Announcements

- Reading for Next week
- Course Paper:
  - Two paragraph prospectus due no later than Monday March 29
- Lab Meets this week
- 3x5s

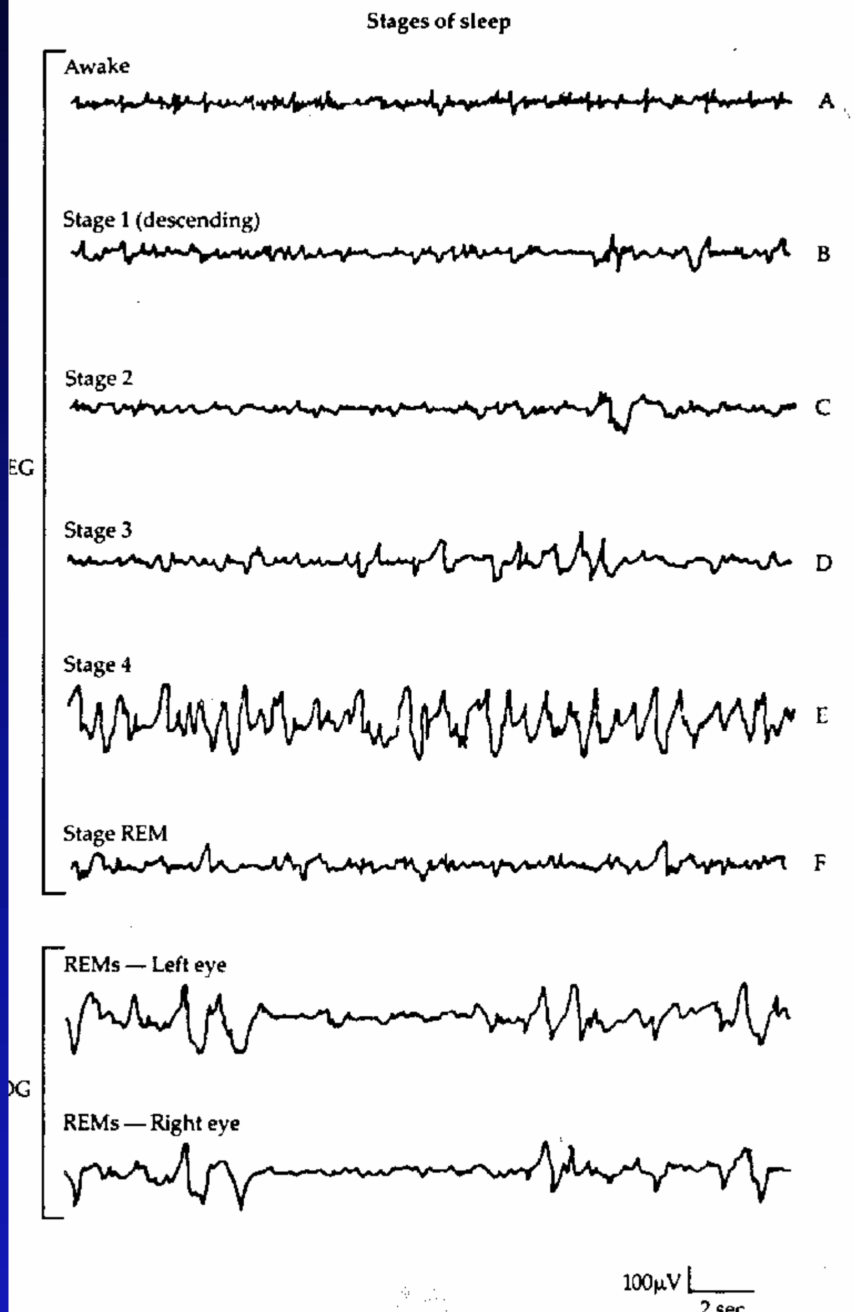
[Continuing…]

The Electroencephalogram

Basics in Recording EEG, Frequency Domain Analysis and its Applications

Electroencephalogram (EEG)

- The EEG--an oscillating voltage recorded on scalp surface
  - Reflects Large # Neurons
  - Is small voltage
- Bands of activity and behavioral correlates
  - Gamma 30-50 Hz
  - Beta 13-30 Hz
  - Alpha 8-13 Hz
  - Theta 4-8 Hz
  - Delta 0.5-4 Hz

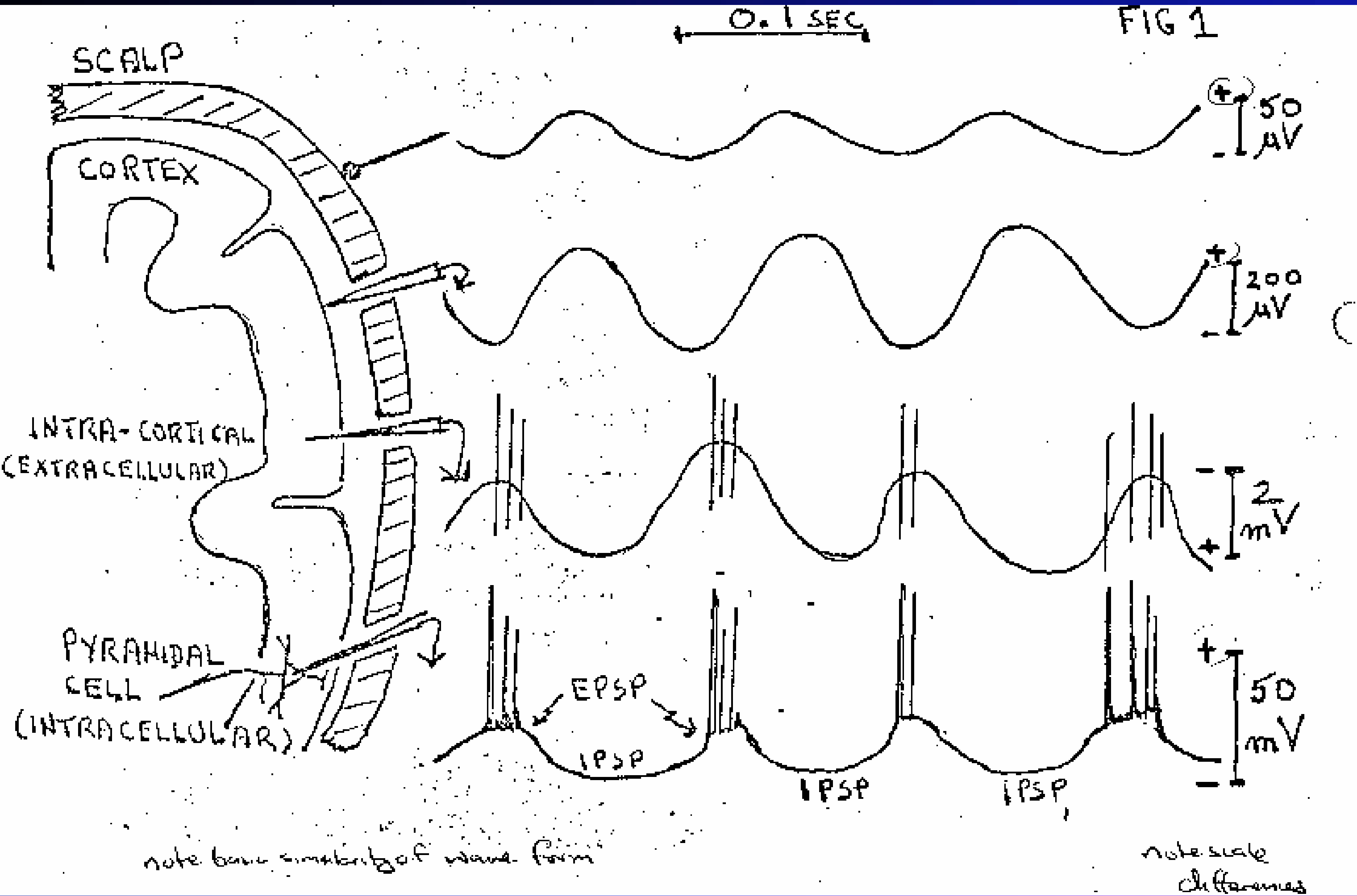

Stages of sleep
Awake
A
Stage 1 (descending)
B
Stage 2
C
EG
Stage 3
D
Stage 4
E
Stage REM
F
REMs — Left eye
OG
REMs — Right eye
100µV
2 sec.

Utility of EEG

- *Relatively* noninvasive
- Excellent time resolution

Sources of scalp potentials

- Glial Cells – minimal, some DC steady potentials
- Neurons
  - Action Potentials – NO, brain tissue has strong capacitance effects, acting as Low Pass filter
  - Slow waves
    - Synaptic potentials – YES, both IPSPs and EPSPs from functional synaptic units are major contributors
    - Afterpotentials – May contribute to a lesser extent

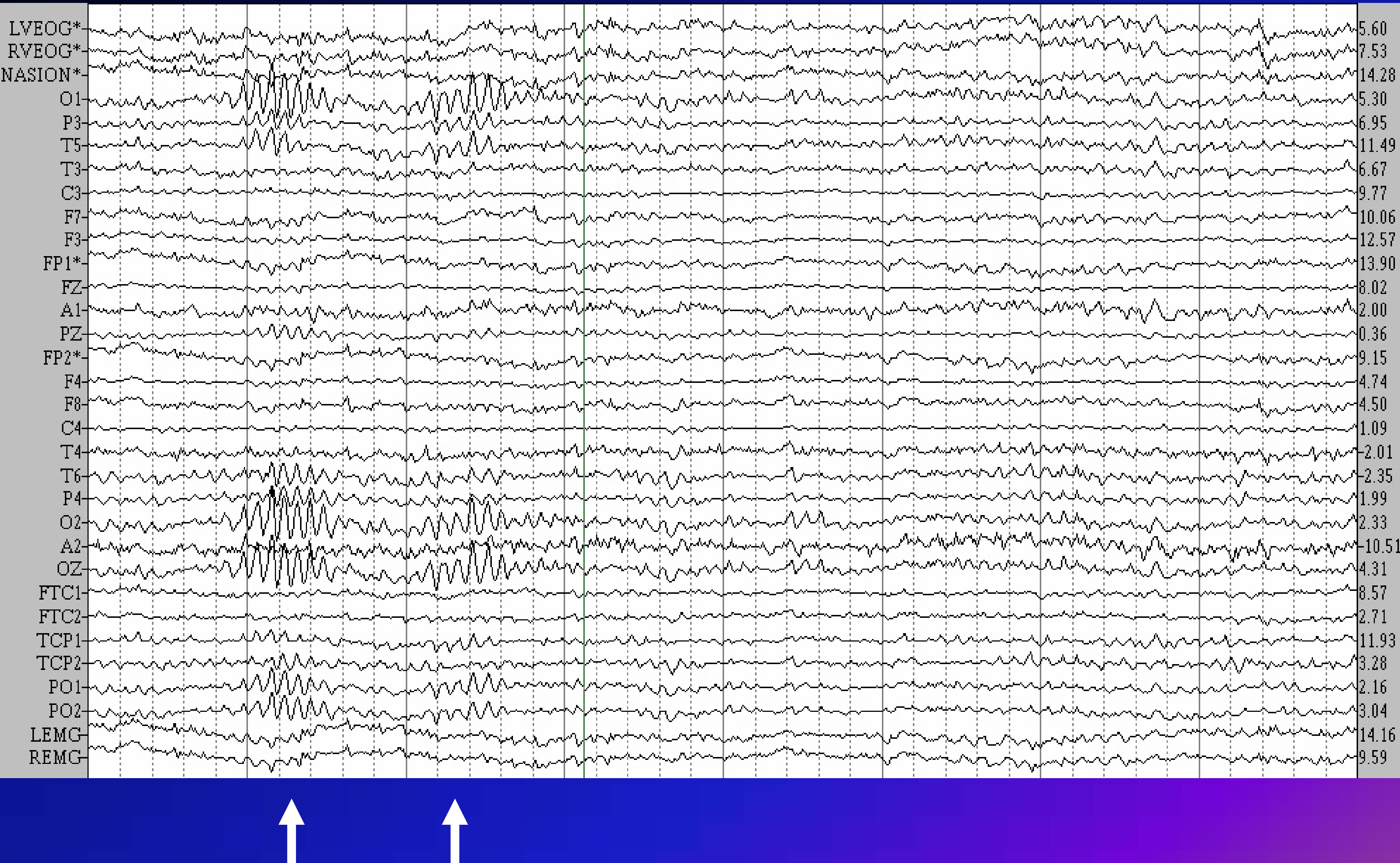


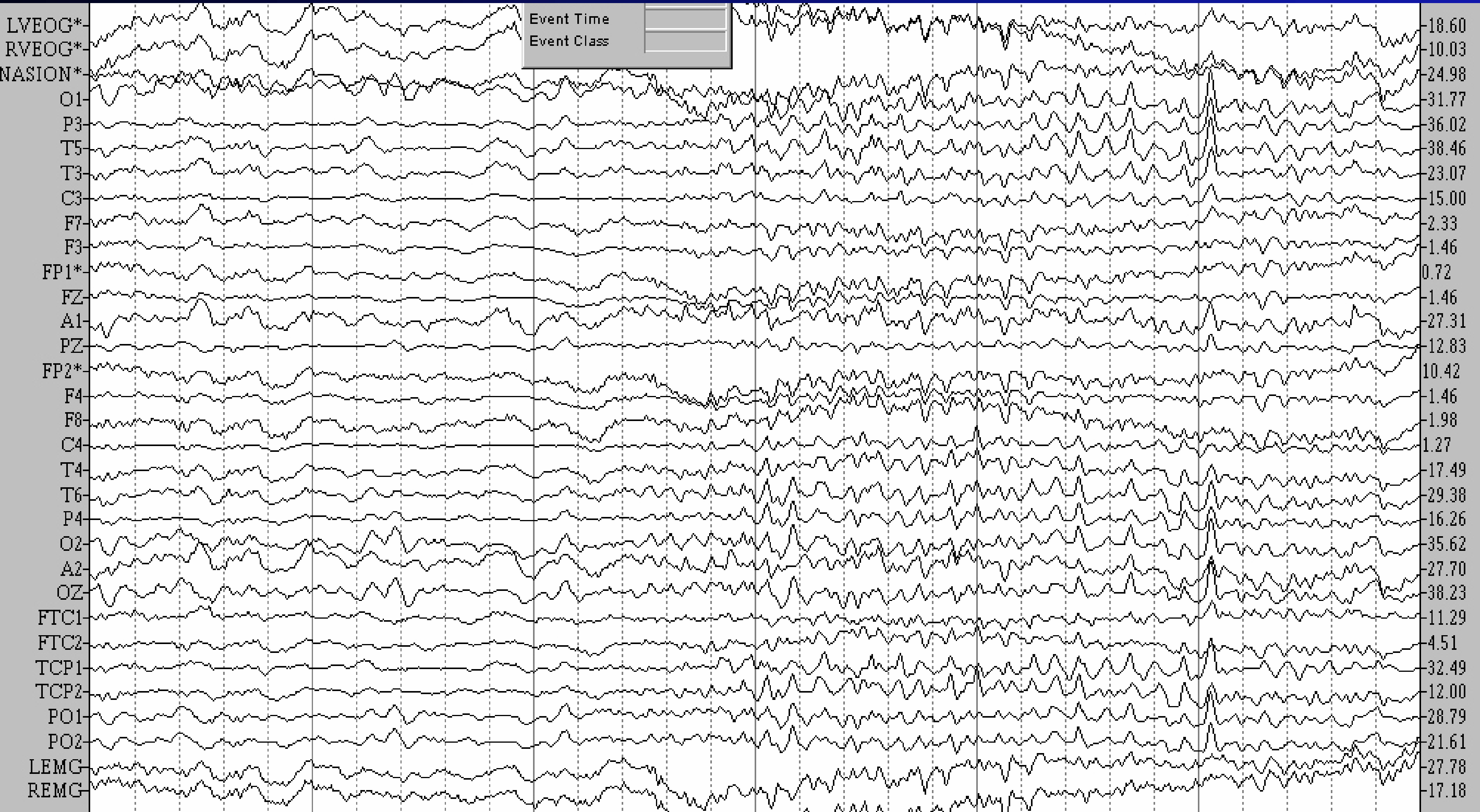
0.1 SEC
FIG 1
SCALP
CORTEX
INTRA-CORTICAL
(EXTRACELLULAR)
PYRAMIDAL
CELL
(INTRACELLULAR)
50 μV
200 μV
2 mV
50 mV
EPSP
IPSP
IPSP
IPSP

Alpha and Synchronization

- Why Alpha?
  - It is obvious and hard to miss!
  - Accounts for ~70% of EEG activity in adult human brain
- From where, Alpha?
  - Historically, thought to be thalamocortial looping
  - Adrian (1935) demolished that theory
    - Recorded EEG simultaneously in cortex and thalamus
    - Damage to cortex did not disrupt thalamic alpha rhythmicity
    - Damage to thalamus DID disrupt cortical alpha rhythmicity
  - Thalamic rhythmicity remains even in decorticate preparations (Adrian, 1941)
  - Removal of ½ thalamus results in ipsilateral loss of cortical alpha

Next


LVEOG* 5.60
RVEOG* 7.53
NASION* 14.28
O1 5.30
P3 6.95
T5 11.49
T3 6.67
C3 9.77
F7 10.06
F3 12.57
FP1* 13.90
FZ 8.02
A1 2.00
PZ 0.36
FP2* 9.15
F4 4.74
F8 4.50
C4 1.09
T4 -2.01
T6 -2.35
P4 1.99
O2 2.33
A2 -10.51
OZ 4.31
FTC1 8.57
FTC2 2.71
TCP1 11.93
TCP2 3.28
PO1 2.16
PO2 3.04
LEMG 14.16
REMG 9.59


Event Time
Event Class
LVEOG*
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C3
F7
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FZ
A1
PZ
FP2*
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35.62
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12.00
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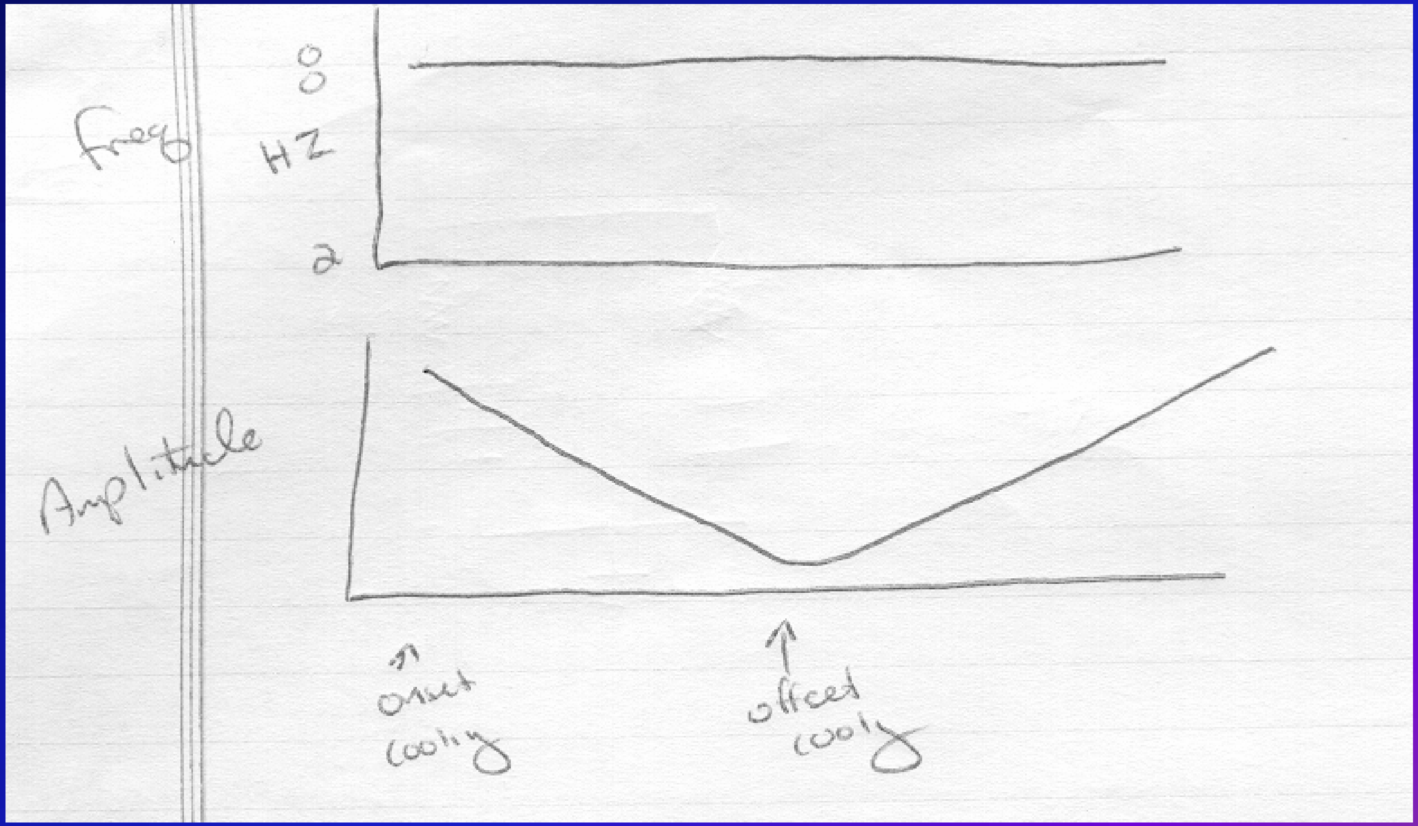
27.78
17.18

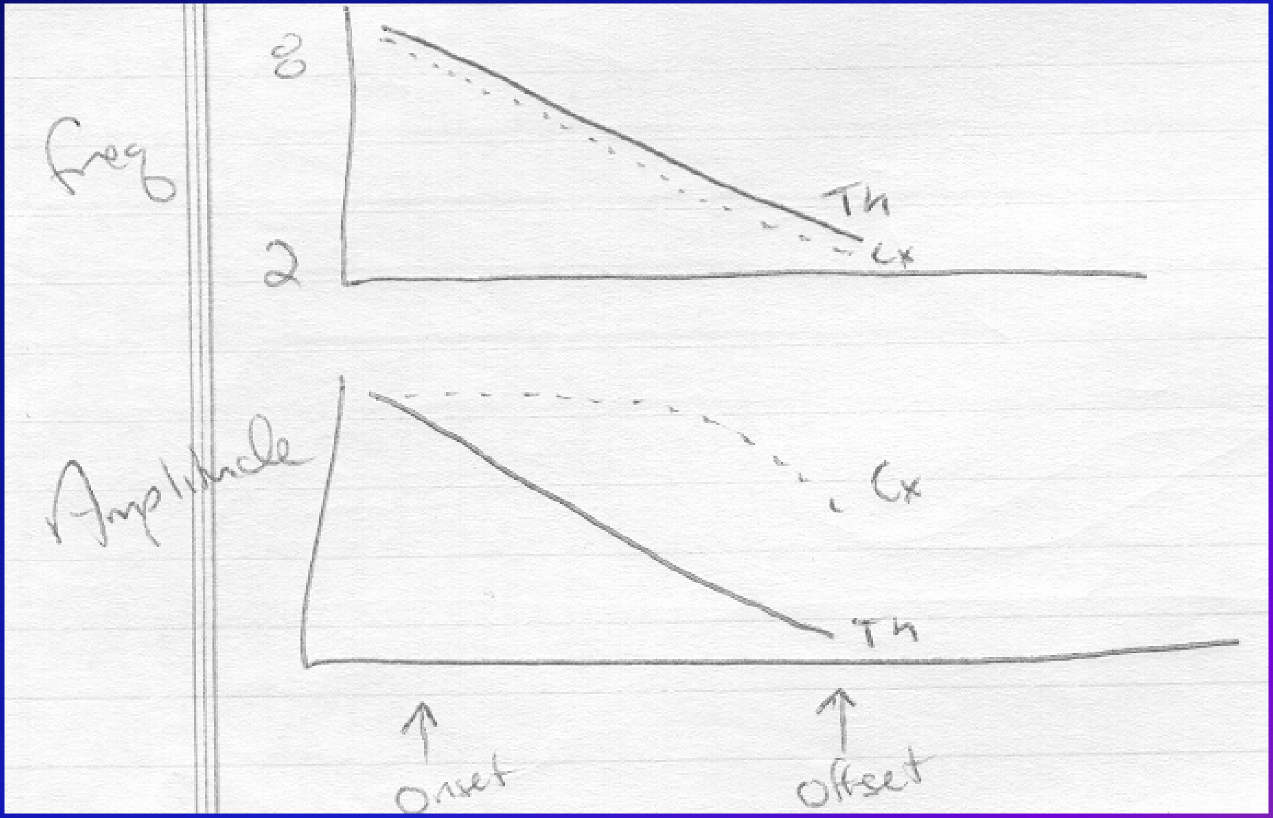
Alpha and Synchronization

- Andersen and Andersen (1968)
  - Cooling of Cortex resulted in change in amplitude but not frequency of Alpha



Alpha and Synchronization

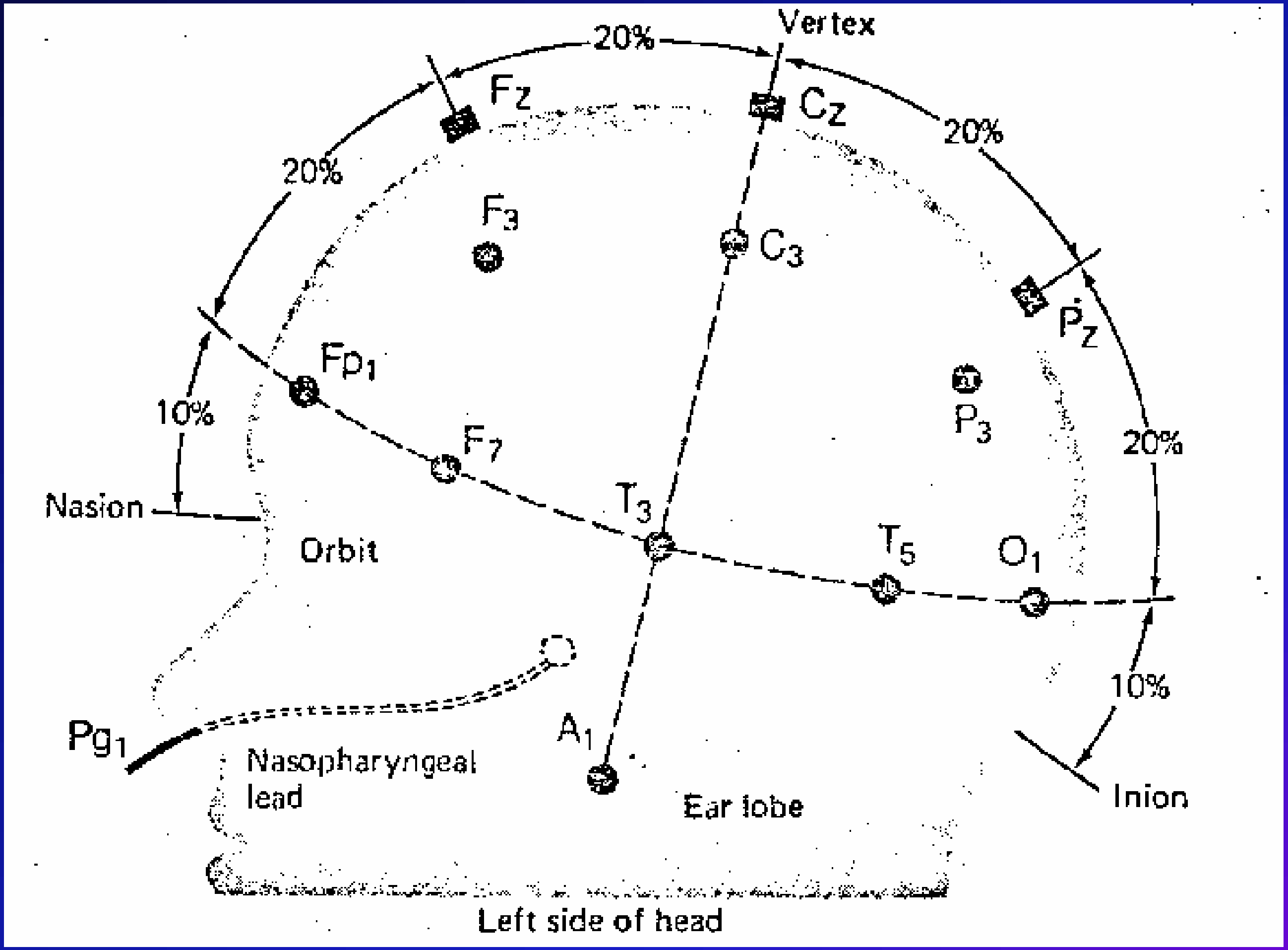
- Andersen and Andersen (1968)
  - Cooling of Thalamus resulted in change in amplitude and frequency of Alpha at both thalamus and cortex



