"Life is like playing a violin in a concert while learning to play and creating the score as you are playing." Rabinovic et al, (2012, p. 2)
IMPORTANT FACTS

1- Approx. 80% of Neurons are Excitatory & 20% are Inhibitory

2- Pyramidal neurons have resonant oscillations controlled by the membrane potential, ionic conductances and feedback loops

3- The EEG is the Summation of Synaptic Potentials and Changes in the Frequency Spectrum Occur by Changes in Synaptic Potentials

4- Neurons are Connected in Loops and are Self-Organizing & Stable because of Refractoriness of Excitatory Neurons

5- Neurons operate in large Modules that are Cross-Frequency Synchronized with Phase Shift and Phase Lock as Basic Mechanisms

6- EEG Biofeedback is Operant Learning in which a EEG event is followed by a signal that predicts a future reward. This results in the release of Dopamine that alters synapses related to a ‘trace’ of the EEG event that occurred in the past.

Gyorgy Buzsaki “Rhythms of the Brain”, Oxford Univ. Press, 2006
Reinforced with In-Phase

Suppressed if Out-of-phase
In-Phase is Reinforced

Out-of-Phase is Suppressed

In-Phase is Reinforced

Out-of-Phase is Suppressed

Thalamic Gating to the Neurocortex
Frontal Lobe
Thinking, Planning, Motor execution, Executive Functions, Mood Control

Temporal Lobe
Language function and auditory perception involved in long term memory and emotion

Parietal Lobe
Somatosensory perception integration of visual & somatospatial information

Occipital Lobe
Visual perception & Spatial processing

Posterior Cingulate
Attention, long-term memory

Anterior Cingulate Gyrus
Volitional movement, attention, long term memory

Parahippocampal Gyrus
Short-term memory, attention

Brodmann Areas
a memory is represented by an assembly of pyramidal cells.

active memories are repeated each theta cycle.

Spatial code for A

Spatial code for B

Theta (4-10 Hz)

Gamma (20-80 Hz)

Inhibitory reset
Phase Difference = $\Phi_1 - \Phi_2 = 90^0$
Coherence is high when phase delays are clustered or grouped together. Magnitude of coherence $= r$

Coherence is lower when phase delays are scattered.
EEG Phase Reset as a Phase Transition in the Time Domain

Phase difference at \(t_1, t_2, t_3, t_4 = 45^0\)

Phase difference at \(t_5, t_6, t_7, t_8 = 10^0\)

Phase difference at \(t_1, t_2, t_3, t_4 = 45^0\)

Phase difference at \(t_5, t_6, t_7, t_8 = 135^0\)

1st Derivative of Phase-Difference

Negative 1st Derivative

Positive 1st Derivative
Phase Difference in Degrees

- Fp1-Fp1
- Fp1-F3
- Fp1-C3
- Fp1-P3
- Fp1-O1

1st Derivative deg/100 msec

- Fp1-Fp1
- Fp1-F3
- Fp1-C3
- Fp1-P3
- Fp1-O1

Phase Shift

Phase Synchrony Interval

Phase Shift Duration
Development of Phase Shift Duration

LEFT Anterior - Posterior

RIGHT Anterior - Posterior

LEFT Posterior - Anterior

RIGHT Posterior - Anterior

AGEs (0.44 – 16.22 Years)

milliseconds

6 cm 12 cm 18 cm 24 cm
Development of Phase Synchrony Interval

**LEFT Anterior - Posterior**

- 6 cm
- 24 cm

**RIGHT Anterior - Posterior**

- 6 cm
- 24 cm

**LEFT Posterior - Anterior**

- 6 cm
- 24 cm

**RIGHT Posterior - Anterior**

- 6 cm
- 24 cm

AGEs (0.44 – 16.22 Years)
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
Pyramidal Cell Model of EEG Phase Reset and Full Scale I.Q.

