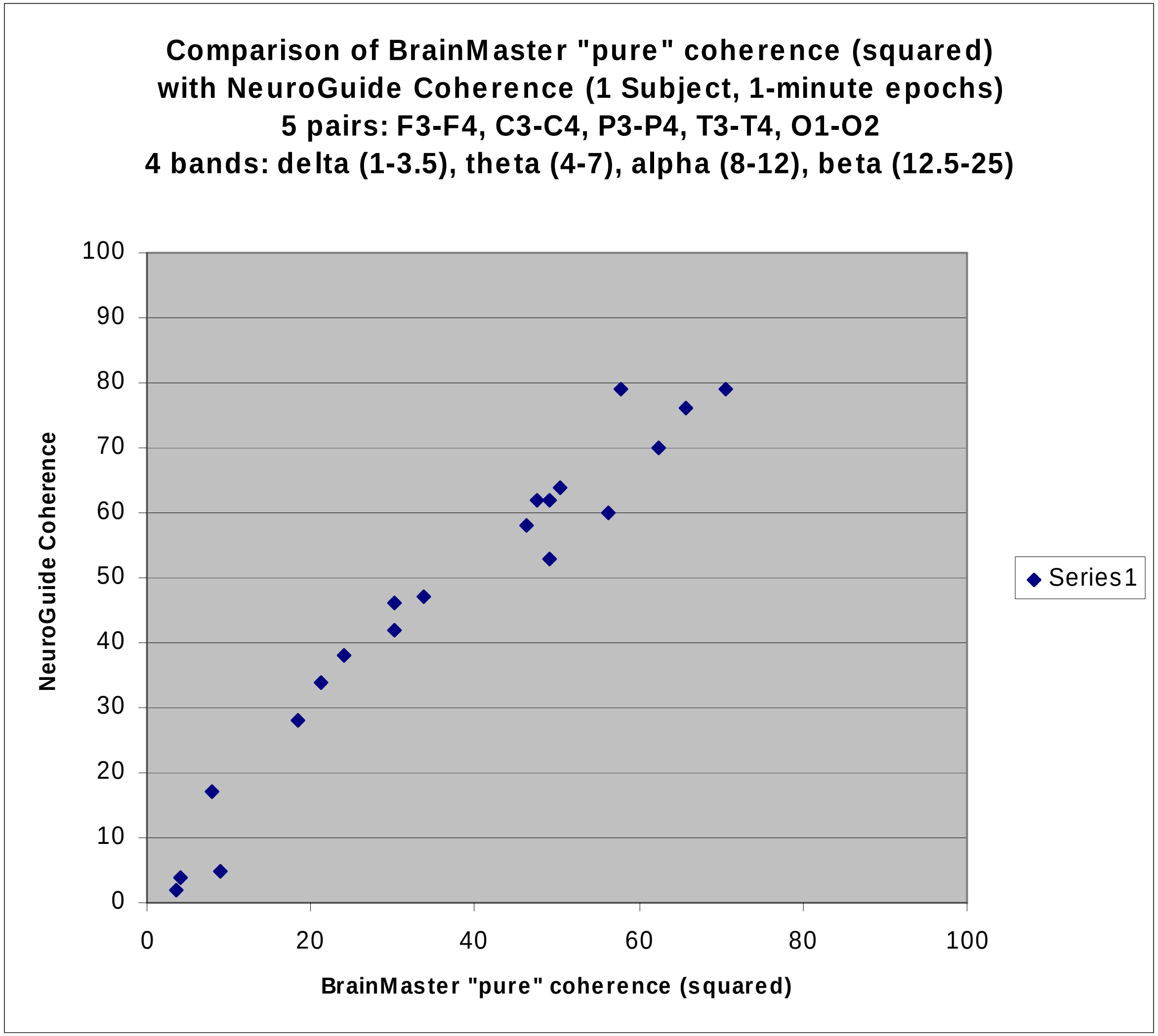
-or- **Use Quadrature Methods to extract and compute cross-terms directly (1-3 cycle delay)** → **Coherence Estimate**

Pure Coherence



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

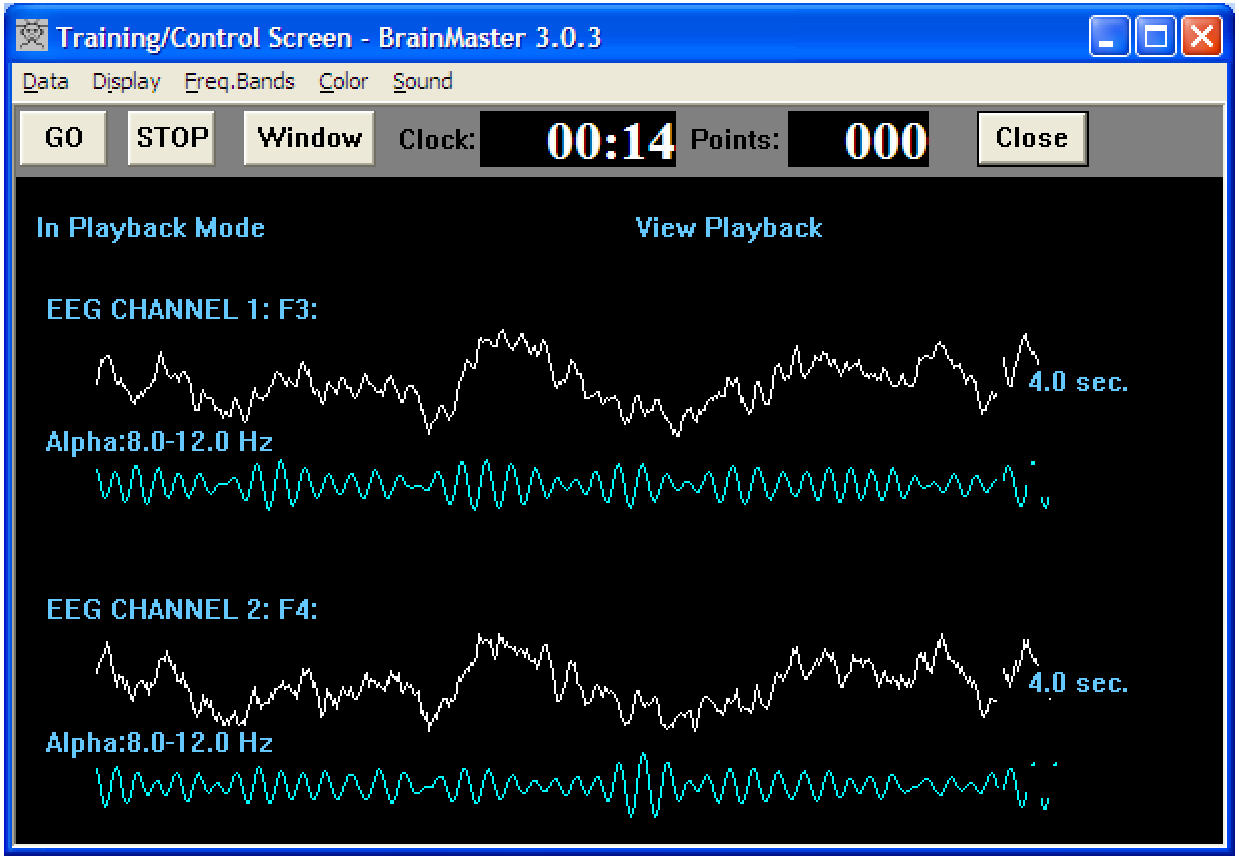
Pure Coherence: BMr-NG Concordance



“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)

