Technical Foundations of Neuronal Dynamics and Z-Scores

Thomas F. Collura, Ph.D

BrainMaster Technologies, Inc.

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Neurofeedback

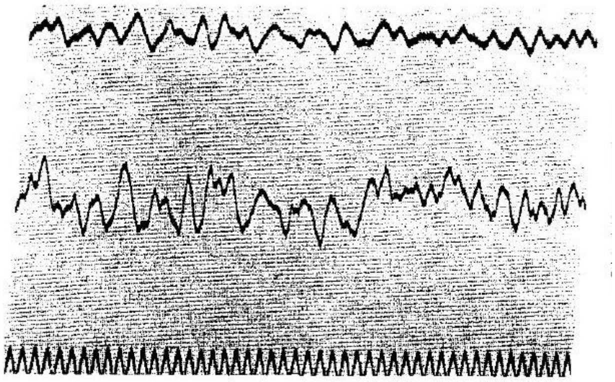
Neurofeedback is a form of biofeedback training that uses the EEG (Electroencephalogram), also known as the "brain wave" as the signal used to control feedback. Sensors applied to the trainee's scalp record the brainwaves, which are converted into feedback signals by a human/machine interface using a computer and software. By using visual, sound, or tactile feedback to produce learning in the brain, it can be used to induce brain relaxation through increasing alpha waves. A variety of additional benefits, derived from the improved ability of the CNS (central nervous system) to modulate the concentration/relaxation cycle and brain connectivity, may also be obtained.

Outline

- Electrophysiology
- Instrumentation
- Computerization
- Signal Processing
- User Interfacing
- System Overview

First Human EEG Studies - 1924

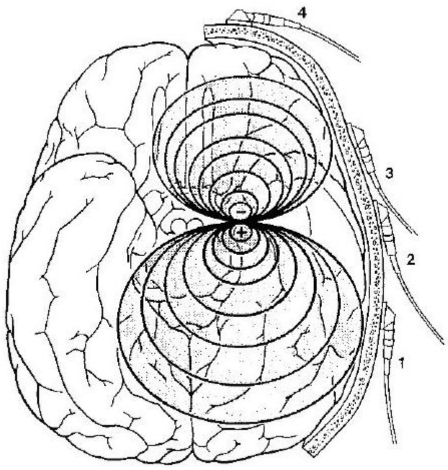
Hans Berger - 1932



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

Realistic Head Dipole Source



Dipoles - summary

- All brain dipoles have:
  - **Location – can “move”**
  - **Magnitude – can oscillate and vary in size**
  - **Orientation – can change as sources move among sulci and gyri**
- It is the population behavior that is “seen” in the EEG

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

Sensor Issues

- Sensor Type – gold, silver, silver-chloride, tin, etc.
- Sensor location – at least one sensor placed on scalp
- Sensor attachment – requires electrolyte paste, gel, or solution
- Maintain an electrically secure connection

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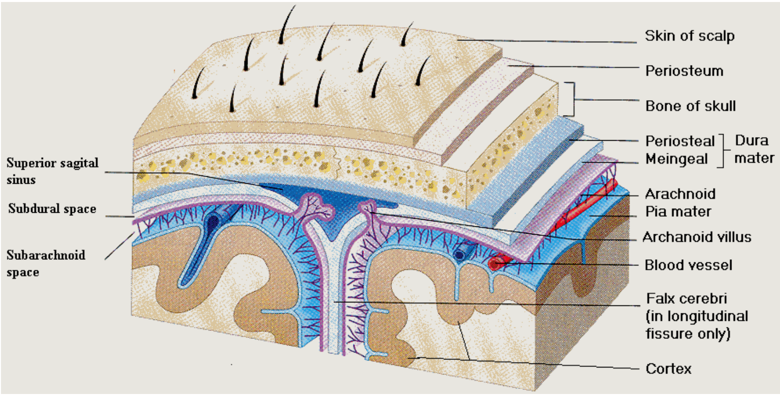
Sensor Types

- Disposable (gel-less and pre-gelled)
- Reusable disc sensors (gold or silver)
- Reusable sensor assemblies
- Headbands, hats, etc.
- Saline based electrodes – sodium chloride or potassium chloride

EEG Instrumentation

- Sensors pick up skin potential
- Amplifiers create difference signal from each pair of sensors
- Cannot measure “one” sensor, only pair
- 3 leads per channel – active, reference, grnd
- Each channel yields a signal consisting of microvolts varying in time

Cortical EEG Sources



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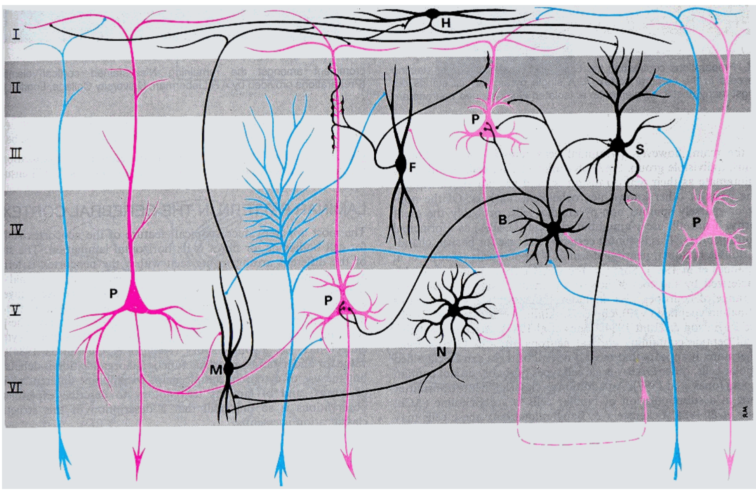
Cortical Layers



EEG Current Flow

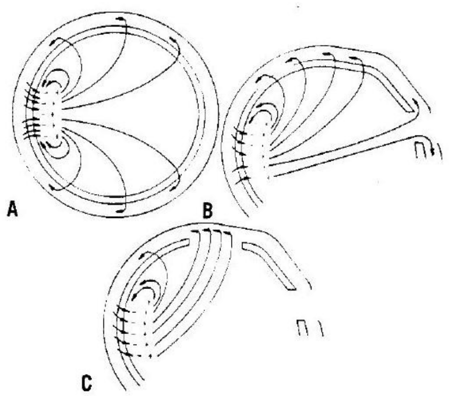
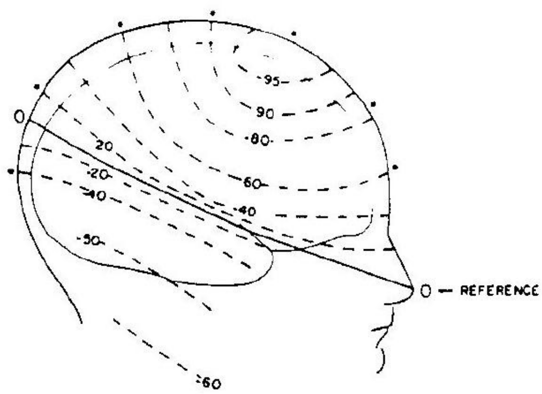


Fig. 16–1. Current flow as a result of a putative dipole layer generator in the occipital cortex. In the spherical head model shown in **A,** the current flow is relatively uniformly distributed. In **B,** a nonspherical head model with orbital openings, and **C,** a nonspherical head model with a surgically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

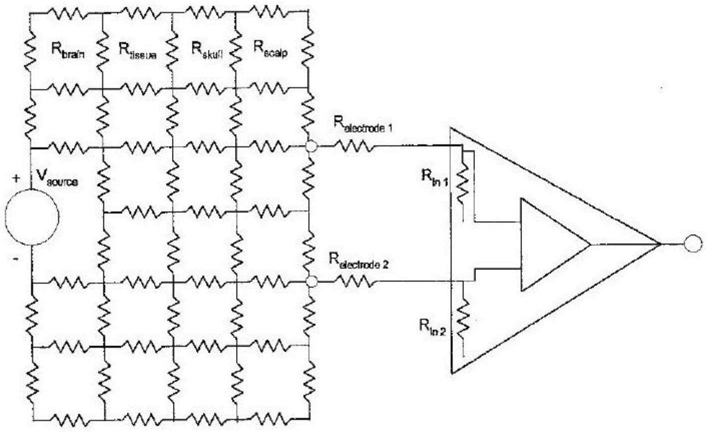
Effect of EEG "blurring"



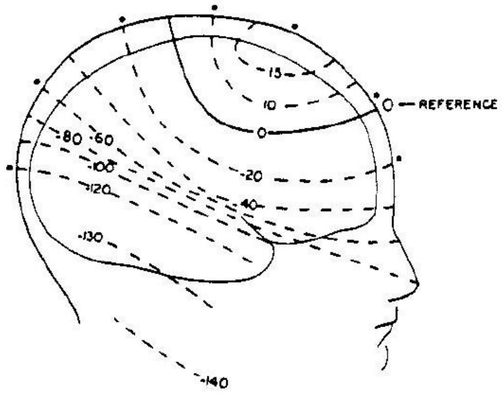
EEG Amplification

- Picks up difference between active & reference via. subtraction
- CMRR – common-mode rejection ratio measures quality of subtraction
- High CMRR rejects 60 Hz, other common-mode signals, amplifies difference
- Sensor pair picks up dipoles near sensors, between sensors, and parallel to sensor

Model for Differential Amplifier & EEG Generators



Effect of Reference Placement



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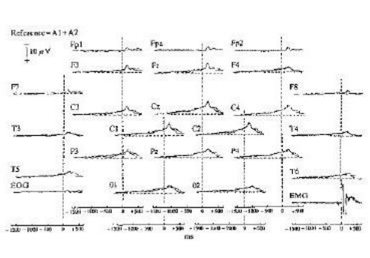
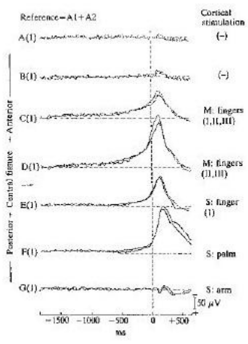
Scalp EEG vs. Invasive EEG (1 cm spacing)





