Foundations of Neuronal Dynamics and Z Scores

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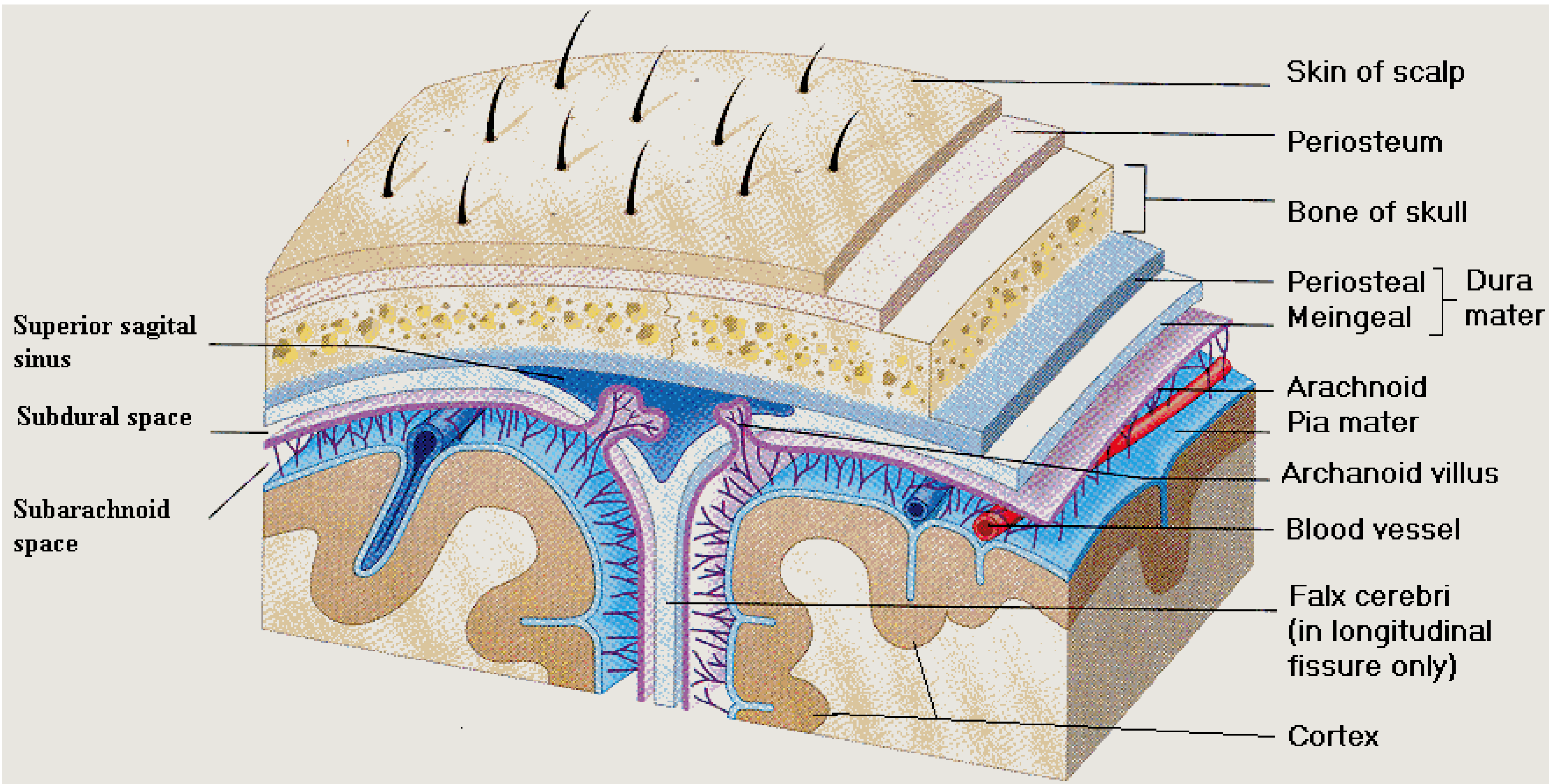
Electrophysiology

- Neuronal Potentials – dipoles generation by single cells
- Population Dynamics – synchrony reinforces strength of signal
- Brain Physiology & anatomy defines electrical generators
- Volume Conduction to scalp through cerebral fluid and tissue
- Skin Interface to sensors

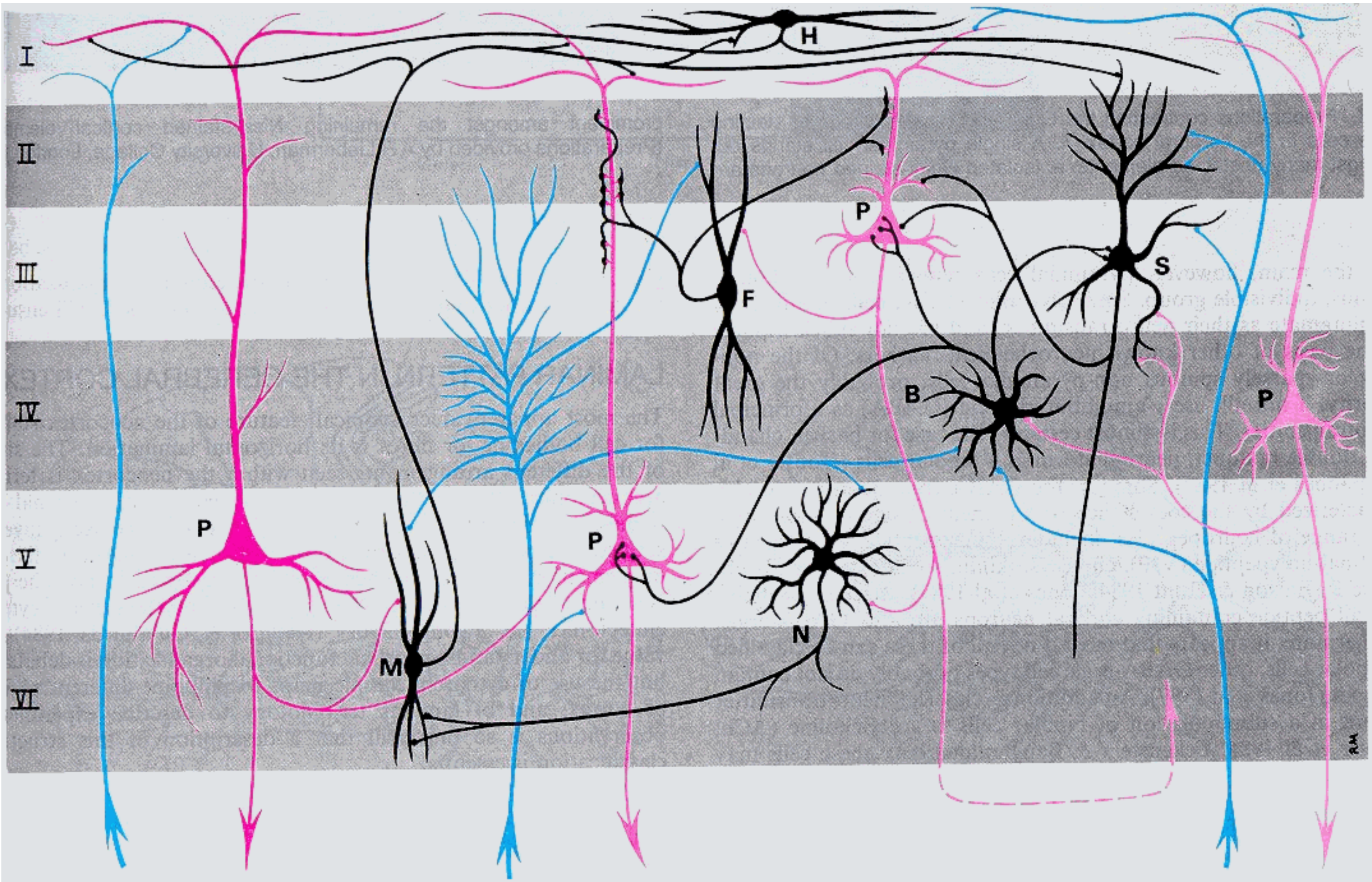
EEG Generation Mechanisms

- Primary mechanism of brain is inhibition
- Rhythms generated when inhibition is relaxed
- Allows thalamocortical reverberation
- Relaxation at cortical level, and at thalamic level
- Allows populations to oscillate in synchrony

