Neuropsychiatry and Quantitative Electroencephalography in the 21st Century

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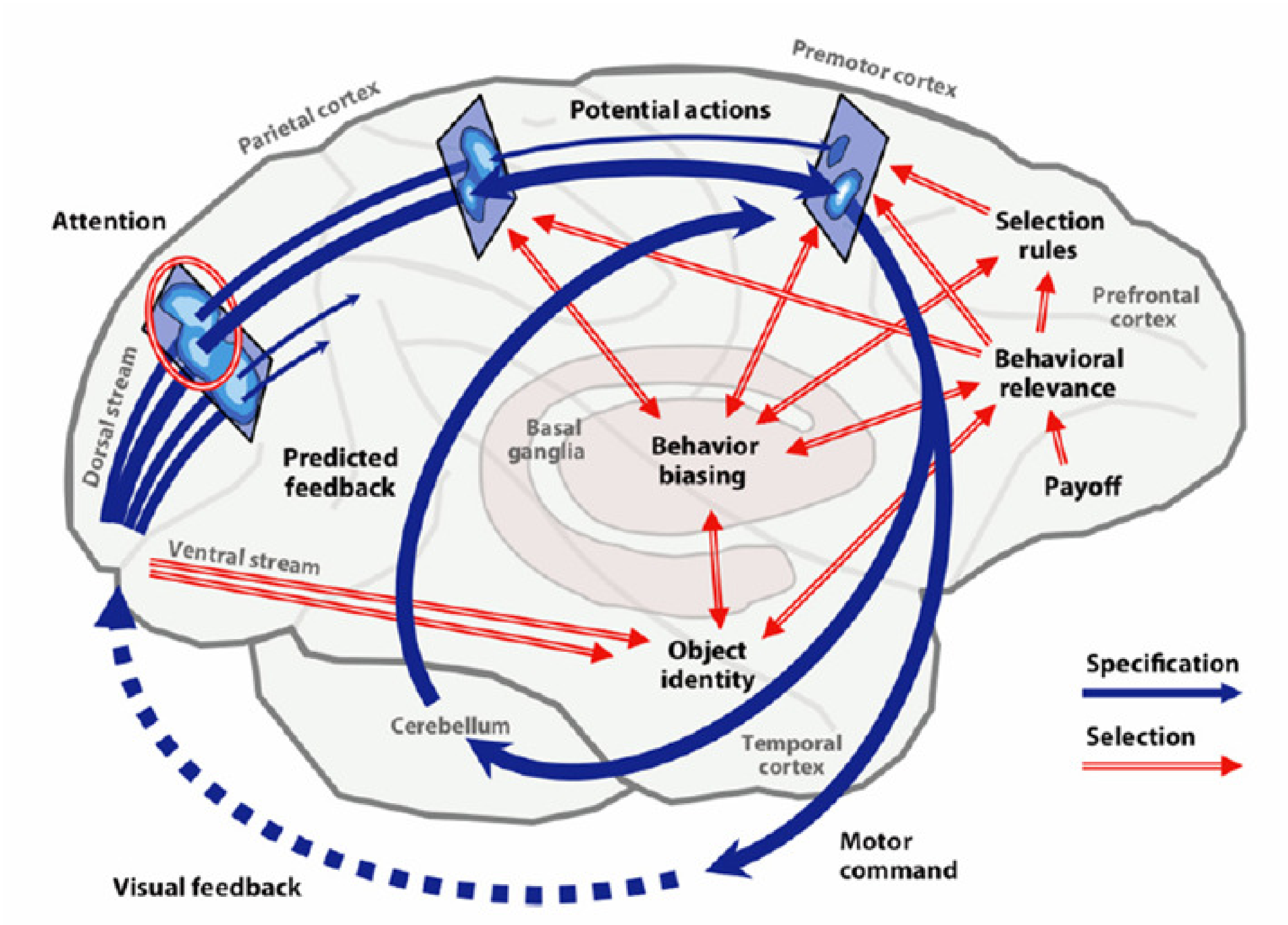
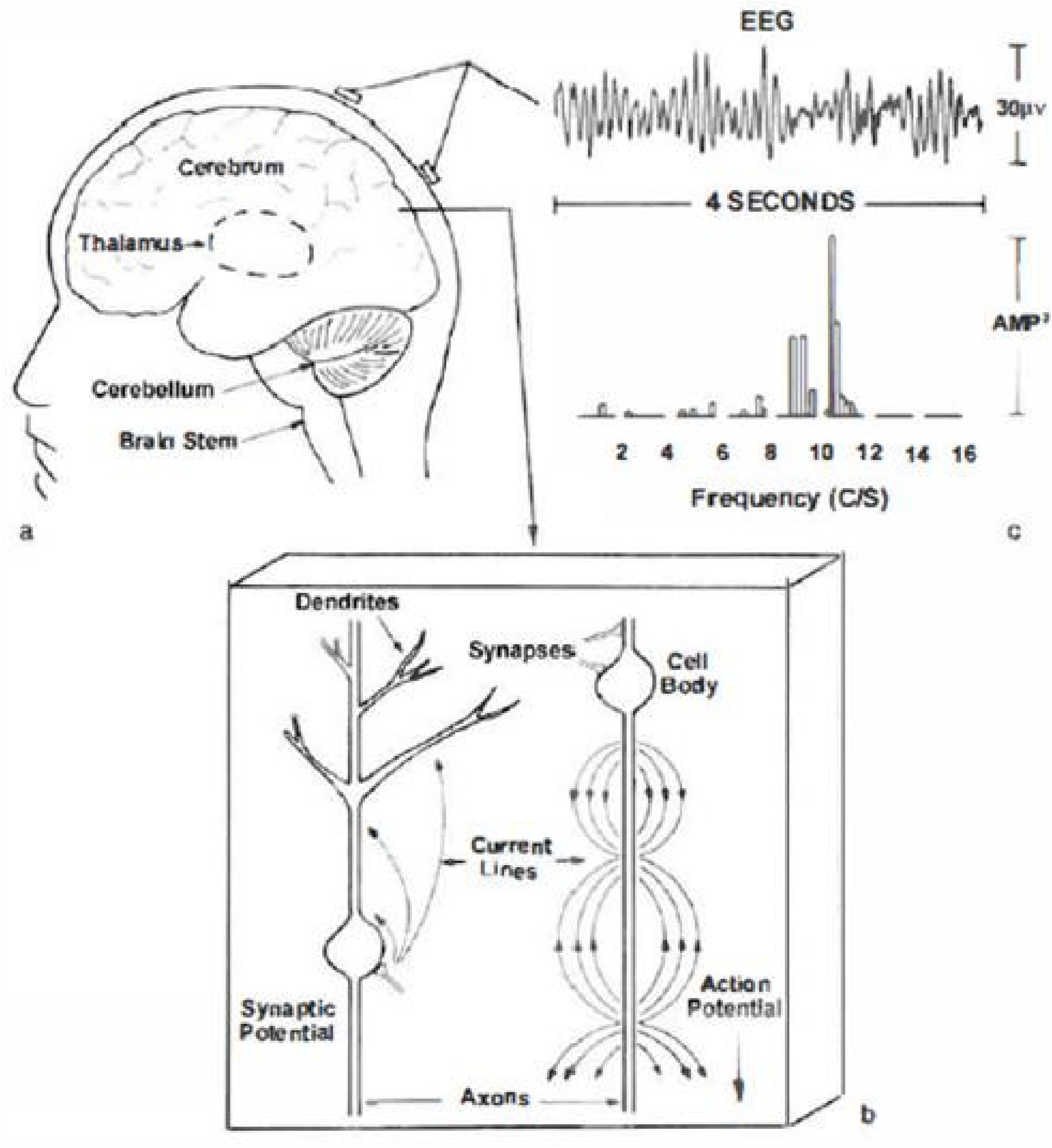
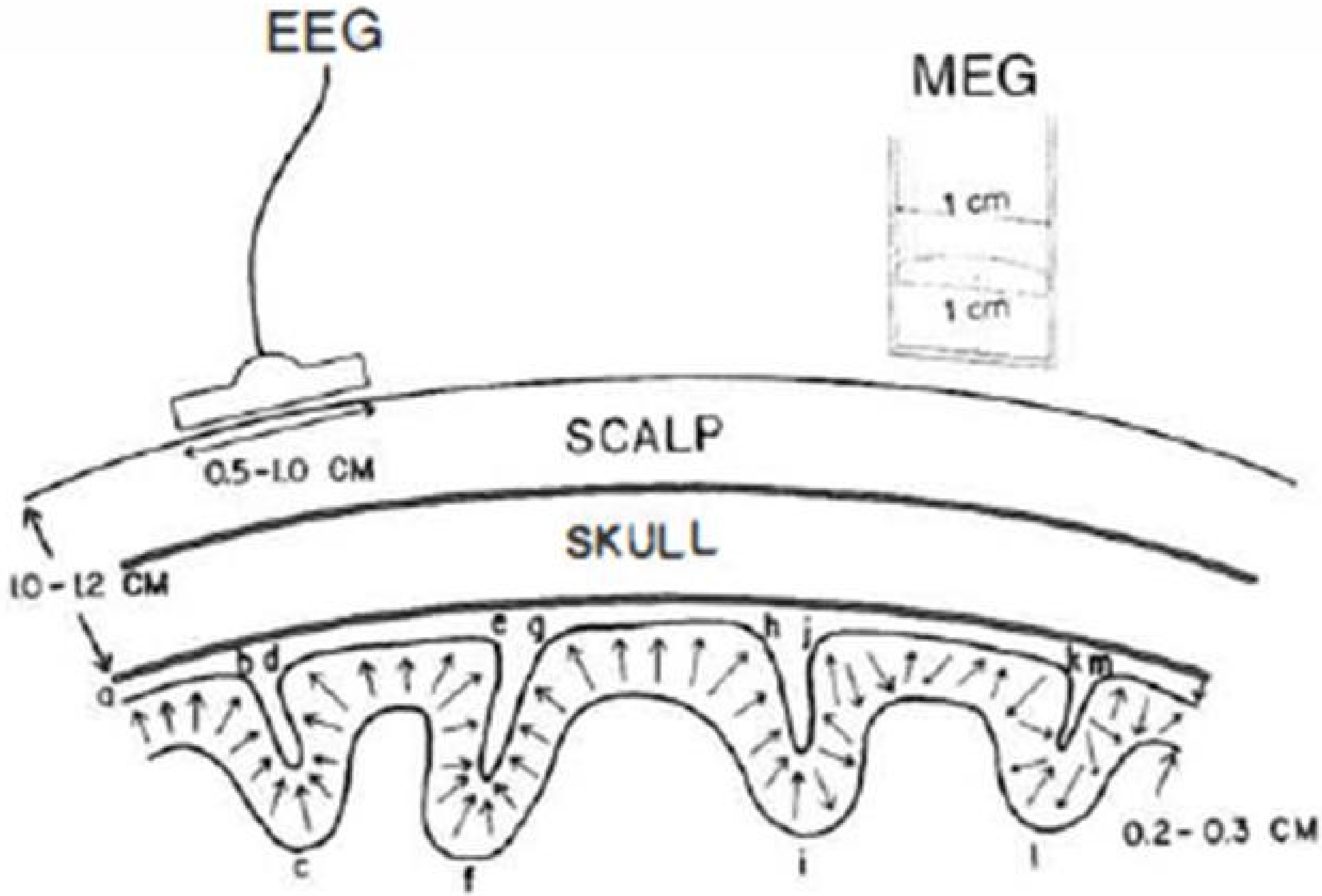


Illustration of brain information flow that can only be measured by the electroencephalogram using computers.
Information flow – Millisecond Match-Mismatch From Rabinovich et al, 2012

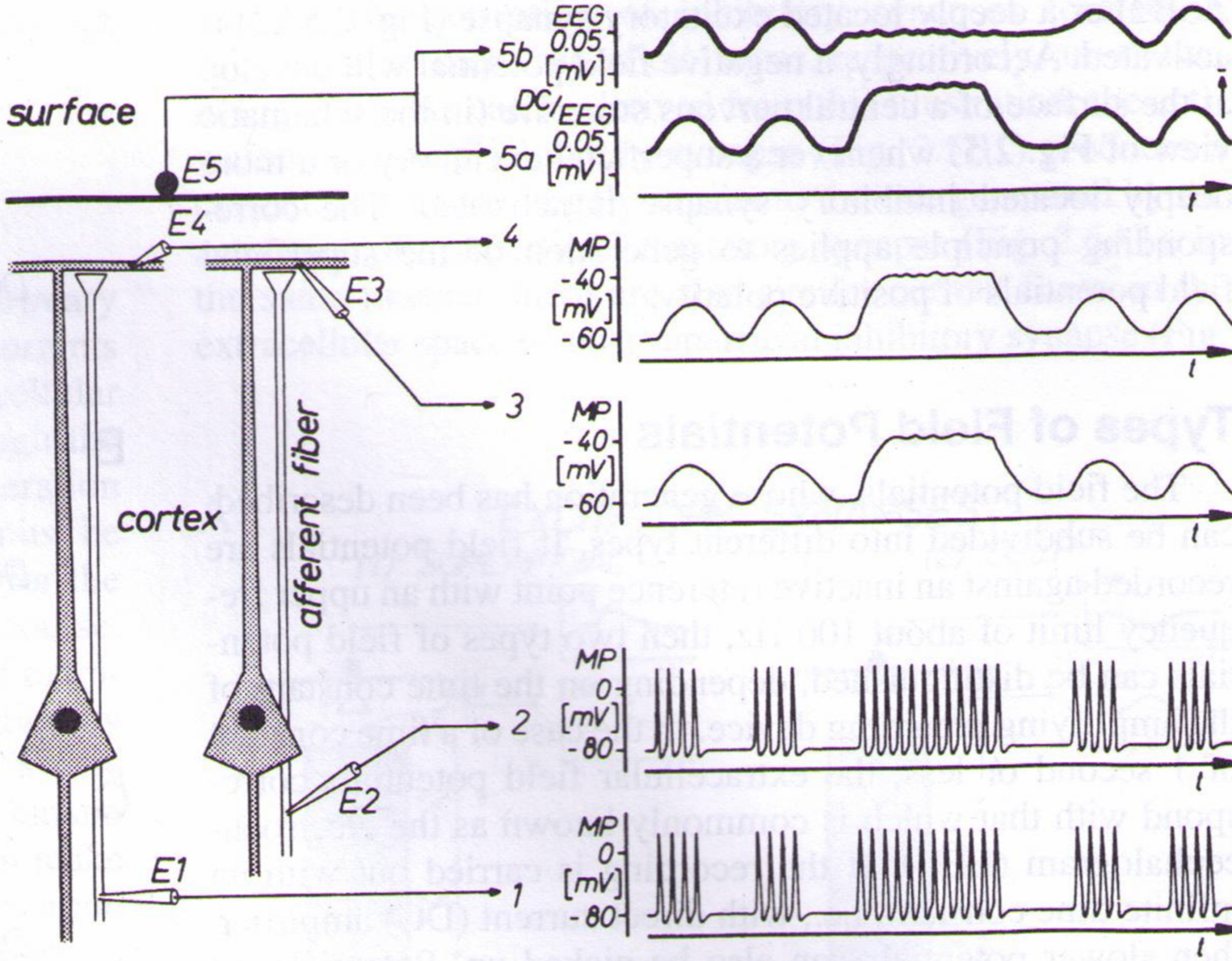
Genesis of the Human Electroencephalogram - EEG

1- Pyramidal Neuron Dipoles
2- Oscillations In an Approx. 2mm thick sheet
3- Summated Local Field Potentials (LFP)
4- Amplitude = Proportion of Synchronous/Square Root
   of Proportion of Asynchronous Generators
5- Pacemakers and Resonance

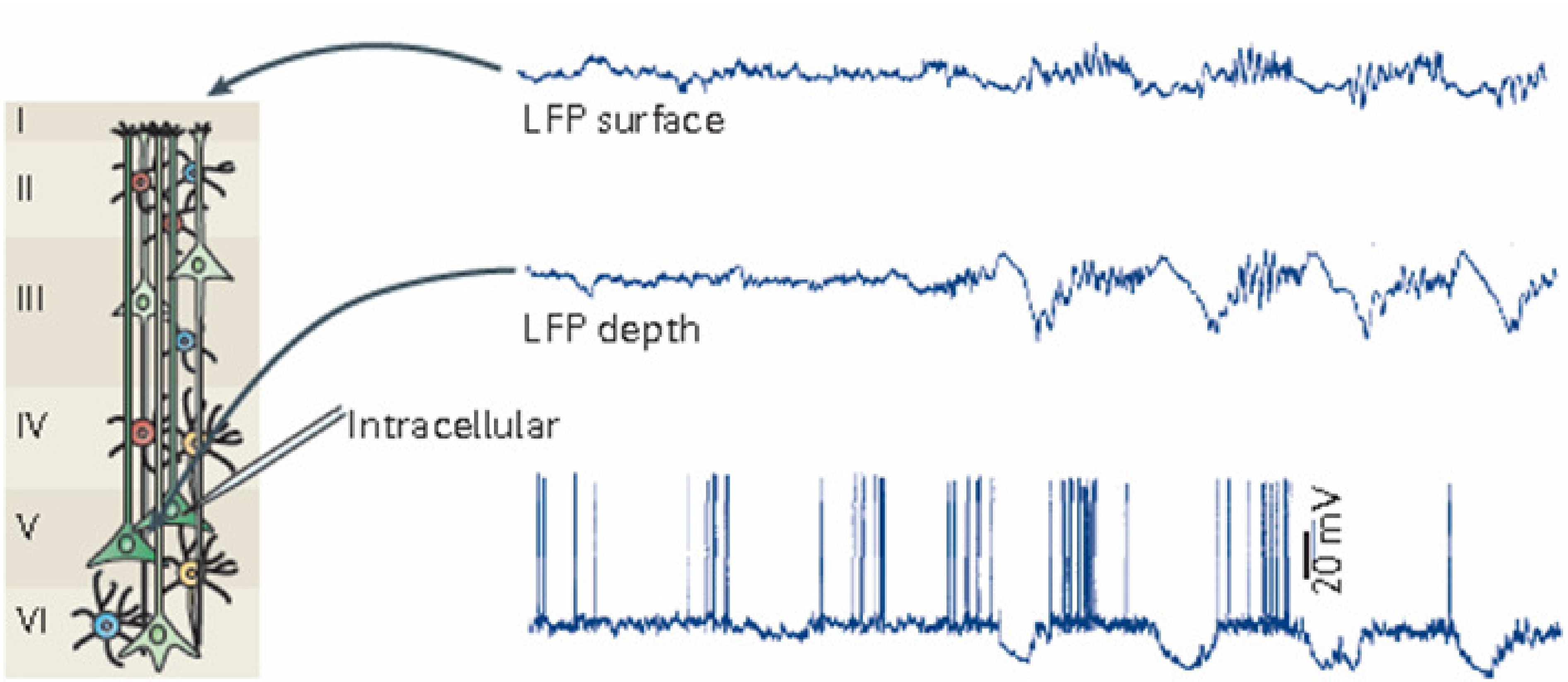

EEG
30µv
4 SECONDS
AMP²
2 4 6 8 10 12 14 16
Frequency (C/S)
Cerebrum
Thalamus
Cerebellum
Brain Stem
a
c
Dendrites
Synapses
Cell Body
Current Lines
Synaptic Potential
Action Potential
Axons
b



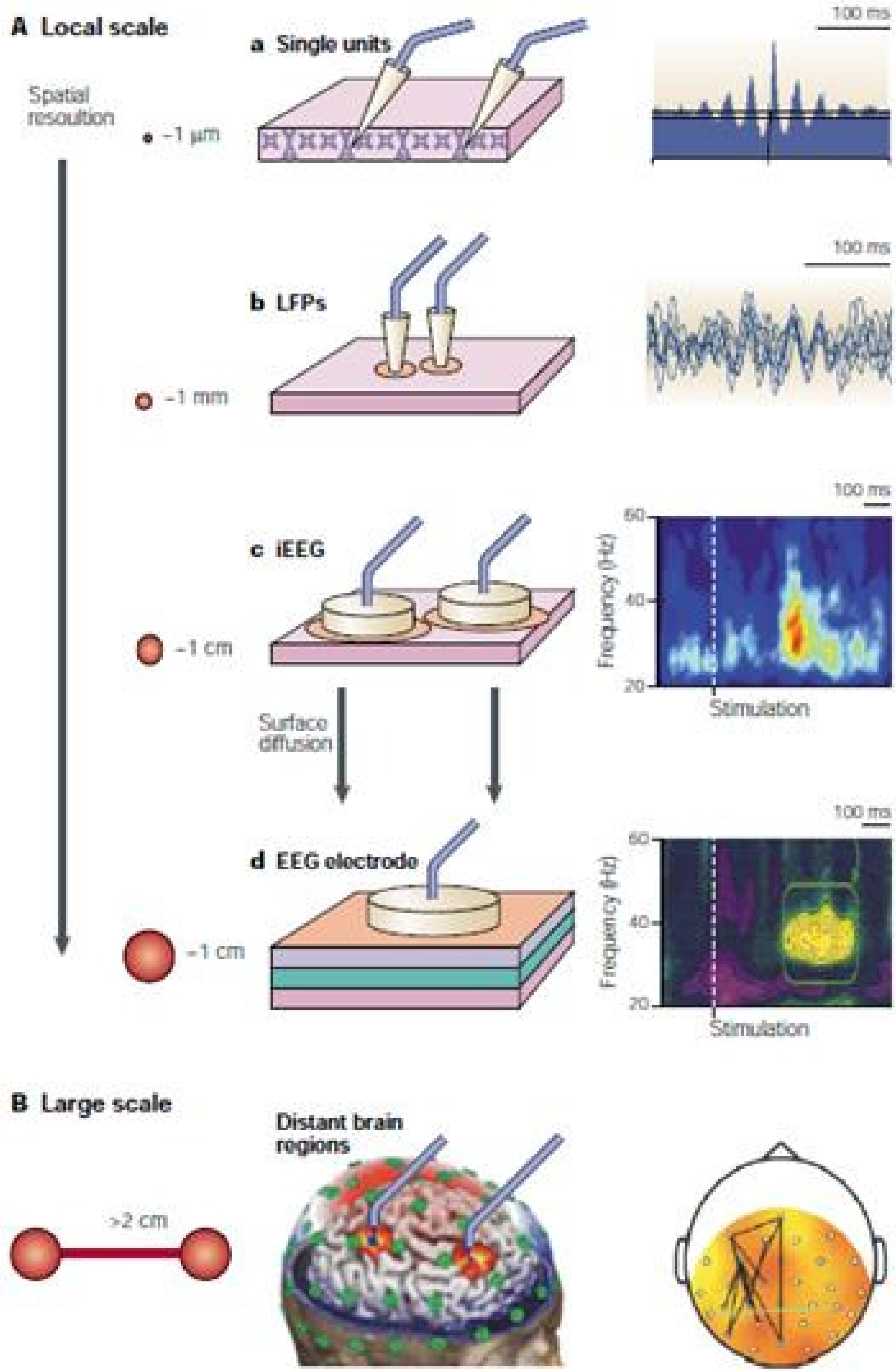
EEG
MEG
1 cm
1 cm
SCALP
0.5-1.0 CM
SKULL
1.0 - 1.2 CM
a
b d
c
e g
f
h j
i
k m
l
0.2 - 0.3 CM



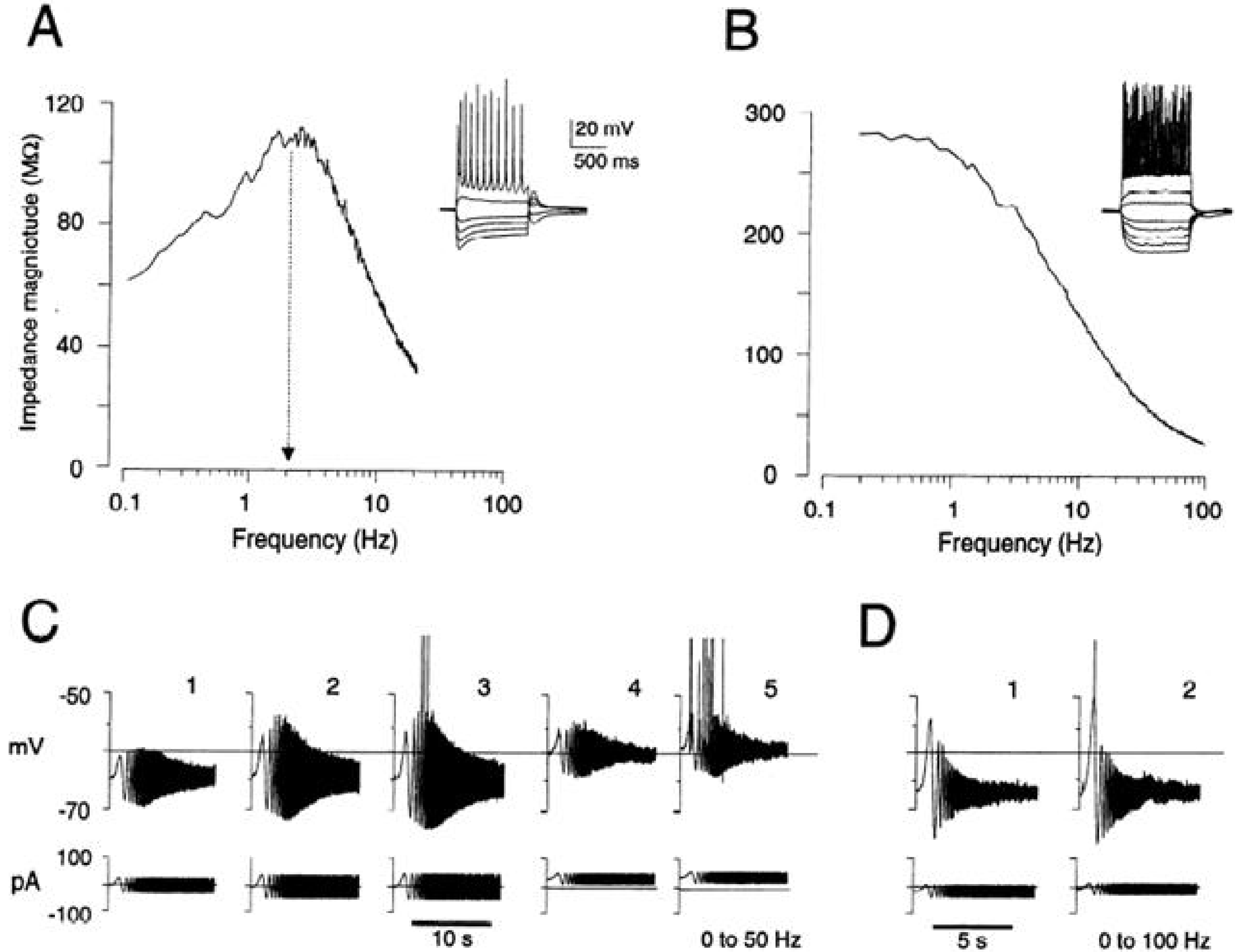
surface
E5
E4
E3
E2
E1
cortex
afferent fiber
5b
5a
4
3
2
1
EEG
0.05
[mV]
DC/EEG
0.05
[mV]
t
MP
-40
[mV]
-60
t
MP
-40
[mV]
-60
MP
0
[mV]
-80
t
MP
0
[mV]
-80
t



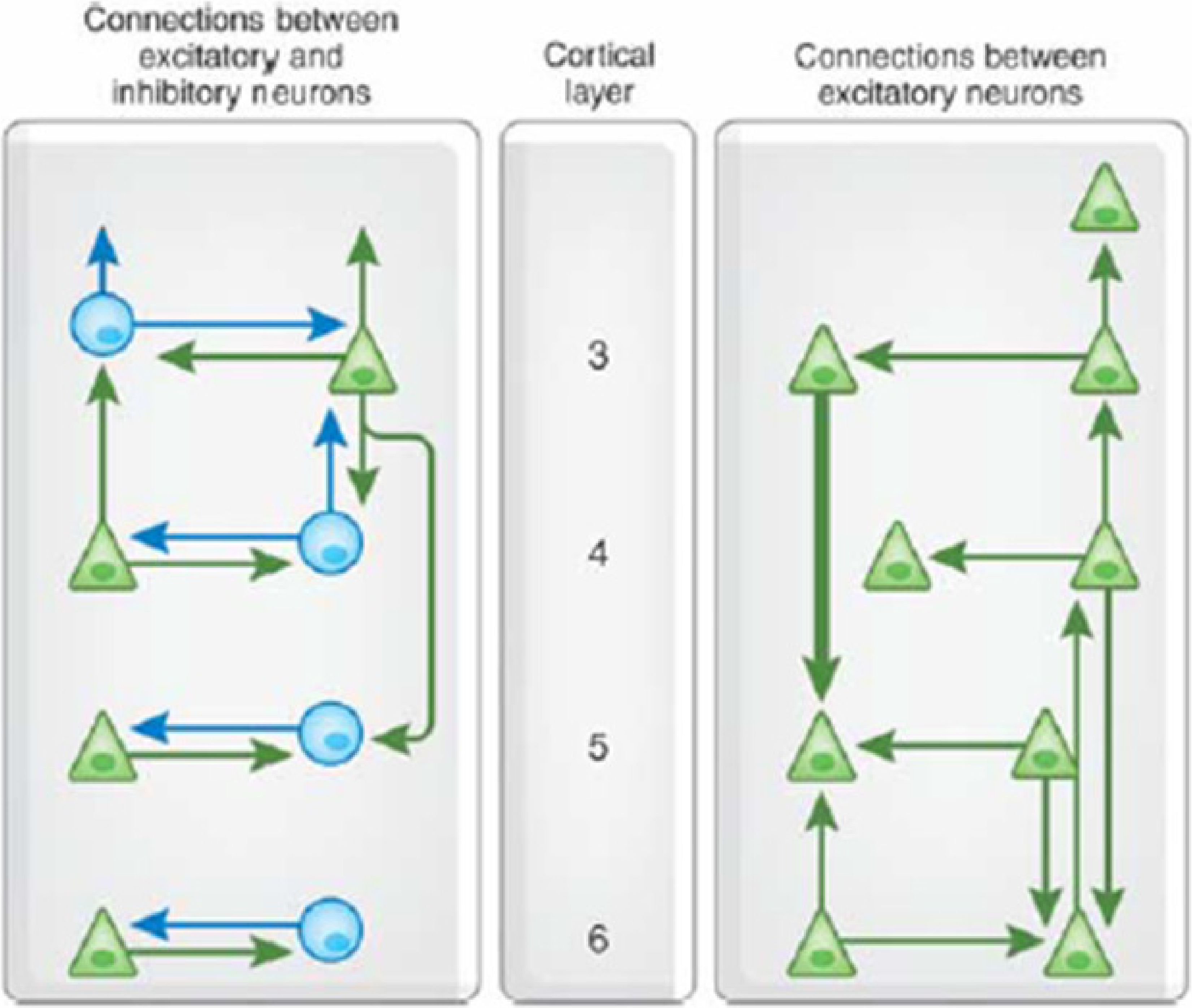
LFP surface
LFP depth
Intracellular
20 mV
I
II
III
IV
V
VI



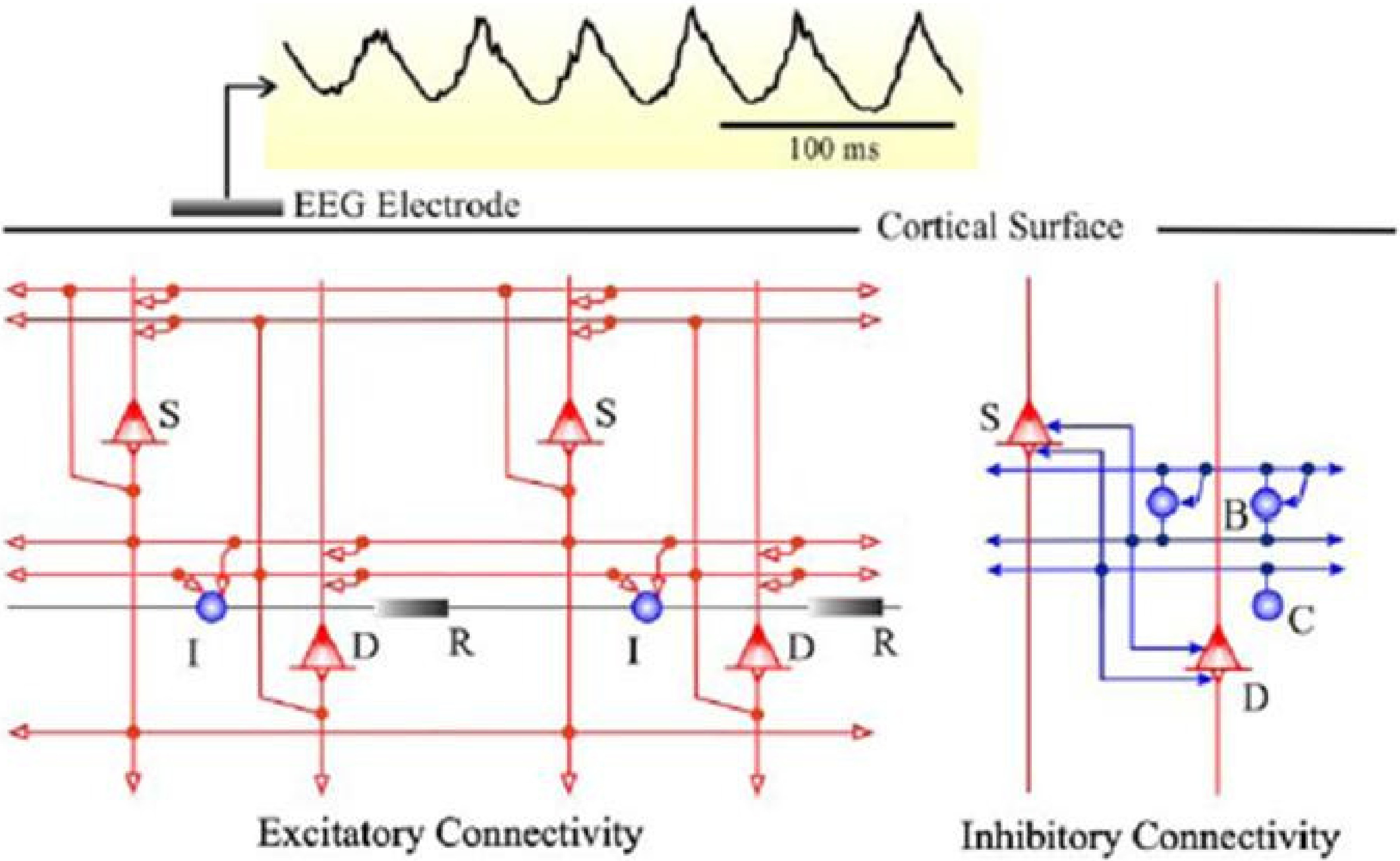
A Local scale
Spatial resolution
a Single units
~1 µm
100 ms
b LFPs
~1 mm
100 ms
c iEEG
~1 cm
100 ms
60
40
20
Frequency (Hz)
Stimulation
Surface diffusion
d EEG electrode
~1 cm
100 ms
60
40
20
Frequency (Hz)
Stimulation
B Large scale
>2 cm
Distant brain regions

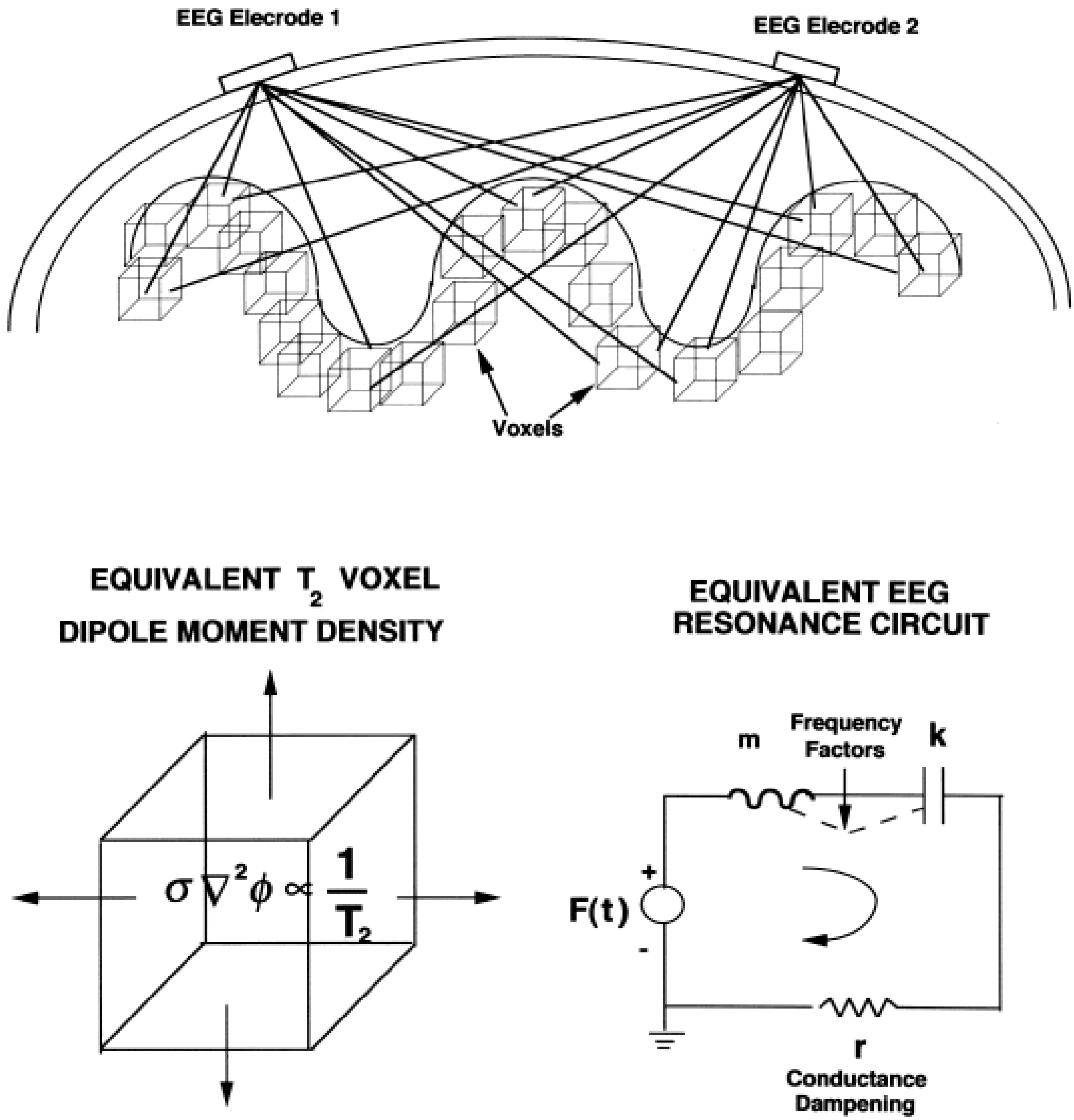


A
B
C
D
Impedance magnictude (MΩ)
120
80
40
0
0.1
1
10
100
Frequency (Hz)
20 mV
500 ms
300
200
100
1
2
3
4
5
-50
mV
-70
100
pA
-100
10 s
0 to 50 Hz
5 s
0 to 100 Hz

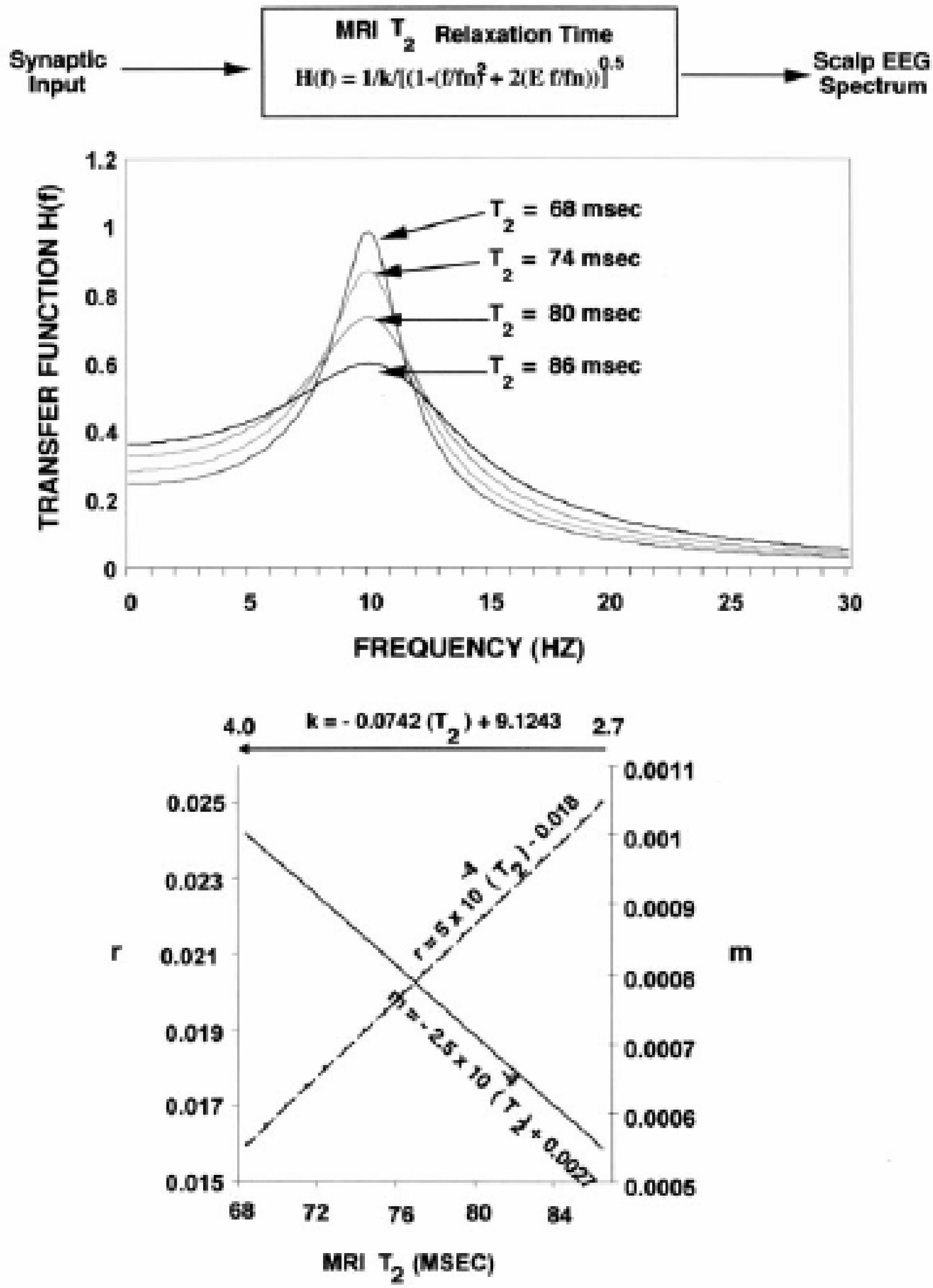


Connections between excitatory and inhibitory neurons
Cortical layer
Connections between excitatory neurons
3
4
5
6


100 ms
EEG Electrode
Cortical Surface
S
S
S
I
D
R
I
D
R
B
C
D
Excitatory Connectivity
Inhibitory Connectivity



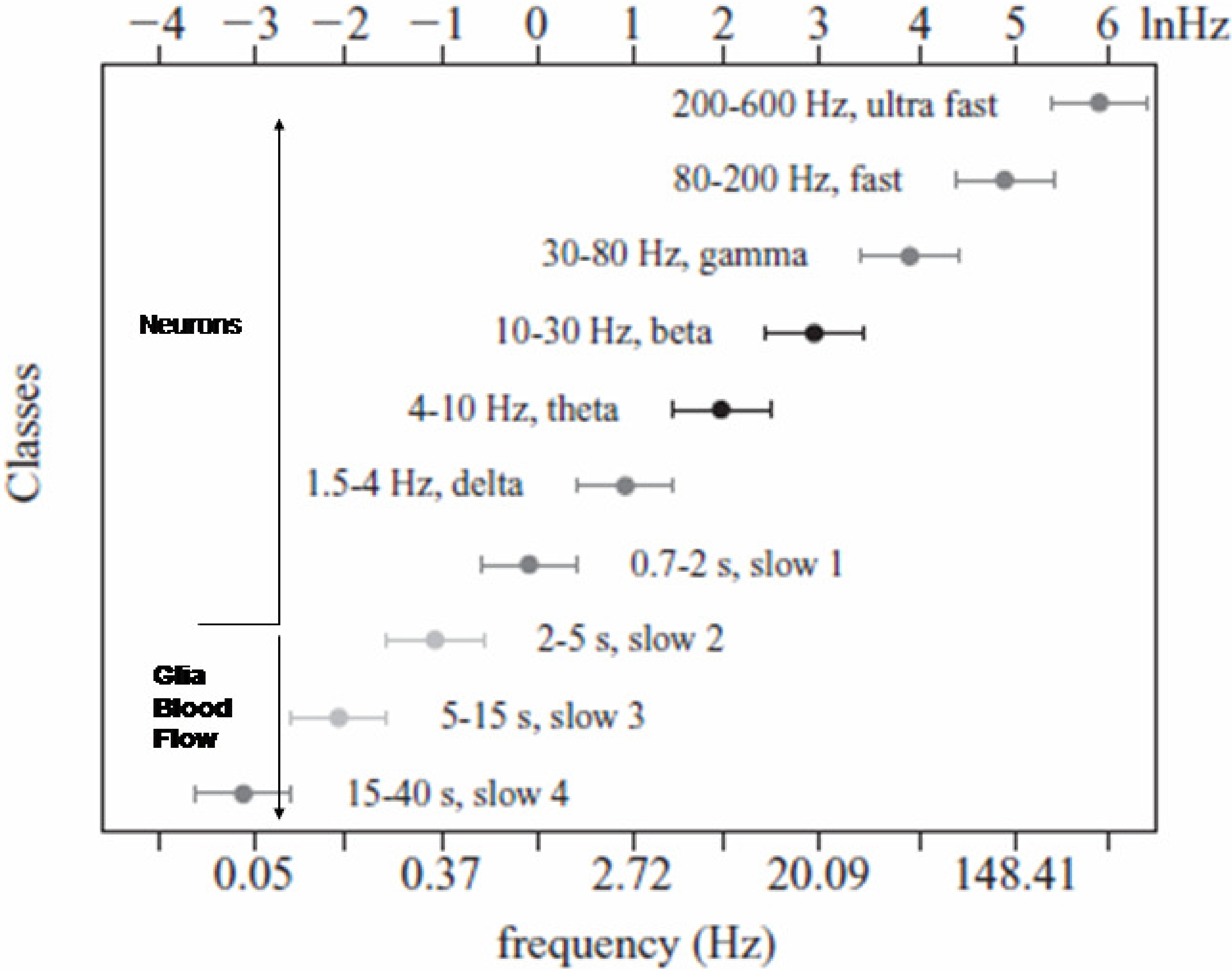
EEG Elecrode 1
EEG Elecrode 2
Voxels
EQUIVALENT T_2 VOXEL
DIPOLE MOMENT DENSITY
$\sigma \nabla^2 \phi \propto \frac{1}{T_2}$
EQUIVALENT EEG
RESONANCE CIRCUIT
m
Frequency
Factors
k
F(t)
+
-
r
Conductance
Dampening