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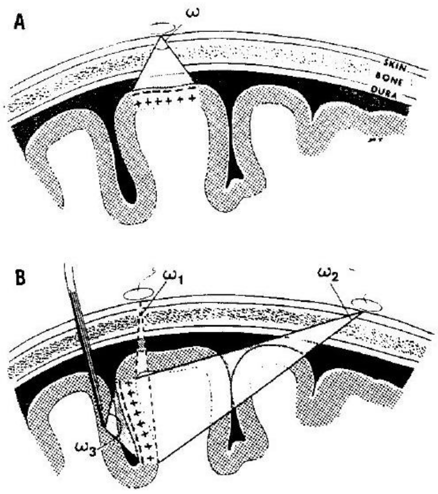
Paradoxical Lateralization



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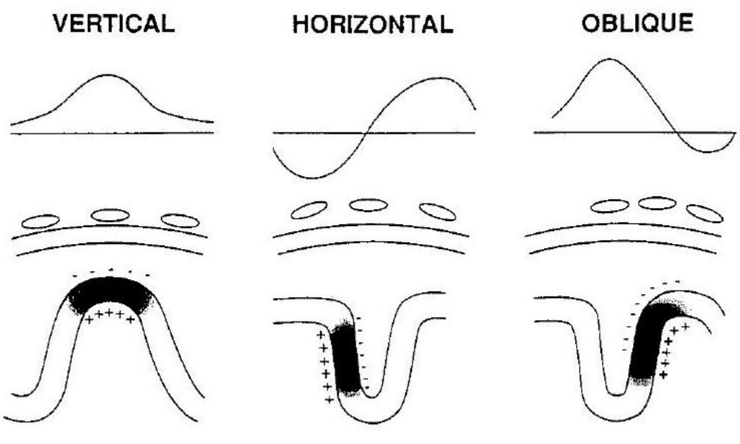
Oblique EEG Generators



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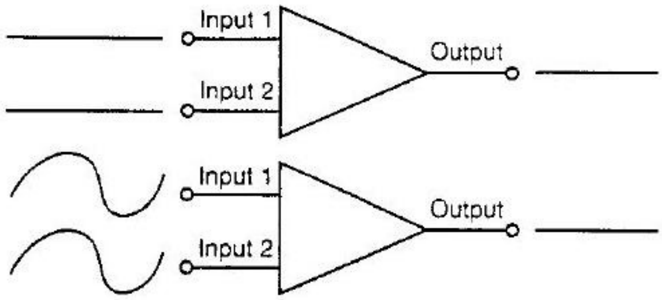
Differential Amplifier – “zero” output



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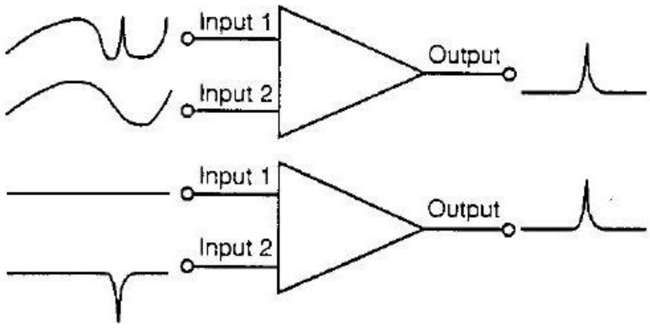
Differential Amplifier – nonzero output



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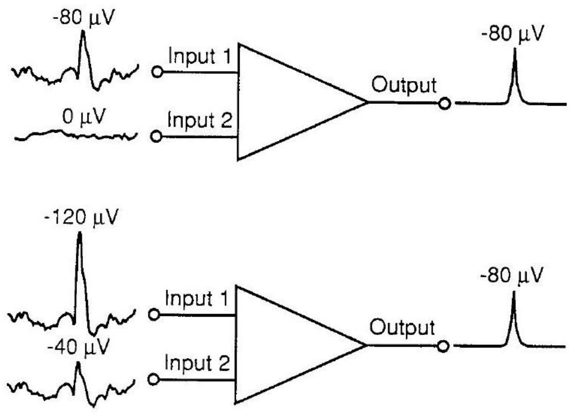
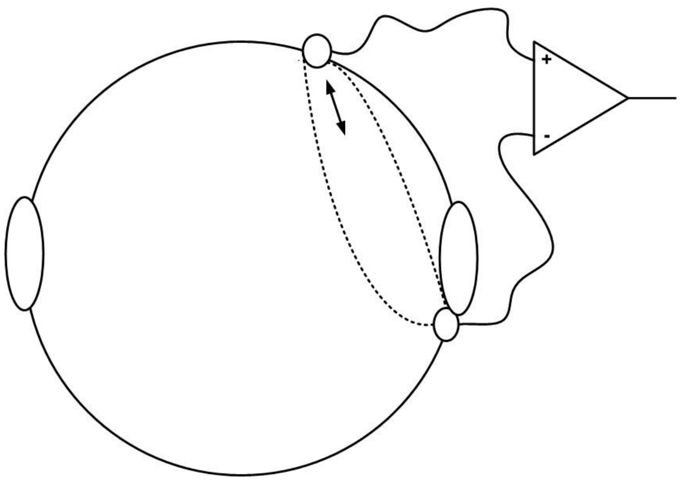
Differential Amplifier – nonzero output



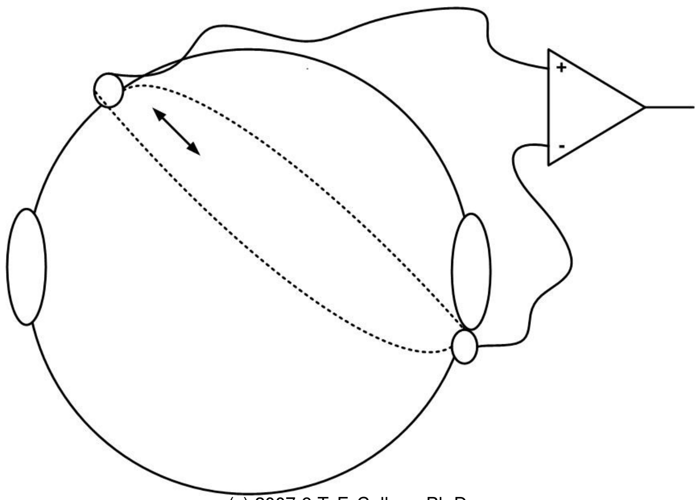
Dipole Sensing

- Sensor pair with differential amplifier picks up:
  - Sources near either sensor
  - Sources between both sensors
  - Sources aligned parallel to sensor axis

Region of Maximum Sensitivity



Contralateral Reference



EEG Electrophysiology

- "Forward problem" – given sources and anatomy, predict surface potentials
  - Solved & deterministic – 1 solution exists for any set of sources and anatomy
- "Inverse problem" given surface potentials, find sources and anatomy
  - Non-deterministic - many solutions exist for any surface potential distribution

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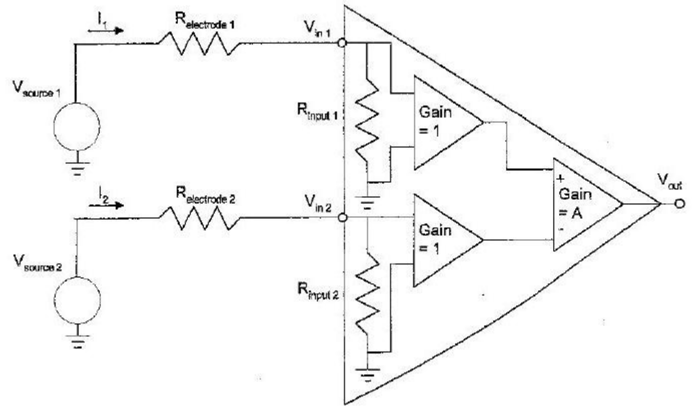

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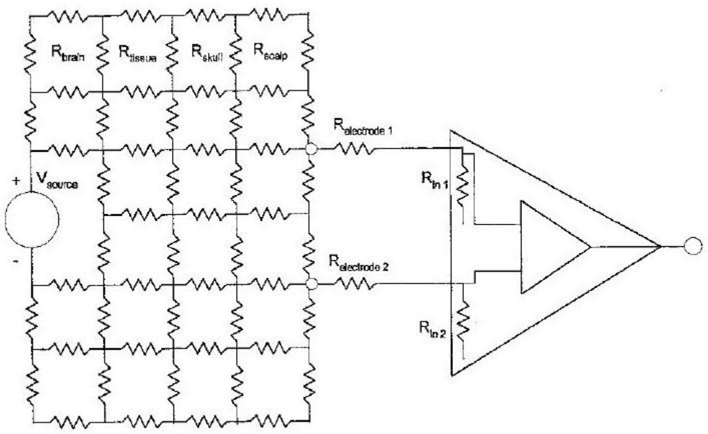
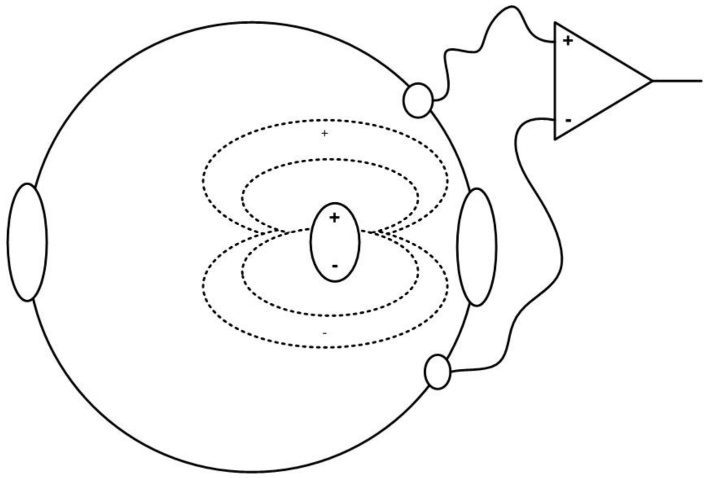