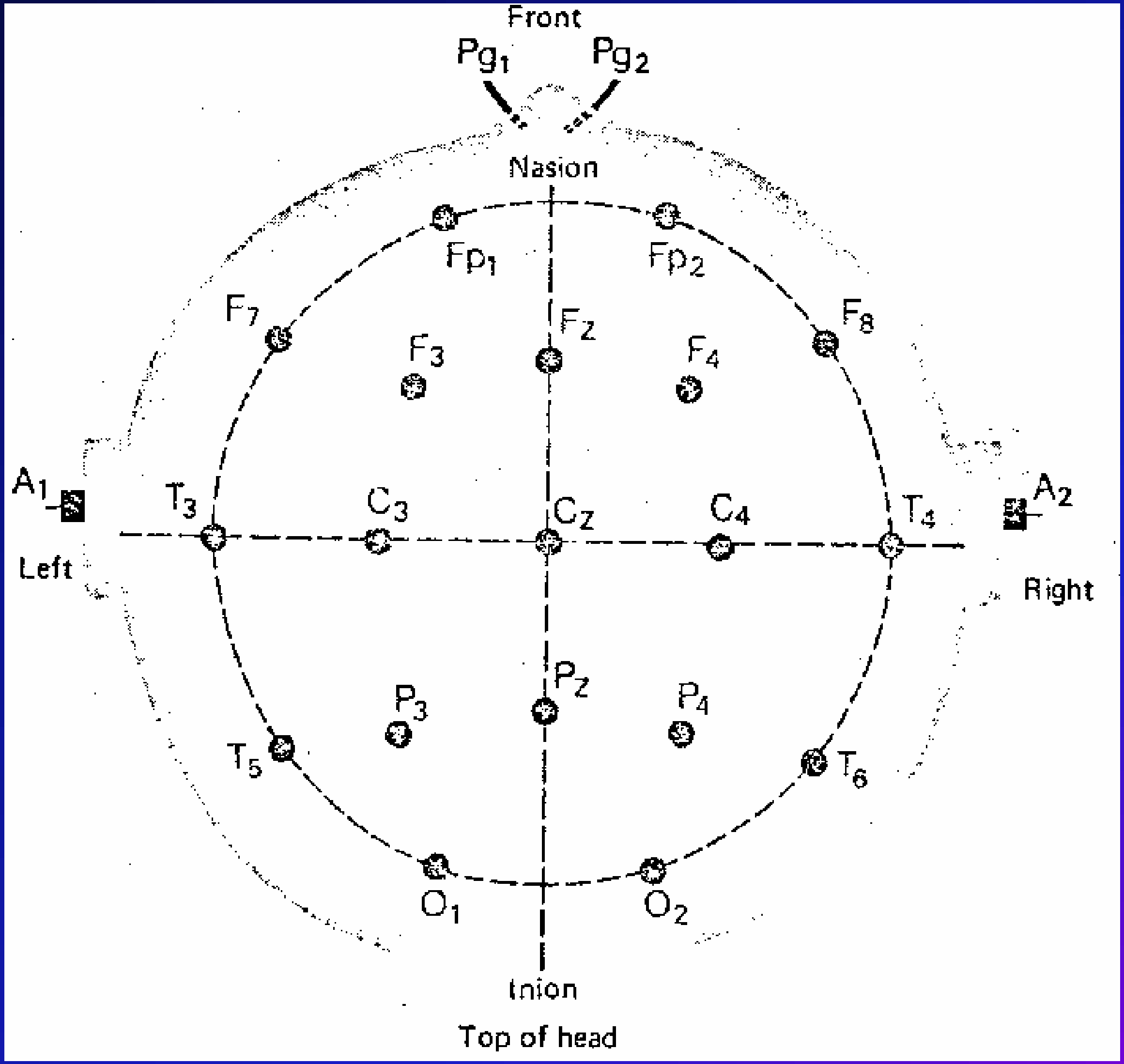
Alpha and Synchronization

- In sum, Thalamus drives the alpha rhythmicity of the EEG
  - Cortex certainly does feedback to thalamus, but thalamus is responsible for driving the EEG
  - Particularly the Reticularis nucleus (Steriade et al. 1985)
- What causes change from rhythmicity to desynchronization?
  - Afferent input to thalamic relay nuclei
  - Mode-specific enhancement observed

Recording EEG



Recording EEG



Electrodes, Electrolyte, Preparation

- Ag-AgCl preferred, Gold OK if slowest frequencies not of interest
  - Polarizing electrodes act as capacitors in series with signal
- Electrolyte: ionic, conductive
- Affixing
  - Subcutaneous needle electrodes (OUCH)
  - Collodion (YUCK)
  - EC-2 paste; lesser of the evils
  - Electrocap

Recording References

- Measure voltage potential differences
  - Difference between what and what else?
- "Monopolar" versus Bipolar
  - No truly inactive site, so monopolar is a relative term
  - Relatively monopolar options
    - Body – BAD IDEA
    - Head
      - Linked Ears or Mastoids
      - Tip of Nose
  - Hypothetical advantages of Monopolar – seldom realized

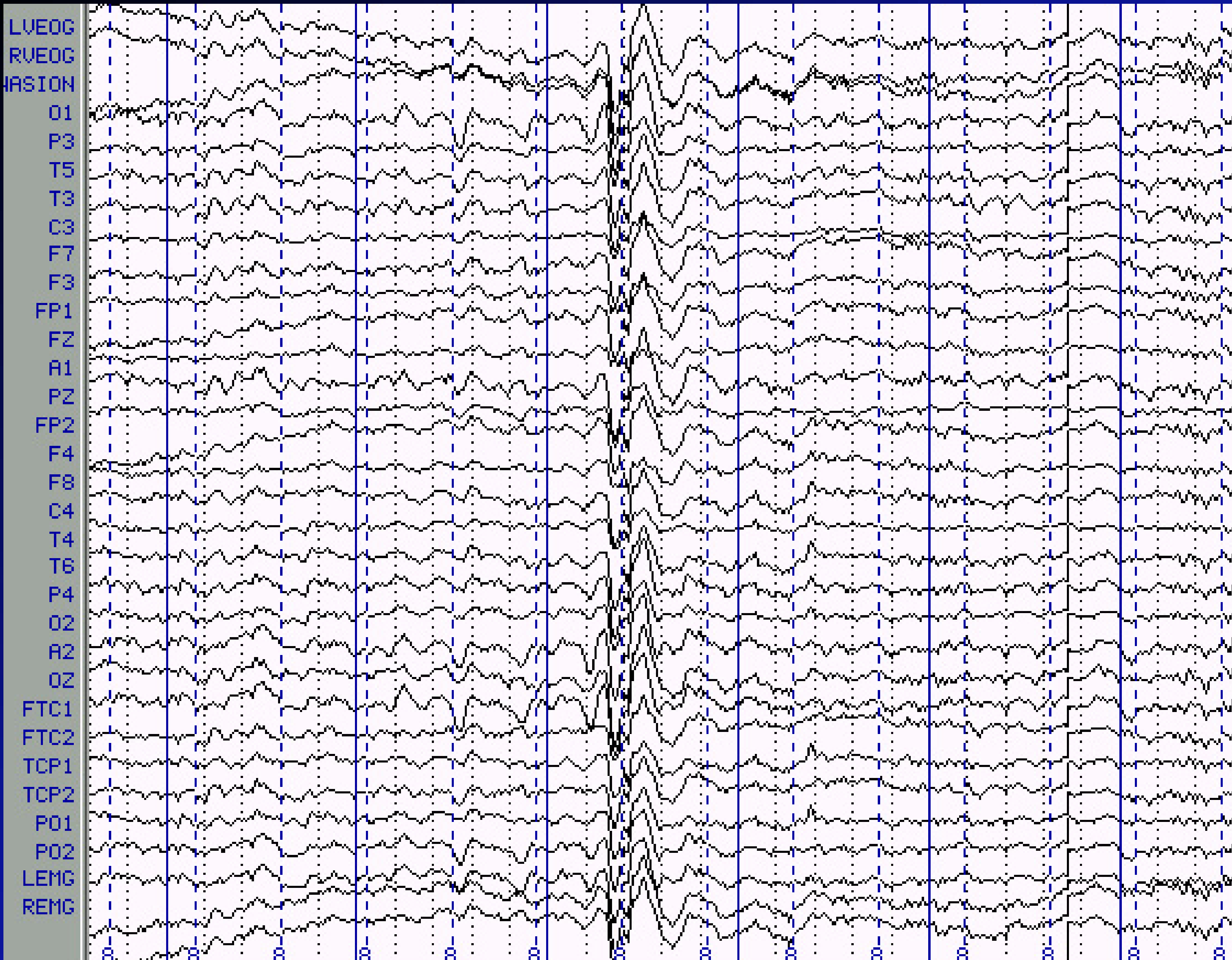
Recording References

- Bipolar recording
  - Multiple active sites
    - Sensitive to differences between electrodes
    - With proper array, sensitive to local fluctuations (e.g. spike localization)
- Off-line derivations
  - Averaged Mastoids
  - Average Reference (of EEG Leads)
    - With sufficient # electrodes and surface coverage, approximates inactive site (signals cancel out)
    - Artifacts “average in”
  - Current Source Density (more in advance topics)

Dreaded Artifacts

- Three sources
  - 60-cycle noise
    - Ground subject
    - 60 Hz Notch filter
  - Muscle artifact
    - No gum!
    - Use headrest
    - Measure EMG and reject/correct for influence
  - Eye Movements
    - Eyes are dipoles
    - Reject ocular deflections including blinks
    - Use correction procedure (more in advance lecture)

Name That Artifact!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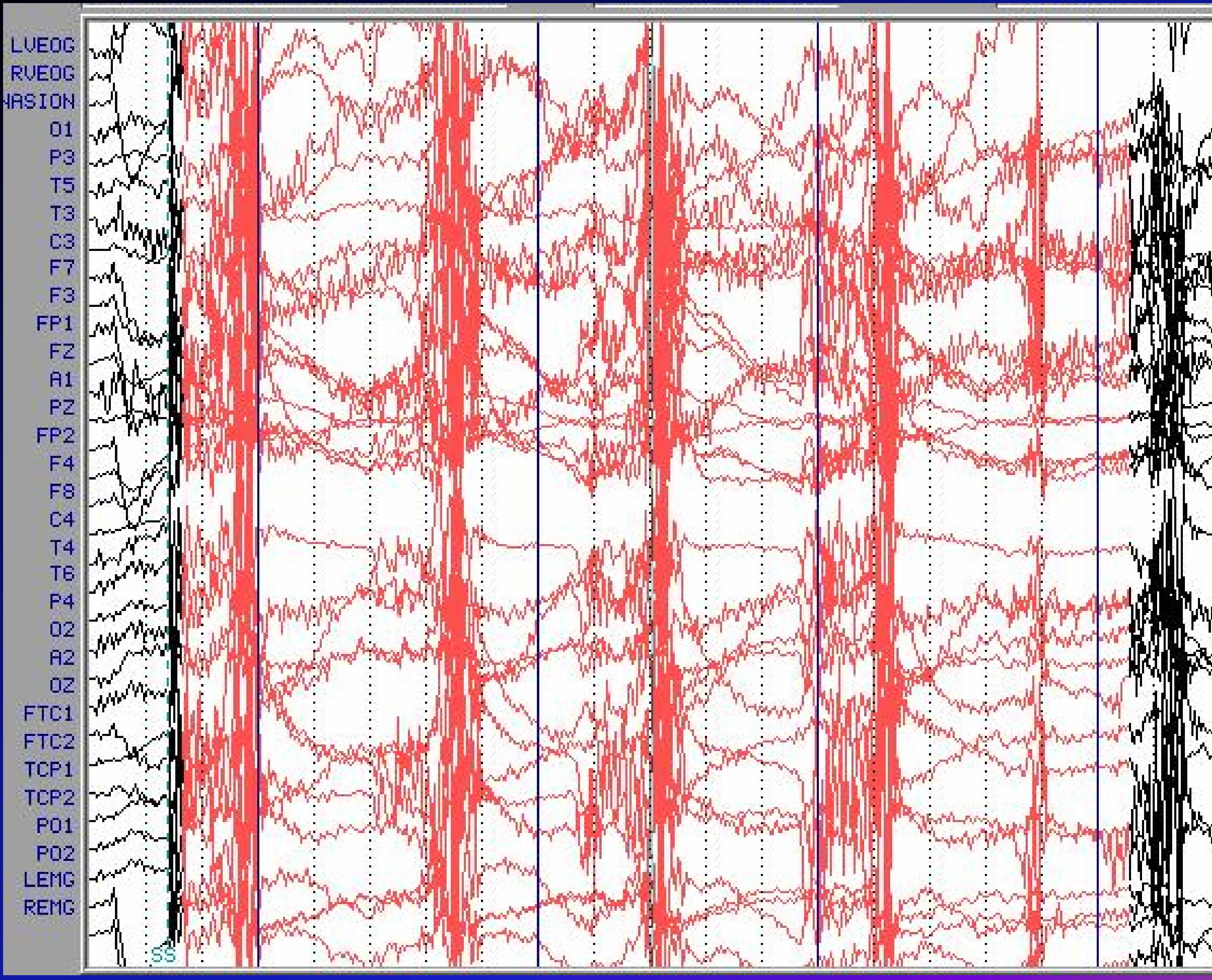
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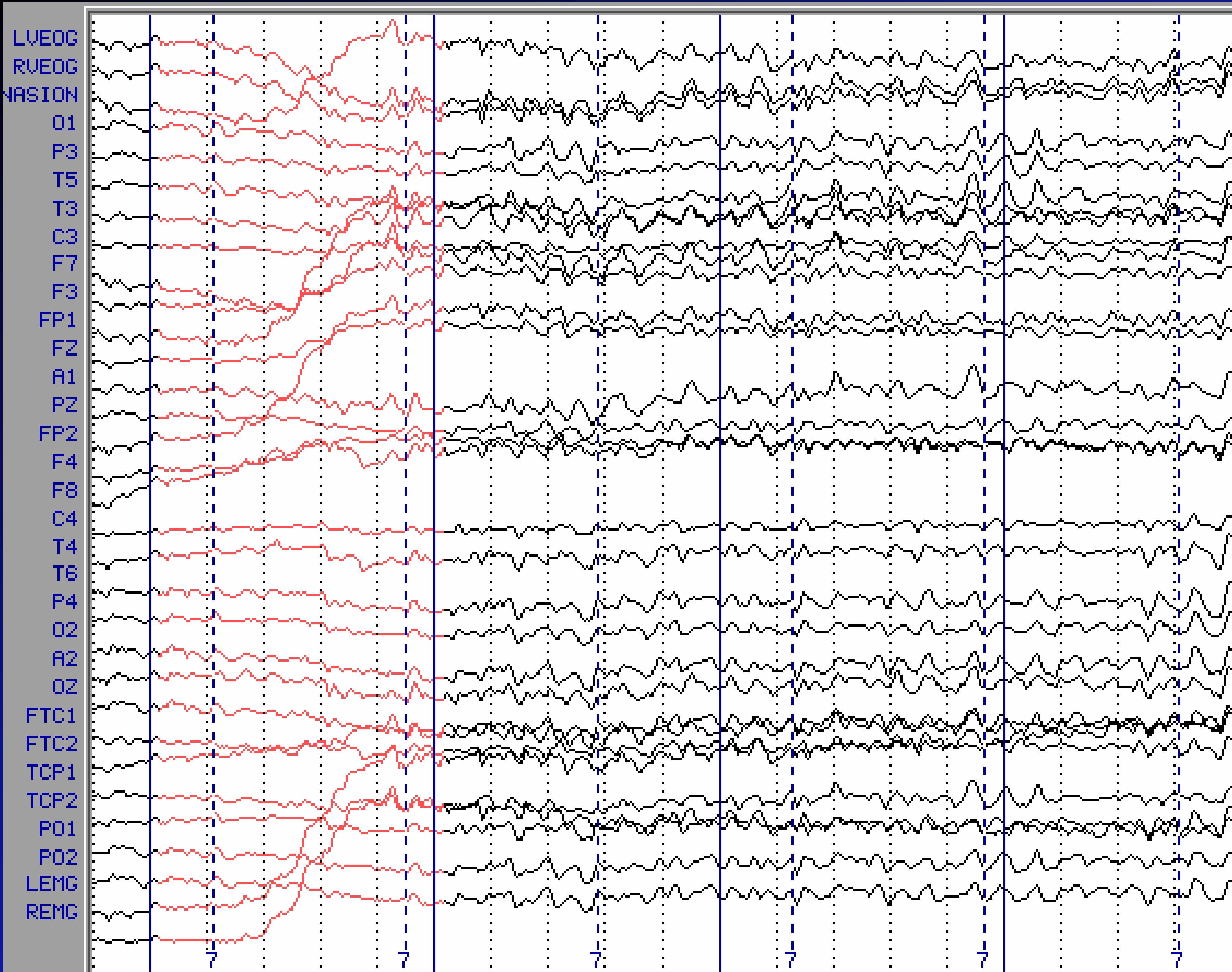
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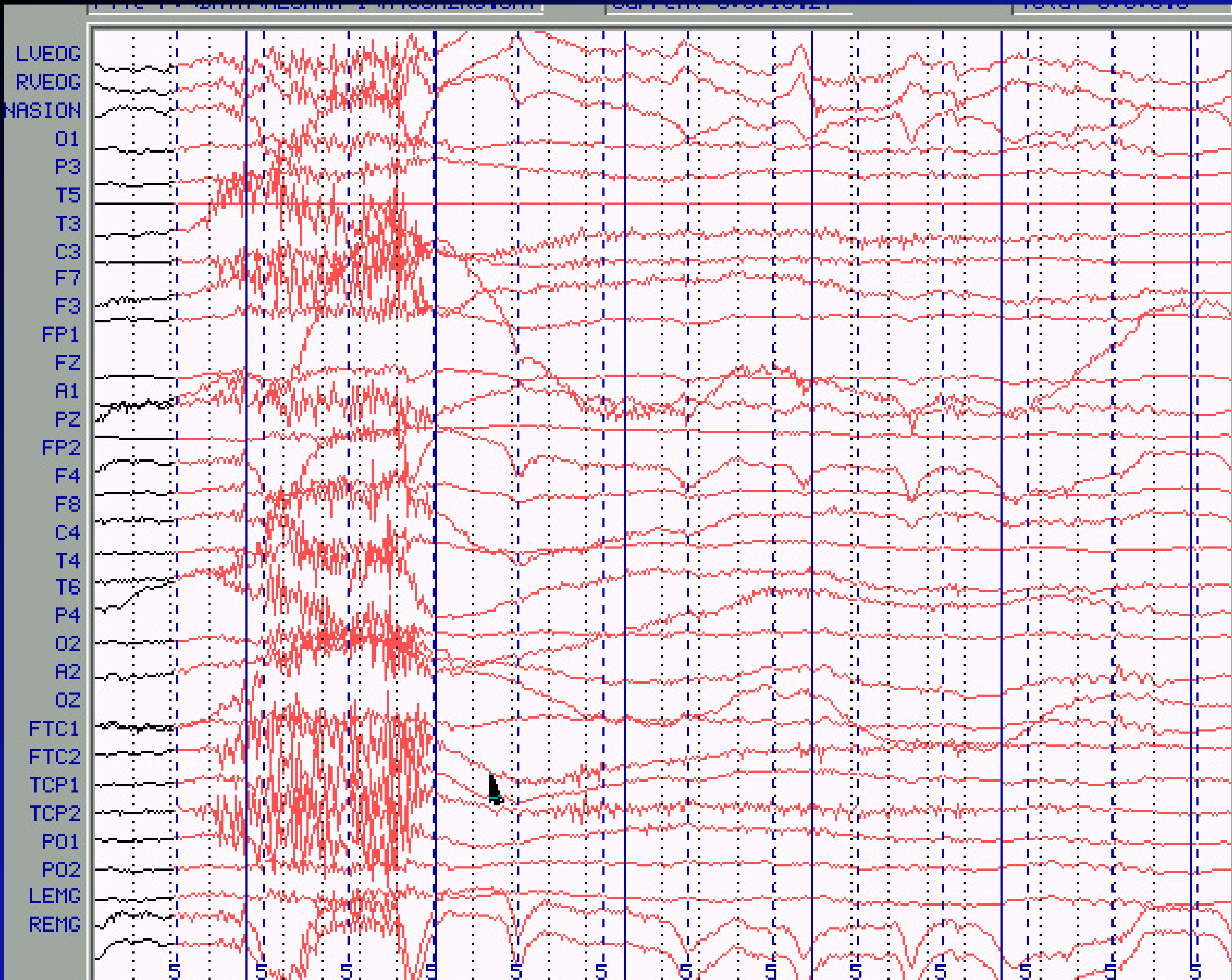
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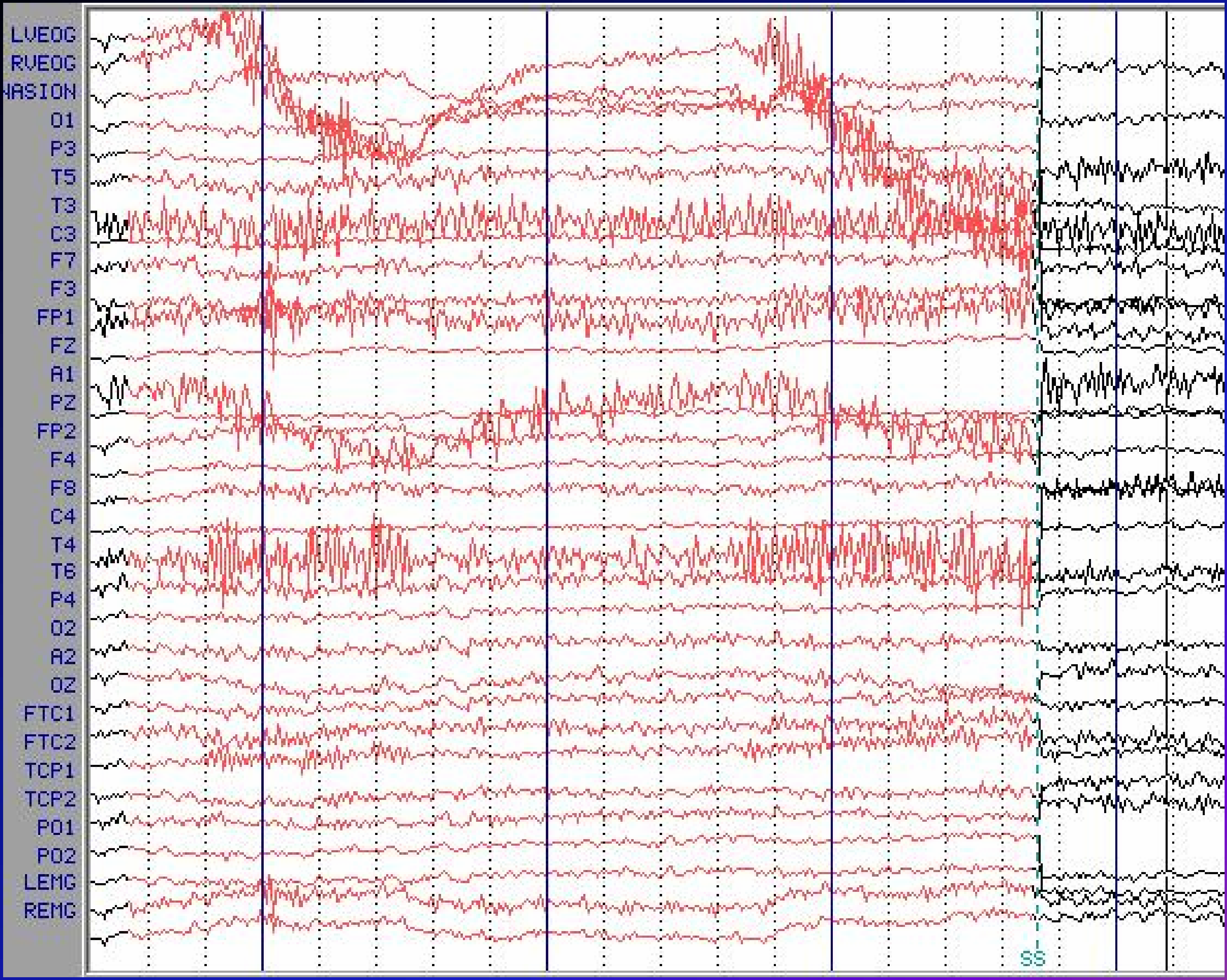
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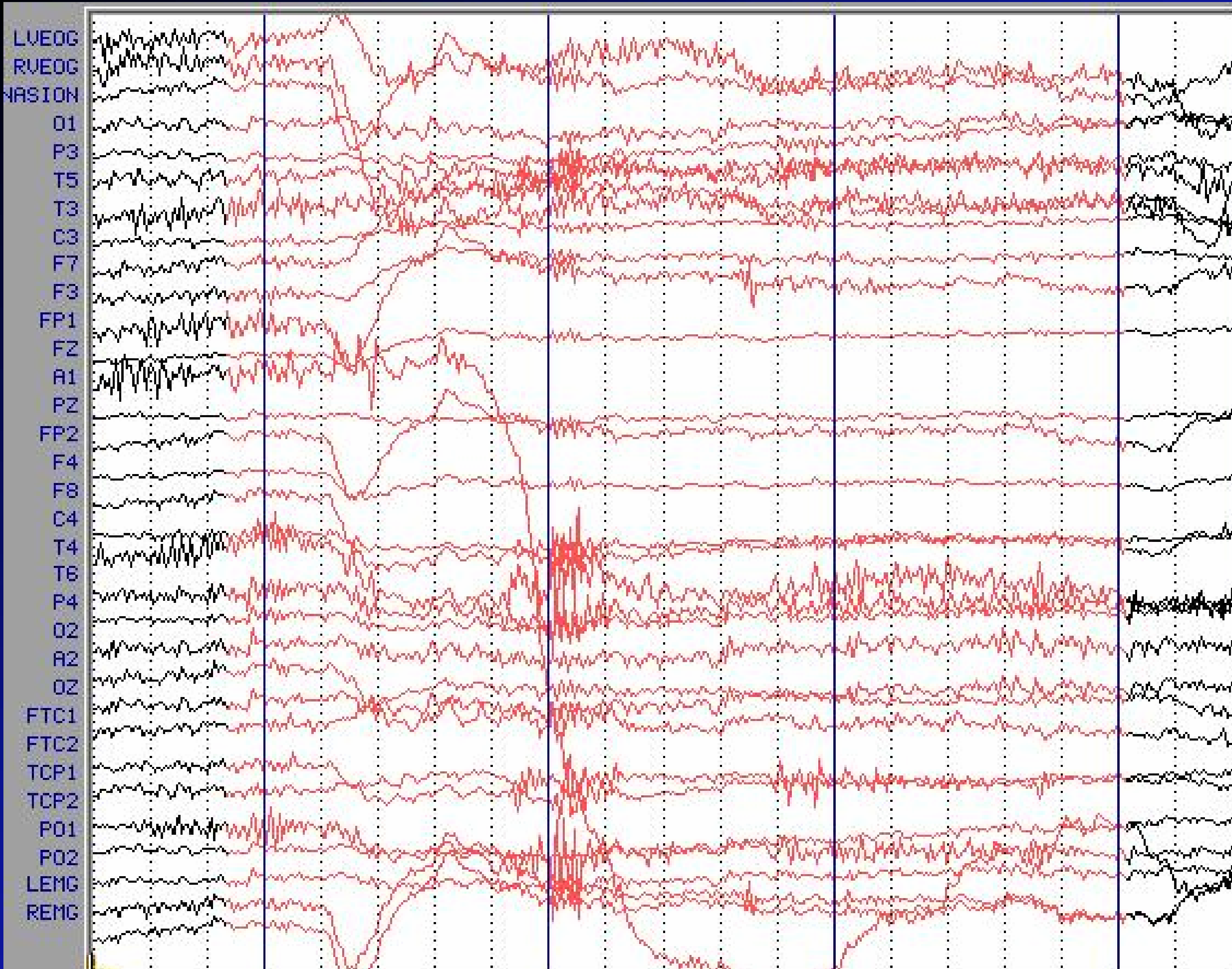
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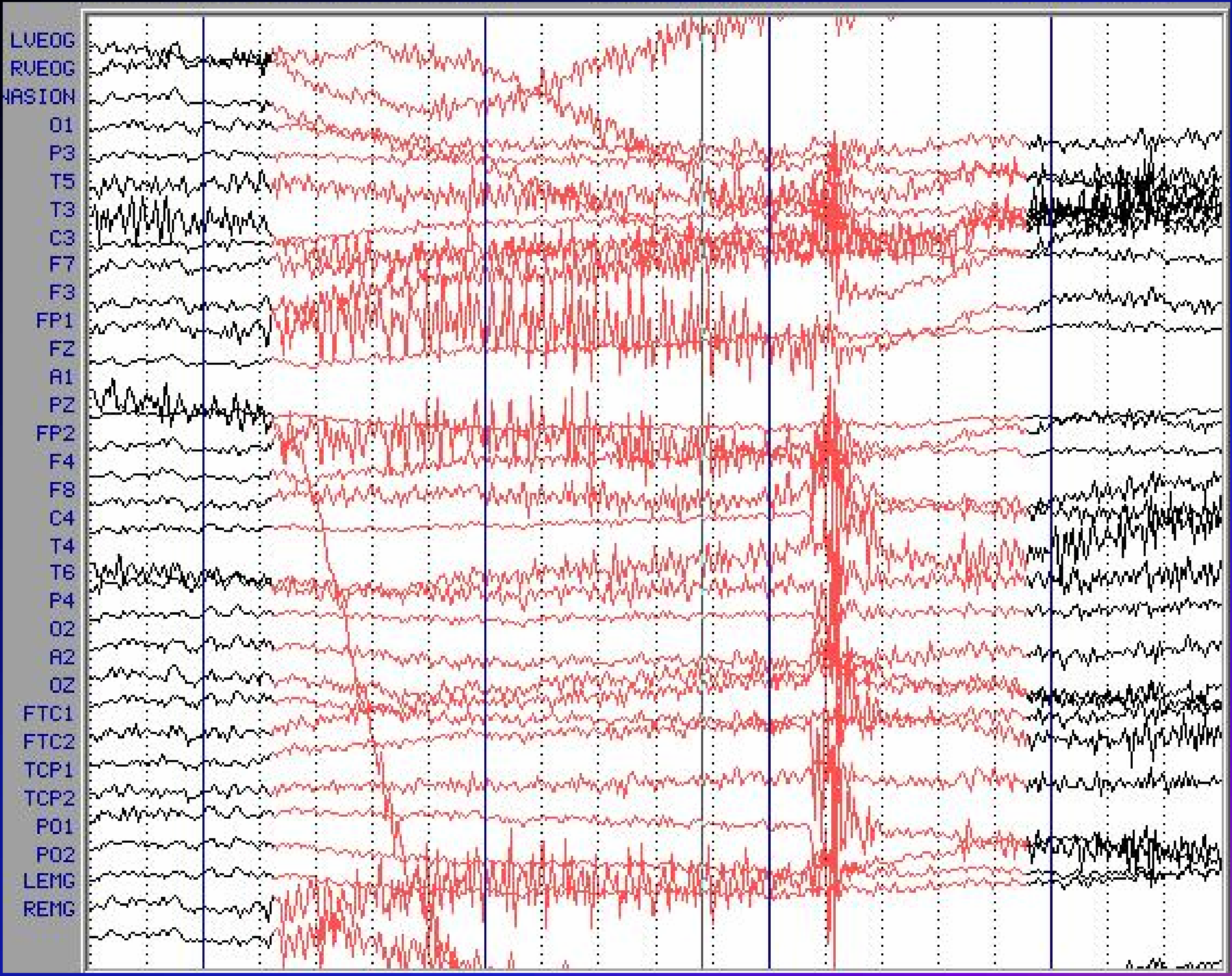
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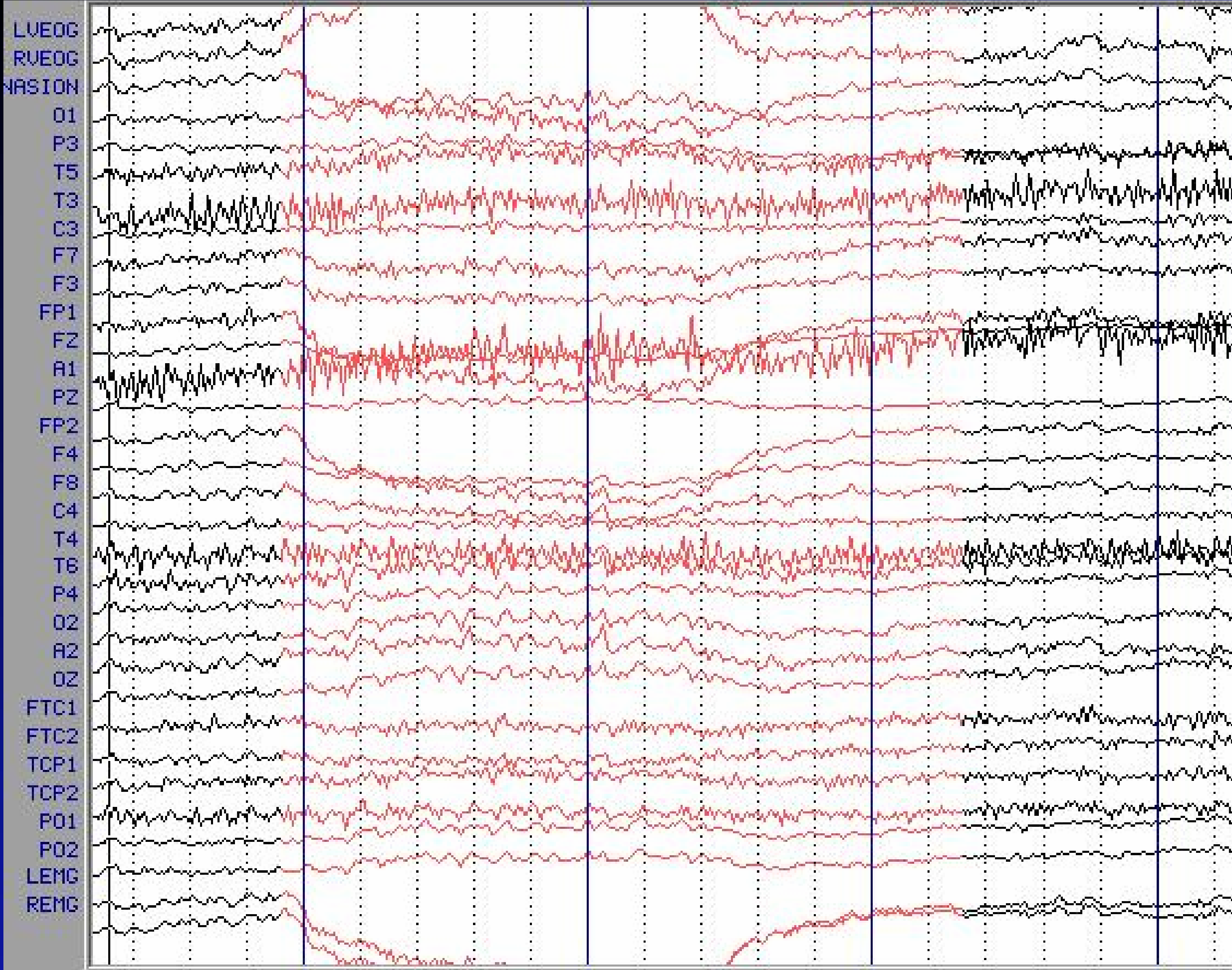
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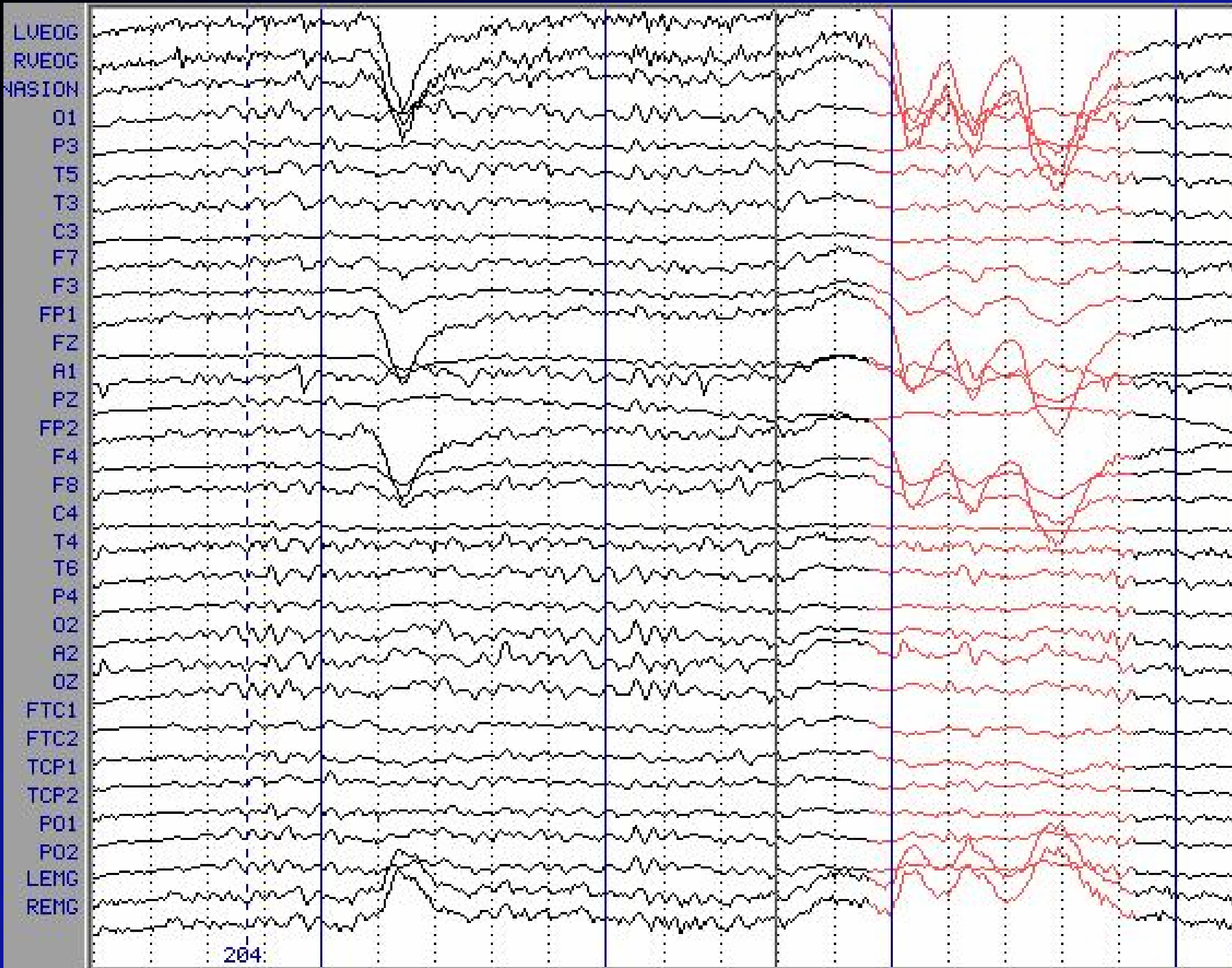
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LEMG
REMG
204