Synaptic Input
MRI T2 Relaxation Time
H(f) = 1/k/[(1-(f/fn)2 + 2(E f/fn))]0.5
Scalp EEG Spectrum
TRANSFER FUNCTION H(f)
T2 = 68 msec
T2 = 74 msec
T2 = 80 msec
T2 = 86 msec
FREQUENCY (HZ)
0
5
10
15
20
25
30
0.2
0.4
0.6
0.8
1
1.2
k = - 0.0742 (T2) + 9.1243
4.0
2.7
r
m
r = 5 x 10-4 (T2) - 0.018
m = - 2.5 x 10-5 (T2) + 0.0027
0.015
0.017
0.019
0.021
0.023
0.025
0.0005
0.0006
0.0007
0.0008
0.0009
0.001
0.0011
68
72
76
80
84
MRI T2 (MSEC)

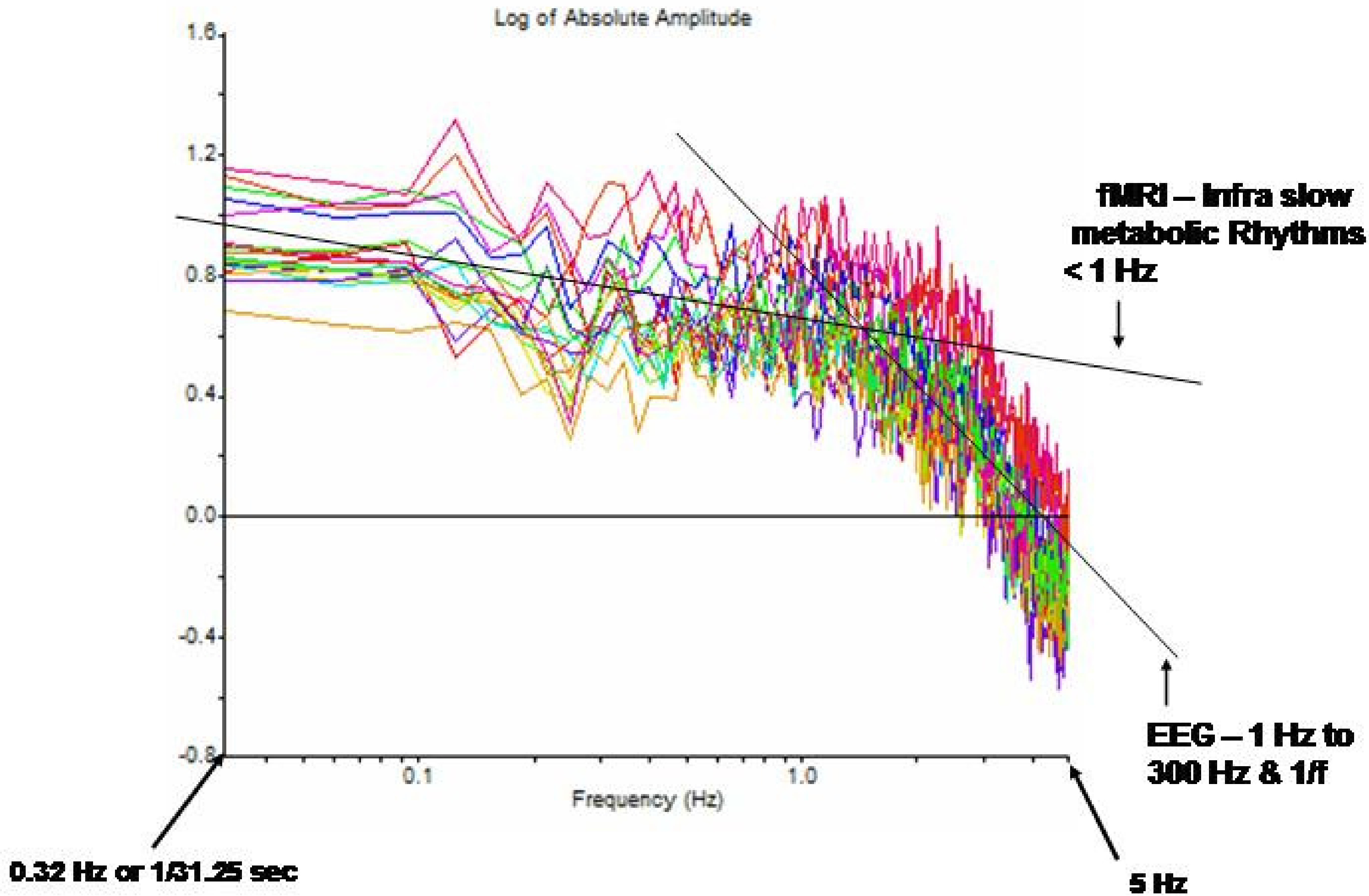
Frequencies of the EEG

1- All Pyramidal Neurons can Oscillate form approx 1 Hz to 300 Hz
2- Membrane Potential & Ca^{++}, Na^{+}, K^{+} ionic conductance 1 – 20 Hz
3- Pacemakers in Limbic, Thalamic and Cortical systems
4- Local Inhibitory Feedback

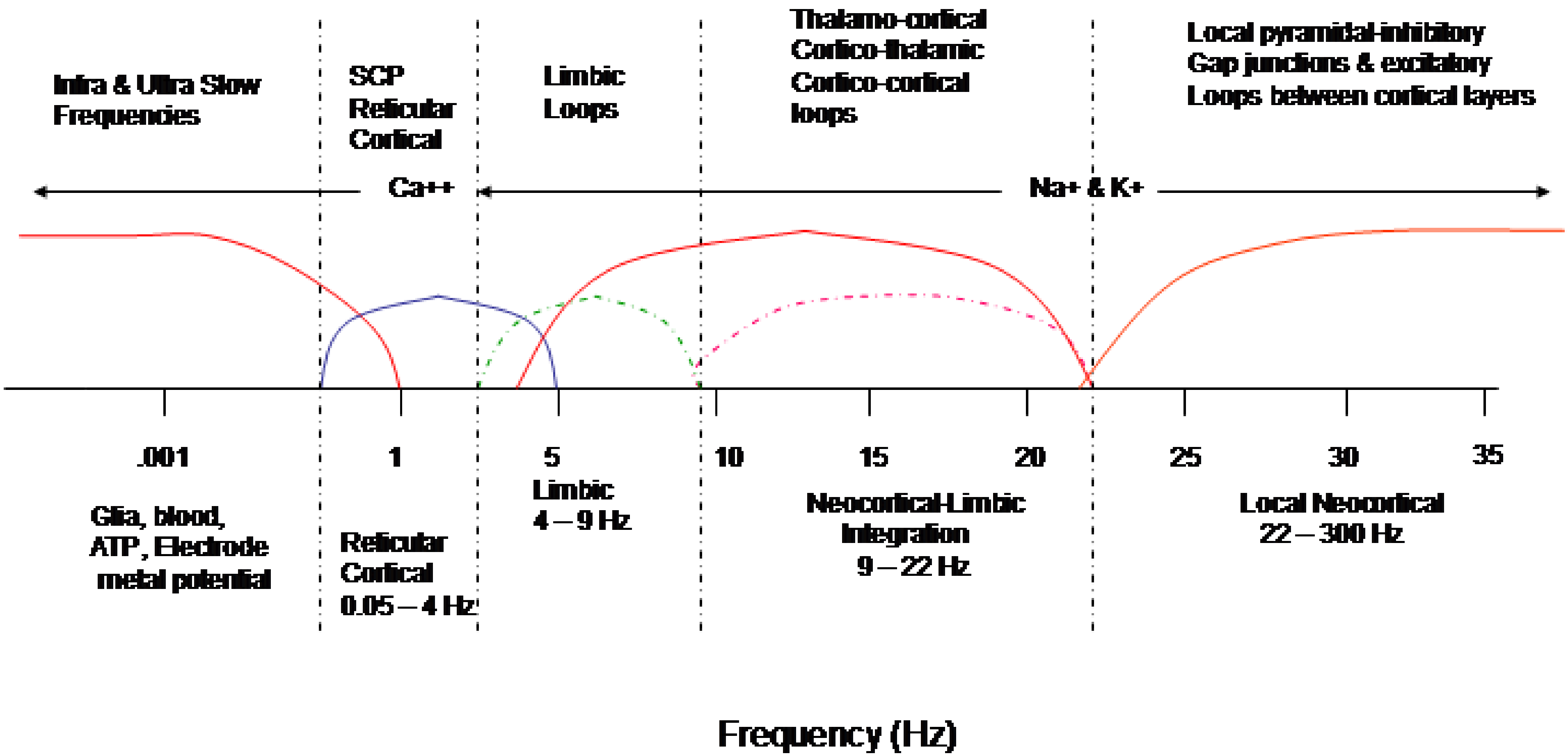


−4 −3 −2 −1 0 1 2 3 4 5 6 lnHz
200-600 Hz, ultra fast
80-200 Hz, fast
30-80 Hz, gamma
10-30 Hz, beta
4-10 Hz, theta
1.5-4 Hz, delta
0.7-2 s, slow 1
2-5 s, slow 2
5-15 s, slow 3
15-40 s, slow 4
Neurons
Glia
Blood
Flow
Classes
0.05 0.37 2.72 20.09 148.41
frequency (Hz)

Two Compartments of the Frequency Spectrum of Bursts in EEG Absolute Amplitude

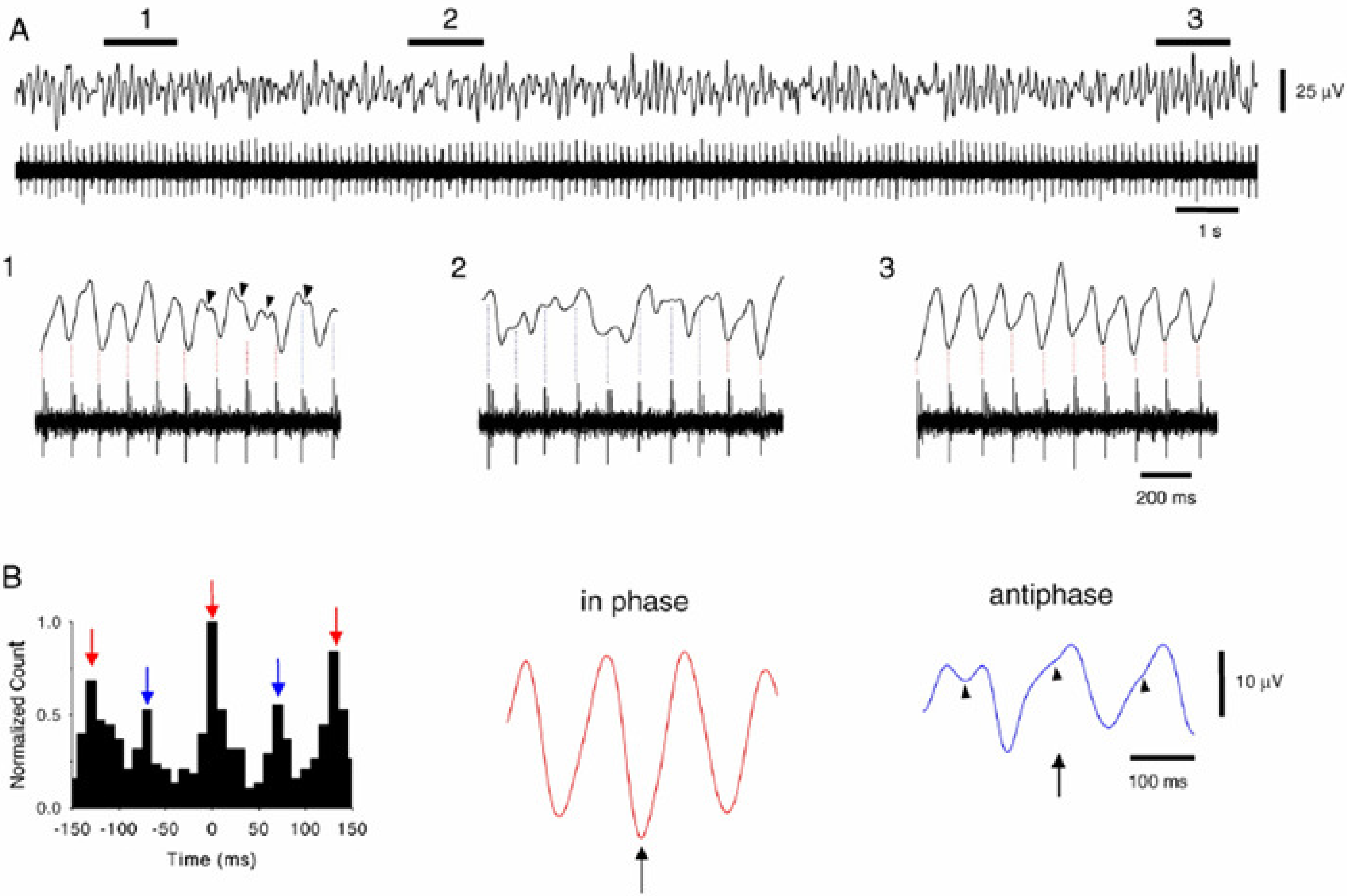


Cross-Frequency Phase Lock and Phase Shift Spectrum

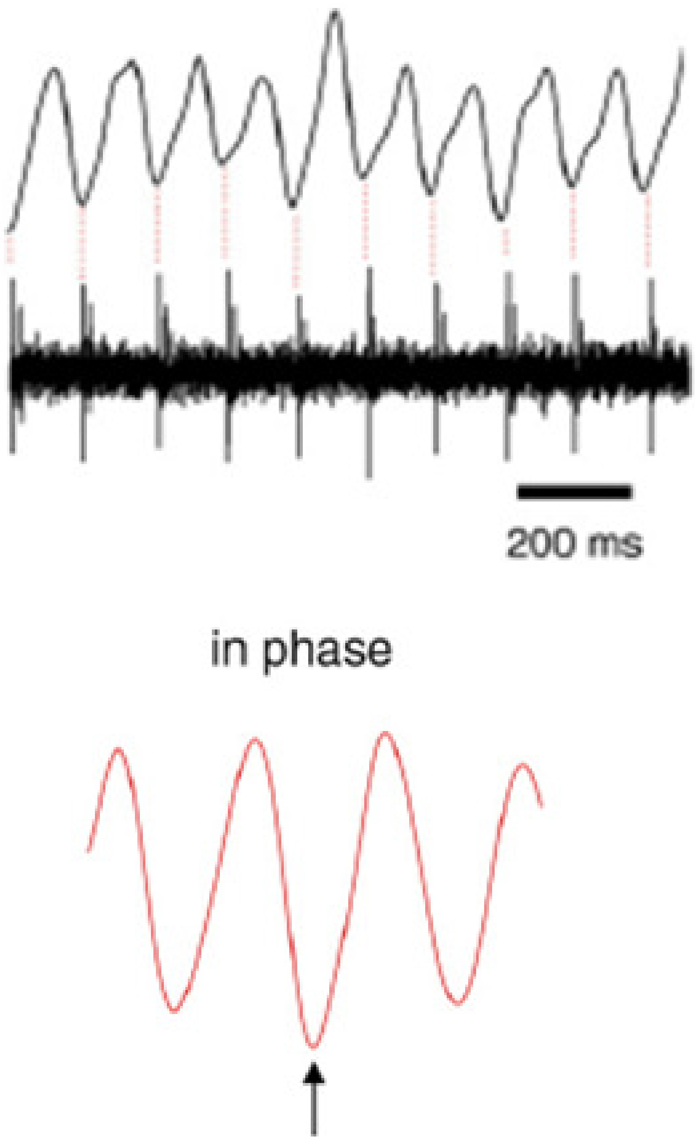


In-Phase vs Anti-Phase

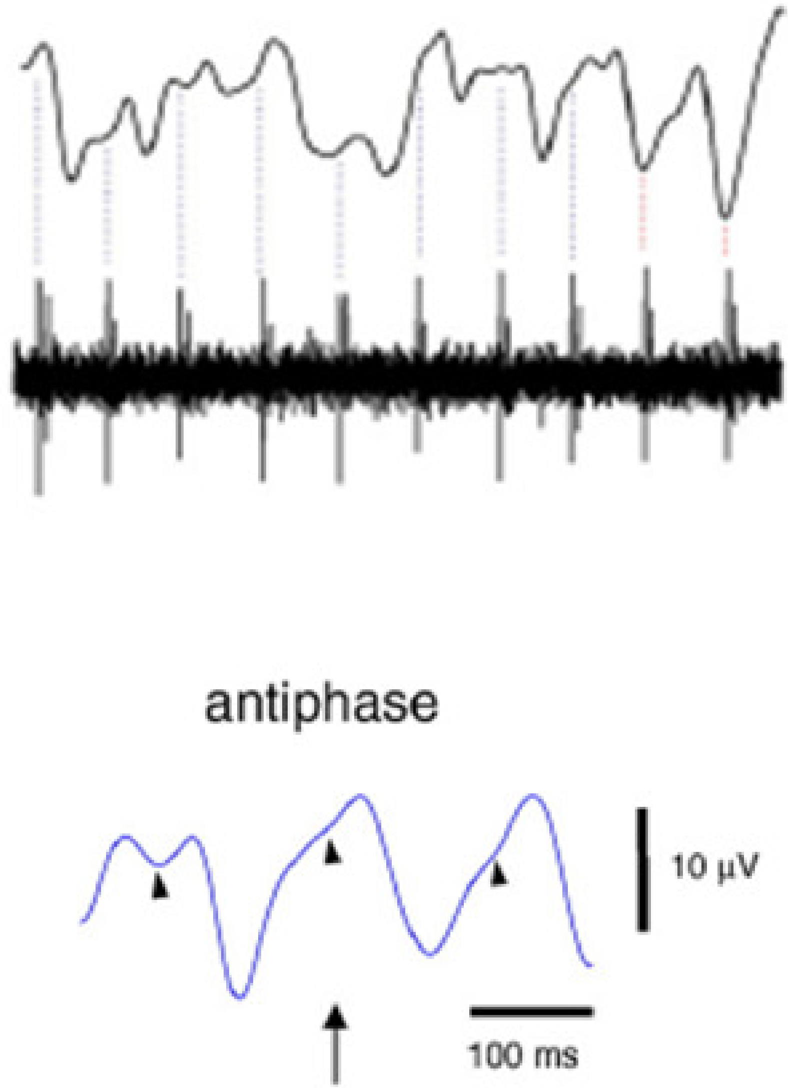
How Neurons are Selected for Brief Periods of Time

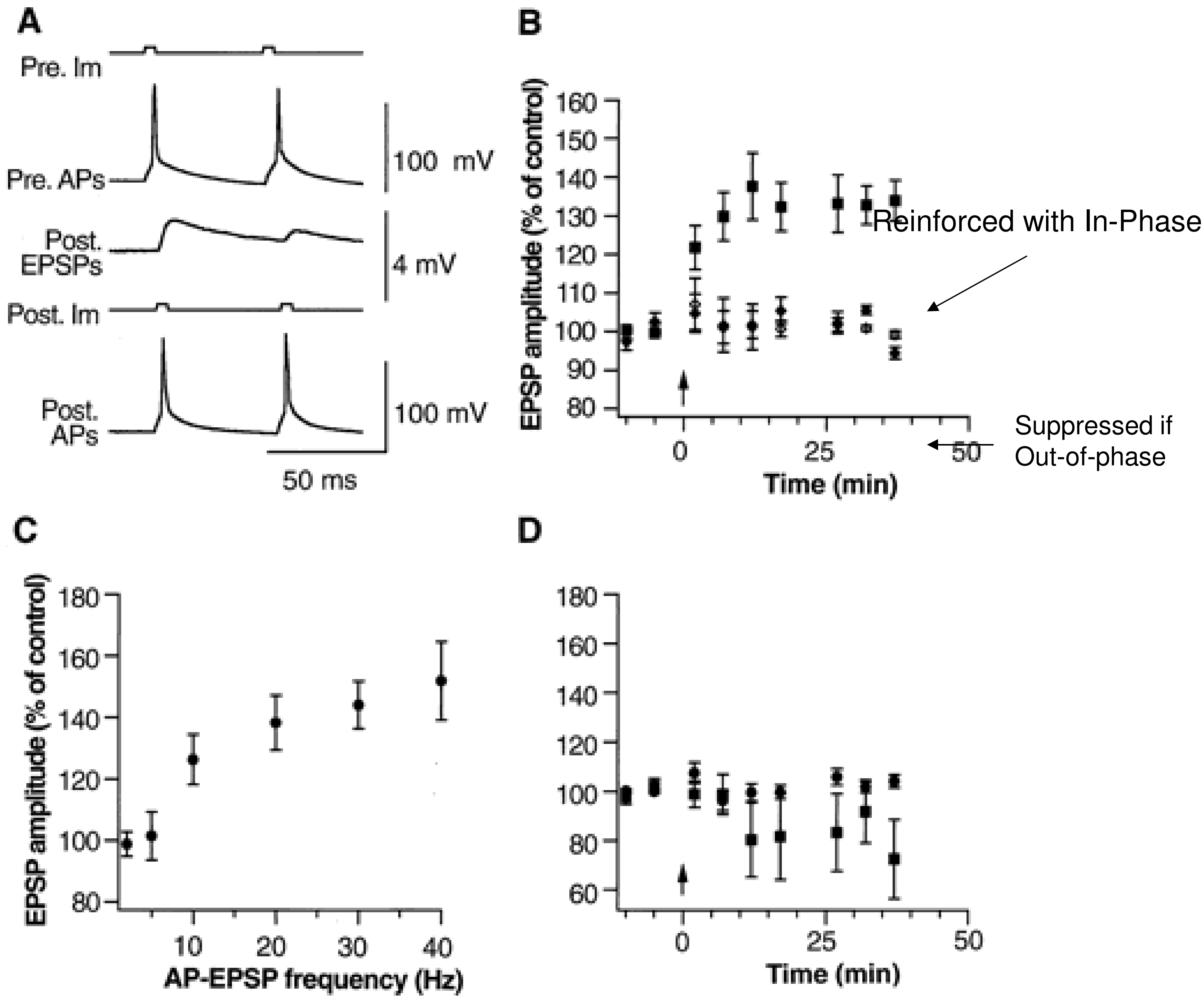

A
1
2
3
25 µV
1 s
1
2
3
200 ms
B
Normalized Count
1.0
0.5
0.0
-150
-100
-50
0
50
100
150
Time (ms)
in phase
antiphase
10 µV
100 ms

LFPs & In-Phase Action Potentials



LFPs & Anti-Phase Action Potentials

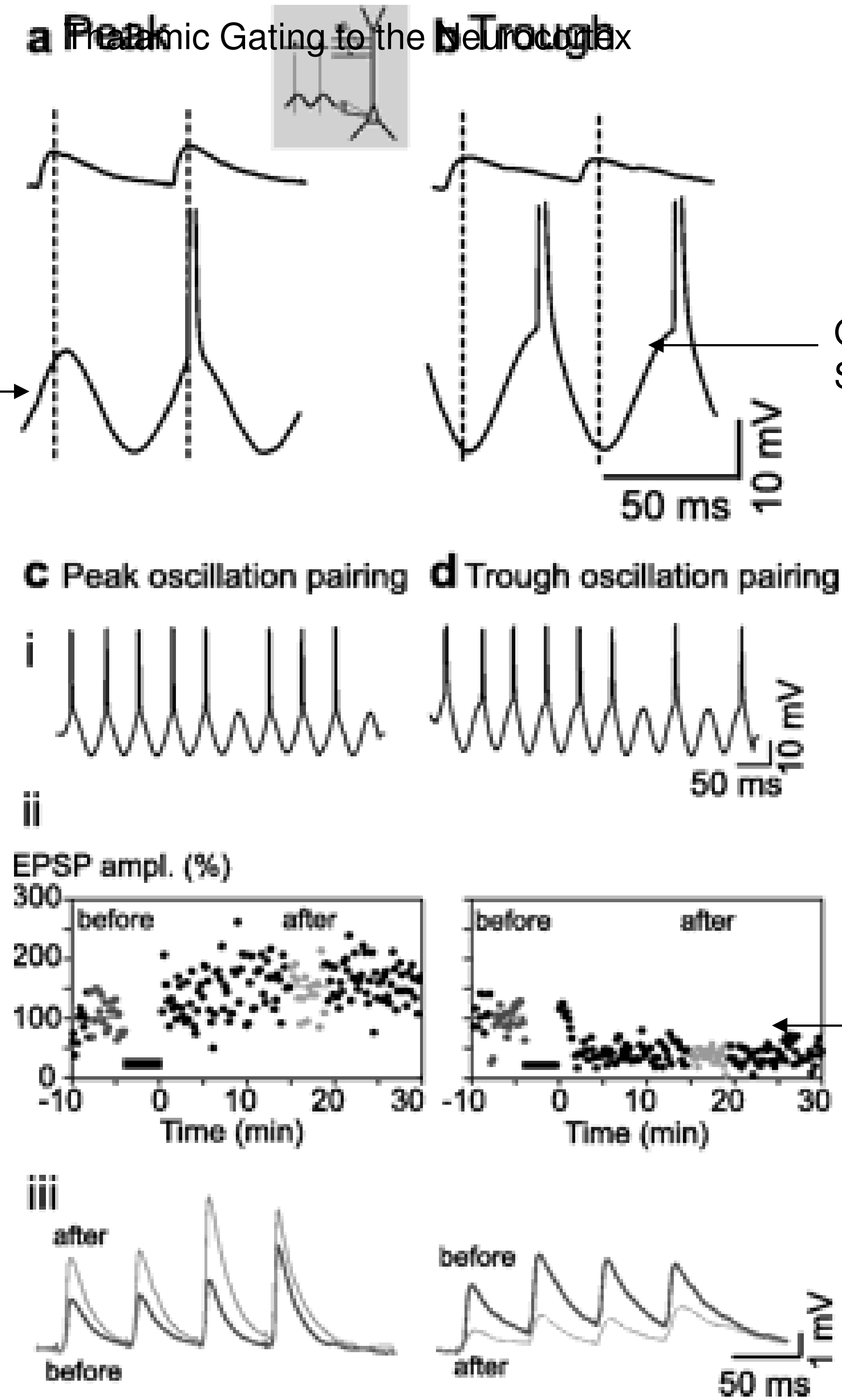



A
Pre. Im
Pre. APs
100 mV
Post. EPSPs
4 mV
Post. Im
Post. APs
100 mV
50 ms
B
EPSP amplitude (% of control)
Time (min)
Reinforced with In-Phase
Suppressed if Out-of-phase
C
EPSP amplitude (% of control)
AP-EPSP frequency (Hz)
D
Time (min)

Thalamic Gating to the Neurocortex

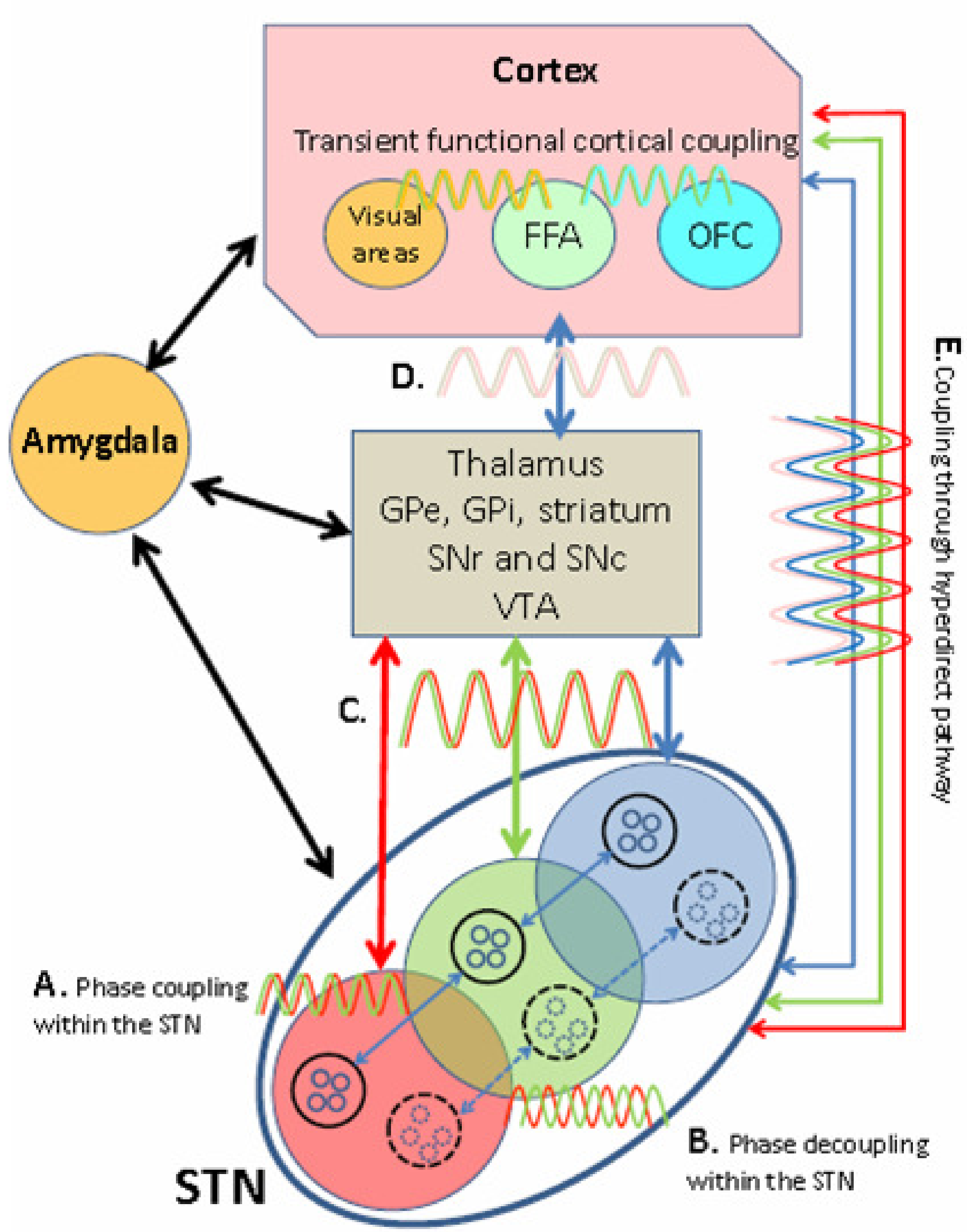
In-Phase is Reinforced

Out-of-Phase is Suppressed



In-Phase is Reinforced

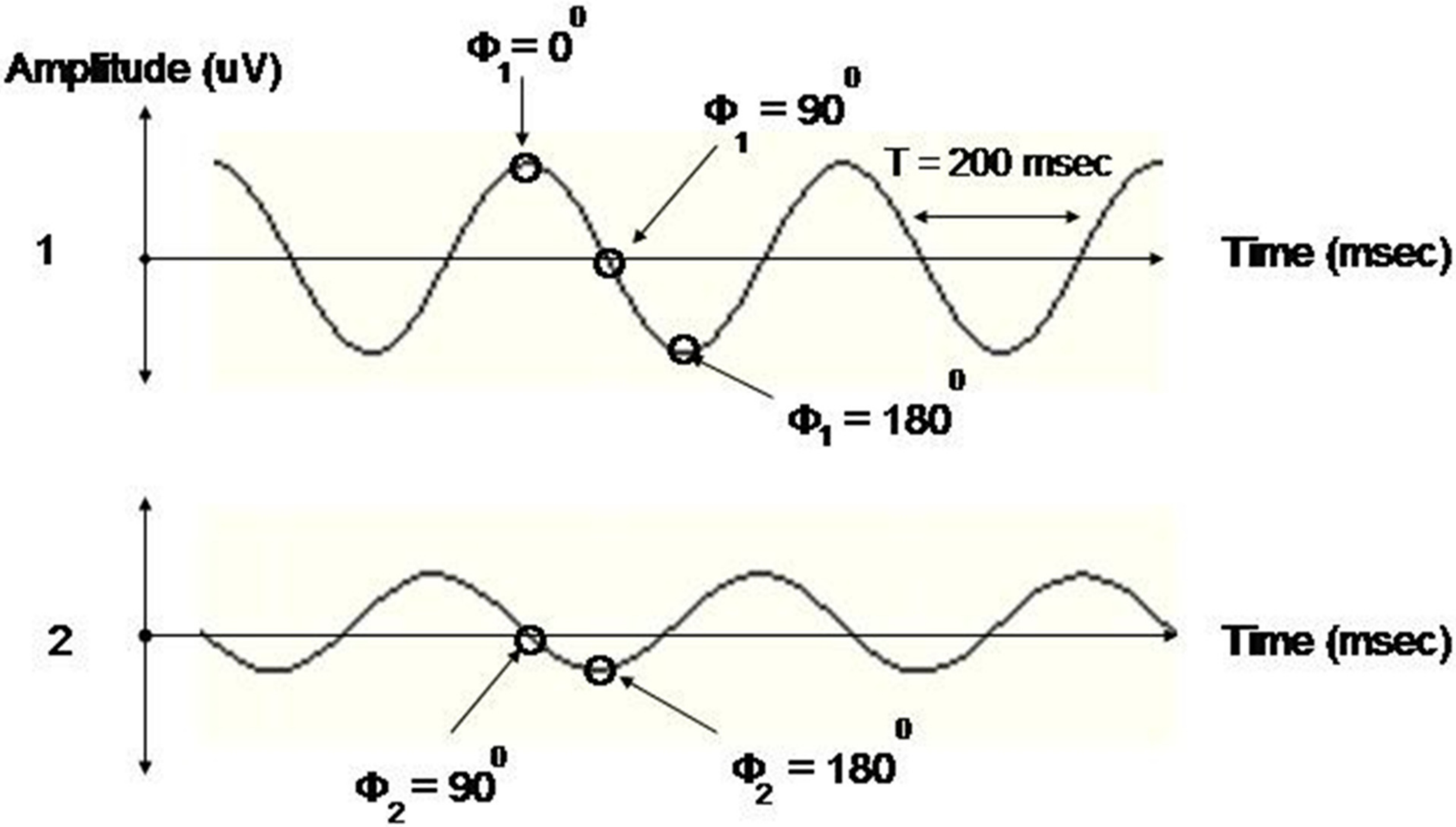
Out-of-Phase is Suppressed



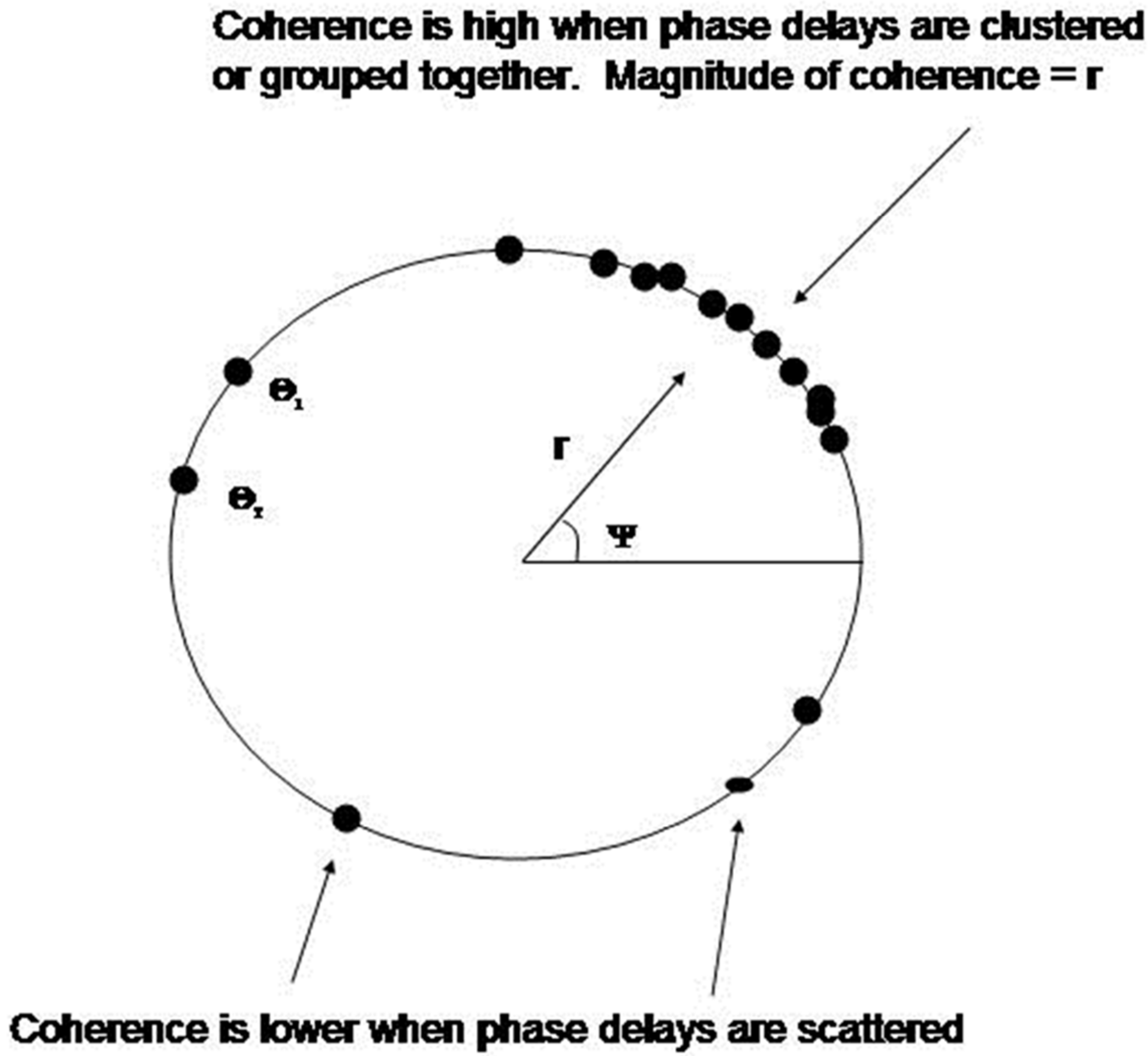
Cortex
Transient functional cortical coupling
Visual areas
FFA
OFC
Amygdala
D.
Thalamus
GPe, GPi, striatum
SNr and SNc
VTA
C.
E. Coupling through hyperdirect pathway
A. Phase coupling within the STN
B. Phase decoupling within the STN
STN

What is EEG Phase Difference and Coherence

Note: ICA & PCA Reconstruction Obliterate the Phase Differences Present in the Original EEG Recording



$$\text{Phase Difference} = \Phi_1 - \Phi_2 = 90^0$$

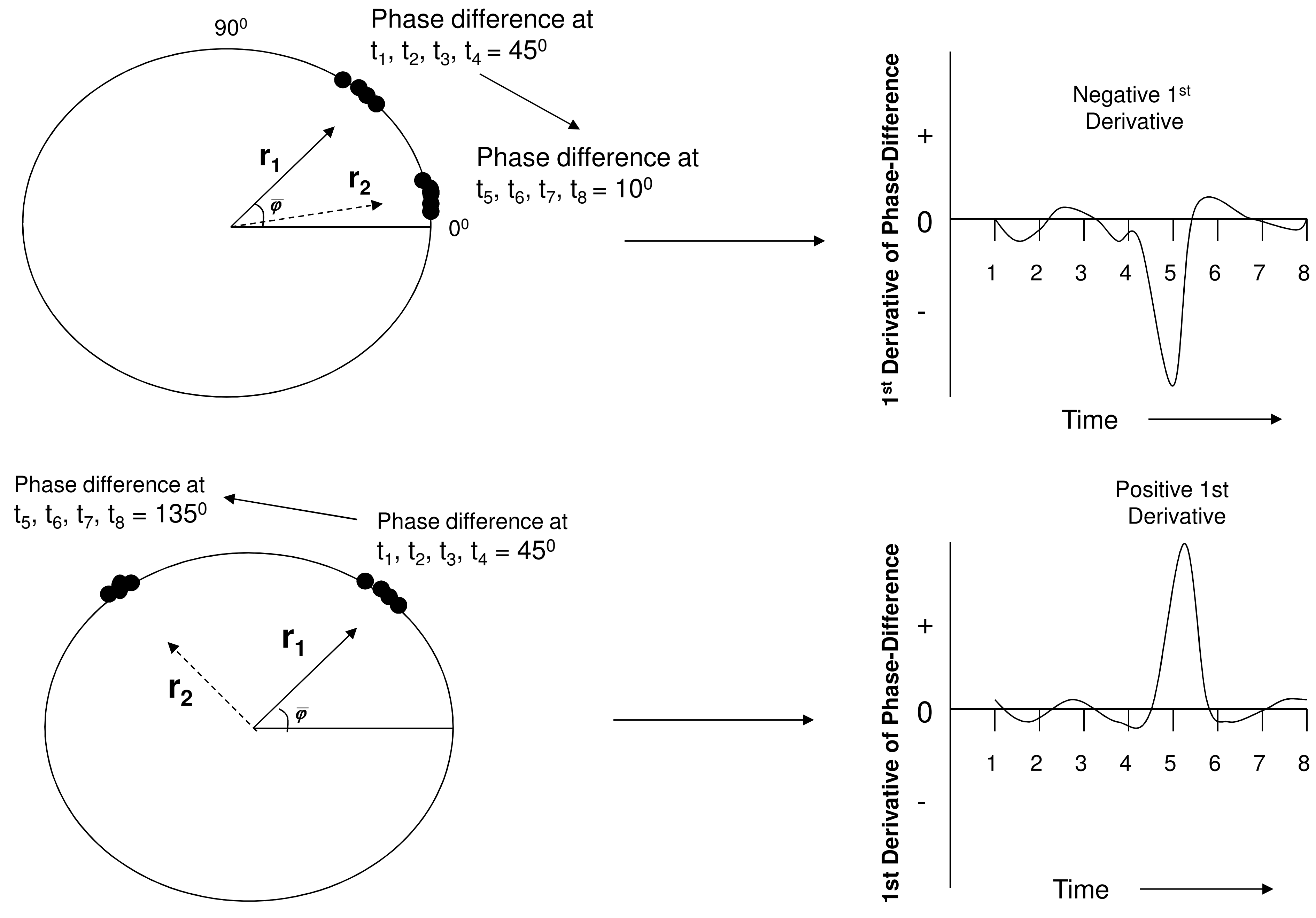

Coherence is high when phase delays are clustered or grouped together. Magnitude of coherence = r
θ1
θ2
r
Ψ
Coherence is lower when phase delays are scattered