Cortical EEG Sources



Cortical Layers



EEG Current Flow

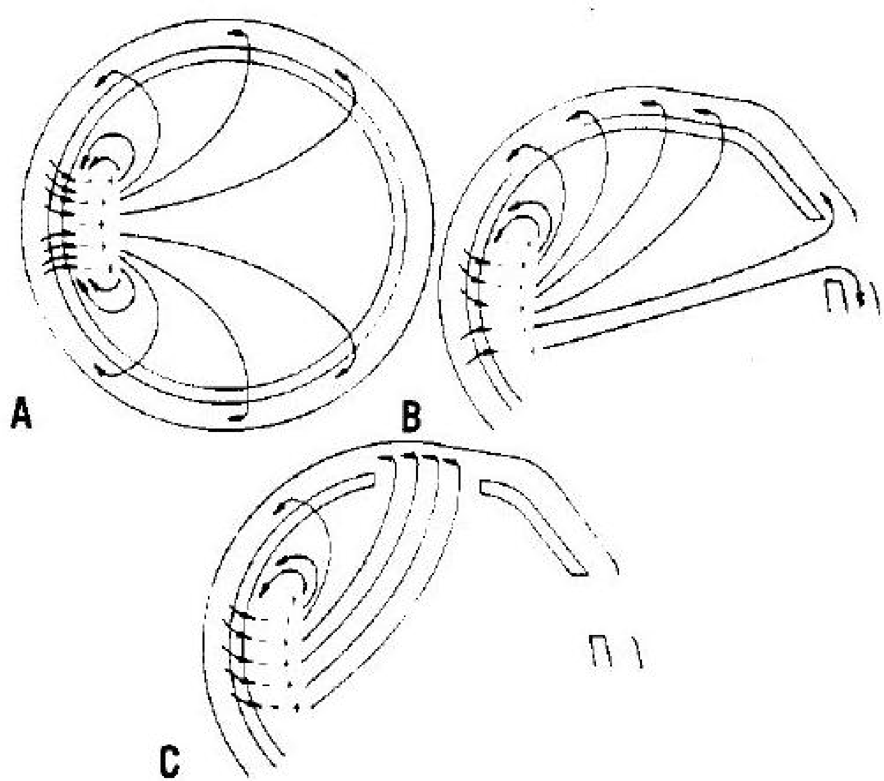
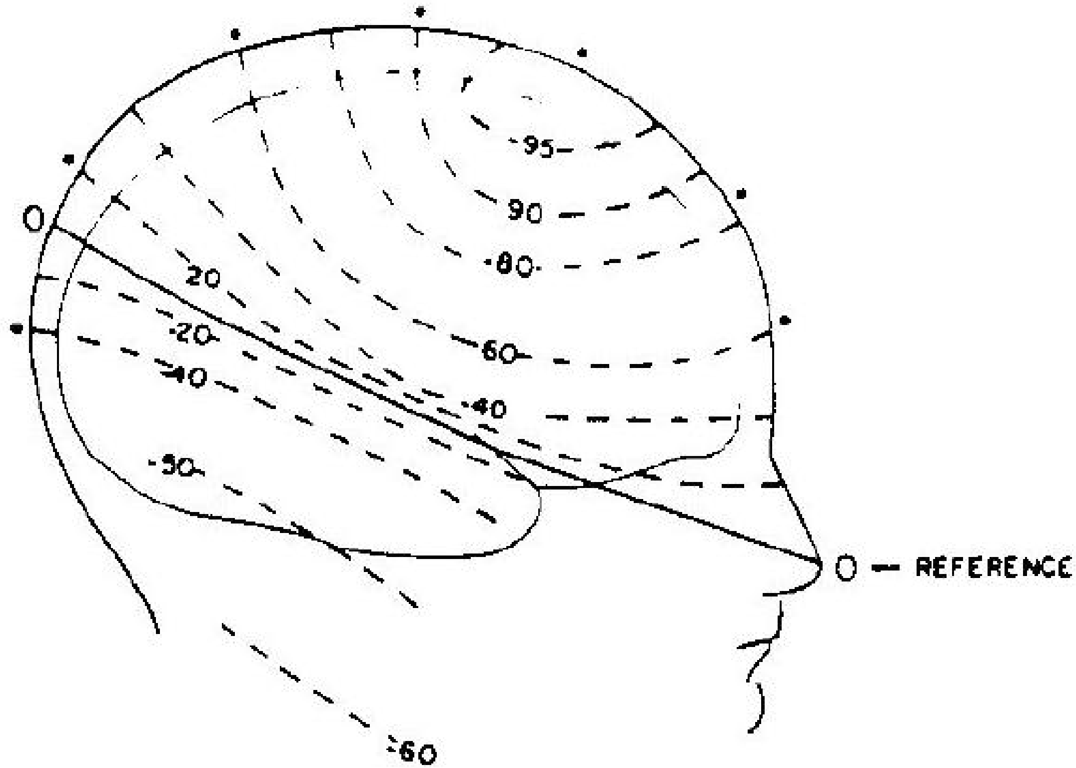
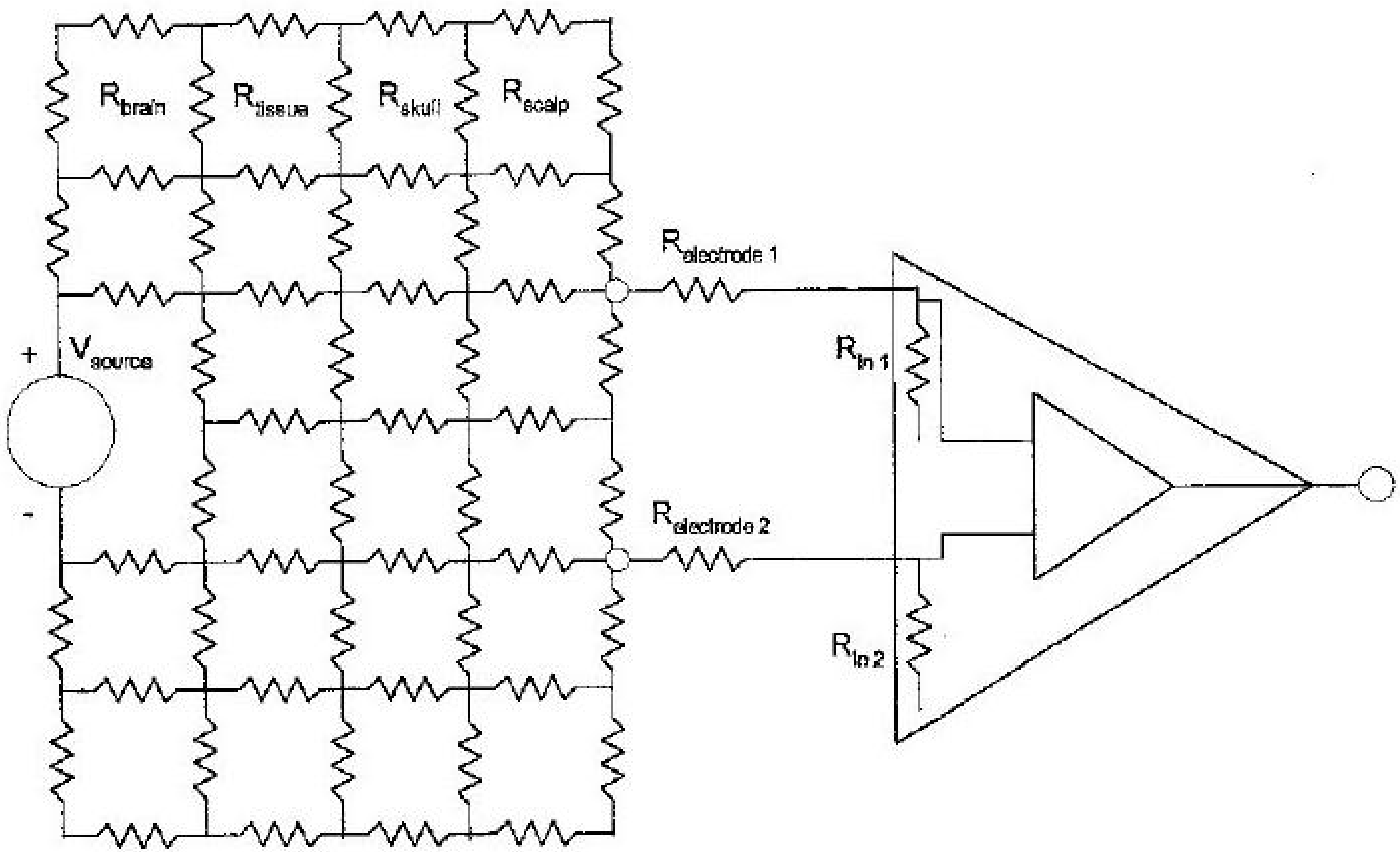


Fig. 16–1. Current flow as a result of a putative dipole layer generator in the occipital cortex. In the spherical head model shown in **A,** the current flow is relatively uniformly distributed. In **B,** a nonspherical head model with orbital openings, and **C,** a nonspherical head model with a surgically induced opening, the current follows the pathways of least resistance. From Nunez,[55] with permission.

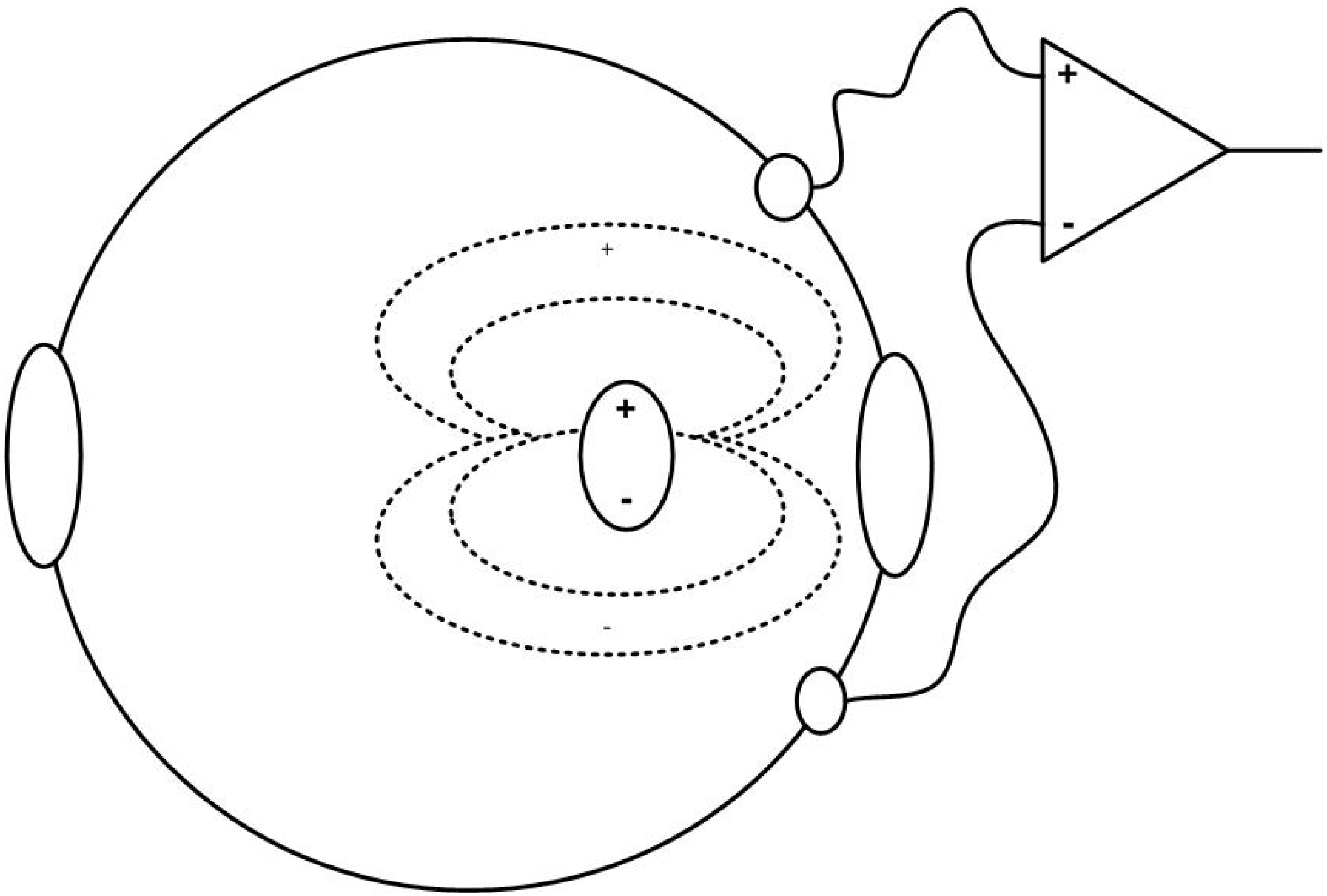
Effect of EEG “blurring”