Phase Shift Duration (SD)

Phase Lock Duration (LD)

Distant EPSP Loop Connections LD

Local IPSP Connections SD

Average EPSP Duration

$\Delta \Phi = \Theta_{LFP} - \Theta_{Pr.of}$

Full Scale I.Q.

Time (msec)

250

40

50

60

150

250

350
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
Shift Duration Short Distances

Lock Duration Short Distances

Shift Duration Long Distances

Lock Duration Long Distances

T-Tests (p):

NS

<.0001

<.0001

<.0001

<.0001

<.0001

<.0001

<.0001

<.0001

<.0001

<.0001
A. Alpha1 Shift Duration Short Distances

B. Alpha1 Shift Duration Long Distances

C. Alpha2 Lock Duration Short Distances

D. Alpha2 Lock Duration Long Distances
AUTISM - ALPHA2 – PHASE LOCK DURATION 6cm INTER-ELECTRODE DISTANCES

![Graph showing the total count of various locations: Central, Occipital, and Frontal against MSEC (milliseconds).](image)
TEMPORAL QUANTA AND EEG LORETA PHASE RESET

Thatcher, R.W. North, D.M. and Biver, C. J.
EEG and NeuroImaging Laboratory, Applied Neuroscience, Inc., St. Petersburg, Fl
Phase Reset Shift Duration LORETA Default Brain Brodmann Area Pairs

X-Shift

- Eyes Closed
- Brodmann Areas (8 & 9) Left
- Brodmann Areas (36 & 39) Left
- Brodmann Areas (30 & 31) Left

Y-Shift

- Eyes Closed
- Brodmann Areas (8 & 9) Left
- Brodmann Areas (9 & 39) Left
- Brodmann Areas (23 & 39) Right

Z-Shift

- Brodmann Areas (28 & 36) Left
- Brodmann Areas (30 & 31) Left
- Brodmann Areas (29 & 39) Right

R-Shift

- Brodmann Areas (28 & 36) Right
- Brodmann Areas (24 & 29) Left
- Brodmann Areas (23 & 39) Right
- Brodmann Areas (31 & 32) Right
Phase Reset Lock Duration LORETA Default Brain Brodmann Area Pairs

X-Lock
- Brodmann Areas (8 & 40) Right
- Brodmann Areas (21 & 36) Right

Y-Lock
- Brodmann Areas (8 & 10) Right
- Eyes Closed
- Eyes Opened

Z-Lock
- Brodmann Areas (28 & 32) Right
- Brodmann Areas (28 & 30) Right

R-Lock
- Brodmann Areas (9 & 30) Right
- Brodmann Areas (24 & 32) Right
Relations Between Phase Reset Shift & Lock Means and the Euclidean Distance Between Voxels

Left Phase Shift

Right Phase Shift

Left Phase Lock

Right Phase Lock

R = .633; p <= .0001

R = .491; p = .0027

R = -.505; p <= .0001

R = -.379; p = .0249
A

Quanta Phase Shift Durations: N = 140  Under Each Quanta Duration

Brodmann Areas (8 & 9) Left

Brodmann Areas (30 & 31) Left

Eyes Closed

Eyes Opened

Brodmann Areas (36 & 39) Left
Non-Linear Exponential Brodmann Area Distances: Shift vs Lock

Phase Lock Duration

Phase Shift Duration

Euclidean Distance Between Brodmann Areas (mm)

Gap = 135 msec
Click View > Dynamic Bi-Spectrum > Absolute Amplitude

Time Series of Instantaneous Absolute Power

Bi-Spectrum = FFT of Instantaneous Absolute Power Time Series

0.32 seconds = once every 32 seconds

FFT

Z Scores

1 Hz 5 Hz
Two Compartments of the Frequency Spectrum of Bursts in EEG Absolute Amplitude

Log of Absolute Amplitude

fMRI – Infra slow metabolic Rhythms < 1 Hz

EEG – 1 Hz to 300 Hz & 1/ff

0.32 Hz or 1/31.25 sec

5 Hz
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 Validation Steps

Reliability
- Digital EEG
- Time Series

Montage
- EC
- EO
- Task
- Etc

Time Domain
- LE
- Ave-Ref
- CSD
- Etc

Frequency Domain
- Real
- Imaginary
- Wavelets
- LORETA
- Hjorth Descriptors
- Eigenfunctions
- JTFA
- Etc

Means & St. Dev.