Demo with Class Member

AC Signal Recording Options

- Time Constant/HP filter
  - Low frequency cutoff is related to TC by:

$$F = \frac{1}{(2\pi(TC))}$$

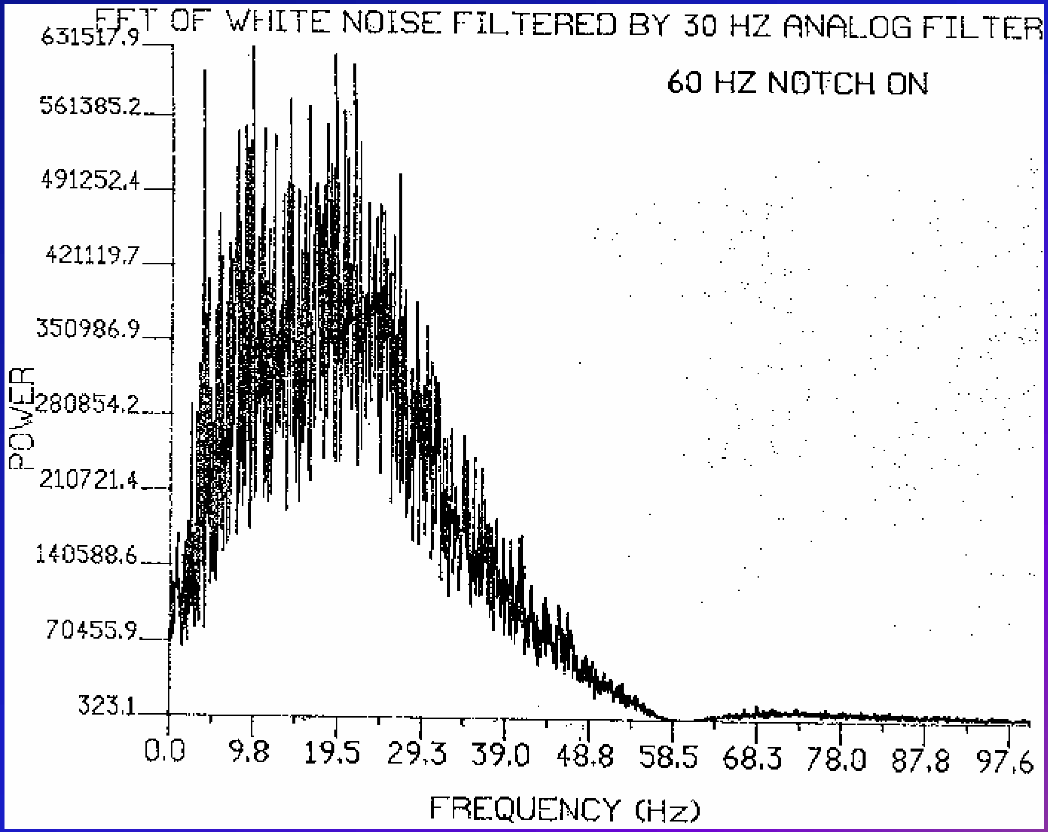
Where F = frequency in Hz, TC = Time Constant in Seconds

Applying formula:

Time Constant (sec)	Frequency (Hz)
10.00	.016
5.00	.032
1.00	.159
.30	.531
.10	1.592
.01	15.915

Hi Frequency/LP Settings

- Do not eliminate frequencies of interest
- Polygraphs have broad roll-off characteristics
- Be mindful of digitization rate (more info soon!)

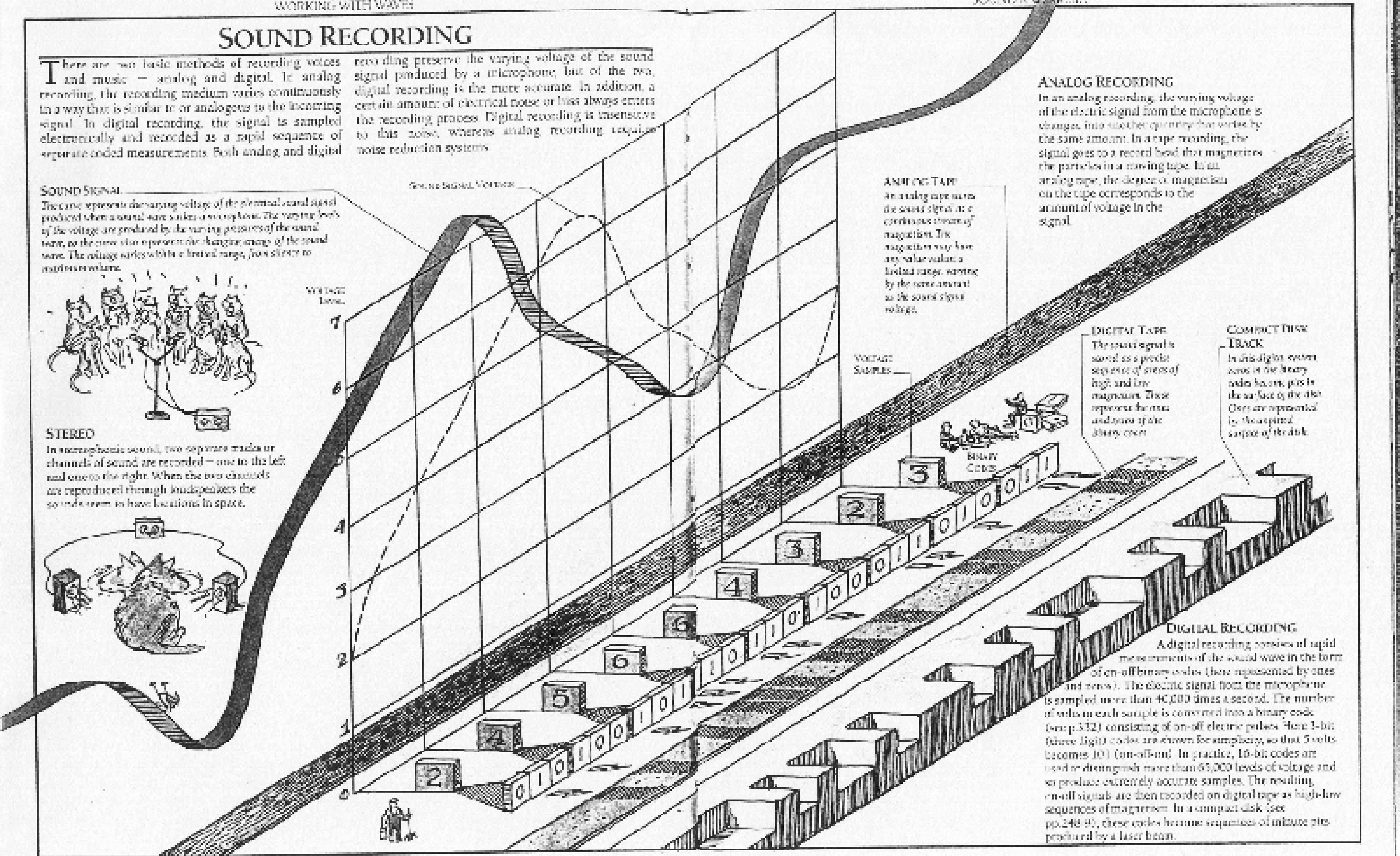


Digital Signal Acquisition

- Analog Vs Digital Signals
  - Analog
    - Continuously varying voltage as fxn of time
  - Discrete Time
    - Discrete points on time axis, but full range in amplitude
  - Digital
    - Discrete time points on x axis represented as a limited range of values (usally 2^x, e.g $2^{12} = 4096$)

A/D converters

- Schmidt Trigger as simple example
- The A/D converter (Schematic diagram)
  - Multiplexing (several channels); A/D converter is serial processor
    - Result is a vector [1 x n samples] of digital values for each channel ([x(t0), x(t1), x(t2),...,x(tn-1)]
  - 12 bit converters allow 212 = 4096 values
  - 16 bit converters allow 216 = 65536 values
- 12 bit is adequate for EEG
  - 4096 values allow 1 value for each ~0.02 µvolts of scalp voltage (depending upon sensitivity of amplifier, which will amplify signal ~20,000 times before polygraph output)
  - e.g.,
    - 2.1130 µvolts => 2481 D.U.'s (2480.74)
    - 2.1131 µ volts => 2481 D.U.'s (2480.76)
    - 2.1250 µ volts => 2483 D.U.'s (2483.20)



SOUND RECORDING

There are two basic methods of recording voices and music — analog and digital. In analog recording, the recording medium varies continuously in a way that is similar to or analogous to the incoming signal. In digital recording, the signal is sampled electronically and recorded as a rapid sequence of separate coded measurements. Both analog and digital recording preserve the varying voltage of the sound signal produced by a microphone, but of the two, digital recording is the more accurate. In addition, a certain amount of electrical noise or hiss always enters the recording process. Digital recording is insensitive to this noise, whereas analog recording requires noise reduction systems.

SOUND SIGNAL
The curve represents the varying voltage of the electrical sound signal produced when a sound wave strikes a microphone. The varying levels of the voltage are produced by the varying pressures of the sound wave, so the curve also represents the changing energy of the sound wave. The voltage varies within a limited range, from silence to maximum volume.

STEREO
In stereophonic sound, two separate tracks or channels of sound are recorded — one to the left and one to the right. When the two channels are reproduced through loudspeakers the sounds seem to have locations in space.

ANALOG TAPE
An analog tape stores the sound signal as a continuous stream of magnetism. The magnetism may have any value within a limited range, varying by the same amount as the sound signal voltage.

ANALOG RECORDING
In an analog recording, the varying voltage of the electric signal from the microphone is changed into another quantity that varies by the same amount. In a tape recording, the signal goes to a record head that magnetizes the particles in a moving tape. In an analog tape, the degree of magnetism on the tape corresponds to the amount of voltage in the signal.

DIGITAL TAPE
The sound signal is stored as a precise sequence of areas of high and low magnetism. These represent the ones and zeros of the binary codes.

COMPACT DISK TRACK
In this digital system, zeros in the binary codes become pits in the surface of the disk. Ones are represented by the unpitted surface of the disk.

DIGITAL RECORDING
A digital recording consists of rapid measurements of the sound wave in the form of on-off binary codes (here represented by ones and zeros). The electric signal from the microphone is sampled more than 40,000 times a second. The number of volts in each sample is converted into a binary code (see p.332) consisting of on-off electric pulses. Here 3-bit (three digit) codes are shown for simplicity, so that 5 volts becomes 101 (on-off-on). In practice, 16-bit codes are used to distinguish more than 65,000 levels of voltage and so produce extremely accurate samples. The resulting on-off signals are then recorded on digital tape as high-low sequences of magnetism. In a compact disk (see pp.248-49), these codes become sequences of minute pits produced by a laser beam.

The Problem of Aliasing

- Definition
  - To properly represent a signal, you must sample at a fast enough rate.
  - Nyquist's (1928) theorem
    - a sample rate twice as fast as the highest signal frequency will capture that signal perfectly
    - Stated differently, the highest frequency which can be accurately represented is one-half of the sampling rate
    - This frequency has come to be known as the Nyquist frequency and equals ½ the sampling rate
- Comments
  - Wave itself looks distorted, but frequency is captured adequately.
  - Frequencies faster than the Nyquist frequency will not be adequately represented
  - Minimum sampling rate required for a given frequency signal is known as Nyquist sampling rate

Harry Nyquist

Aliasing and the Nyquist Frequency

- In fact, frequencies above Nyquist frequency represented as frequencies lower than Nyquist frequency
  - F_{Ny} + x Hz will be seen as F_{Ny} - x Hz
  - “folding back”
    - frequency $2F_{Ny}$ seen as 0,
    - frequency $3F_{Ny}$ will be seen as F_{Ny}
    - accordion-like folding of frequency axis

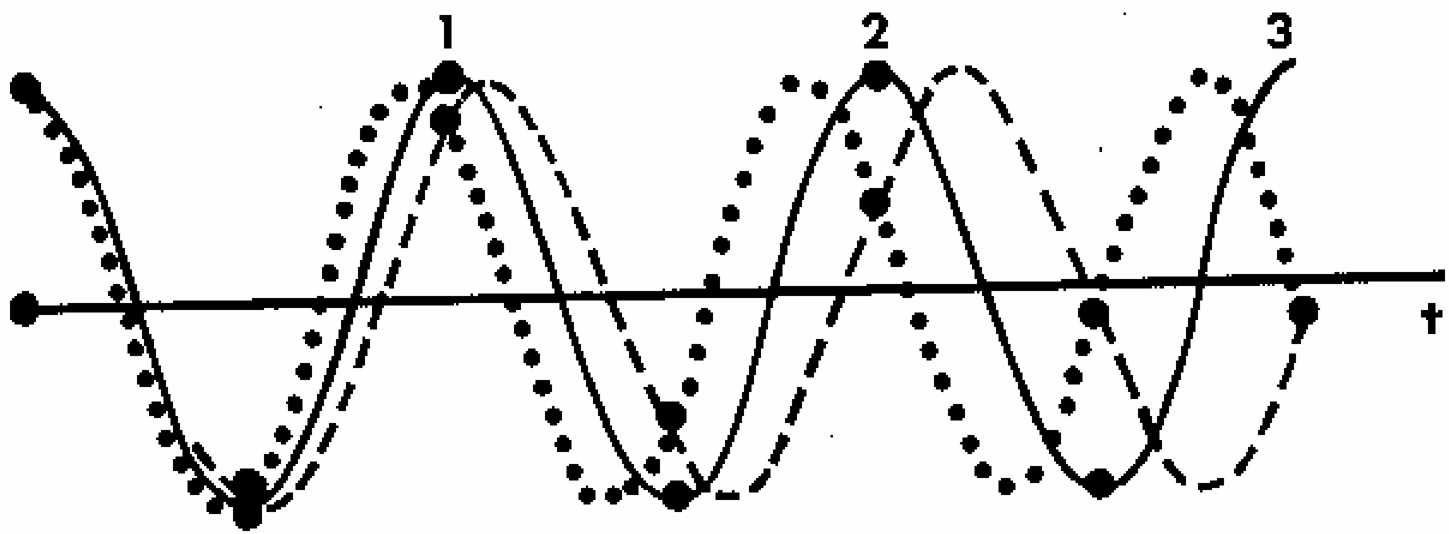


Fig. 3.1. A cosine wave of frequency F (solid line) sampled at its Nyquist rate. A higher frequency (dotted) wave, frequency F + a, is shown sampled at the same rate. At the sample times it is indistinguishable from a lower frequency (dashed) wave, frequency F - a.