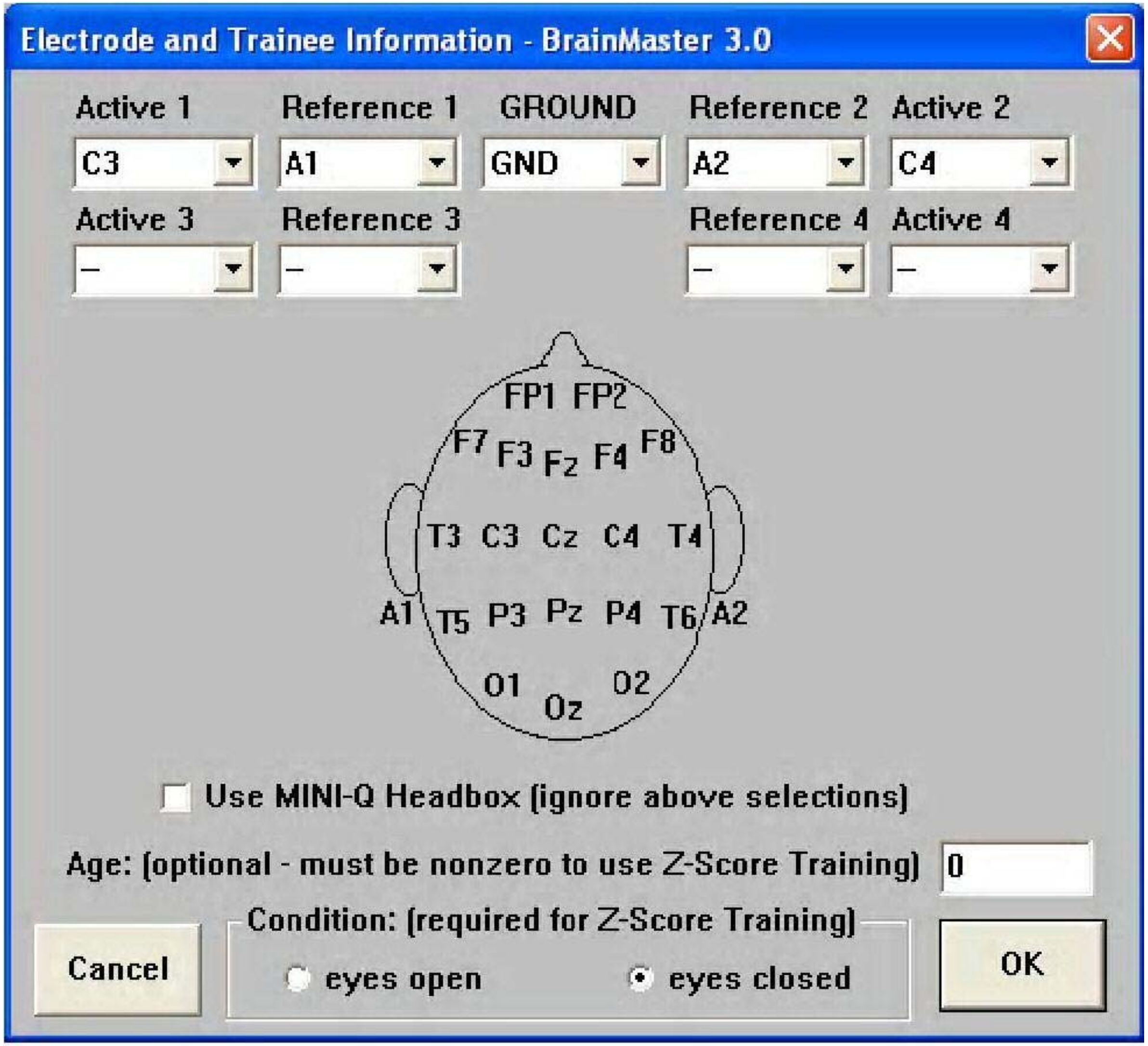
Model for Differential Amplifier & EEG Generators



Sample EEG Computation



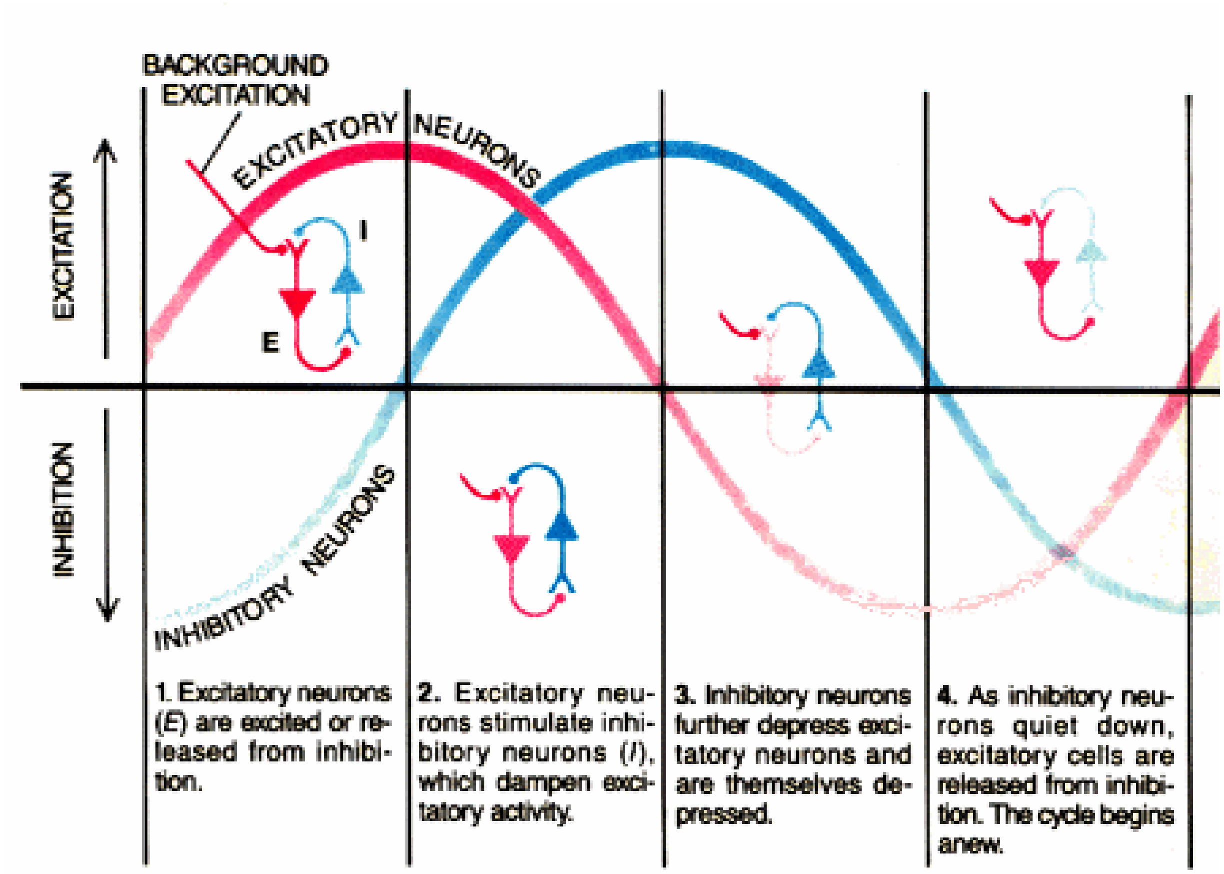
10-20 system


Electrode and Trainee Information - BrainMaster 3.0
Active 1
Reference 1
GROUND
Reference 2
Active 2
C3
A1
GND
A2
C4
Active 3
Reference 3
Reference 4
Active 4
FP1 FP2
F7 F3 Fz F4 F8
T3 C3 Cz C4 T4
A1 T5 P3 Pz P4 T6 A2
O1 Oz O2
Use MINI-Q Headbox (ignore above selections)
Age: (optional - must be nonzero to use Z-Score Training)
0
Cancel
Condition: (required for Z-Score Training)
eyes open
eyes closed
OK

EEG montages

- Referential – e.g. ear reference
- Reference is assumed inactive
- Linked ears commonly used as reference
- Bipolar – e.g. T3 active T4 reference
- Measures difference between two sites