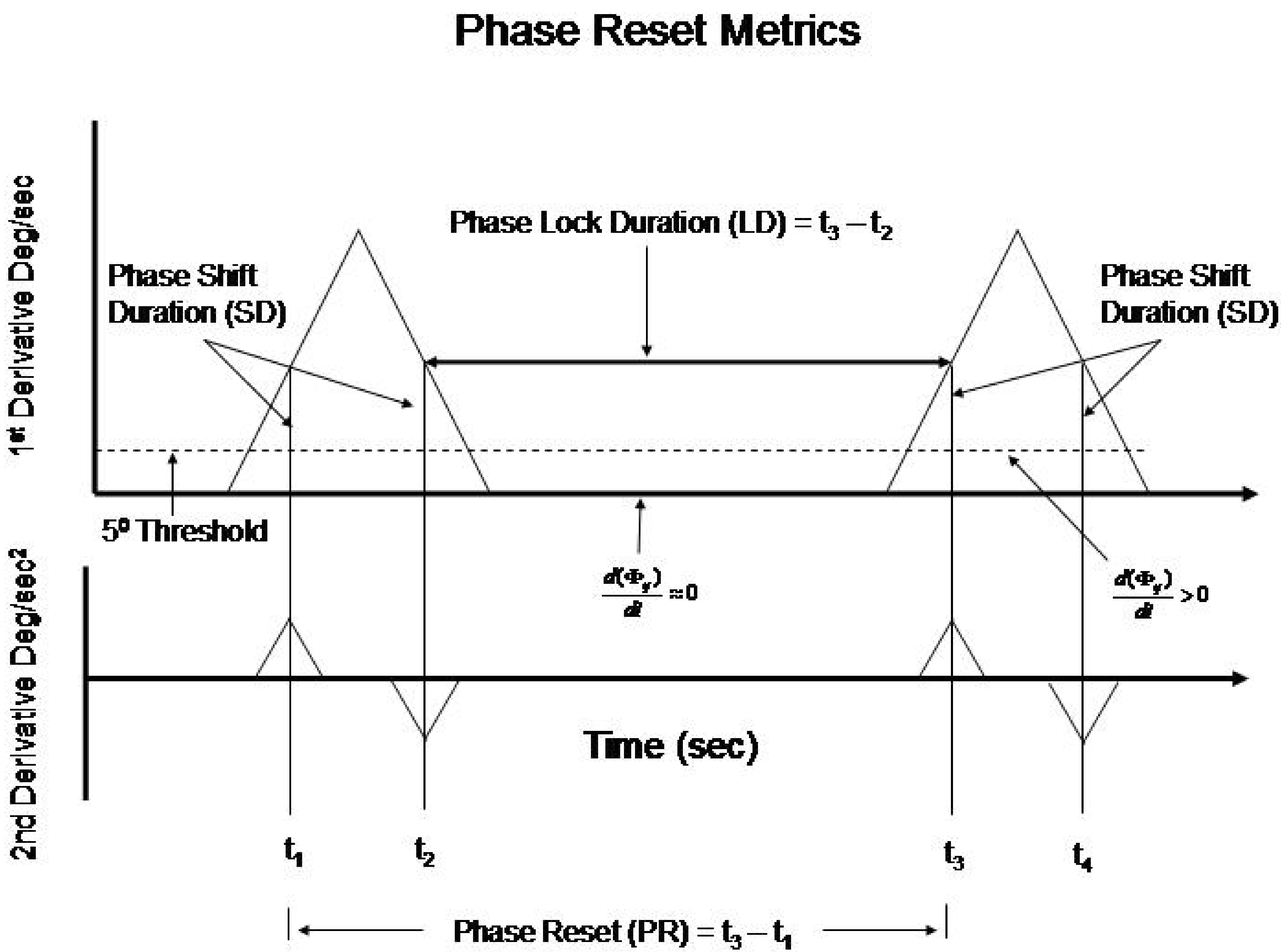
How to Measure Phase Shift and Phase Lock

Phase Reset and Neural Resource Selection and Allocation

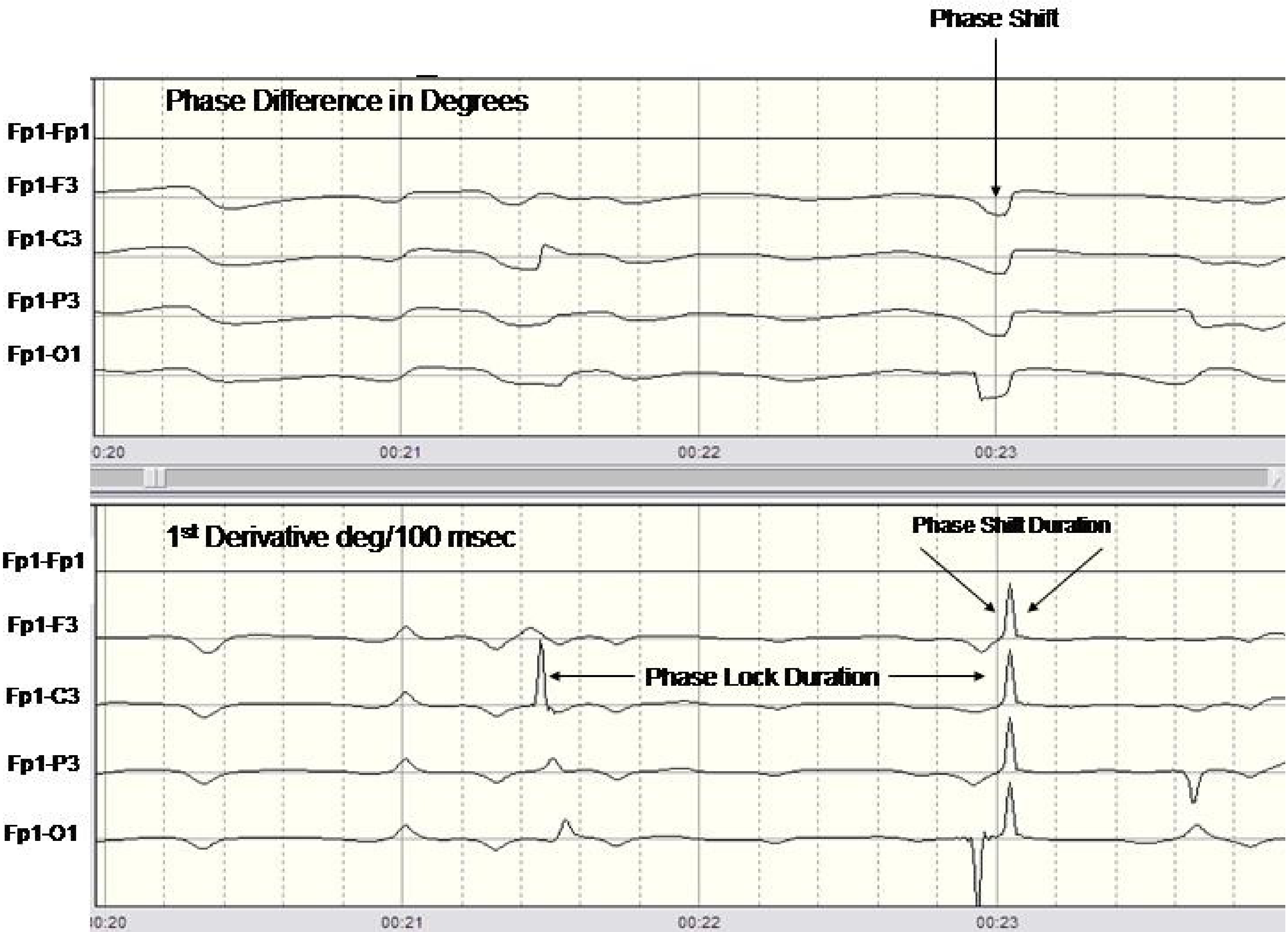
Note: ICA Obliterates Time & Phase Differences Between Channels and Cannot be Used for These Type of Analyses

EEG Phase Reset as a Phase Transition in the Time Domain



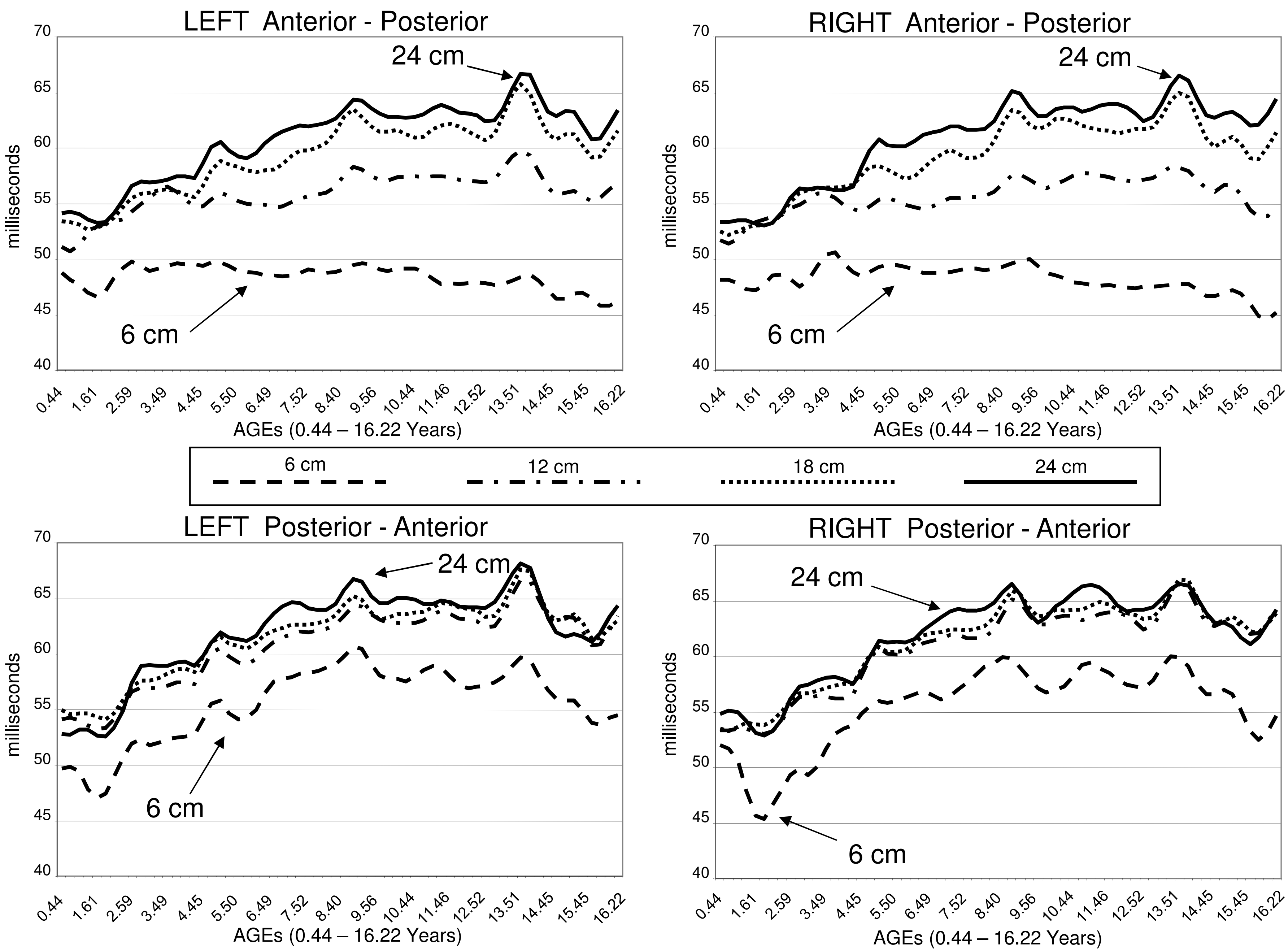


Phase Reset Metrics
1st Derivative Deg/sec
2nd Derivative Deg/sec2
Phase Lock Duration (LD) = t3 – t2
Phase Shift Duration (SD)
Phase Shift Duration (SD)
5º Threshold
d(Φy)/dt ≈0
d(Φy)/dt >0
Time (sec)
t1
t2
t3
t4
Phase Reset (PR) = t3 – t1



Phase Shift
Phase Difference in Degrees
Fp1-Fp1
Fp1-F3
Fp1-C3
Fp1-P3
Fp1-O1
0:20
00:21
00:22
00:23
1st Derivative deg/100 msec
Phase Shift Duration
Fp1-Fp1
Fp1-F3
Phase Lock Duration
Fp1-C3
Fp1-P3
Fp1-O1
0:20
00:21
00:22
00:23

Development of Phase Shift Duration



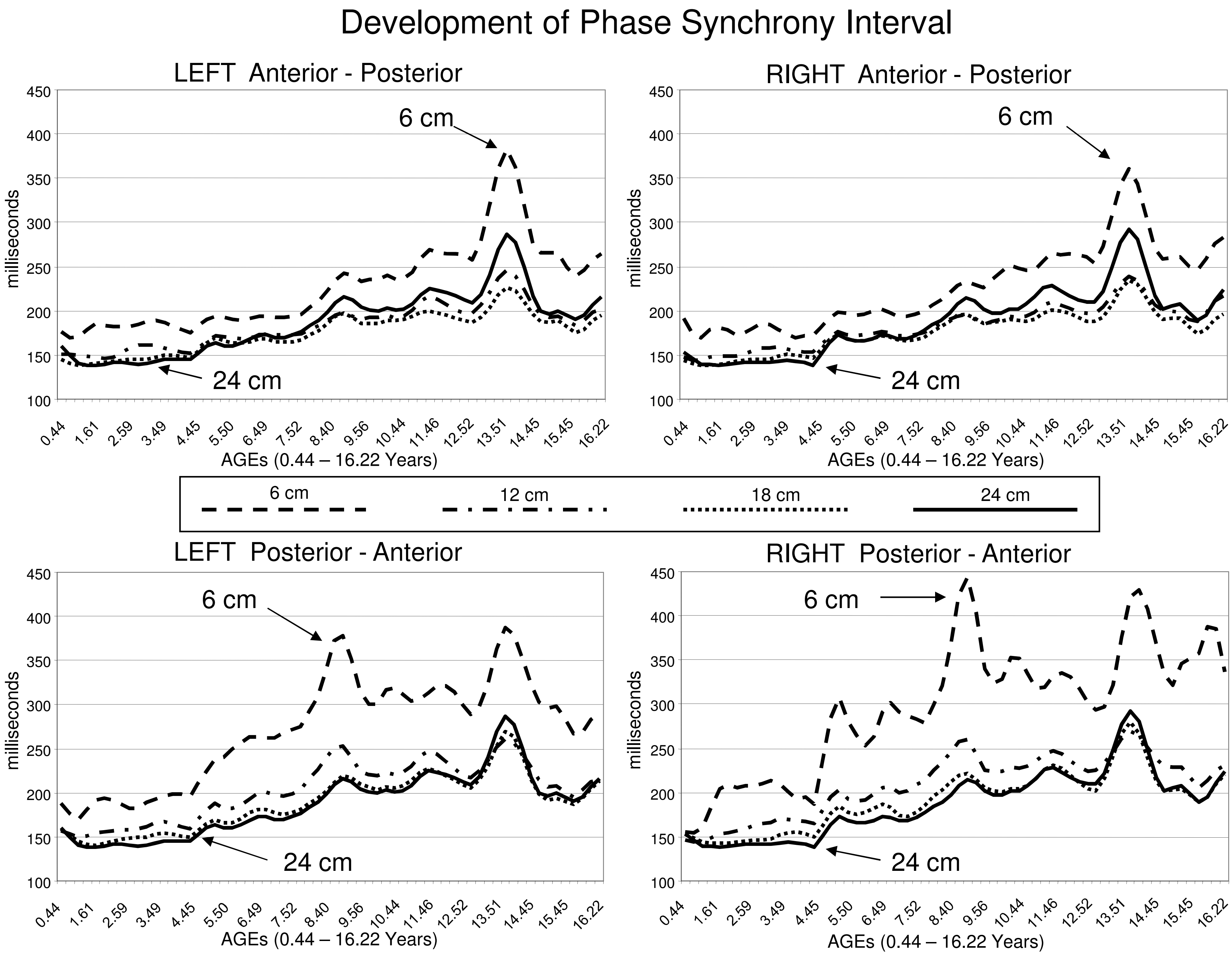

Development of Phase Synchrony Interval
LEFT Anterior - Posterior
RIGHT Anterior - Posterior
LEFT Posterior - Anterior
RIGHT Posterior - Anterior
6 cm
24 cm
6 cm
12 cm
18 cm
24 cm
milliseconds
100
150
200
250
300
350
400
450
0.44
1.61
2.59
3.49
4.45
5.50
6.49
7.52
8.40
9.56
10.44
11.46
12.52
13.51
14.45
15.45
16.22
AGEs (0.44 – 16.22 Years)

Table V
Correlations between Coherence and Phase Shift (Chaos) and Phase Synchrony (Stability)

	Chaos	Stability
Coherence	- 0.547	0.863
Chaos	---------	- 0.386
Stability	- 0.386	--------

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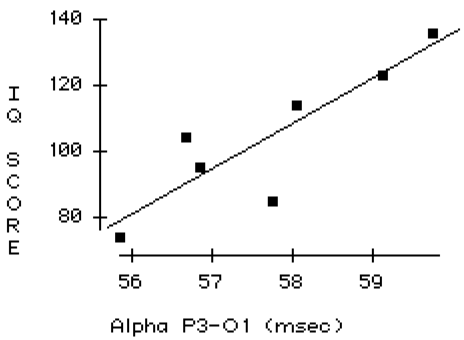
INTELLIGENCE AND EEG PHASE RESET:
A TWO COMPARTMENTAL MODEL OF PHASE SHIFT AND LOCK

Thatcher, R. W. 1,2, North, D. M.1, and Biver, C. J.1

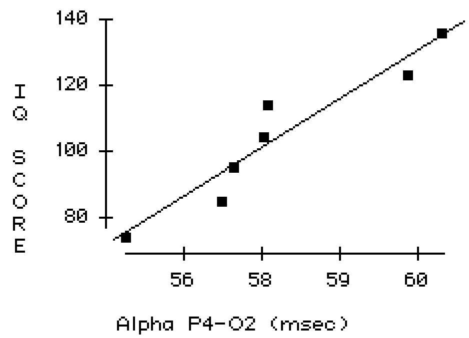
**EEG and NeuroImaging Laboratory, Applied Neuroscience Research Institute.
St. Petersburg, Fl1 and Department of Neurology, University of South Florida
College of Medicine, Tampa, Fl.2**

Regressions & Correlations of Phase Shift Duration Short Distances (6 cm)

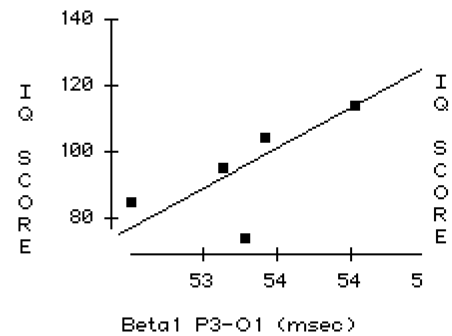
IQ = 78 + 13.78 x (msec)
r = .876 @ p< .01



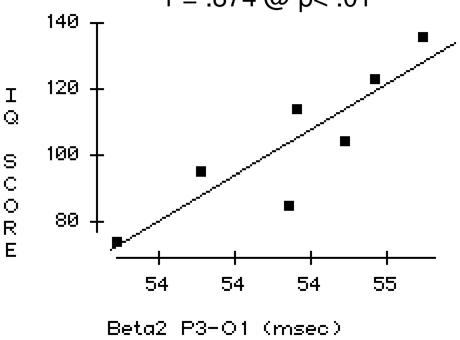
IQ = 70 +11.85 x (msec)
r = .954 @ p< .0001



IQ = 75 + 24.45 x (msec)
r = .868 @ p< .01

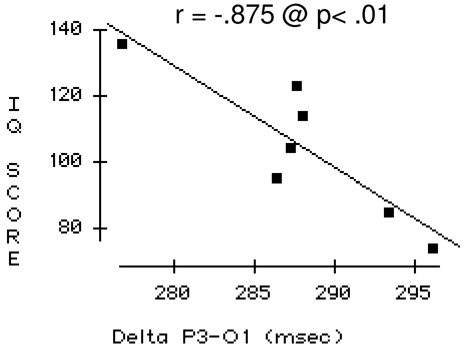


IQ = 68 + 34.40 x (msec)
r = .874 @ p< .01

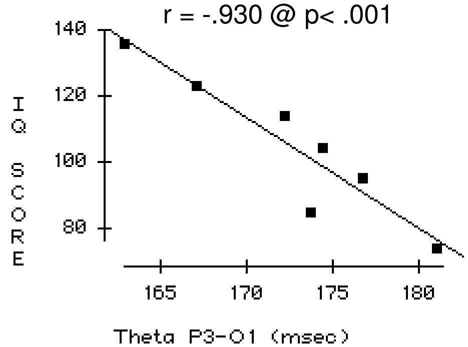


Regressions & Correlations of Phase Locking Interval Short Distances (6 cm)

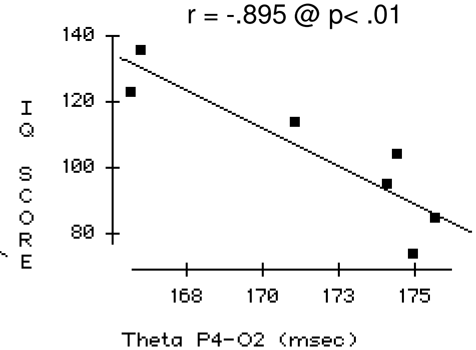
IQ = 143 - 3.11 x (msec)
r = -.875 @ p< .01



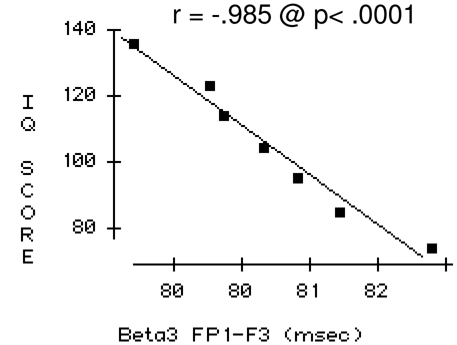
IQ = 142 - 3.36 x (msec)
r = -.930 @ p< .001

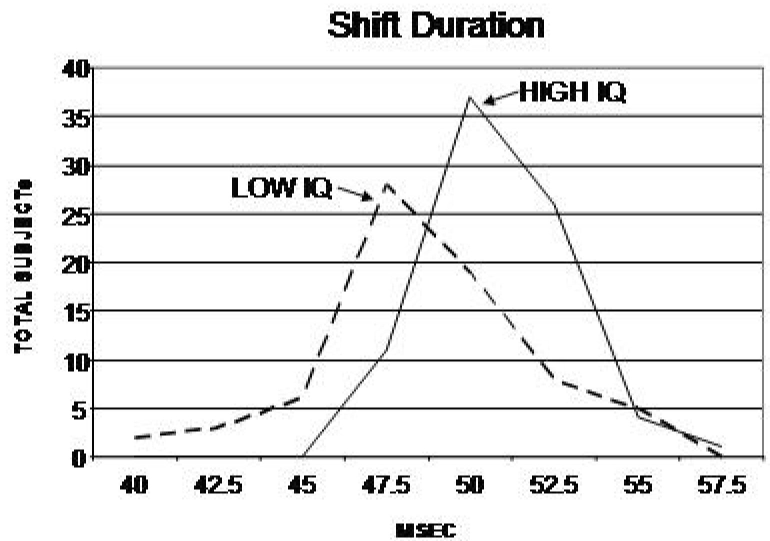


IQ = 132 - 4.57 x (msec)
r = -.895 @ p< .01

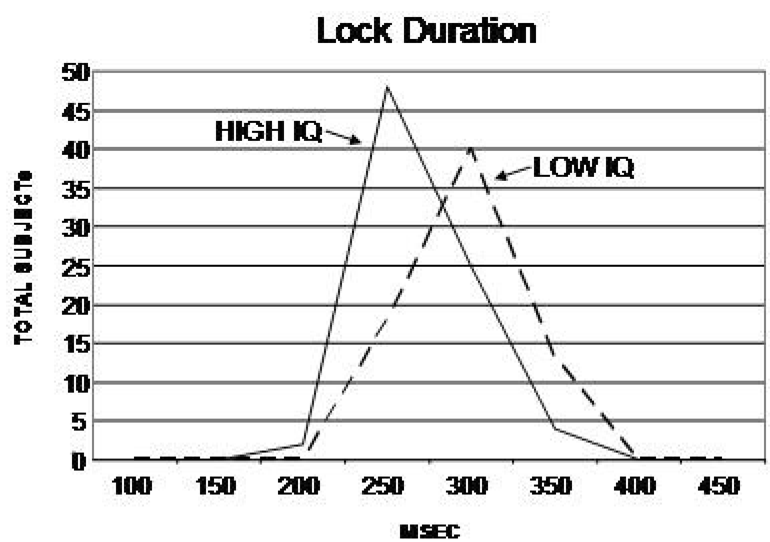


IQ = 140 - 20.08 x (msec)
r = -.985 @ p< .0001





Shift Duration
TOTAL SUBJECTS
MSEC
HIGH IQ
LOW IQ
0
5
10
15
20
25
30
35
40
40
42.5
45
47.5
50
52.5
55
57.5



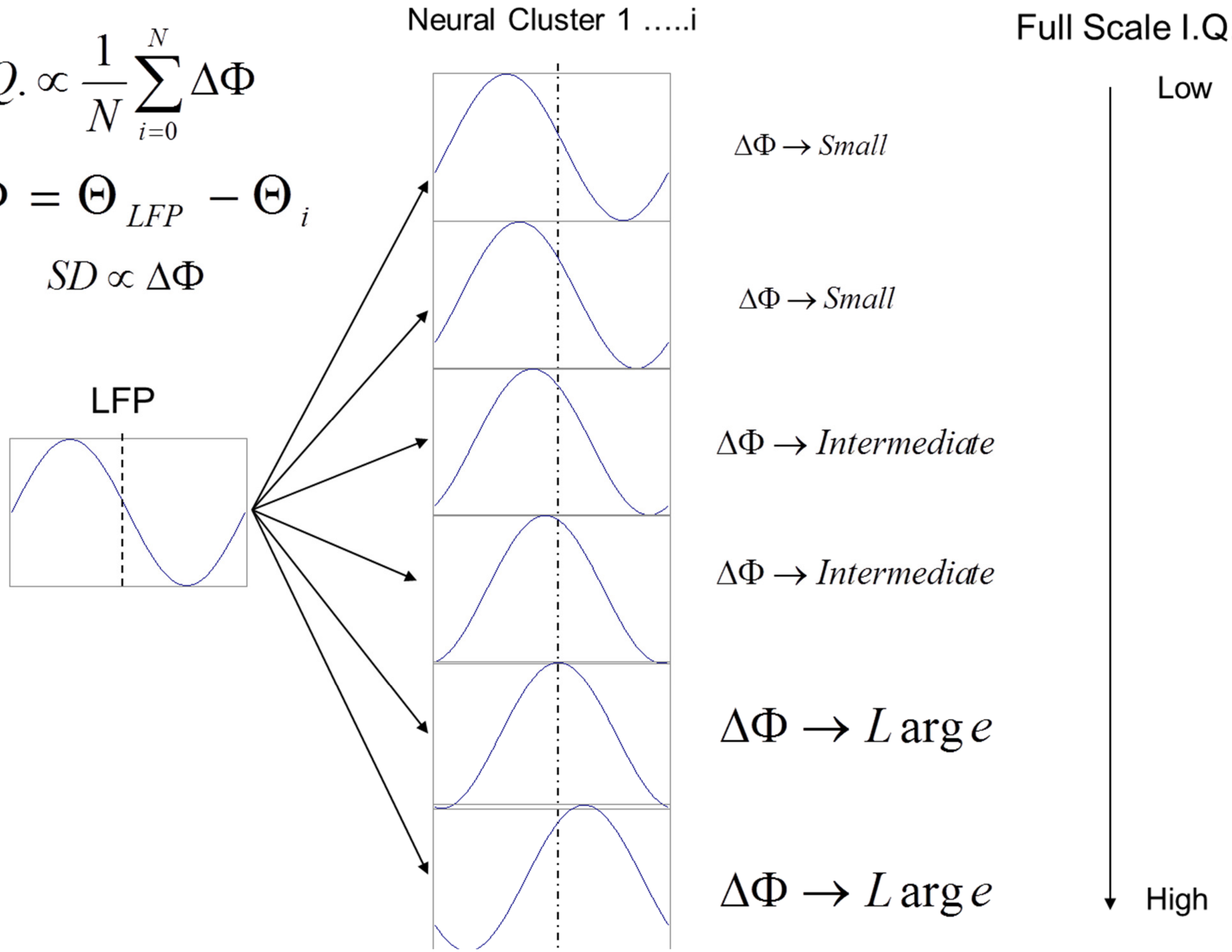
Lock Duration
TOTAL SUBJECTS
MSEC
HIGH IQ
LOW IQ
0
5
10
15
20
25
30
35
40
45
50
100
150
200
250
300
350
400
450

Local Field Potential (LFP) Model of Phase Shift Duration and Full Scale I.Q.

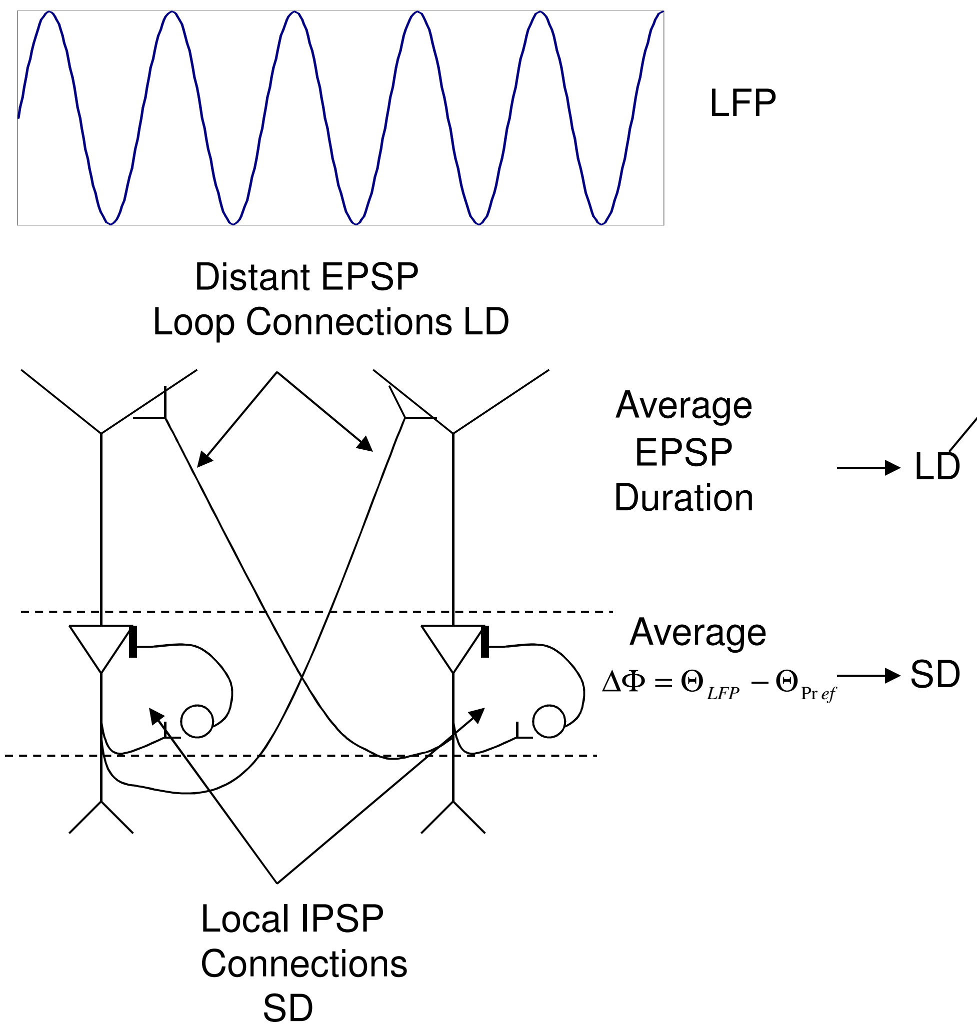
$$I.Q. \propto \frac{1}{N}\sum_{i=0}^{N}\Delta\Phi$$

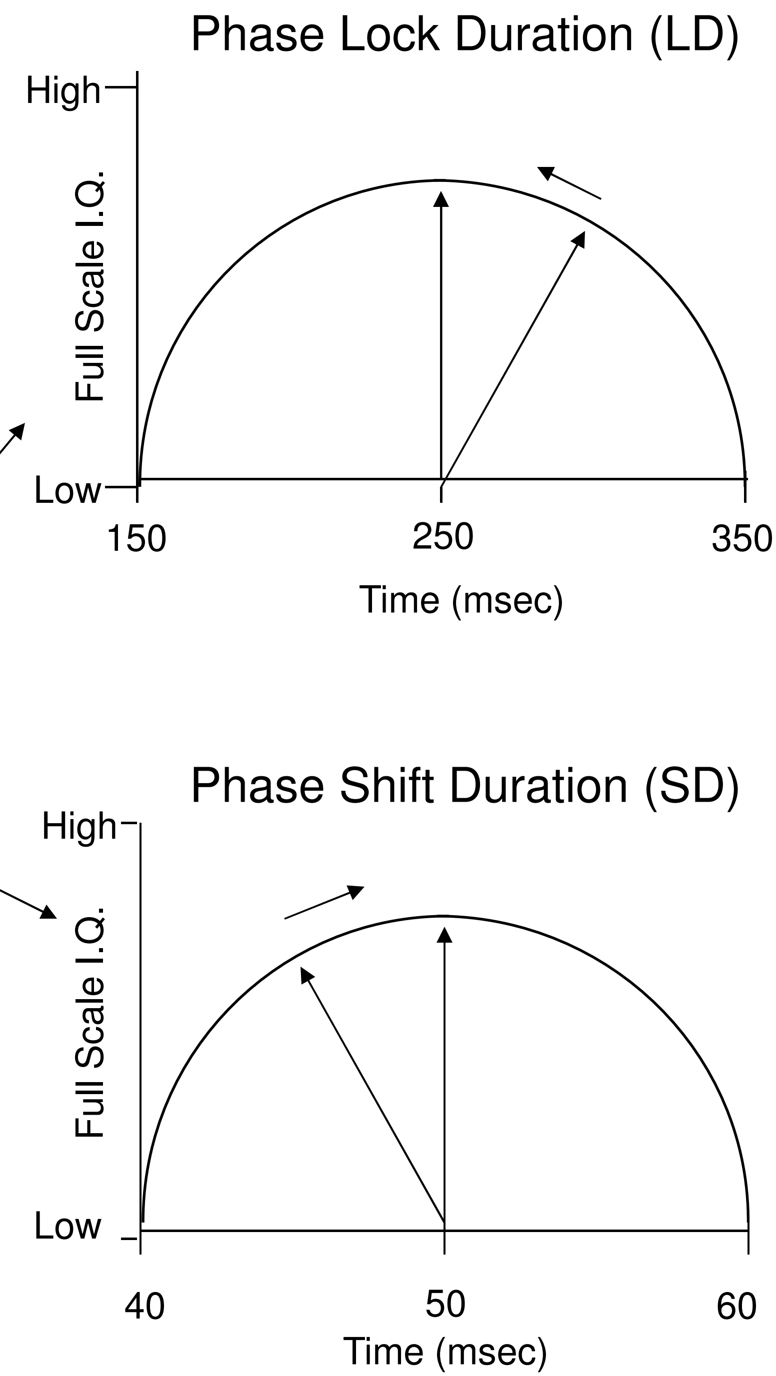
$$\Delta\Phi = \Theta_{LFP} - \Theta_{i}$$

$$SD \propto \Delta\Phi$$



Pyramidal Cell Model of EEG Phase Reset and Full Scale I.Q.

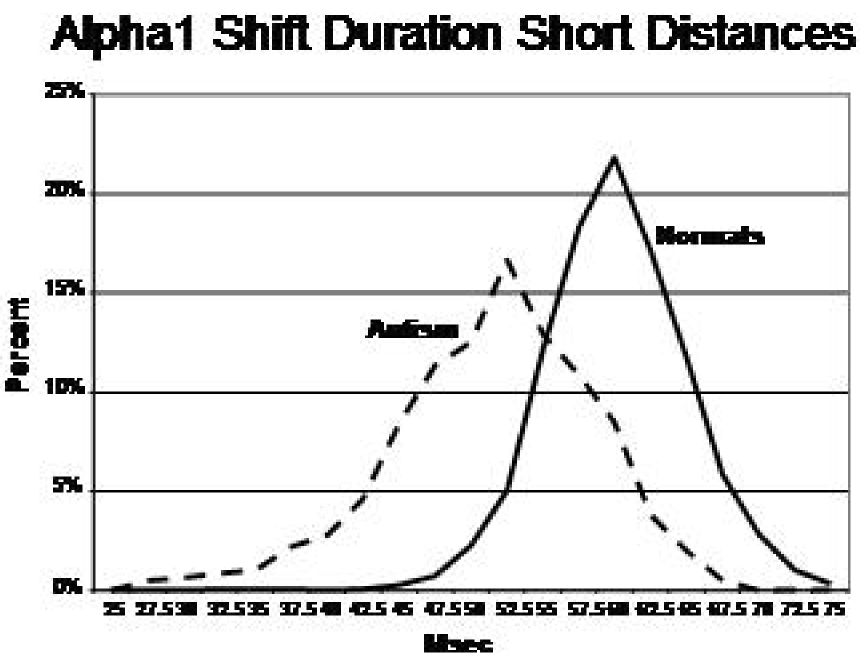


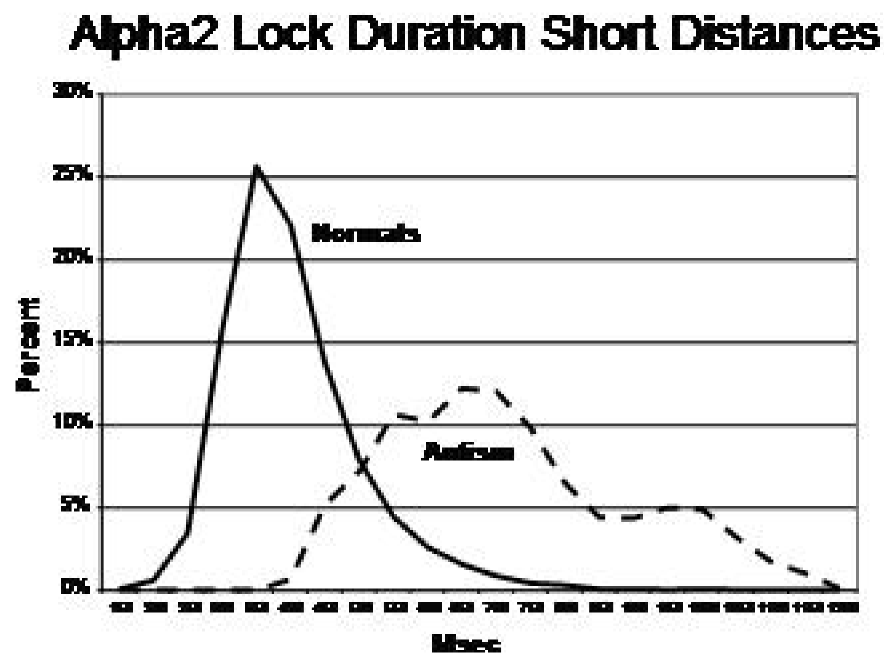


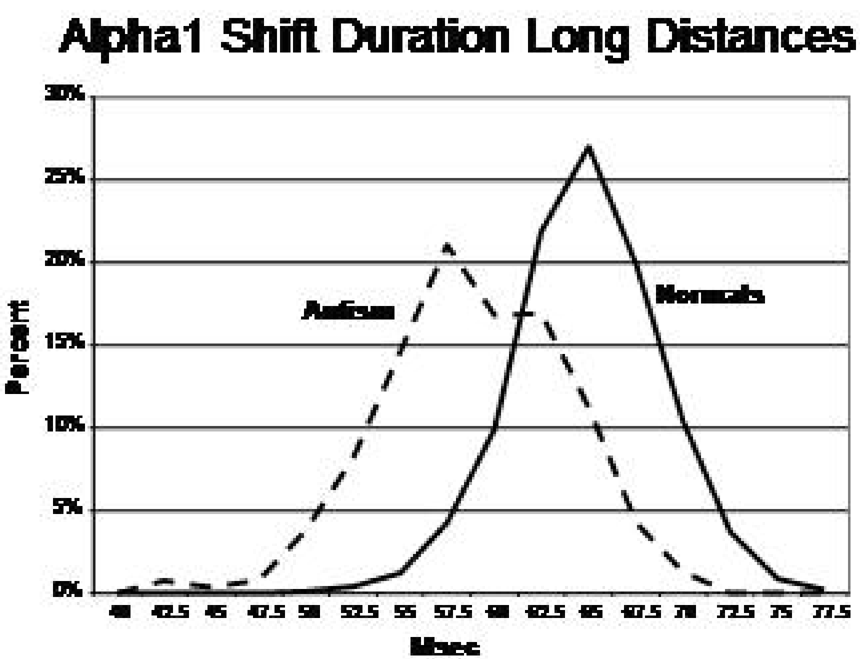
AUTISM AND EEG PHASE RESET: A UNIFIED THEORY OF DEFICIENT GABA MEDIATED INHIBITION IN THALAMO-CORTICAL CONNECTIONS

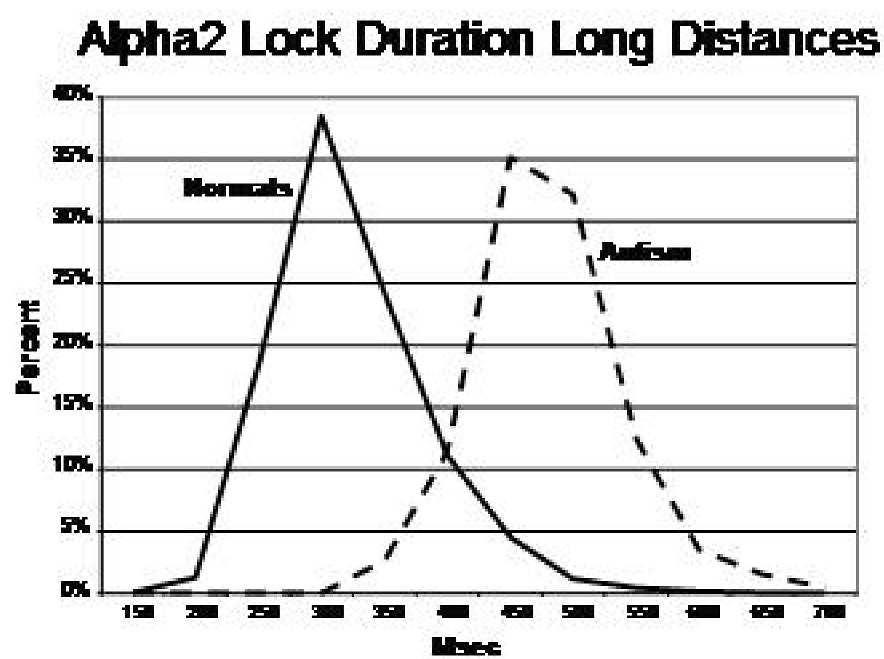
Thatcher, R. W. 1,2, Phillip DeFina2, James Neurbrander2, North, D. M.1, and Biver, C. J.1

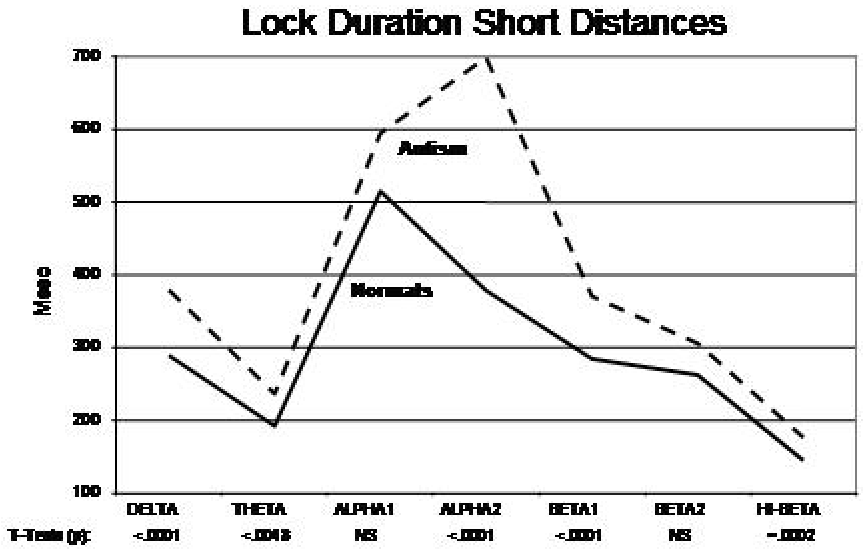
EEG and NeuroImaging Laboratory, Applied Neuroscience Research Institute., St. Petersburg, Fl1 and the International Brain Research Foundation, Menlo Park, NJ2