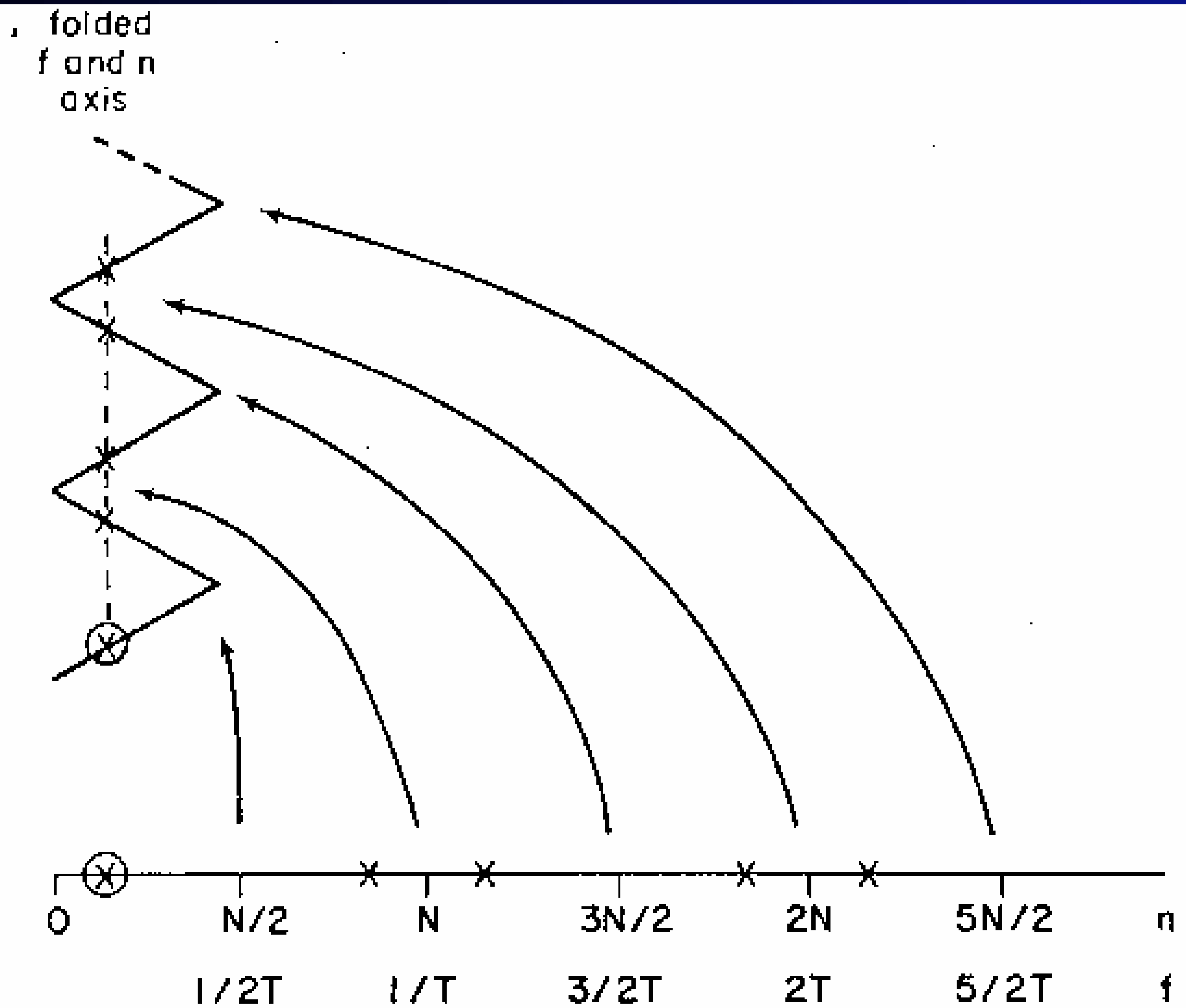
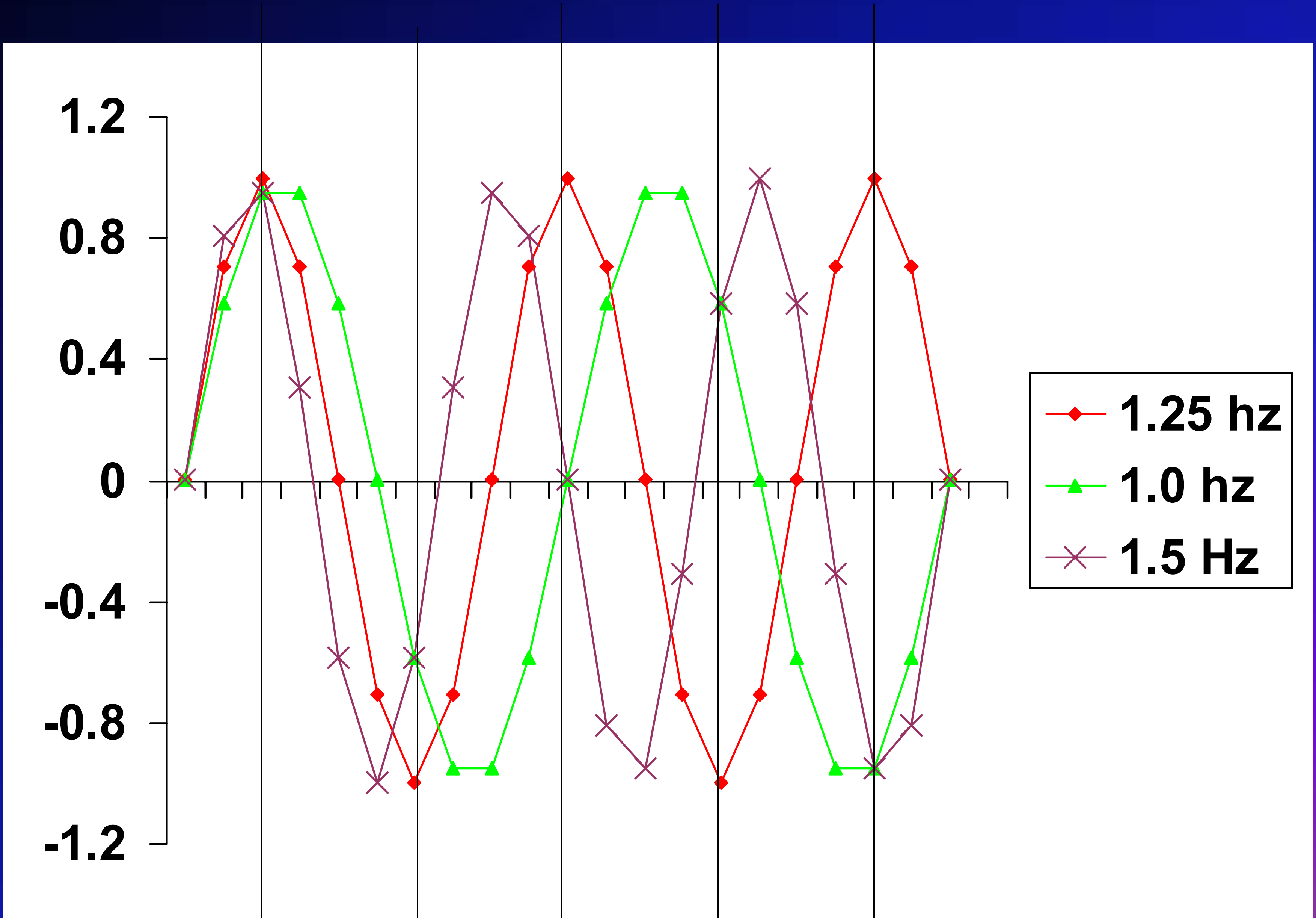
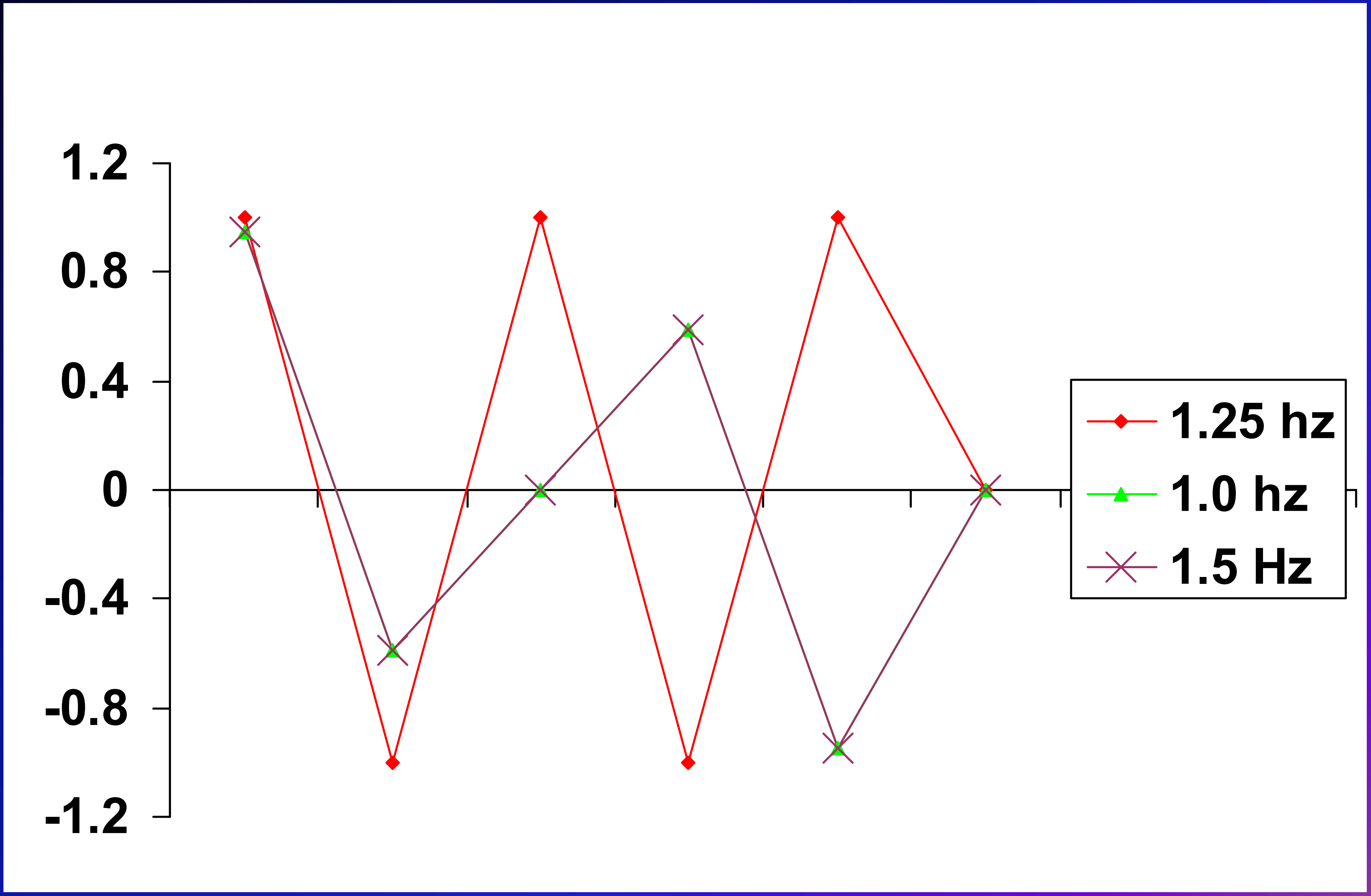


Fig. 3.2. The accordionlike folding of the frequency (or n) axis due to sampling of a continuous signal. Frequency components of the original signal marked with x's on the f axis are interpreted in the sampled version as belonging to the lowest frequency, an encircled x.

Aliasing Demo (Part 1, 10 Hz Sampling Rate)



Aliasing Demo (Part 2, 2.5 Hz Sampling Rate)



Solutions to Aliasing

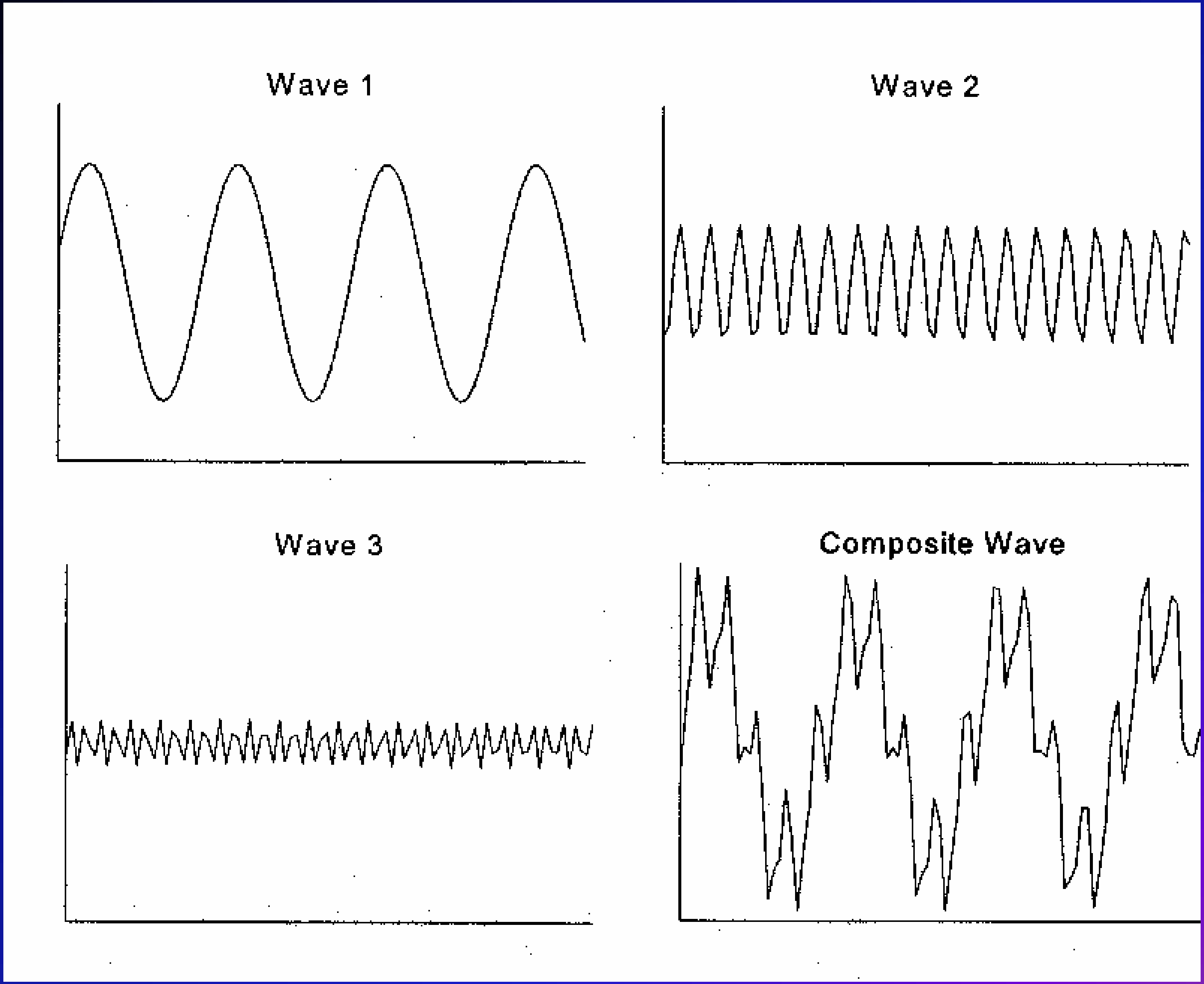
- Sample very fast
- Use anti-aliasing filters
- KNOW YOUR SIGNAL!

Time Domain Vs Frequency Domain Analysis

- Time Domain Analysis involves viewing the signal as a series of voltages as a function of time, [x(0), x(t1), x(t2),...,x(tn-1)]
  - e.g., skin conductance response, event-related potential
  - Relevant dependent variables
    - latency of a particular response
    - amplitude of that response within the time window
- More about time domain next time

Time Domain Vs Frequency Domain Analysis

- Frequency Domain Analysis involves characterizing the signal in terms of its component frequencies
  - Assumes periodic signals
- Periodic signals (definition):
  - Repetitive
  - Repetitive
  - Repetition occurs at uniformly spaced intervals of time
- Periodic signal is assumed to persist from infinite past to infinite future


Wave 1
Wave 2
Wave 3
Composite Wave

Fourier Series Representation

- If a signal is periodic, the signal can be expressed as the sum of sine and cosine waves of different amplitudes and frequencies
- This is known as the Fourier Series Representation of a signal
- In Conceptual (but mathematically imprecise) terms:

$$x(t) = \mathrm{Phase}(t0) + \sum_{1}^{\frac{N}{2}} [\mathrm{Amp}_{\cos} * \cos(\mathrm{fxn}(n, t, T)) + \mathrm{Amp}_{\sin} * \sin(\mathrm{fxn}(n, t, T))]$$

Where

Where N=number of samples

T=period sampled by the N samples

n=frequency from 0 to Nyquist, in 1/T increments

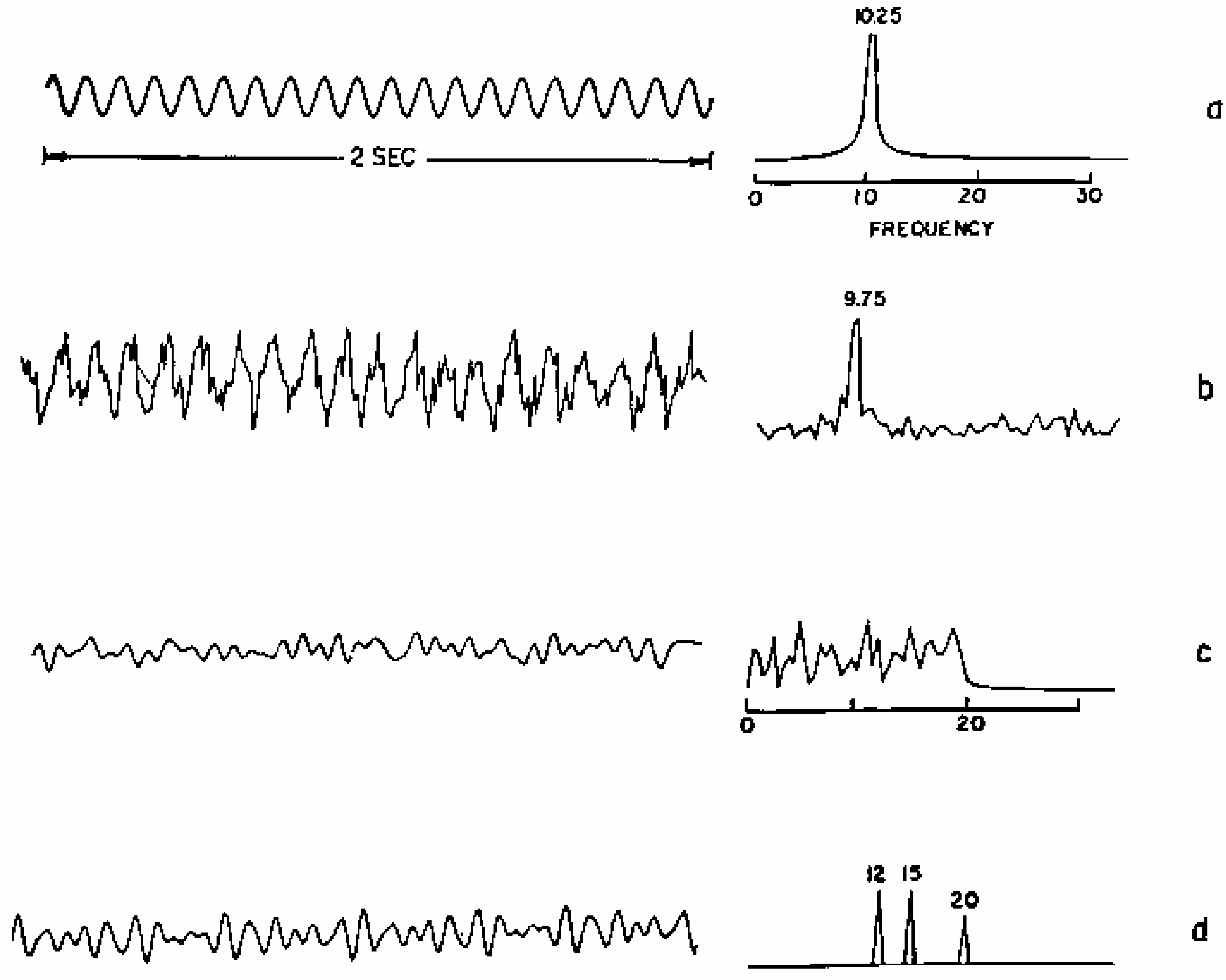
Fourier Series Representation

- Pragmatic Details
  - Lowest Fundamental Frequency is 1/T
  - Resolution is 1/T
- Phase and Power
  - There exist a phase component and an amplitude component to the Fourier series representation
    - Using both, it is possible to completely reconstruct the waveform.
- Psychophysiologist usually only interested in amplitude component:
  - Power spectrum; for each frequency n/T

$$|Amp_{cos}^2 + Amp_{sin}^2|$$

  - Amplitude Spectrum (may conform better to assumptions of statistical procedures); for each frequency n/T

$$|Amp_{cos}^2 + Amp_{sin}^2|^{1/2}$$

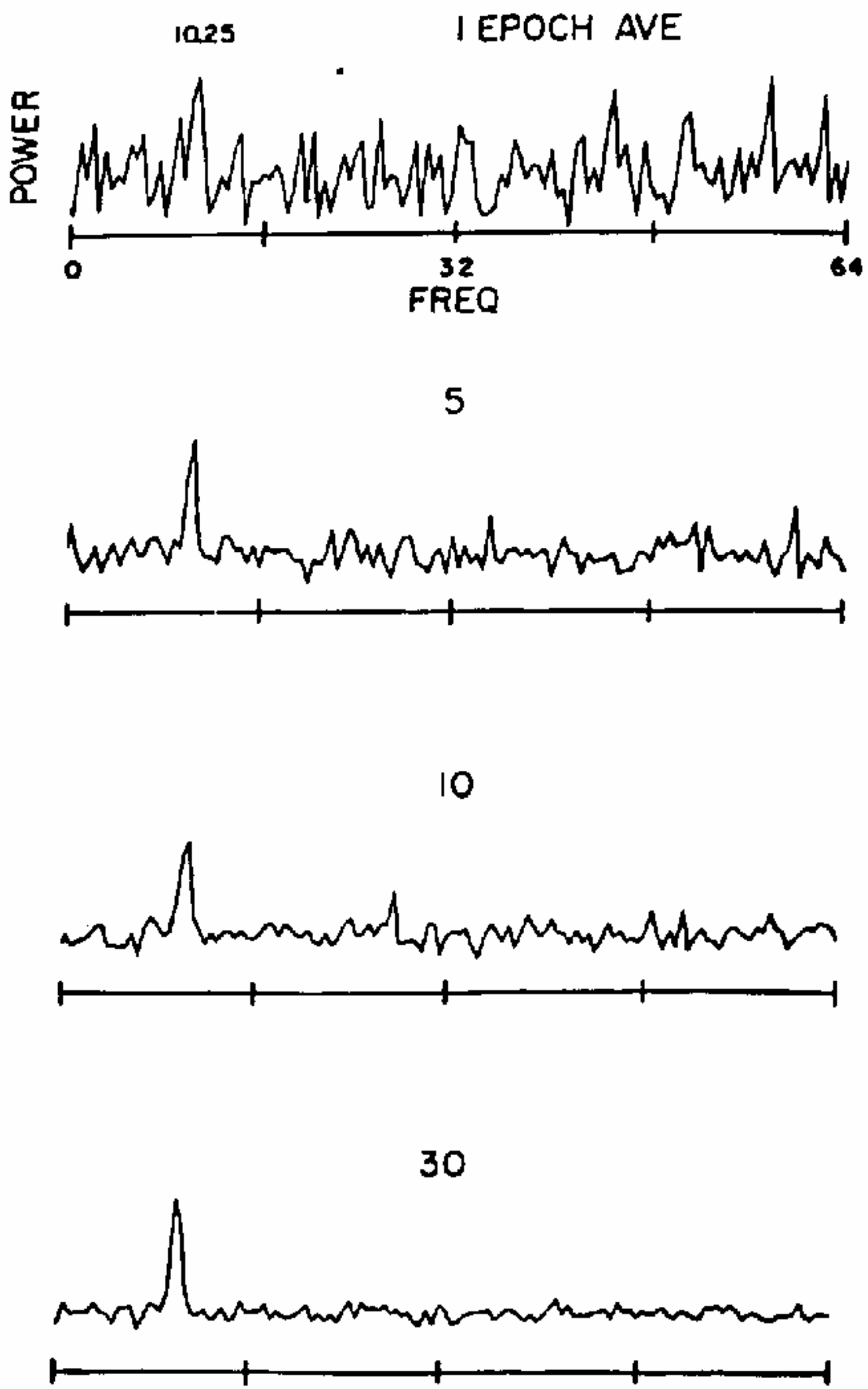


Time Domain

Frequency Domain

. . .

Averaging Multiple Epochs improves ability to resolve signal

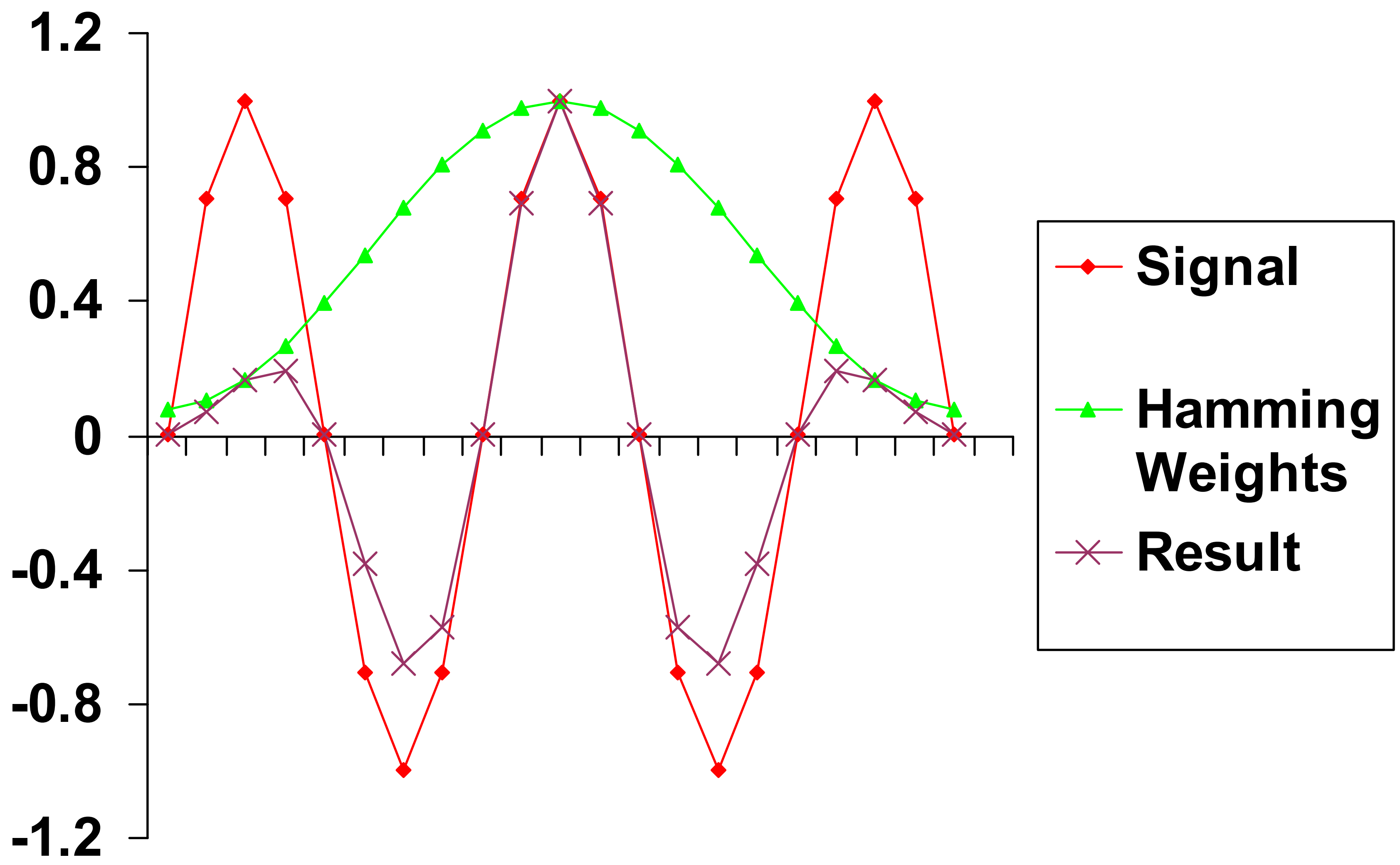


Note noise is twice amplitude of the signal

Lingering details

- In absence of phase information, it is impossible to reconstruct the original signal
  - **Infinite** number of signals that could produce the same amplitude or power spectrum
- Spectra most often derived via a **Fast** Fourier transform (FFT); a fourier transform of a discretely sampled band-limited signal with a power of 2 samples
- Sometimes **autocovariance function** is used (a signal covaries with itself at various phase lags; greater covariation at fundamental frequencies)
- Windowing: the Hamming Taper

Hamming Demo



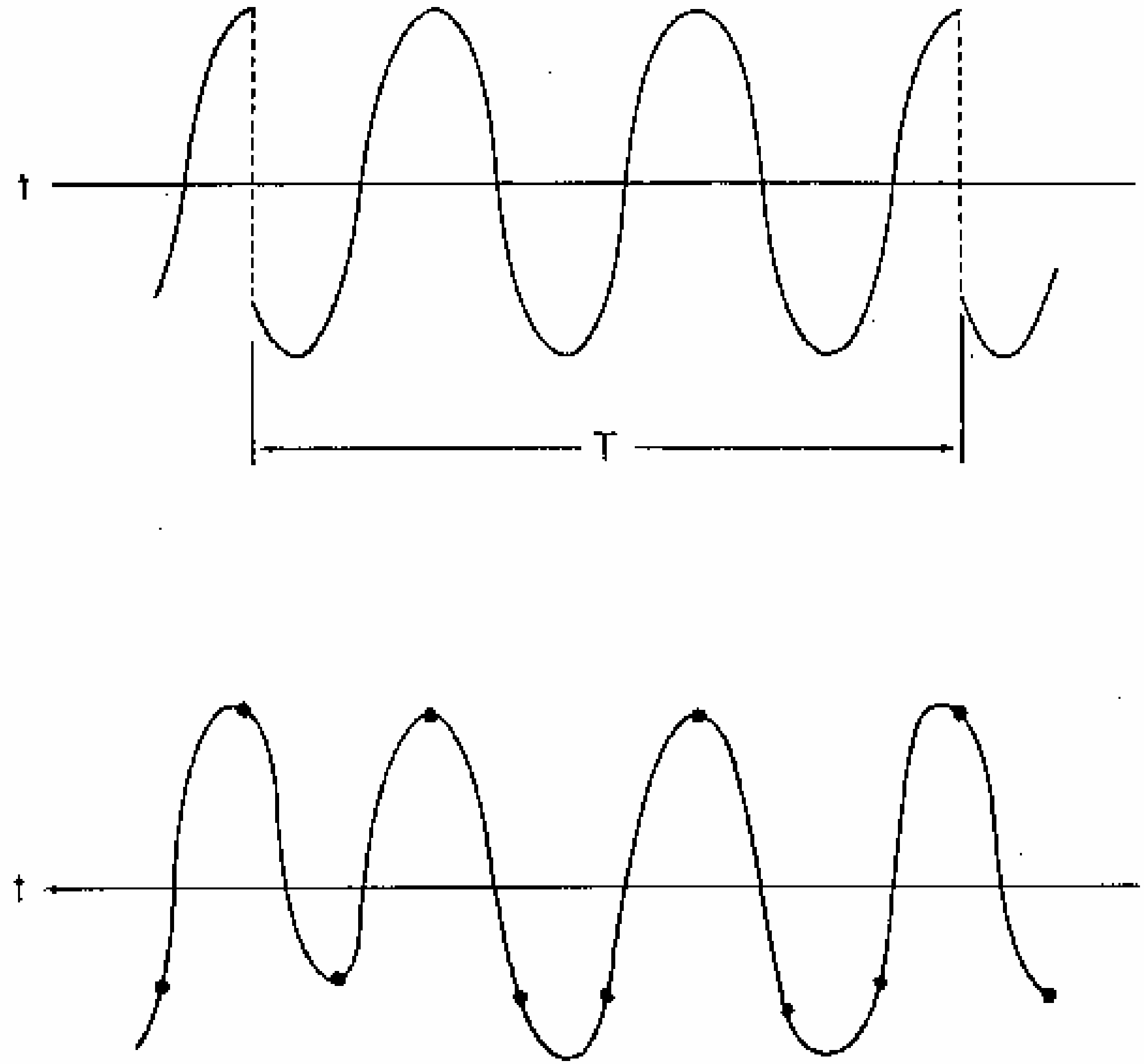


Fig. 3.3. Top, a periodicized segment of a cosine wave. T is the observation time and $3T/8$ the period of the wave. Note the discontinuities at 0 and T. Bottom, a continuous and periodic band-limited wave drawn through the sample points $\Delta = T/16$ sec apart.