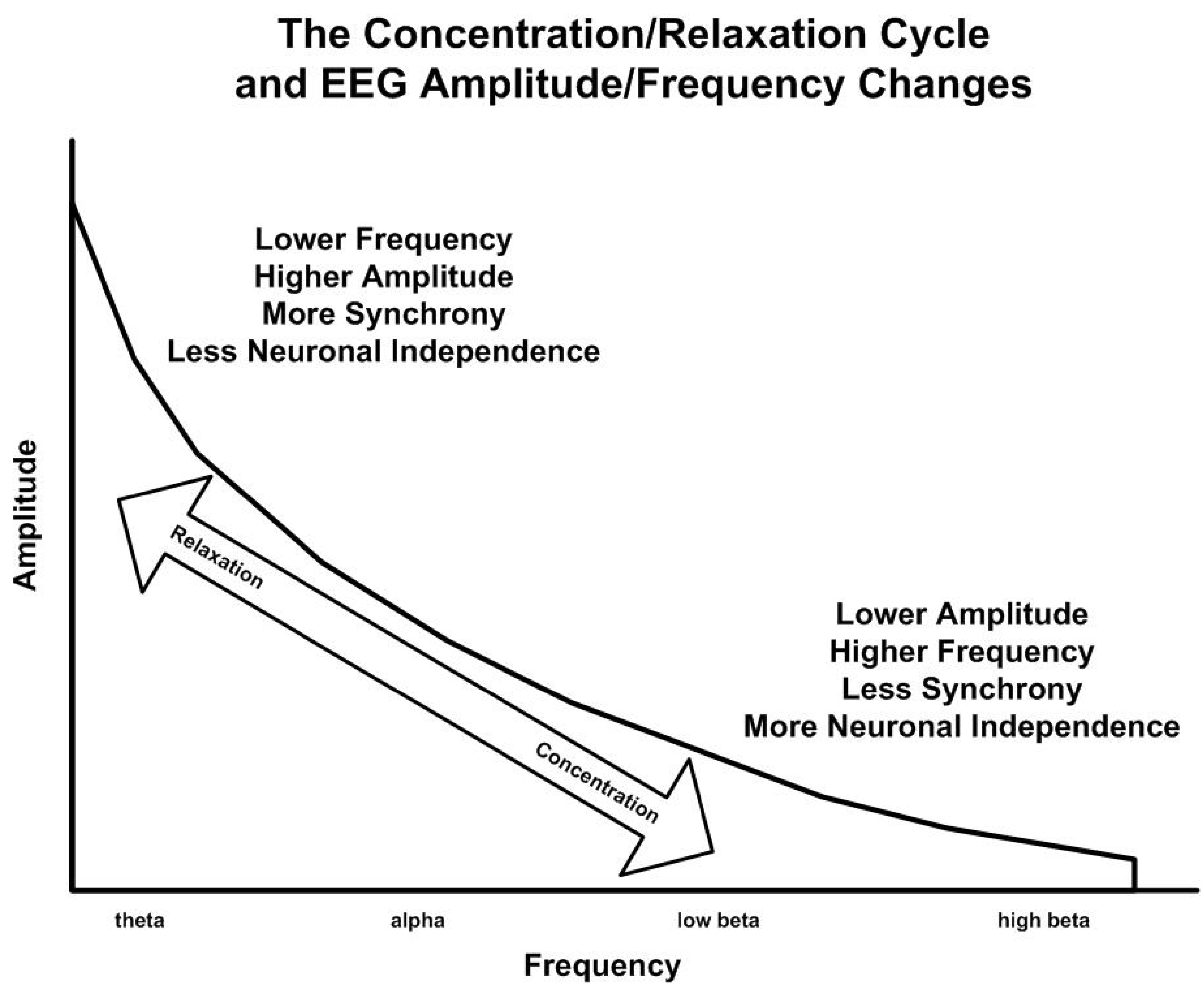
Thalamo-Cortical Cycles



Concentration/Relaxation Cycle

- Discovered by Dr. Barry Sterman in pilots
- “good” pilots preceded each task item with high-frequency, low-amplitude EEG
- Also followed task item with low-frequency, high-amplitude EEG (“PRS”)
- Poorer pilots did not exhibit control of the concentration/relaxation cycle
- Slower reaction time, more fatigue

Concentration/Relaxation Cycle



EEG Analysis Methods

- Digital Filtering (“IIR” or “FIR”)
  - Fast response, uses predefined bands
  - Like using a colored lens
  - Fast, useful for training or assessment
- Fast Fourier Transform (“FFT”)
  - Analyzes all frequencies
  - Like a prism
  - Response is slower, useful for assessment

Typical EEG Component Bands

- Delta (1 – 4 Hz)
- Theta (4 – 7 Hz)
- Alpha (8 – 12 Hz)
- Low Beta (12 – 15 Hz)
- Beta (15 – 20 Hz)
- High Beta (20 – 30 Hz)
- Gamma (40 Hz and above)
- Ranges are typical, not definitive

Typical EEG metrics

- Amplitude (microvolts)
- Frequency (Hz, peak or modal)
- Percent energy
- Variability
- Coherence between 2 channels (percent)
- Phase between 2 channels (degrees or percent)
- Asymmetry between 2 channels (ratio or percent)

MINI-Q

- External headbox connected to 2-channel EEG
- Scans sensor pairs sequentially
- Uses linked ears reference
- Uses 12 selected sites
- 2 channels, 6 positions
- Allows head scan using 2-channel EEG
- Take e.g. 1 minute per position
- Software assists with prompts, organizes data
- Primarily for assessment, can also be used for training

MINI-Q Sites

- Fz Cz
- F3 F4
- C3 C4
- P3 P4
- T3 T4
- O1 O2
- All referenced to linked ears

MINI-Q Analysis

- Manually inspect summary data
- DCN128 provides norms, analysis, protocol suggestions
- NeuroGuide provides normative analysis, z scores, connectivity maps
- Live z DLL can be used for live viewing of z scores

Purpose of z scores

- Method to understand a population
- Method to understand an individual
- Uses statistics to evaluate quantities
- Standard method applicable to any measurement
- Important for connectivity, phase, asymmetry measures

Basic Concepts

- Normative population
- Normative statistics
- Database of values
- Method to quantify any individual

Concepts of z scores

- Measure a large population
- Determine population statistics
- Mean
- Standard deviation
- Convert any single measurement into a z score
- Standard measure of “how normal”

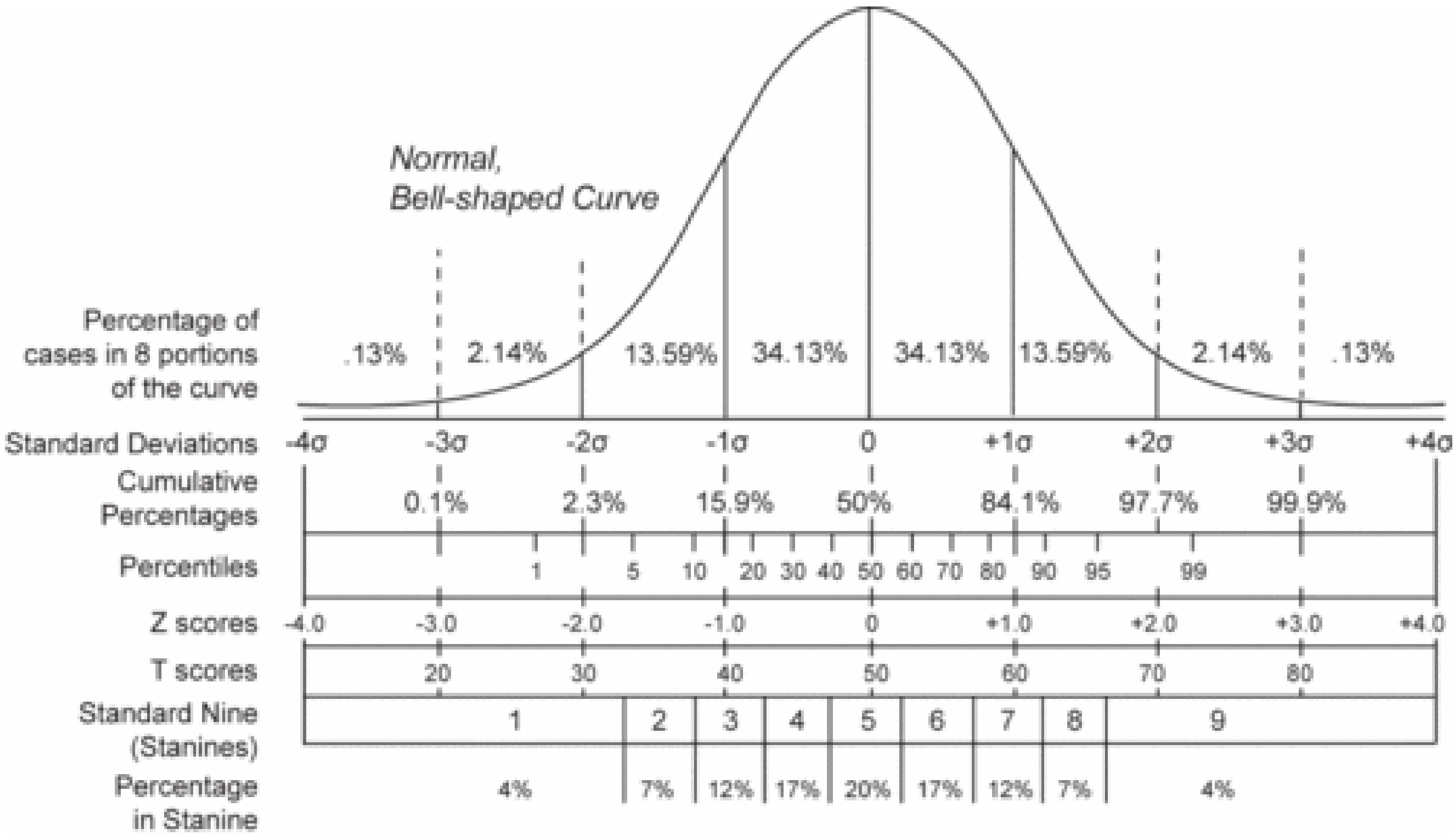
Normal Distribution - males

Photo by Gregory S. Pryor, Francis Marion University, Florence, SC.