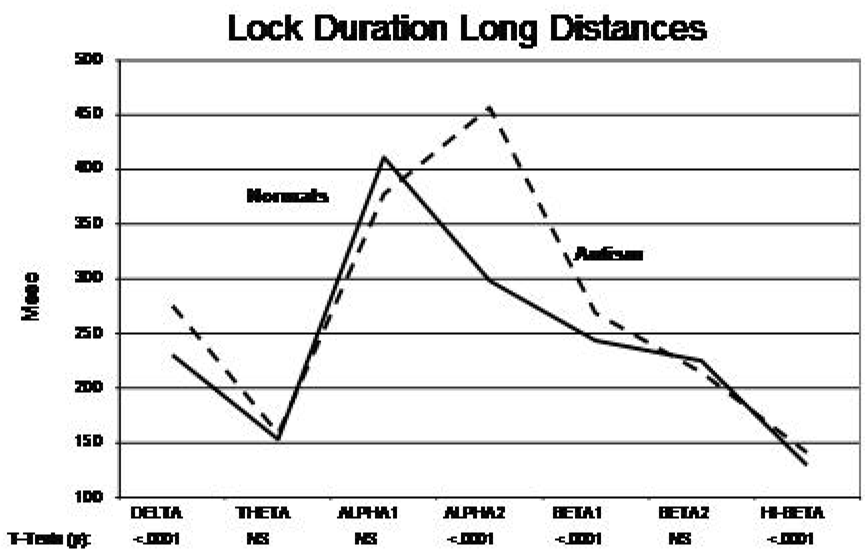

Alpha1 Shift Duration Short Distances
Normals
Autism
Percent
Msec

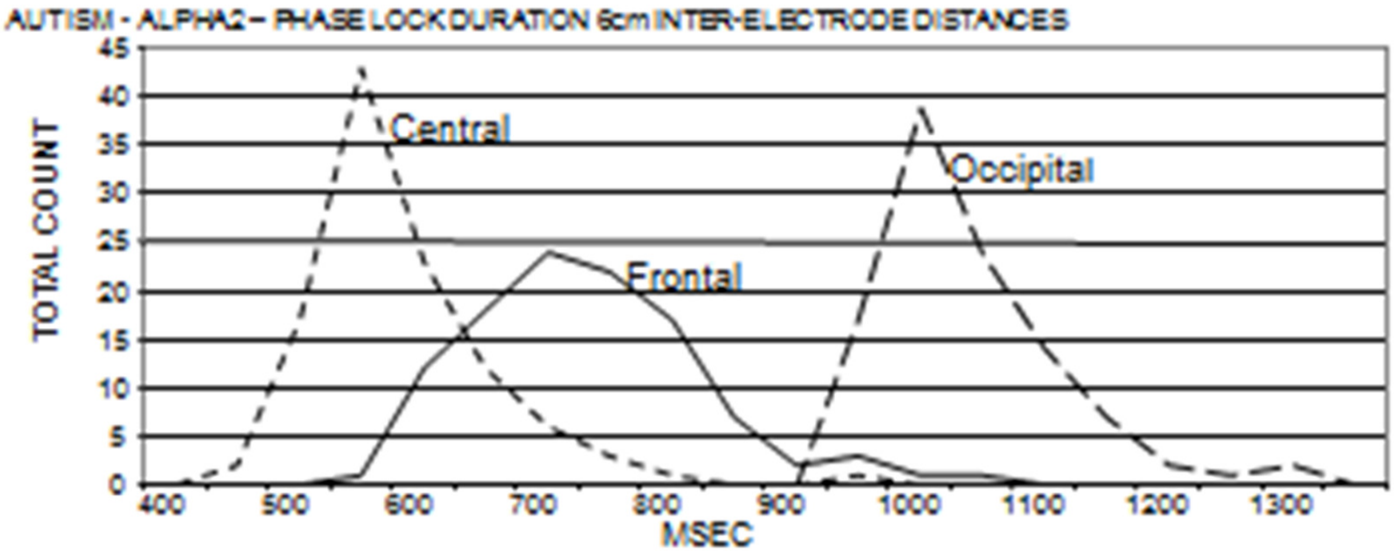

Alpha2 Lock Duration Short Distances
Normals
Autism
Percent
Msec


Alpha1 Shift Duration Long Distances
Autism
Normals
Percent
Msec


Alpha2 Lock Duration Long Distances
Normals
Autism
Percent
Msec


Lock Duration Short Distances
700
600
500
400
300
200
100
Msec
Autism
Normals
DELTA
THETA
ALPHA1
ALPHA2
BETA1
BETA2
HI-BETA
T-Tests (p):
<.0001
<.0048
NS
<.0001
<.0001
NS
=.0002

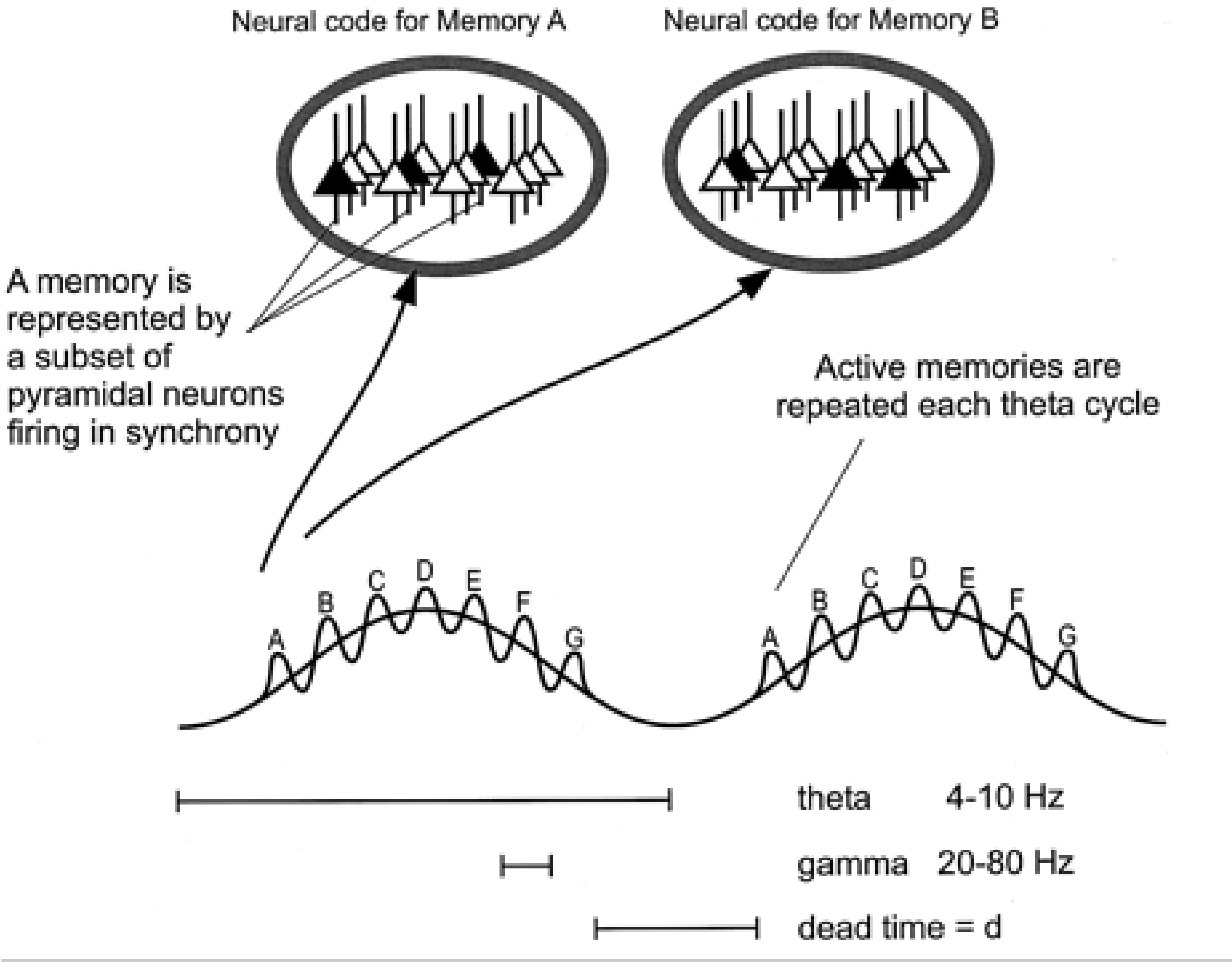

Lock Duration Long Distances
500
450
400
350
300
250
200
150
100
Msec
Normals
Autism
DELTA
THETA
ALPHA1
ALPHA2
BETA1
BETA2
HI-BETA
T-Tests (p):
<.0001
NS
NS
<.0001
<.0001
NS
<.0001

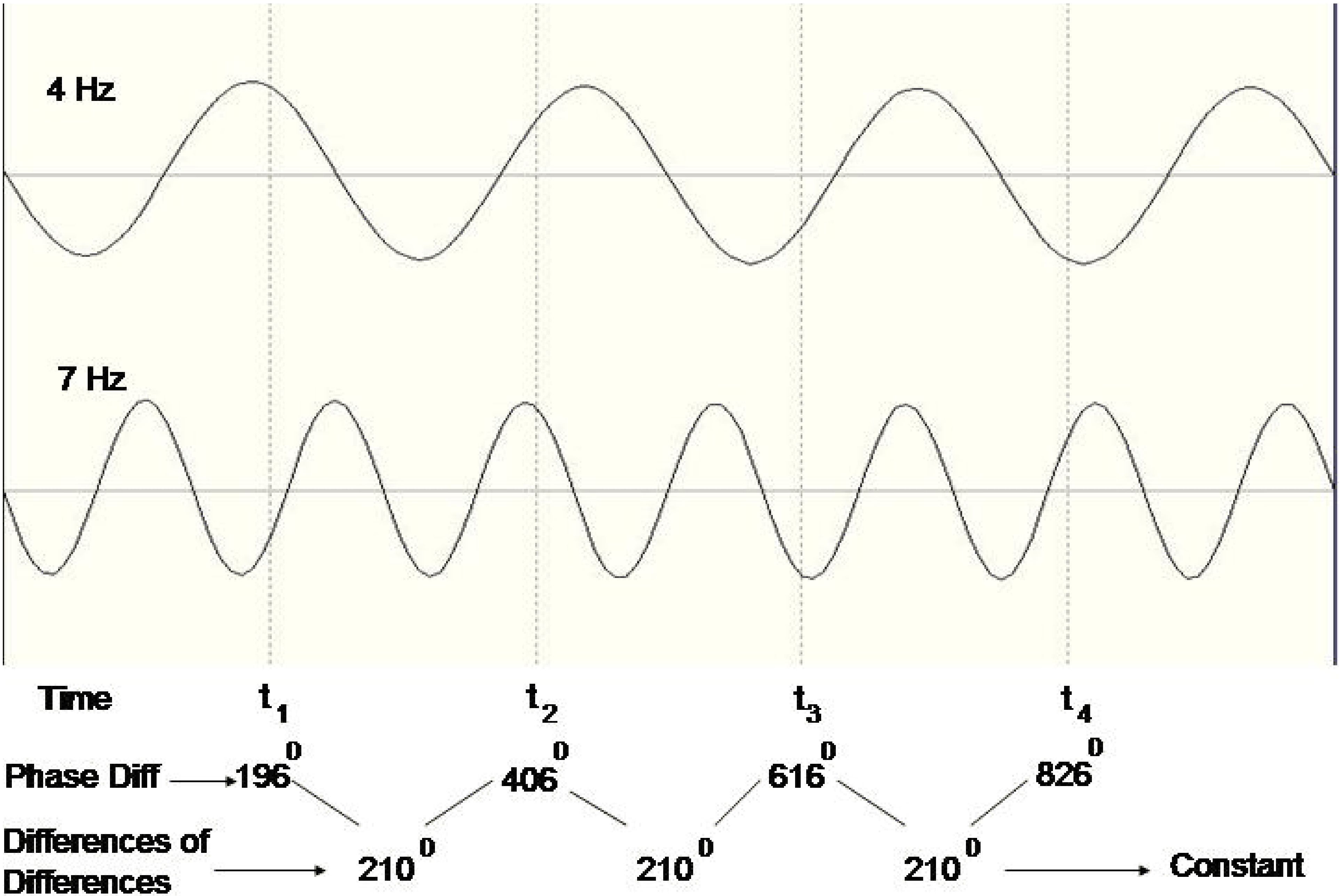


AUTISM - ALPHA2 – PHASE LOCK DURATION 6cm INTER-ELECTRODE DISTANCES
TOTAL COUNT
45
40
35
30
25
20
15
10
5
0
400
500
600
700
800
900
1000
1100
1200
1300
MSEC
Central
Occipital
Frontal

Cross-Frequency Phase Shift and Phase Lock

**Note: ICA Obliterates Time & Phase Differences
Between Channels and Cannot be Used
for These Type of Analyses**

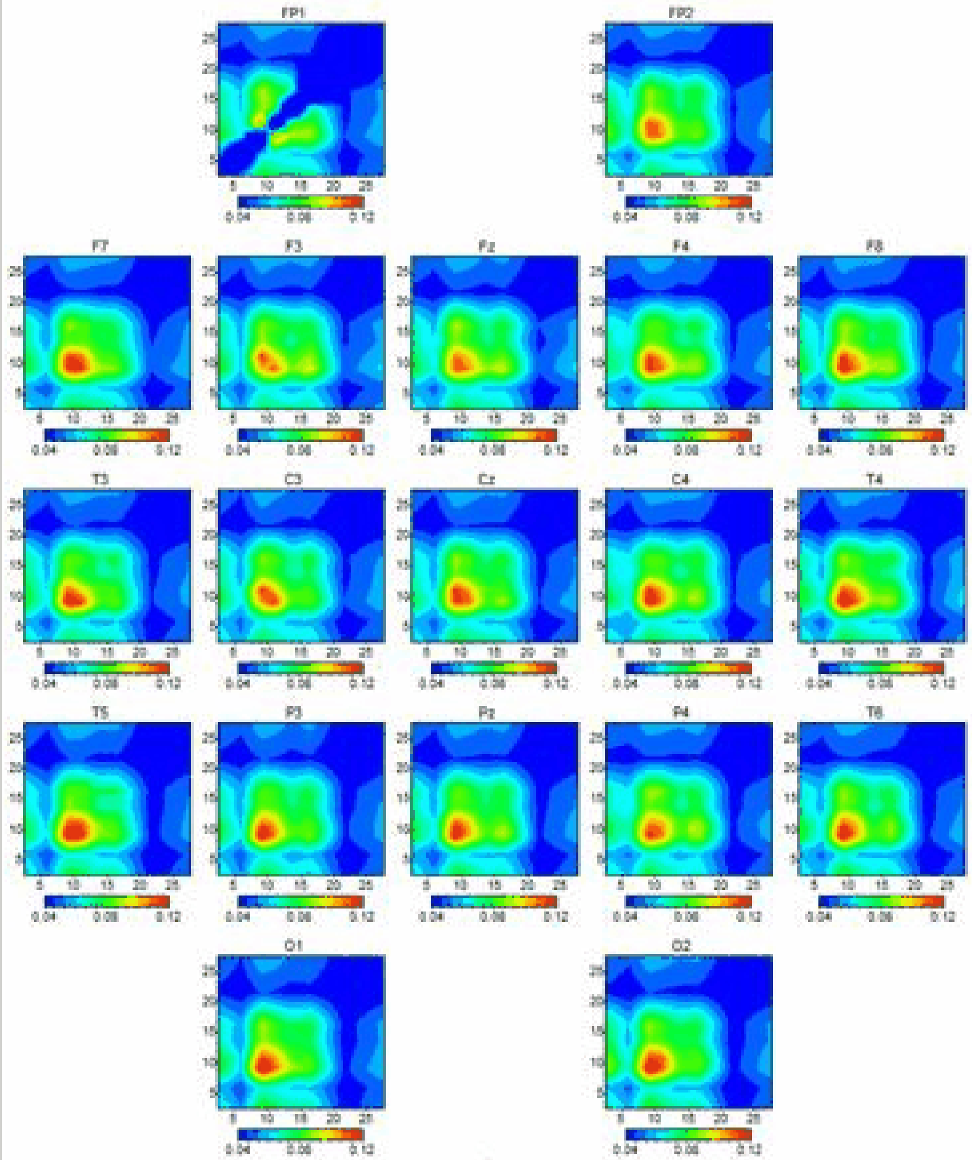

Neural code for Memory A
Neural code for Memory B
A memory is represented by a subset of pyramidal neurons firing in synchrony
Active memories are repeated each theta cycle
A
B
C
D
E
F
G
A
B
C
D
E
F
G
theta 4-10 Hz
gamma 20-80 Hz
dead time = d



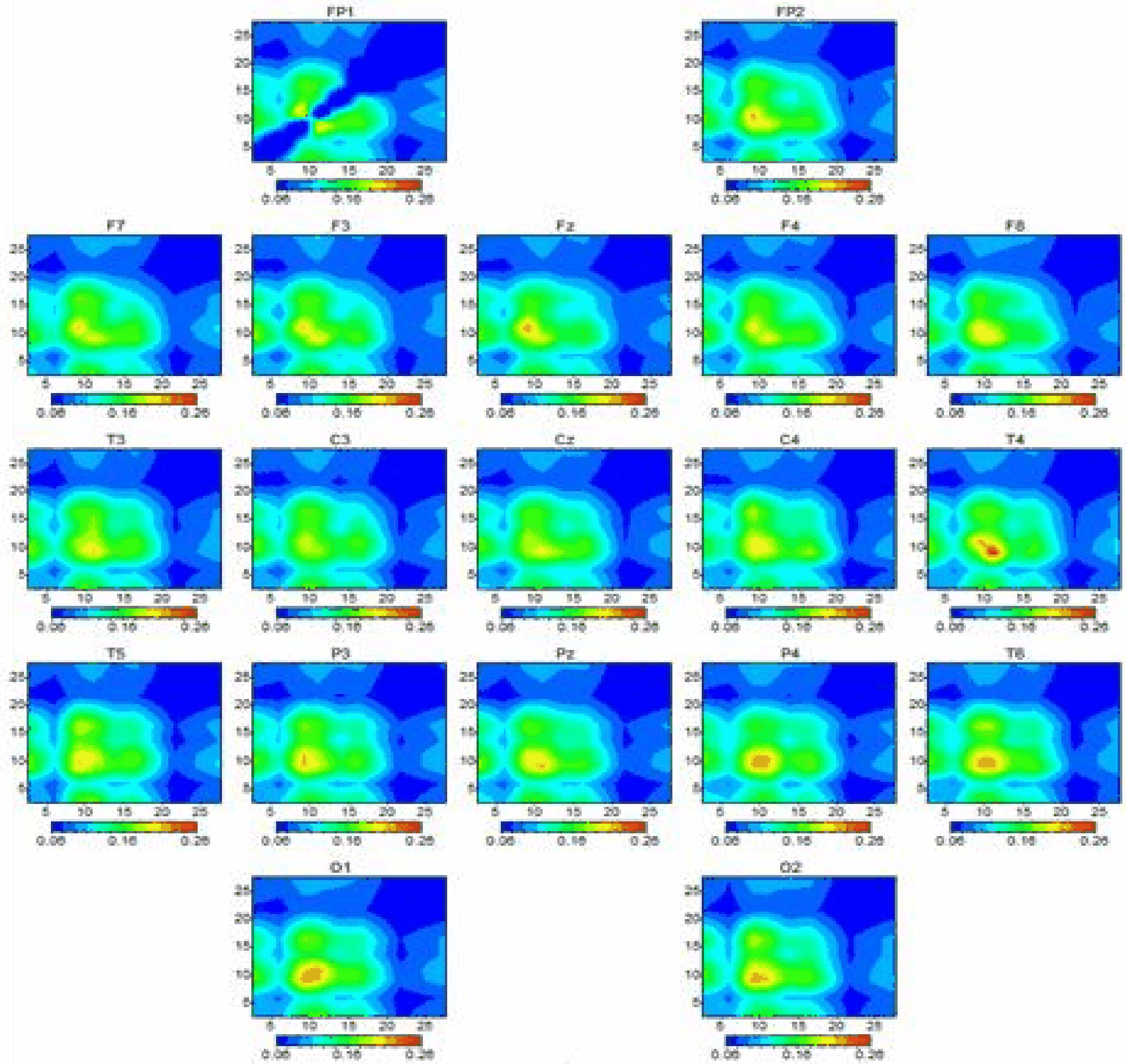
1st Derivative = $\frac{d'(\Theta_{f1}-\Theta_{f2})}{dt} = Const$

2nd Derivative = $\frac{d''(\Theta_{f1}-\Theta_{f2})}{dt} = 0$

FP1 Cross-Frequency Phase Shift Duration



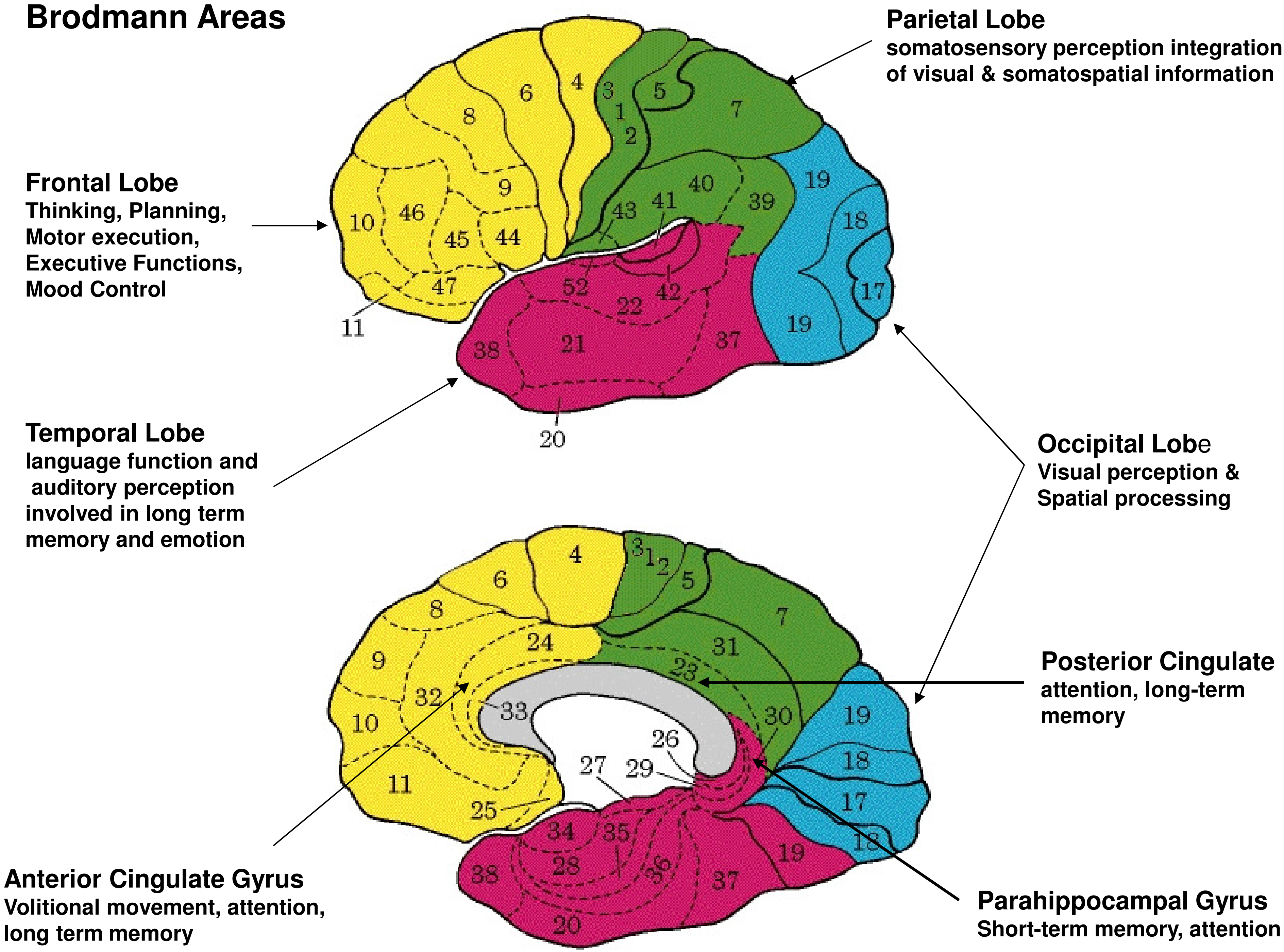
FP1 Cross-Frequency Phase Lock Duration

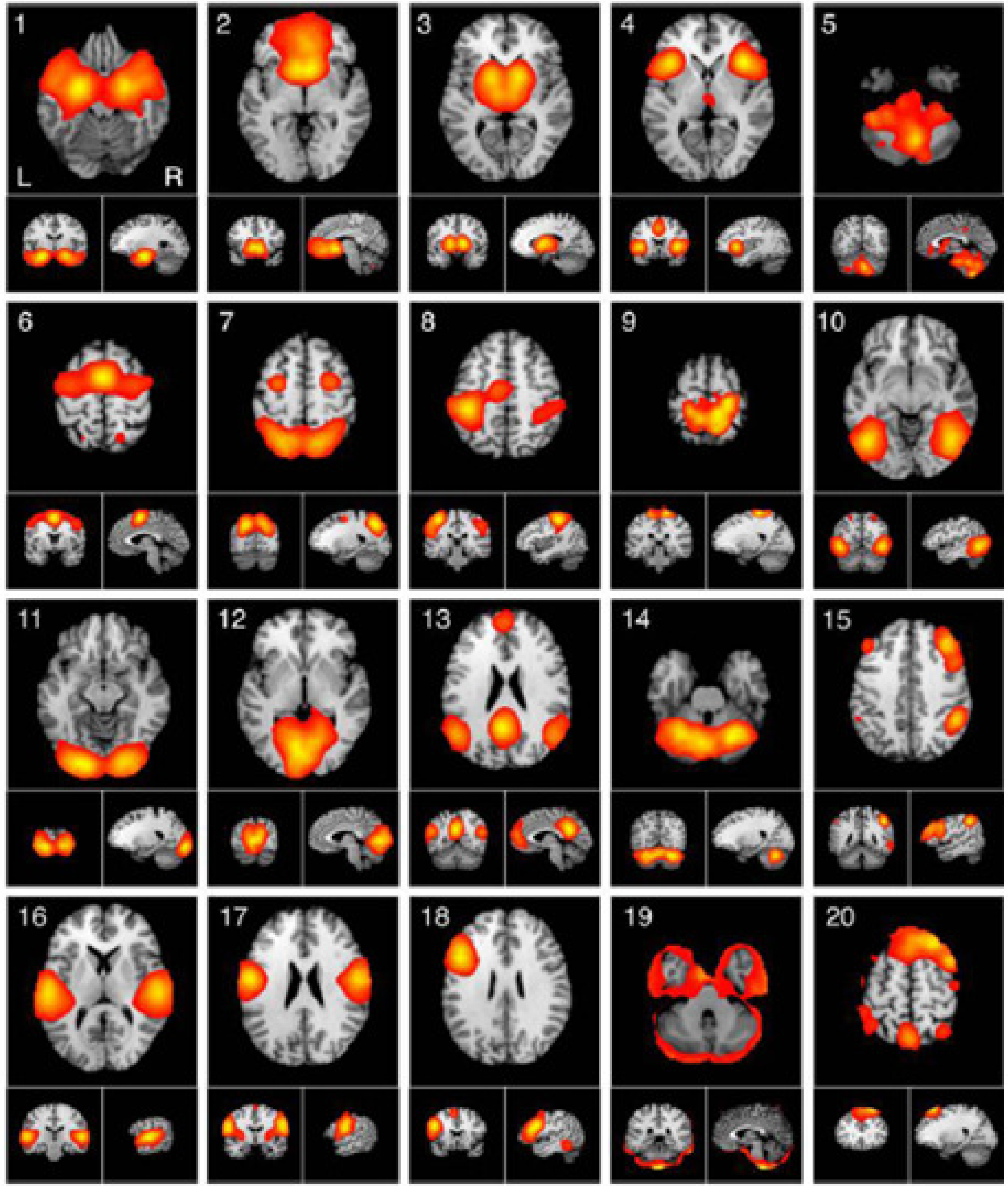


Electrical NeuroImaging of Functional Modules and Hubs as Measured by fMRI and PET

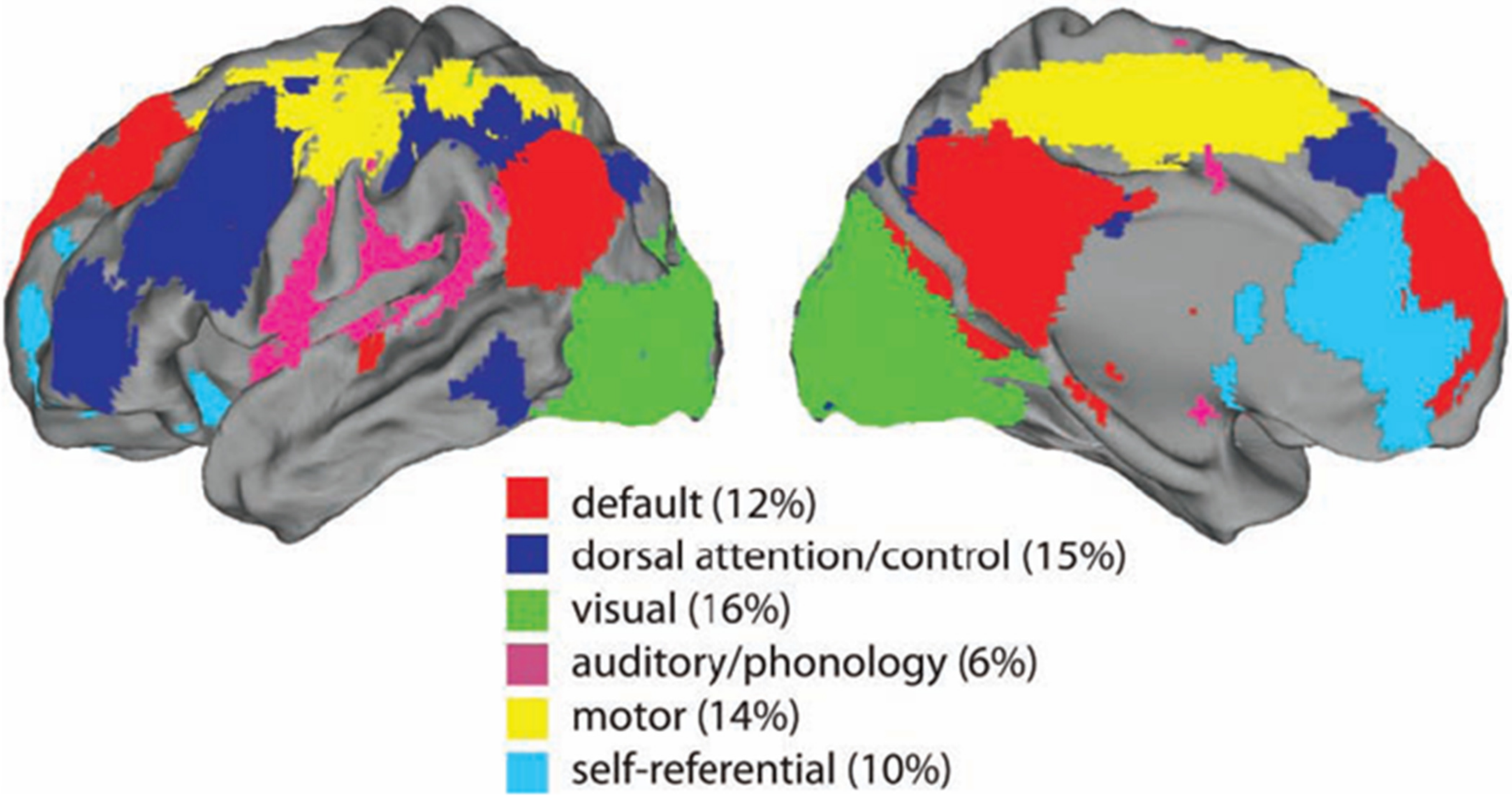
Phase Shift and Phase Lock Switch Dynamics that "Animate" Information Flow Within and Between Modules and Hubs

Brodmann Areas

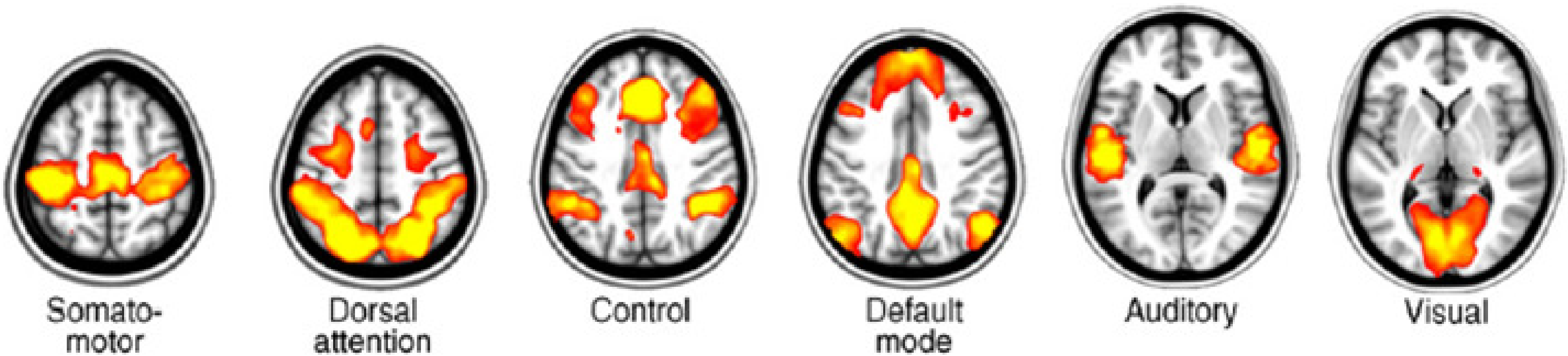




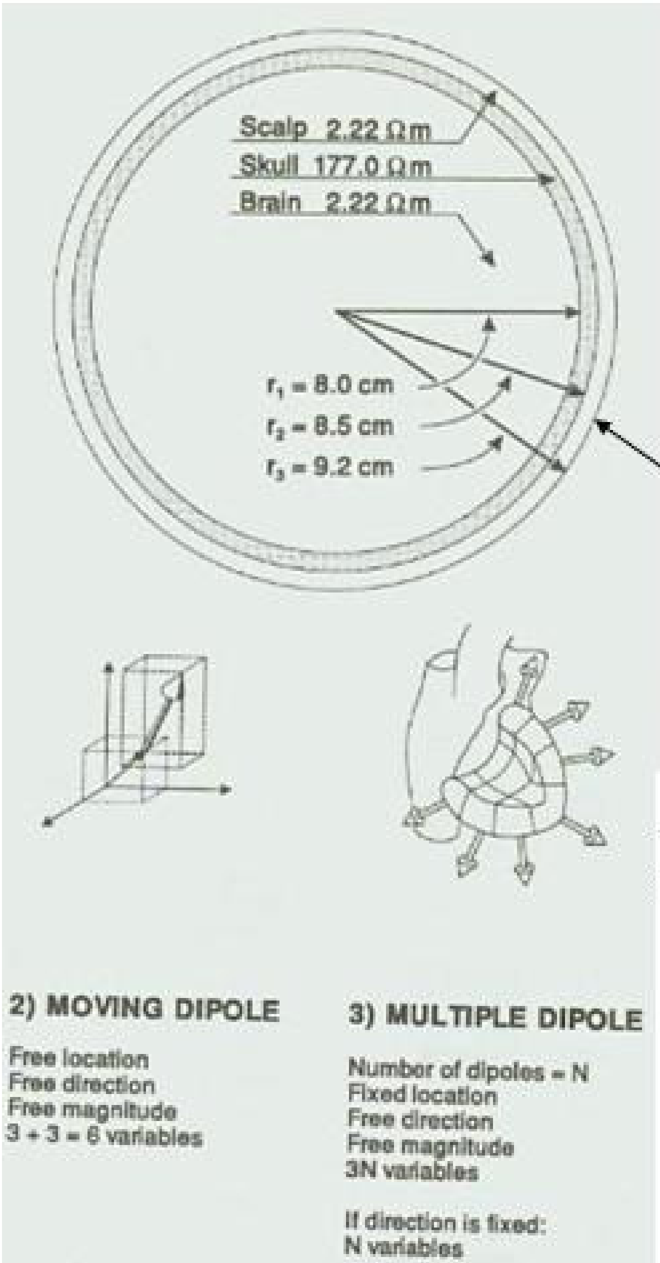
Laird et al (2011) summarized the various "intrinsic connectivity networks" or ICNs into eighteen specific groupings based upon 30,000 fMRI and PET studies


default (12%)
dorsal attention/control (15%)
visual (16%)
auditory/phonology (6%)
motor (14%)
self-referential (10%)

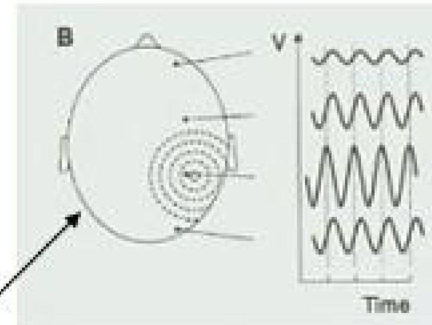
Six Functional Modules as Measured by fMRI



Estimation of Cortical Source Current Density



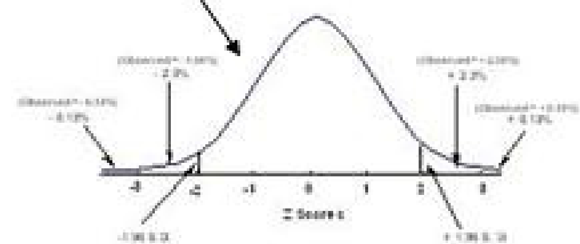
Electrical Potentials - EEG



Lead Field

$$KJ = E + n$$

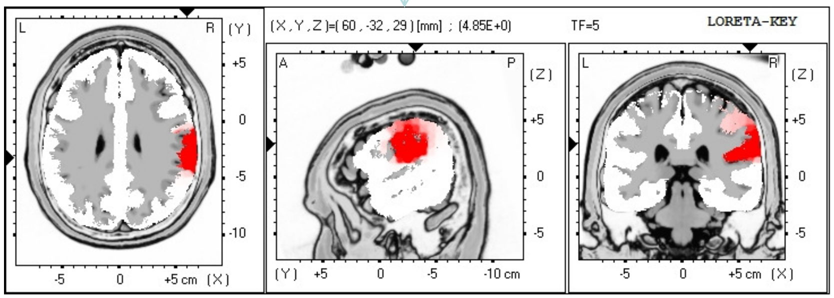
Current Sources



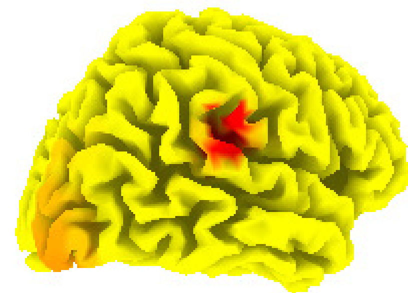
Gaussian Distributed Noise

Electrical Neuroimaging and Cortical Source Localization

Horizontal, Sagital & Coronal Views of a Single Slice



Cortical Surface Projection



Tomographic Slice Display

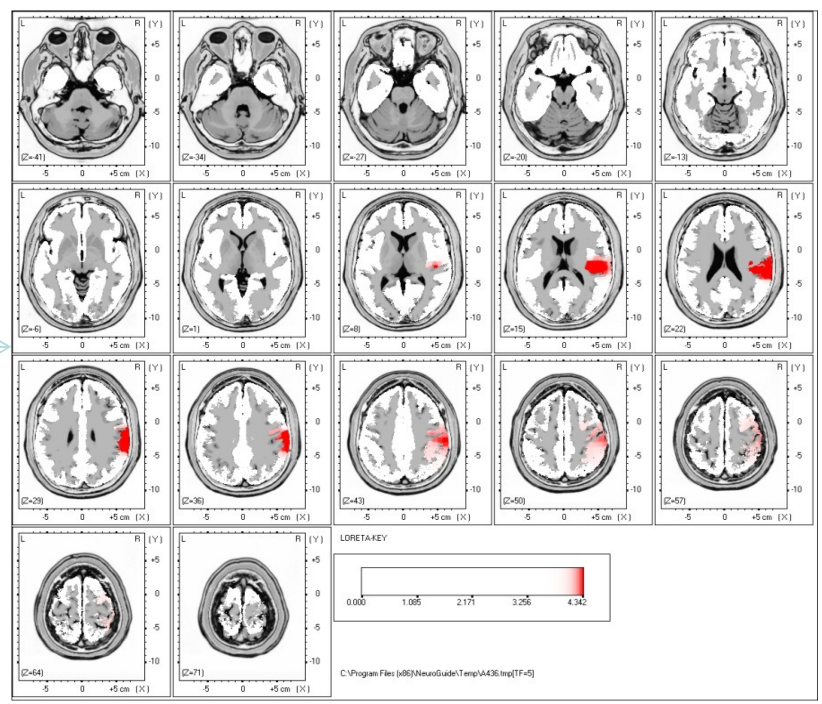
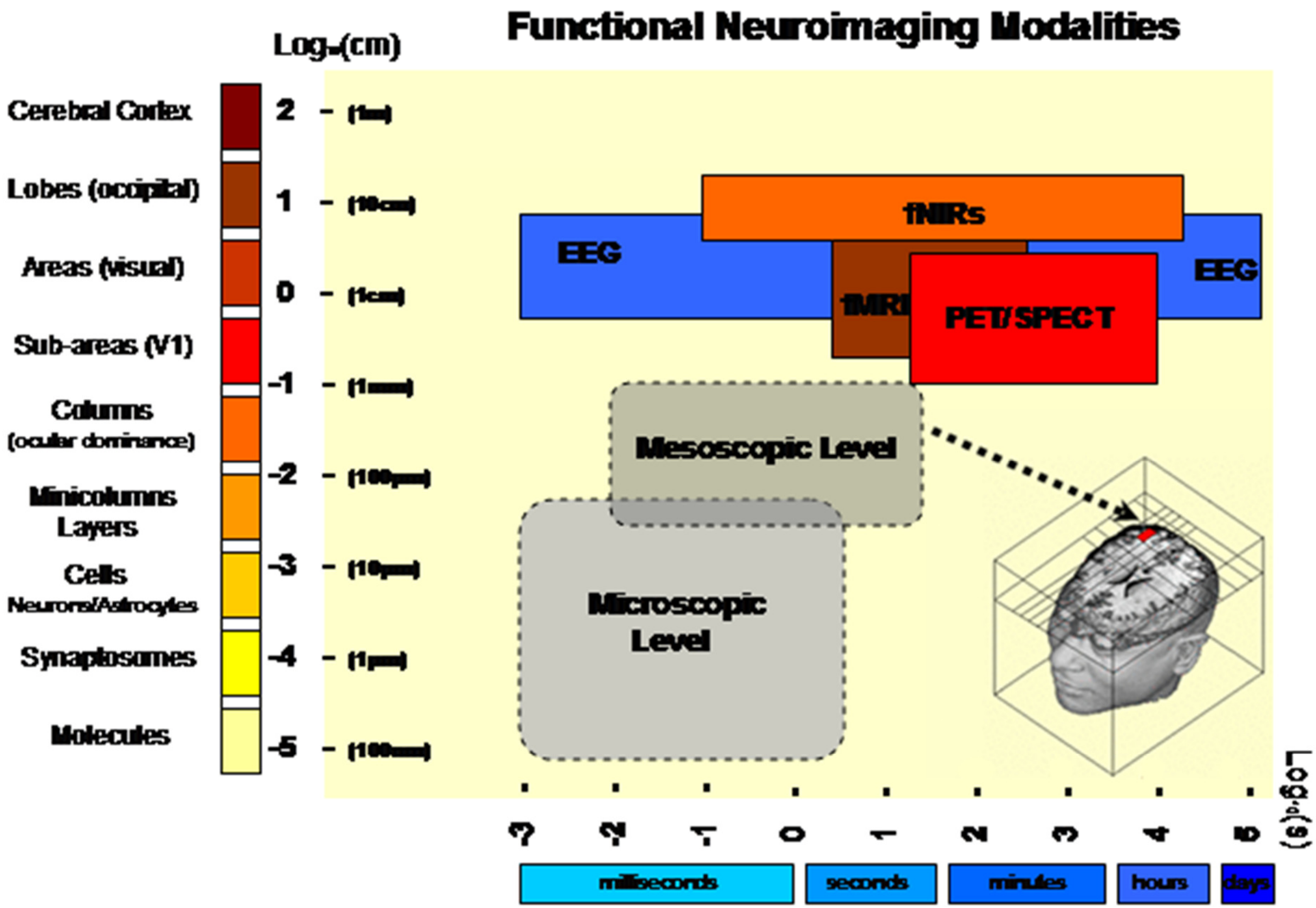


Table 5: Error measure ED1 for the four inverse algorithms, with regularization, under four different noise levels: 25 dB, 15 dB, 10 dB and 5 dB. Each cell value gives the mean and standard deviation.

