Whole Brain Training using EEG Connectivity and Asymmetry

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The Purpose of Connectivity Training

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

Generalized Connectivity Model



Generalized Model for EEG Generation

System Identification and Parameter Estimation



Connectivity Measures

- Many ways to measure connectivity
- Always asking "how similar are the signals?"
- Relative Phase sensitive or insensitive
- Absolute phase sensitive or insensitive
- Amplitude sensitive or insensitive
- Measurement across time or across frequency
- Source of raw data
 - Waveform
 - FFT
 - Digital Filter (IIR or FIR) or Quadrature Filter

Connectivity Measures - Summary

- Pure Coherence (is relative phase stable?)
 - joint energy / product of self-energy
- Synchrony Metric (do phase and amplitude match?)
 - Joint energy (real parts)/ sum of self-energy
- Spectral Correlation Coefficient (FFT amplitudes same?)
 - Correlation (f) between amplitude spectra
- Comodulation (do components wax & wane together?)
 - Correlation (t) between amplitude time-series
- Asymmetry
 - Relative amplitude between two sites
- Phase (is relative timing stable or same?)
 - Arctan of ratio of quadrature components
- Sum & Difference Channels (arithmetic comparison)
 - Simply add or subtract raw waveforms

Classical or "pure" Coherence

- Measure of phase stability between two signals
 gets "inside" signals
- Wants them to be at the same frequency
- Doesn't care about absolute phase separation
- Doesn't care about relative amplitude
- Measures of amount of shared information
- Useful when sites have different timing
- Can use FFT or Quadrature filters to calculate

Coherence Estimation in Real Time

Given two EEG signals in real time,



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



Pure Coherence



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

Pure Coherence: BMr-NG Concordance



"Training" Coherence/Similarity (BrainMaster)

- Similarity measure using Quad filters
- Measure of phase and amplitude match between two signals – gets "inside" signals
- Wants them to have zero phase separation
- Wants them to have same amplitude
- Useful for synchrony training
- Random signals will have low coherence

Training Coherence (Similarity)



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

Spectral Correlation Coefficient (Lexicor)

- Measure of amplitude similarity in spectral energy – uses FFT amplitude data
- Wants two signals to have similar power spectral shape
- Completely ignores phase relationship
- Meaningful for a single epoch
- Random signals may have large correlation if spectra are similar

Spectral Correlation Coefficient (SCC/"Lexicor")



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

SCC: BMr – Lexicor Concordance (G, B, A, T, D; as of 1/12/07)



Comodulation (Sterman/Kaiser)

- Measures similarity in amplitudes across time classically uses FFT amplitude data
- Correlation between envelopes of two signals
- Completely ignores phase relationship
- Must be considered across time epoch
- Reflects how similarly signals wax and wane together
- Can be computed using digital filters
- Random signals will have low comodulation

Comodulation (SKIL)



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

Phase measurement

- Various methods to compute
- Attempts to extract phase relationship using mathematical technique
- Stability and "wraparound" issues
- FFT or Quad Digital Filters
- Reflects how well signals line up in time
- Measure of speed of information sharing
- Useful for synchrony training

Phase



• Exactly how do the peaks and valleys line up? (What is their phase separation at any instant?)

Sum-channel

- Adds two signals together in time domain
- Gets "inside" signals
- Peaks and valleys reinforce in time
- Very sensitive to phase relationship
- Wants signals to be in phase
- Largest when both signals are large
- Useful for synchrony training
- Can uptrain coherence with sum-channel mode
- Random signals: sum & difference will look the same

Difference-channel

- Same as bipolar montage
- Similar signals will cancel
- Emphasizes differences
- Useful for coherence downtraining
- Cannot uptrain coherence with bipolar
- Random (uncorrelated) signals: sum & difference signals will look the same

Channel Sum & Difference



Channel Recombination – BrainScape JTFA F3 & F4



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Channel Recombination – BrainScape JTFA C3 and C4



Channel Recombination – BrainScape JTFA T3 and T4



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Channel Recombination – BrainScape JTFA O1 and O2



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Live Z-Scores

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

Live Z Scores – 2 channels (76 targets)