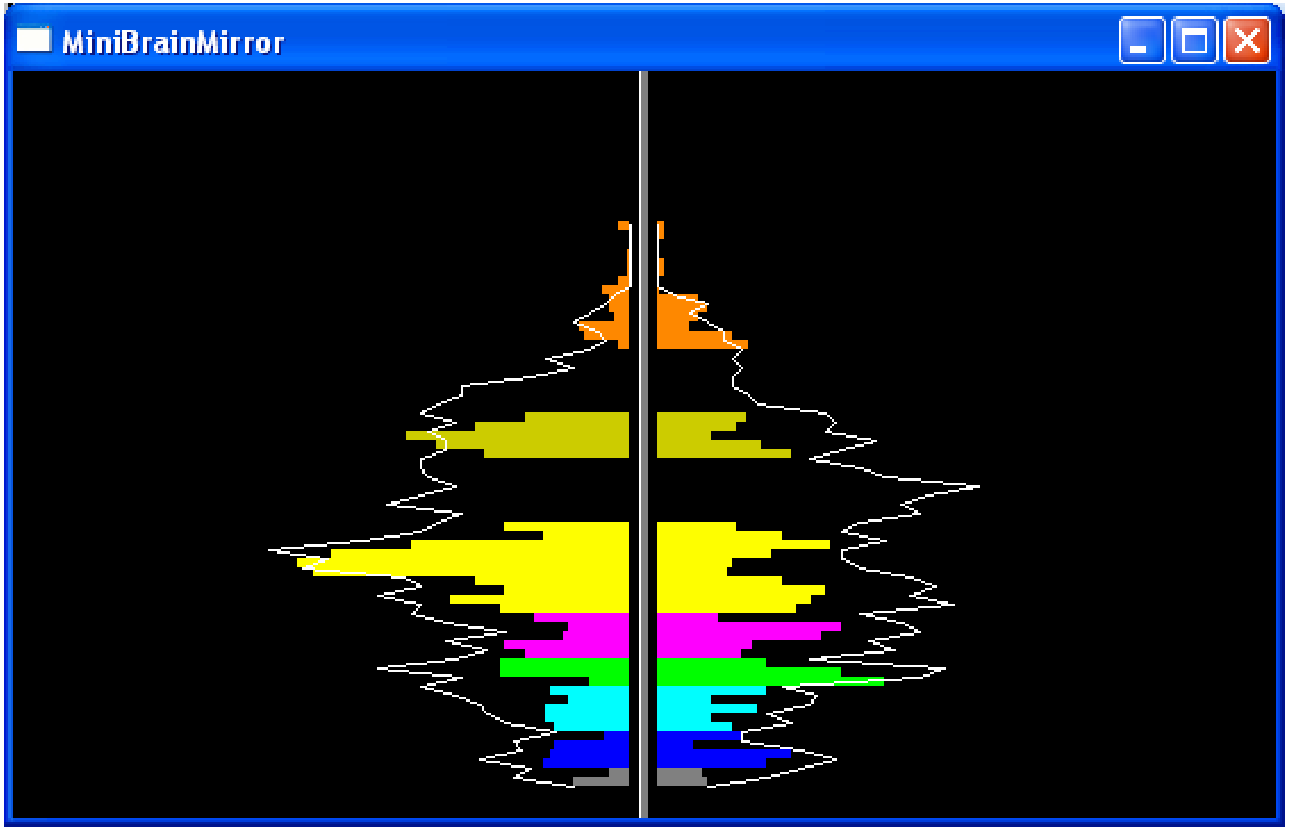


- Are the two channels consistently in phase and of the same size?

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

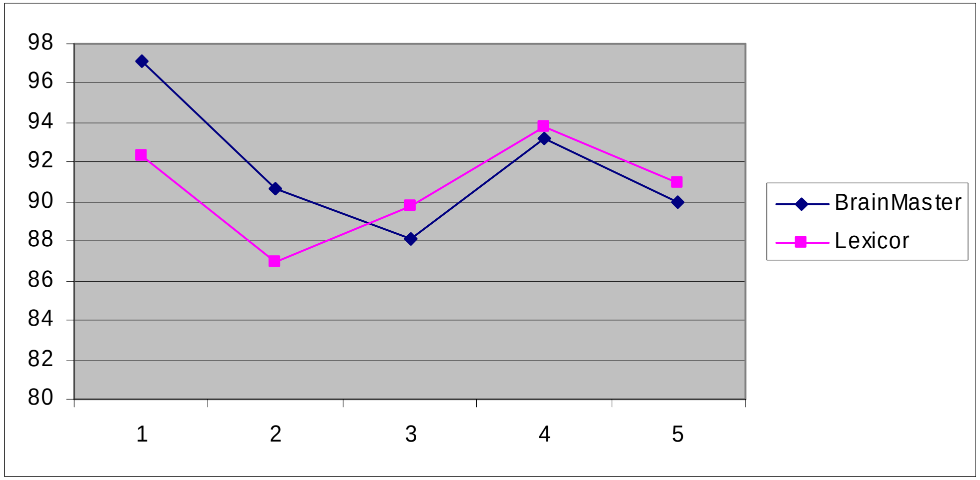
Spectral Correlation Coefficient (SCC/"Lexicor")

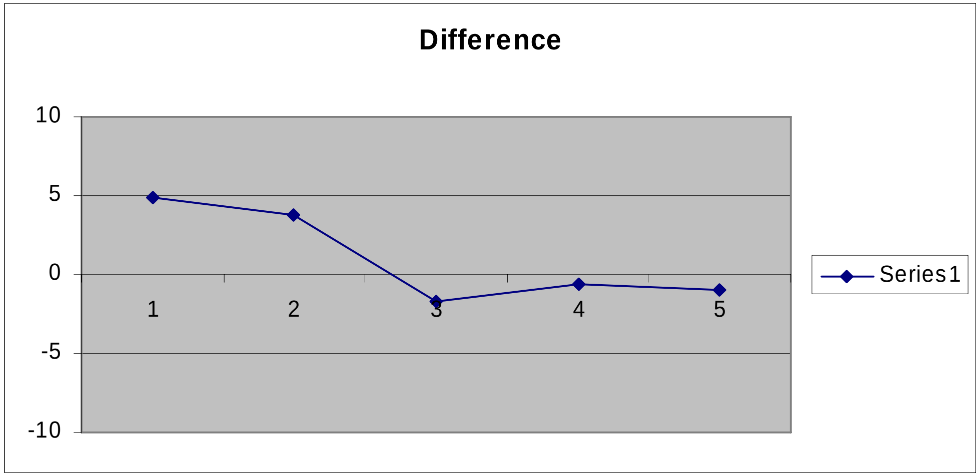


- How similar (symmetrical) is the shape of the spectral amplitude of the two channels in a particular band?

SCC: BMr – Lexicor Concordance

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

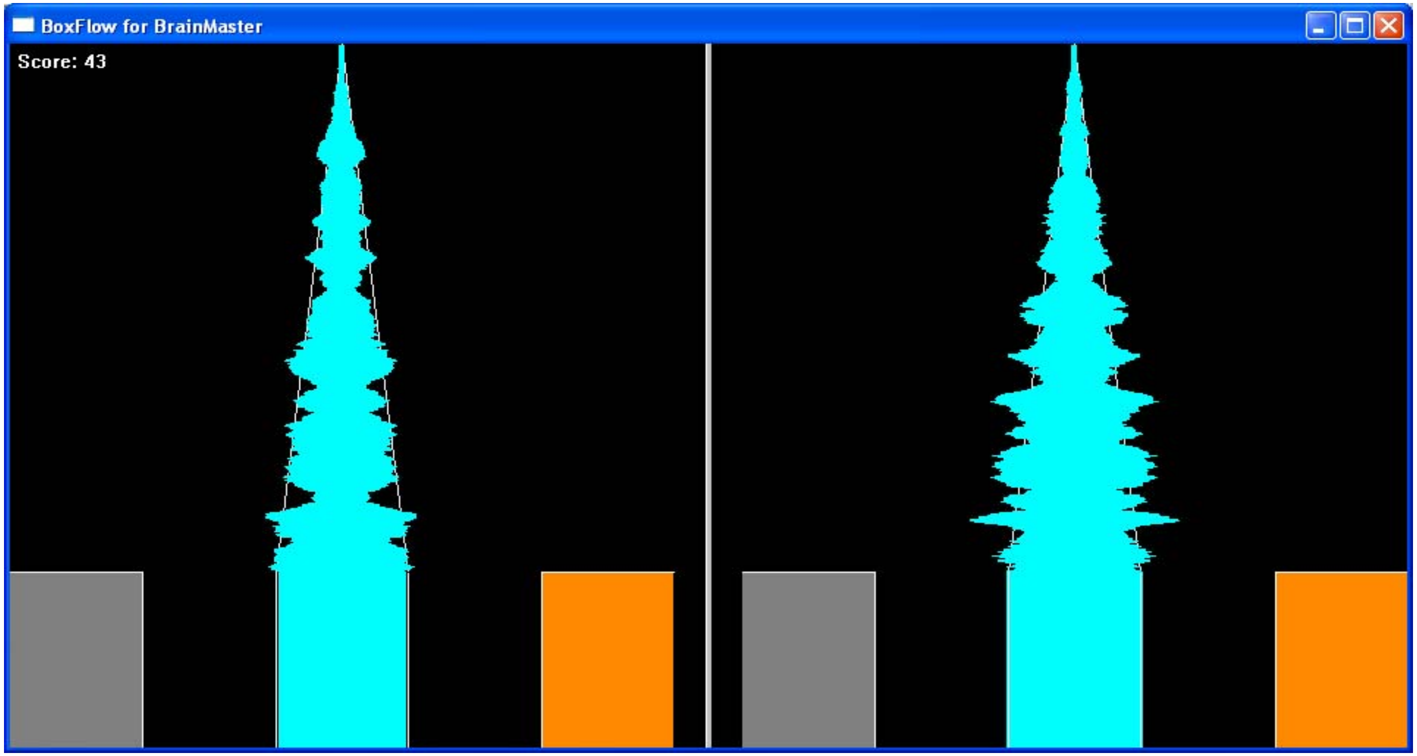




Comodulation (Sterman/Kaiser)