Pragmatic Concerns

- Sample fast enough so no frequencies exceed Nyquist
  - signal bandwidth must be limited to less than Nyquist
  - Violation = ERROR
- Sample a long enough epoch so that lowest frequency will go through at least one period
  - Violation = ERROR
- Sample a periodic signal
  - if subject engaging in task, make sure that subject is engaged during entire epoch
  - Violation = ??, probably introduce some additional frequencies to account for change

Demo of EEG Data

- CNT Data to Frequency Domain Representation

Applications

- Emotion Asymmetries
  - Lesion findings
    - Catastrophic reaction (LH)
    - RH damage show a belle indifference
  - EEG studies
    - Trait (40+ studies)
    - State (25 + studies)

Most of them positive!

Types of Studies

- Trait
  - Resting EEG asymmetry related to other traits (e.g. BAS)
  - Resting EEG asymmetry related to psychopathology (e.g. depression)
  - Resting EEG asymmetry predicts subsequent emotional responses (e.g. infant/mom separation
- State
  - State EEG asymmetry covaries with current emotional state (e.g., self report, spontaneous emotional expressions)

Left Hypofrontality in Depression

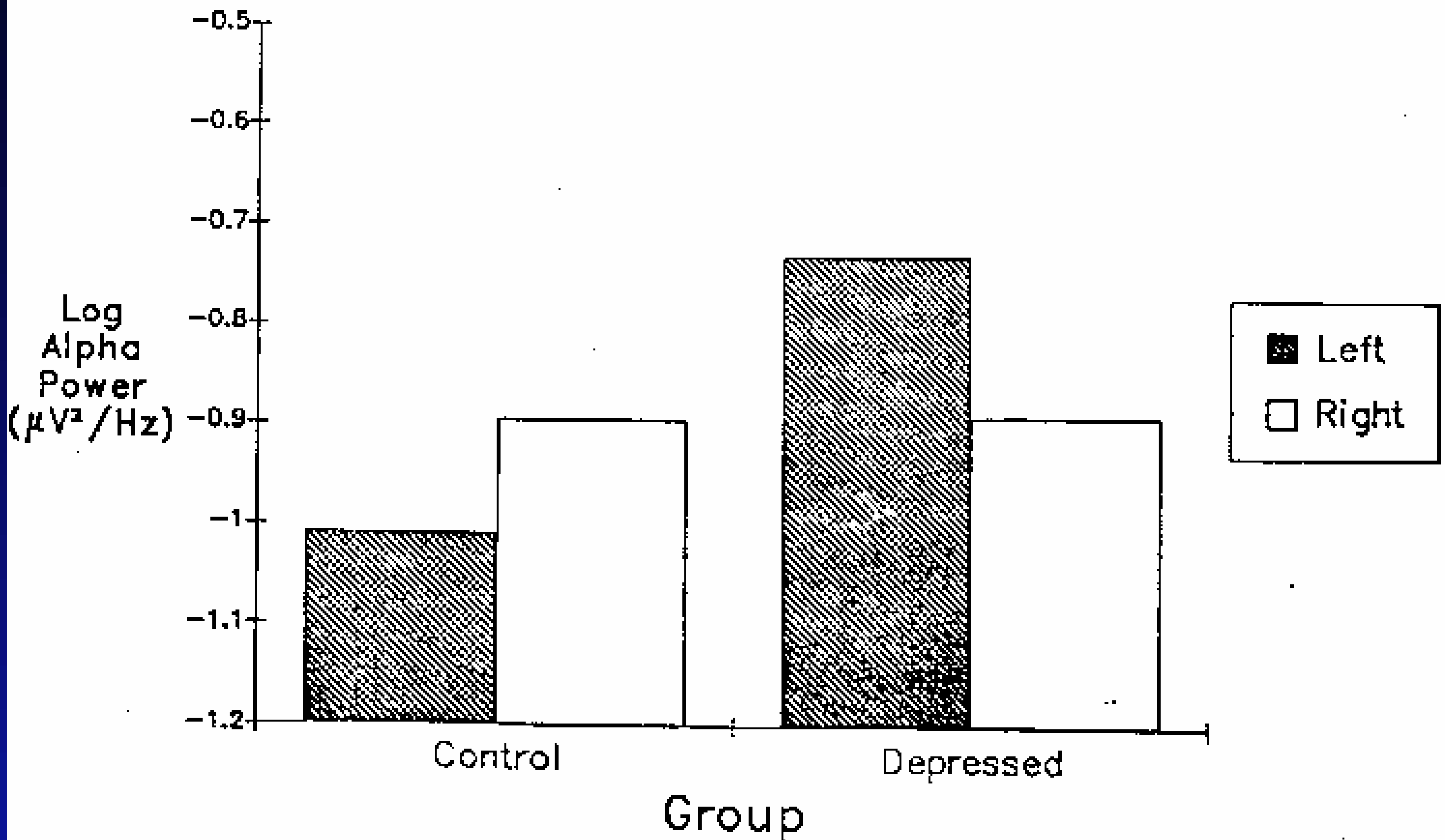
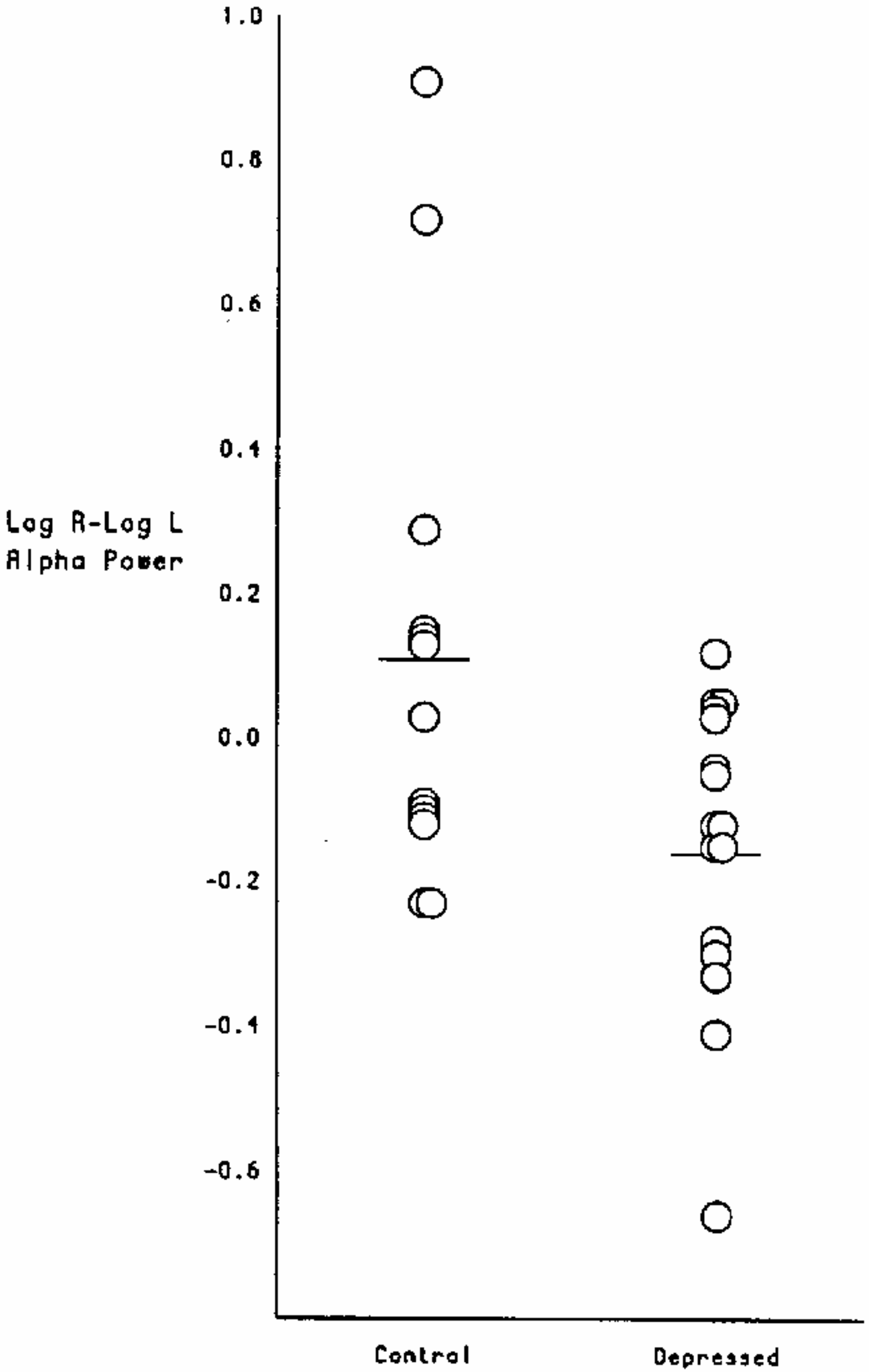


Figure 1. Mean log-transformed alpha (8–13 Hz) power (in $\mu V^2/Hz$) for Cz-referenced electroencephalograms (averaged across eyes-open and eyes-closed baselines), split by group and hemisphere, for the mid-frontal region. (Decreases in alpha power are indicative of increased activation.)

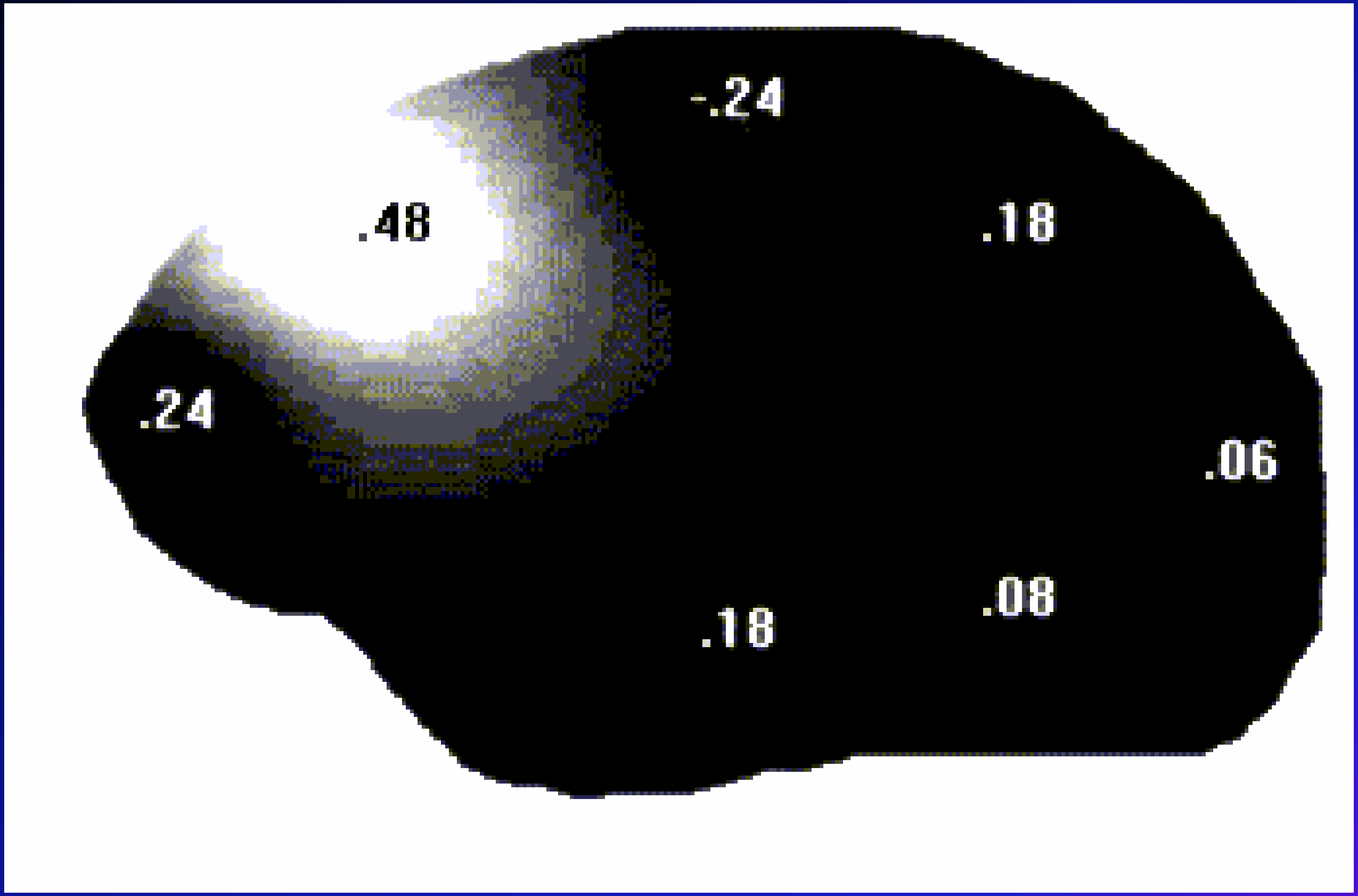
Henriques & Davidson (1991); see also, Allen et al. (1993), Gotlib et al. (1998); Henriques & Davidson (1990); Reid Duke and Allen (1998); Shaffer et al (1983)

Individual Subjects' Data



Valence Vs Motivation

- Valence hypothesis
  - Left frontal is positive
  - Right frontal is negative
- Motivation hypothesis
  - Left frontal is Approach
  - Right frontal is Withdrawal
- Hypotheses are confounded
  - With possible exception of Anger



Correlation with alpha asymmetry (ln[right]-ln[left]) and trait anger. Positive correlations reflect greater left activity (less left alpha) is related to greater anger. After Harmon-Jones and Allen (1998).

State Anger and Frontal Asymmetry

- Would situationally-induced anger relate to relative left frontal activity?

Harmon-Jones & Sigelman, *JPSP*, 2001

Method

- Cover story: two perception tasks – person perception & taste perception
- Person perception task – participant writes essay on important social issue; another ostensible participant gives written feedback on essay
- Feedback is neutral or insulting
  - negative ratings + “I can’t believe an educated person would think like this. I hope this person learns something while at UW.”

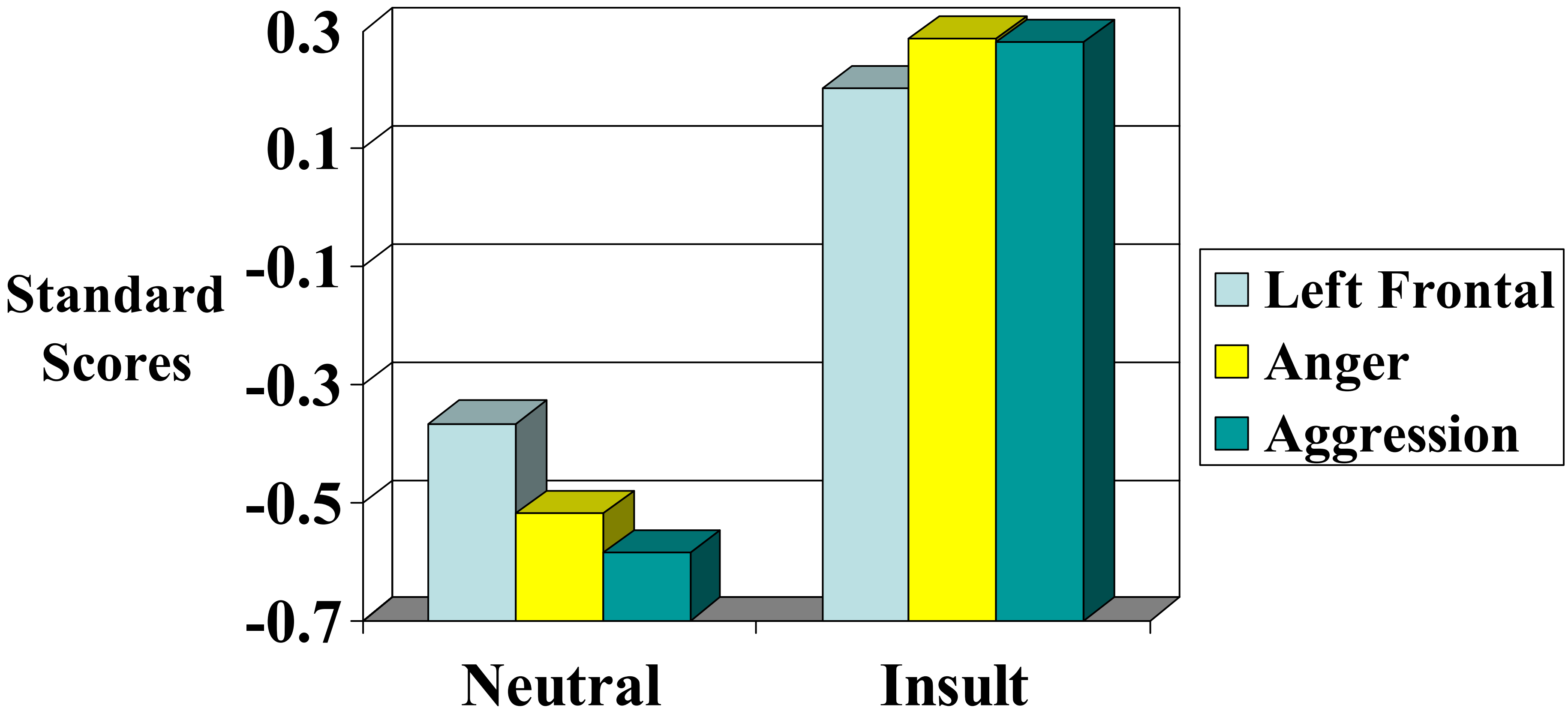
Harmon-Jones & Sigelman, *JPSP*, 2001

- Record EEG immediately after feedback
- Then, taste perception task, where participant selects beverage for other participant, “so that experimenter can remain blind to type of beverage.”
- 6 beverages; range from pleasant-tasting (sweetened water) to unpleasant-tasting (water with hot sauce)
  - Aggression measure

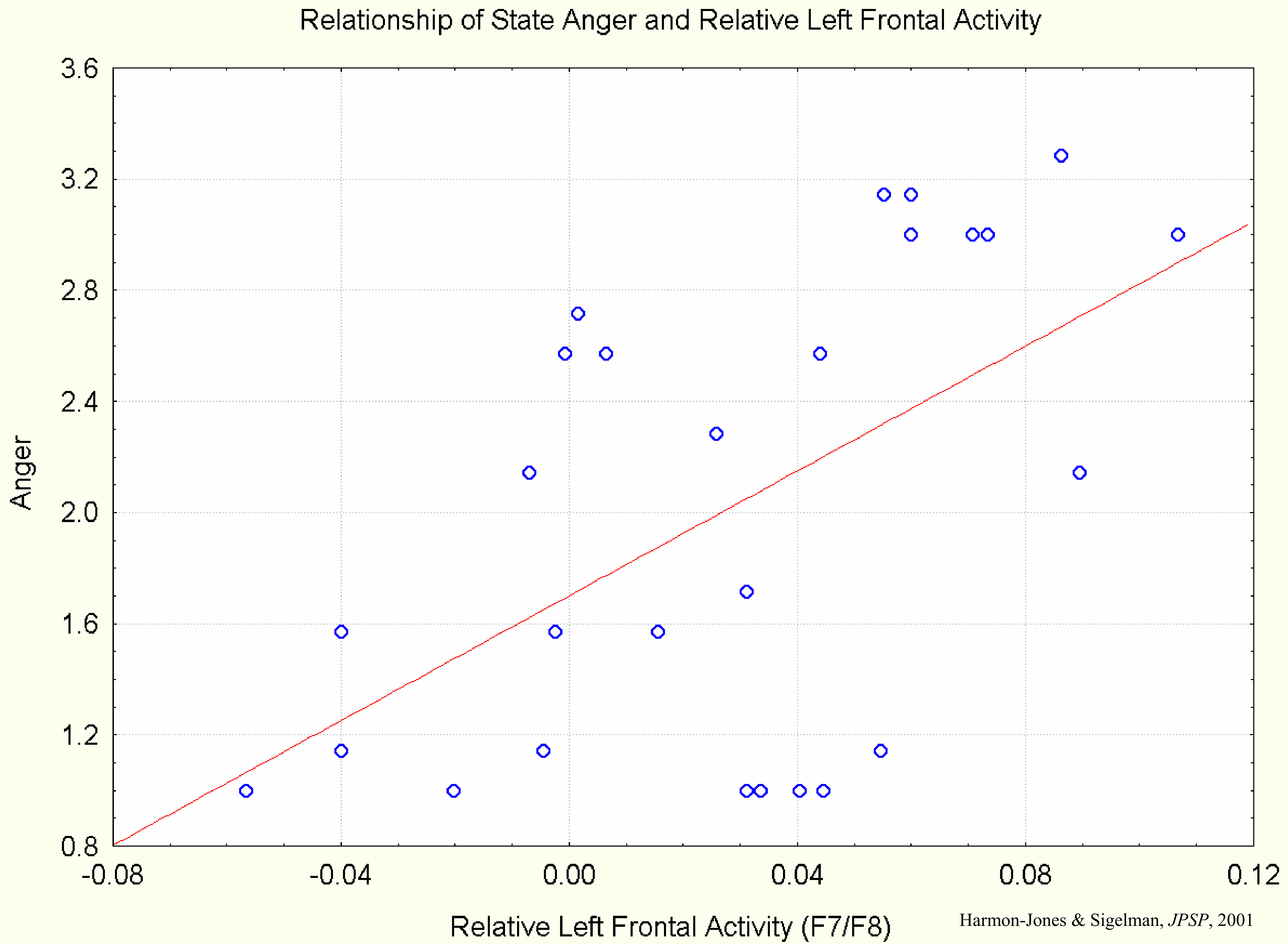
Harmon-Jones & Sigelman, *JPSP*, 2001

Harmon-Jones & Sigelman, *JPSP*, 2001

Relative Left Frontal, Anger, & Aggression as a Function of Condition



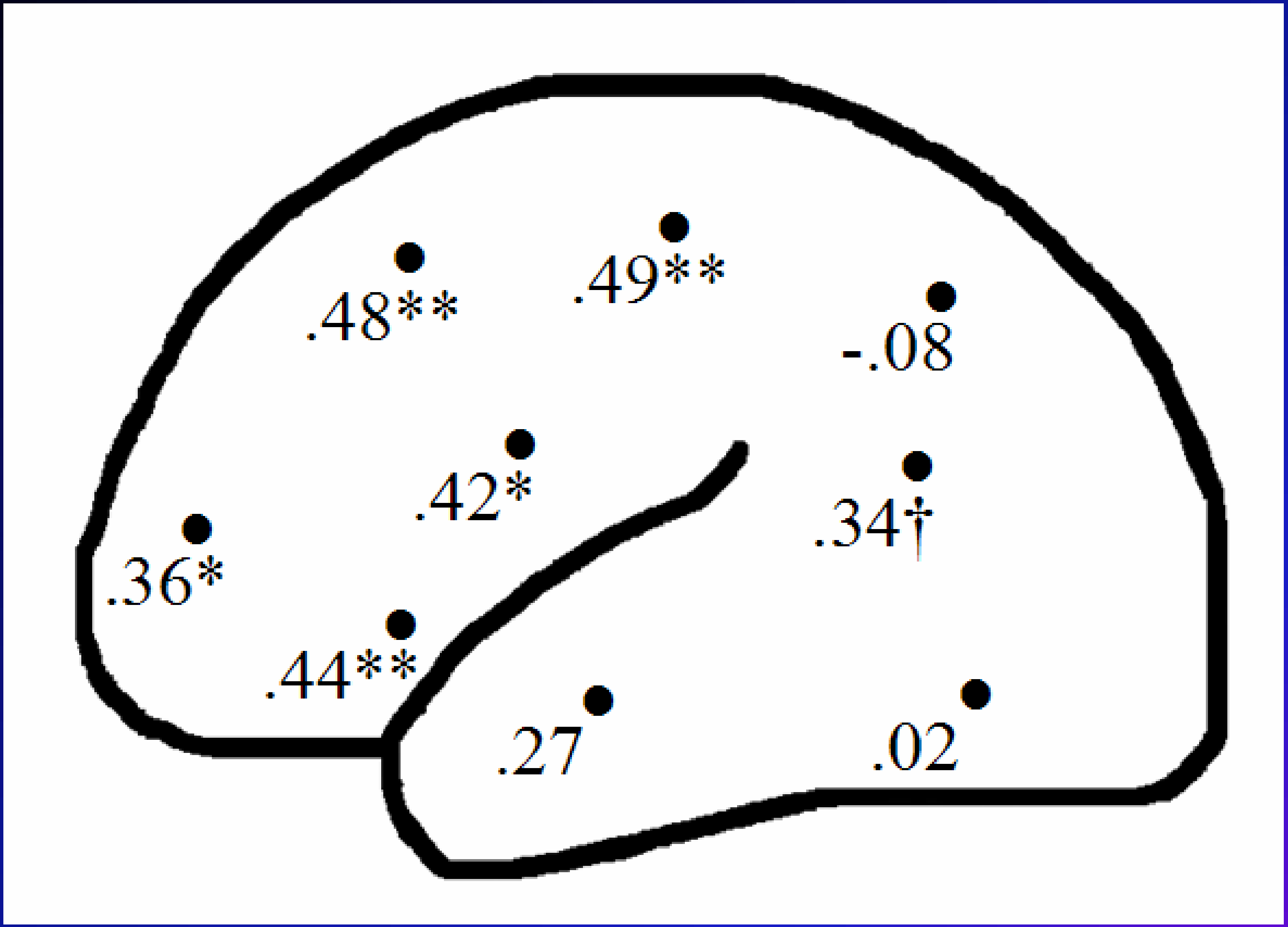
Harmon-Jones & Sigelman, *JPSP*, 2001



Harmon-Jones & Sigelman, *JPSP*, 2001

The BAS/BFS/Approach System

- **sensitive to signals of**
  - **conditioned reward**
  - **nonpunishment**
  - **escape from punishment**
- **Results in:**
  - **driven pursuit of appetitive stimuli**
  - **appetitive or incentive motivation**
  - **Decreased propensity for depression (Depue & Iacono, 1989; Fowles 1988)**



Correlations with alpha asymmetry (ln[right]-ln[left]) and self-reported Behavioral Activation Sensitivity. Positive correlations reflect greater left activity (less left alpha) is related to greater BAS scores. From Coan and Allen (2003); see also Harmon-Jones and Allen (1997).