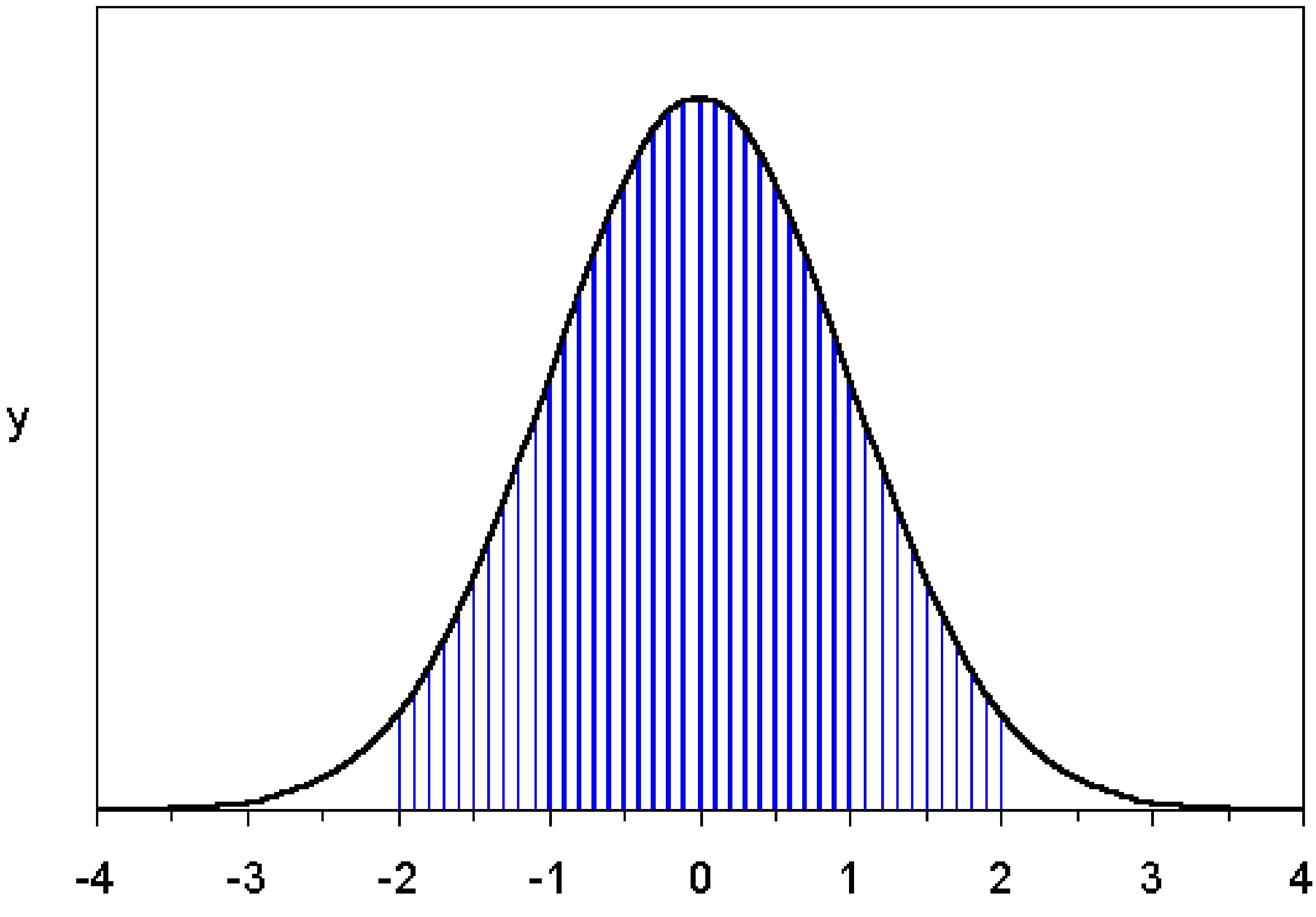
From: (C. Starr and R. Taggart. 2003. *The Unity and Diversity of Life.* 10th Ed. Page 189.)

Normal Distribution - females

Normal Distribution



Bell Curve using z scores



Z Scores - equations

Standard Normal Distribution:

$$y = \left(\frac{1}{\sigma\sqrt{2\pi}} \right) e^{\frac{-z^2}{2}}$$

Z score for any sample value x:

$$z = \frac{x - \mu}{\sigma}$$

What is a z score

- A metric based on any measurement and the associated population statistics
- Tells “how many standard deviations away from the mean”
- Defined as:

$$zscore = \frac{measurement - mean}{stdev}$$

Z score ranges

- +/- 1 sigma:
  - Includes middle 68% of population
  - From 16% to 84% points
- +/- 2 sigma:
  - Includes middle 95% of population
  - From 2% to 98% points
- +/- 3 sigma:
  - Includes middle 99.8% of population
  - From .1% to 99.9% points
- +/- 4 sigma:
  - Forget about it

Z score example
Adult height

- Mean height = 6 feet
- Standard deviation = 3 inches = .25 ft.
- Height 6 feet 6 inches
  - Compute Z = 6.5 – 6.0 / .25 = 2.0
- Height 5 feet 9 inches
  - Compute Z = 5.75 – 6.0 / .25 = -1.0
- Height 5 feet
  - Compute z = 5.0 – 6.0 / .25 = -4.0

Z score training approach

- Compute ongoing z scores
- Apply as training variables
- Establish targets and criteria
- Provide feedback
- Uses unique predefined bands, not adjustable in z DLL software
- Bands are independent of those used in the main EEG software

Z scores used for EEG

- Absolute power
- Relative power
- Power ratios
- Asymmetry
- Coherence
- Phase

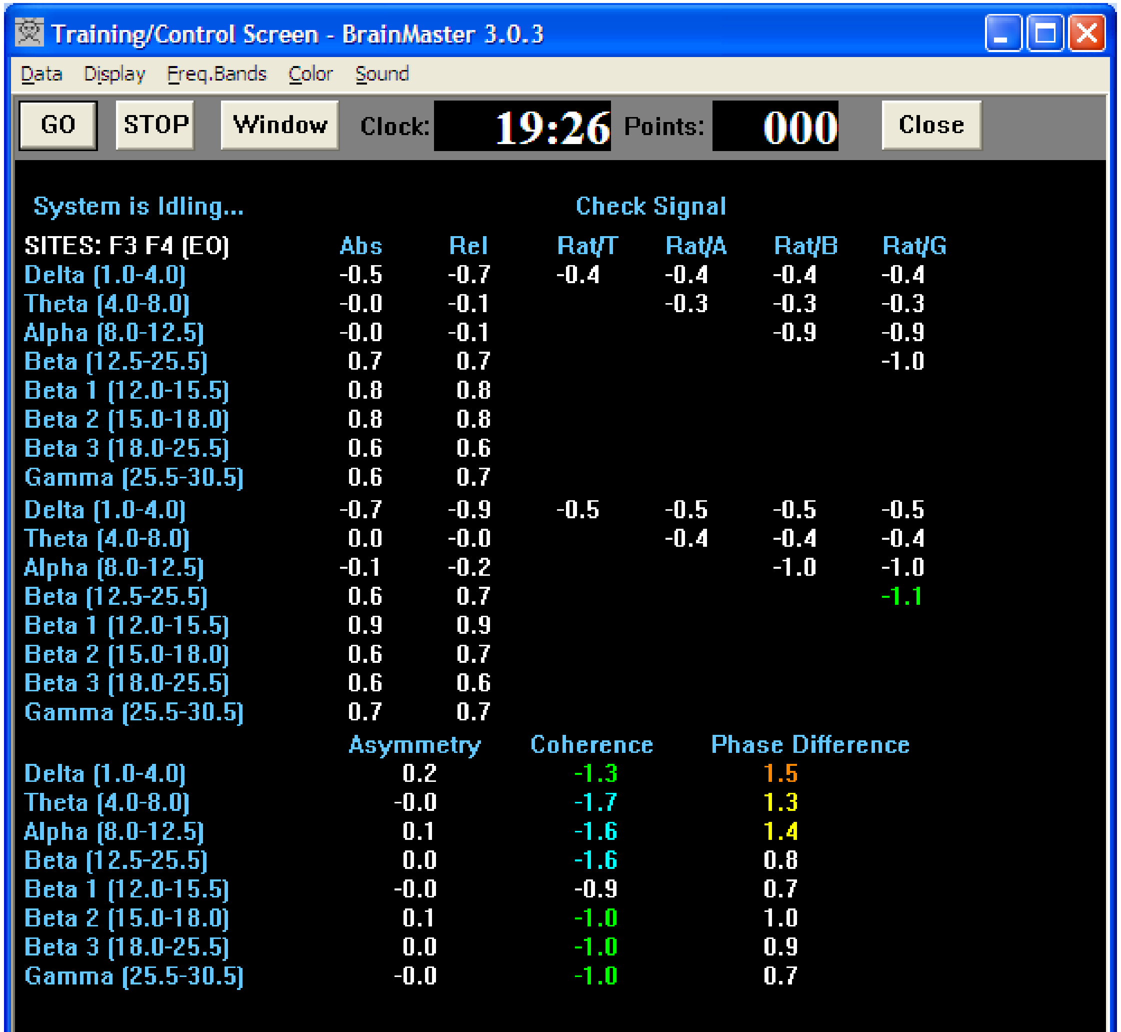
Component bands in Z DLL

- Delta (1 - 4 Hz)
- Theta (4 - 8 Hz)
- Alpha (8 – 12.5 Hz)
- Beta (12.5 – 25.5 Hz)
- Beta1 (12.0 – 15.5 Hz)
- Beta2 (15.0 – 18.0 Hz)
- Beta3 (18.0 – 25.5 Hz)
- Gamma (25.5 – 30.5 Hz)

Z scores – 2 channels

- For each site (2 sites)
  - 8 absolute power
  - 8 relative power
  - 10 power ratios
- For the connection (1 pathway)
  - 8 asymmetry
  - 8 coherence
  - 8 phase

Live Z Scores – 2 channels (76 targets)