- 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)

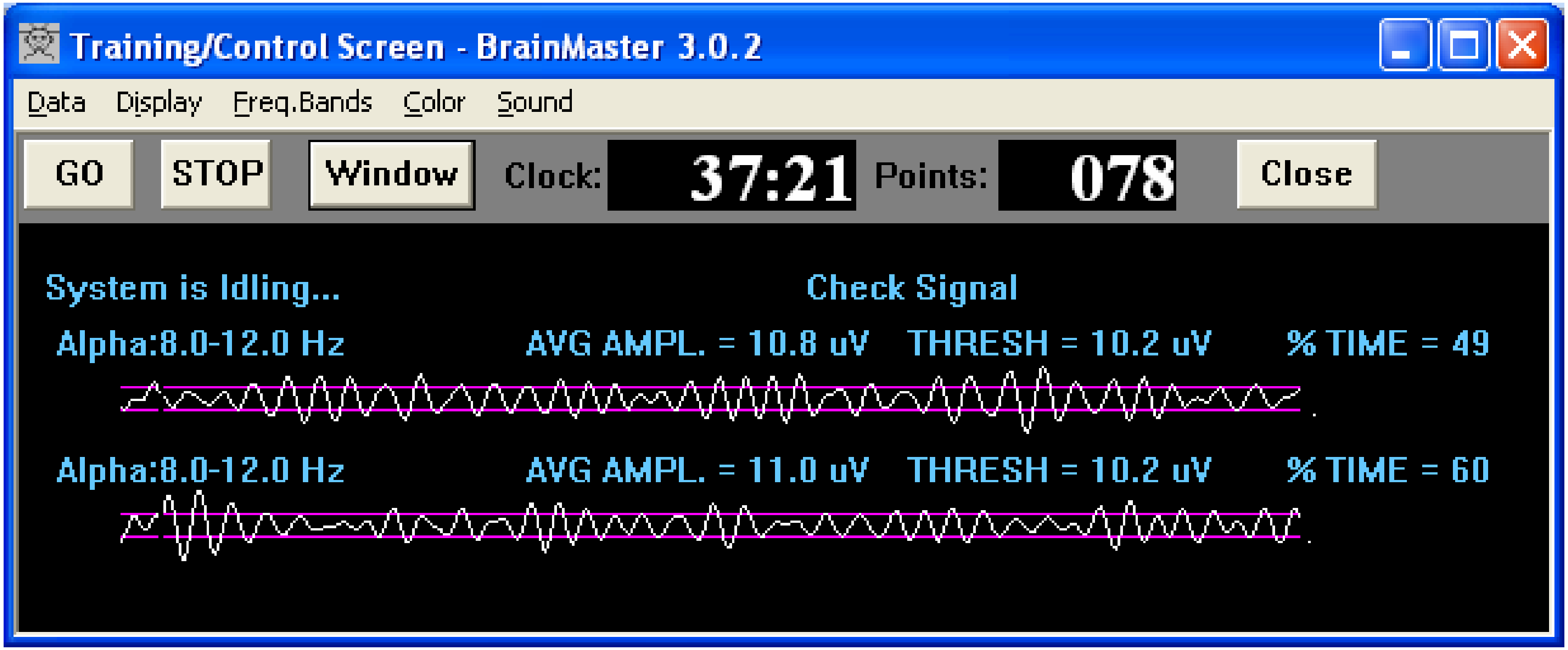


- How similar is the waxing and waning of the amplitudes in the two channels over time?

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?)