		ED1			
		Regularised			
	SNR/dB	5	10	15	25
	Layer				
WMN	Surface	3.46 ± 0.42	2.10 ± 0.28	1.34 ± 0.11	1.13 ± 0.03
	Middle	5.08 ± 0.50	3.94 ± 0.38	2.95 ± 0.21	2.40 ± 0.03
	Deep	5.91 ± 0.39	5.31 ± 0.36	4.61 ± 0.24	3.89 ± 0.15
sLORETA	Surface	0.99 ± 0.1	0.49 ± 0.08	0.11 ± 0.04	0.00 ± 0.00
	Middle	1.61 ± 0.13	0.84 ± 0.11	0.25 ± 0.07	0.00 ± 0.00
	Deep	1.79 ± 0.25	0.95 ± 0.16	0.39 ± 0.13	0.00 ± 0.00
LORETA	Surface	2.32 ± 0.08	2.18 ± 0.04	2.16 ± 0.03	2.21 ± 0.02
	Middle	1.51 ± 0.13	1.15 ± 0.08	0.95 ± 0.07	1.05 ± 0.06
	Deep	2.30 ± 0.21	1.81 ± 0.13	1.59 ± 0.11	1.53 ± 0.09
SLF	Surface	5.27 ± 0.30	4.50 ± 0.28	3.81 ± 0.20	2.98 ± 0.13
	Middle	4.53 ± 0.39	4.09 ± 0.35	3.50 ± 0.31	2.51 ± 0.15
	Deep	3.89 ± 0.55	3.70 ± 0.45	3.27 ± 0.48	1.73 ± 0.30

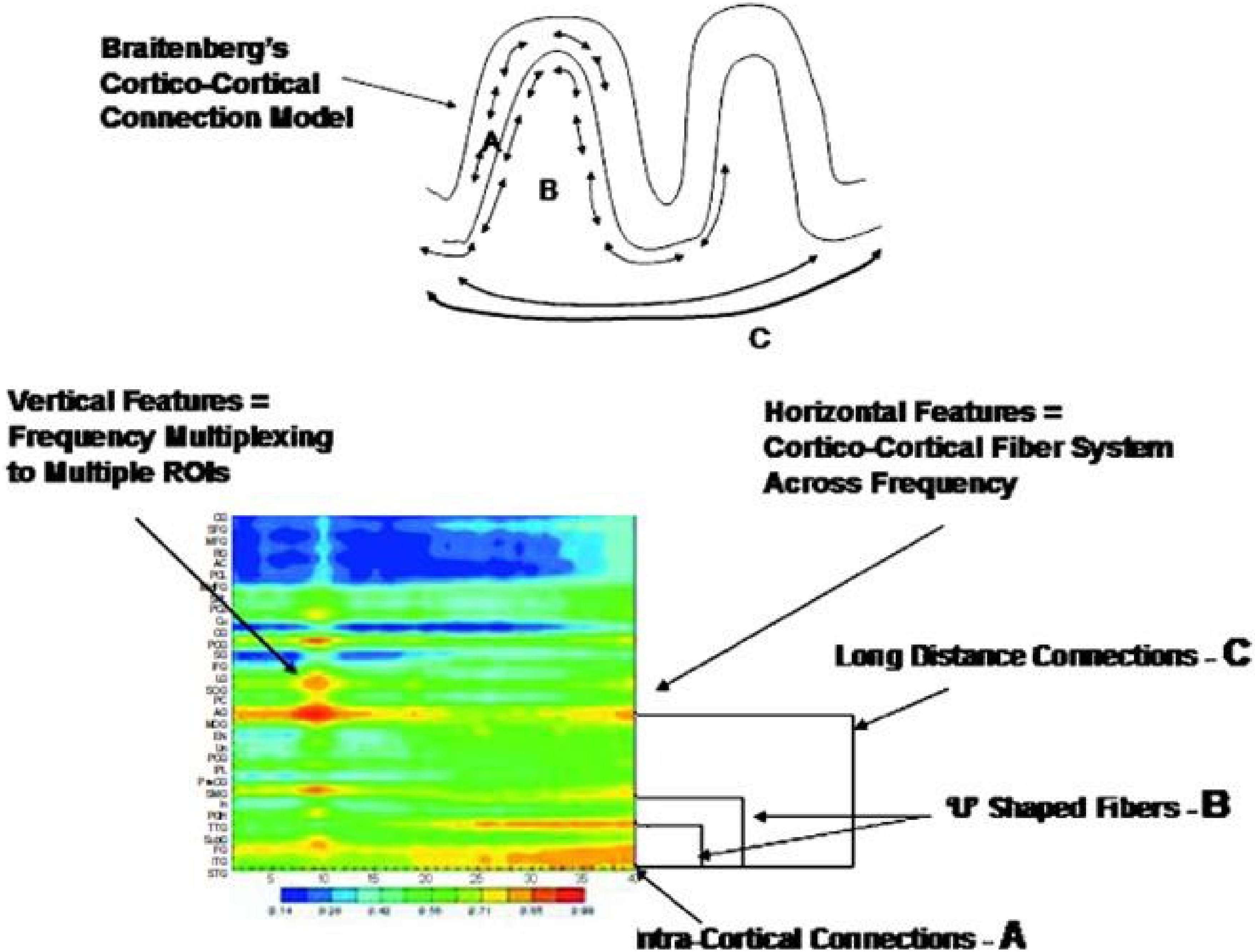


Functional Neuroimaging Modalities
Log10(cm)
Cerebral Cortex
Lobes (occipital)
Areas (visual)
Sub-areas (V1)
Columns
(ocular dominance)
Minicolumns
Layers
Cells
Neurons/Astrocytes
Synaptosomes
Molecules
2
1
0
-1
-2
-3
-4
-5
(1m)
(10cm)
(1cm)
(1mm)
(100µm)
(10µm)
(1µm)
(100nm)
fNIRs
EEG
EEG
fMRI
PET/SPECT
Mesoscopic Level
Microscopic Level
-3
-2
-1
0
1
2
3
4
5
Log10(s)
milliseconds
seconds
minutes
hours
days

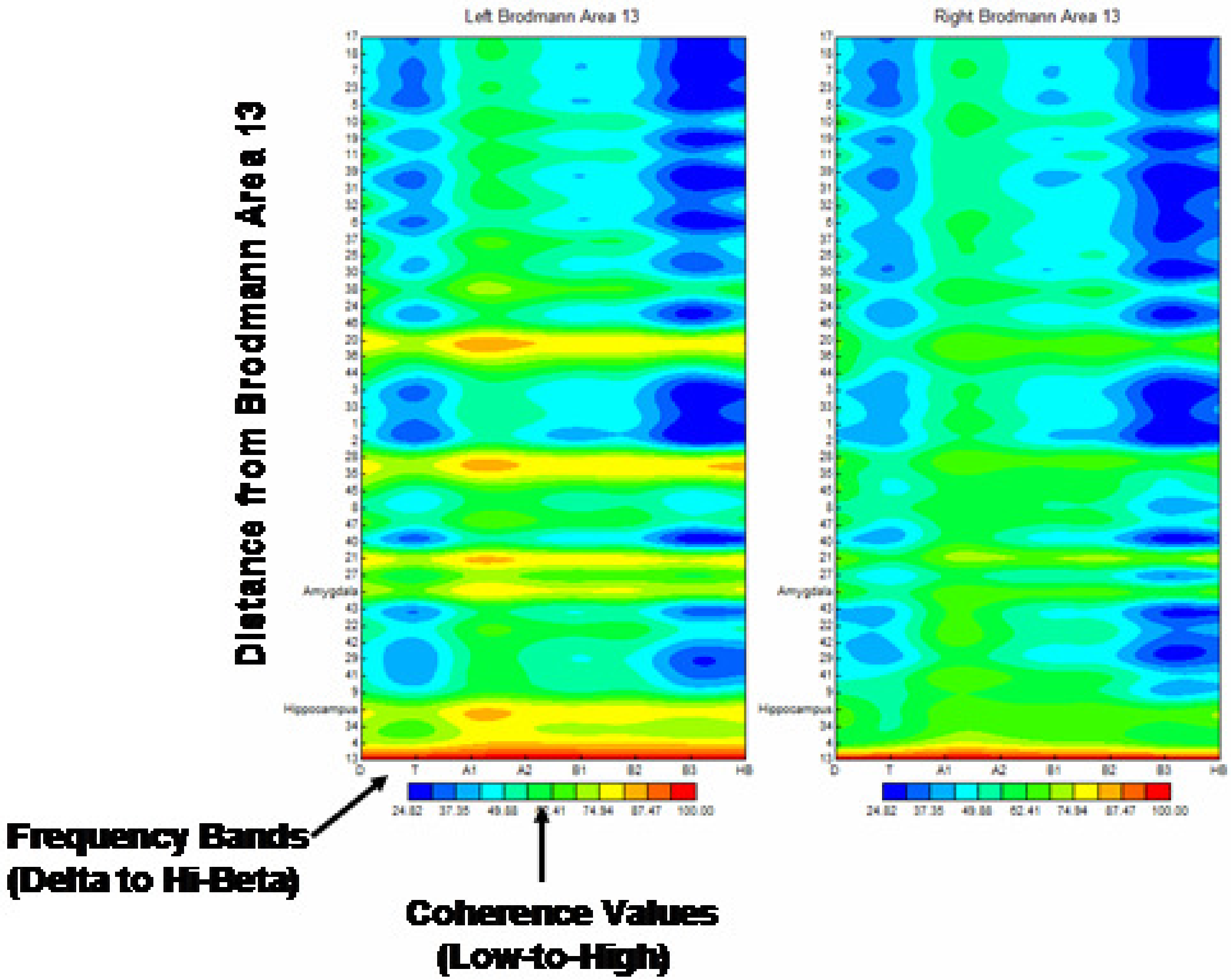
Electrical Neuroimaging – Assessment and Treatment

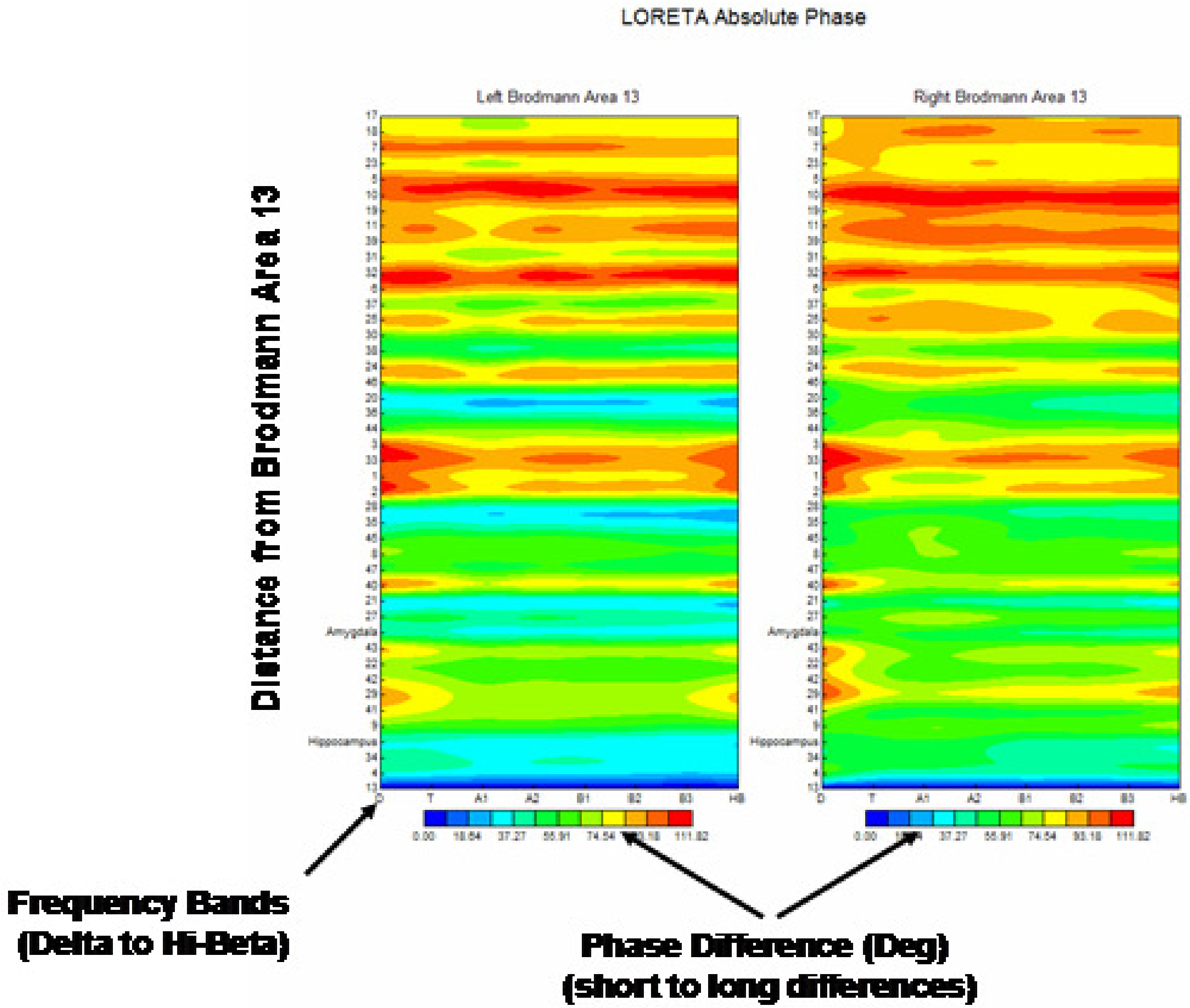
Advantages of Electrical Neuroimaging

1- Spatial Resolution – 1 cm to 3 cm
2- Temporal Resolution – 1 msec
3- Imaging of Current Sources
4- Imaging of Network Connections
5- Integration with DTI & fMRI (Brodmann Areas)
6- Inexpensive ($10,000 vs $3,000,000)
7- Dry Electrodes & Wireless Caps
8- Portable
9- Integration with Smart Phones & Tablets
10- Can Assess & Treat in Real-Time1


Braitenberg's
Cortico-Cortical
Connection Model
A
B
C
Vertical Features =
Frequency Multiplexing
to Multiple ROIs
Horizontal Features =
Cortico-Cortical Fiber System
Across Frequency
Long Distance Connections - C
'U' Shaped Fibers - B
ntra-Cortical Connections - A

LORETA Coherence




LORETA Absolute Phase
Left Brodmann Area 13
Right Brodmann Area 13
Distance from Brodmann Area 13
Amygdala
Hippocampus
D T A1 A2 B1 B2 B3 HB
0.00 18.64 37.27 55.91 74.54 93.18 111.82
Frequency Bands
(Delta to Hi-Beta)
Phase Difference (Deg)
(short to long differences)

Graph Theory and Neural Topology

1- A Node is the principle unit of a network in which nodes are connected (linked) to other *nodes*,

2- A Network consists of a number of nodes connected by links. Nodes are also called *vertices.*

3- A link is a connection between two nodes in the network. Links are also referred to as *edges* or simply *network connections. Axons are the links between neurons.*

4- The degree of a node is the number of nearest neighbors to which a node is connected. The mean degree of the network is the mean of the individual degrees of all nodes in the network.

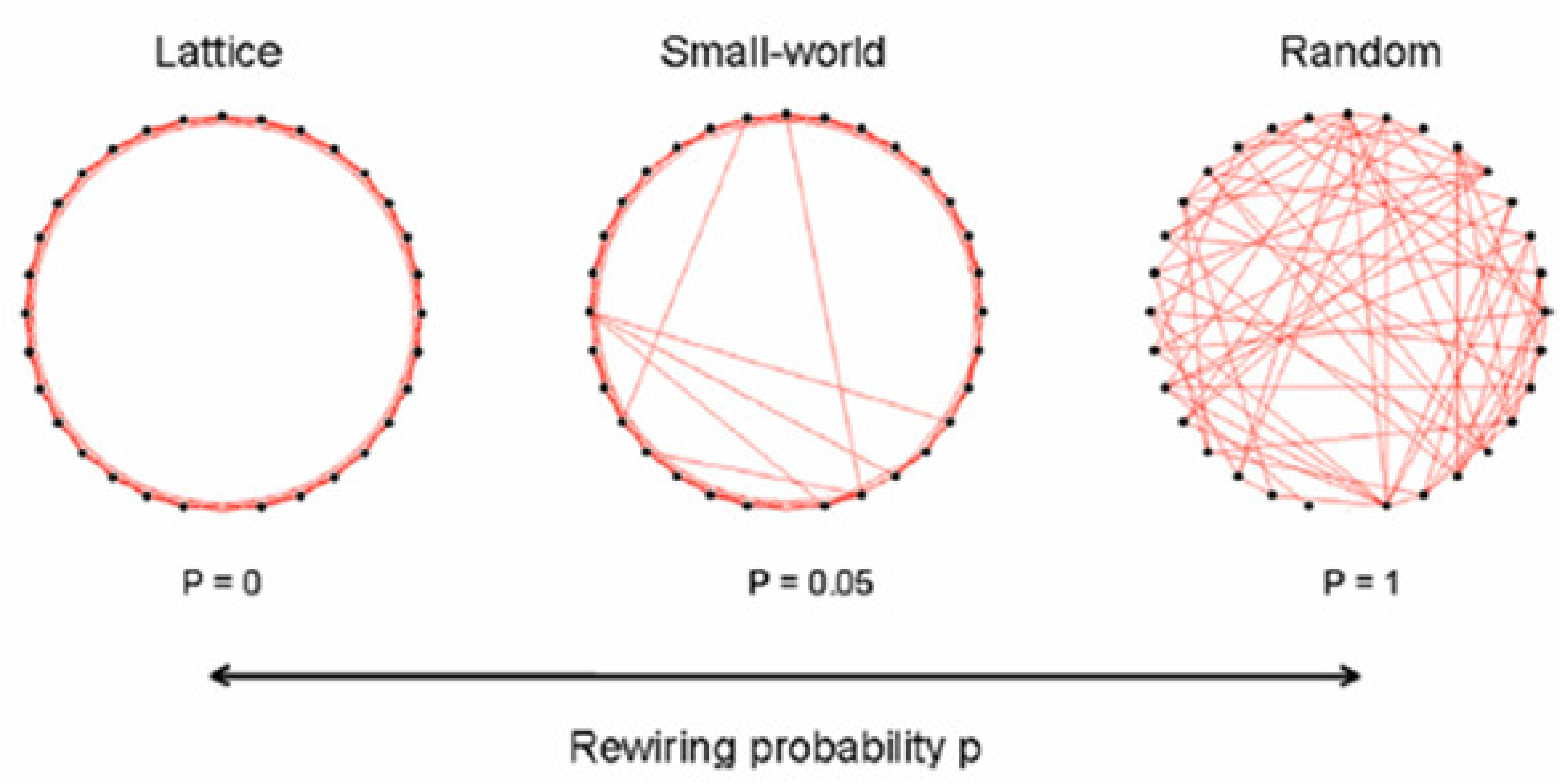
5- Modules are clusters of neurons with high density of nearest neighbors and are high degree nodes.

6- Hubs are regions that link distinct clusters or modules. Provincial hubs are hub regions that are highly connected within one module and connector hubs are hub regions that link multiple modules.

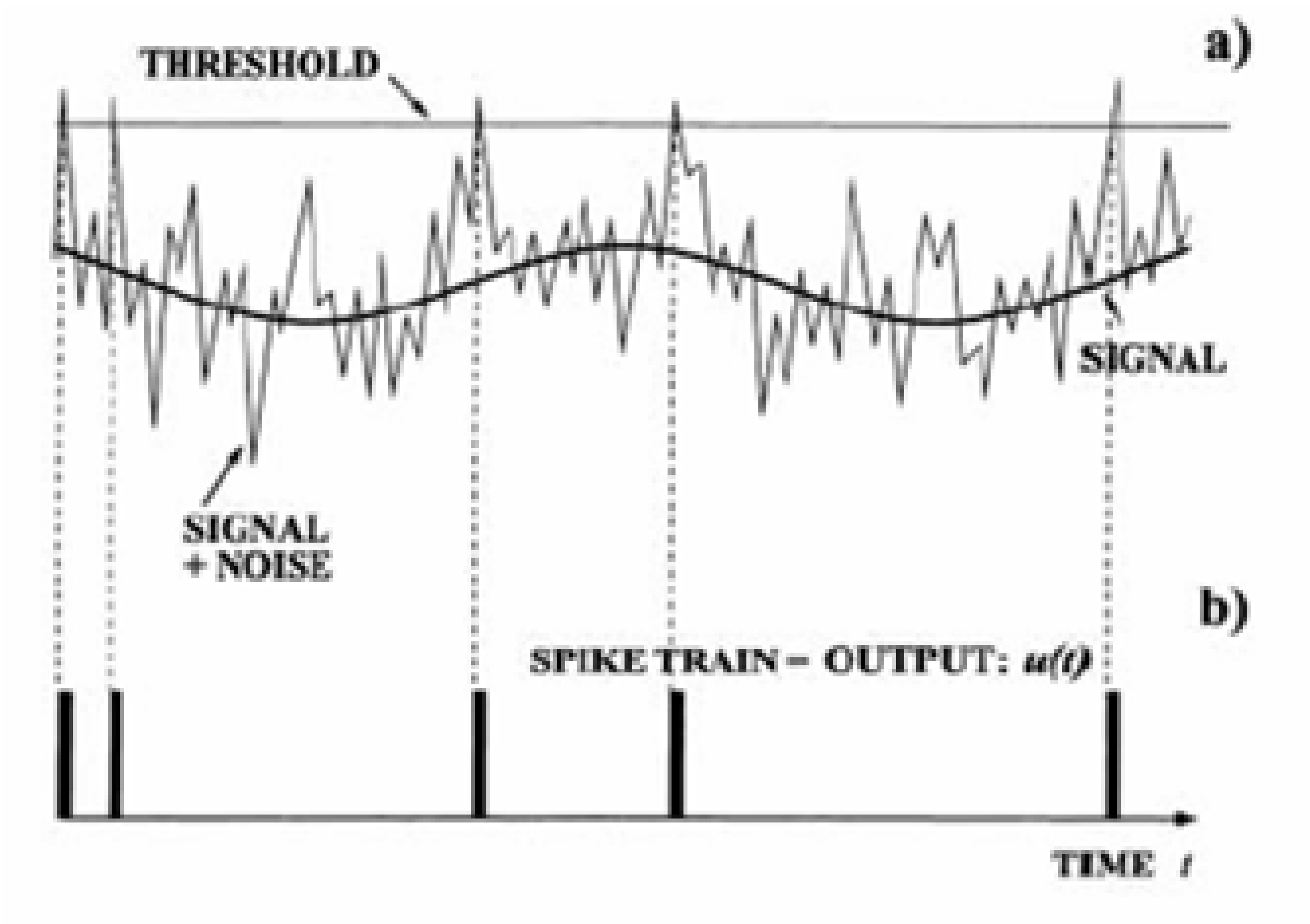
7- A scale-free network is where the distribution of node number follows a power law.

8- A specific pattern of links or connections defines the network's *Topology.*

Small world models emphasizes the intermediate position of total regularity and randomness where the small world model while containing random connections involves a small set of preferred long distance connections.



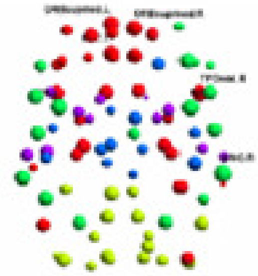
Noisy Ionic Channels, Action Potentials and Stochastic Resonance



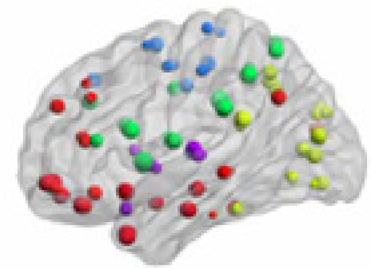
The 'Small-World' models are considered to be the best balance of these opposing factors.

Benefit: Increased brain size. Enlarging size by adding more neurons increases processing capacity. **Trade-offs:** Neurons consume a lot of energy. And as brains get bigger the axons or "wires" that connect neurons have to become longer, which makes them slower.
Benefit:: Increase interconnectedness. Adding more links between distant neurons enables brain parts to communicate better. **Trade-offs:** The added wiring eats up-energy and takes up space.
Benefit:: Increase signaling speed is achieved by making axons thicker. **Trade-offs:** Thicker axons consume more energy and take up more space than thinner ones do.
Benefit:: Pack more neurons in the existing space. Achievable by shrinking neurons or axons or both. **Trade-offs:** If axons or neurons get too small, they tend to fire randomly (stochastic resonance).

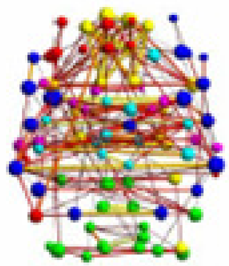
1) Brain Surface



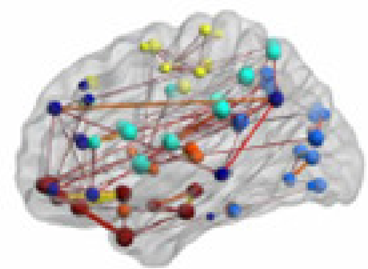
2) Nodes



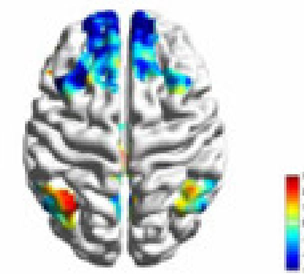
3) Surface & Nodes



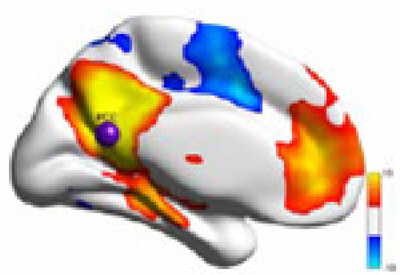
4) Nodes & Edges



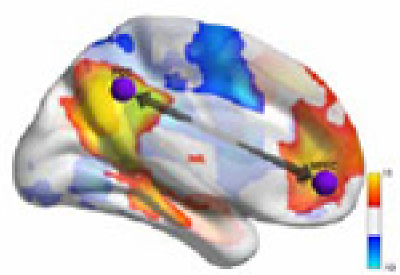
5) Surface, Nodes & Edges



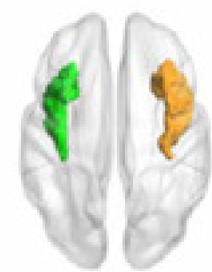
6) Surface mapping



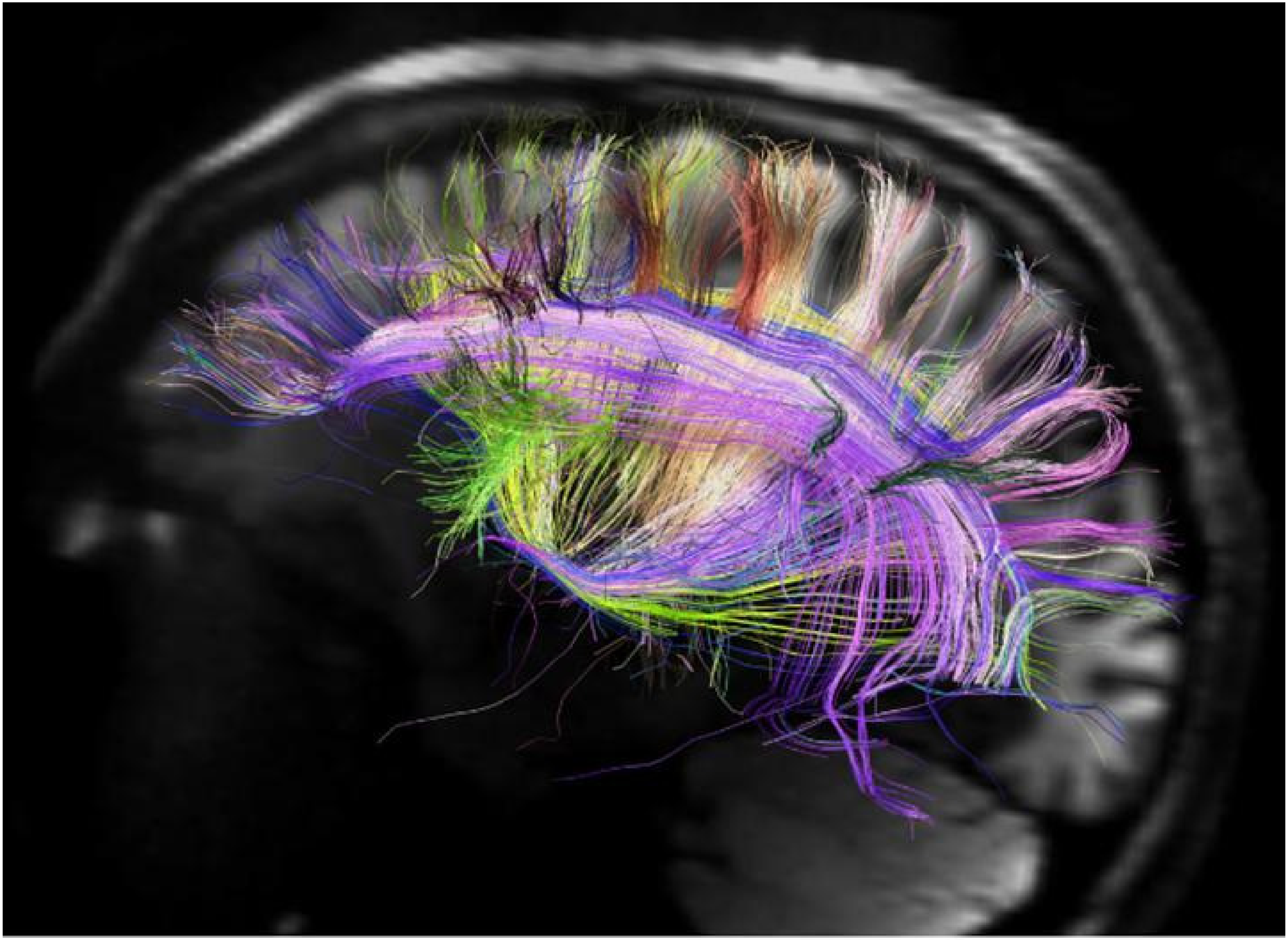
7) Surface mapping & node

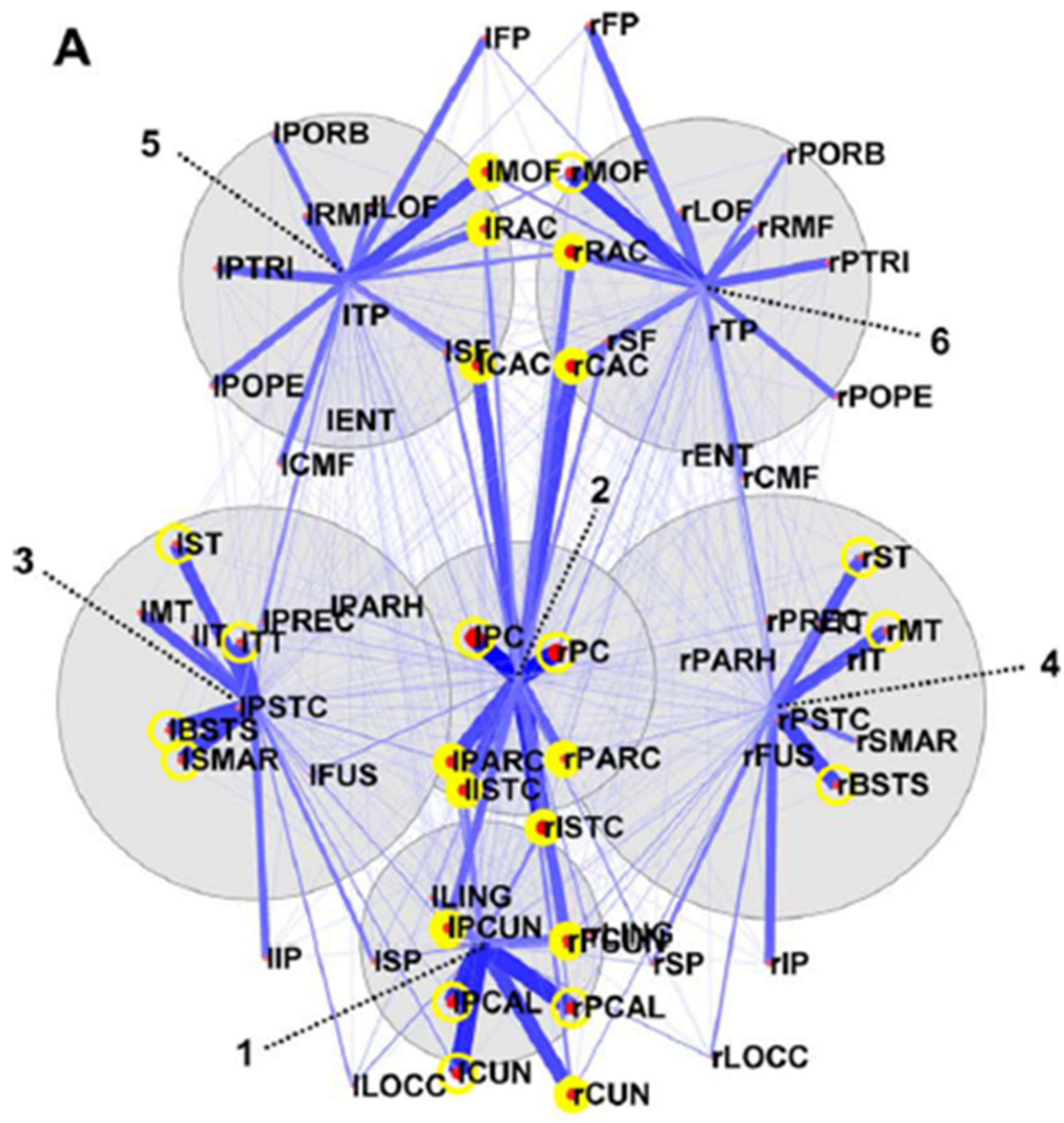


8) Surface mapping with node & edge



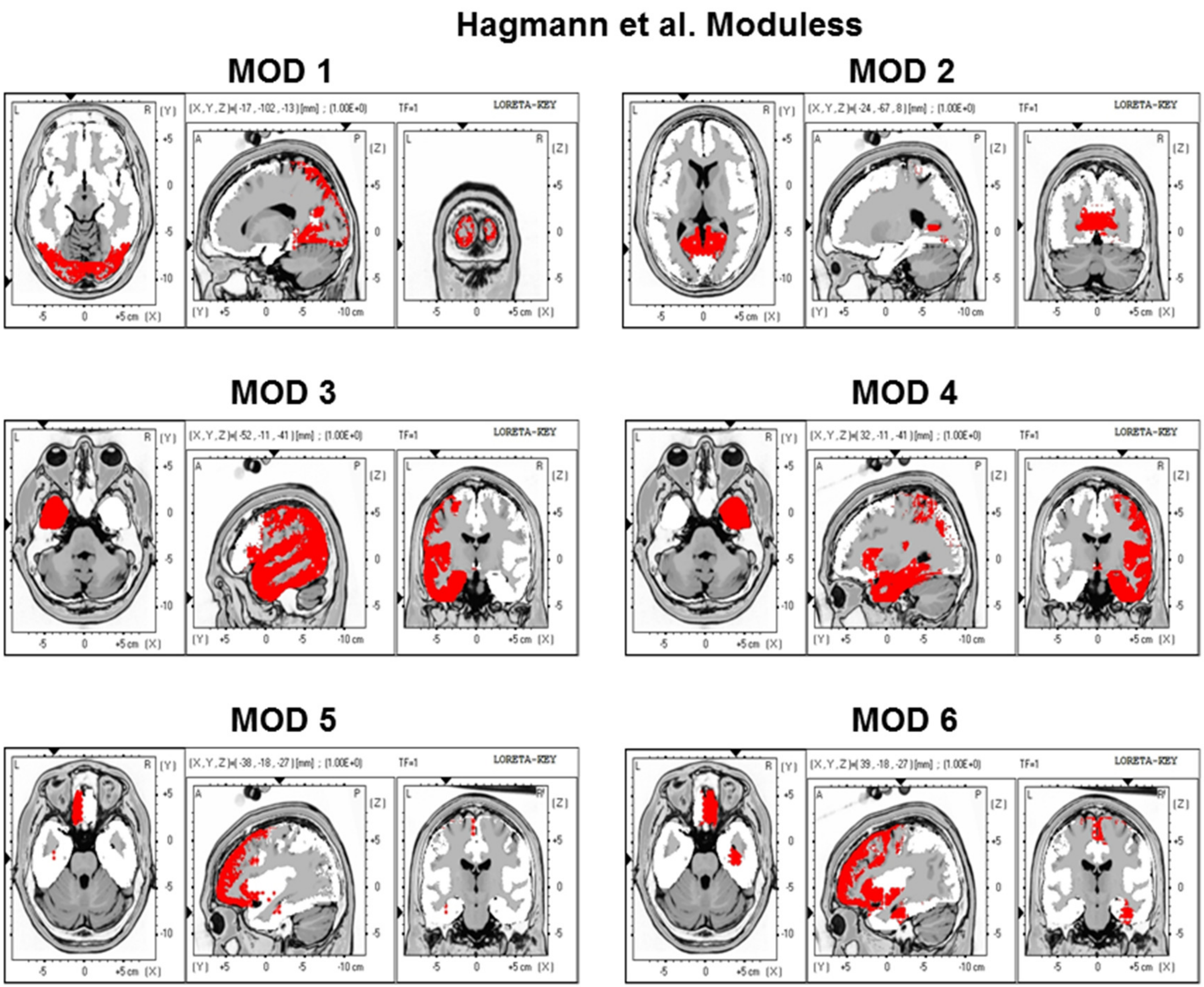
9) ROI in Volume

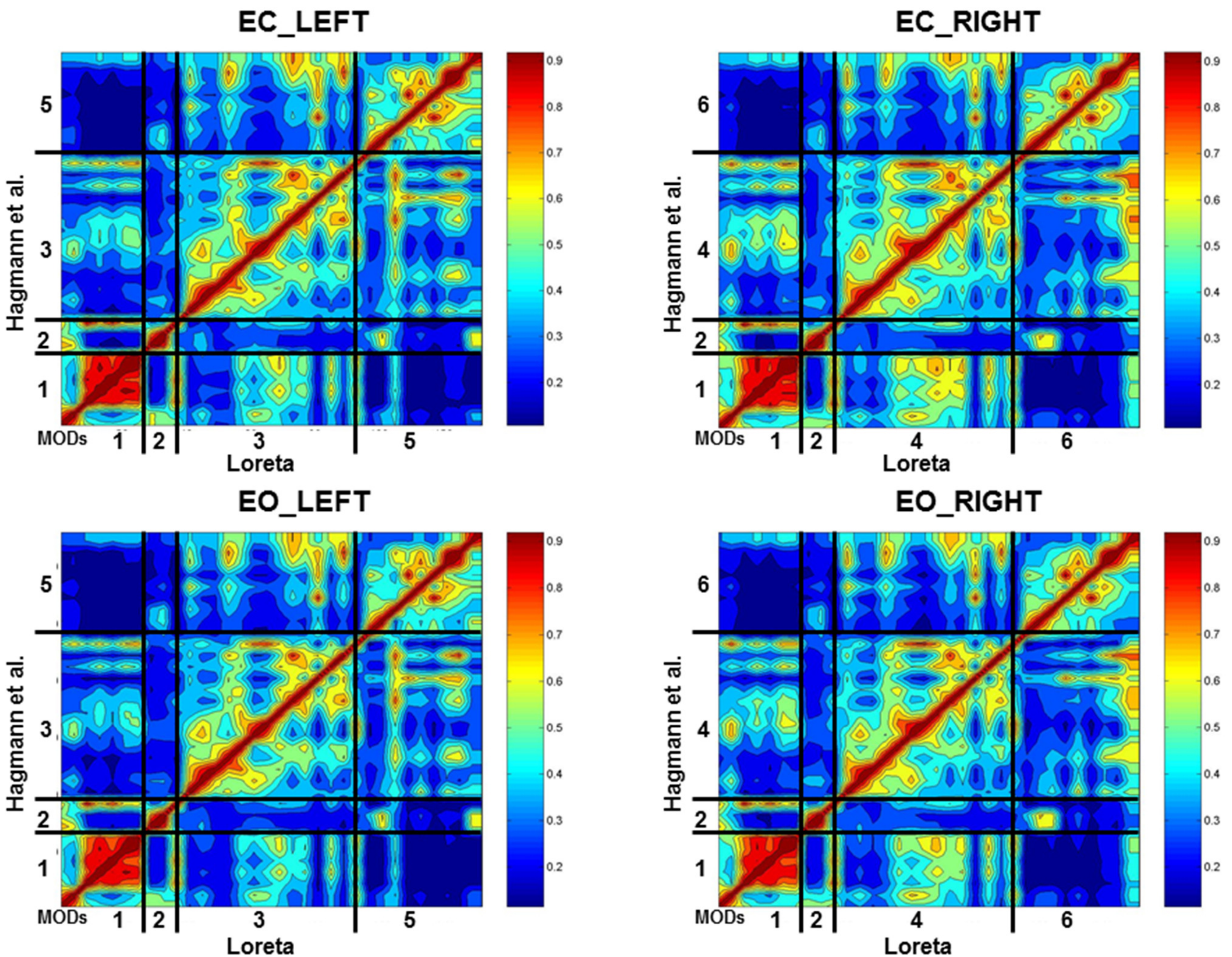


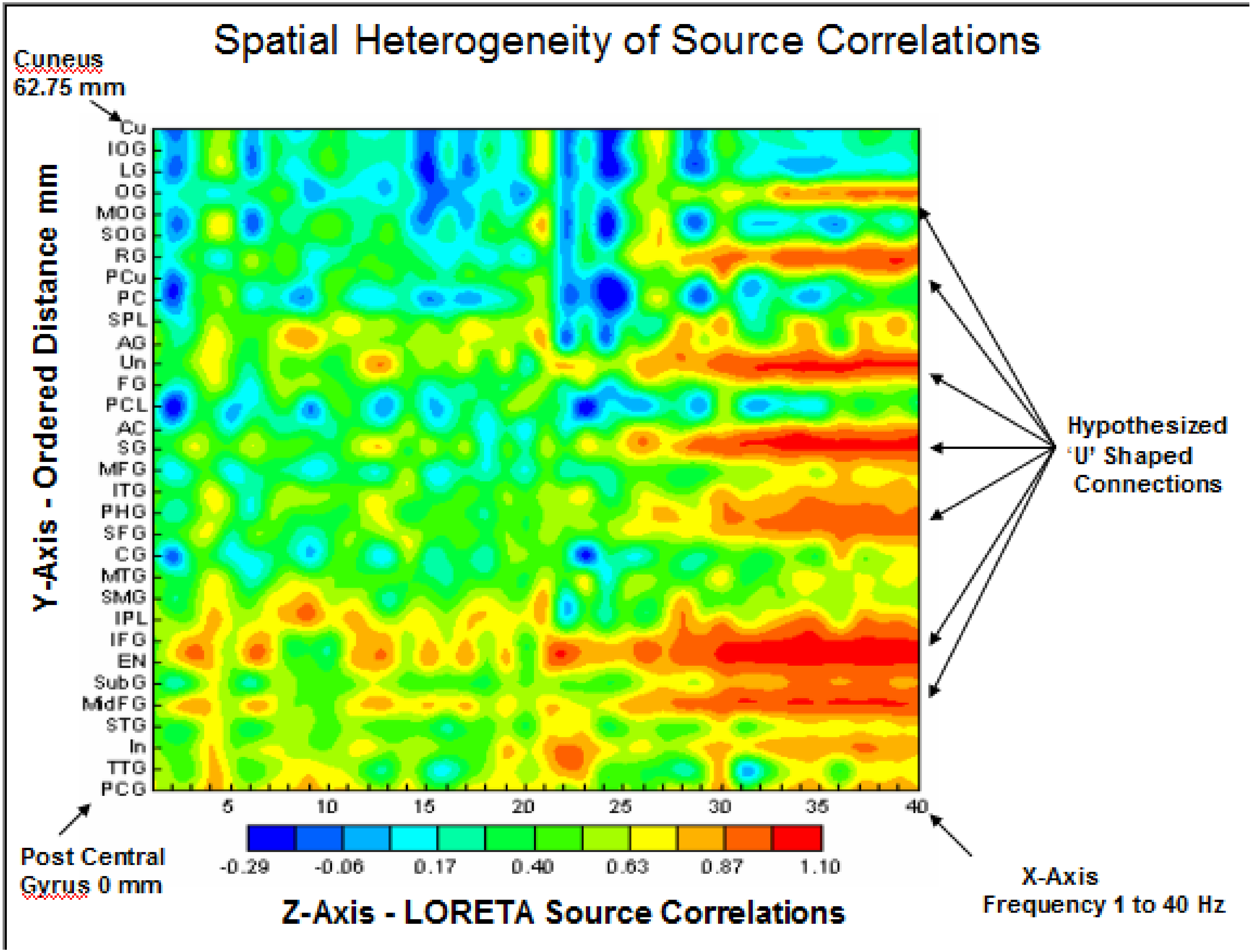


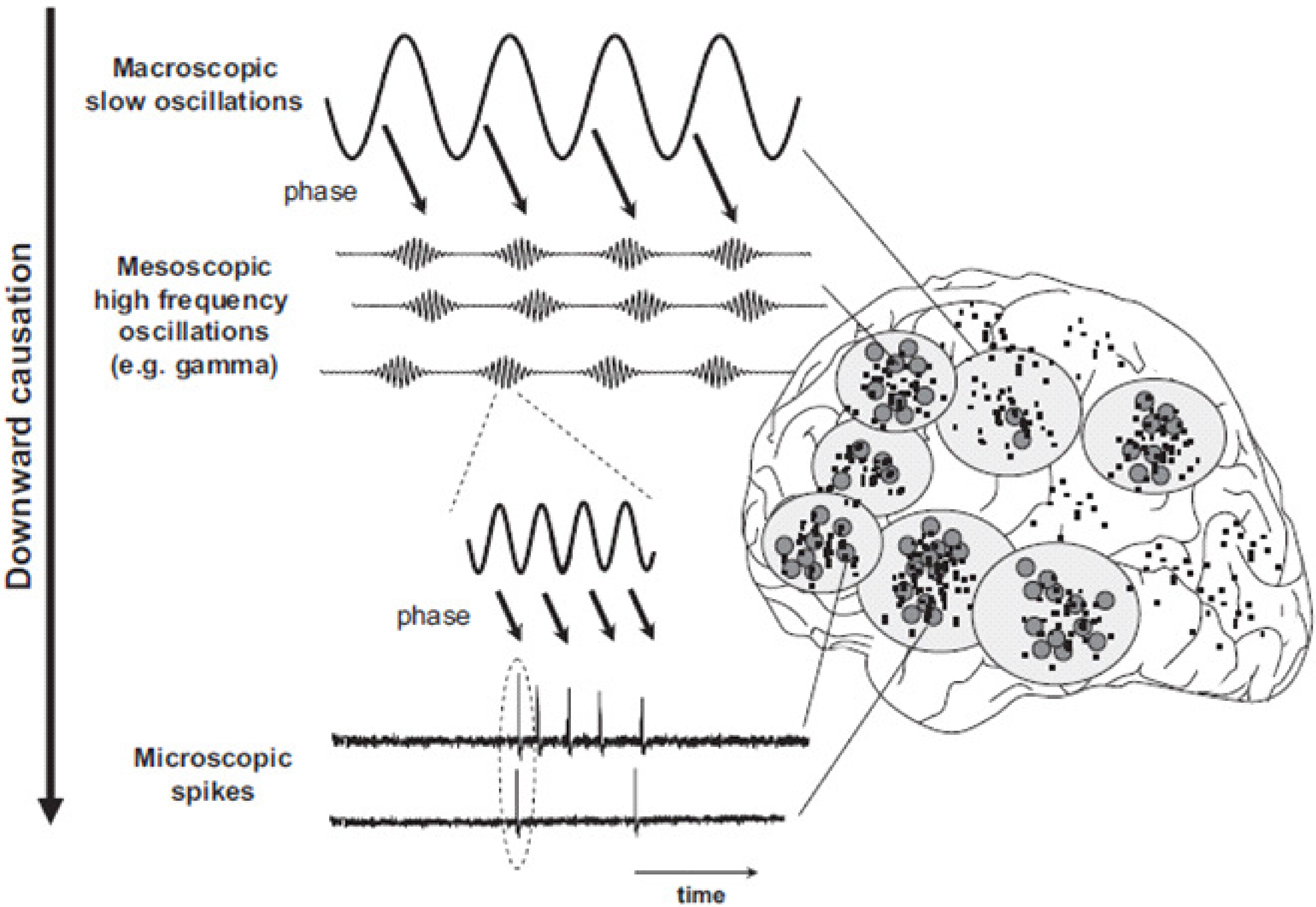
A
lFP
rFP
lPORB
rPORB
lMOF
rMOF
lRMF
lLOF
rLOF
rRMF
lRAC
rRAC
lPTRI
rPTRI
lTP
rTP
lSF
rSF
lCAC
rCAC
lPOPE
rPOPE
lENT
rENT
lCMF
rCMF
lST
rST
lMT
rMT
lIT
lTT
lPREC
lPARH
rPREC
lPC
rPC
rPARH
rIT
lPSTC
rPSTC
lBSTS
rBSTS
lSMAR
rSMAR
lFUS
rFUS
lPARC
rPARC
lISTC
rISTC
lLING
lPCUN
lIP
lSP
rSP
rIP
lPCAL
rPCAL
rLOCC
lLOCC
lCUN
rCUN
1
2
3
4
5
6