L>R Activity (R>L Alpha) characterizes:

- an approach-related motivational style (e.g. Harmon-Jones & Allen, 1997; Sutton & Davidson, 1997)
- higher positive affect (e.g. Tomarken, Davidson, Wheeler, & Doss, 1992)
- higher trait anger (e.g. Harmon-Jones & Allen, 1998)
- lower shyness and greater sociability (e.g. Schmidt & Fox, 1994; Schmidt, Fox, Schulkin, & Gold, 1999)
- and greater defensiveness (e.g. Kline, Allen, & Schwartz, 1998; Kline, Knapp-Kline, Schwartz, & Russek, in press; Tomarken & Davidson, 1994)

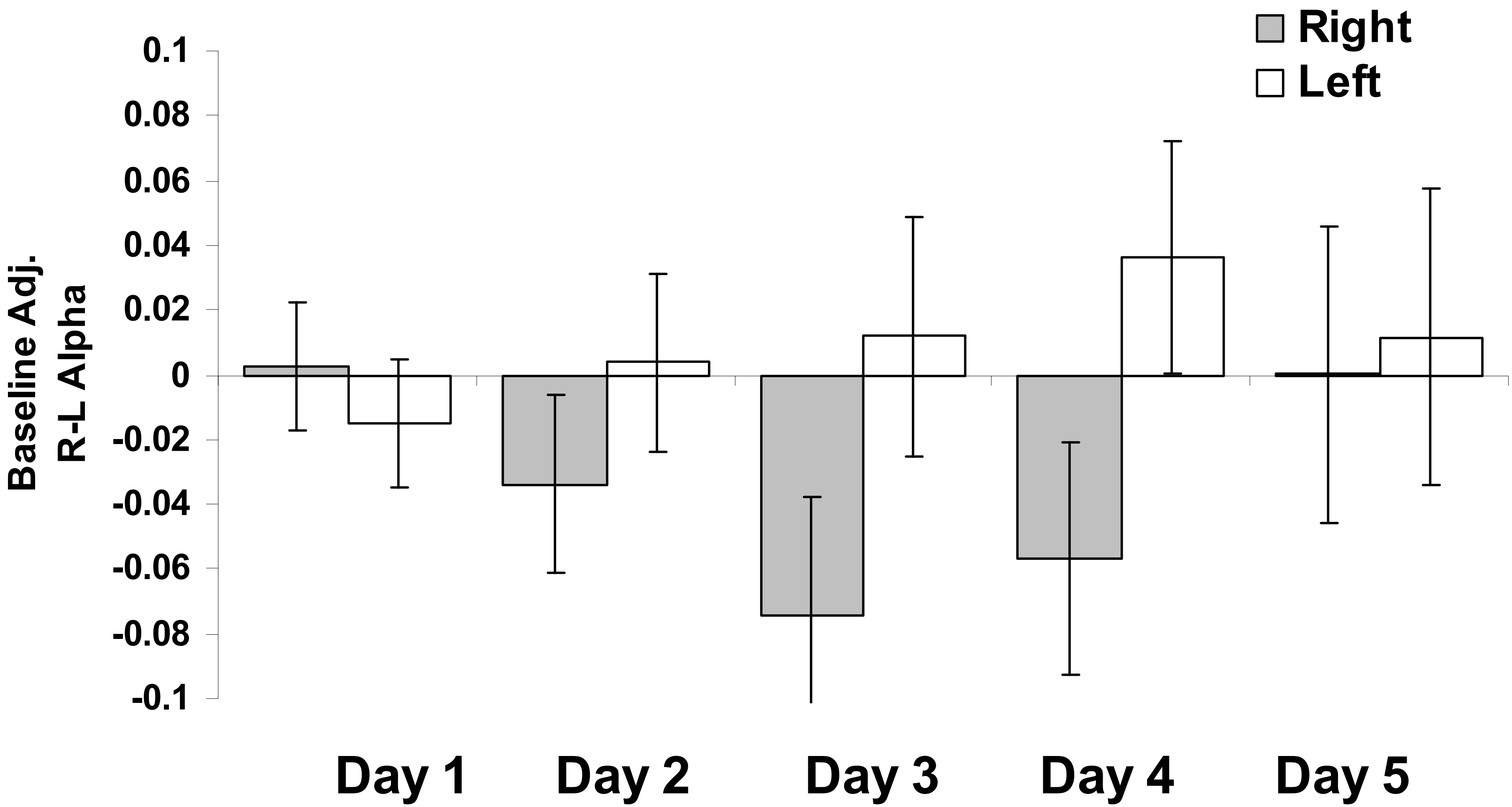
R>L Activity (L>R Alpha) characterizes:

- depressive disorders and risk for depression (e.g. Allen, Iacono, Depue, & Arbisi, 1993; Gotlib, Ranganath, & Rosenfeld, 1998; Henriques & Davidson, 1990; Henriques & Davidson, 1991 but see also Reid, Duke, & Allen, 1998
- certain anxiety disorders (e.g. Davidson, Marshall, Tomarken, & Henriques, 2000; Wiedemann et al., 1999)

Correlations ≠ Causality

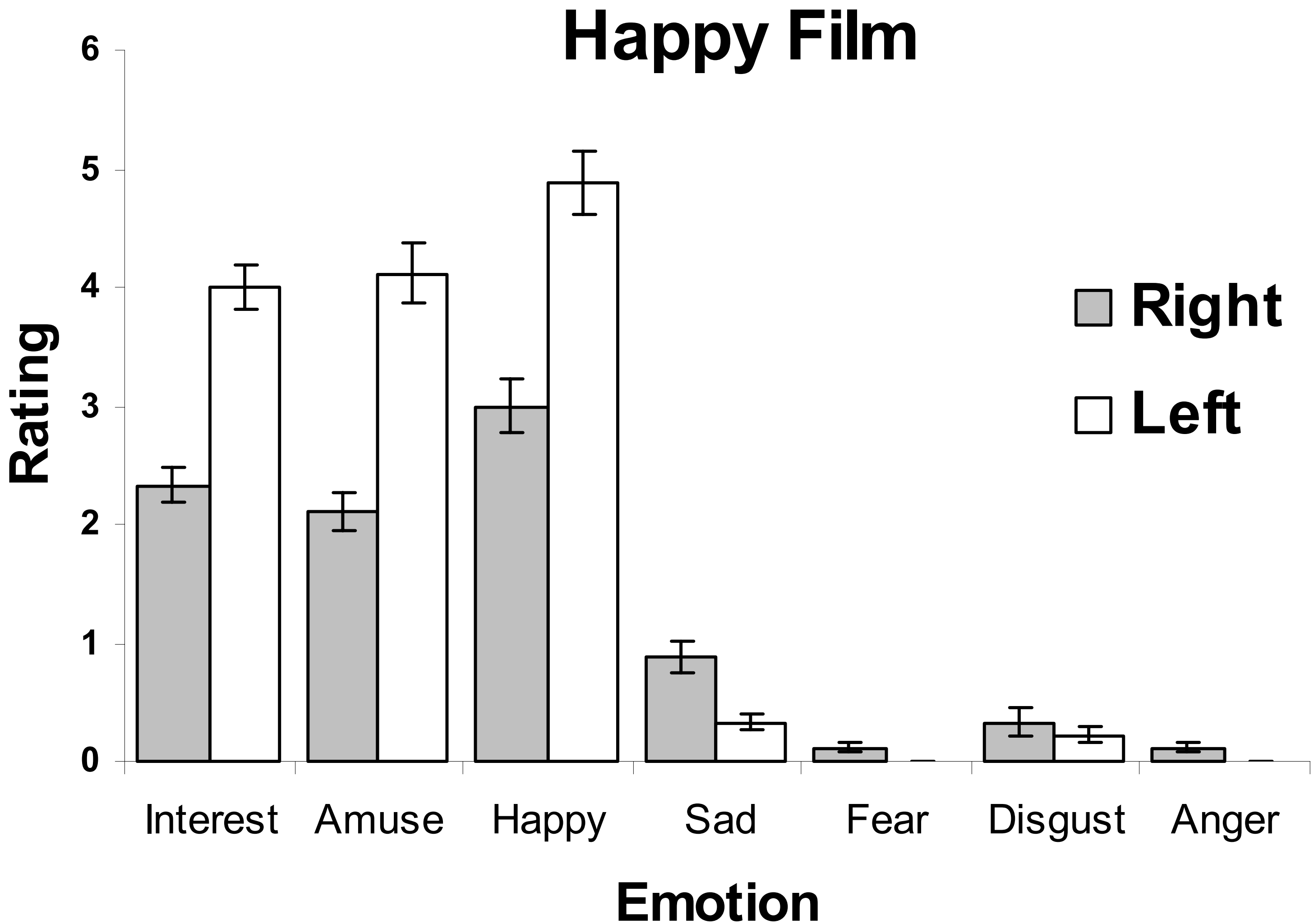
- Study to manipulate EEG Asymmetry
- Five consecutive days of biofeedback training (R vs L)
  - Nine subjects trained “Left”; Nine “Right”
  - Criterion titrated to keep reinforcement equal
- Tones presented when asymmetry exceeds a threshold, adjusted for recent performance
- Films before first training and after last training

Training Effects: Asymmetry Scores



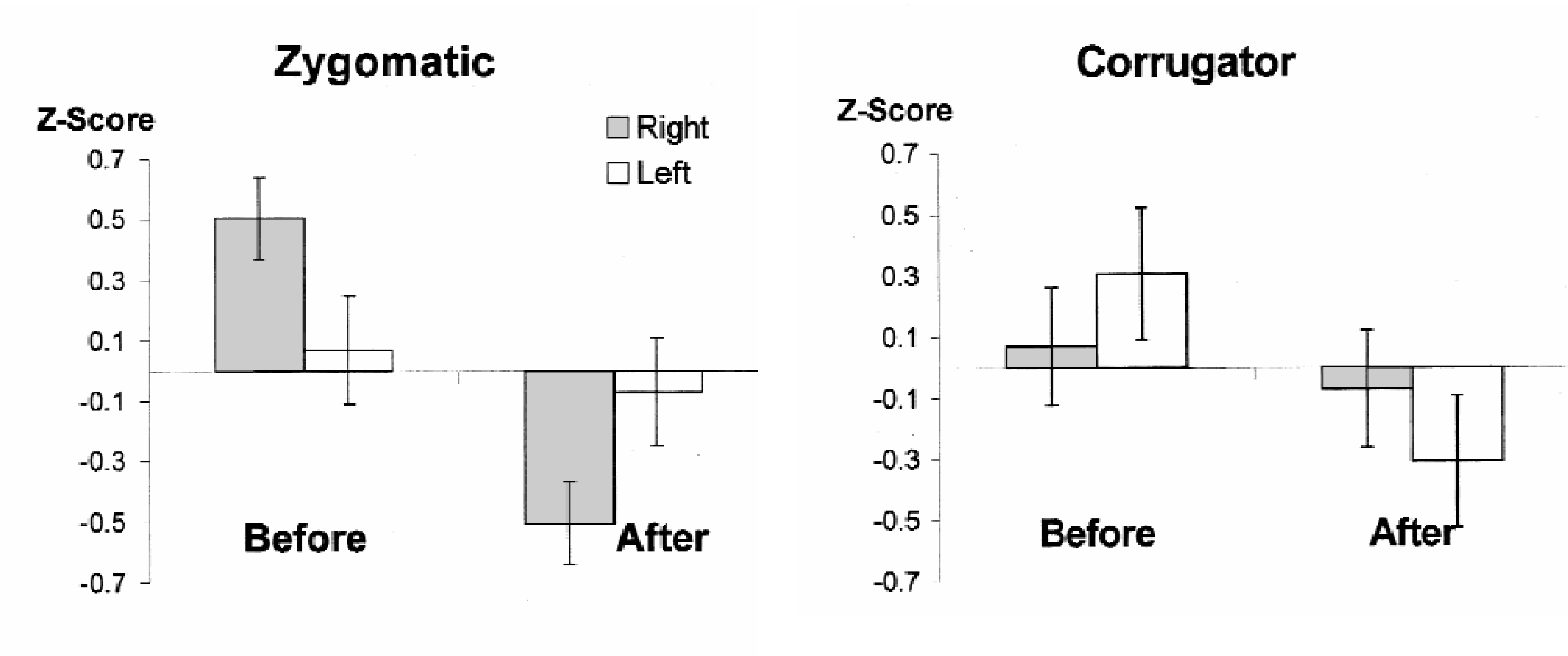
Manipulation of EEG asymmetry with biofeedback produced differential change across 5 days of training; Regression on Day 5

From Allen, Harmon-Jones, and Cavender (2001)



Despite no differences prior to training, following manipulation of EEG asymmetry with biofeedback subjects trained to increase left frontal activity report greater positive affect.

From Allen, Harmon-Jones, and Cavender (2001)

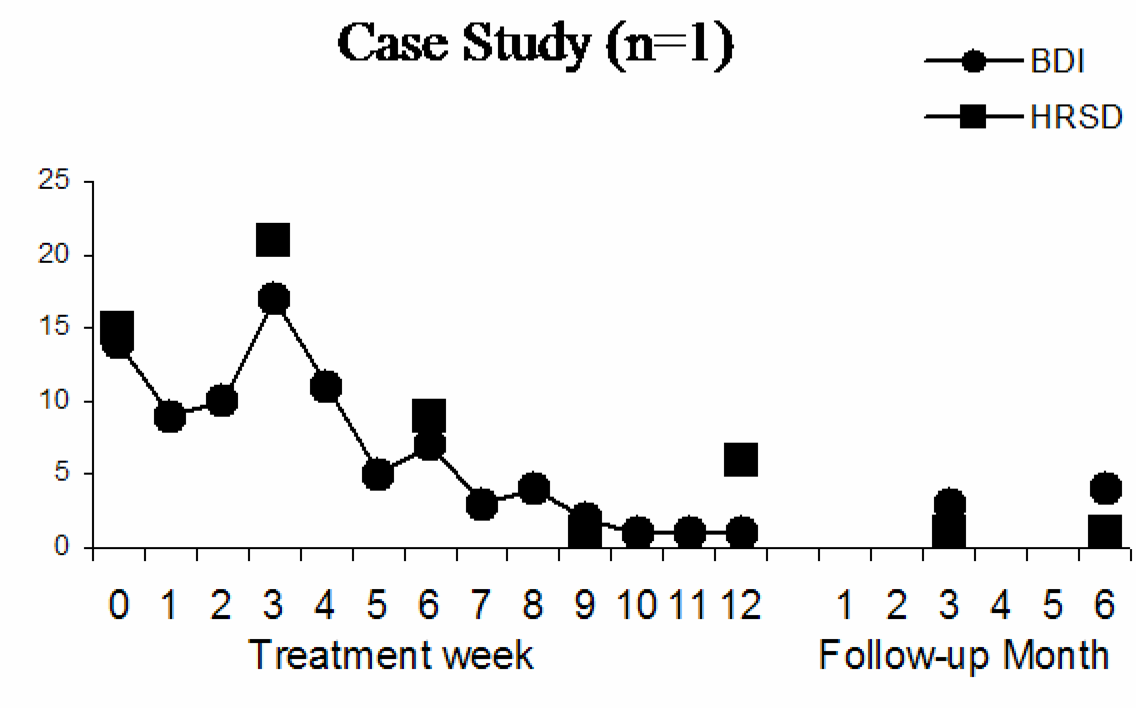


From Allen, Harmon-Jones, and Cavender (2001)

Manipulation of Asymmetry using Biofeedback

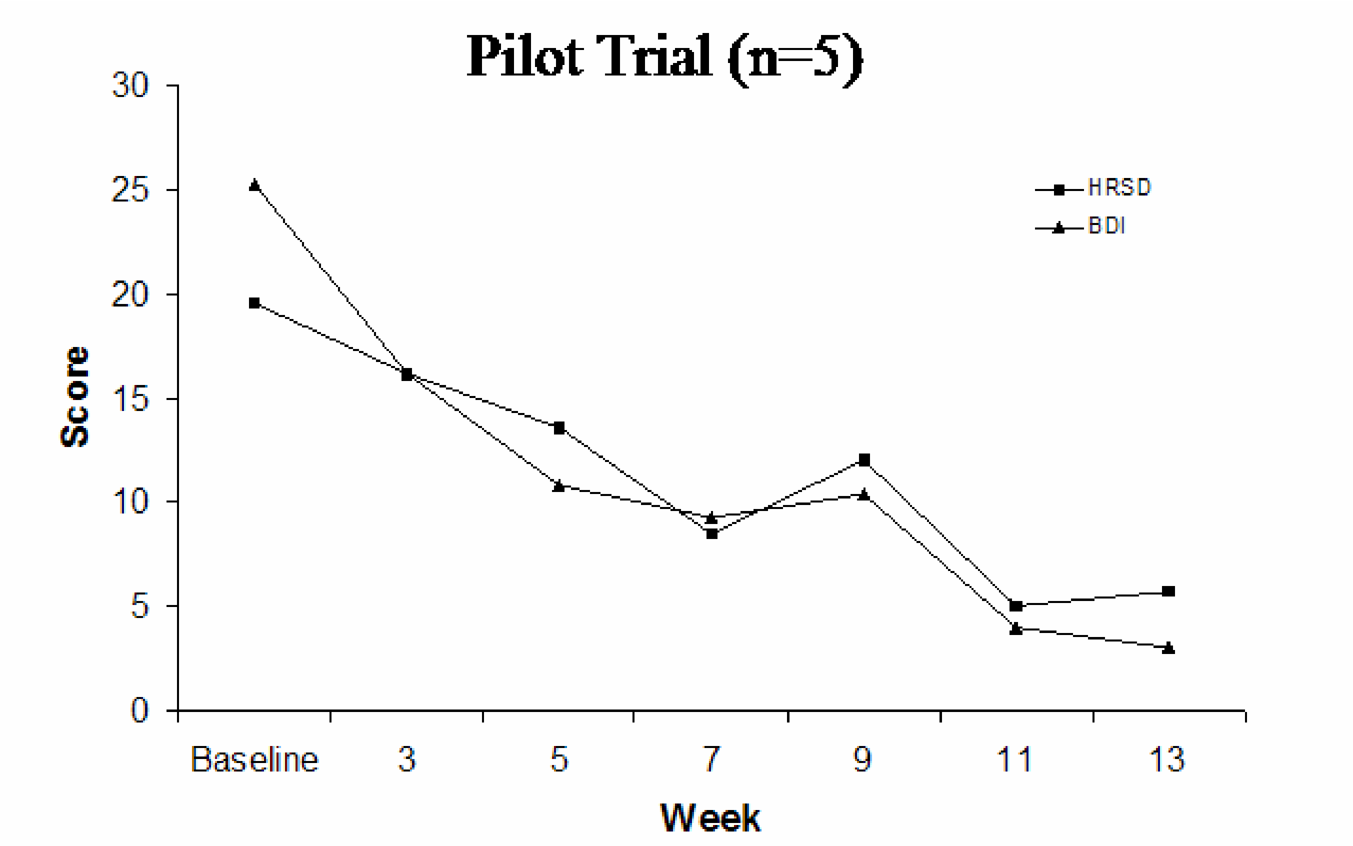
- Phase 1: Demonstrate that manipulation of EEG asymmetry is possible
- Phase 2: Determine whether EEG manipulation has emotion-relevant consequences
- Phase 3: Examine whether EEG manipulation produces clinically meaningful effects
- Phase 4: Conduct efficacy trial

Phase 3a



Biofeedback provided 3 times per week for 12 weeks

Phase 3b



"Open Label" pilot trial, with biofeedback provided 3 times per week for 12 weeks

Phase 3c: Randomized Control Pilot Trial ongoing

- 20 depressed subjects ages 18-60 to be recruited through newspaper ads
- Ad offers treatment for depression but does not mention biofeedback
- Participants meet DSM-IV criteria for Major Depressive Episode (nonchronic)

Design

- Contingent-noncontingent yoked partial crossover design
- Participants randomly assigned to:
  - *Contingent Biofeedback*: tones presented in response to subject's EEG alpha asymmetry
  - *Noncontingent Yoked*: tones presented that another subject had heard, but tones not contingent upon subject's EEG alpha asymmetry
- Treatments 3 times per week for 6 weeks
- After 6 weeks, all subjects receive contingent biofeedback 3 times per week for another 6 weeks

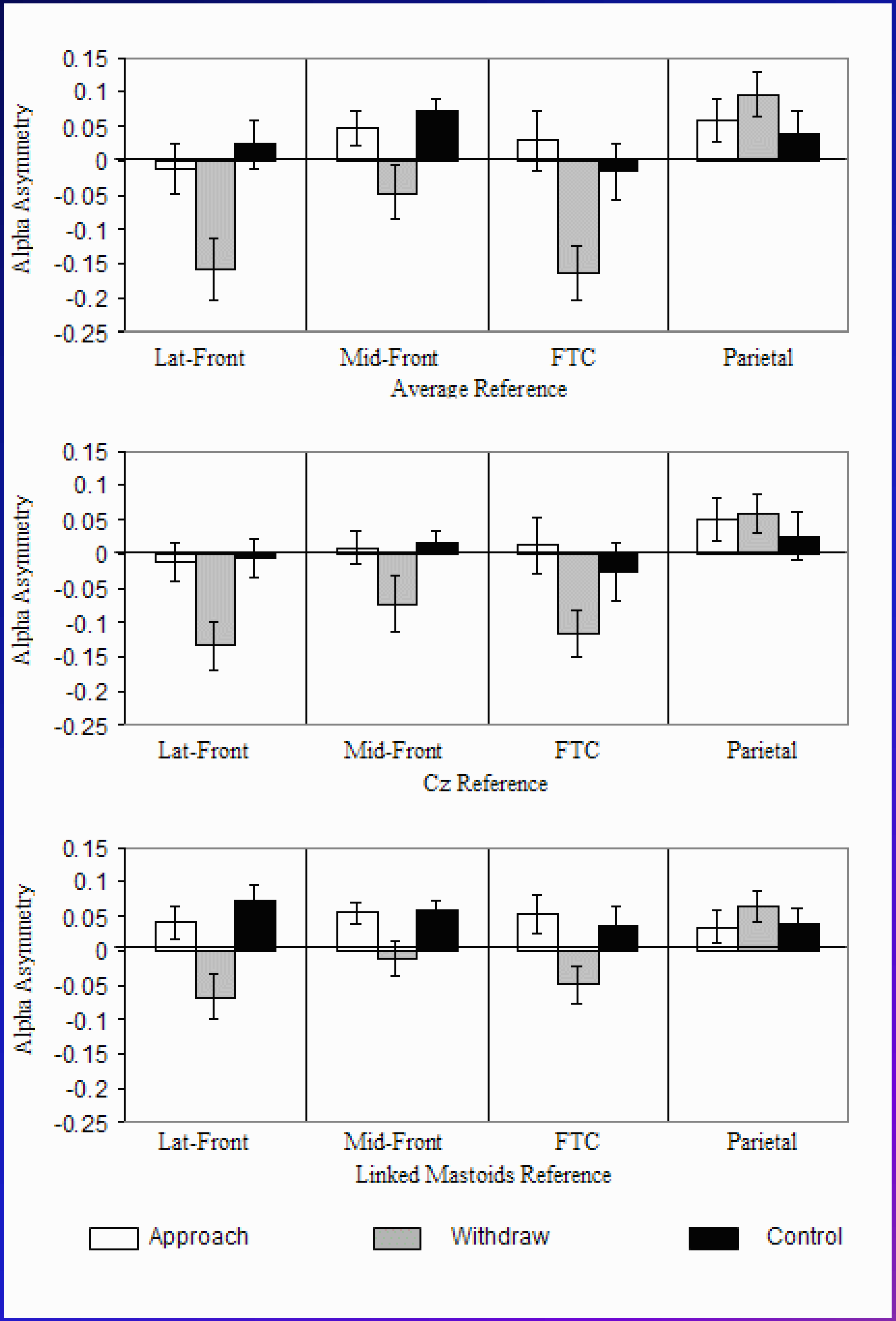
State Changes

- Infants
  - Stanger/Mother paradigm (Fox & Davidson, 1986)
  - Sucrose Vs water (Fox & Davidson, 1988)
  - Films of facial expressions (Jones & Fox, 1992; Davidson & Fox, 1982)
- Primates
  - Benzodiazepines increases LF (Davidson et al., 1992)

State Changes

- Adults
  - Spontaneous facial expressions (Ekman & Davidson, 1993; Ekman et al., 1990; Davidson et al., 1990)
  - Directed facial actions (Coan, Allen, & Harmon-Jones, 2001)
  - Smokers anticipating lighting up (Zinser et al., 1999)

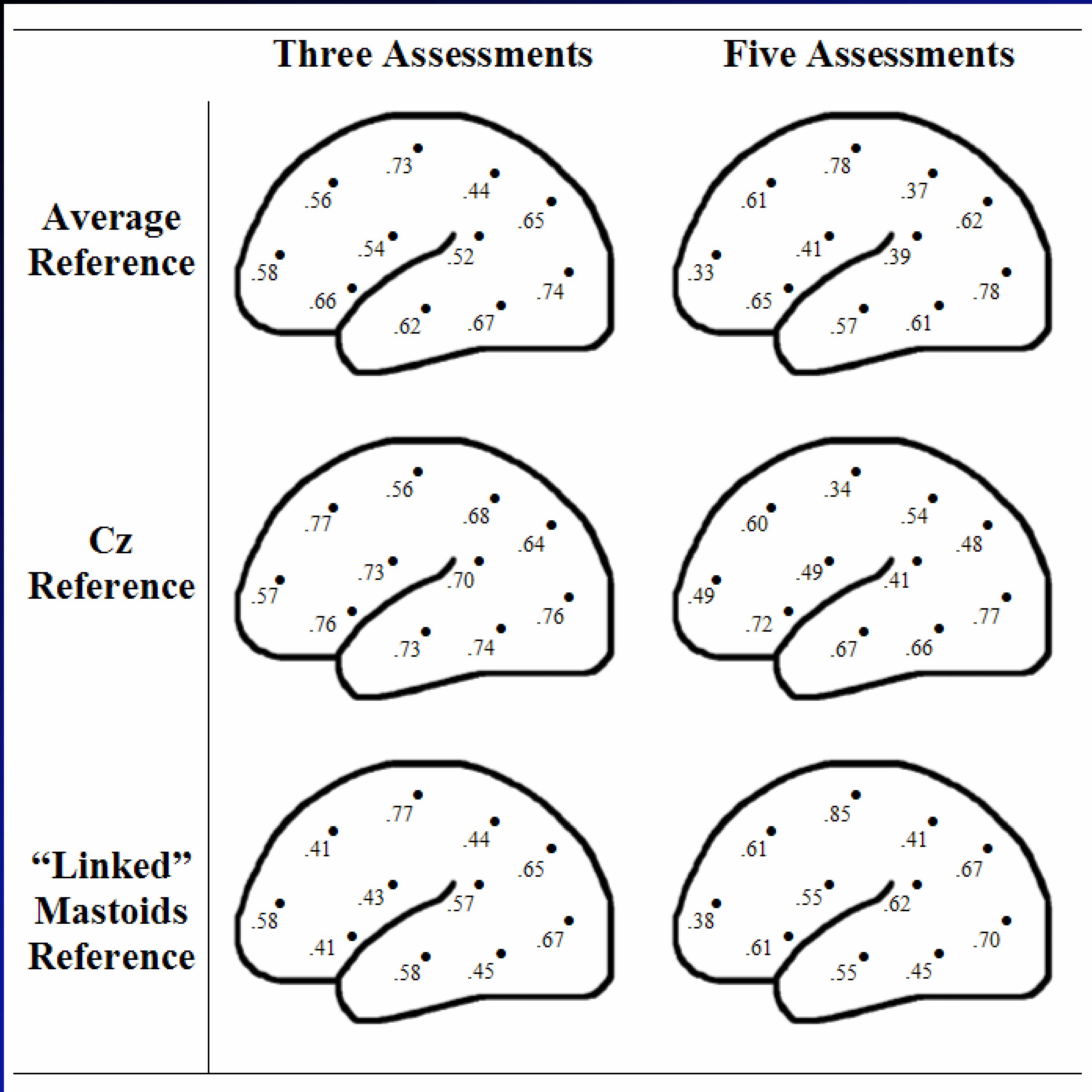
EEG responds to directed facial actions



From Coan, Allen, and Harmon-Jones (2001)

Can EEG Asymmetry serve as Trait Indicator of Risk for _____?

- test-retest stability in nonclinical populations
  - ICCs.53 to .72 across three weeks (Tomarken et al., 1992)
  - ICC of .57 for five sessions across two years (Tomarken et al., 1994)
  - Correlation of .66 between asymmetry at 3 months and asymmetry at 3 years of age (Jones et al., 1997)
  - 52-64% of variance across 4 sessions due to temporally stable latent trait (Hagemann et al., 2002)
- Test-retest stability in depressed folks (Allen et al., in press)
  - median ICC across three assessments was .56, .76, .41 for AR, Cz, and LM referenced data
  - across five assessments, the comparable medians were .61, .60, and .61 for AR, Cz, and LM referenced data.