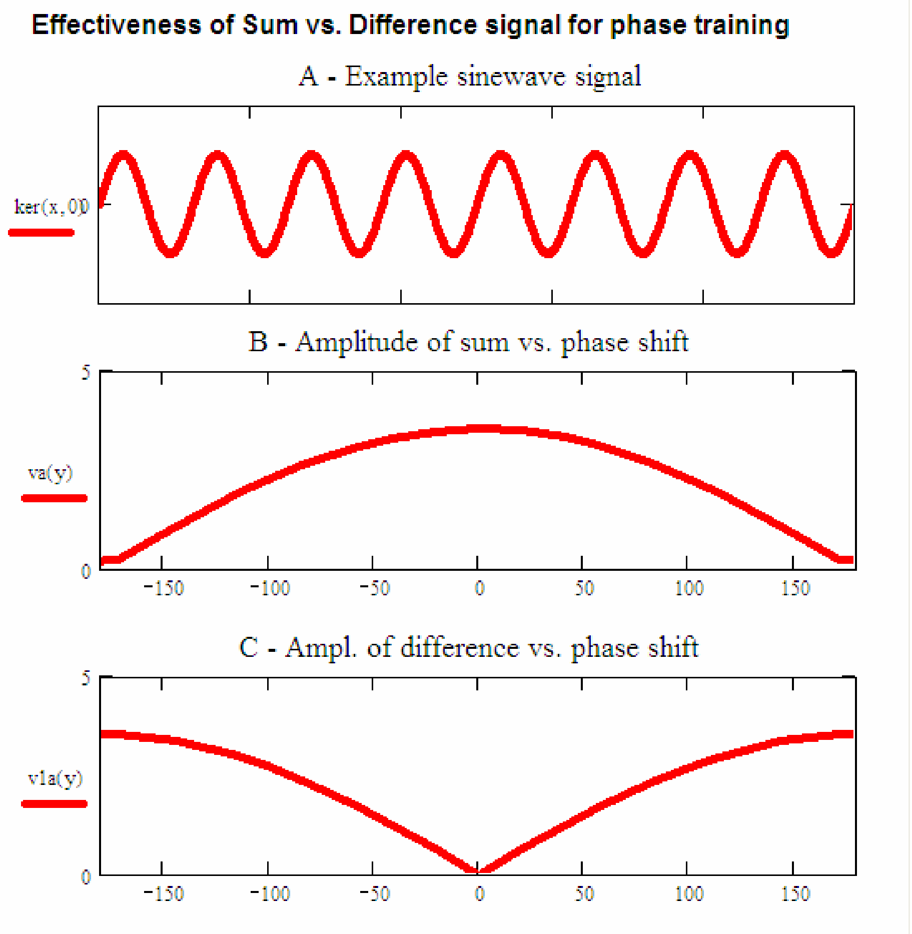
Sum-channel

- 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

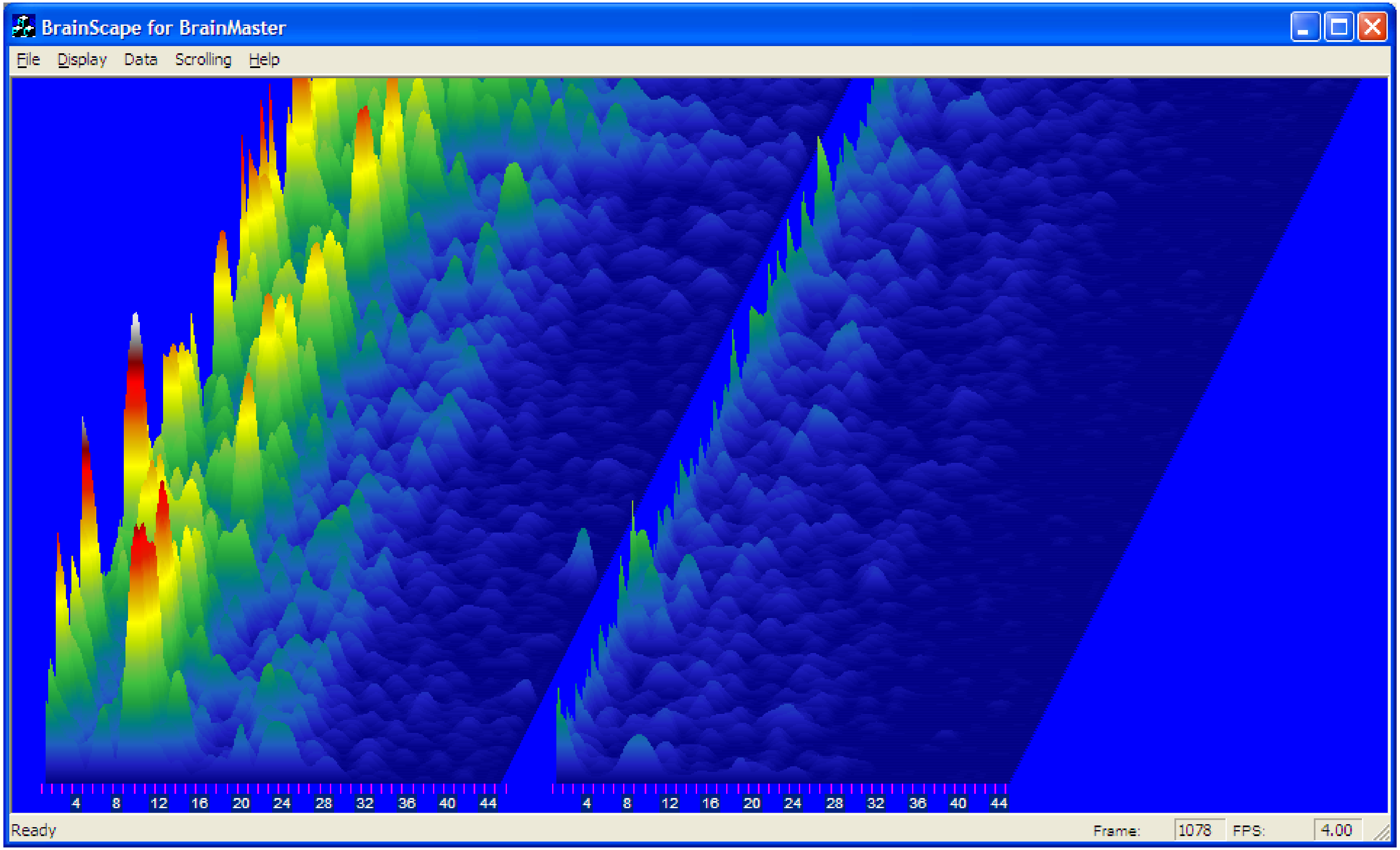
Difference-channel

- 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

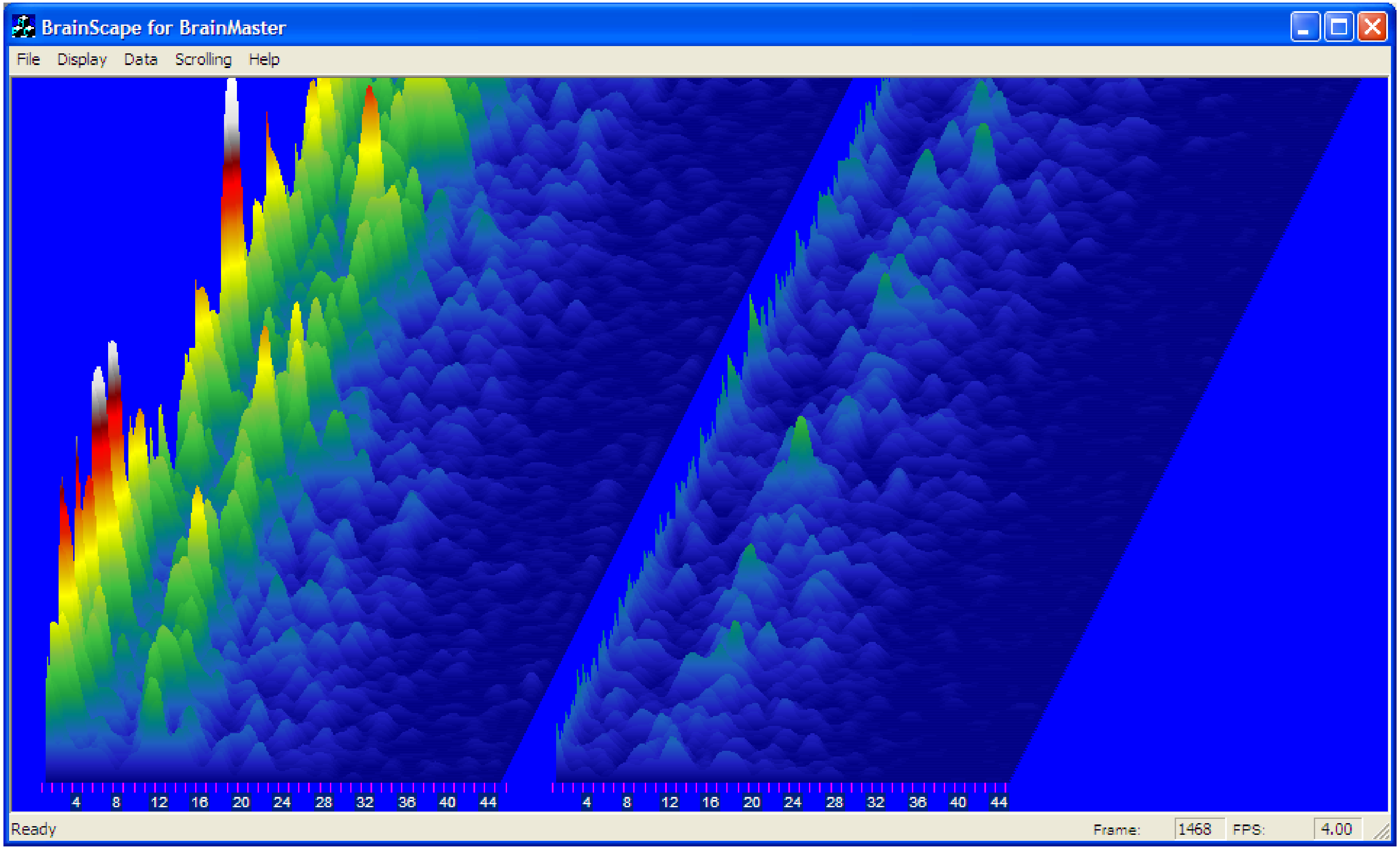
Channel Sum & Difference