Correlations Between EEG Neuroimaging and Diffusion Spectral Imaging (DTI)




EC_LEFT
EC_RIGHT
EO_LEFT
EO_RIGHT
Hagmann et al.
MODs
Loreta
1
2
3
4
5
6
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2

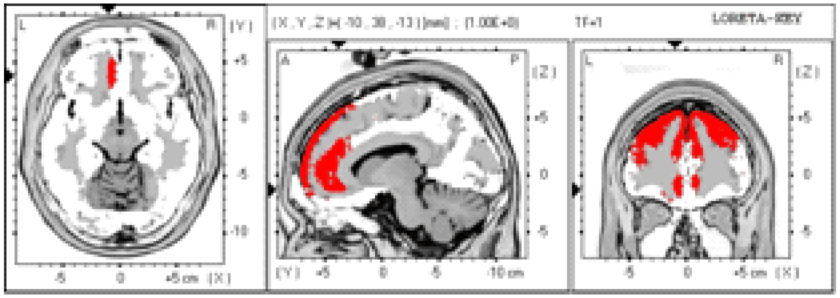

Spatial Heterogeneity of Source Correlations
Cuneus 62.75 mm
Cu
IOG
LG
OG
MOG
SOG
RG
PCu
PC
SPL
AG
Un
FG
PCL
AC
SG
MFG
ITG
PHG
SFG
CG
MTG
SMG
IPL
IFG
EN
SubG
MidFG
STG
In
TTG
PCG
Y-Axis - Ordered Distance mm
5
10
15
20
25
30
35
40
-0.29
-0.06
0.17
0.40
0.63
0.87
1.10
Hypothesized
'U' Shaped
Connections
Post Central Gyrus 0 mm
Z-Axis - LORETA Source Correlations
X-Axis
Frequency 1 to 40 Hz



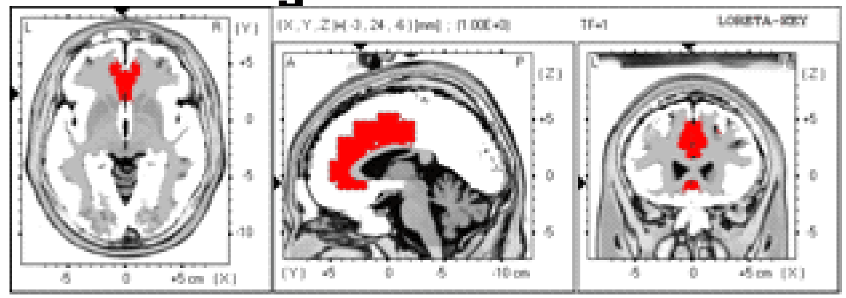
Downward causation
Macroscopic
slow oscillations
phase
Mesoscopic
high frequency
oscillations
(e.g. gamma)
phase
Microscopic
spikes
time

Loreta Default Brain Network

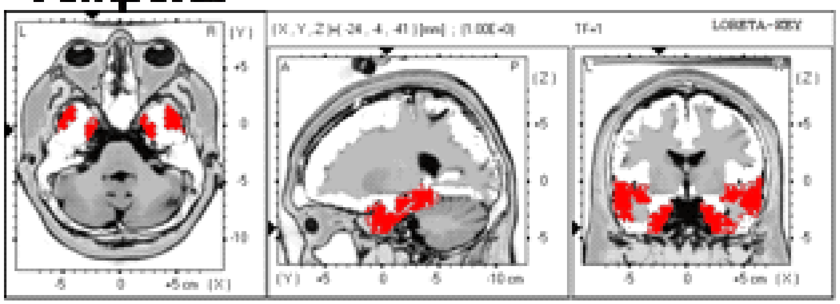
Frontal



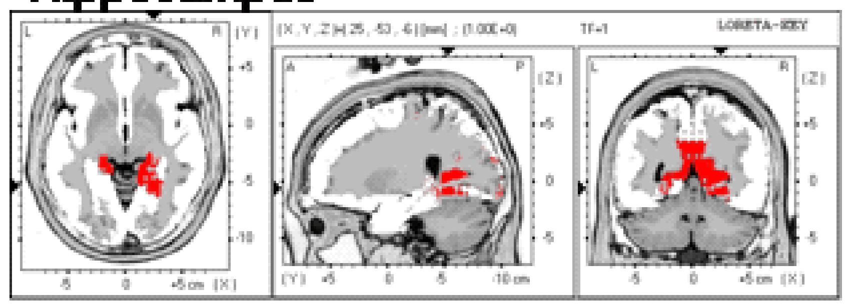
Anterior Cingulate



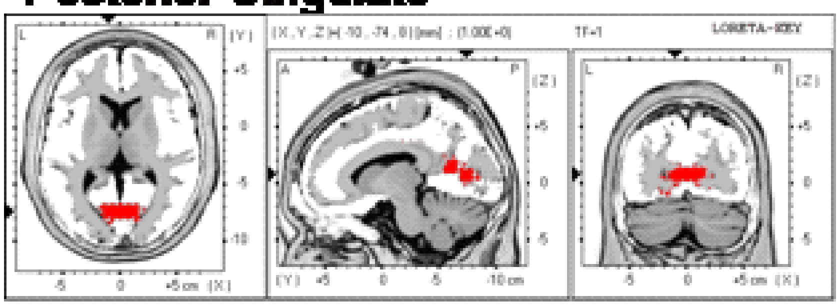
Temporal



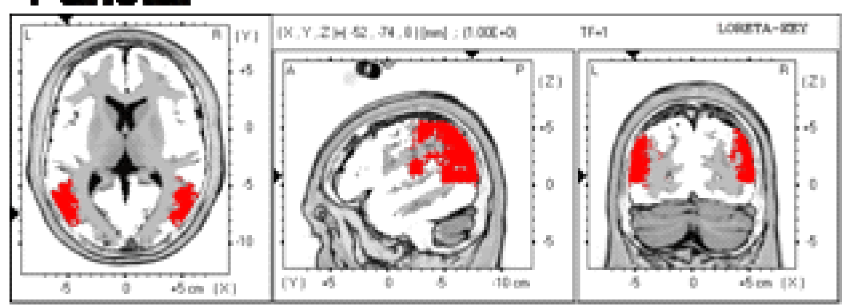
Hippocampus



Posterior Cingulate

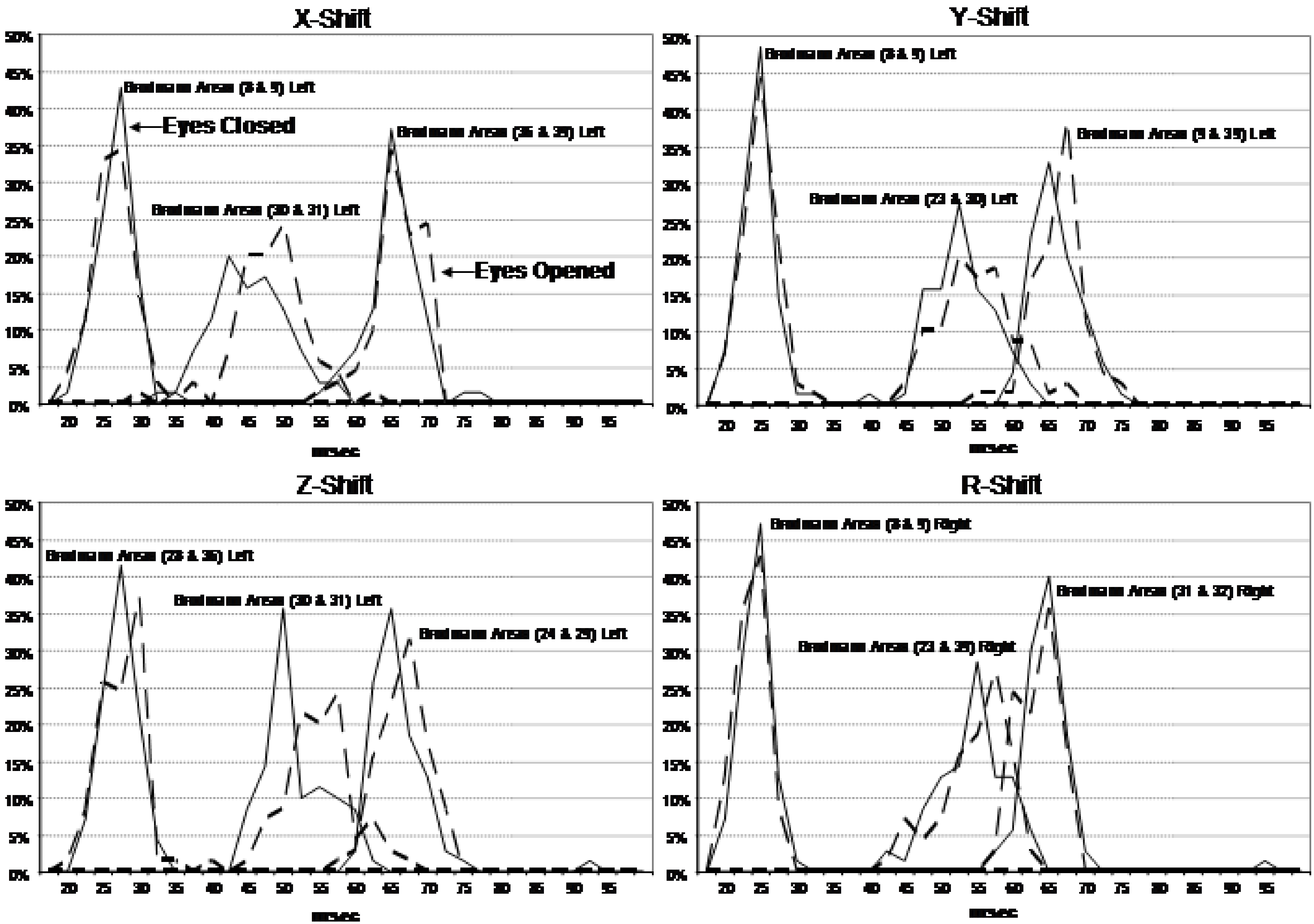


Parietal

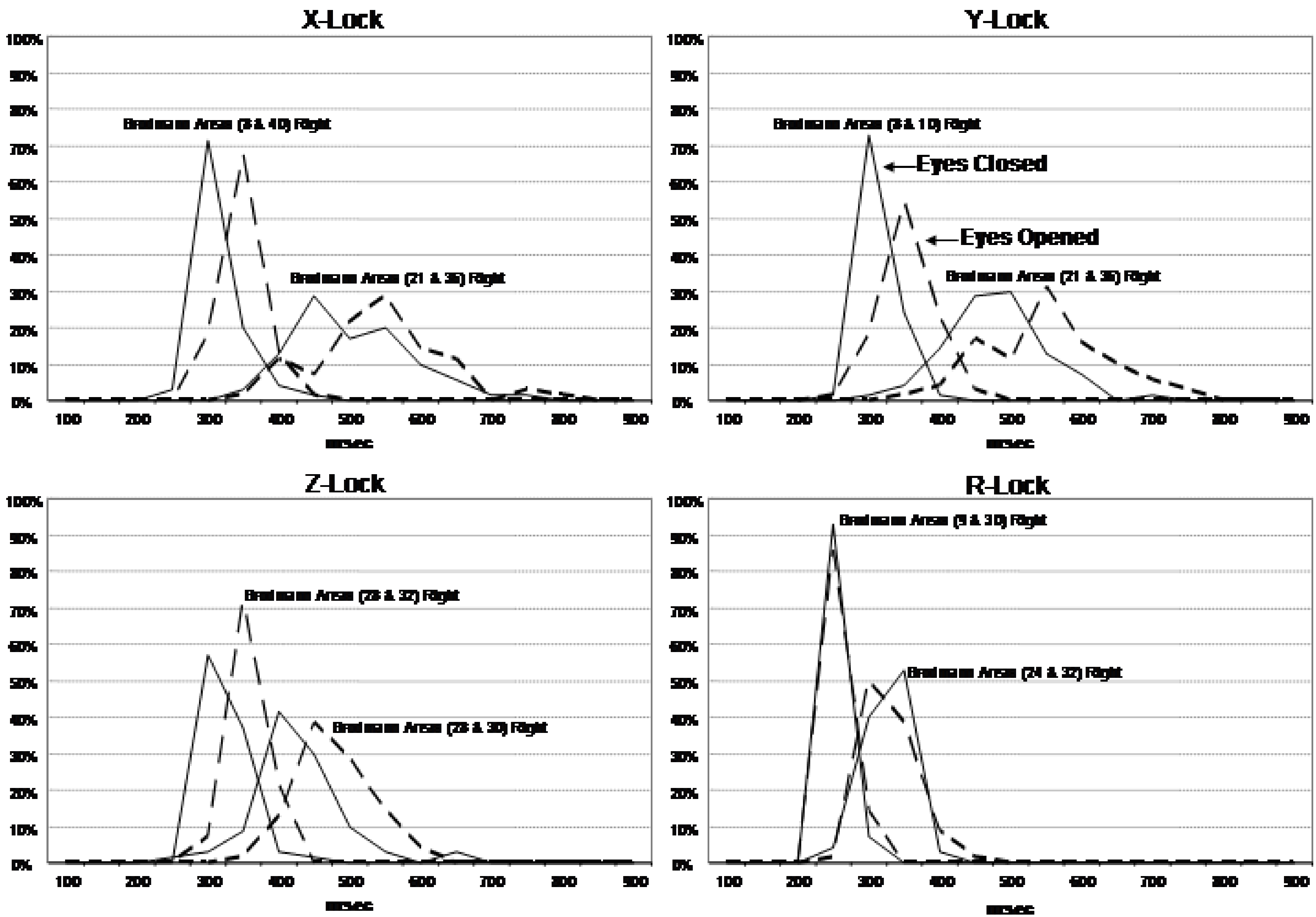



Phase Difference in Degrees
Phase Shift
BA 8L
BA 28L
BA 35L
BA 36L
BA 39L
:20
00:21
00:22
00:23
1st Derivative Deg/100 msec
Phase Shift Duration
BA 8L
BA 28L
BA 35L
Phase Lock
Duration
BA 36L
BA 39L
:20
00:21
00:22
00:23

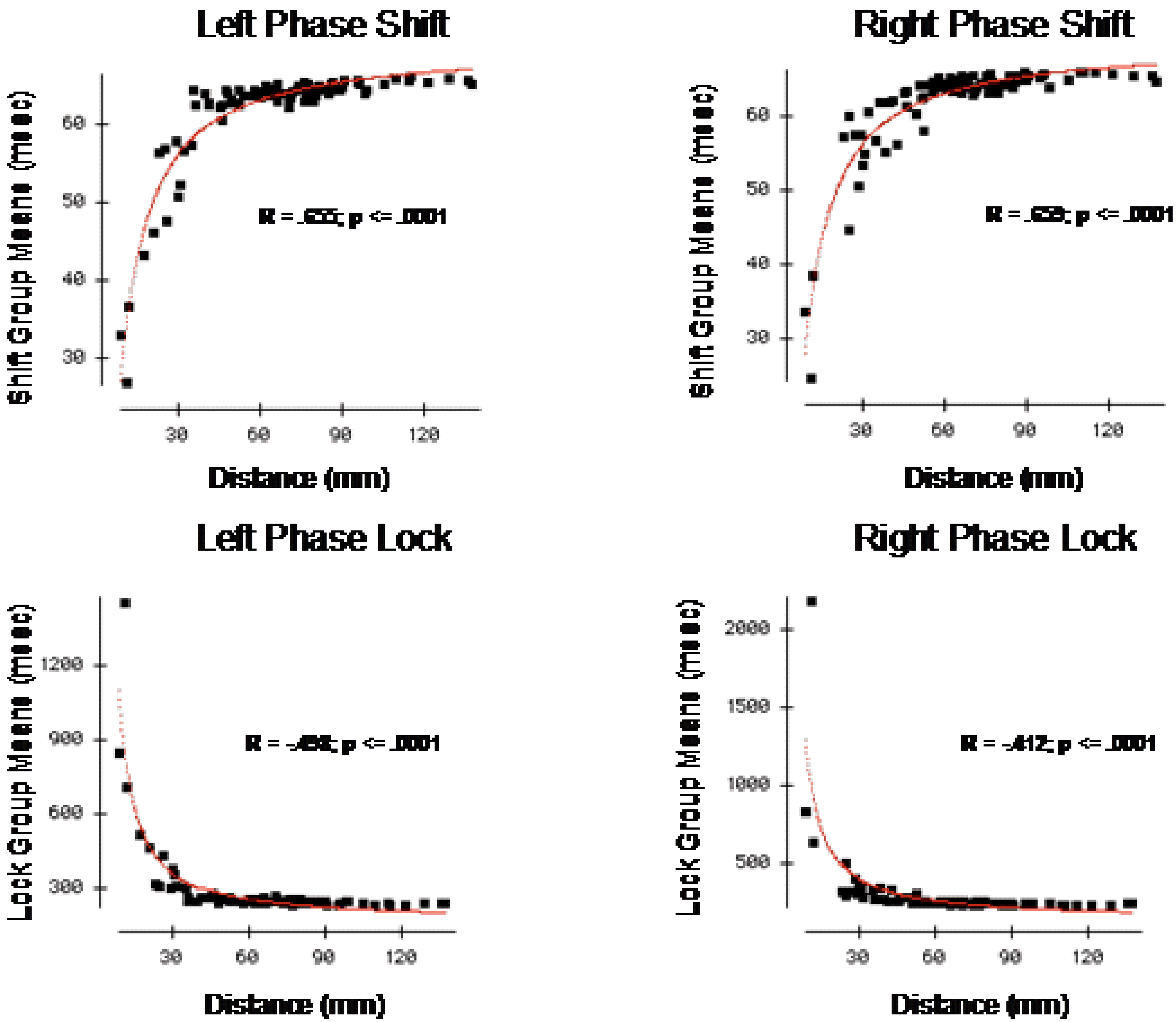
Phase Reset Shift Duration LORETA Default Brain Brodmann Area Pairs



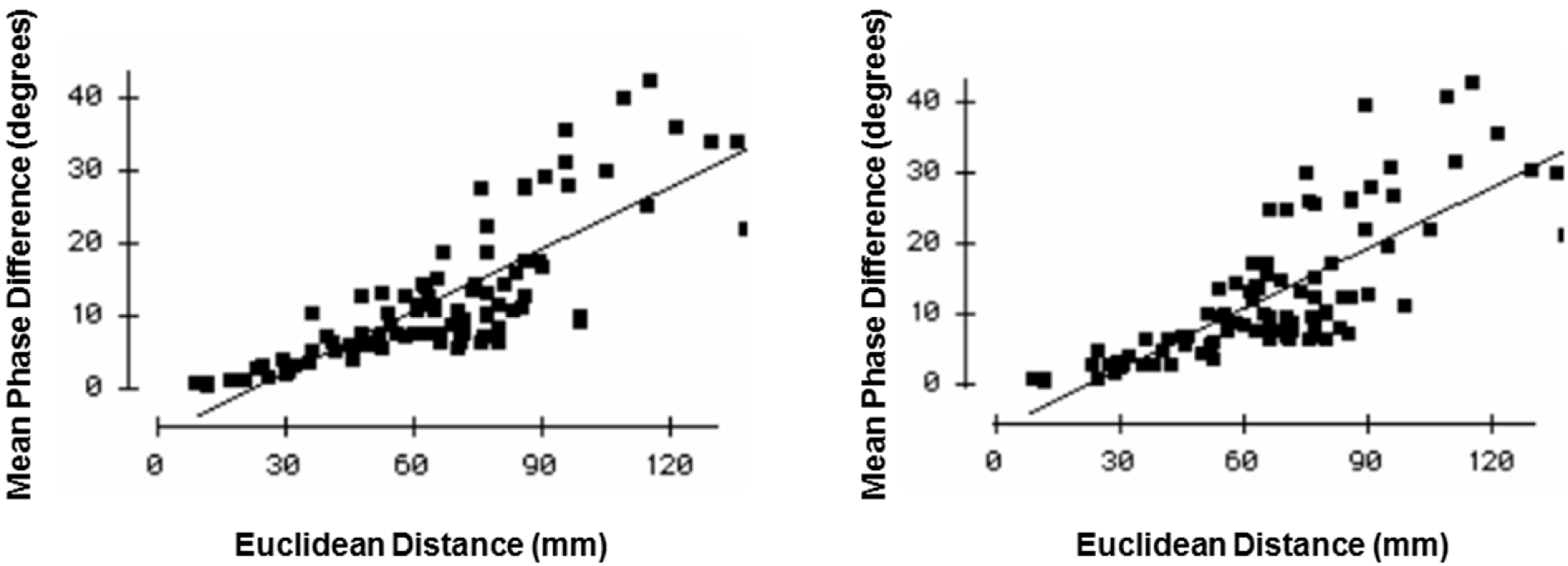
Phase Reset Lock Duration LORETA Default Brain Brodmann Area Pairs

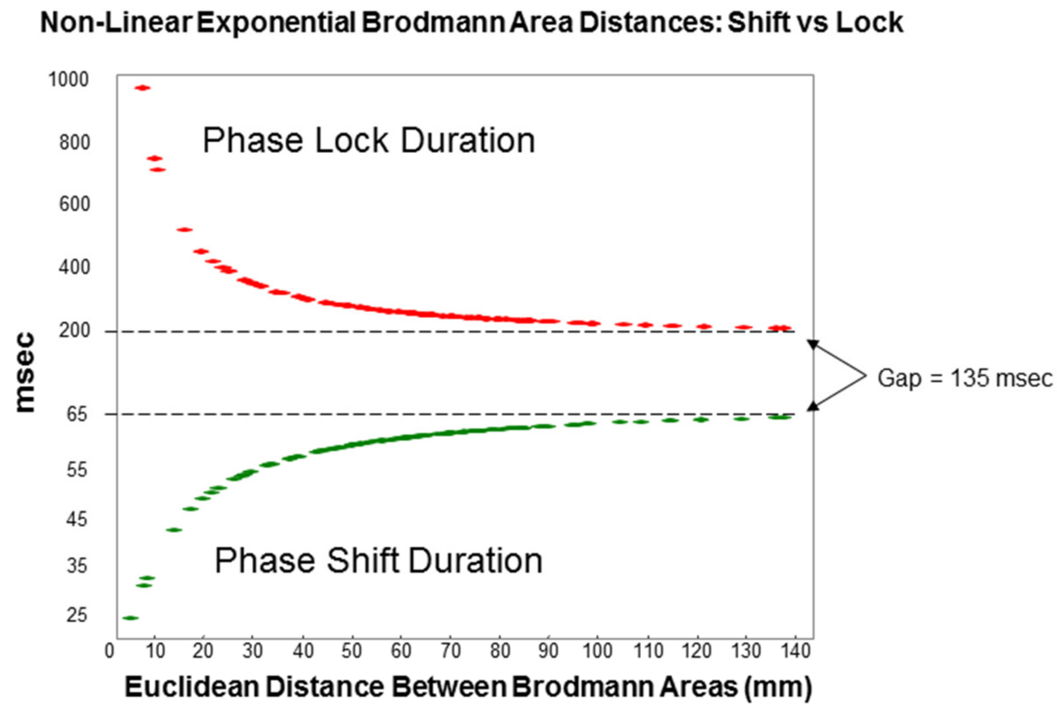


Relations Between Phase Reset Shift & Lock Means and the Euclidean Distance Between Voxels



Correlations of Default Brain Phase Difference with Euclidean Difference Distances





Non-Linear Exponential Brodmann Area Distances: Shift vs Lock
Phase Lock Duration
Phase Shift Duration
Gap = 135 msec
msec
1000
800
600
400
200
65
55
45
35
25
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Euclidean Distance Between Brodmann Areas (mm)

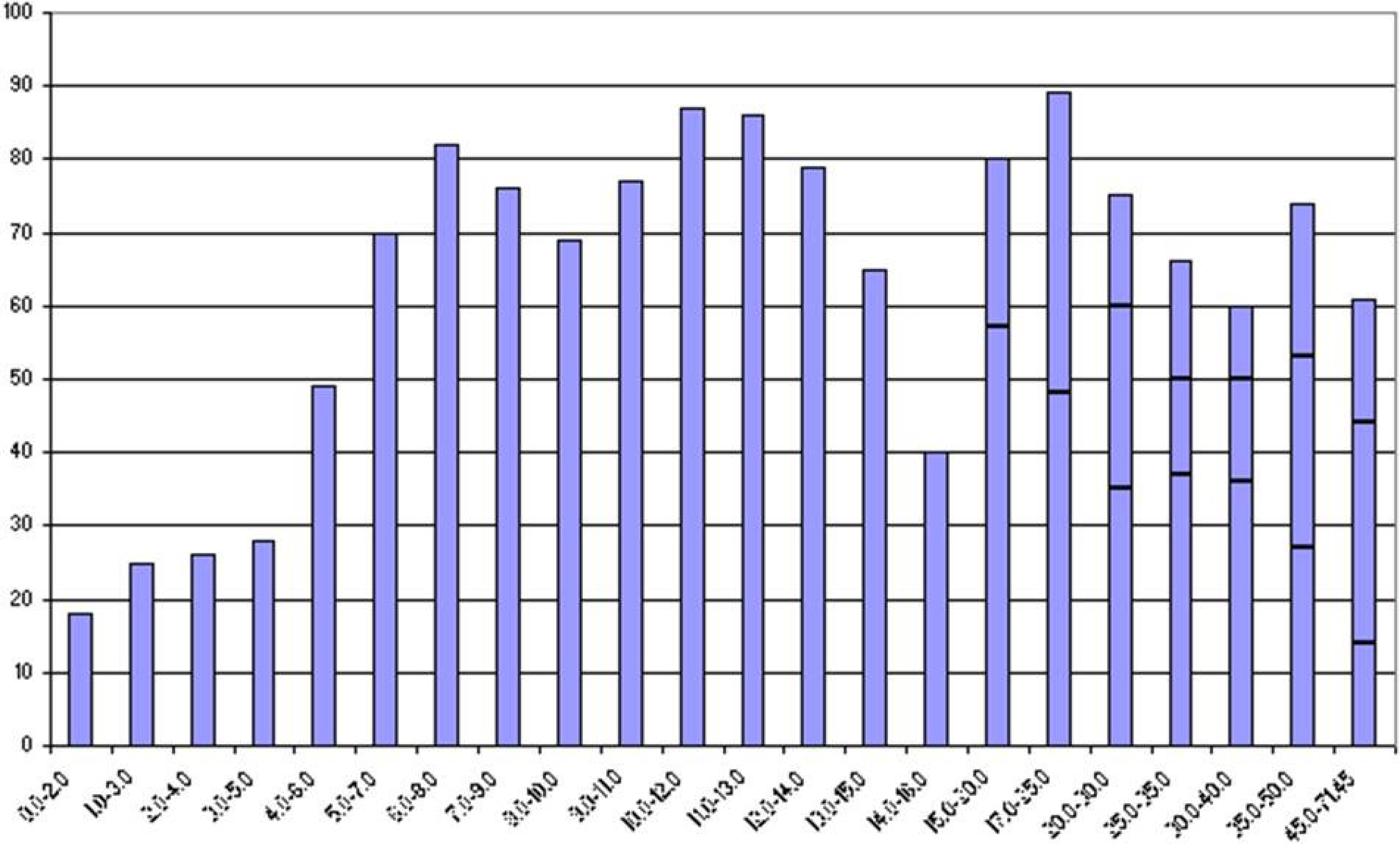
Published as a chapter in "Introduction to QEEG and Neurofeedback: Advanced Theory and Applications" Thomas Budzinsky, H. Budzinski, J. Evans and A. Abarbanel editors, Academic Press, San Diego, Calif, 2008.

HISTORY OF THE SCIENTIFIC STANDARDS OF QEEG NORMATIVE DATABASES

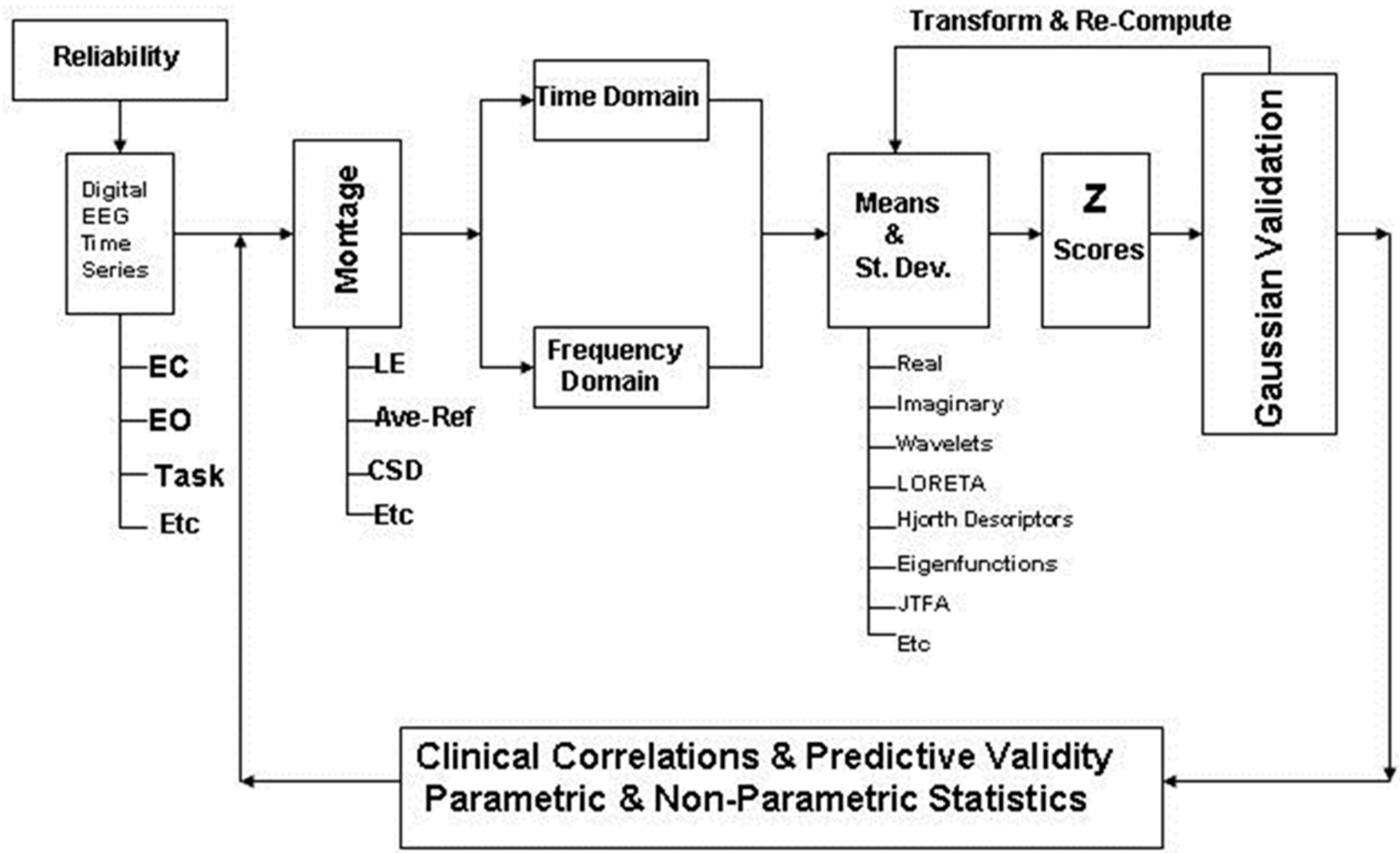
Thatcher, R.W. [1,2] and Lubar, J.F.[3]

Department of Neurology, University of South Florida College of Medicine, Tampa, Fl.[1] and EEG and NeuroImaging Laboratory, Applied Neuroscience, Inc., St. Petersburg, Fl[2] , Brain Research and Neuropsychology Lab, University of Tennessee, Knoxville, TN[3].

NORMATIVE DATABASE N = 727 Subjects as of 8/24/2011

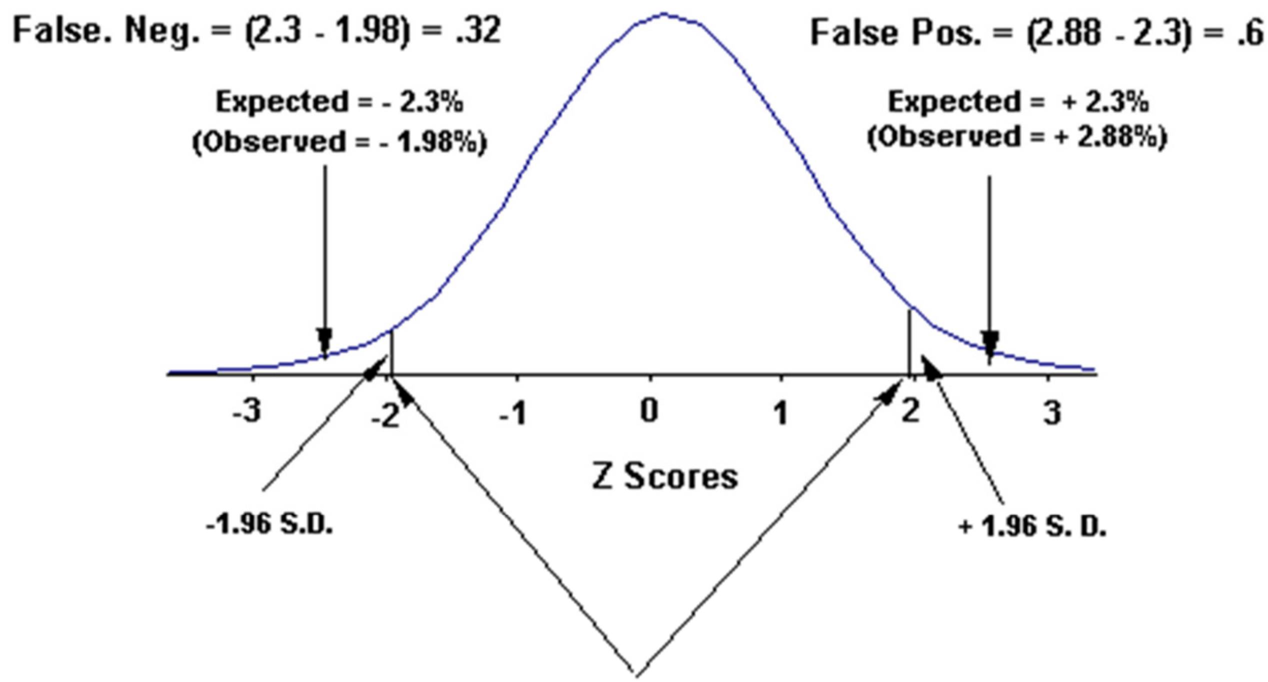


Normative Database Validation Steps



Sensitivity Based on Deviation from Gaussian

Cross-Validation Accuracy N = 625 Subjects

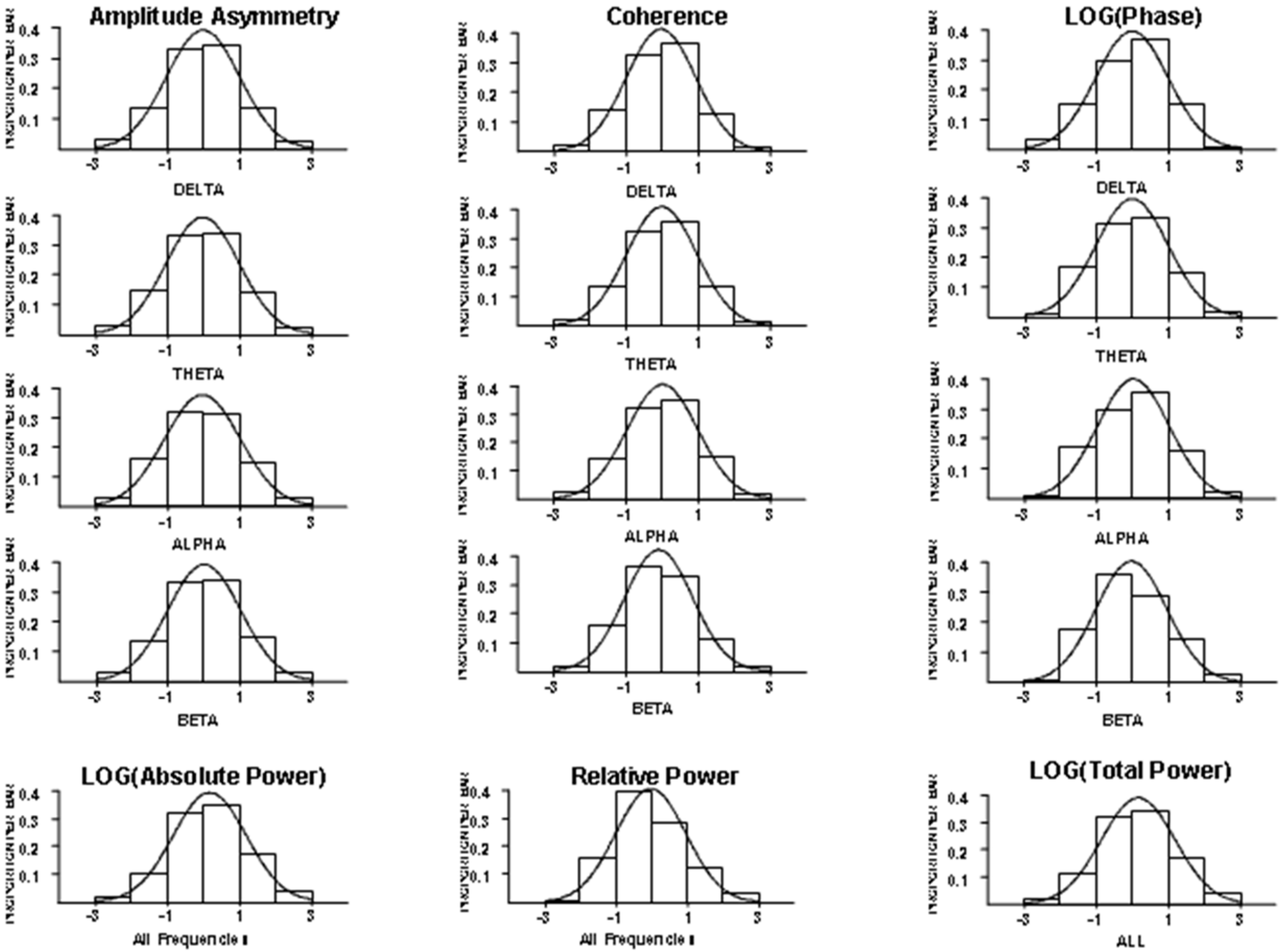


True Positive = (100 - (1.98 + 2.88) = 95.14%

$$\text{Sensitivity} = \frac{TP}{TP + (FP + FN)} = \frac{95.14}{95.14 + 1.0} = 98.96\%$$

$$\text{Specificity} = \frac{TN}{TN + (FP + FN)} = \text{Undefined}$$

Cross-Validation Birth to 82 Year EEG Normative Database



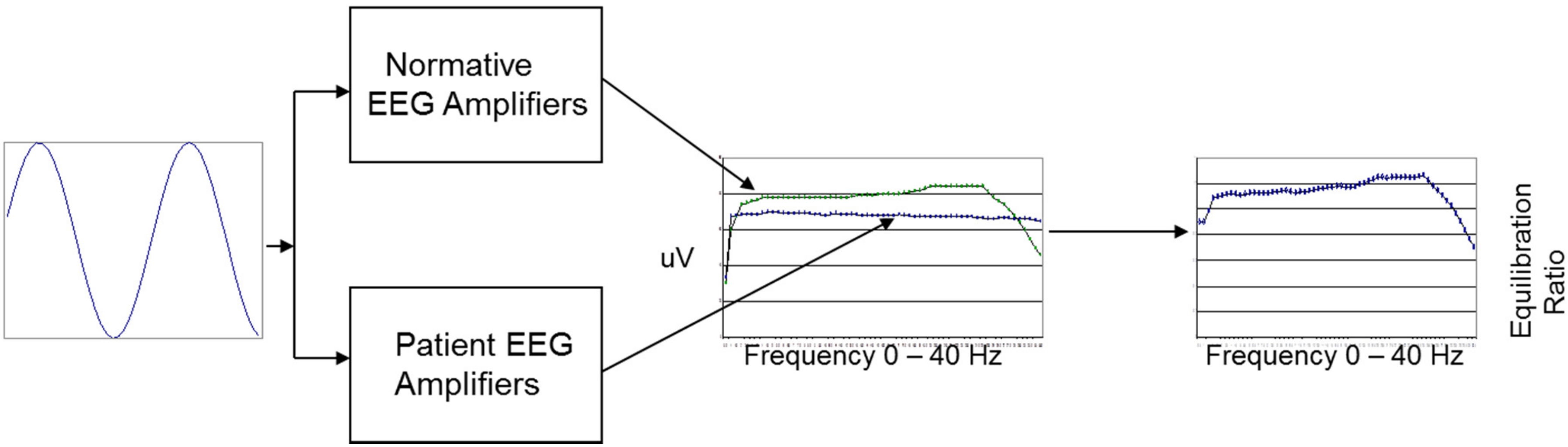
FFT Normative Database Sensitivities

2 STDEVs	CALC SENSITIVITY: FP=TP/(TP+FP) or FN=TP/(TP+FN)			
AGES	(+/- 2 SD)	(>= 2 SD)	(<= -2 SD)	
0-5.99	0.95448265	0.9771774	0.97730526	
6-9.99	0.95440363	0.9772031	0.97720054	**+/- 2 Std. Dev.**
10-12.99	0.9543997	0.97724346	0.97715624	
13-15.99	0.95440512	0.97723601	0.97716911	
16-ADULT	0.9543945	0.97718143	0.97721307	
ALL	0.95442375	0.97720714	0.97721661	

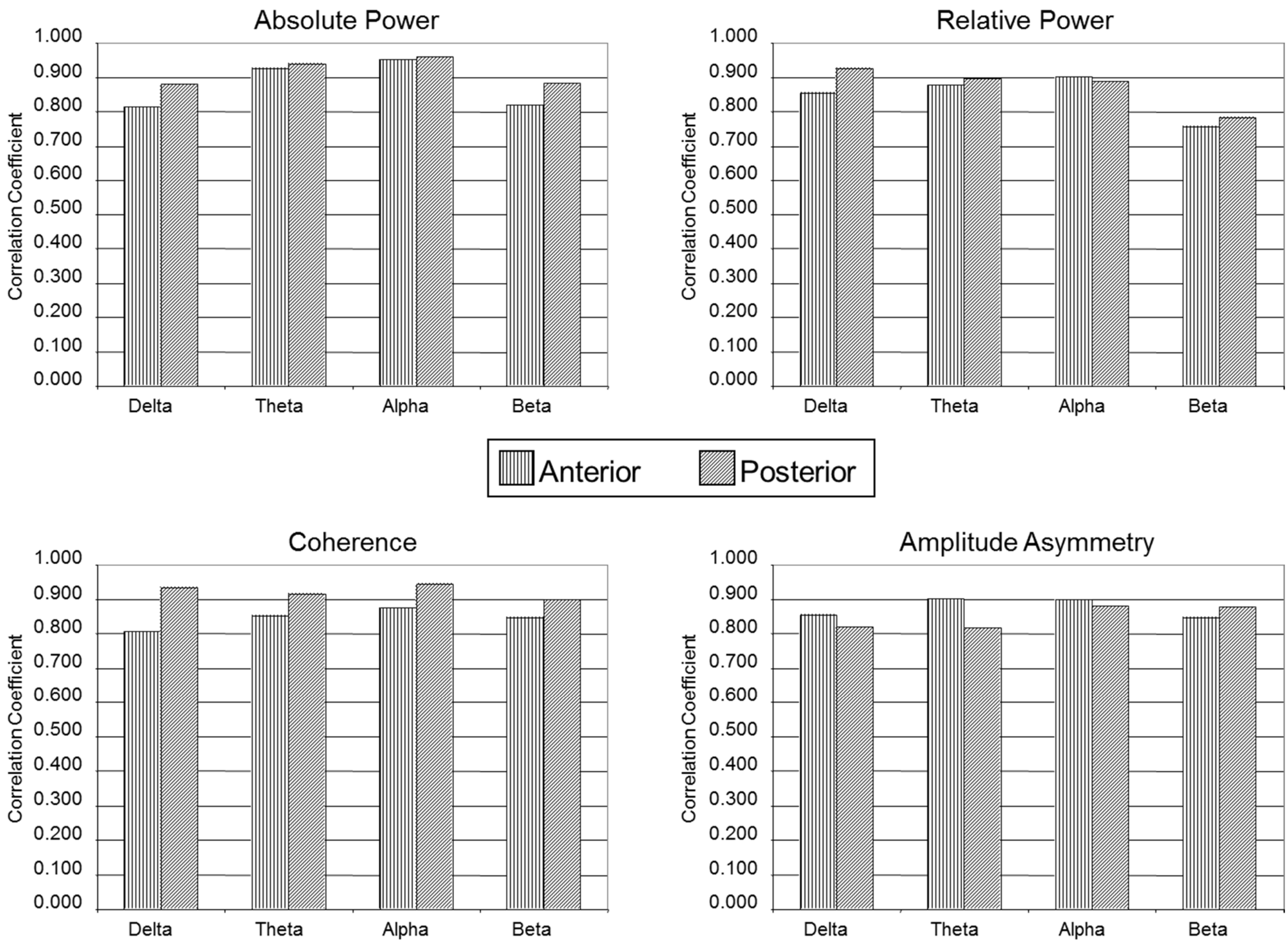
3 STDEVs	CALC SENSITIVITY: FP=TP/(TP+FP) or FN=TP/(TP+FN)			
AGES	(+/- 3 SD)	(>= 3 SD)	(<= -3 SD)	
0-5.99	0.99743898	0.99871123	0.99872774	
6-9.99	0.99744112	0.99871611	0.99872501	**+/- 3 Std. Dev.**
10-12.99	0.99744688	0.99873171	0.99871518	
13-15.99	0.99743186	0.99871951	0.99871234	
16-ADULT	0.99743835	0.99870216	0.99873619	
ALL	0.99744002	0.99871716	0.99872286	