	🕅 Training/Control Screen	- BrainMa	ster 3.	0.3				
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	System is Idling			Check Signal				
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	Theta (4.0-8.0)	-0.0	-0.1		-0.3	-0.3	-0.3	
	Alpha (8.0-12.5)	-0.0	-0.1			-0.9	-0.9	
	Beta (12.5-25.5)	0.7	0.7				-1.0	
	Beta 1 (12.0-15.5)	0.8	0.8					
	Beta 2 (15.0-18.0)	0.8	0.8					
	Beta 3 (18.0-25.5)	0.6	0.6					
	Gamma (25.5-30.5)	0.6	0.7					
	Delta (1.0-4.0)	-0.7	-0.9	-0.5	-0.5	-0.5	-0.5	
	Theta (4.0-8.0)	0.0	-0.0		-0.4	-0.4	-0.4	
	Alpha (8.0-12.5)	-0.1	-0.2			-1.0	-1.0	
	Beta (12.5-25.5)	0.6	0.7				-1.1	
	Beta 1 [12.0-15.5]	0.9	0.9					
	Beta 2 [15.0-18.0]	0.6	0.7					
	Beta 3 [18.0-25.5]	0.6	0.6					
	Gamma (25.5-30.5)	0.7	0.7	- ·				
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1		U.I		-1.0		1.0		
1		U.U		-1.0		0.9		
	Gamma (25.5-30.5)	-0.0		-1.0		0.7		

26 x 2 + 24 = 76

Live Z Scores – 4 channels (248 targets)

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Beta (12.5-25.5) 3.2	0.8		-1.3	Beta (12.5-25.5)	3.0 0.8		-1.4
Beta 1 (12.0-15.5) 3.4	1.1			Beta 1 (12.0-15.5)	4.0 1.5		
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Theta (4.0-8.0) 0.1	-1.7 1.5	0.1 -2.0 2.	0.1	-1.1 0.9 0.0	-1.5 1.3 0.0	-0.8 0.5 -0	.1 -0.3 0.6
Alpha (8.0-12.5) -0.1	-2.0 1.9	-0.4 -2.6 2.	0.6	-0.5 0.3 -0.3	-1.9 1.1 0.6	-1.0 0.2 0	.7 -0.4 0.2
Beta (12.5-25.5) 0.0	-1.9 1.2	-0.2 -2.1 1.	2 0.2	-0.6 0.6 -0.2	-1.7 1.0 0.2	-0.3 0.4 (.3 -0.4 0.2
Beta 1 (12.0-15.5) 0.3	-1.0 0.8	-0.2 -1.7 1	J -U.U	-0.4 0.7 -0.1	-1.1 0.8 -0.2	-0.2 0.3 -l	.1 -0.0 0.5
Beta 3 (18.0-25.5) 0.2	-0.9 1.5	-0.2 -1.0 1	0.1	-0.3 0.6 -0.4	-1.1 1.3 0.1	0.1 0.5	.4 -0.4 0.2
Gamma (25.5-30.5) -0.1	-1.5 1.0	-0.3 -1.4 1.	0.1	-0.4 0.5 -0.2	-1.2 1.0 0.2	-0.5 0.5 (.4 -0.3 0.2

26 x 4 + 24 x 6 = 248

Z-Score Targeting Options

- Train Z Score(s) up or down
 Simple directional training
- Train Z Score(s) using Rng()
 Set size and location of target(s)
- Train Z Score(s) using PercentZOK()
 - Set Width of Z Window via. PercentZOK(range)
 - Set Percent Floor as a threshold

Range Function

- Rng(VAR, RANGE, CENTER)
- = 1 if VAR is within RANGE of CENTER
- = 0 else
- Rng(BCOH, 10, 30)
 - -1 if Beta coherence is within +/-10 of 30
- Rng(ZCOB, 2, 0)
 - -1 if Beta coherence z score is within +/-2 of 0

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



Range training with multiple ranges

- X = Rng(ZCOD, 2,0) + Rng(ZCOT, 2, 0), + Rng(ZCOA, 2, 0) + Rng(ZCOB, 2. 0)
- = 0 if no coherences are in range
- = 1 if 1 coherence is in range
- = 2 if 2 coherences are in range
- = 3 if 3 coherences are in range
- = 4 if all 4 coherences are in range
- Creates new training variable, target > 3

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



PercentZOK() function

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

• Value = 0 to 100

Z Score training using percent Z's in target range



Size of range window (UTHR - currently 1.4 standard deviations)

Threshold % for Reward (CT: between 70% and 80%)

%Z Scores in range (between 50 and 90%)

% Time criterion is met (between 30% and 40%)

Effect of changing %Z threshold

Threshold down -> percent time meeting criteria increases



Effect of widening Z target window window wider -> higher % achievable



Summary

- Wide range of methods available
- All have strengths and weaknesses
- Important to understand basis of each metric and its application to NF
- All have value
- Importance of normative data to interpret