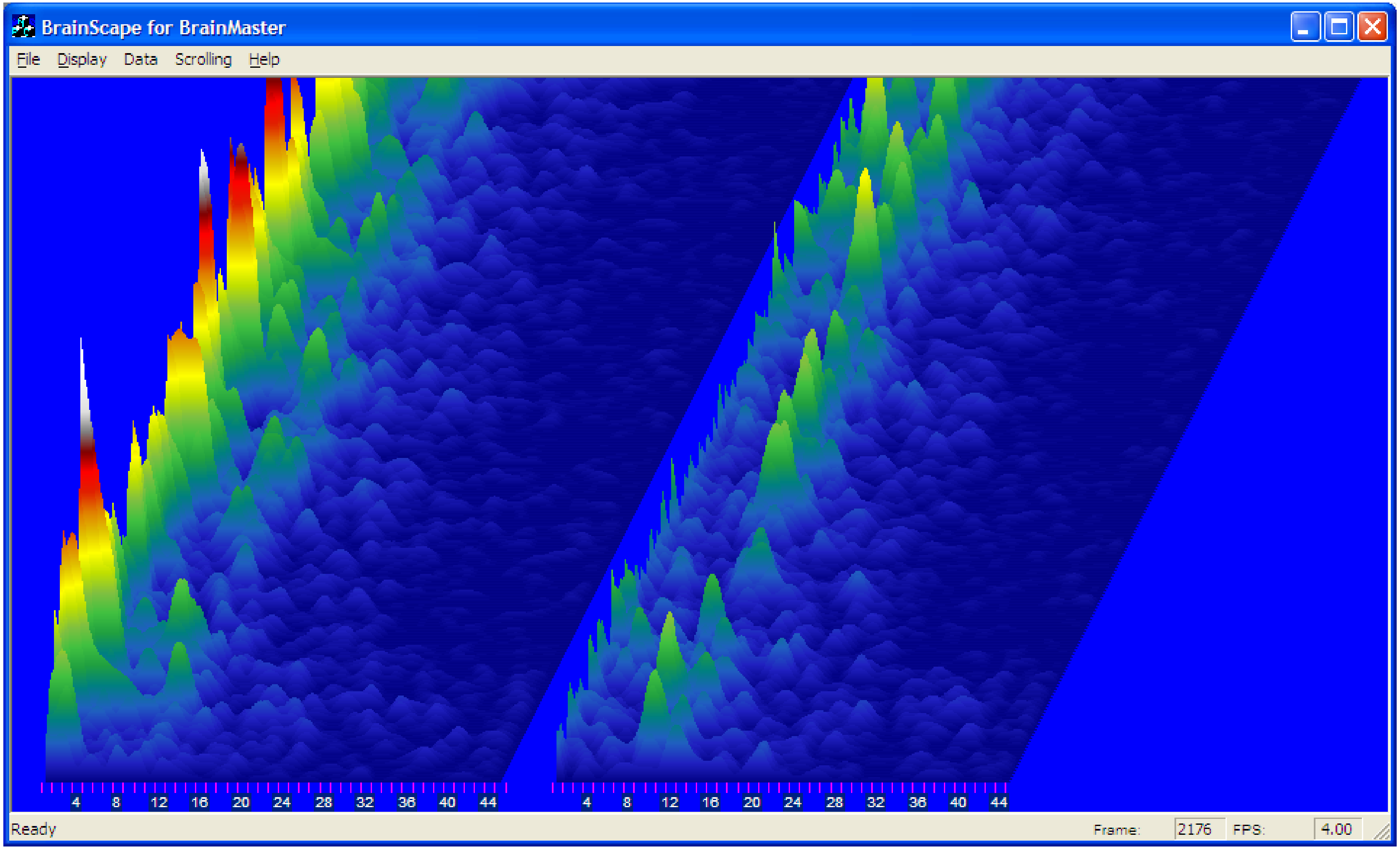
Channel Recombination – BrainScape JTFA F3 & F4



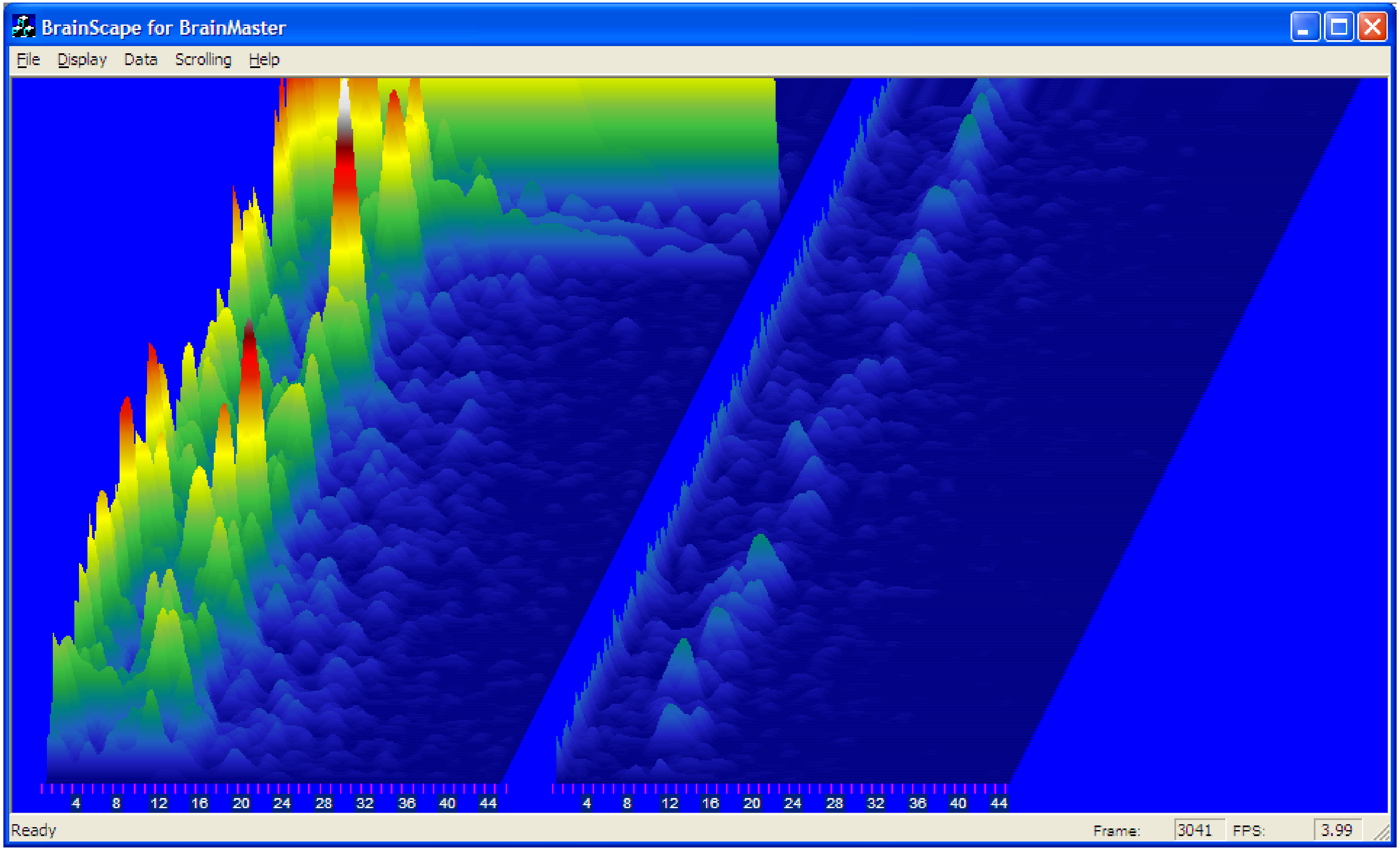
Channel Recombination – BrainScape JTFA C3 and C4



Channel Recombination – BrainScape JTFA T3 and T4



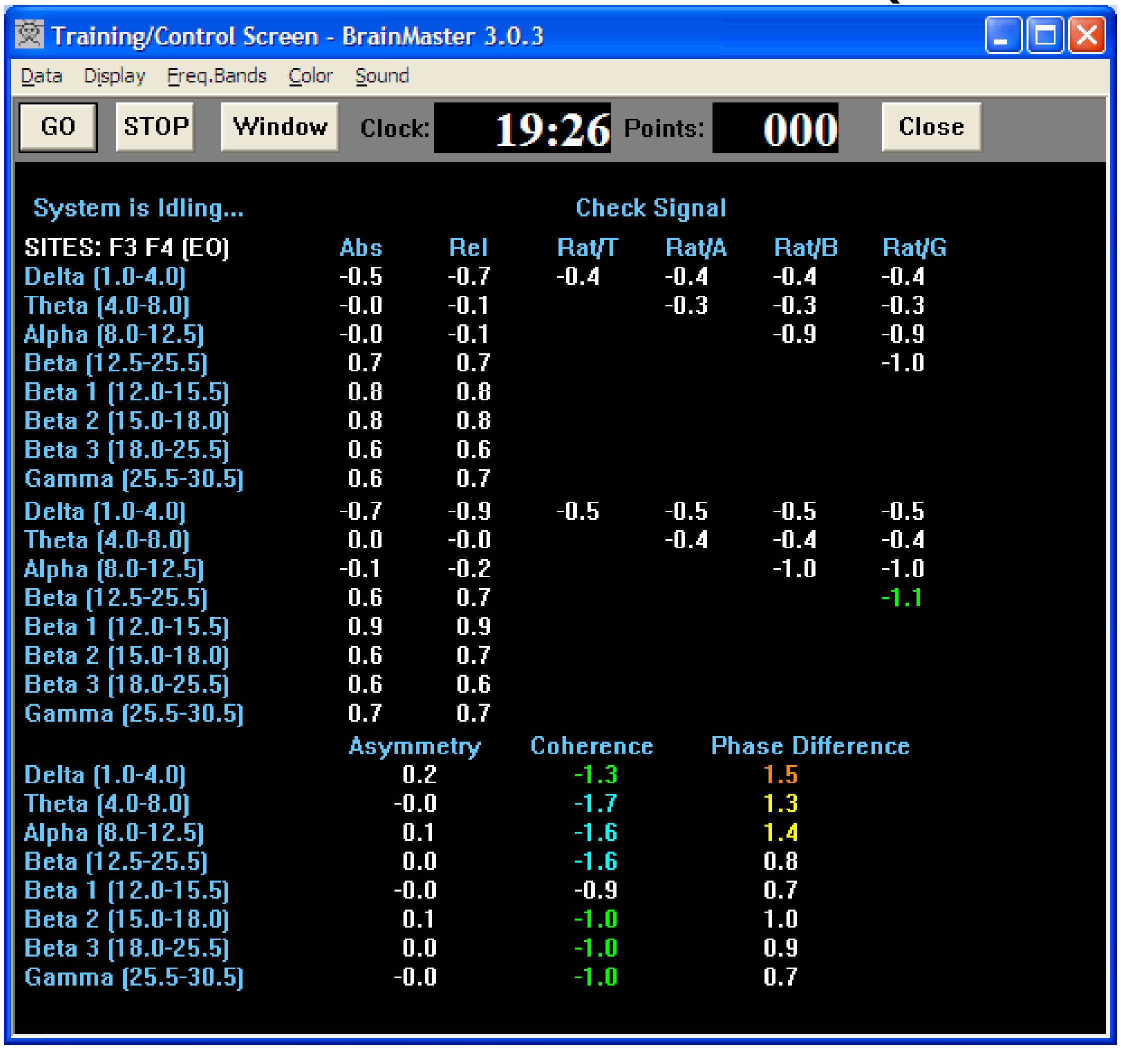
Channel Recombination – BrainScape JTFA O1 and O2