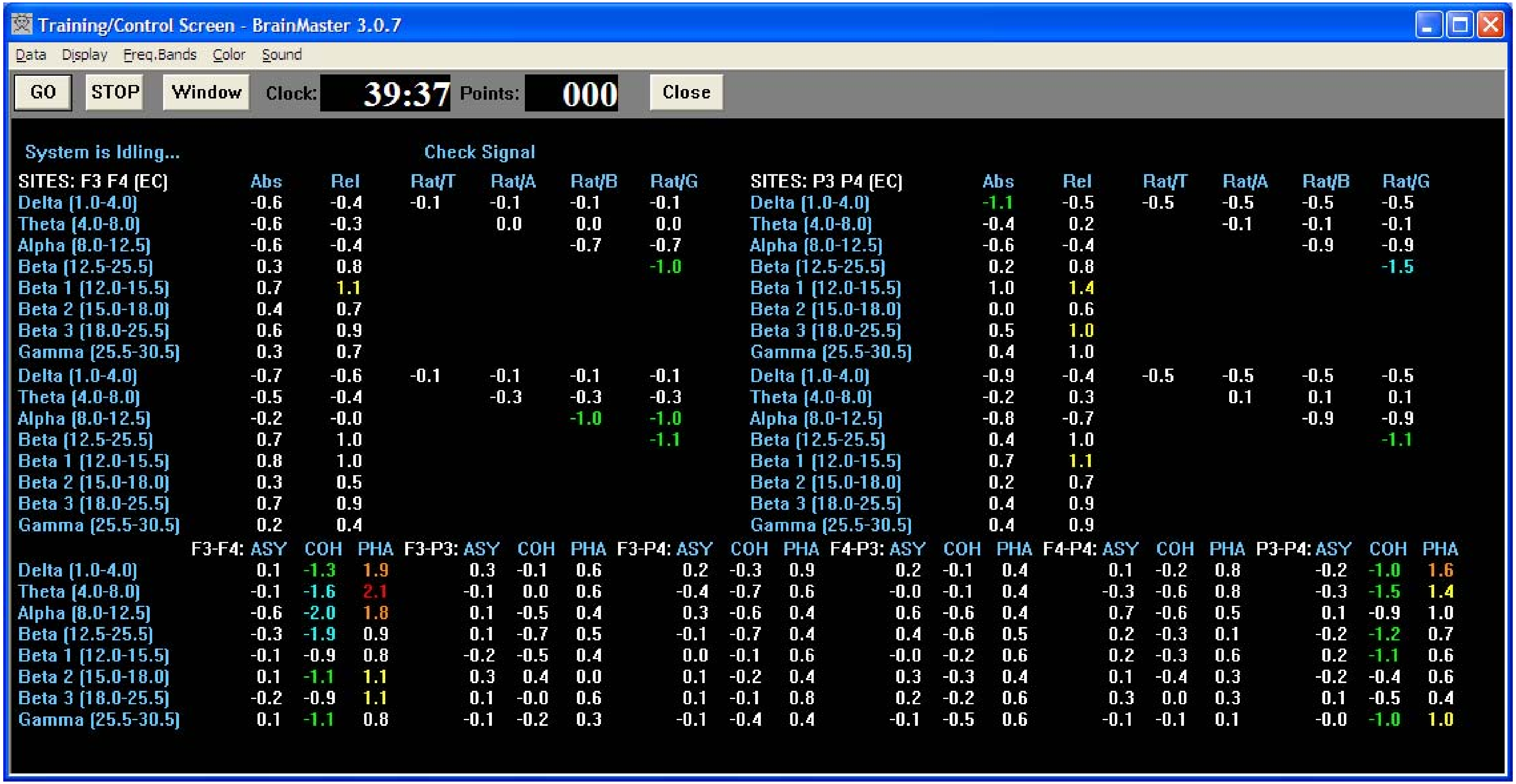


26 x 2 + 24 = 76 (52 power, 24 connectivity)

Z scores – 4 channels

- For each site (4 sites)
  - 8 absolute power
  - 8 relative power
  - 10 power ratios
- For the connection (6 pathways)
  - 8 asymmetry
  - 8 coherence
  - 8 phase

Live Z Scores – 4 channels (248 targets)



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

SITES: P3 P4 (EC)	Abs	Rel	Rat/T	Rat/A	Rat/B	Rat/G
Delta (1.0-4.0)	-1.1	-0.5	-0.5	-0.5	-0.5	-0.5
Theta (4.0-8.0)	-0.4	0.2		-0.1	-0.1	-0.1
Alpha (8.0-12.5)	-0.6	-0.4			-0.9	-0.9
Beta (12.5-25.5)	0.2	0.8				-1.5
Beta 1 (12.0-15.5)	1.0	1.4				
Beta 2 (15.0-18.0)	0.0	0.6				
Beta 3 (18.0-25.5)	0.5	1.0				
Gamma (25.5-30.5)	0.4	1.0				
Delta (1.0-4.0)	-0.9	-0.4	-0.5	-0.5	-0.5	-0.5
Theta (4.0-8.0)	-0.2	0.3		0.1	0.1	0.1
Alpha (8.0-12.5)	-0.8	-0.7			-0.9	-0.9
Beta (12.5-25.5)	0.4	1.0				-1.1
Beta 1 (12.0-15.5)	0.7	1.1				
Beta 2 (15.0-18.0)	0.2	0.7				
Beta 3 (18.0-25.5)	0.4	0.9				
Gamma (25.5-30.5)	0.4	0.9				

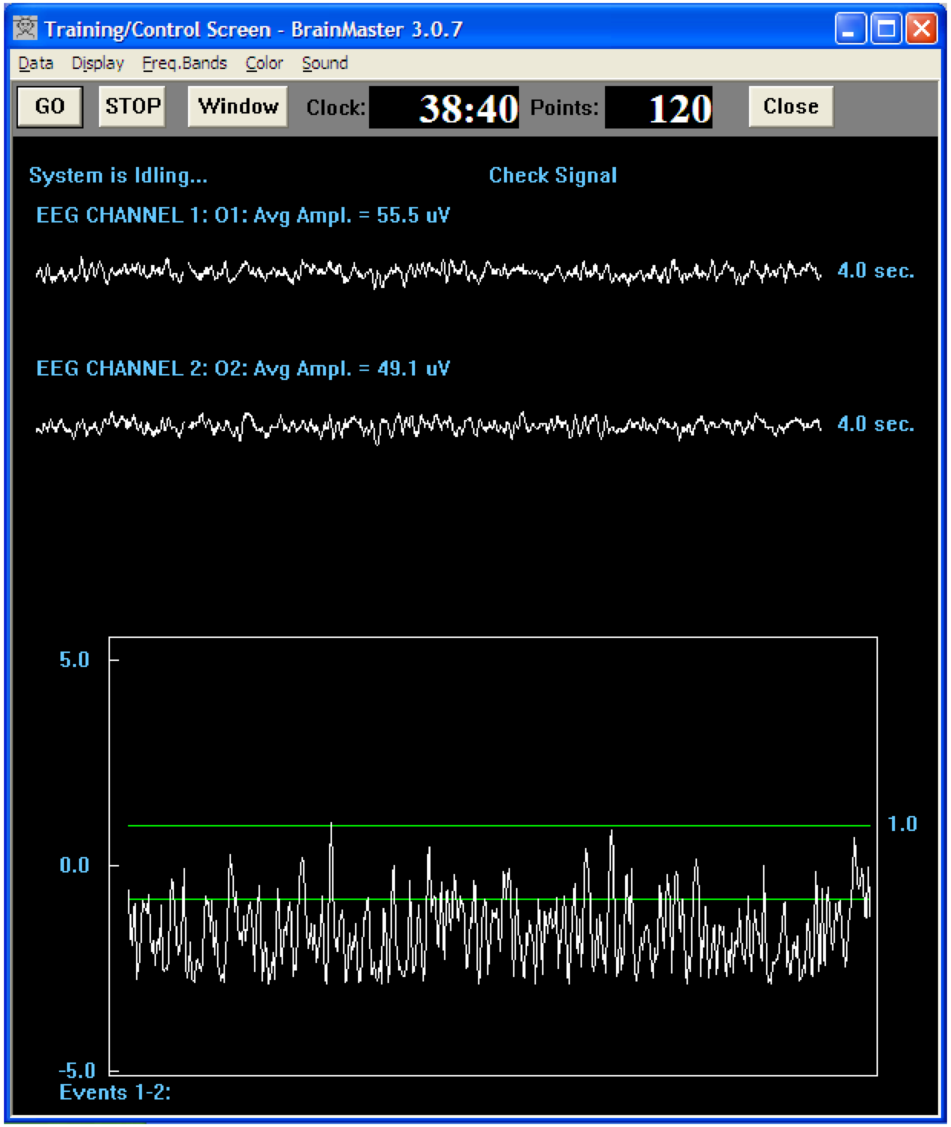
	F3-F4: ASY	COH	PHA	F3-P3: ASY	COH	PHA	F3-P4: ASY	COH	PHA	F4-P3: ASY	COH	PHA	F4-P4: ASY	COH	PHA	P3-P4: ASY	COH	PHA
Delta (1.0-4.0)	0.1	-1.3	1.9	0.3	-0.1	0.6	0.2	-0.3	0.9	0.2	-0.1	0.4	0.1	-0.2	0.8	-0.2	-1.0	1.6
Theta (4.0-8.0)	-0.1	-1.6	2.1	-0.1	0.0	0.6	-0.4	-0.7	0.6	-0.0	-0.1	0.4	-0.3	-0.6	0.8	-0.3	-1.5	1.4
Alpha (8.0-12.5)	-0.6	-2.0	1.8	0.1	-0.5	0.4	0.3	-0.6	0.4	0.6	-0.6	0.4	0.7	-0.6	0.5	0.1	-0.9	1.0
Beta (12.5-25.5)	-0.3	-1.9	0.9	0.1	-0.7	0.5	-0.1	-0.7	0.4	0.4	-0.6	0.5	0.2	-0.3	0.1	-0.2	-1.2	0.7
Beta 1 (12.0-15.5)	-0.1	-0.9	0.8	-0.2	-0.5	0.4	0.0	-0.1	0.6	-0.0	-0.2	0.6	0.2	-0.3	0.6	0.2	-1.1	0.6
Beta 2 (15.0-18.0)	0.1	-1.1	1.1	0.3	0.4	0.0	0.1	-0.2	0.4	0.3	-0.3	0.4	0.1	-0.4	0.3	-0.2	-0.4	0.6
Beta 3 (18.0-25.5)	-0.2	-0.9	1.1	0.1	-0.0	0.6	0.1	-0.1	0.8	0.2	-0.2	0.6	0.3	0.0	0.3	0.1	-0.5	0.4
Gamma (25.5-30.5)	0.1	-1.1	0.8	-0.1	-0.2	0.3	-0.1	-0.4	0.4	-0.1	-0.5	0.6	-0.1	-0.1	0.1	-0.0	-1.0	1.0

26 x 4 + 24 x 6 = 248 (104 power, 144 connectivity)

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
- Combine the above with other, e.g. power training