Sample EEG Computation



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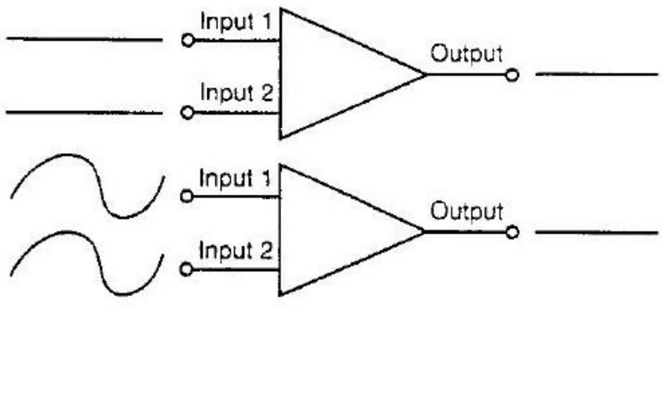
Differential Amplifier – “zero” output



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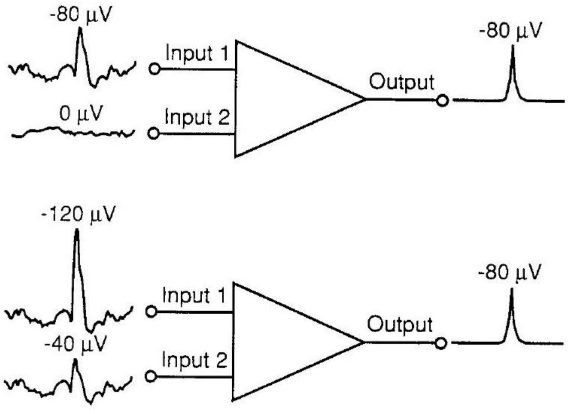

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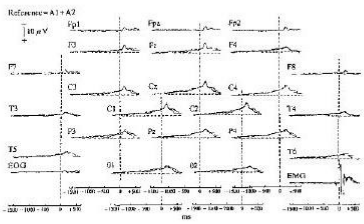

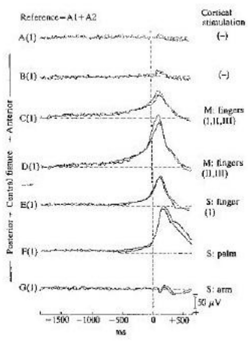

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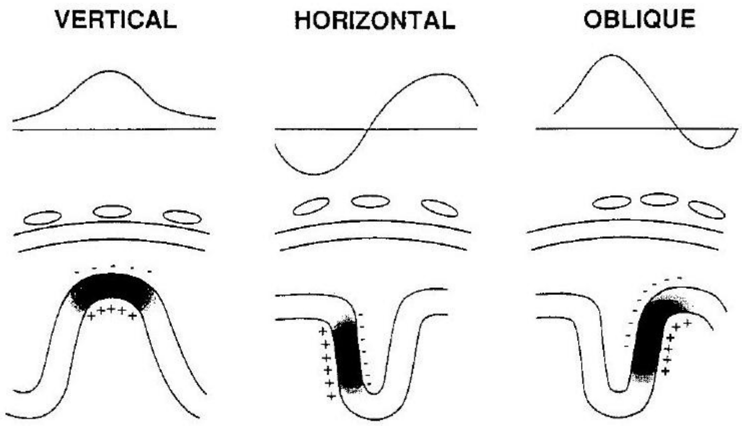

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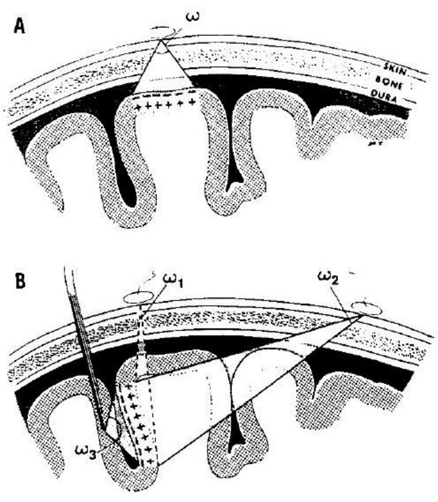

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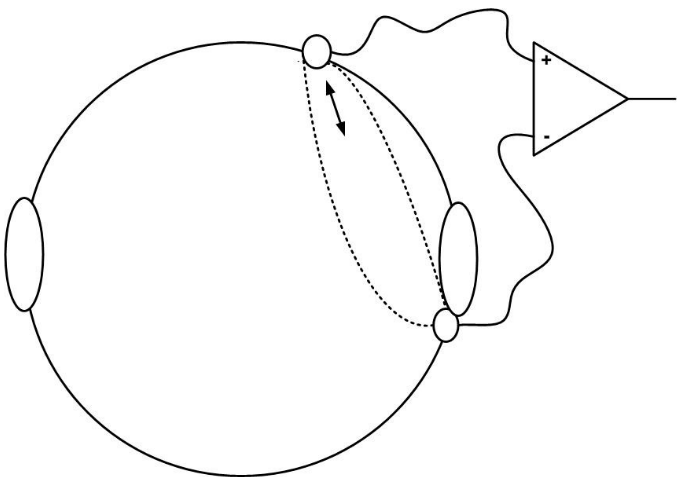

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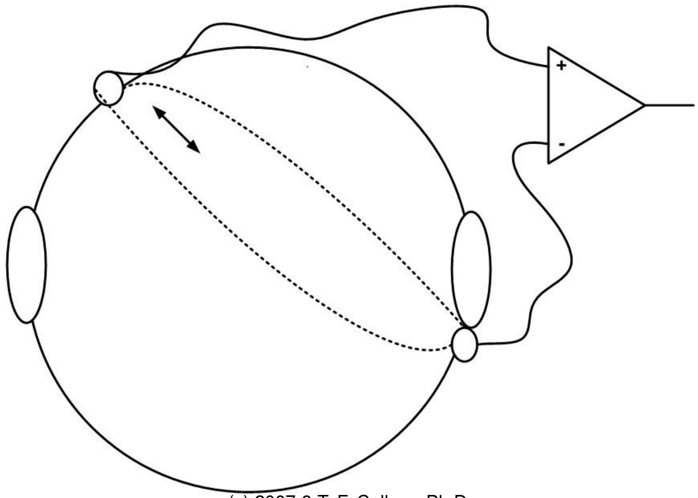
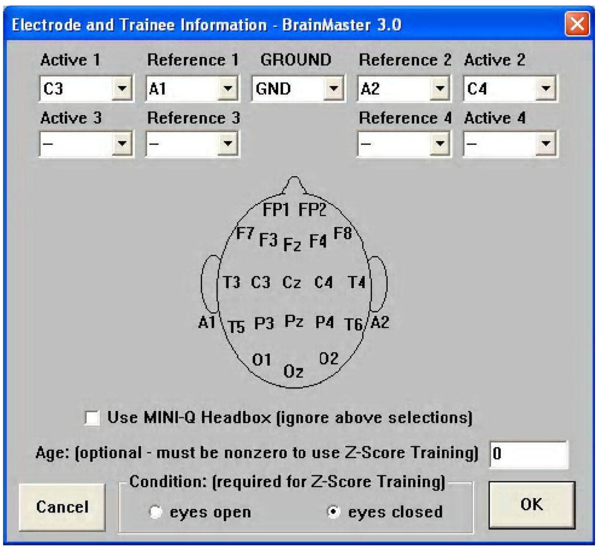
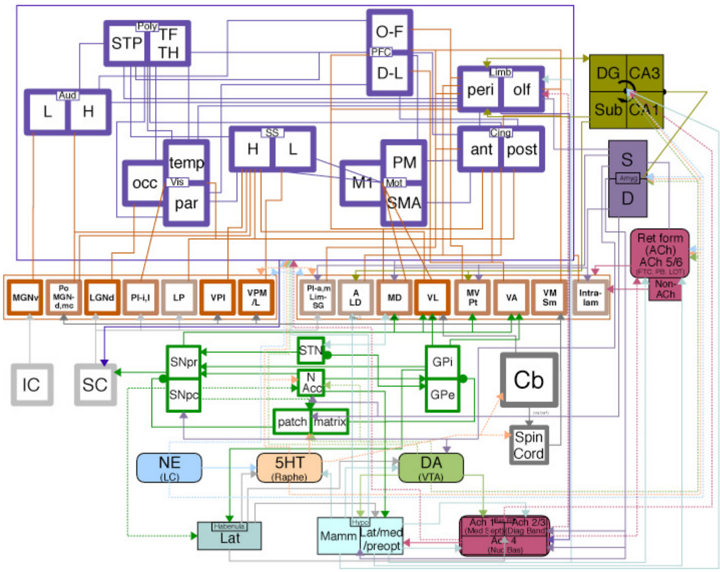