Live Z-Scores

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

Live Z Scores – 2 channels (76 targets)

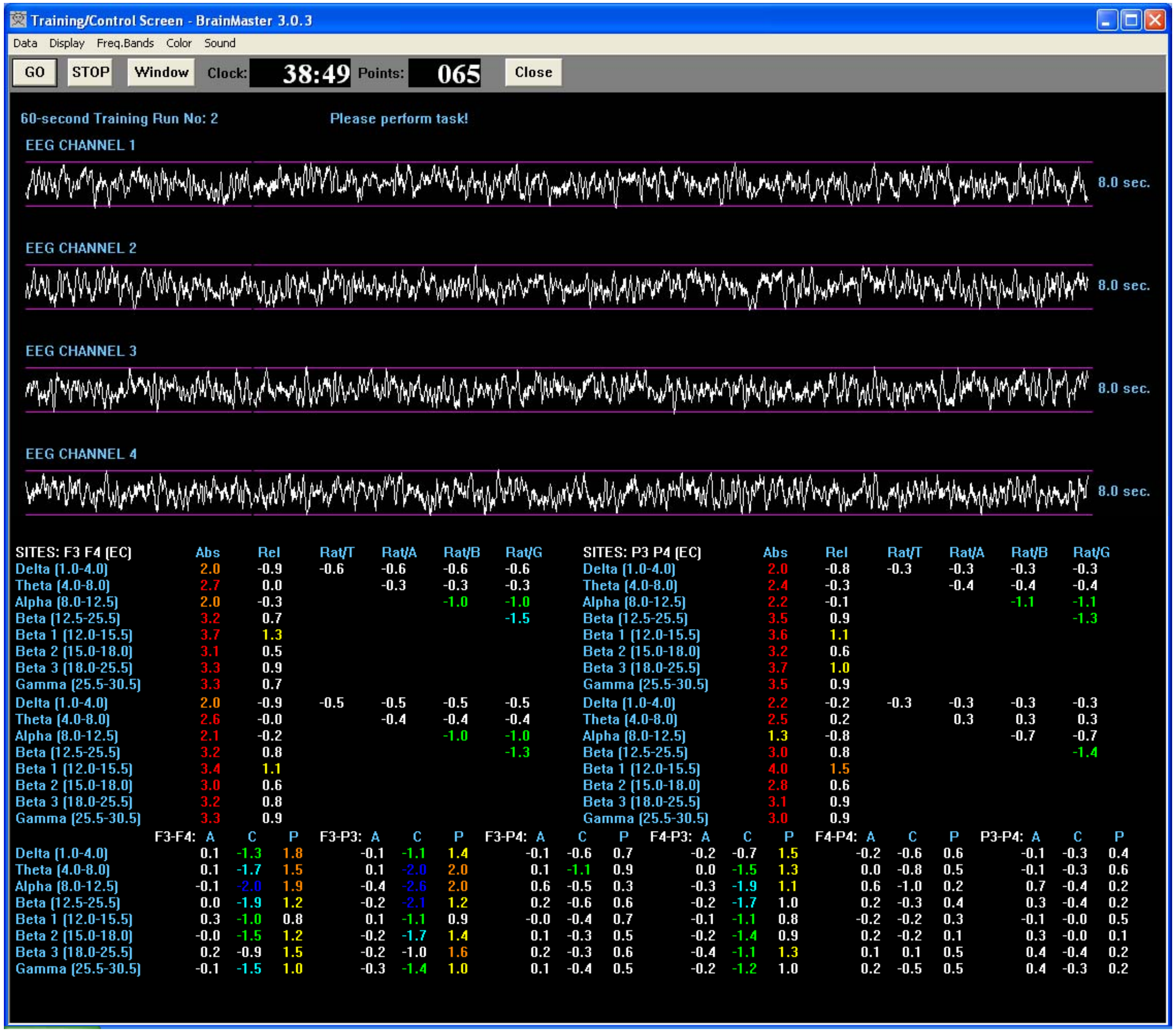


SITES: F3 F4 (EO)	Abs	Rel	Rat/T	Rat/A	Rat/B	Rat/G
Delta (1.0-4.0)	-0.5	-0.7	-0.4	-0.4	-0.4	-0.4
Theta (4.0-8.0)	-0.0	-0.1		-0.3	-0.3	-0.3
Alpha (8.0-12.5)	-0.0	-0.1			-0.9	-0.9
Beta (12.5-25.5)	0.7	0.7				-1.0
Beta 1 (12.0-15.5)	0.8	0.8				
Beta 2 (15.0-18.0)	0.8	0.8				
Beta 3 (18.0-25.5)	0.6	0.6				
Gamma (25.5-30.5)	0.6	0.7				
Delta (1.0-4.0)	-0.7	-0.9	-0.5	-0.5	-0.5	-0.5
Theta (4.0-8.0)	0.0	-0.0		-0.4	-0.4	-0.4
Alpha (8.0-12.5)	-0.1	-0.2			-1.0	-1.0
Beta (12.5-25.5)	0.6	0.7				-1.1
Beta 1 (12.0-15.5)	0.9	0.9				
Beta 2 (15.0-18.0)	0.6	0.7				
Beta 3 (18.0-25.5)	0.6	0.6				
Gamma (25.5-30.5)	0.7	0.7				

	Asymmetry	Coherence	Phase Difference
Delta (1.0-4.0)	0.2	-1.3	1.5
Theta (4.0-8.0)	-0.0	-1.7	1.3
Alpha (8.0-12.5)	0.1	-1.6	1.4
Beta (12.5-25.5)	0.0	-1.6	0.8
Beta 1 (12.0-15.5)	-0.0	-0.9	0.7
Beta 2 (15.0-18.0)	0.1	-1.0	1.0
Beta 3 (18.0-25.5)	0.0	-1.0	0.9
Gamma (25.5-30.5)	-0.0	-1.0	0.7

26 x 2 + 24 = 76

Live Z Scores – 4 channels (248 targets)