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



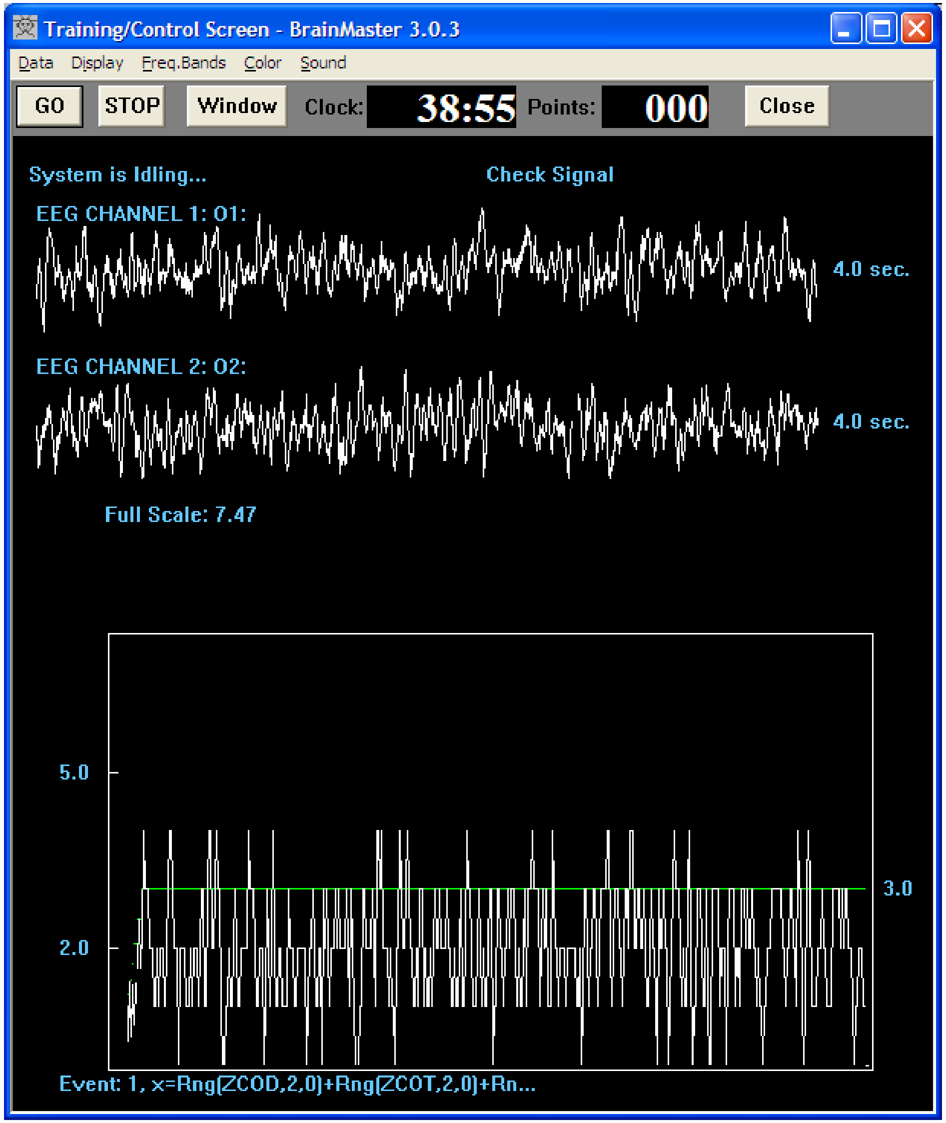
Range Function

- 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

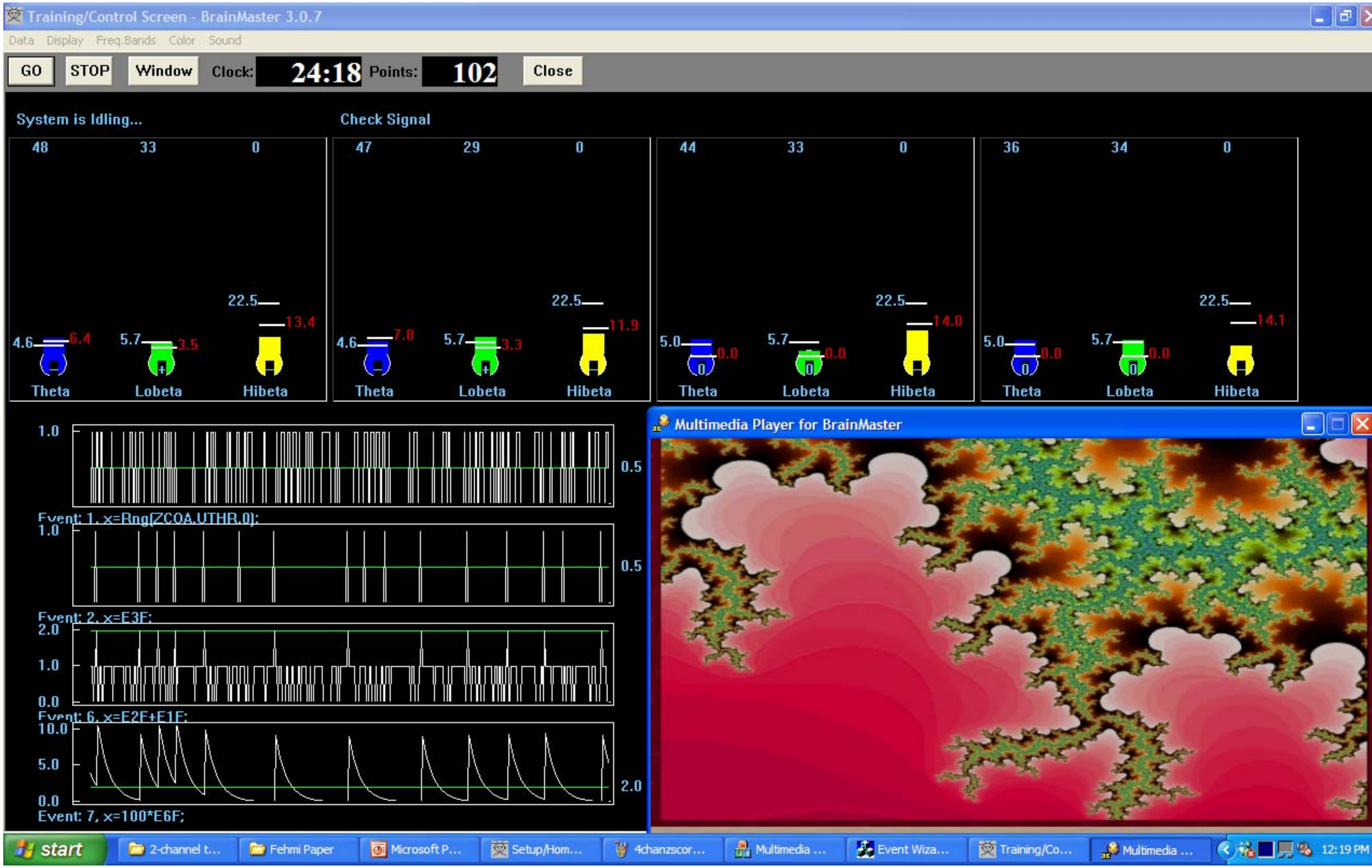
Range training with multiple ranges

- 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 = 4

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



Combined Amplitude and Coherence-based protocol



If (point awarded for amplitudes) AND (coherence is normal) THEN (play video for 1 second)

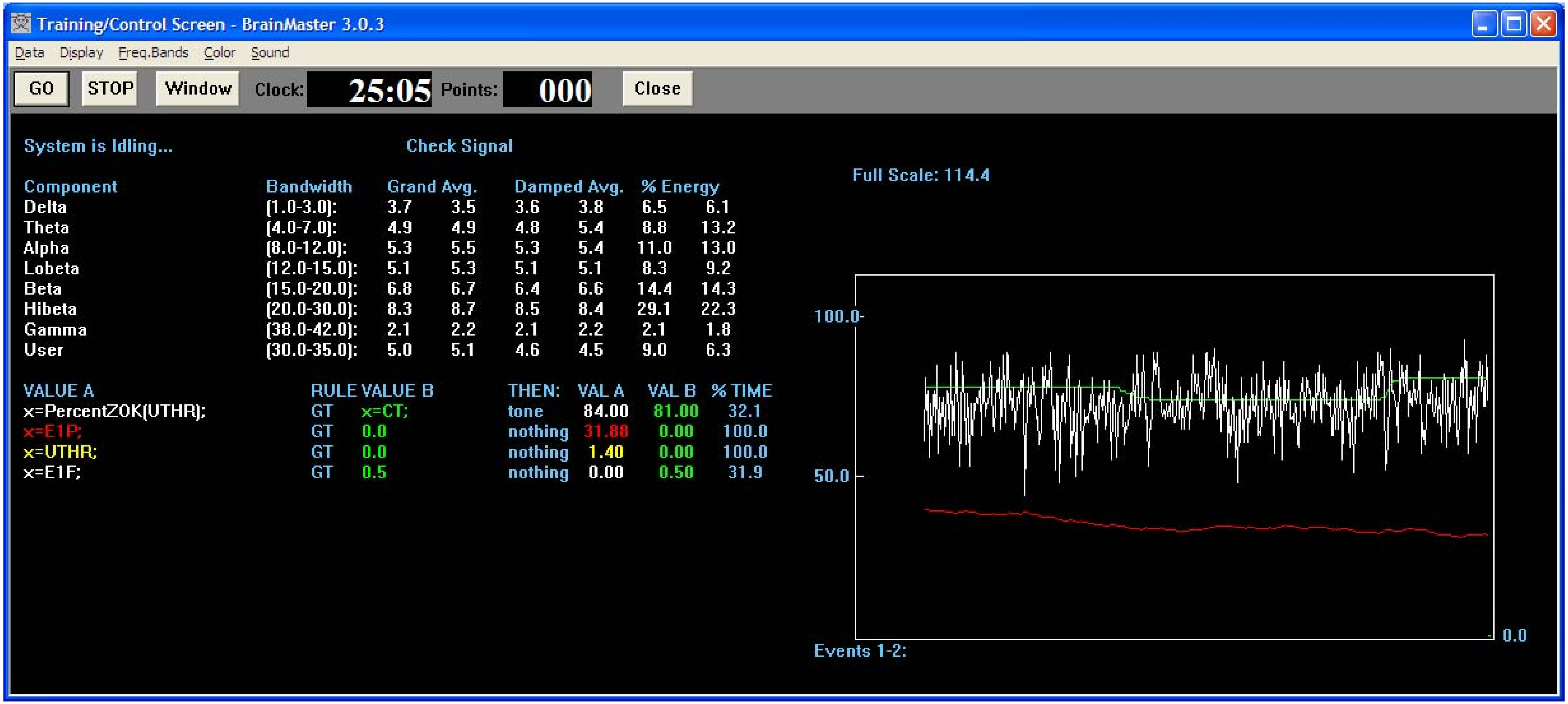
PercentZOK() function

- 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
- Measure of “How Normal?”
- All targets have a specified size “bulls-eye”