Z Scores

Transform & Re-Compute

Gaussian Validation

Clinical Correlations & Predictive Validity
- Parametric & Non-Parametric Statistics
Sensitivity Based on Deviation from Gaussian
Cross-Validation Accuracy N = 625 Subjects

False Neg. = (2.3 - 1.98) = .32
False Pos. = (2.88 - 2.3) = .6

Expected = - 2.3%
(Observed = - 1.98%)

Expected = + 2.3%
(Observed = + 2.88%)

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

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

Specificity = \[ \frac{TN}{TN + (FP + FN)} \] = Undefined
Cross-Validation Birth to 82 Year EEG Normative Database
## FFT Normative Database Sensitivities

<table>
<thead>
<tr>
<th>AGES</th>
<th>2 STDEVs</th>
<th>CALC SENSITIVITY: FP=TP/(TP+FP) or FN=TP/(TP+FN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(+/- 2 SD)</td>
<td>(= = 2 SD)</td>
<td>(= = -2 SD)</td>
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<tr>
<td>0-5.99</td>
<td>0.95448265</td>
<td>0.9771774</td>
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<td>0.95440363</td>
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<td>0.95440512</td>
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<tr>
<td>16-ADULT</td>
<td>0.9543945</td>
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<td>ALL</td>
<td>0.95442375</td>
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<table>
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<th>3 STDEVs</th>
<th>CALC SENSITIVITY: FP=TP/(TP+FP) or FN=TP/(TP+FN)</th>
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<td>(+/- 3 SD)</td>
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<td>(= = -3 SD)</td>
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<td>0-5.99</td>
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<td>ALL</td>
<td>0.99744002</td>
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Normative Database Amplifier Matching – Microvolt Sine Waves 0 to 40 Hz
Equilibration Ratios to Match Frequency Responses
Cross-Validation of NeuroGuide vs NxLink

Absolute Power

- Delta
- Theta
- Alpha
- Beta

Relative Power

- Delta
- Theta
- Alpha
- Beta

Coherence

- Delta
- Theta
- Alpha
- Beta

Amplitude Asymmetry

- Delta
- Theta
- Alpha
- Beta
### Table IV
List of “Gold Standards” by which to judge QEEG Normative databases

<table>
<thead>
<tr>
<th>Standards</th>
<th>Yes</th>
<th>No</th>
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<tbody>
<tr>
<td>1 Peer reviewed publications</td>
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<tr>
<td>2 Amplifier Matching</td>
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<tr>
<td>3 Artifact Rejection</td>
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<tr>
<td>4 Test Re-Test Reliability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Inclusion/exclusion criteria</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Adequate Sample size per age group</td>
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<td></td>
</tr>
<tr>
<td>7 Approximation to a Gaussian</td>
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<tr>
<td>8 Cross-Validation</td>
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<td></td>
</tr>
<tr>
<td>9 Clinical Correlation</td>
<td></td>
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<tr>
<td>10 FDA Registered</td>
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<td></td>
</tr>
</tbody>
</table>
Correlations between DSCOREs with FULL IQ, VERB IQ, & PERF IQ

FULL IQ Discriminant Scores with FULL IQ

\[ r = -0.800 \]
\[ p < 0.0001 \]

VERB IQ Discriminant Scores with VERB IQ

\[ r = -0.815 \]
\[ p < 0.0001 \]

PERF IQ Discriminant Scores with PERF IQ

\[ r = 0.829 \]
\[ p < 0.0001 \]
Histograms of Discriminant Functions using IQ Score Measures