10-20 system



Engineering Diagram of the Brain



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From interstitiality.net

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

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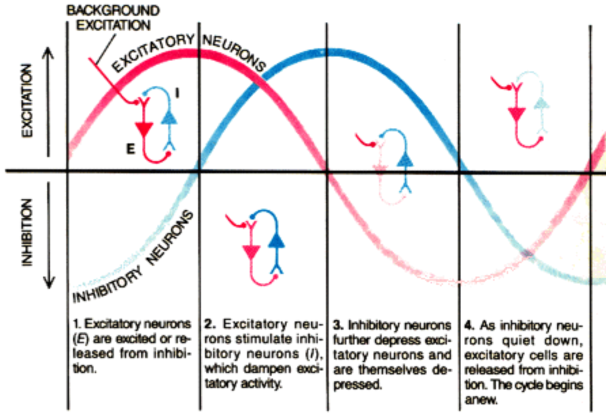
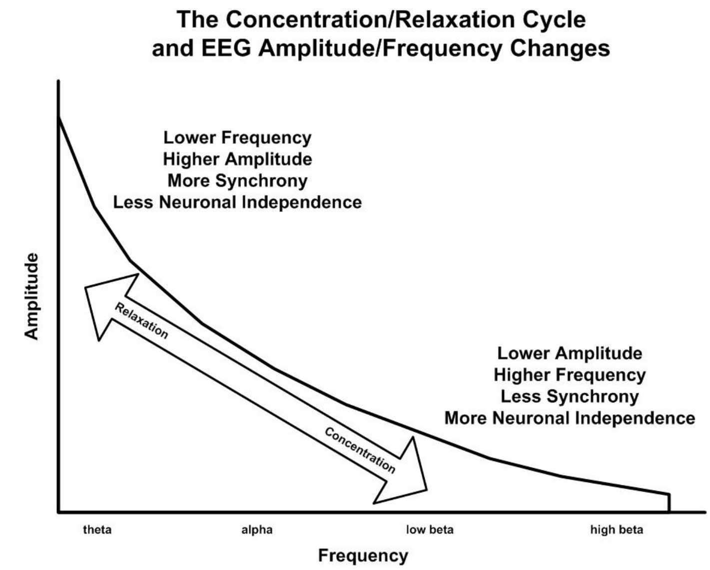
Thalamo-Cortical Cycles



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



Connectivity (coherence & phase)

- Coherence: Amount of shared information
- Phase: Speed of shared information
- Thalamocortical
  - Theta, Alpha, SMR
- Corticortical
  - Beta, Gamma
    - Intrahemispheric – e.g. language
    - Interhemispheric
    - Fronto-frontal – attention, control
    - occipito-parietal – sensory integration, aging

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 in an “epoch”
  - Like a prism
  - Response is slower, useful for assessment

Filtering Dynamics

- Wider filter follows waxing and waning better
- Need filter bandwidth >= 1 / burst length
- E.g. to see a 250 msec burst, filter must be 4 Hz wide
- To see a 100 msec burst, filter must be 10 Hz wide

Filter Order

- Describes slope of “reject” area outside of main passband
- Low order = “shallow” skirts
  - Faster, but less selective
- High order = “steep” skirts
  - Slower, but more selective
- Typical values 2, 3, … 6 order filters

Filter order recommendations

- Low order (2, 3)
  - High frequency training – SMR, beta, gamma
  - Beginners, children, peak performance
  - Response has more “pop”, picks up short bursts
- High order (5, 6)
  - Low frequency training – theta, alpha
  - Advanced, adults, meditation
  - Response is more accurate, requires longer bursts

Thresholding

- Sets amplitude criterion for rewards
- Compares signal amplitude with set value
- Can be constant, or can be varying
- Percent time over threshold is indicator of how often signal exceeds threshold

Thresholding

- Threshold is generally amplitude value
- Feedback is controlled via thresholds for each trained component
- Component may be "enhance" ("go") or "inhibit" ("stop")
- May use more than 1 component in combination in a protocol
- "Percent time over threshold" (%TOT)is average time the component is above threshold

Threshold Targets

- Enhance – being over threshold allows positive feedback
  - Reward rate = % TOT
- Inhibit – being over threshold inhibits feedback
  - success is being below threshold
  - Reward rate would be 100 - % TOT
- Total reward rate is product of individual success rates for each component

Threshold Targets

- Low inhibit – 20% TOT
  - 80% success rate = 100 - 20
- Midrange enhance – 60% TOT
  - 60% success rate
- High inhibit – 10% TOT
  - 90% success rate = 100 - 90
- Expected reward rate:
  - 0.8 x 0.6 x 0.9 = 0.43 = 43%
- SMR enhance is emphasized

Threshold Targets – Example 1

- Theta inhibit – 20% TOT
- SMR enhance – 60% TOT
- Hi Beta inhibit – 10% TOT
- Expected reward rate:
  - 0.8 x 0.6 x 0.9 = 0.43 = 43%
- SMR enhance is emphasized

Threshold Targets – Example 2

- Theta inhibit – 40% TOT
- SMR enhance – 80% TOT
- Hi Beta inhibit – 10% TOT
- Expected reward rate:
  - 0.6 x 0.8 x 0.9 = 0.43 = 43%
- Theta Inhibit is emphasized

Threshold Targets – Example 3

- Theta inhibit – 60% TOT
- SMR enhance – 100% TOT
- Hi Beta inhibit – 0% TOT
- Expected reward rate:
  - 0.4 x 1.0 x 1.0 = 0.40 = 40%
- Theta Inhibit is all there is – Theta "squash"

When to adjust thresholds?

- Never (Lubar)
  - Don't frustrate trainee
  - Allow to see improvement in scores
- Once for each session (Ayers)
  - Tell trainee new threshold
  - Goal of consistent number of points per session
- Every 2-5 minutes (Othmer, Soutar)
  - Optimal rate of reward
  - Show trainee improvement in EEG scores
- Continually (Brown & Brown)
  - Brain is a dynamical system
  - Provide information regarding emergent variability

Squash Protocol

- Based on downtraining amplitude
- Generally directed toward activation
- Lower amplitude -> higher frequency
- “Bench press” model – work then relax
- Easy to learn, especially theta squash

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

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Delta (typ. 1 – 3 Hz)

- Distribution: broad, diffused, bilateral, widespread
- Subjective states: deep, dreamless sleep, trance, unconscious
- Tasks & behaviors: lethargic, not attentive
- Physiological correlates: not moving, low-level arousal
- Effects: drowsiness, trance, deeply relaxed

Theta (typ. 4 – 7 Hz)

- Low-frequency rhythm associated with internalized thoughts
- Mediated by subthalamic mechanisms
- Associated with memory consolidation
- Generally non-sinusoidal, irregular
- Seen during hypnogogic reverie
- Seen as precursor, and sequel to sleep
- Edison's "creativity" state

Theta (typ. 4 – 7 Hz)

- Distribution: regional, many lobes, laterlized or diffuse
- Subjective states: intuitive, creative, recall, fantasy, imagery, dreamlike
- Tasks & behavior: creative, but may be distracted, unfocussed
- Physiological correlates: healing, integration of mind and body
- Effects: enhanced, drifting, trance like, suppressed, concentration, focus
- Typically 4 – 8 Hz

Three types of “theta”

- “True” theta
  - Subthalamic control
- Slow alpha
  - Slowed due to increased processing
  - Evident in adults, meditators
- Glial theta
  - DC potential, modulated at up to 4 Hz

Alpha (typ. 8 – 12 Hz)

- Resting rhythm of the visual system
- Increases when eyes are closed
- Largest occipital – O1, O2
- Characteristic waxing and waning
- Generally sinusoidal, hemispheric symmetrical
- Indicates relaxation
- Role in background memory scanning
- Round trip thalamus-cortex-thalamus ~ 100 ms
- Typically 8 – 12 Hz, but may be 4 – 20 Hz

Alpha (typ. 8 – 12 Hz)

- Distribution: regional, evolves entire lobes, strong occipital with closed eyes
- Subjective states: relaxed, not drowsy
- Tasks & behavior: meditation, no action
- Physiological correlates: relaxed, healing
- Effects: relaxation

Alpha vs. activation

- Paradox – when alpha appears, brain is less active
- Activation is accompanied by high frequency, lower amplitude EEG
- Can achieve activation by training amplitude down – “squash” protocol

Frontal Alpha Asymmetry

- Davidson, Rosenfeld, Baehr found:
- Right alpha should be 10 – 15% > left alpha
- Required for positive mood
- Can train left alpha down to treat depression
- Activates left hemisphere

Two Alphas

- Alpha actually shows 2 bands
- May wax and wane independently
- 9 – 12 Hz
  - Standard resting rhythm
  - Typical occipital alpha wave
- 7 – 9 Hz
  - Related to emotional processing
  - Important to frontal asymmetry
  - Longer round-trip may indicate more processing

Low Beta (typ. 12 – 15 Hz)

- Distribution: localized by side and lobe
- Subjective states: relaxed, focused, integrated
- Tasks & behavior: relaxed, attentive
- Physiological correlates: inhibited motion (when at sensorimotor cortex)
- Effects: relaxed focus, improved attentive ability

Sensorimotor Rhythm (SMR) (typ. 12 – 15 Hz)

- Resting rhythm of the motor system
- Largest when body is inactive
- Indicates intention not to move
- Measured over sensorimotor strip C3/Cz/C4
- Round-trip thalamus-cortex-thalamus ~ 80 ms
- Typically 12 – 15 Hz
- Also called “14 Hz” or “Tansey” rhythm

Beta (typ. 16 – 20 Hz)

- Distribution: localized, over various areas
- Subjective states: thinking, aware of self and surroundings
- Tasks & behavior: mental activity
- Physiological correlates: alert, active
- Effects: increase mental ability, focus, alertness

High Beta (typ. 20 – 30 Hz)

- Distribution: localized, very focused
- Subjective states: alertness, agitation
- Tasks & behavior: mental activities (math, planning, etc)
- Physiological correlates: activation of mind and body functions
- Effects: alertness, agitation

Gamma (“40 Hz”)

- AKA “Sheer” rhythm
- Collura (1985) found 6-7 bursts/second in PSI states using FFT technique
- Davidson found sustained gamma in advanced meditators
- Short bursts require wide (35 – 45) filters to detect
- Others define:
  - 25-30 Hz (Thatcher)
  - 32-64 Hz (Thornton)