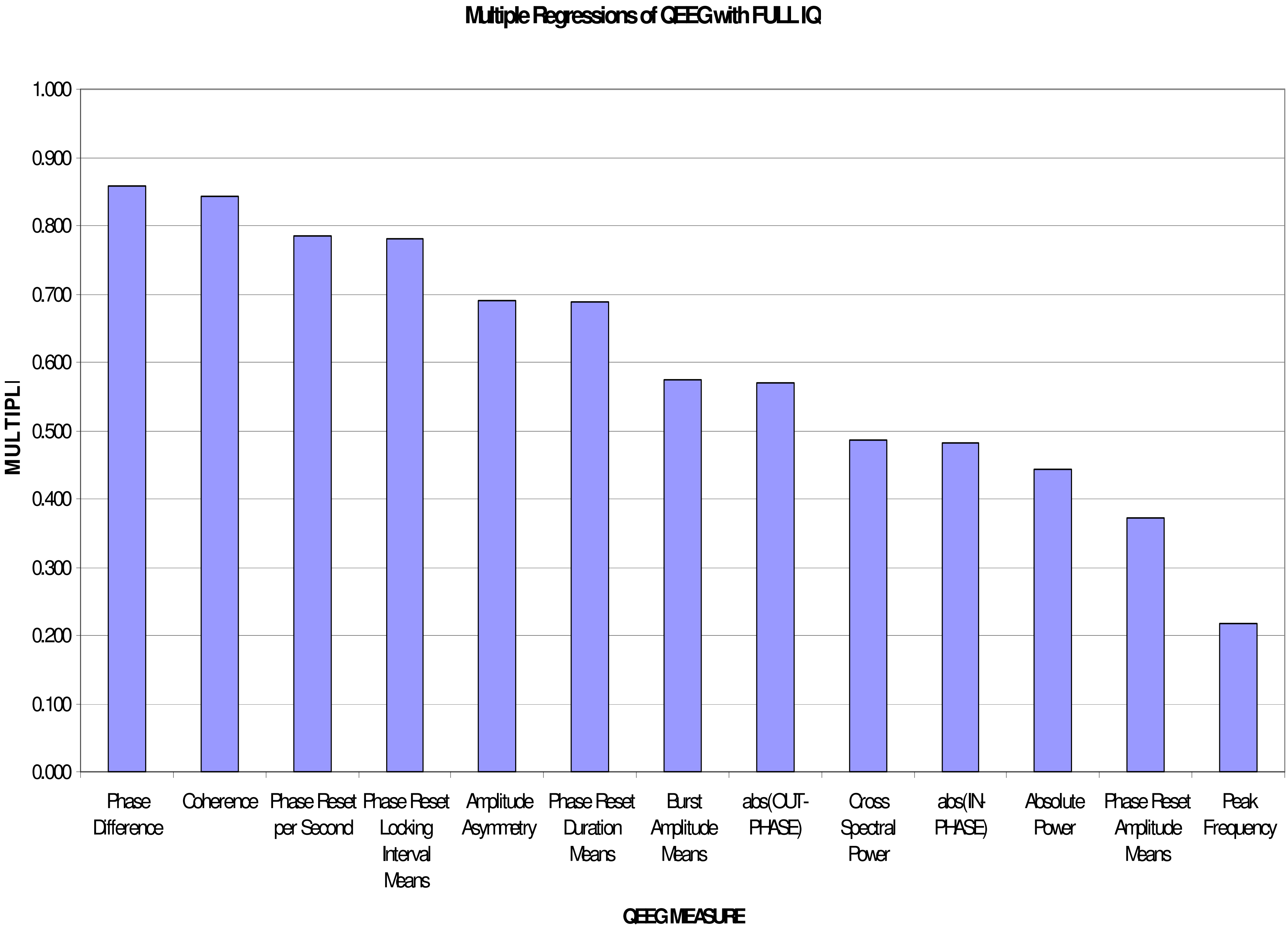
Normative Database Amplifier Matching – Microvolt Sine Waves 0 to 40 Hz

Equilibration Ratios to Match Frequency Responses



Cross-Validation of NeuroGuide vs NxLink





Multiple Regressions of QEEG with FULL IQ
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
MULTIPLI
Phase Difference
Coherence
Phase Reset per Second
Phase Reset Locking Interval Means
Amplitude Asymmetry
Phase Reset Duration Means
Burst Amplitude Means
abs(OUT-PHASE)
Cross Spectral Power
abs(IN-PHASE)
Absolute Power
Phase Reset Amplitude Means
Peak Frequency
QEEG MEASURE

Table IV
List of "Gold Standards" by which to judge
QEEG Normative databases

	Standards	Yes	No
1	Peer reviewed publications		
2	Amplifier Matching		
3	Artifact Rejection		
4	Test Re-Test Reliability		
5	Inclusion/exclusion criteria		
6	Adequate Sample size per age group		
7	Approximation to a Gaussian		
8	Cross-Validation		
9	Clinical Correlation		
10	FDA Registered		

Some Relevant Items and Questions

Loops in the Brain and Why Homeostasis and Equilibrium are Critical for Brain Function

The EEG is Produced Exclusively by Summated Synaptic Potentials

How does EEG Biofeedback Change the EEG?

How does EEG Biofeedback Change Synaptic Potentials?

What are the Mechanisms of Modification of Synapses by Operant Conditioning of EEG at the Molecular Level? (nu. Accumbens & reinforcement)

Eric Kandel "In Search of Memory" Norton & Co., 2006 – Nobel Prize 2000

Gyorgy Buzsaki "Rhythms of the Brain", Oxford Univ. Press, 2006

Essentials of Operant Conditioning

1- There must be a 'real' & 'valid' neural event to be reinforced

2- The 'Reinforcement' must be distinct and clear

3- The interval of time between the spontaneous 'emitted event' & the 'reinforcement' can not be too short, approx. < 250 msec? or too long approx. > 20 sec

4- The Schedule of Reinforcement is Important with two General Types "Continuous' vs 'Partial' Reinforcement - Continuous is good at the beginning but not as resistent to extinction as is Partial Reinforcement

A General Theory of EEG Operant Conditioning and Z Score Biofeedback

Definitions

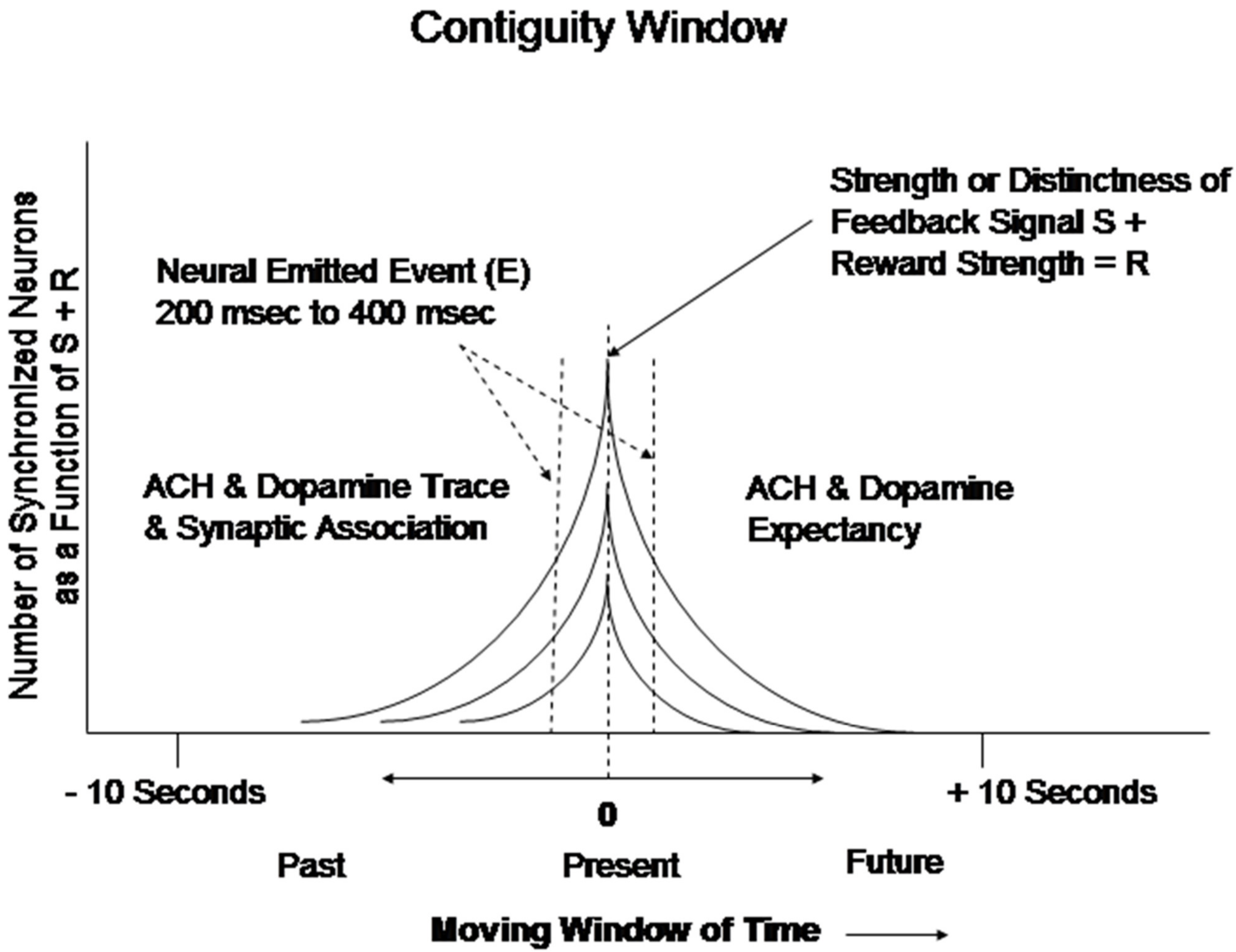
1- Duration of Spontaneous EEG Event (E) = Neural State Interval (I)

2- Contiguity Window (C) = Time period preceding and following a E

3- Reward Signal (S) = Feedback signal time locked to E

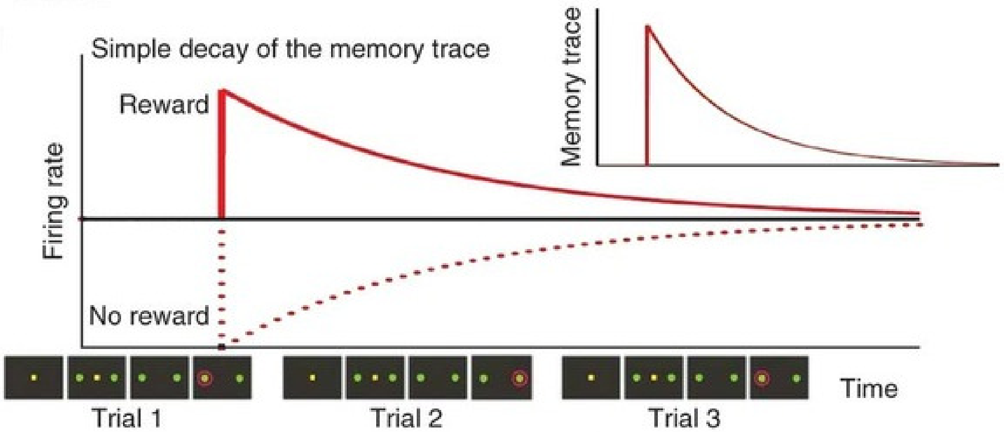
4- Reward Strength (R) = Value of the reward if N successes occur in an interval of time, e.g., toys, candy, cookies, money, etc.

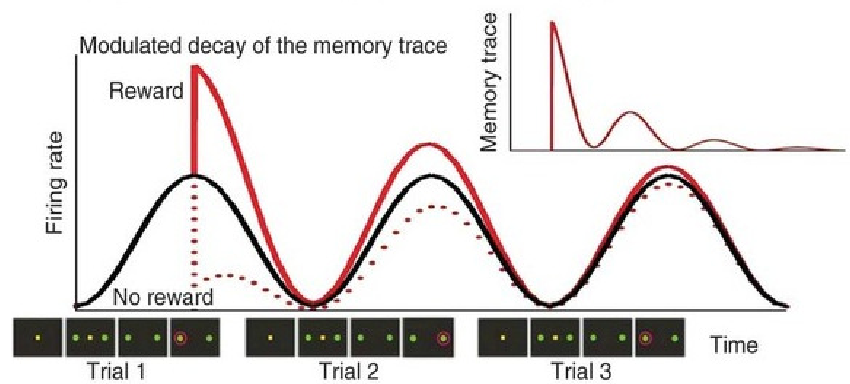
Category	Measurement
Duration of Spontaneous EEG Event (E)	Neural State Interval (I) (msec)
Contiguity Window (C)	Time preceding/following E (msec – sec)
Reward Signal (S)	Feedback signal time locked to E (msec)
Reward Strength (R)	Ordinal or Nominal measure

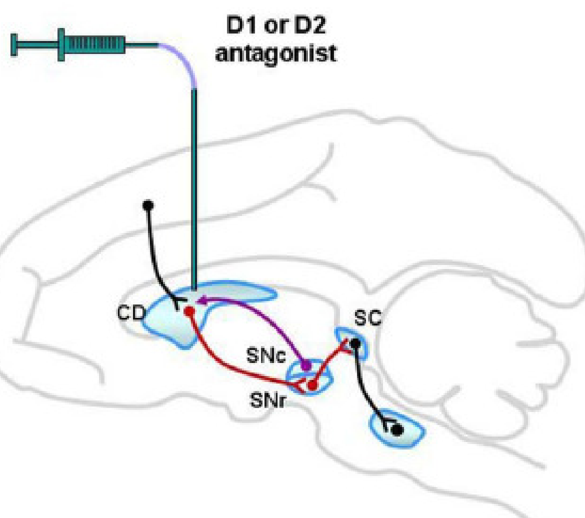


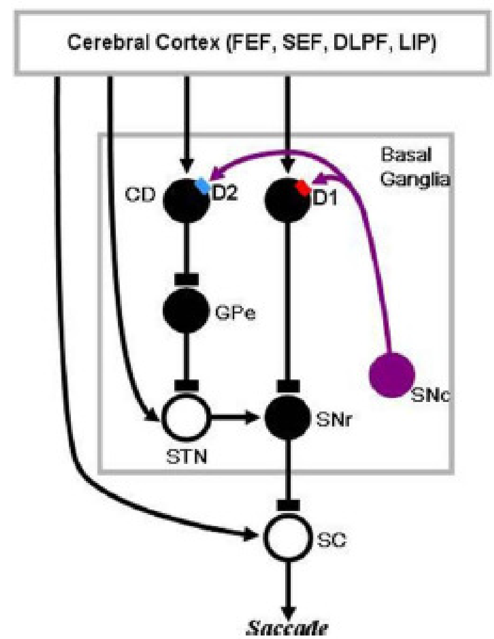
Contiguity Window
Number of Synchronized Neurons as a Function of S + R
Strength or Distinctness of Feedback Signal S + Reward Strength = R
Neural Emitted Event (E) 200 msec to 400 msec
ACH & Dopamine Trace & Synaptic Association
ACH & Dopamine Expectancy
- 10 Seconds
+ 10 Seconds
0
Past
Present
Future
Moving Window of Time

EEG Neurofeedback

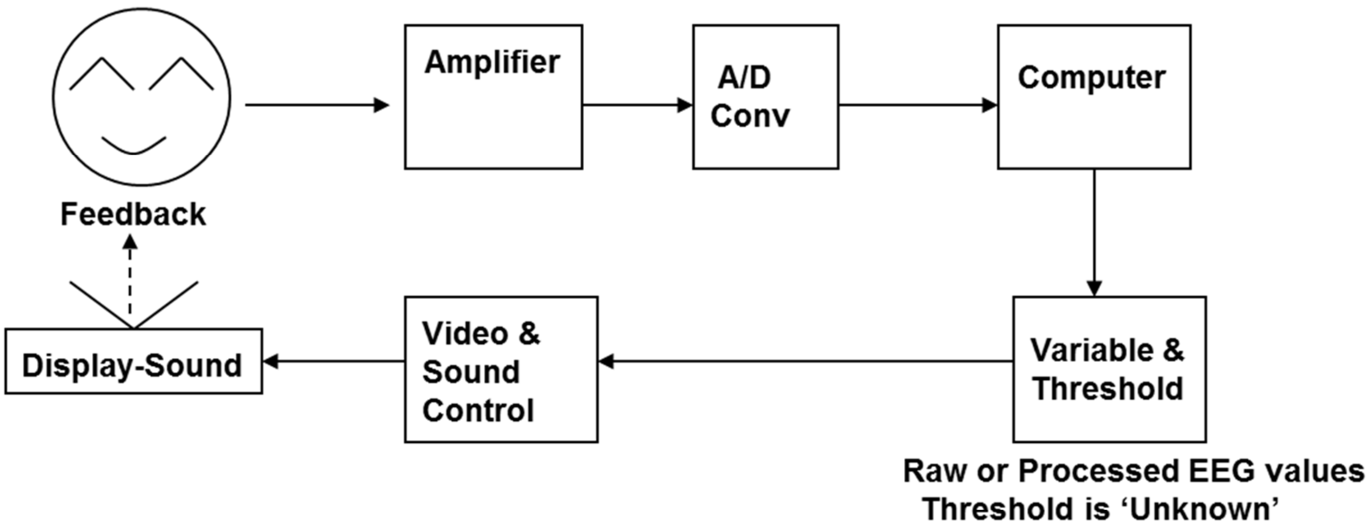






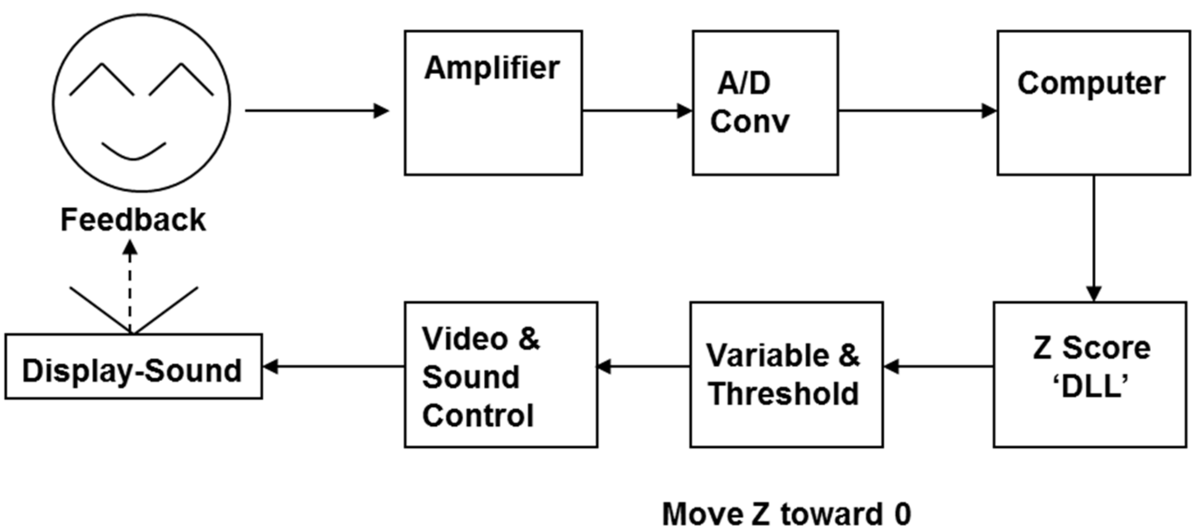


Difference Between Standard Neurofeedback vs Z Score Neurofeedback



Standard EEG Neurofeedback

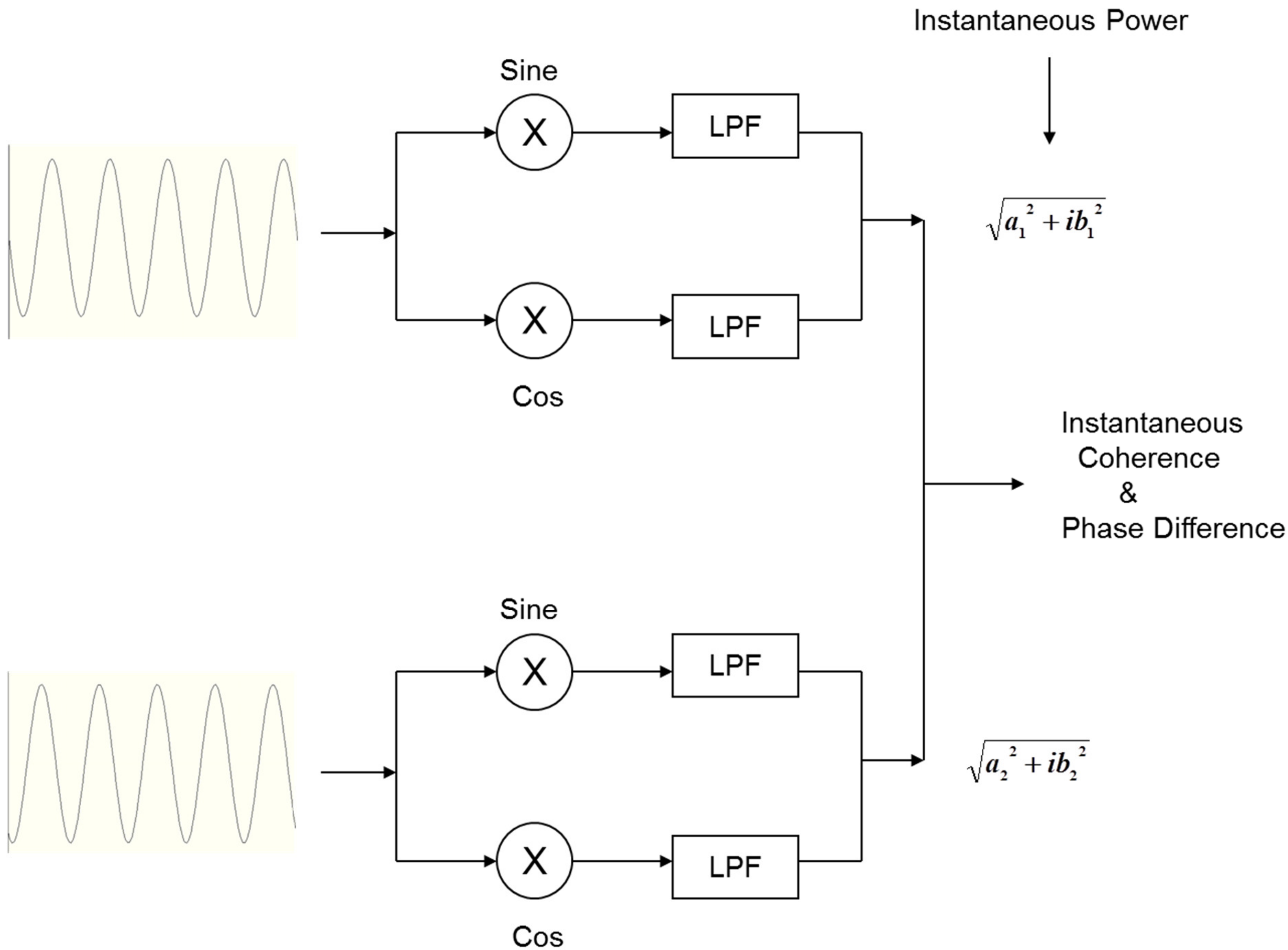
1- Apples & Organges
2- Arbitrary Threshold
3- No reference to Guide NF

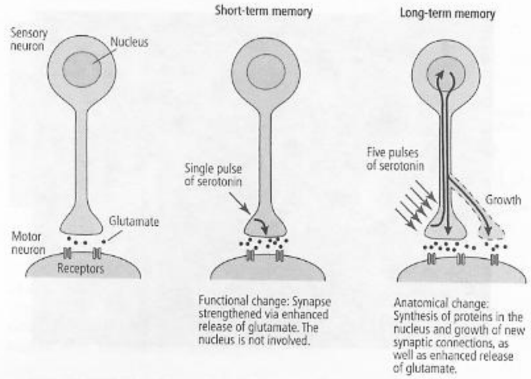


Real-Time or "Live" Z Score Neurofeedback

1- Metric, i.e., a 'Z' Score
2- Threshold toward '0'
3- Instantaneous Comparison to a normative database

Complex Demodulation



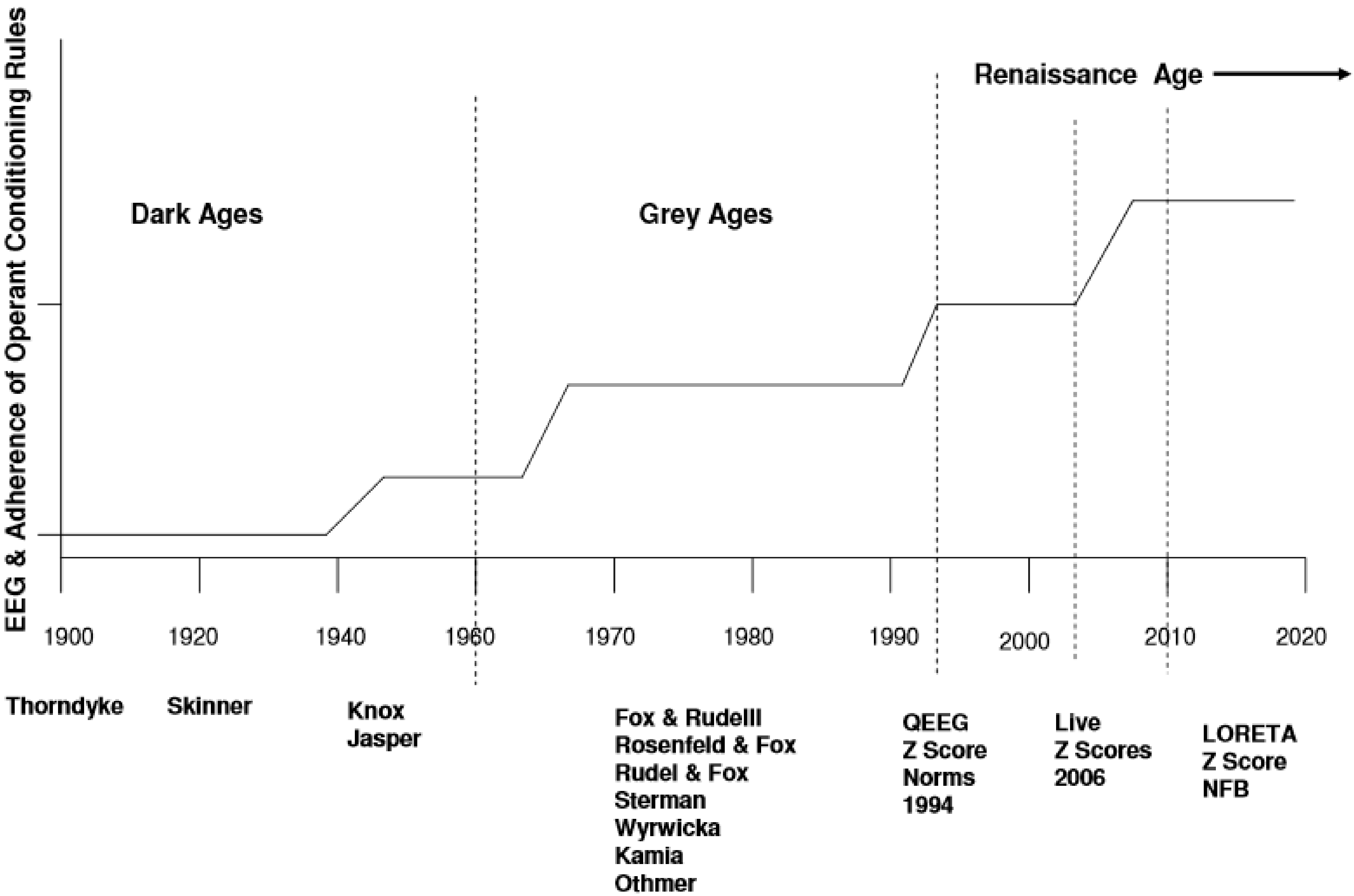


18-4 Changes underlying short- and long-term memory in a single sensory and motor neuron.

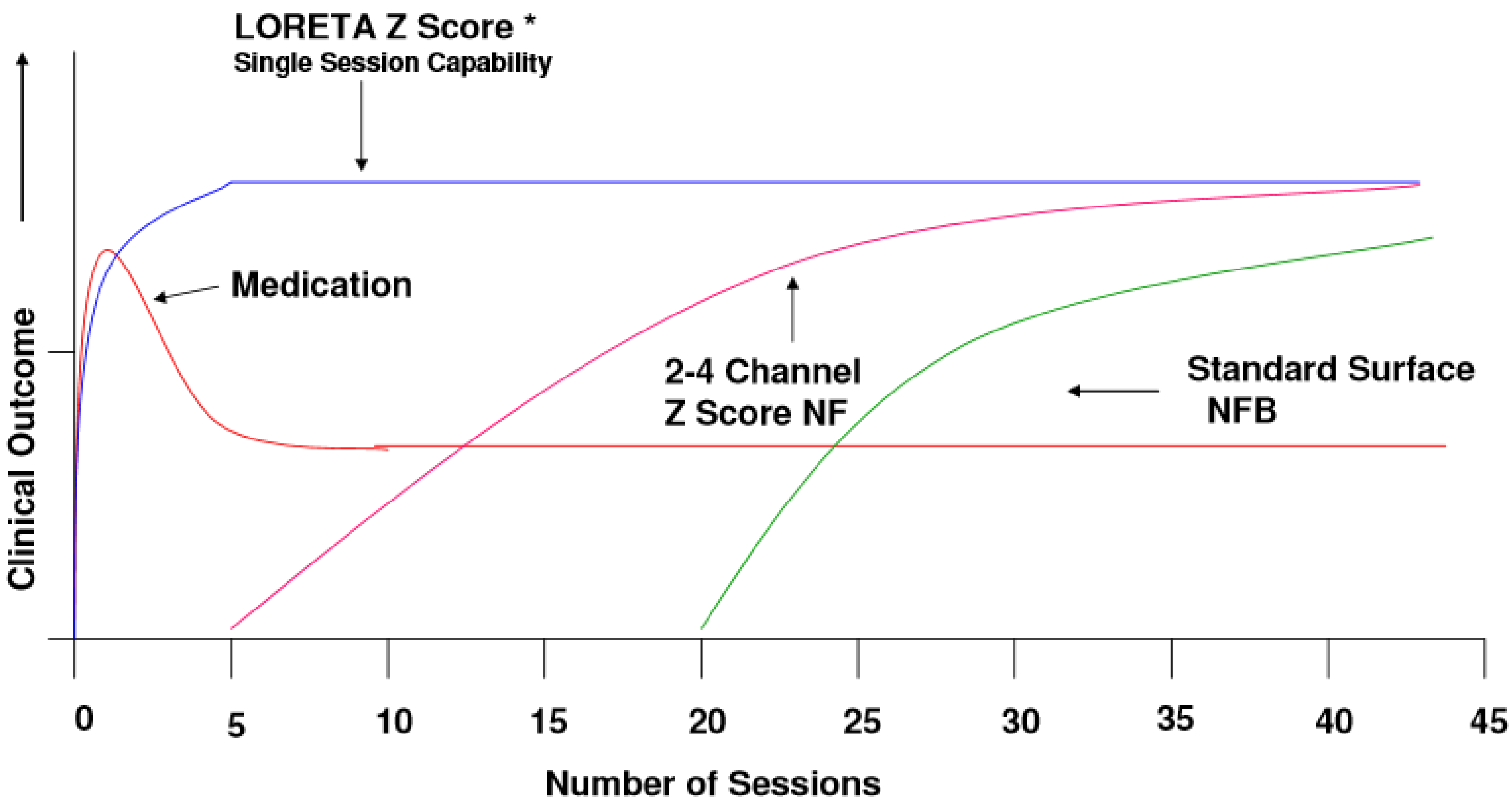
days and led to the growth of new synaptic connections, an anatomical change that did involve the synthesis of new protein (figure 18-4). This showed us that we could initiate new synaptic growth in the sensory neuron in tissue culture, but we still needed to find out what proteins are important for long-term memory.

My career in neurobiology now intersected with one of the great intellectual adventures of modern biology: the unraveling of the molecular machinery for regulating genes, the coded hereditary information at the heart of every life form on earth.

THIS ADVENTURE BEGAN IN 1961 WHEN FRANÇOIS JACOB AND Jacques Monod of the Institut Pasteur in Paris published a paper entitled "Genetic Regulatory Mechanisms in the Synthesis of Protein." Using bacteria as a model system, they made the remarkable discovery that genes can be regulated—that is, they can be switched on and off like a water faucet.

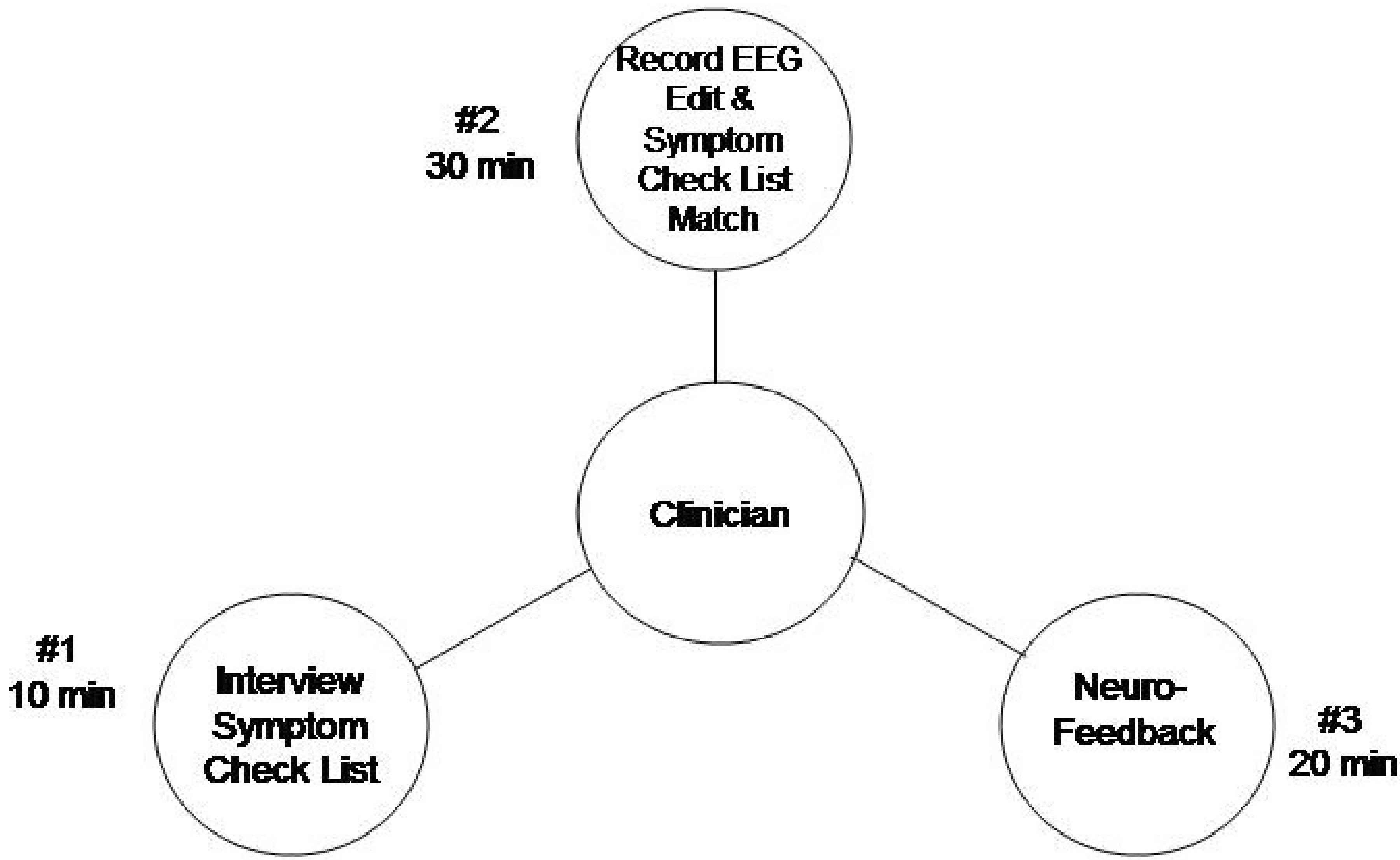


EEG & Adherence of Operant Conditioning Rules
Renaissance Age
Dark Ages
Grey Ages
1900
1920
1940
1960
1970
1980
1990
2000
2010
2020
Thorndyke
Skinner
Knox
Jasper
Fox & Rudelll
Rosenfeld & Fox
Rudel & Fox
Sterman
Wyrwicka
Kamia
Othmer
QEEG
Z Score
Norms
1994
Live
Z Scores
2006
LORETA
Z Score
NFB

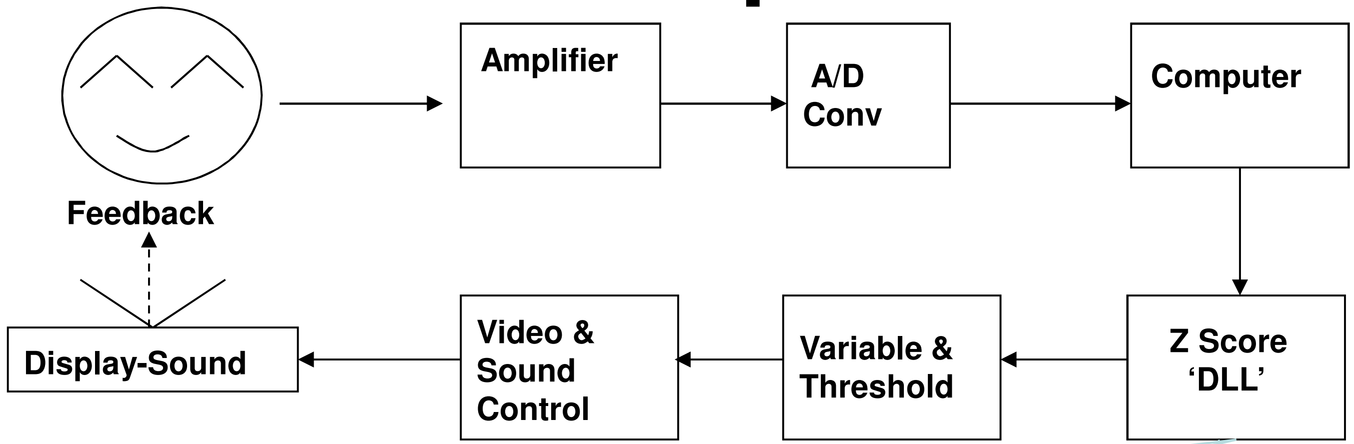


* Combine with Neurofield in
cases to reset or "unstick" the brain

Seamless QEEG and Neurofeedback – approx. 50 – 60 minutes for a single Session in four Steps from Clinical Interview to QEEG to Neurotherapy



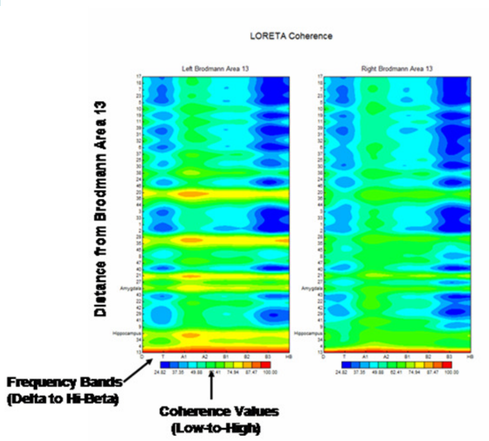
Neuroimaging Neurofeedback – Fort Campbell

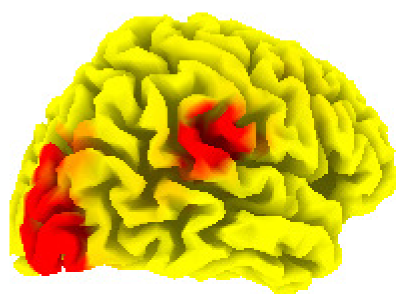


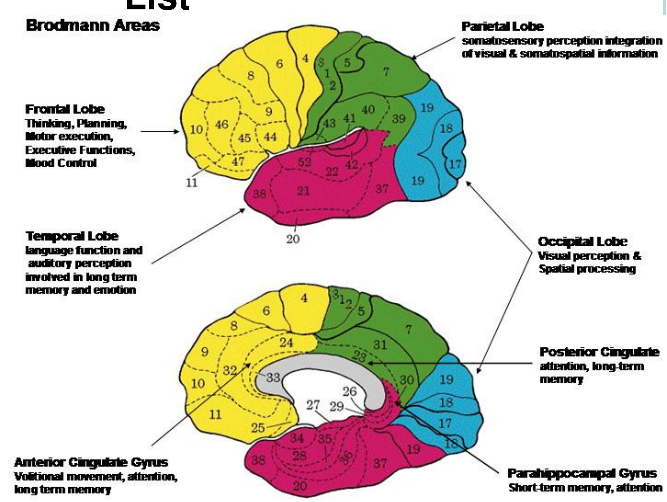
Coherence & Phase

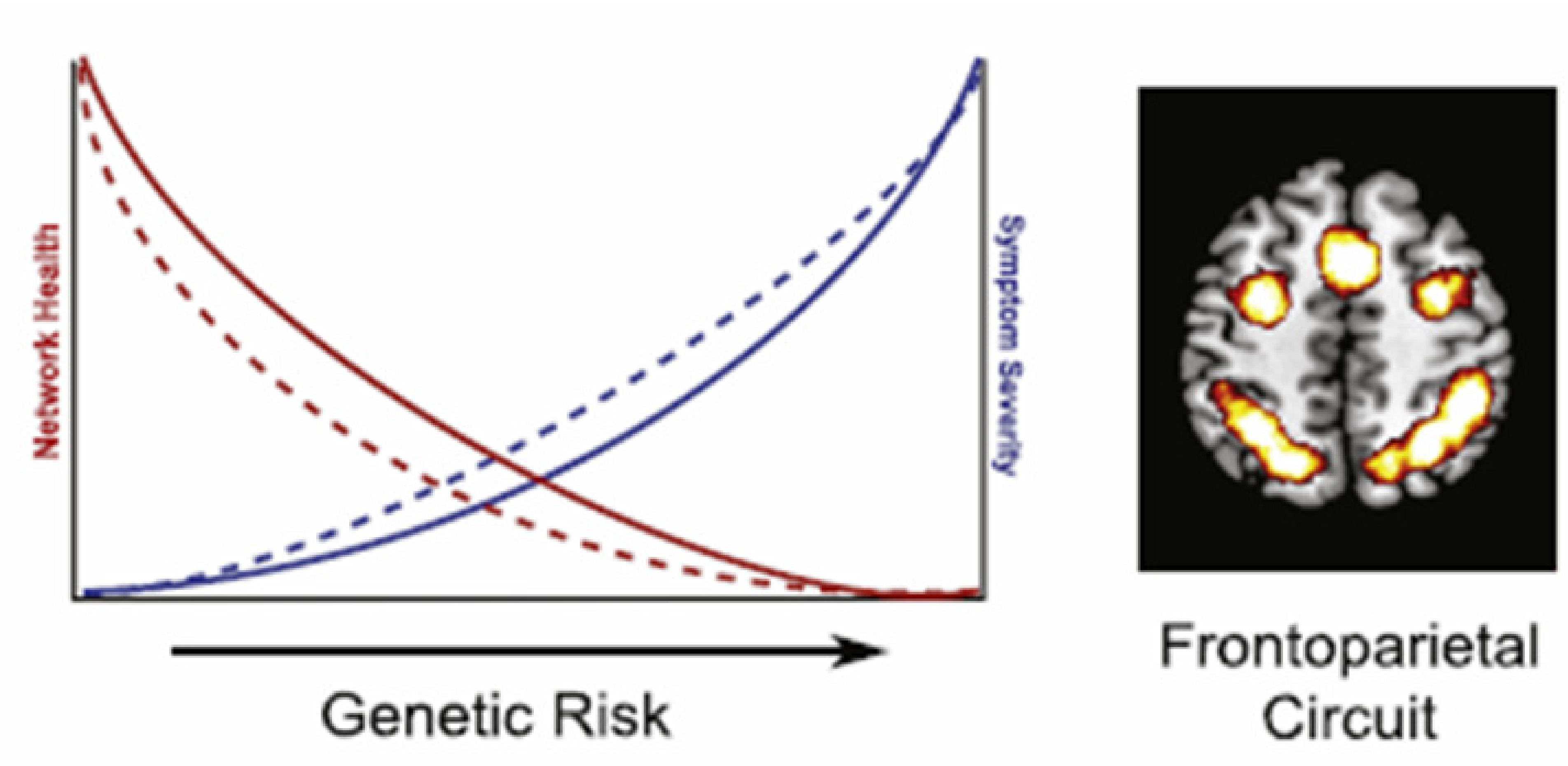
Current Sources

Symptom Check List








Network Health
Symptom Severity
Genetic Risk
Frontoparietal
Circuit

Z Score Neurofeedback Panel

Select Frequency Bands & 1 to 19 Channels & Combinations of Channels for Cross-Spectra