Allen, Urry, Hitt, & Coan (2004), *Psychophysiology*

Episode	Liability	Genetic
Characterizes most depressed persons (sensitivity)[1,4,5,8,-9,11]	Characterizes most depressed persons (sensitivity) [1,4,5,8,-9,11]	Characterizes most depressed persons (sensitivity) [1,4,5,8,-9,11]
Differentiates depressed from nondepressed (specificity) [1,-3,4,5-6,-13]	Differentiates depressed from nondepressed, not only in episode but in remission as well[1,-3,7]	Differentiates depressed from nondepressed, not only in episode but in remission as well[1,-3,7]
Changes with variations in clinical state[10]	Demonstrates stability in both depressed and nondepressed individuals[1,-4,12,present report]	Demonstrates stability in both depressed and nondepressed individuals[1,-4,12,present report]
	Predicts the future development of depression in individuals currently not depressed[NA]	Predicts the future development of depression in individuals currently not depressed[NA]
		Is heritable within the normal population[2]
		Is more common in depressed persons with a strong family history of depression than those without a such a history[NA]
		Is more prevalent in families of depressed individuals than in families of nondepressed individuals[NA]
		Identifies those family members at risk for depression[NA]

[1]Allen et al., 1993
[2]Allen, Reiner, Katsanis, & Iacono, 1997
[3]Davidson et al., 2000
[4]Debener et al., 2000
[5]Gotlib et al., 1998
[6]Heller et al., 1997
[7]Henriques & Davidson, 1990
[8]Henriques & Davidson, 1991
[9]Reid et al., 1998
[10]Rosenfeld, Baehr, Baehr, Gotlib, & Ranganath, 1996
[11]Schaffer et al., 1983
[12]Tomarken, Davidson, Wheeler, & Kinney, 1992
[13]Wiedemann et al., 1999

Framework after Iacono & Ficken, 1989

Heritability of EEG Power Spectra

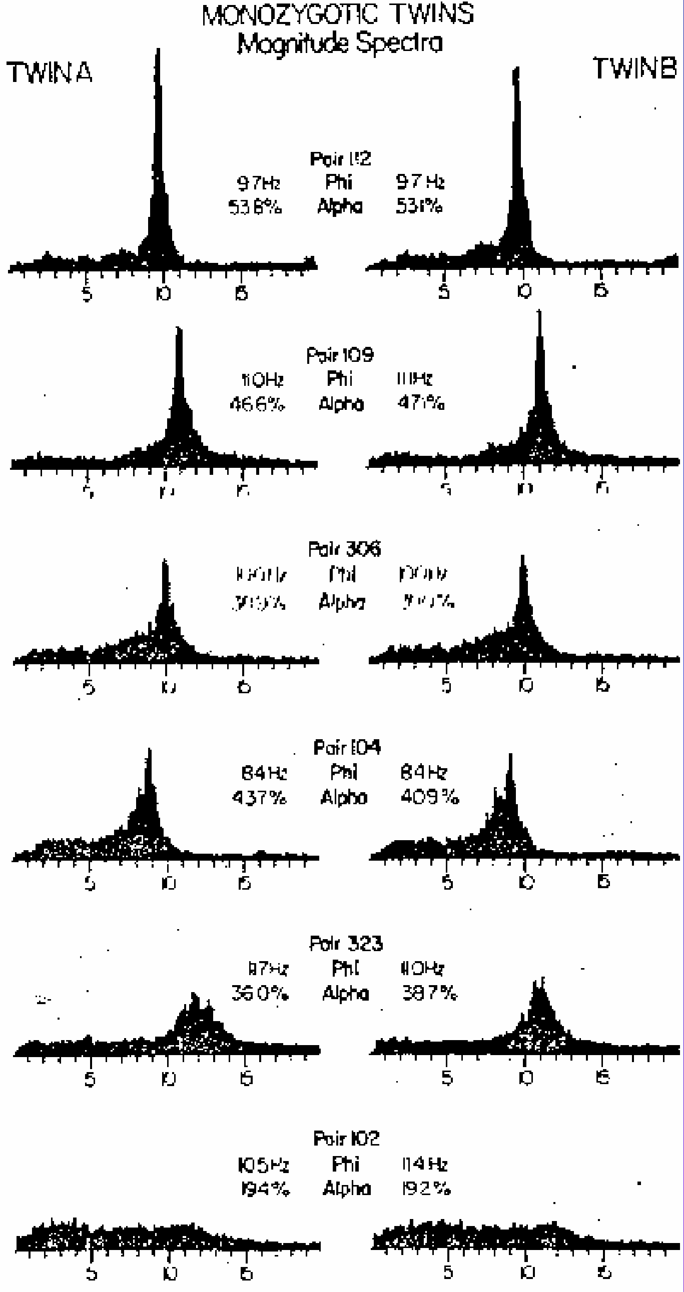


Figure 1. EEG spectra from 6 of the 39 monozygotic (MZ) twin pairs studied in 1974, selected to show the range of amount of alpha activity. Phi is the median frequency in a 3-Hz band centered on the central peak. All spectra are standardized to unit area. (Reprinted from Lykken, Tellegen, & Thorkelson, 1974.)

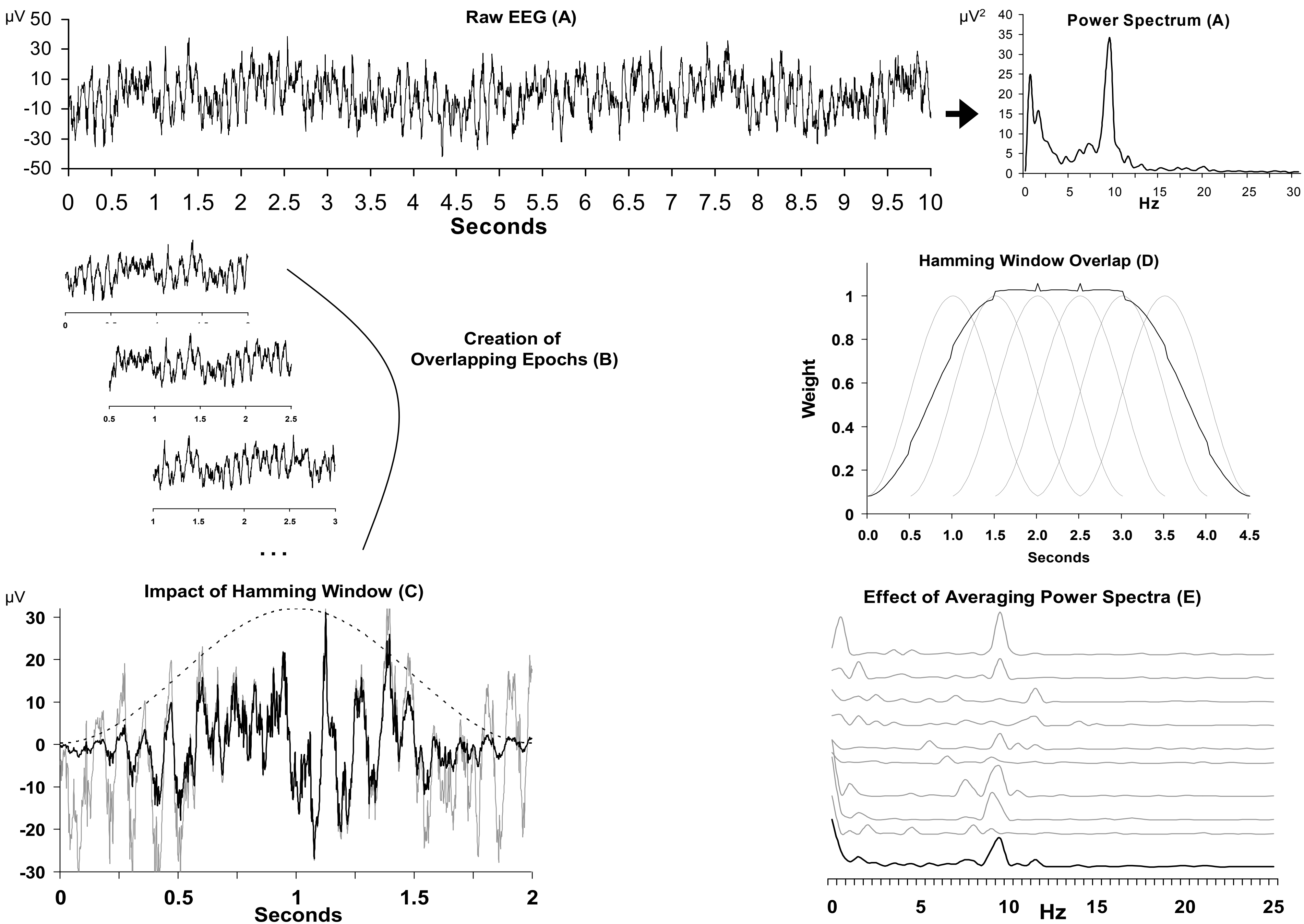
Trait, Occasion, and State variance

- Three sources of reliable variance for EEG Asymmetry
  - *Stable trait consistency* across multiple assessments
  - *Occasion-specific* variance
    - reliable variations in frontal asymmetry across multiple sessions of measurement
    - may reflect systematic but unmeasured sources such as current mood, recent life events and/or factors in the testing situation.
  - *State-specific* variance
    - changes within a single assessment that characterize
      - the difference between two experimental conditions
      - the difference between baseline resting levels and an experimental condition.
      - conceptualized as proximal effects in response to specific experimental manipulations
      - should be reversible and of relatively short duration
- Unreliability of Measurement (small)

Synopsis of Signal Processing and…

Issues and Assumptions on the Road from Raw Signals to Metrics of Frontal EEG Asymmetry in Emotion

These next few slides and concepts based loosely on the best-selling manuscript of the same name by Allen, Coan, & Nazarian (in press)



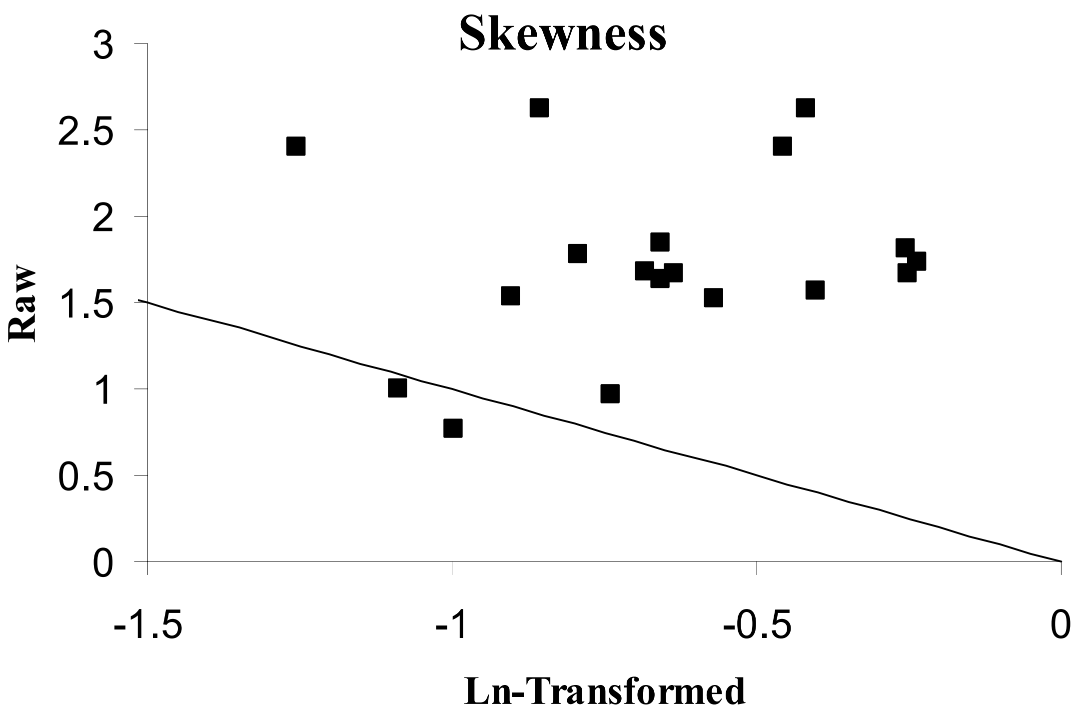
Raw EEG (A)
μV
50
30
10
-10
-30
-50
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
Seconds
Power Spectrum (A)
μV²
40 35 30 25 20 15 10 5 0
0 5 10 15 20 25 30
Hz
Creation of
Overlapping Epochs (B)
0.5 1 1.5 2 2.5
1 1.5 2 2.5 3
Hamming Window Overlap (D)
Weight
1 0.8 0.6 0.4 0.2 0
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5
Seconds
Impact of Hamming Window (C)
μV
30 20 10 0 -10 -20 -30
0 0.5 1 1.5 2
Seconds
Effect of Averaging Power Spectra (E)
0 5 10 15 20 25
Hz

Assessing Asymmetry

- Difference Score
  - Sites typically natural log transformed prior to taking difference
  - Right minus left alpha: *ln(Right)-ln(Left)*
- Higher Scores:
  - Greater relative right alpha
  - By inference, less relative right activity

(Natural) Log Transforms

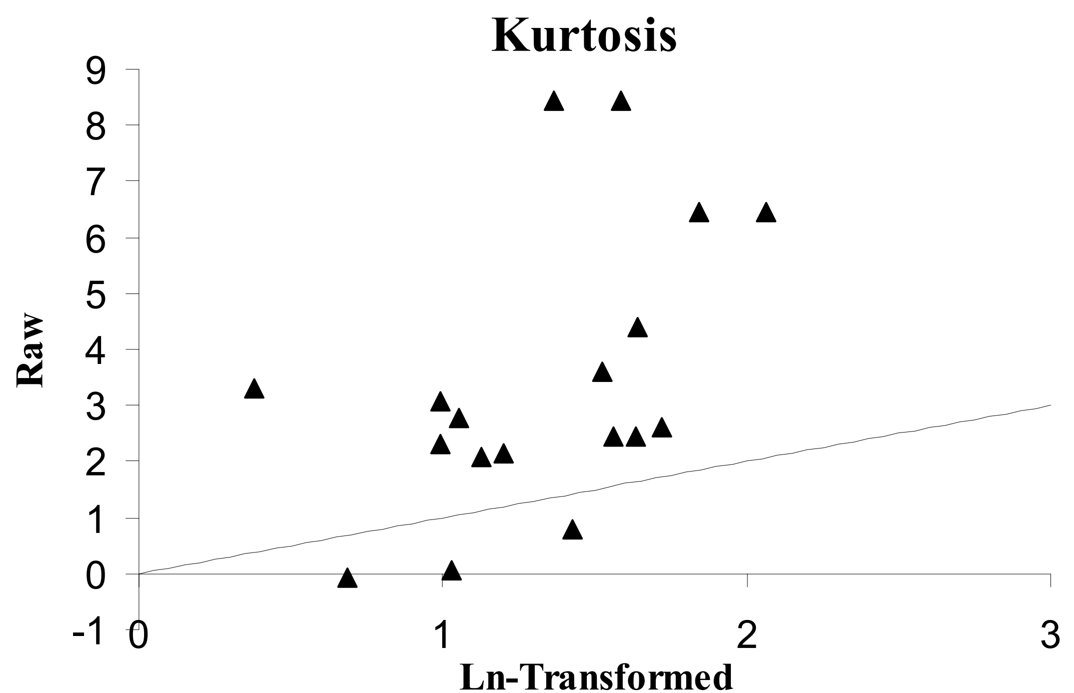
- Why?
  - Everyone is doing it!
  - Folks say power values are skewed



Transformation improves skewness for 89% of the scalp sites, and improves kurtosis for 83% of the scalp sites

% Sites deviating from Normality

	Before Ln-Transform	After Ln-Transform
Skewness	94%	33%
Kurtosis	83%	39%



Difference of ln-Transforms

- Individual sites are therefore ln-transformed prior to taking the difference score

% Asymmetry scores deviating from Normality

	Before Ln-Transform	After Ln-Transform
Skewness	67%	22%
Kurtosis	67%	33%

Asymmetry Metric Vs Individual Sites

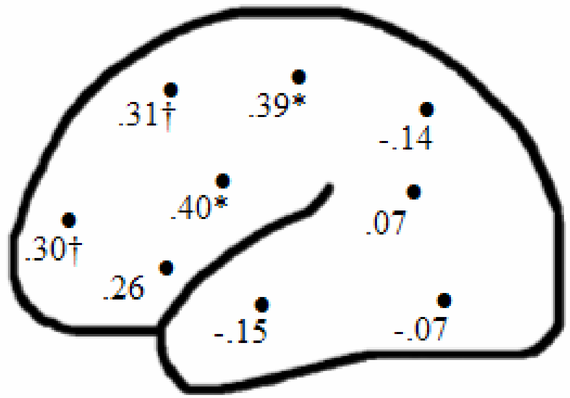
- Is it left or is it right?
- Can assess using ANOVA with hemisphere as a factor
  - Removes overall power before testing for interaction of emotion/temperament/psychopathology with hemisphere
  - But not easily amenable for assessing relationship of EEG at given site to continuous variables

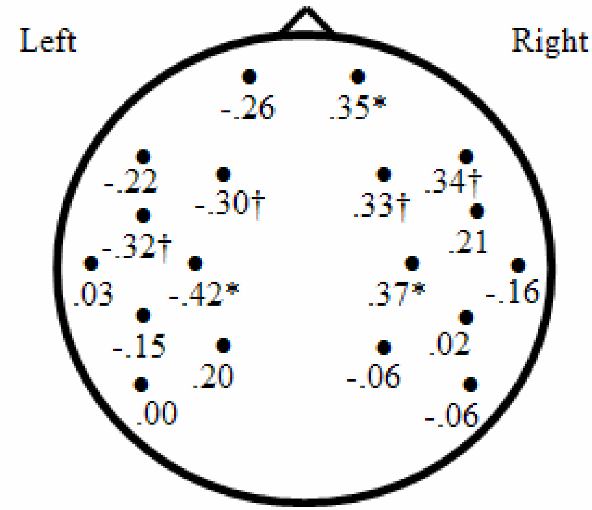
Asymmetry Metric Vs Individual Sites

- The Problem:
  - Power at an individual site reflects:
    - Underlying neural activity
    - Scalp thickness
- An early (nonoptimal) solution
  - Residualize power at each lead based on
    - Whole head power (reasonable)
    - Homologous lead power (troublesome)

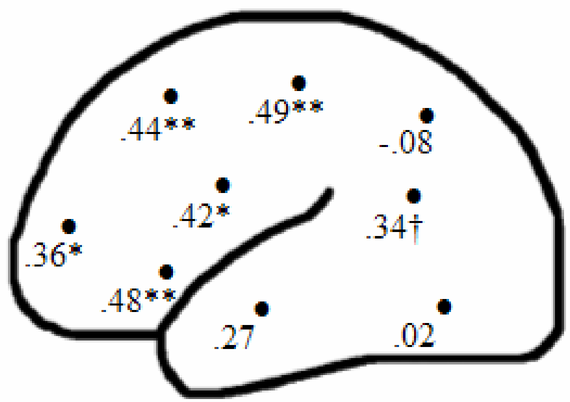
Ln(Right)-Ln(Left) | **Residualized Power**

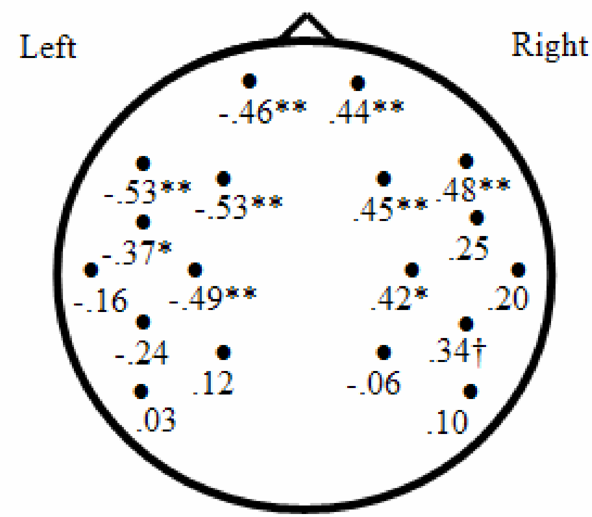
Average Reference





Linked Mastoids Reference





†p < .10; *p < .05; ** p < .01

Why does it do *that?!*

- This double residualization results in correlations with the outcome variable similar in magnitude to the difference score, but with opposite signs for the two hemispheres.
- This is actually to be expected when the predictor and criterion variable are highly correlated

Alpha Power at Homologous Sites is *Highly* Correlated

Sites	Reference	
	AR	LM
FP1 .. FP2	.997	.998
F7 .. F8	.983	.971
F3 .. F4	.990	.992
FTC1 .. FTC2	.975	.943
C3 .. C4	.977	.981
T3 .. T4	.918	.891
TCP1 .. TCP2	.944	.948
P3 .. P4	.965	.982
T5 .. T6	.907	.932

Consider residualized left lead power when L ≈ R

$$L_{resid} = L - \hat{L}$$

$$\hat{L} = a + b(R)$$

In limiting case where $r_{lr} \rightarrow 1.0$

$$\hat{L} = 0 + 1(R) = R$$

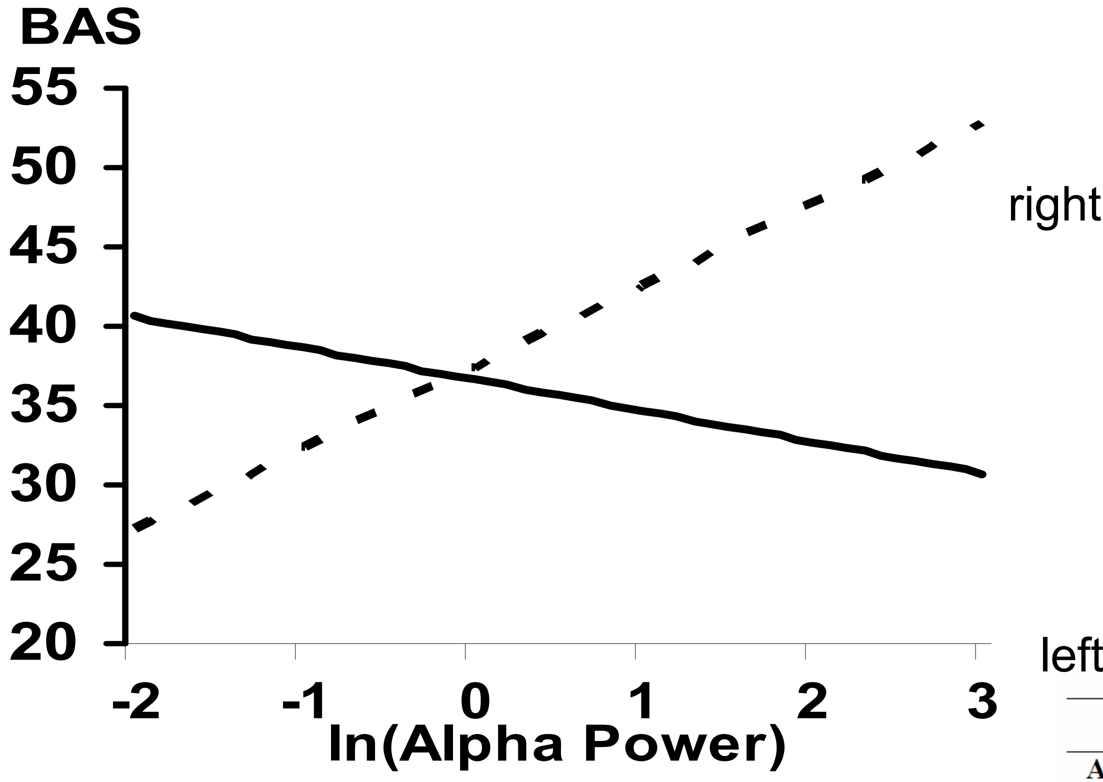
$$L_{resid} = L - \hat{L} = L - R$$

Fancy That!

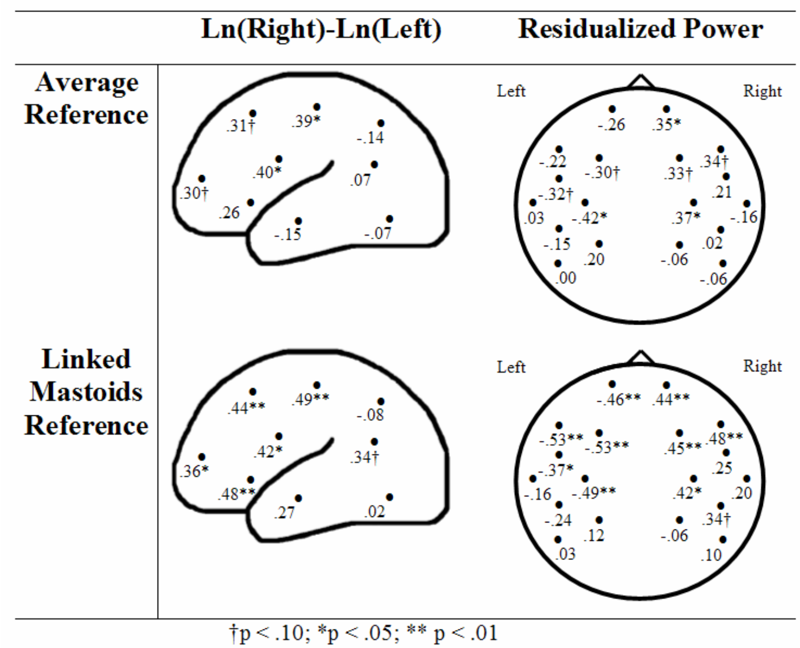
- Residual values for left hemisphere leads approaches *L* – *R* as the correlation between left and right leads approaches 1.0.
- Residual values for right hemisphere approaches the value *R* – *L* as the correlation between left and right leads approaches 1.0.
- Therefore, this procedure will make it appear that right hemisphere leads correlate with a criterion variable in the same direction and magnitude as the *R* – *L* difference score, and that left hemisphere leads correlate with a criterion variable in the opposite direction but same magnitude as the *R* – *L* difference score.
- Therefore, *don't do that!*

What to do?