Gamma ("40 Hz")

- Distribution: very localized
- Subjective states: thinking, integrated thoughts
- Tasks & behavior: high-level information processing "binding"
- Physiological correlates: information-rich tasks, integration of new material
- Effects: improved mental clarity, efficiency

DC ("Direct Current")

- Standing potential, 0.0 – 1 Hz
- Reflects glial, other mechanisms
- Includes sensor offset and drift
- May include "injury" potential
- Difficult to record, may be unstable
- Requires Ag/AgCl sensors
- SCP is more useful clinically

SCP (“Slow Cortical Potentials”)

- Typically 0.01 – 2 Hz
- Primarily glial origin
- Associated with general brain activation
- “Bareitschaft” potential evident preceding voluntary motor movement
- Large shifts seen preceding seizures
- Training useful in epilepsy, BCI

Coherence Training

- Coherence reflects similarity between 2 channels
- Measure of information sharing
- Coherence may be trained up or down
- “Goldilocks” effect – may be too high or too low at any given site
- Alpha coherence can be trained up bilaterally (occipital or parietal) without adverse reaction

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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)

Effective Feedback

- Fast – provides timely information to allow temporal binding
- Accurate – so brain has good information to work with, not ambiguous or superfluous
- Aesthetic – so brain will respond well to the content of the feedback without undue effort or confusion

Learning Mechanisms

- Operant Conditioning
- Classical Conditional
- Concurrent Learning
- Self-Efficacy
- Generalization

Instructions to Trainee

- Allow the sounds to come
- Do not “try” to do anything
- Allow yourself to learn what it feels like when you get a point
- Relax and pay attention to the screen
- Let the sounds tell you when you are in the desired state

Standard Protocols

- Alert C3 – beta up; theta, hibeta down
- Deep Pz – (Penniston) alpha up, theta up
- Focus C4 – SMR up; theta, hibeta down
- Peak C3-C4 – alpha coherence up
- Peak2 C3-C4 – alert and focus combined
- Relax Oz – alpha up; theta, hibeta down
- Sharp Fz – broadband squash

Additional Activities

- **Reading**
- **Legos**
- **Drawing**
- **Tetris**
- **Coloring book**
- **Puzzles**
- **Homework**
- **Allow trainee to attain relaxed, focused state even while under a task**

Deep States Training

- Alpha/Theta Training
- Penniston / Kulkowsky; Bill Scott
- Induces Hypnogogic State
- De-activates fear mechanisms
- Engages memory consolidation
- Effecting internal change
- Used in conjunction with psychotherapy
- Possibility of abreaction

Low Freq vs. High Freq Training

Characteristics	**Low Freq Training**	**High Frequency Training**
Components	Alpha: reinforce Theta: reinforce	Beta: reinforced Smr: reinforced Theta: inhibited
Goal	Deeper awareness	Balance, control, alertness
Level of effort	Effortless, letting go	Effort, relaxed
Speed of response	Brain responds slow, feedback can be slow	Brain responds quickly, rapid feedback
Use of feedback	Primarily an indicator	Want to "crank" thresholds & perform
Reward percent	Generally 80%	Generally 50-60%
Type of feedback	Mostly "yes" some "no"	Mostly "no" some "yes"

Low Freq vs. High Freq (cont)

Characteristic	Low Freq Training	High Freq Training
Trainee context	Immersion into relaxed state	Tuning, improving brain
Application	Exploration and recovery	Mental fitness
Brain areas	Parietal, Occipital	Motor area
Modality	Auditory, trancelike	Visual, game like
Sessions	30min to 3hours no breaks	20-30min, may have breaks
Relaxation	Total relaxation	Relaxation with muscle tone
Environment	Quiet, low lighting	Normal surrounding
Clinical Use	Deep seated issues, recovery	Attention, Depression, Other

Low Freq vs. High Freq (cont 2)

Characteristics	Low Freq Training	High Freq Training
Volition	Abandon volition	Has volitional element
Self-Improvement	Awareness, one-ness, growth	Peak-performance
Eyes	Eyes closed	Eyes open
Crossovers	Yes (from alpha state to theta state)	No
Increase	Look for 2x to 3x	Optional sustained increase
End state	Altered state of consciousness	Awake & alert state
Spatial	Widespread in space (brain)	Localized in space (brain)
Follow on goal	Experience altered state now, reap follow-on benefits	Ability to reproduce state during daily life
Age	Not done with children	All ages

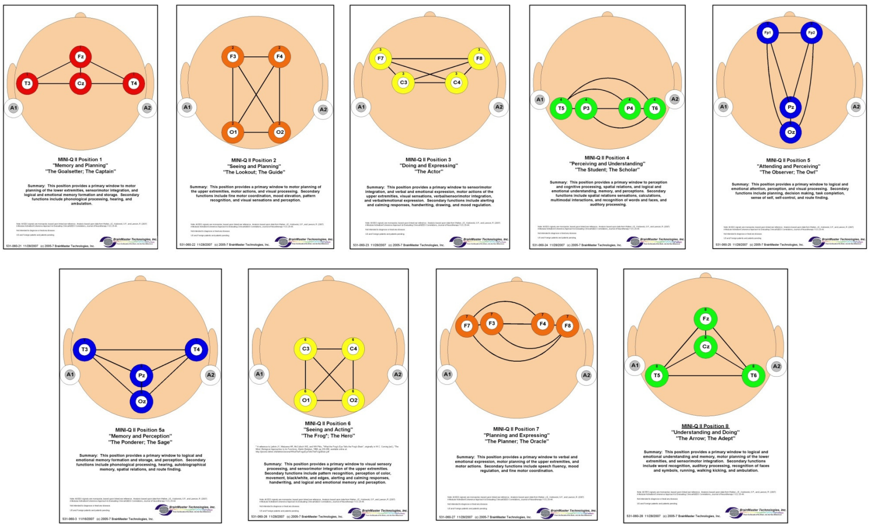
MINI-Q

- 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 Quads

- 1. Fz Cz T3 T4 – Memory / Planning
- 2. F3 F4 O1 O2 – Seeing / Planning
- 3. C3 C4 F7 F8 – Doing / Expressing
- 4. P3 P4 T5 T6 – Perception / Understanding
- 5. Fp1 Fp2 Pz Oz – Attention / Perception
- 5a. T3 T4 Pz Oz – Memory / Perception
- 6. O1 O2 C3 C4 – Seeing / Doing
- 7. F7 F8 F3 F4 – Planning / Expressing
- 8. T5 T6 Fz Cz – Understanding / Doing

MINI-Q II Quads



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

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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”

Live versus Static z scores

- LZ-scores measure instantaneous deviation
- LZ-scores typically smaller in magnitude
- Sustained LZ-score results in larger static Z-score
- “Score on a hole” versus “Score for the game”
- No standard to convert between
- Typical target is 0 for either

Normal Distribution males vs. females

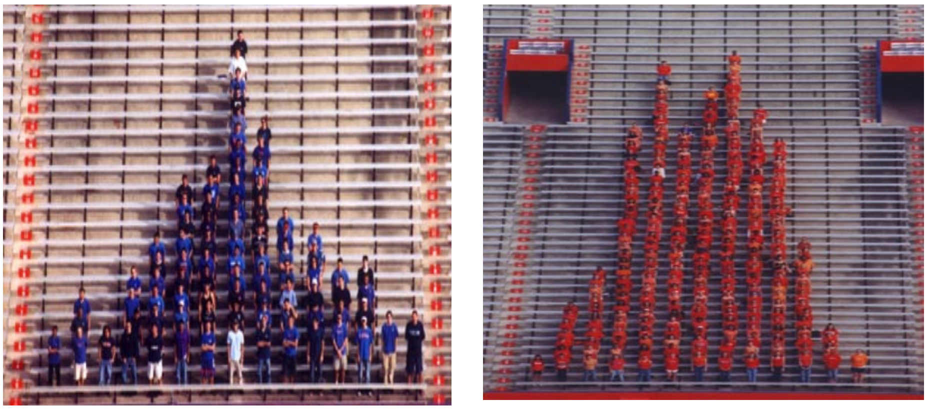
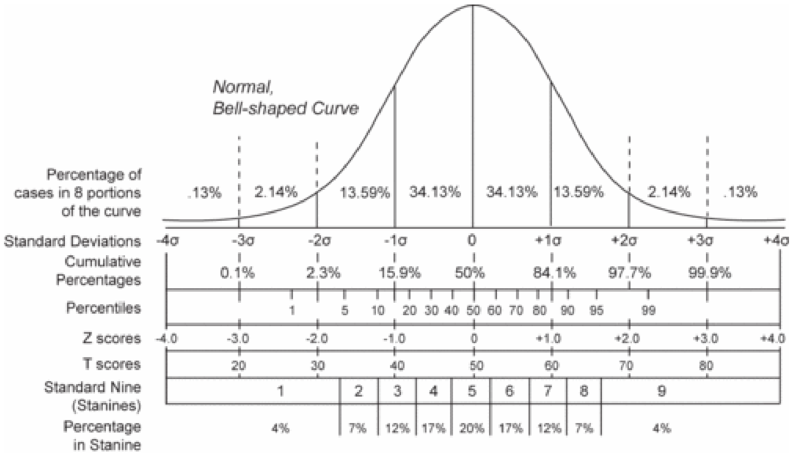


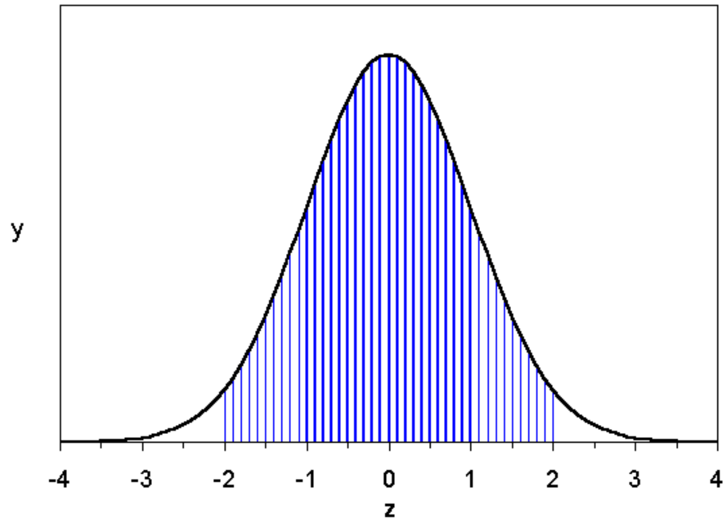
Photo by Gregory S. Pryor, Francis Marion University, Florence, SC.