Settings or Progress Chart Tabs

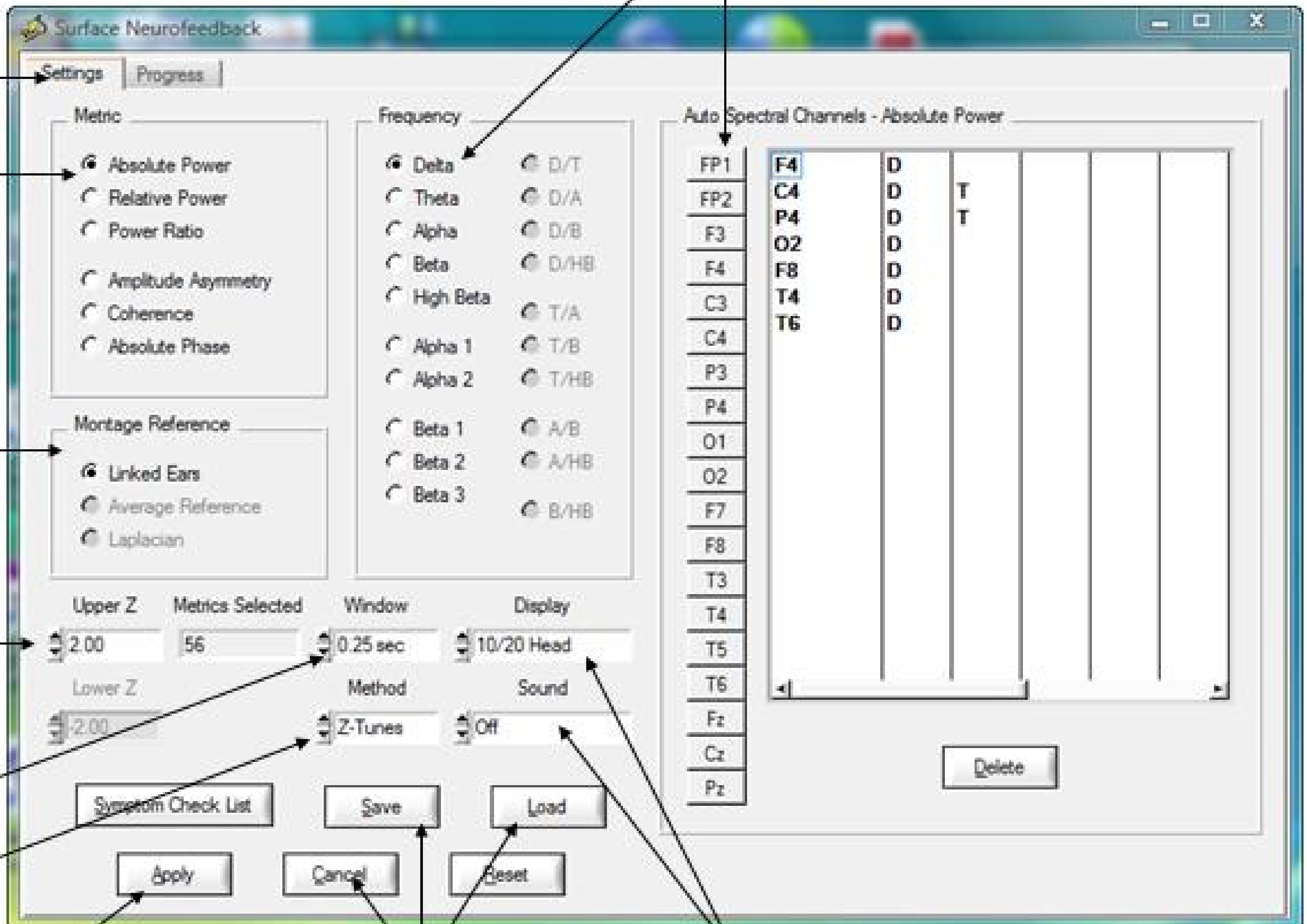
Select Power or Coherence, Phase Amp. Asym

Select Montage Laplacian, Ave. Ref & Linked Ears

Z Score Threshold Reward if Less Than Or greater than

Event Integration Interval (Variability)

Z Tunes is the Reward Default



Symptom Check List

Save, Load & Cancel

Sound on/off & Visual Displays & DVD/Flash

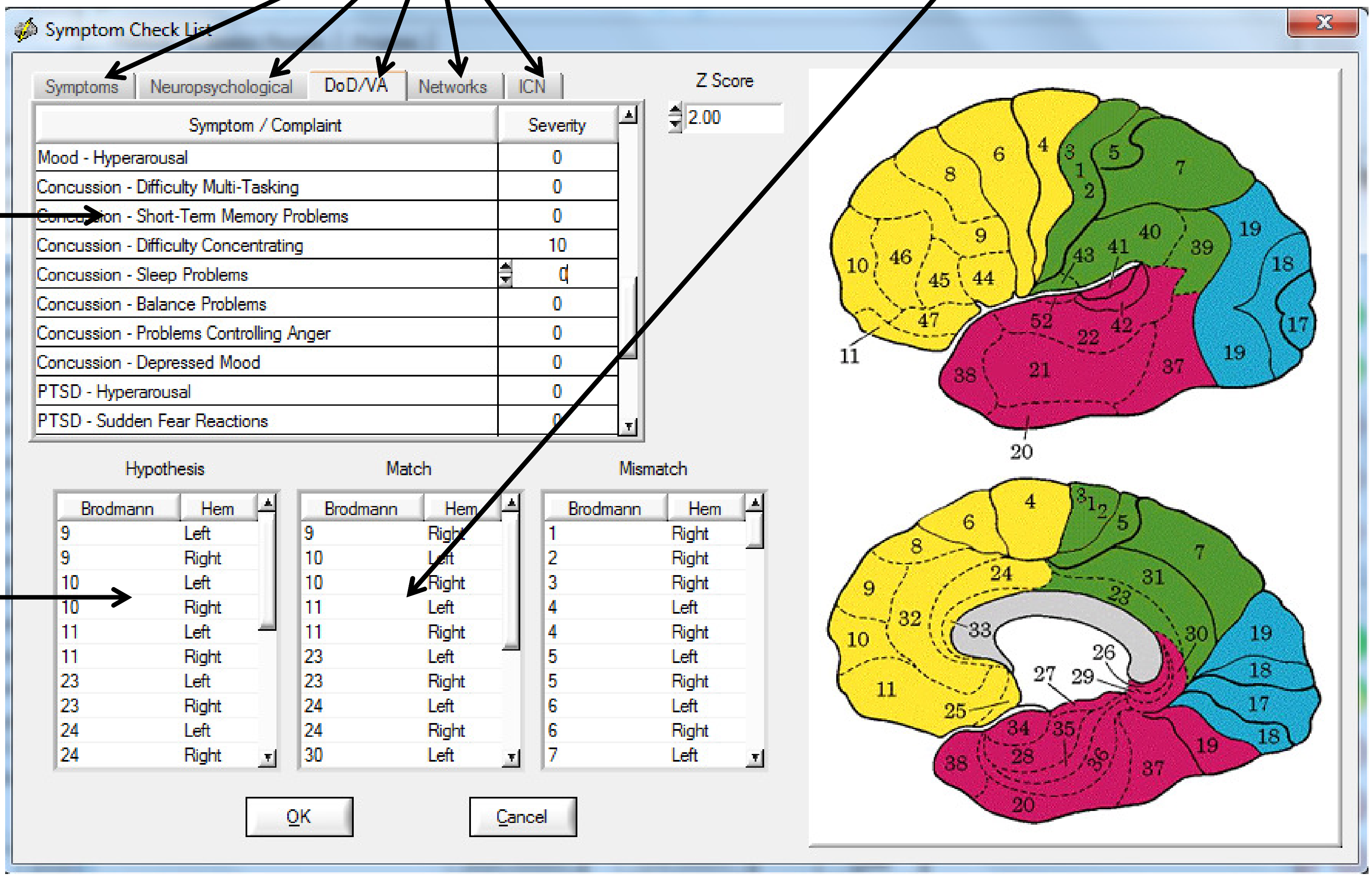
Neuroimaging Neurofeedback Symptom Check List

Click Symptoms or Neuropsychological Diagnoses or Dod/VA List or Networks & Severity

List of Matching Brodmann Areas

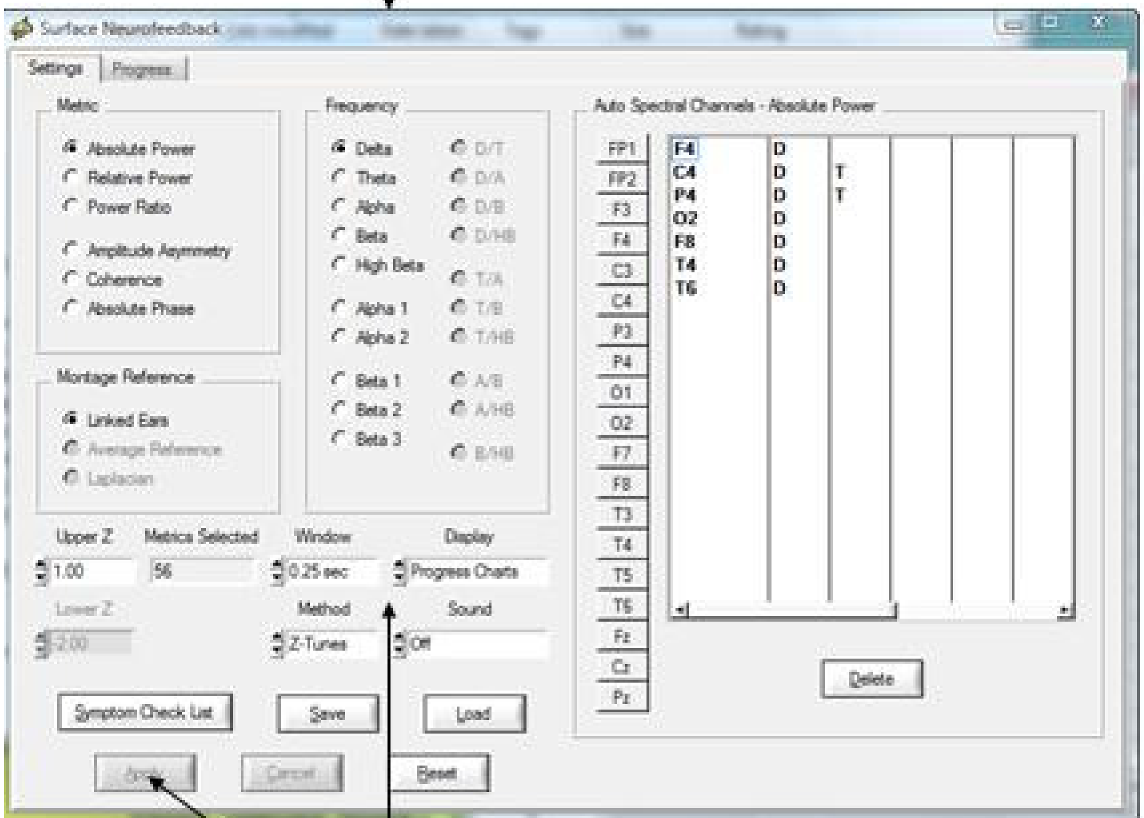
List of Symptoms

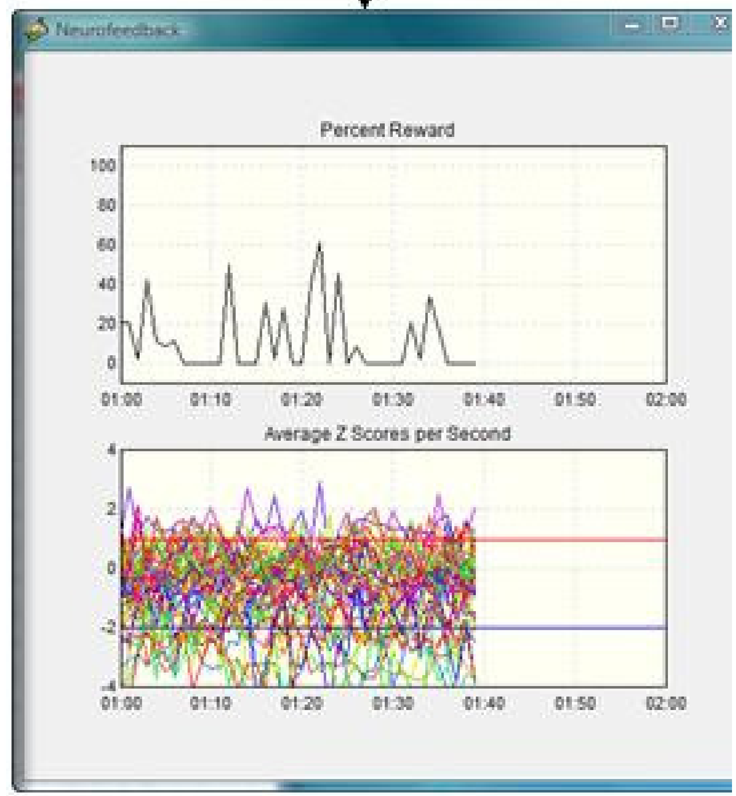
Anatomical Hypotheses



Use the Progress Chart as a Feedback Display and Move the Display to the Client's Monitor

Neurofeedback Setup Panel





Select Progress Charts as Feedback to A Client and then Click Apply

Move to the Client's Monitor

Progress Charts to be Monitored by the Clinician During Neurofeedback

Toggle back & forth between to Settings Window & Progress Charts

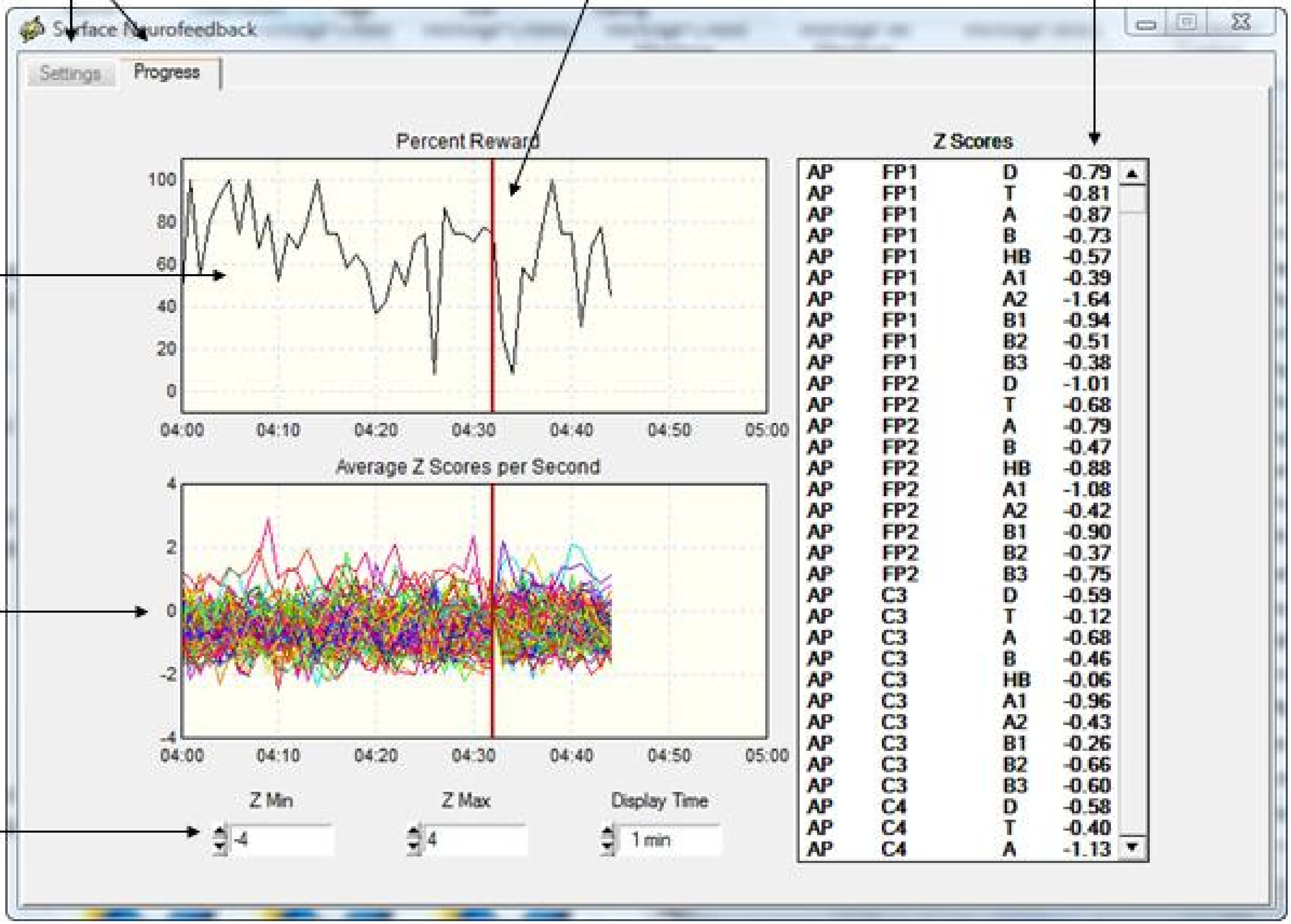
Red Mark Designates Settings Change

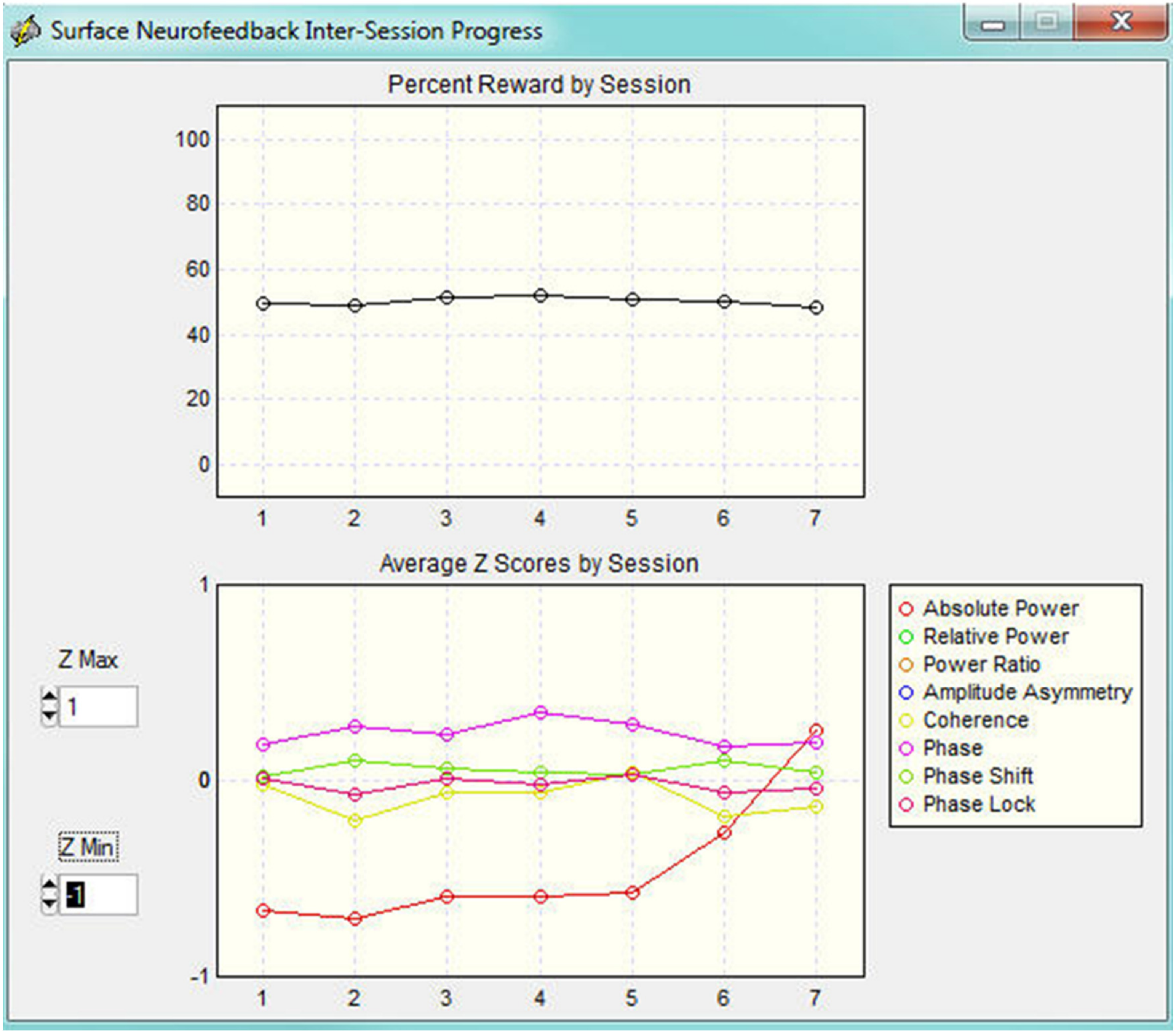
View Instantaneous Z Scores

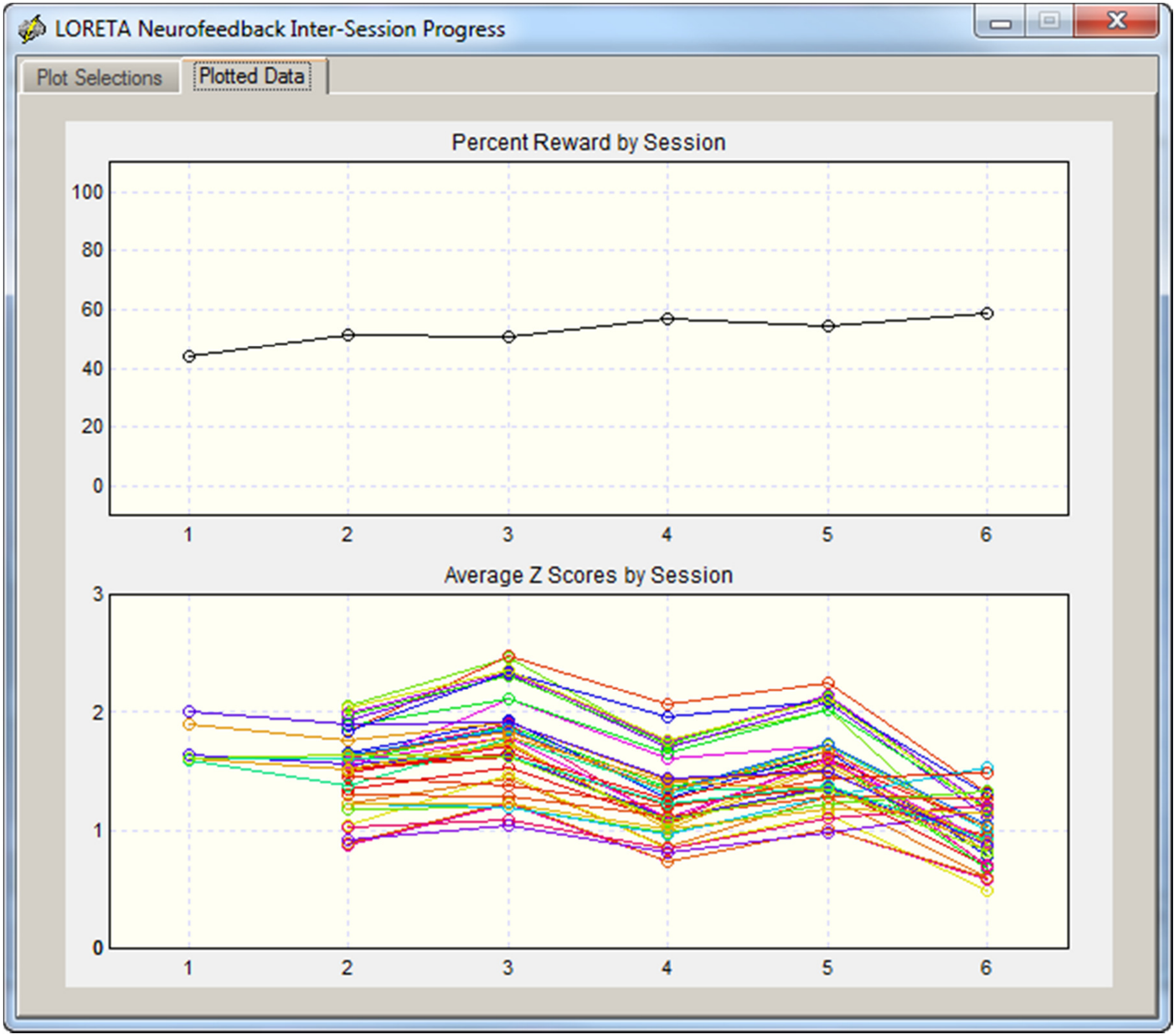
Percentage of Time that a Reward was Delivered (per sec)

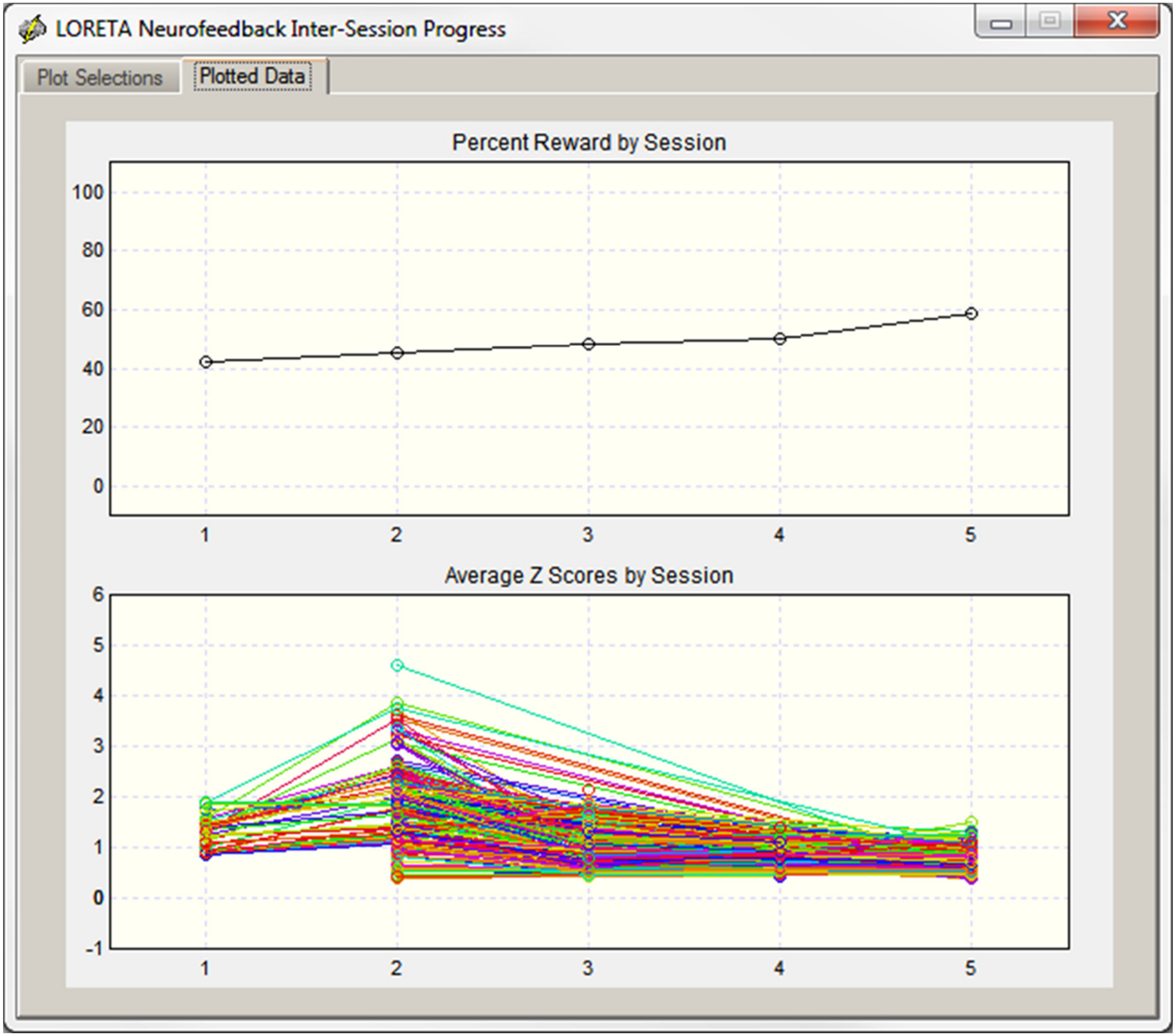
Average Z Scores Updated Each Second

Z Score Range & Display Time Base 1 min to 30 min

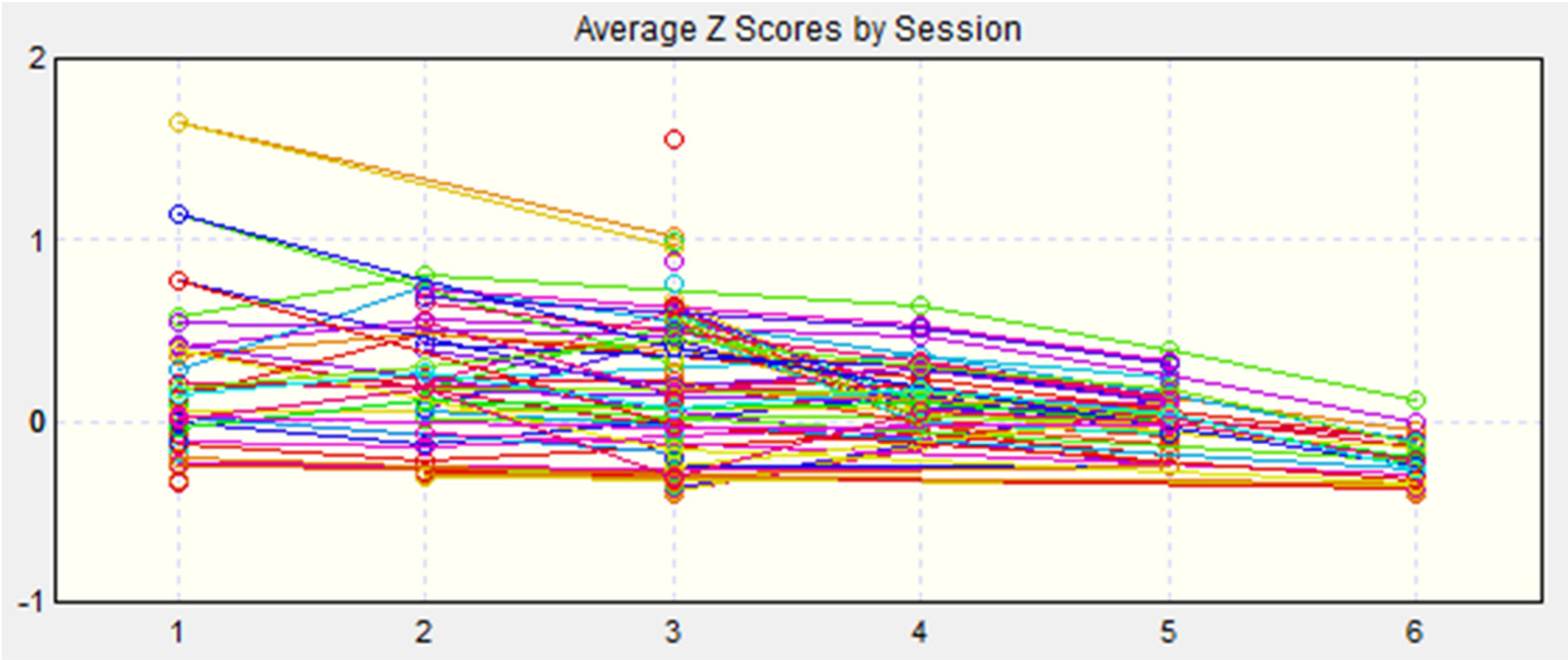


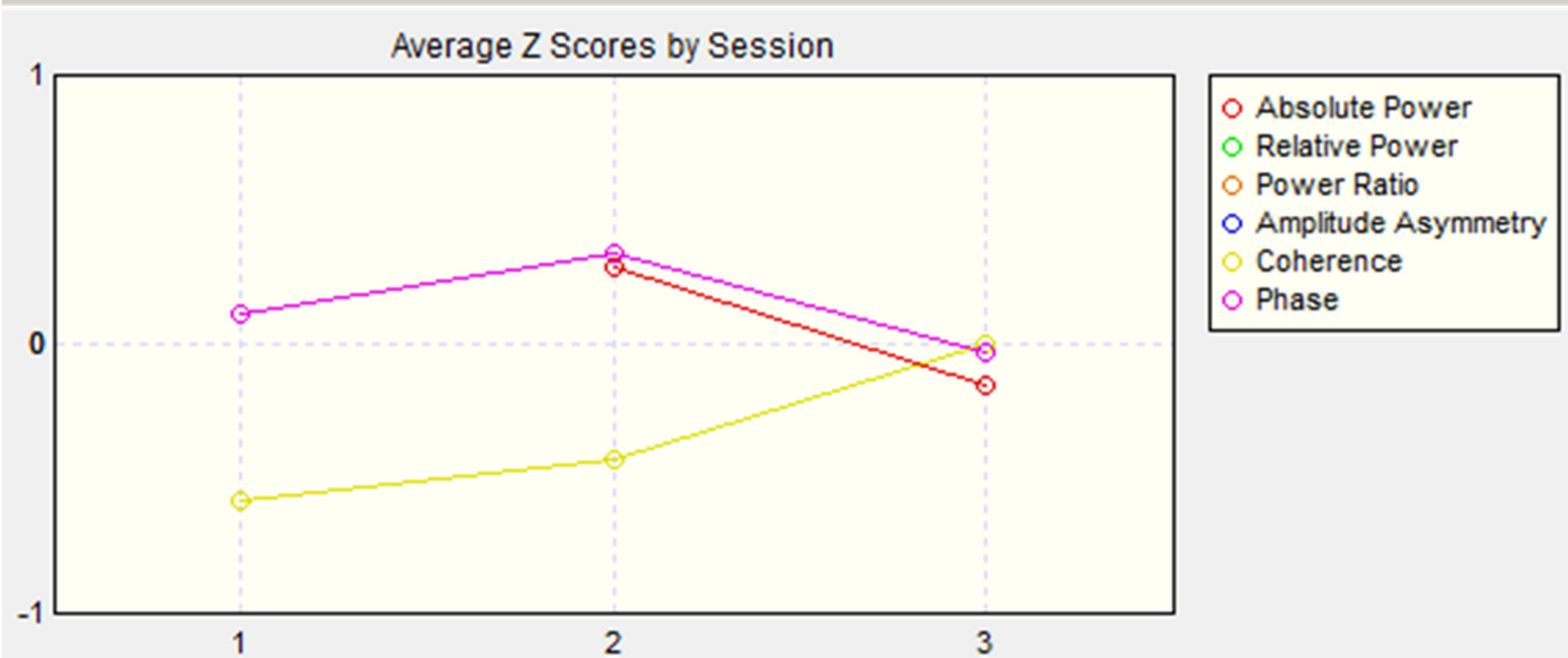

Surface Neurofeedback Inter-Session Progress
Percent Reward by Session
100
80
60
40
20
0
1
2
3
4
5
6
7
Average Z Scores by Session
1
0
-1
Z Max
1
Z Min
-1
Absolute Power
Relative Power
Power Ratio
Amplitude Asymmetry
Coherence
Phase
Phase Shift
Phase Lock


LORETA Neurofeedback Inter-Session Progress
Plot Selections
Plotted Data
Percent Reward by Session
100
80
60
40
20
0
1
2
3
4
5
6
Average Z Scores by Session
3
2
1
0
1
2
3
4
5
6



LORETA Neurofeedback Inter-Session Progress
Plot Selections
Plotted Data
Percent Reward by Session
100
80
60
40
20
0
1
2
3
4
5
Average Z Scores by Session
6
5
4
3
2
1
0
-1
1
2
3
4
5

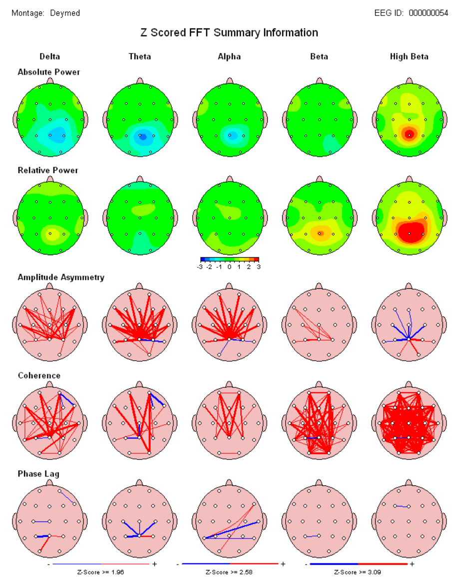

Average Z Scores by Session
2
1
0
-1
1
2
3
4
5
6

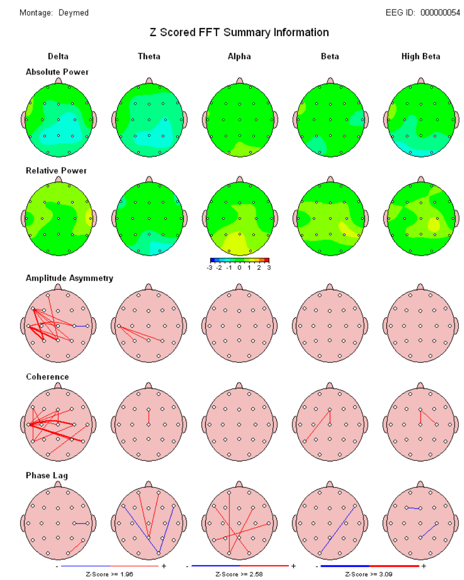

Average Z Scores by Session
1
0
-1
1
2
3
Absolute Power
Relative Power
Power Ratio
Amplitude Asymmetry
Coherence
Phase

Examples of Surface EEG Changes After EEG Neurofeedback

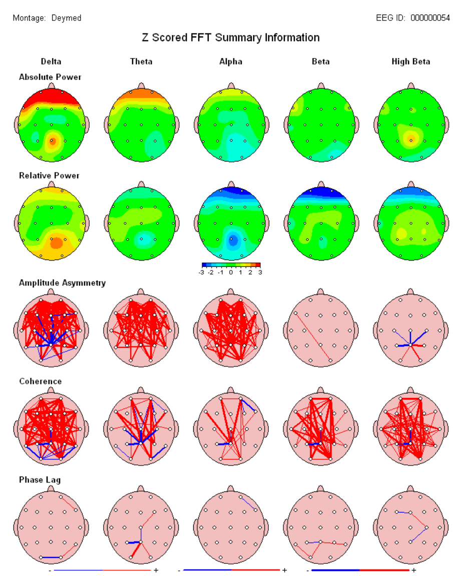
Pre-Treatment | Post – 10 Treatments

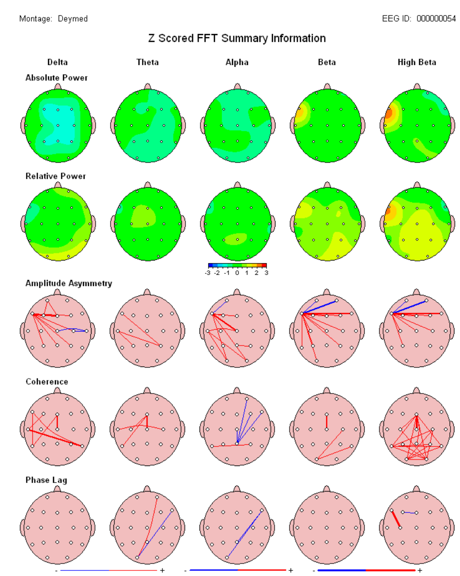
TBI Subject #1





TBI Subject #2

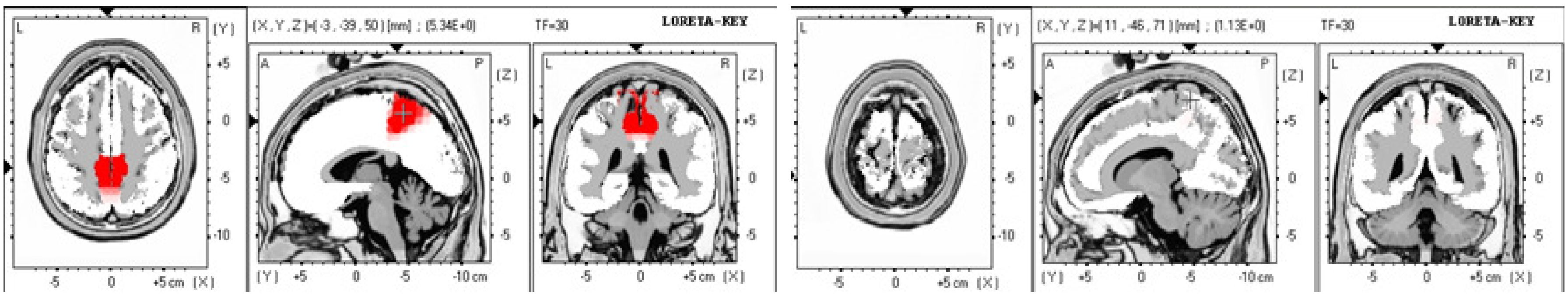




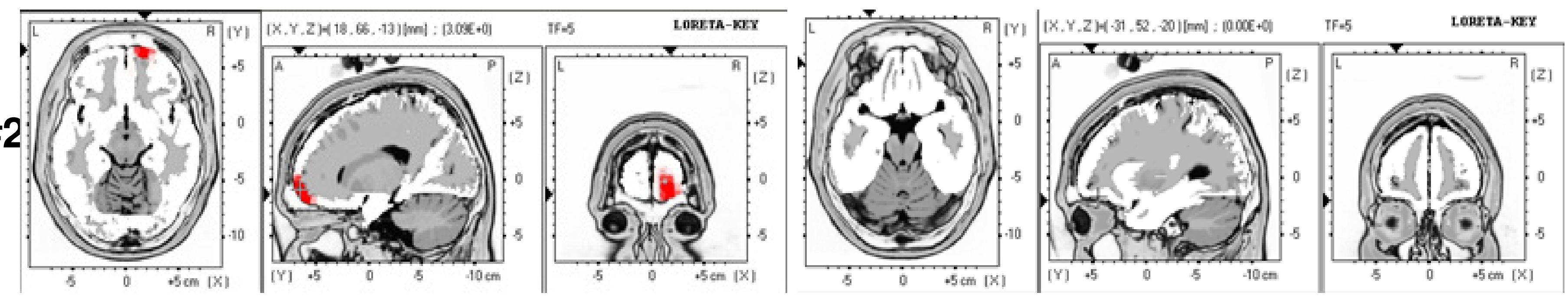
Examples of Electrical Neuroimaging After Neurofeedback

Pre-Treatment **Post – 10 Treatments**

S #1



S #2



Select a Network, Frequency and Metric

- Addiction Network
- Anxiety Network
- Attention-Dorsal Network
- Attention-Ventral Network
- Attention-Emotional Network
- Default Mode Network
- Mood Network
- Pain Network
- Pleasure Network
- Schizophrenia Network
- Working Memory Network
- ICN 1 (Limbic and Medial)
- ICN 2 (Subgenual ACC and OFC)
- ICN 3 (Bilateral BG and Thalamus)
- ICN 4 (Anterior Insula, Orbital Frontal & Ant. Cingulate)
- ICN 6 (Superior and Middle Frontal Gyri)
- ICN 7 (Middle Frontal Gyri, Prefrontal & Parietal Gyri)
- ICN 8 (Ventral Precentral Gyri, Central Sulci, Postcentral Gyri)
- ICN 9 (Superior & Posterior Parietal Lobule)
- ICN 10 (Middle and Inferior Temporal Gyri)
- ICN 11, 12 (Lateral and Medial Posterior Occipital Cortices)
- ICN 13 (Medial Prefrontal, Posterior Cingulate/Precuneus)
- ICN 15 (Right-Lateralized Fronto-Parietal Regions)
- Hagmann Module 1 (Vision)
- Hagmann Module 2 (Attention, Working Memory)
- Hagmann Module 3 (Auditory, Language, Memory)
- Hagmann Module 4 (Auditory, Language, Memory)
- Hagmann Module 5 (Executive, Sequential Planning)
- Hagmann Module 6 (Executive, Social Skills)