Z Score "percent" Targeting Strategy

- Feedback contingency based upon:
  - Size of target bulls-eyes ("range")
  - Number of targets required ('target percent hits")
  - Possibility of biasing targets up or down
  - Targets may be enhances and/or inhibits
- Wide targets will automatically select most deviant scores
- Training automatically combines and/or alternates between amplitude & connectivity

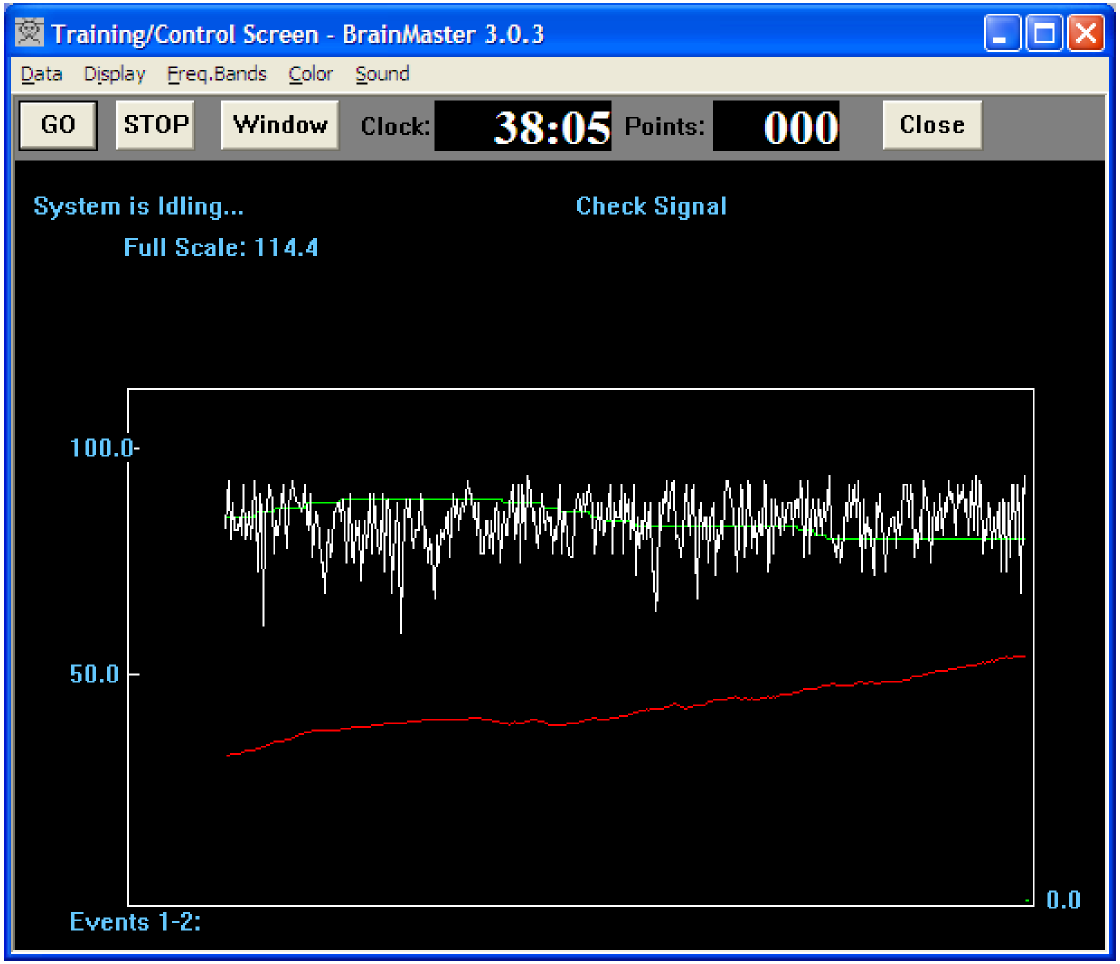
Z Score training using percent Z's in target range



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%)

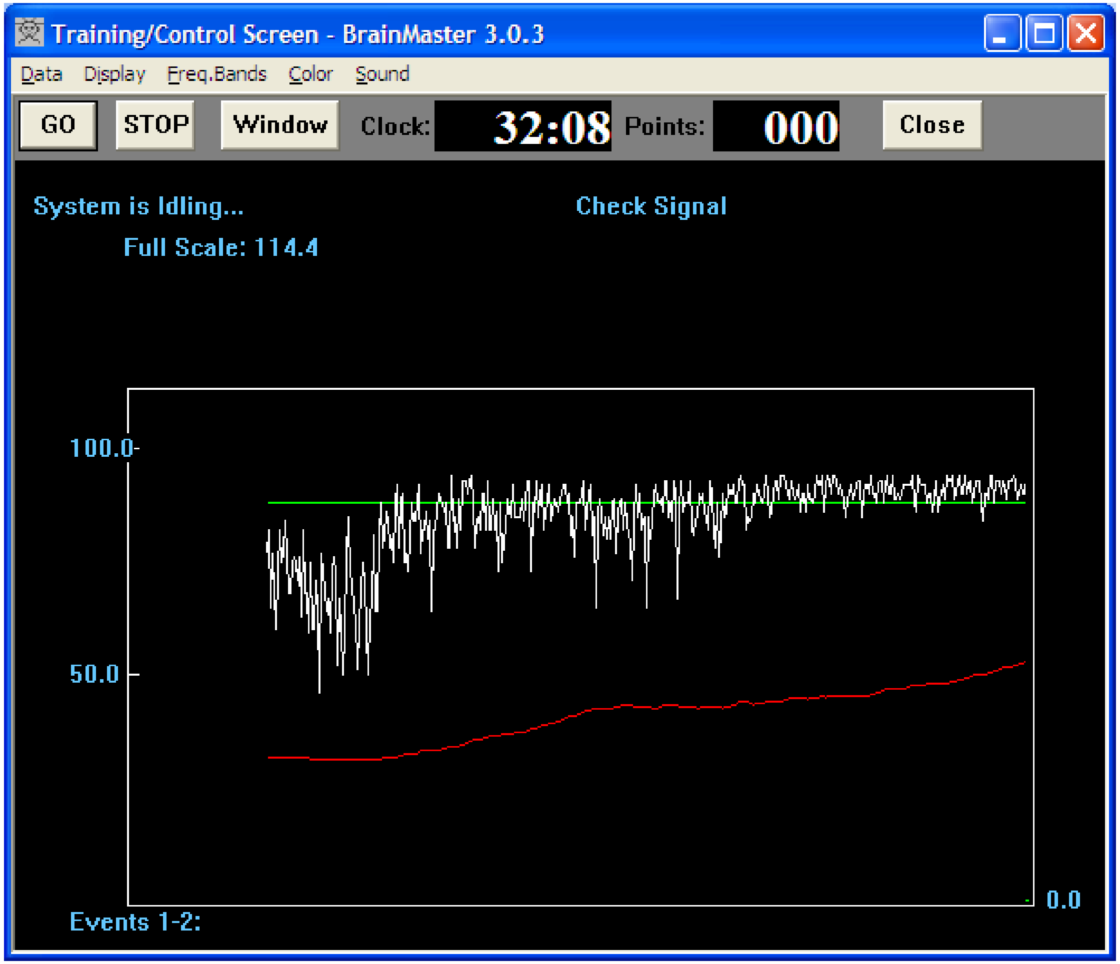
Effect of changing %Z threshold

Reduce threshold -> percent time meeting criteria increases



Effect of widening Z target window

Widen window -> higher % achievable, selects most deviant scores



Z-score based targeting

- Threshold replaced with target size
- Feedback contingency determined by target size and % hits required
- Eliminates need for “autothresholding”
- Integrates QEEG analysis with training in real time
- Protocol automatically and dynamically adapts to what is most needed
- Consistent with established QEEG-based procedures with demonstrated efficacy

References

- Thatcher, R.W., Walker, R.A. and Guidice, S. Human cerebral hemispheres develop at different rates and ages. Science, 236: 1110-1113, 1987. (This was our first publication with N = 577).
- Thatcher, R.W. EEG normative databases and EEG biofeedback. Journal of Neurotherapy, 2(4): 8-39, 1998. (N = 577 with many details).
- Thatcher, R.W. EEG database guided neurotherapy. In: J.R. Evans and A. Abarbanel Editors, Introduction to Quantitative EEG and Neurofeedback, Academic Press, San Diego, 1999. (N = 577 with many details).
- Thatcher, R.W., Walker, R.A., Biver, C., North, D., Curtin, R., Quantitative EEG Normative databases: Validation and Clinical Correlation, J. Neurotherapy, 7 (No. ¾): 87 - 122, 2003. (61 adult subjects were added so that the N = 625. This is the number currently in use in the database).
- POSITION PAPER **Standards for the Use of Quantitative Electroencephalography (QEEG) in Neurofeedback: A Position Paper of the International Society for Neuronal Regulation** Journal of Neurotherapy vol. 8 no. 1 p. 5-27 2004 Contributors: D. Corydon Hammond PhD, Professor, Physical Medicine and Rehabilitation, University of Utah, School of Medicine, Salt Lake City, UT Jonathan Walker MD, Clinical Professor of Neurology, Texas Southwestern Medical School, Dallas, TX Daniel Hoffman MD, Medical Director and Neuropsychiatrist, Neuro-Therapy Clinic, Englewood, CO Joel F. Lubar PhD, Professor of Psychology, University of Tennessee, Knoxville, TN David Trudeau MD, Adjunct Associate Professor, Family Practice and Community Health, University of Minnesota, Department of Psychiatry, Minneapolis, VAMC, Minneapolis, MN Robert Gurnee MSW, Director, Scottsdale Neurofeedback Institute/ADD Clinic, Scottsdale, AZ Joseph Horvat PhD, Private Practice, Corpus Christi, TX