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

Normal Distribution



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

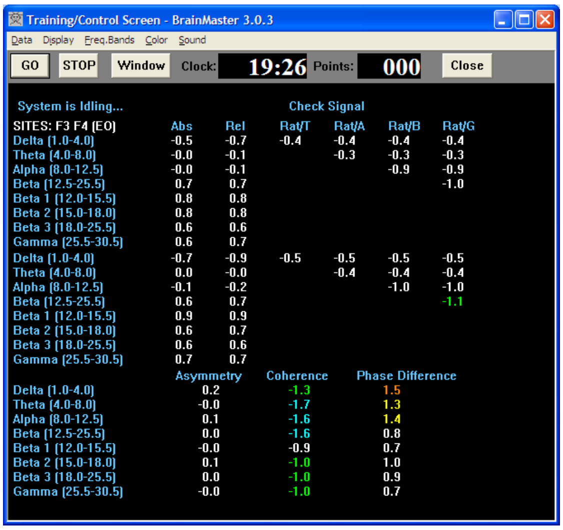
Component bands in Z DLL

- 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)

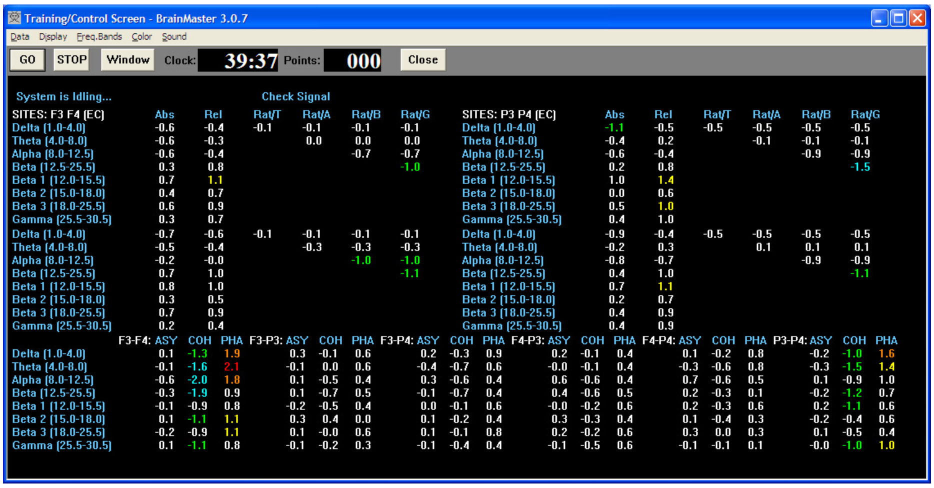


26 x 2 + 24 = 76 (52 power, 24 connectivity)

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)

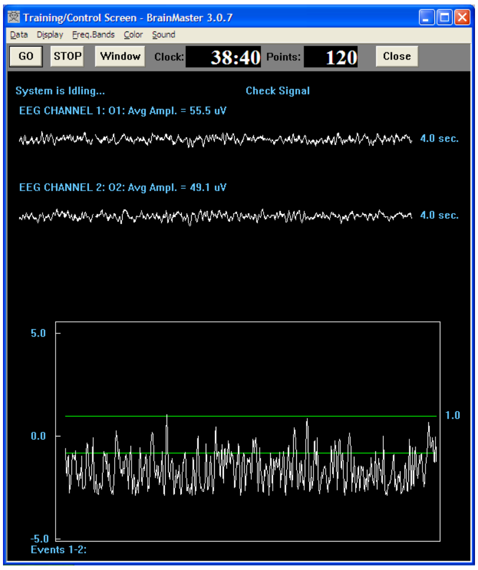


26 x 4 + 24 x 6 = 248 (104 power, 144 connectivity)

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)



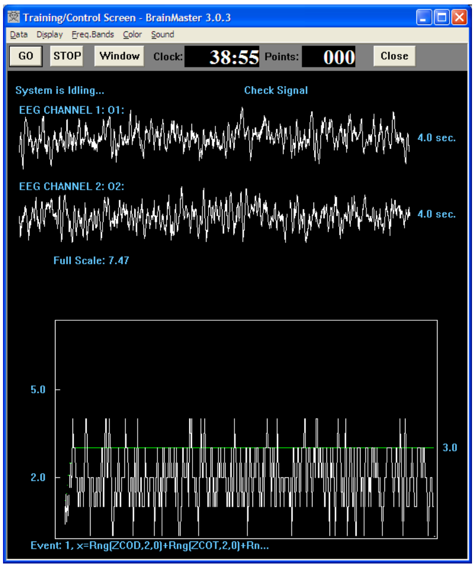
Range Function

- 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

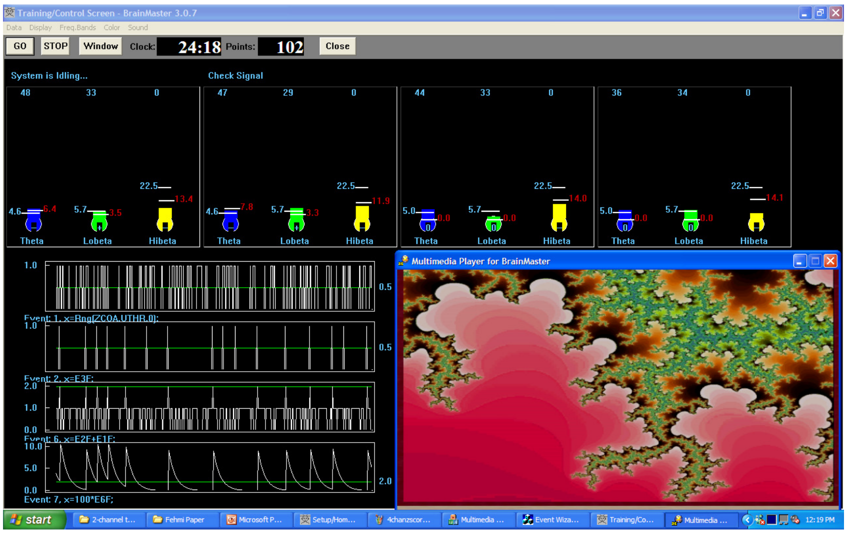
Range training with multiple ranges

- 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)

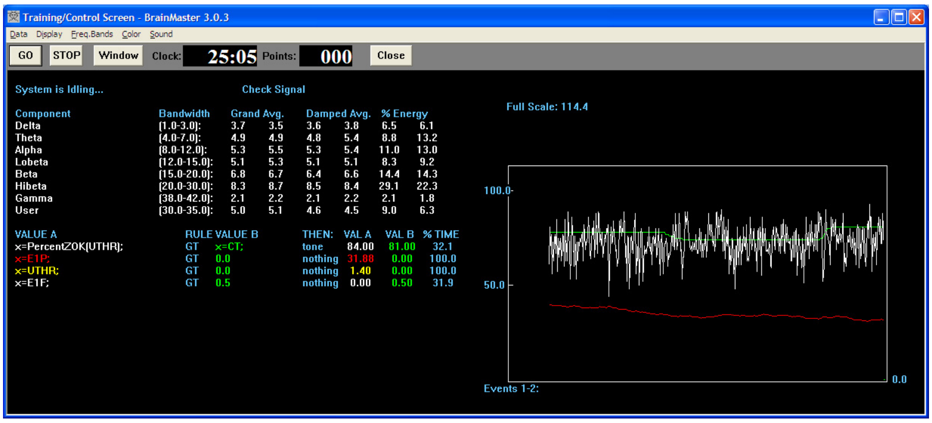
PercentZOK() function

- 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

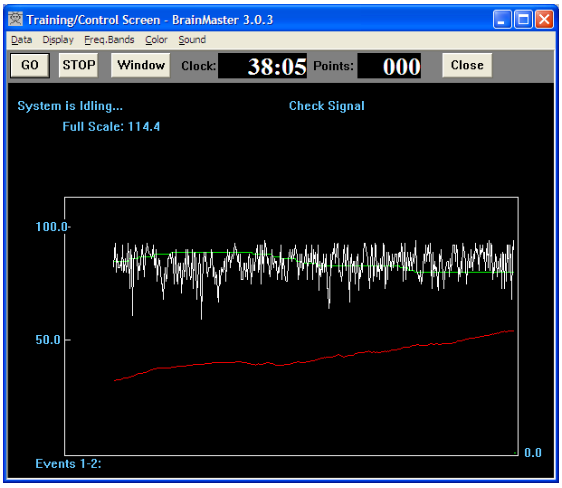
Z Score training using Multivariate Proportional (MVP) Feedback