**FULL IQ**
- $\text{FULL IQ} \geq 120$  
  $N = 97$
- $\text{FULL IQ} \leq 90$  
  $N = 70$
- $90 < \text{FULL IQ} < 120$  
  $N = 267$

**VERBAL IQ**
- $\text{VERB IQ} \geq 120$  
  $N = 95$
- $\text{VERB IQ} \leq 90$  
  $N = 77$
- $90 < \text{VERB IQ} < 120$  
  $N = 270$

**PERFORMANCE IQ**
- $\text{PERF IQ} \leq 90$  
  $N = 67$
- $\text{PERF IQ} \geq 120$  
  $N = 73$
- $90 < \text{PERF IQ} < 120$  
  $N = 302$
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<th>DQFULL</th>
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<th>IQ SCOREs</th>
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<tr>
<td></td>
<td>Frequency:</td>
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<td>Coherence</td>
<td>Absolute Phase</td>
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<td></td>
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<td>Frequency:</td>
<td>Absolute Power</td>
<td>Coherence</td>
<td>Absolute Phase</td>
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<tr>
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<td>Frequency:</td>
<td>Absolute Power</td>
<td>Coherence</td>
<td>Absolute Phase</td>
<td></td>
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</tr>
<tr>
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<td>POS +</td>
<td>NEG -</td>
<td>POS +</td>
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<td>POS +</td>
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<td>21</td>
<td>201</td>
<td>106</td>
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Multiple Regressions of QEEG with FULL IQ

<table>
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<tr>
<th>QEEG Measure</th>
<th>MULTIPLE R</th>
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<tbody>
<tr>
<td>Phase Difference</td>
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<tr>
<td>Coherence</td>
<td>0.86</td>
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<tr>
<td>Phase Reset per Second</td>
<td>0.73</td>
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<tr>
<td>Phase Reset Locking Interval Means</td>
<td>0.74</td>
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<tr>
<td>Amplitude Asymmetry</td>
<td>0.70</td>
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<tr>
<td>Phase Reset Duration Means</td>
<td>0.65</td>
</tr>
<tr>
<td>Burst Amplitude Means</td>
<td>0.59</td>
</tr>
<tr>
<td>abs(OUT-PHASE)</td>
<td>0.57</td>
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<tr>
<td>Cross Spectral Power</td>
<td>0.45</td>
</tr>
<tr>
<td>abs(IN-PHASE)</td>
<td>0.44</td>
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<td>Absolute Power</td>
<td>0.39</td>
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<tr>
<td>Phase Reset Amplitude Means</td>
<td>0.28</td>
</tr>
<tr>
<td>Peak Frequency</td>
<td>0.17</td>
</tr>
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</table>
Essentials of Operant Conditioning


2- The ‘Feedback Signal’ must predict a large & significant future reward

3- Discrete and novel feedback signals increase the probability of linking the signal and a future reward, i.e., “contingency”

4- The interval of time between the spontaneous ‘emitted EEG event’ & the ‘feedback signal’ can not be too short, approx. < 250 msec? or too long approx. 20 sec?
Principles of Operant Learning

- Probability of Learning or Association
- Signal Strength in Contingency Window
- Reward Value
A General Theory of EEG Operant Conditioning and Z Score Biofeedback

Principles
1- Specificity of EEG Event (E) = Neural State Interval (I)
2- Contiguity Window (C) = Time period preceding and following a E
3- Contingency of 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.