26 x 4 + 24 x 6 = 248

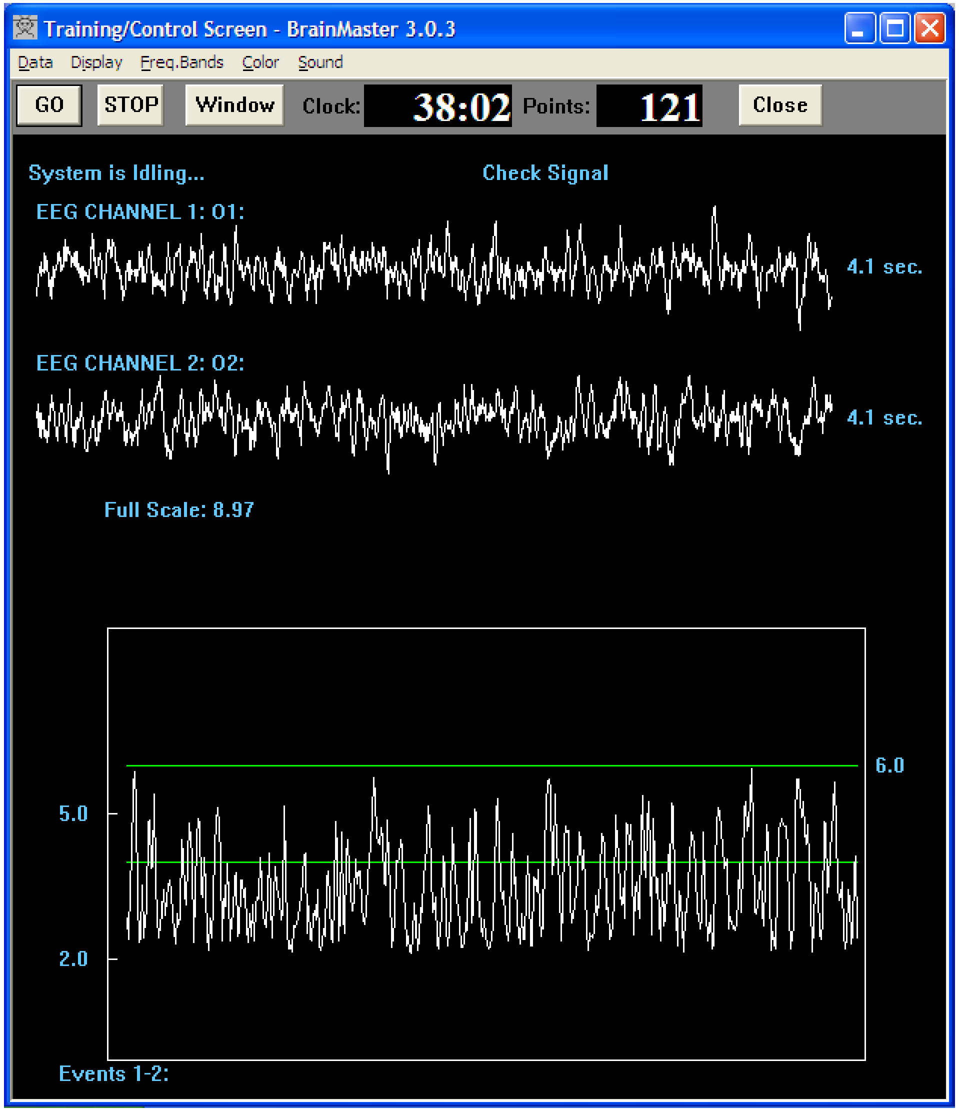
Z-Score Targeting Options

- 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

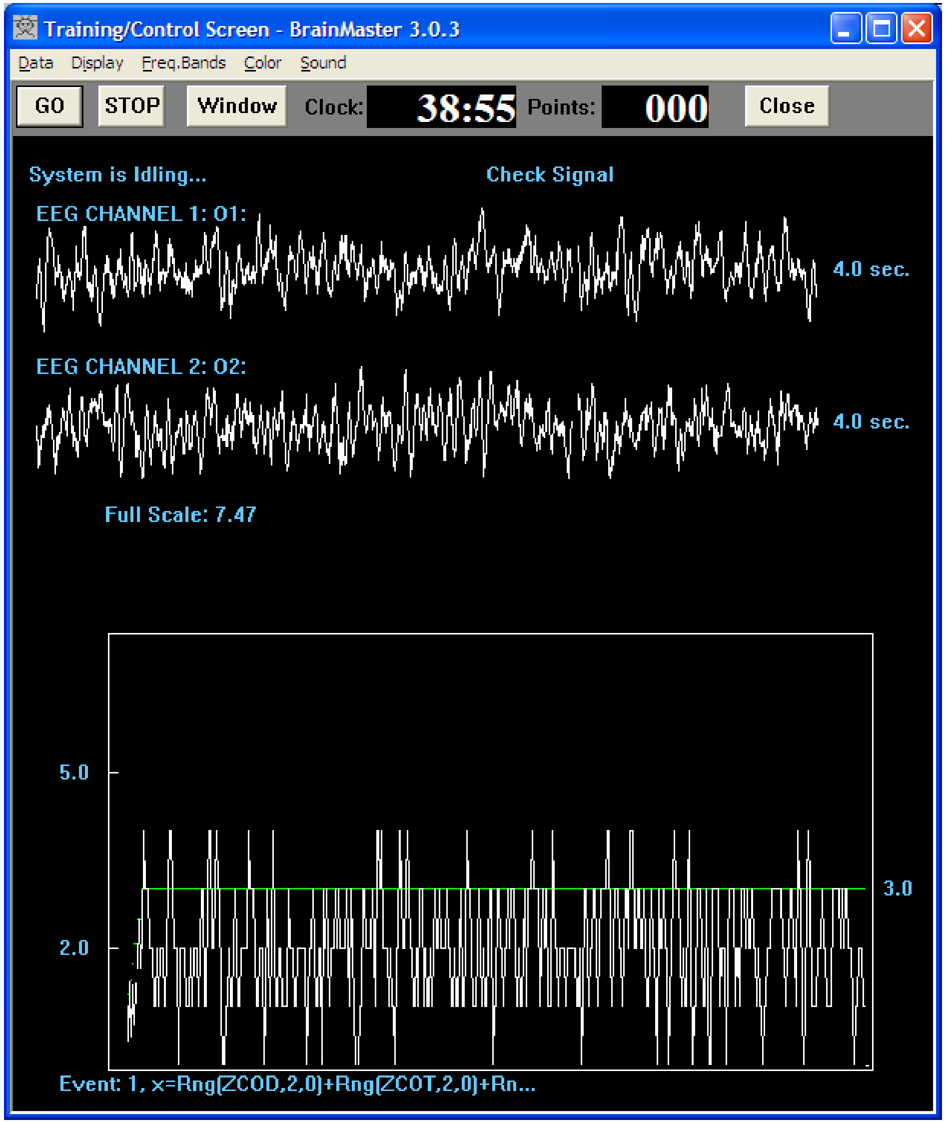
Z-score Coherence Range Training
(feedback when z score is in desired range)



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

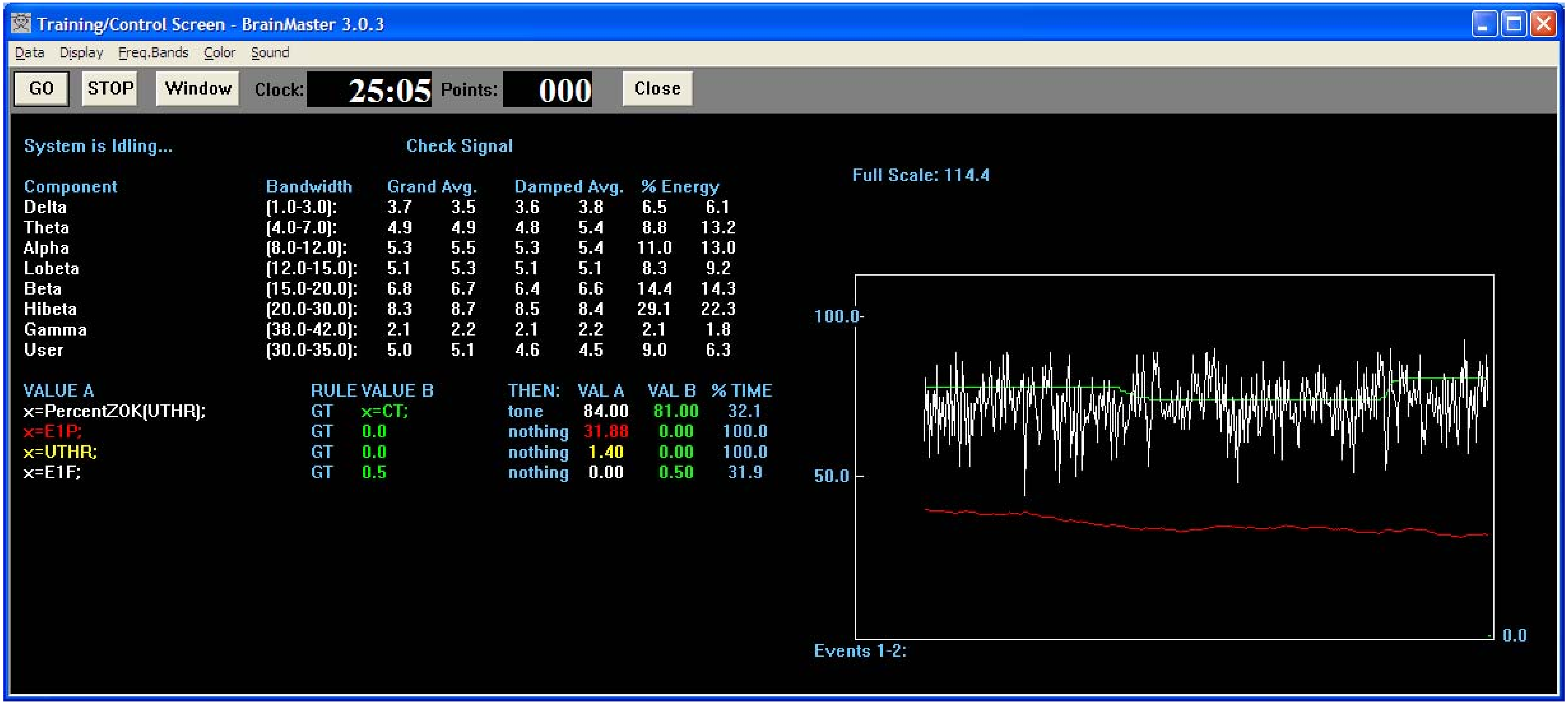
Coherence ranges training with Z Scores (4 coherences in range)