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



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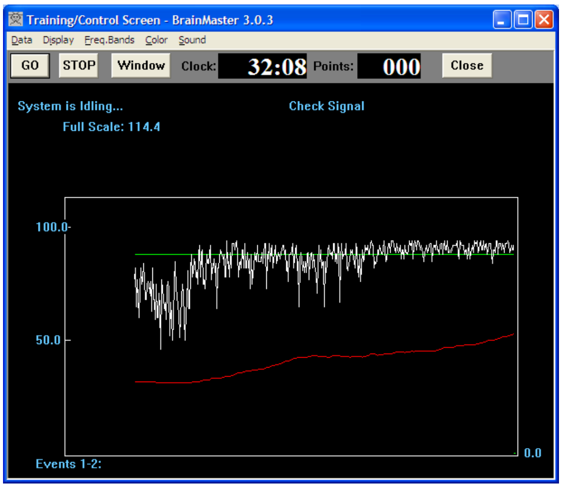
Effect of widening Z target window

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



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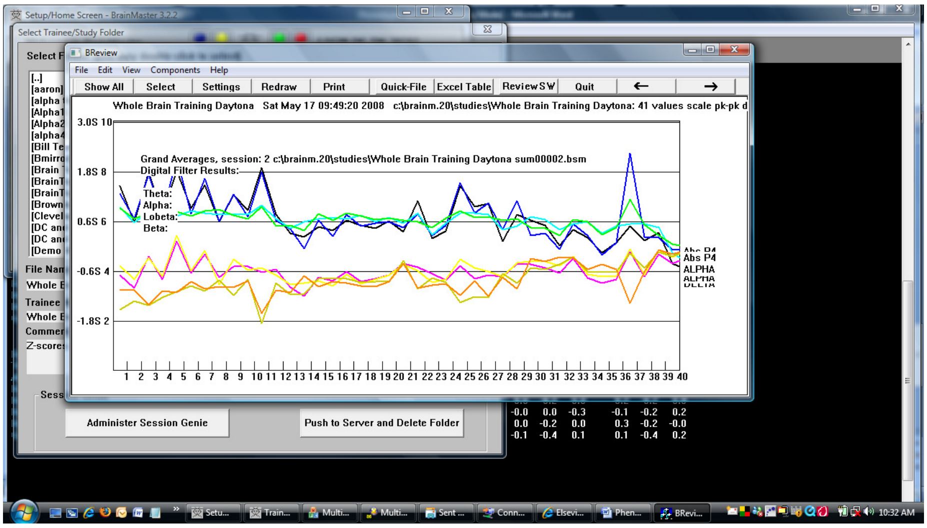
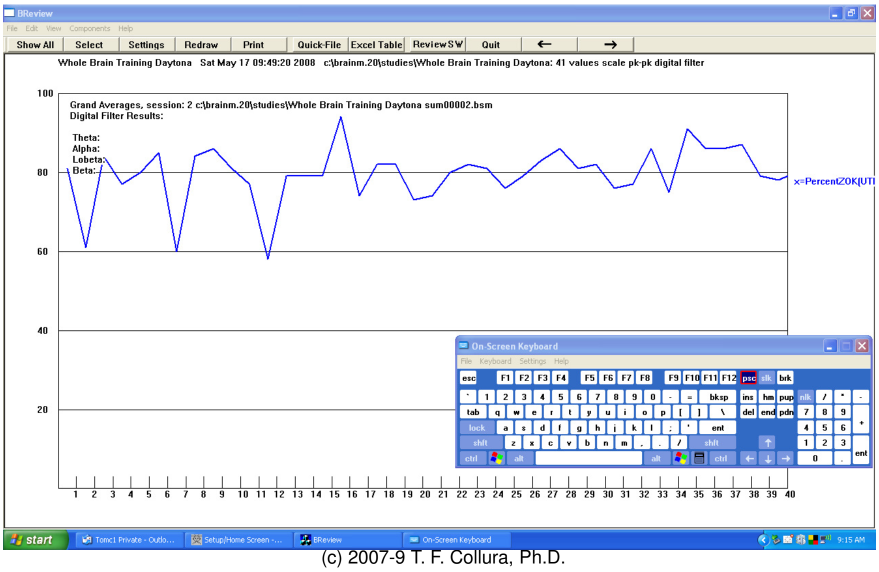
Z-score based targeting

- 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

Progress of Live Z-Score Training



Progress of MVP Variable



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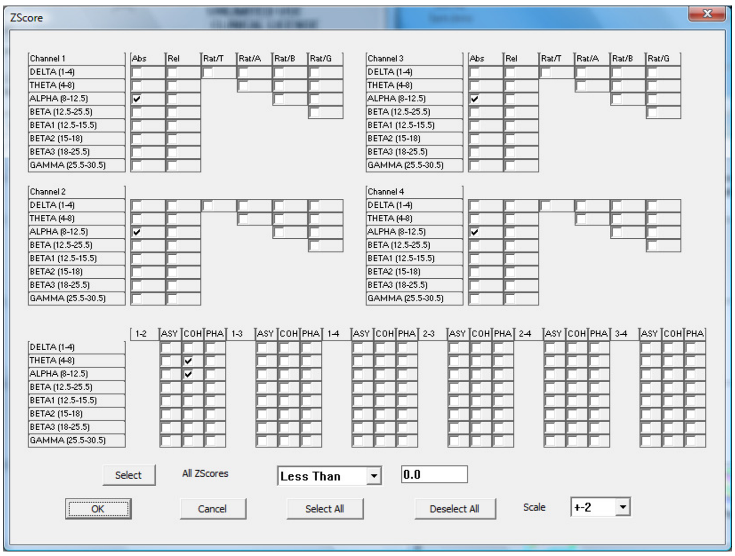
Live Z-Score Selection



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Live Z-Score Training Policy

- EEG deviation(s) should be consistent with clinical presentation(s)
- EEG normalization should be reasonable
- Consider coping, compensatory traits
- Consider “peak performance” traits
- Consider phenotypes & recommendations
- Monitor subjective and clinical changes

Normalize using Live Z-Scores

- Excessive Frontal Slowing
- Excessive Beta or high beta
- Hypercoherence, not left hemisphere (F3-P3)
- Hypocoherence, not central (C3-C4)
- Localized (focal) excess or deficit

Coping/Compensating Z-Scores

- Diffuse Low alpha
  - chronic pain (barrier)
- Diffuse high alpha
  - chronic anxiety coping mechanism
- Posterior asymmetries
  - PTSD, stress coping, cognitive dissonance
- Substance Abuse, Addiction
  - Effects of EEG normalization not well understood

"Peak Performance" Z-Scores

- Left Hemispheric Hypercoherence(F3-P3)
- Central Intrahemispheric Hypocoherence (C3-C4)
- "Excess" SMR C4
- "Excess" posterior alpha
- "Fast" posterior alpha

- Note: normalization can be avoided by keeping EEG sensors away from affected sites

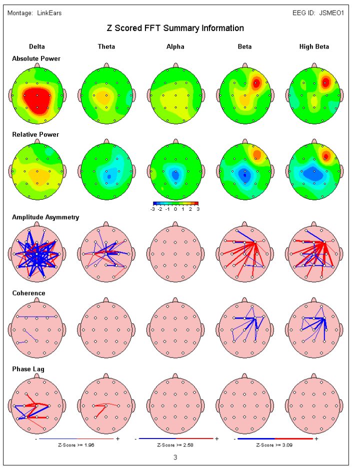
Phenotypes and Live Z-Scores

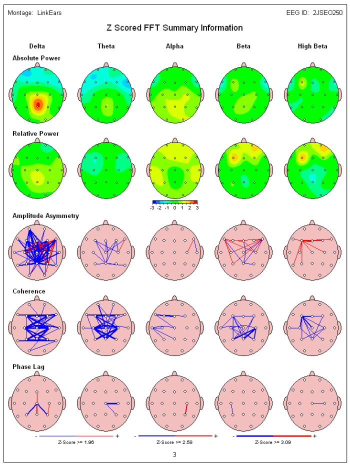
- Most Phenotypes “map” to live z-scores
  - Diffuse Slow
  - Focal Abnormalities, not epileptiform
  - Mixed Fast & Slow
  - Frontal Lobe Disturbances – excess slow
  - Frontal Asymmetries
  - Excess Temporal Lobe Alpha
  - Spindling Excessive Beta
  - Generally Low Magnitudes
  - Persistent Alpha
  - + Diffuse Alpha deficit
- Exceptions:
  - “Epileptiform” (requires visual inspection of EEG waveforms)
  - Faster Alpha Variants, not Low Voltage (requires live z-score for peak frequency)
- Many phenotypes can be addressed via. LZT Training
  - Inhibits, rewards referenced to normal population or biased for enhance/inhibit
- Phenotypes do not (currently) consider connectivity deviations
  - Hypocoherent Intrahemispheric (L or R)
  - Hypercoherent Interhemispheric (e.g. frontal)
  - Diffuse Coherence / Phase Abnormalities

Case of Jack

- 3 YO Male
- Mild concussive head injury
- Atonic, absence, myoclonic seizures
- Multi-spike focus, 300-400 uV
- Initially used inhibit & coherence training
- Temporarily improved, then declined
- Then switched to z-score “all coherences normal” training
- Seizures stopped after 3 sessions
- Data courtesy of M. L. Smith

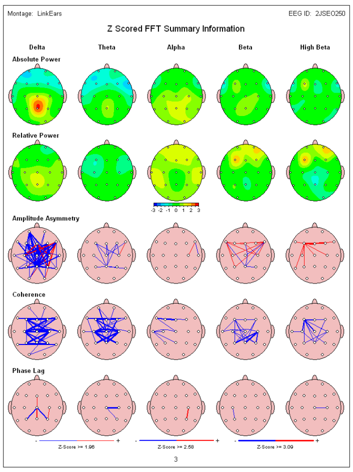
Jack QEEG pre and post conventional training