<table>
<thead>
<tr>
<th>Category</th>
<th>Measurement</th>
</tr>
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<tbody>
<tr>
<td>Specificity of EEG Event (E)</td>
<td>Z Scores and Brodmann areas linked to symptoms</td>
</tr>
<tr>
<td>Contiguity Window (C)</td>
<td>Time preceding/following E (msec – sec)</td>
</tr>
<tr>
<td>Contingency of Reward Signal (S)</td>
<td>Feedback signal time locked to E (msec)</td>
</tr>
<tr>
<td>Reward Strength (R)</td>
<td>Ordinal or Nominal measure</td>
</tr>
</tbody>
</table>
Contiguity Window

Number of Synchronized Neurons as a Function of $S + R$

Neural Emitted Event (E)
200 msec to 400 msec

ACH & Dopamine Trace & Synaptic Association

Strength or Distinctness of Feedback Signal $S + R$

Reward Strength $= R$

ACH & Dopamine Expectancy

- 10 Seconds

Past

Present

Future

+ 10 Seconds

Moving Window of Time

-10

0

+10

Moving Window of Time

-10

0

+10
Nested Neural State Intervals

EEG Event

Attention

Drives

Contiguity Window

Milliseconds

Seconds

Minutes/Hours

Moving Window of Time
Example of Bursts of SMR (13 – 18 Hz) in the Human EEG
Burst Duration approx. 200 msec to 400 msec
Example of Bursts of Theta Rhythms (4 – 8 Hz) in the Human EEG
Burst Duration approx. 200 msec to 600 msec
Moving Window of Operant Learning Quanta

Phase Shift Neural Recruitment

Preconscious

Spontaneous Neural State

Operant Association Window

Time (msec)
Predictive Error

$|Z| = 0$

$\Delta[Z] = (0 - [Z])$

Associative Strength

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

1. Interview
   10 min
   Symptom Check List

2. Record EEG
   Edit & Symptom Check List Match
   30 min

3. Neuro-Feedback
   20 min

Clinician
1- “Behavioral approaches emphasize compensation” (p. 21)

2- “Restorative approaches emphasize improving weak or lost function” (p. 21)

“A compensation occurs when a Noninjured brain region takes over The function of the injured region. True recovery involves improvement In function in an injured area.” (p. 22)
Z Score Neurofeedback Panel

- 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

[Image of software interface with various options and settings]

- Upper Z
- Lower Z
- Metrics Selected
- Window
- Display
- Method
- Sound
- Apply
- Cancel
- Reset
- Save, Load & Cancel
- Symptom Check List
- Sound on/off & Visual Displays & DVD/Flash

Select Frequency Bands & 1 to 19 Channels & Combinations of Channels for Cross-Spectra
Double click the Severity of a Symptom and Grade Severity 1 to 10.

Set the Z score threshold from the QEEG Analyses.

Match to Symptoms & QEEG Z Scores

Symptom Check List

Hypothesis

Mismatch of Symptoms & QEEG Z Scores
Example of a Slow Reader Symptom Check List Hypotheses and the Test Of the Hypothesis using QEEG Z Scores. Note how the mismatch items Move to the match 10/20 head display as Symptoms are matched.
Use the Progress Chart as a Feedback Display and Move the Display to the Client's Monitor.

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
After Plot Selections then Click Plotted Data to View the Inter-Session Progress Charts
## LORETA Neurofeedback Setup Panel

### Database Montage
- **Linked Ears**
- **Average Reference**

### Select Frequency Band
- Delta
- Theta
- Alpha
- Beta
- High Beta
- Alpha 1
- Alpha 2
- Beta 1
- Beta 2
- Beta 3

### Region of Interest
- Amygdala
- Angular Gyrus
- Anterior Cingulate
- Cingulate Gyrus
- Extra-Nuclear
- Fusiform Gyrus
- Hippocampus
- Inferior Frontal Gyrus

### Brodmann Areas
- 36, 37, 38, 39, 40, 41, 42, 43, 44, 45
- D, T, A, B, A1, B1

### High Light the Brodmann Area to Change Frequency

### Threshold & Z Tune is the Default

After creating a Symptom Check List Match – Click Symptom Check List

### Metrics Selected
- Upper Z
- Lower Z

### Window
- 0.25 sec

### Display
- Cz Head

### Method
- Sound

### Buttons
- Apply
- Cancel
- Reset
- Save
- Load


98 Brodmann Areas