PercentZOK() function

- PercentZOK(RANGE)
  - Gives percent of Z Scores within RANGE of 0
  - 1 channel: 26 Z Scores total
  - 2 channels: 76 Z Scores total
  - 4 channels: 248 Z Scores total
- Value = 0 to 100

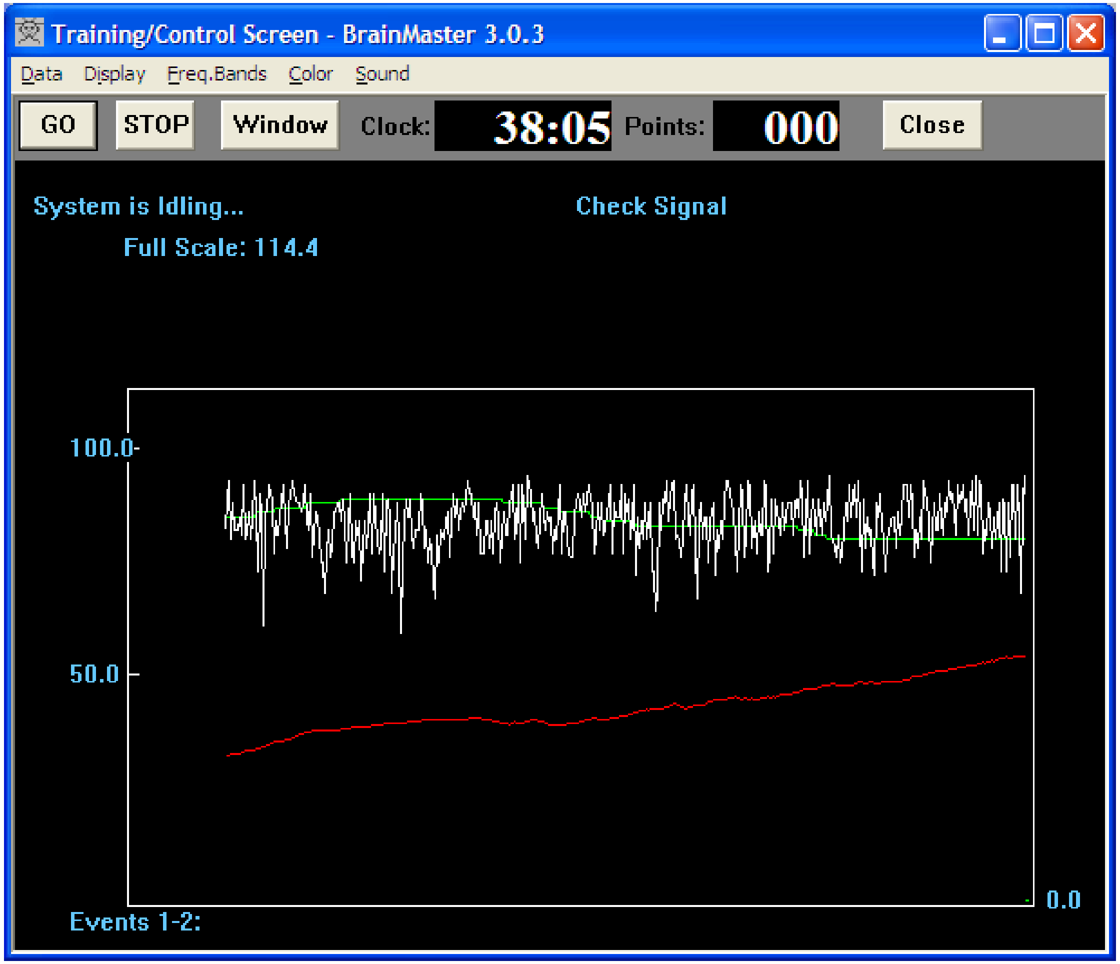
Z Score training using percent Z's in target range



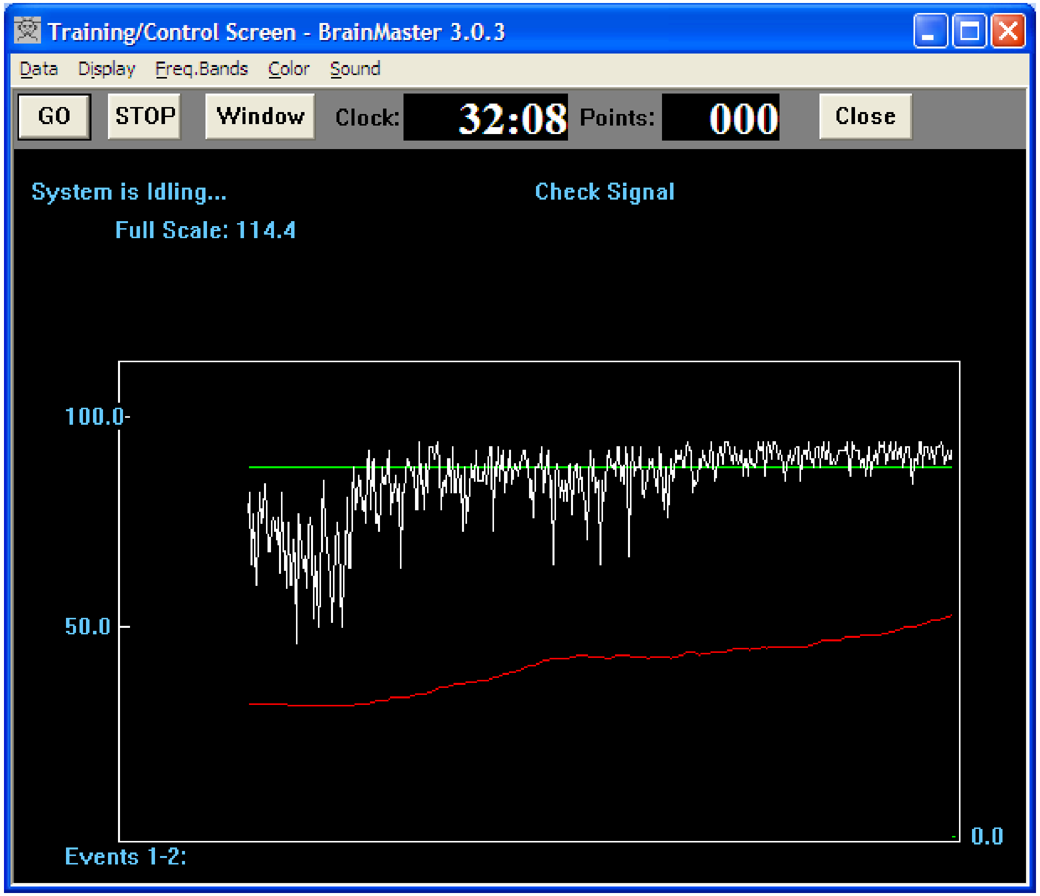
Size of range window (UTHR - currently 1.4 standard deviations)
Threshold % for Reward (CT: between 70% and 80%)
%Z Scores in range (between 50 and 90%)
% Time criterion is met (between 30% and 40%)

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