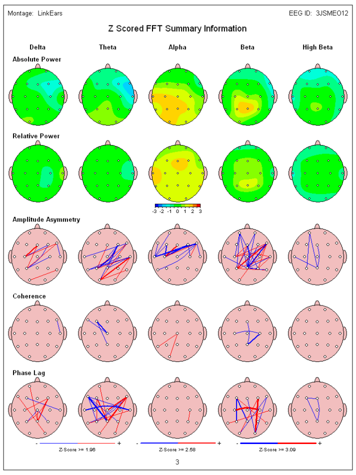




 Data from M.L. Smith

Jack QEEG pre and post Z-score training



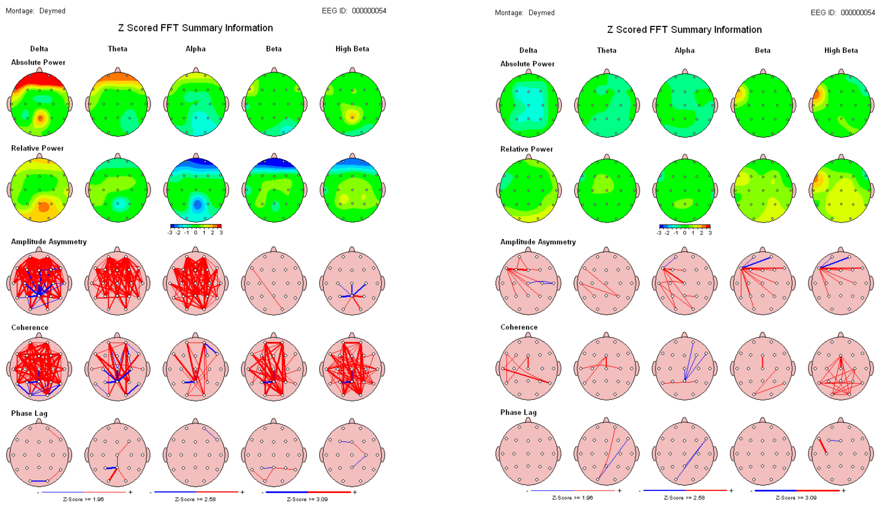


 Data from M.L. Smith

Case of SL

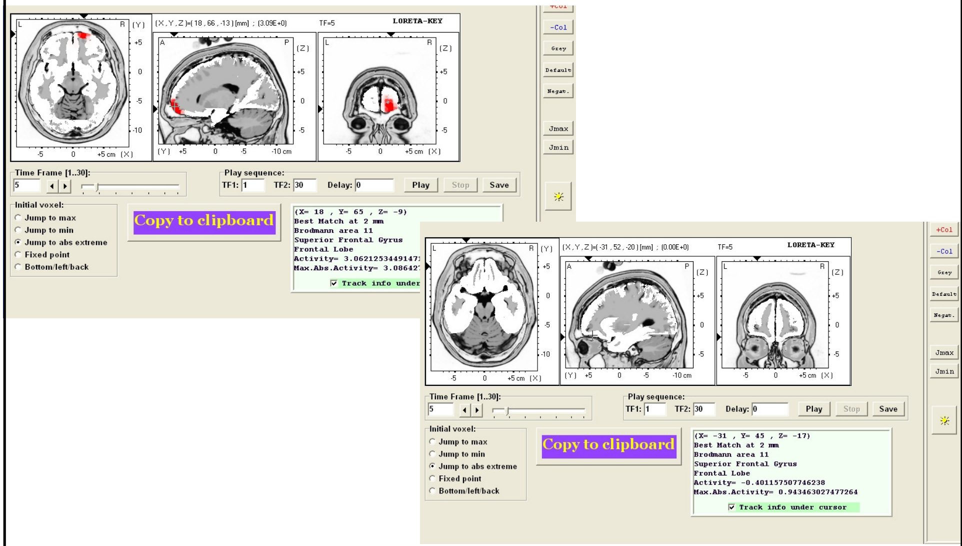
- 7YO Male, discipline problem, AD/HD, easily excited, aggressive
- QEEG Pre and post z-score training
- 21 sessions between QEEG's
- PercentZ training at 85% reward
- Begin F3 F4 P3 P4, later F3 F4 C3 C4
- Begin at +/- 2.0 S.D.
- All scores except 1 within 1.5 S.D. after training
- Significant clinical improvement
- Data courtesy Drs. C. Stark & W. Lambos

SL - EO Pre and Post



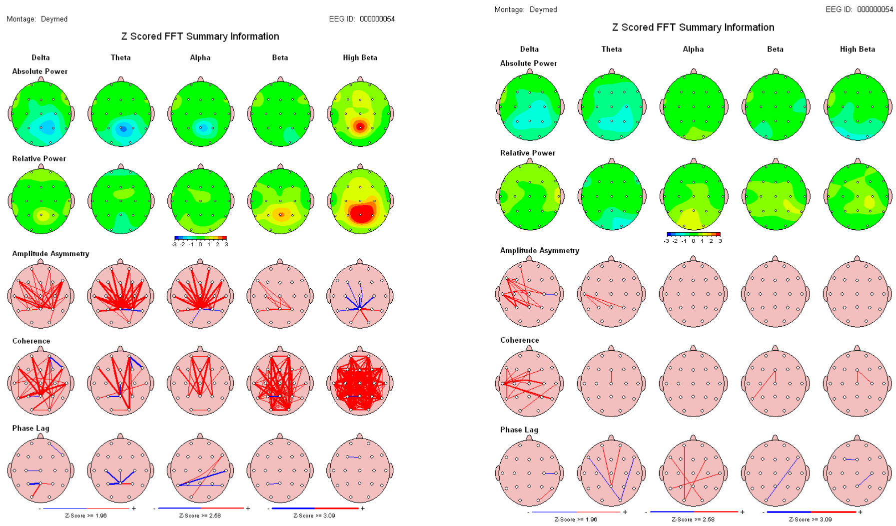
Data from Stark & Lambos

SL - EO Loreta Pre and Post



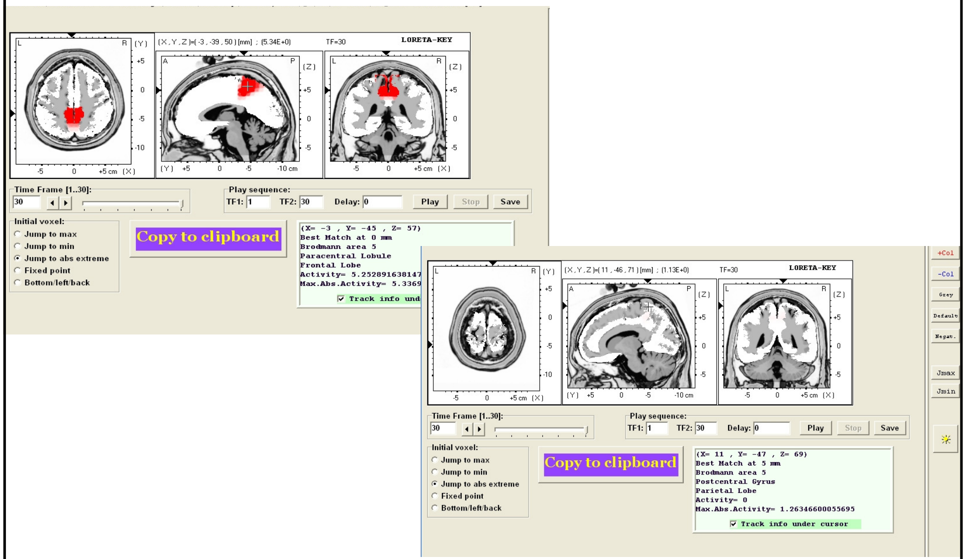
 Data from Stark & Lambos

SL - EC Pre and Post



 Data from Stark & Lambos

SL - EC Loreta Pre and Post



Data from Stark & Lambos

Summary

- New method using normative data
- Comprehensive whole-head approach
- Normalizes both activation & connectivity
- Multiple targeting & biasing capability
- Consistent with QEEG & Phenotype approaches
- Provides brain with complex information
- Simple training format
- Effective for assessment & training

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- 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

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Questions

- 1. If you reverse the active and reference leads of an EEG amplifier, which of the following would result?
  - A. The frequency content would shift up or down
  - B. The waveforms would be displayed upside down
  - C. The amplitude of the waveform could change
  - D. There would be no change in the signals at all

Questions

- 2. CMRR or “common-mode rejection ratio” should be high in order to:
  - A. Reduce the effects of 60 Hz interference
  - B. Reduce the effects of motion artifact
  - C. Reduce the effects of electrode imbalance
  - D. All of the above

Questions

- 3. SMR or “sensorimotor rhythm” can be described as the following:
  - A. A high-frequency alpha wave from the sensorimotor cortex
  - B. A low-frequency beta wave recorded from C3, Cz, or C4
  - C. A brain rhythm associated with the intention not to move
  - D. All of the above

Questions

- 4. Which of the following apply to Penniston style “alpha/theta” training?
  - A. Alpha is rewarded, and theta is inhibited.
  - B. Alpha is rewarded, and theta is also rewarded
  - C. Alpha is inhibited, and theta is inhibited
  - D. None of the above

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Questions

- 6. As defined, “percent time over threshold” reflects which of the following?
  - A. The proportional amount of time that a signal exceeds the defined threshold
  - B. The overall size of the signal
  - C. The level of effort of the trainee
  - D. The amount of noise in the EEG

Questions

- 7. Two bandpass filters are being used. They are identical. However, one is set for 8-12 Hz and the other is set for 7-13 Hz. The second filter will be able to do which of the following?
  - A. Reject out of band signals better than the first filter
  - B. Respond faster to component “waxing and waning”
  - C. Have more precise cutoff frequencies
  - D. All of the above

Questions

- 8. What is a "Z-Score"?
  - A. A measure of how large a value is
  - B. A measure of how much a value is different from a population mean
  - C. A measure of how healthy an individual is
  - D. None of the above

Questions

- 8. Which of the following are true of live Z-Score training?
  - A. It depends on a database
  - B. It addresses brain connectivity
  - C. It can teach the brain complex patterns
  - D. All of the above