- Residualize only on whole head power, not additionally on homologous lead power
- Use hierarchical general linear models
  - can include both categorical and continuous predictors
  - can be constructed to test a variety of specific hypotheses of interest, including those related to overall power, hemisphere, and even reference scheme, all in a single model

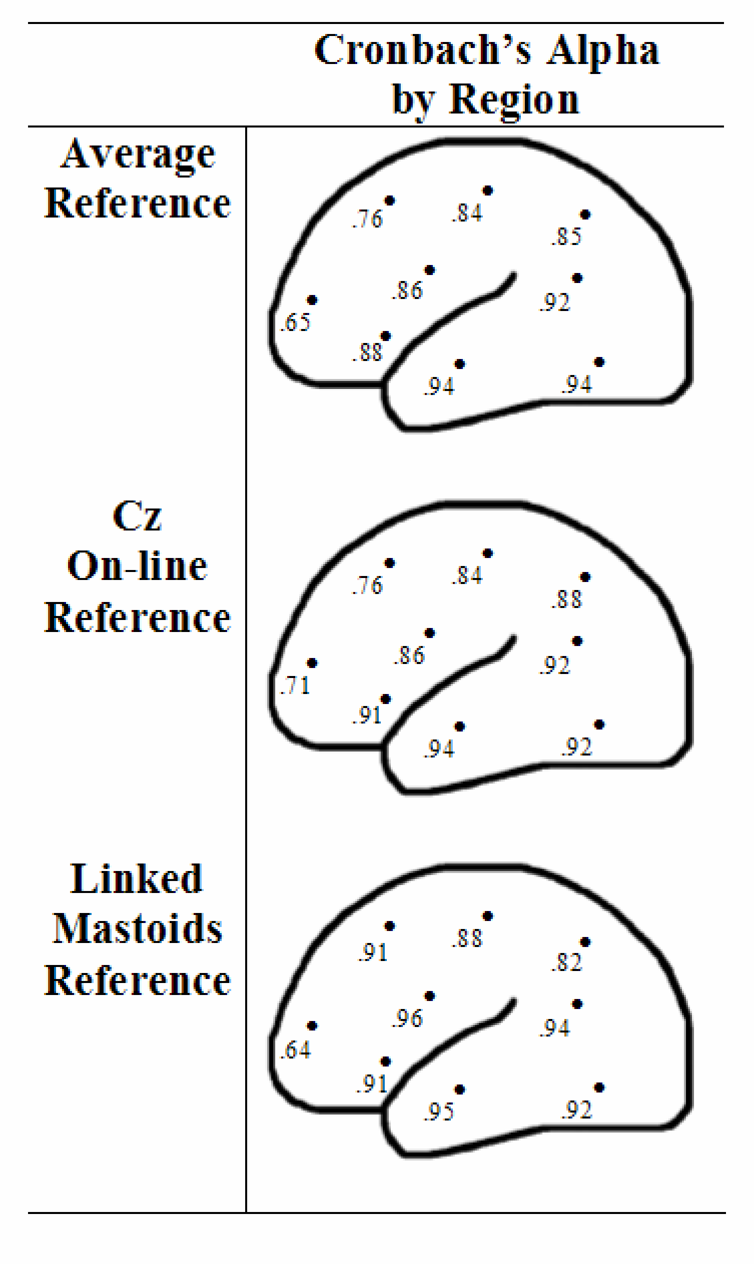


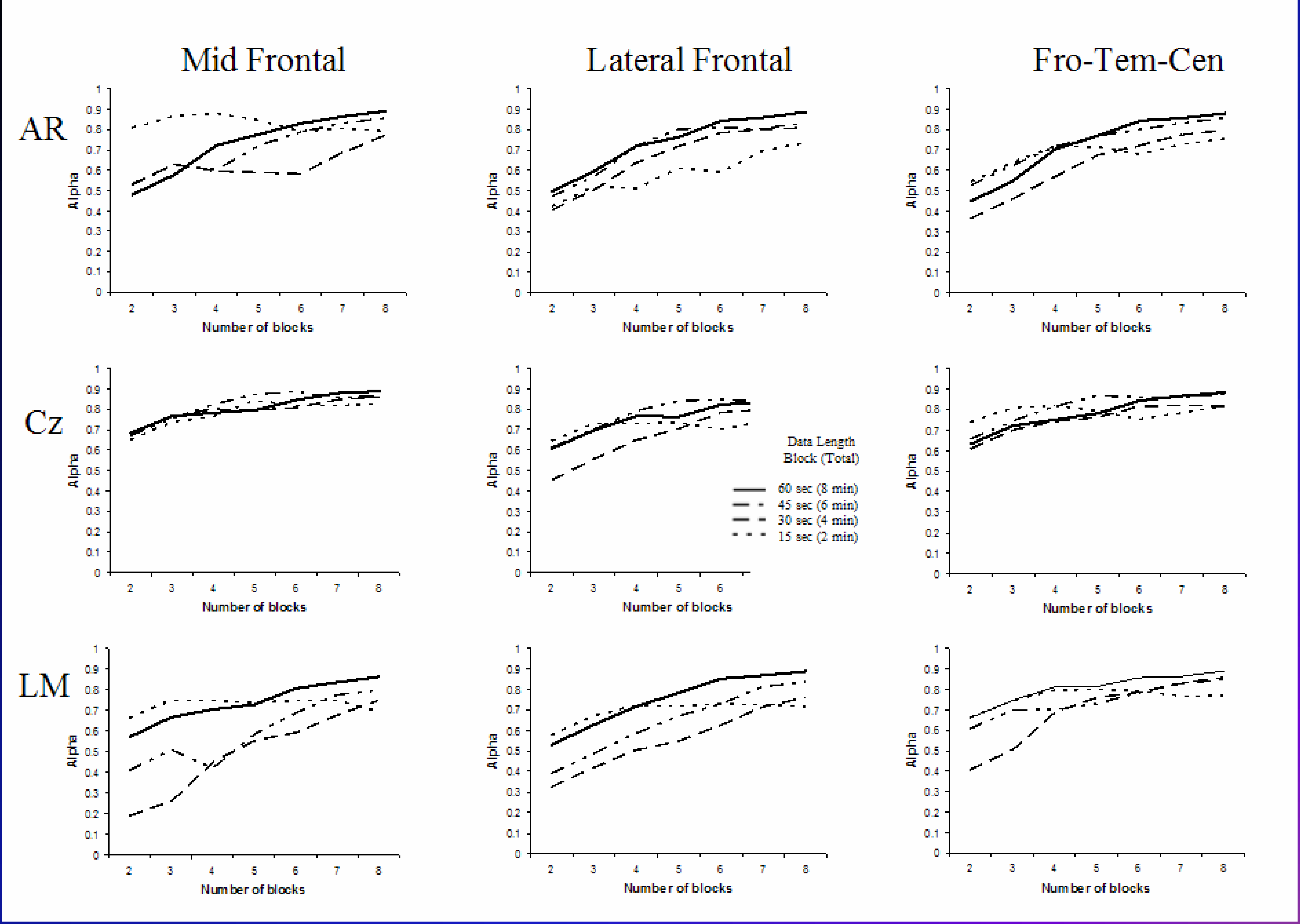
Regression equations: BAS = (5.12)*(Left) + 37.41; BAS = (-1.98)*(Right) + 36.658, and independent of reference scheme.



How Long to Record for Reliable Data?

- Resting Data of 8 minutes typically produce highly reliable asymmetry scores
- Tomarken et al. (1992) suggested fewer minutes may unacceptably unreliable, but based this on fewer “items”



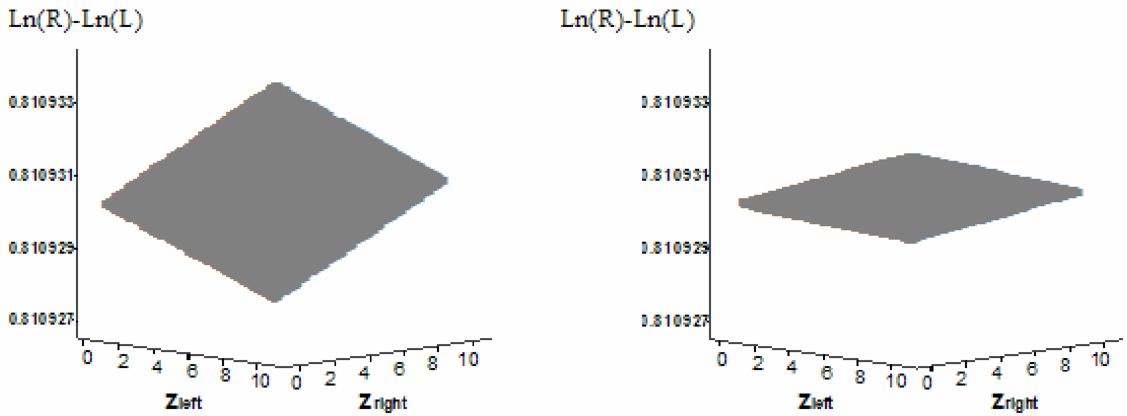


Mid Frontal
Lateral Frontal
Fro-Tem-Cen
AR
Cz
LM
Alpha
Number of blocks
Data Length
Block (Total)
60 sec (8 min)
45 sec (6 min)
30 sec (4 min)
15 sec (2 min)

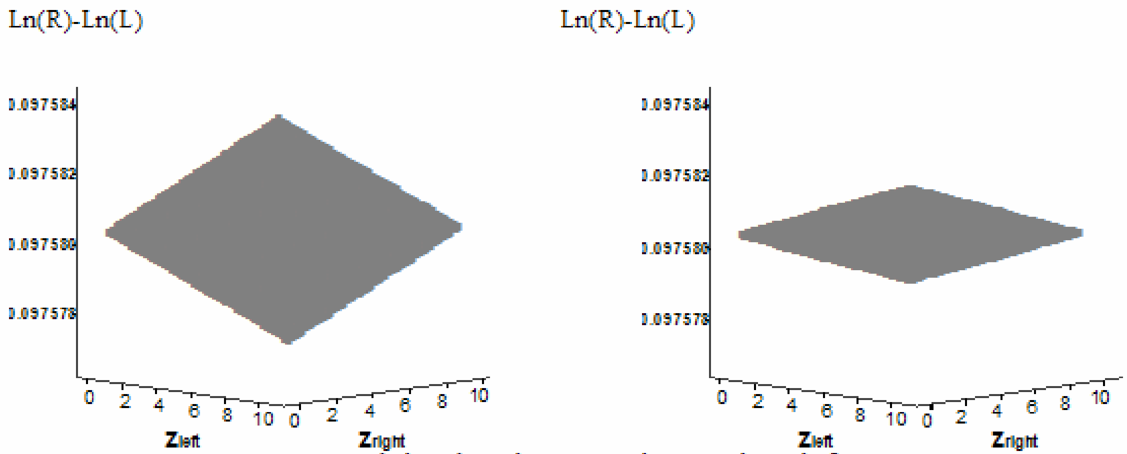
Impedances

How important is it to match homologous impedances?

10 mΩ   20 mΩ



Right signal 5 µV larger than left

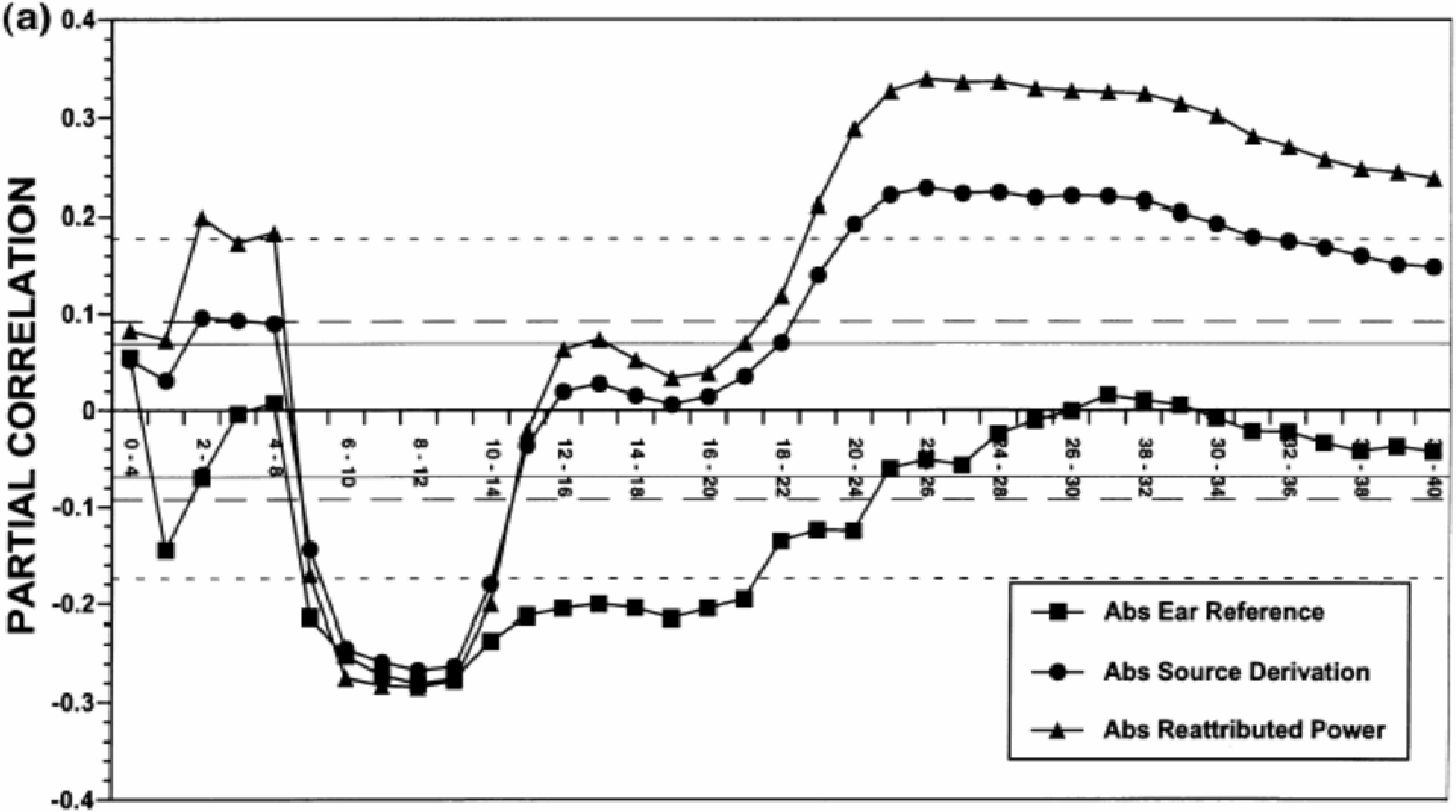


Right signal 0.5 µV larger than left

Answer: Not that important

$$(V_E - V_R) = V_D\left(2 - \frac{Z_E + Z_R}{Z_{in}}\right) + V_C\left(\frac{Z_E - Z_R}{Z_{in}}\right) + O\left(\frac{1}{Z_{in}}\right)^2$$

Is Alpha the opposite of “Activity”



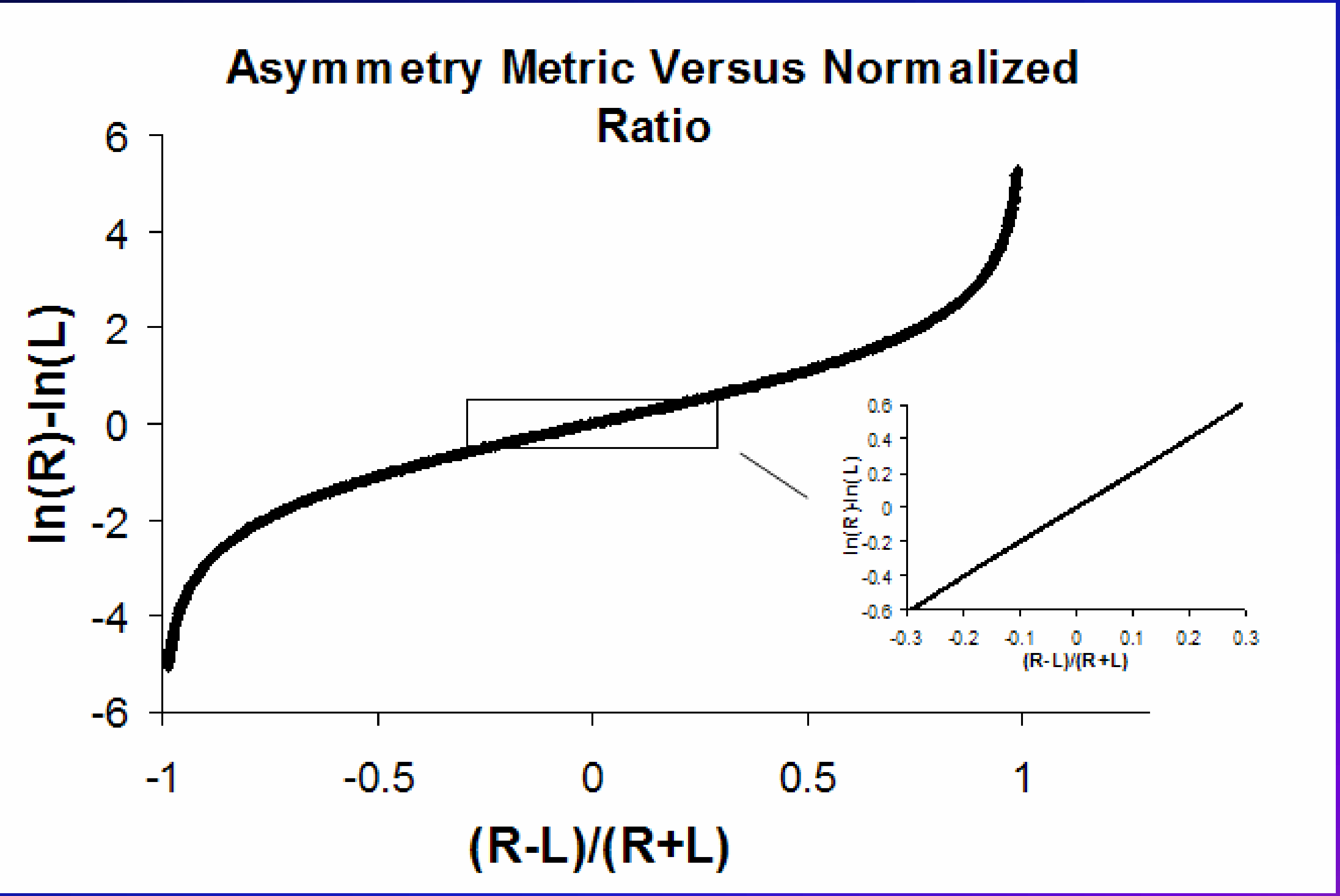
From Cook et al. 1998

Is Asymmetry related to Overall Power?

- Not in any obvious way….
  - Sum of left and right power is NOT correlated with the difference score:
    - Sum (ln[Right]+ln[Left]) correlated difference score (ln[Right]-ln[Left]), at each of 11 scalp regions under all three reference schemes. Only one of these 33 correlations was significant
  - Total Power?
    - a total alpha power correlated with asymmetry scores;
    - only 2 of the 33 correlations between this total power score and the asymmetry metric were significant
- This may reflect that difference of logs has built-in correction for power, as difference of logs is log of quotient

Is Asymmetry related to Overall Power?

- Not in any obvious way….



Parting Thought on Asymmetry

The frontal EEG asymmetry and emotion literature involves a collection of findings that generally converge despite rather dramatic differences in:

1) the conditions under which data were recorded
2) the manner in which data were reduced
3) the manner in which data were subsequently analyzed

The optimist will see this as a testament to the robustness of the underlying systems reflected in frontal EEG asymmetry, and the curmudgeon will see this as representing considerable literature-wide alpha slippage due to the many permutations of data reduction and analysis.

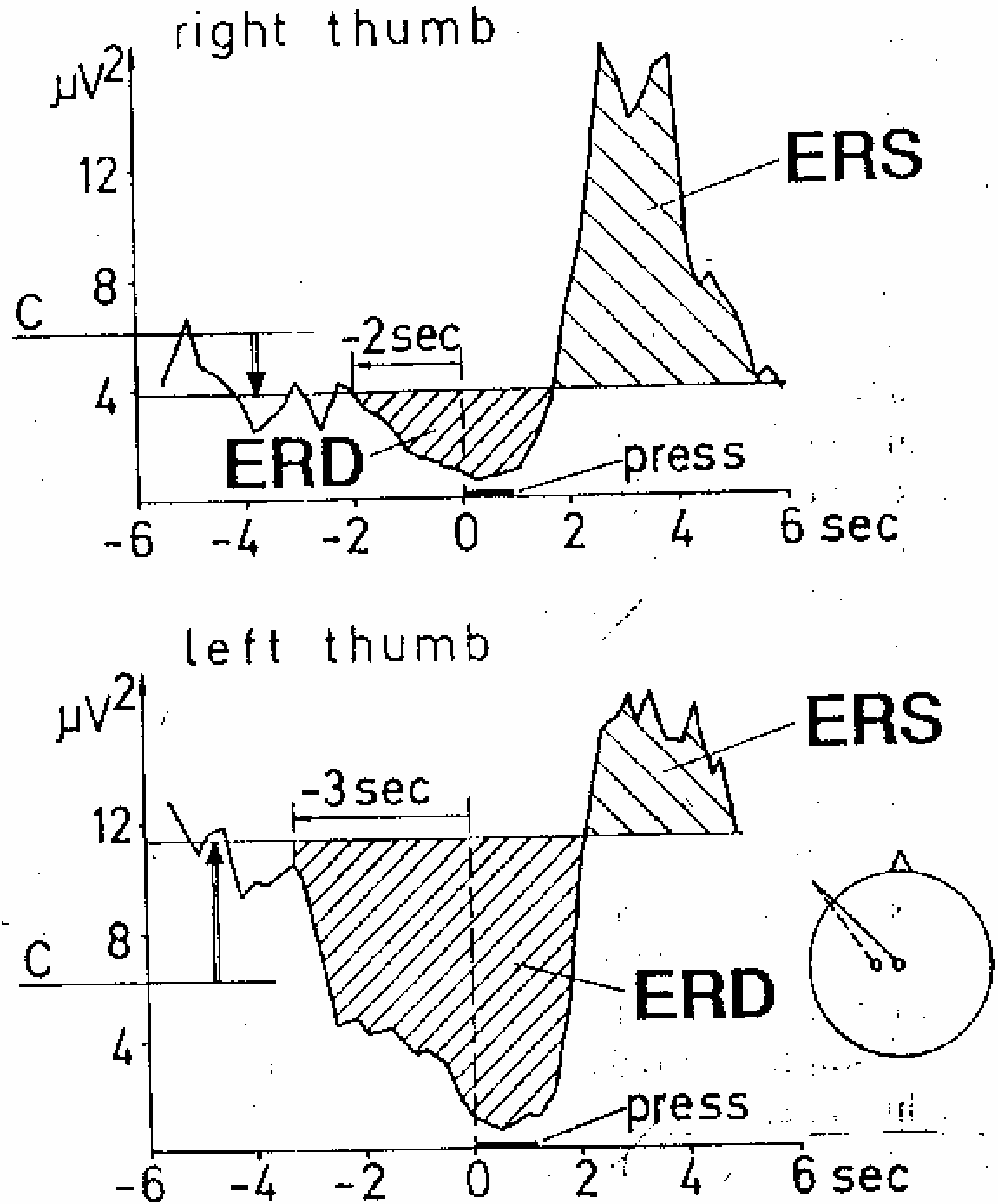
New Handout

Synchronization and Desynchronization

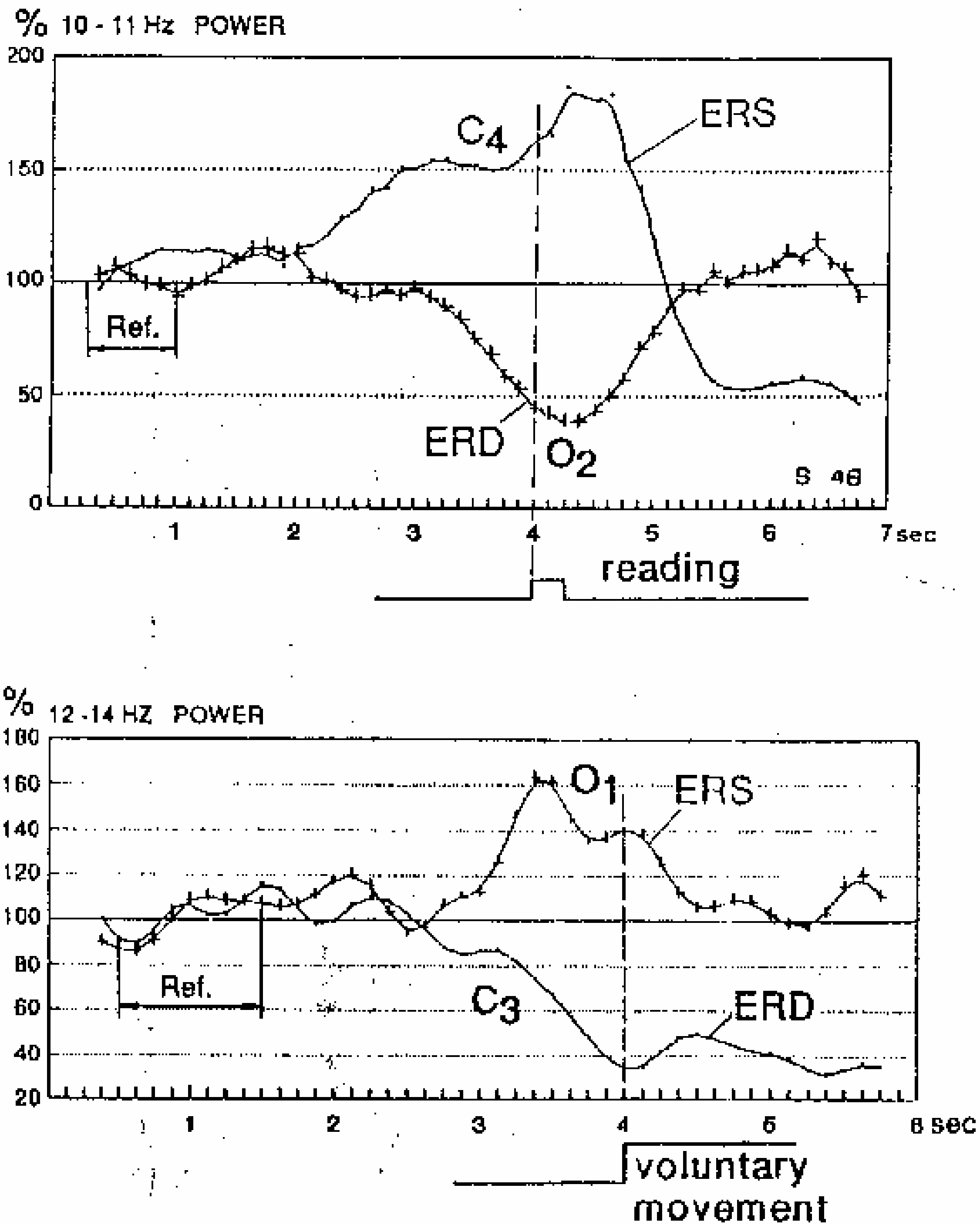
- Supposition that alpha blocking meant that the EEG had become desynchronized
  - Yet the activity is still highly synchronized -- not at 8-13 Hz
  - May involve fewer neuronal ensembles in synchrony

Event-related Synchronization and Desynchronization

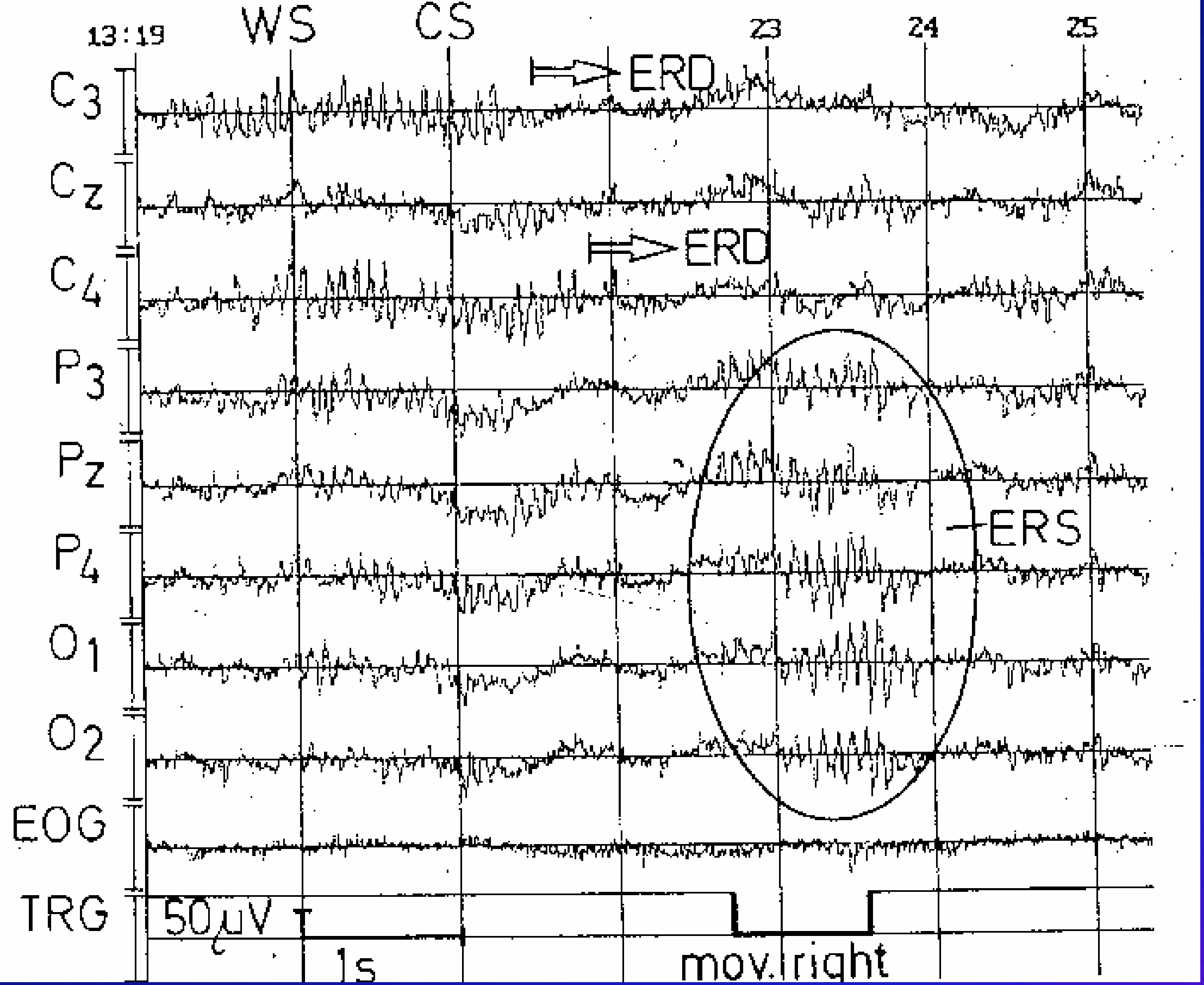
- Pfurtscheller (1992) -- Two types of ERS
  - Secondary (follows ERD)
  - Primary (**Figure 3 & Figure 4**)



Alpha Power time course over left central region during voluntary movements with right and left thumb

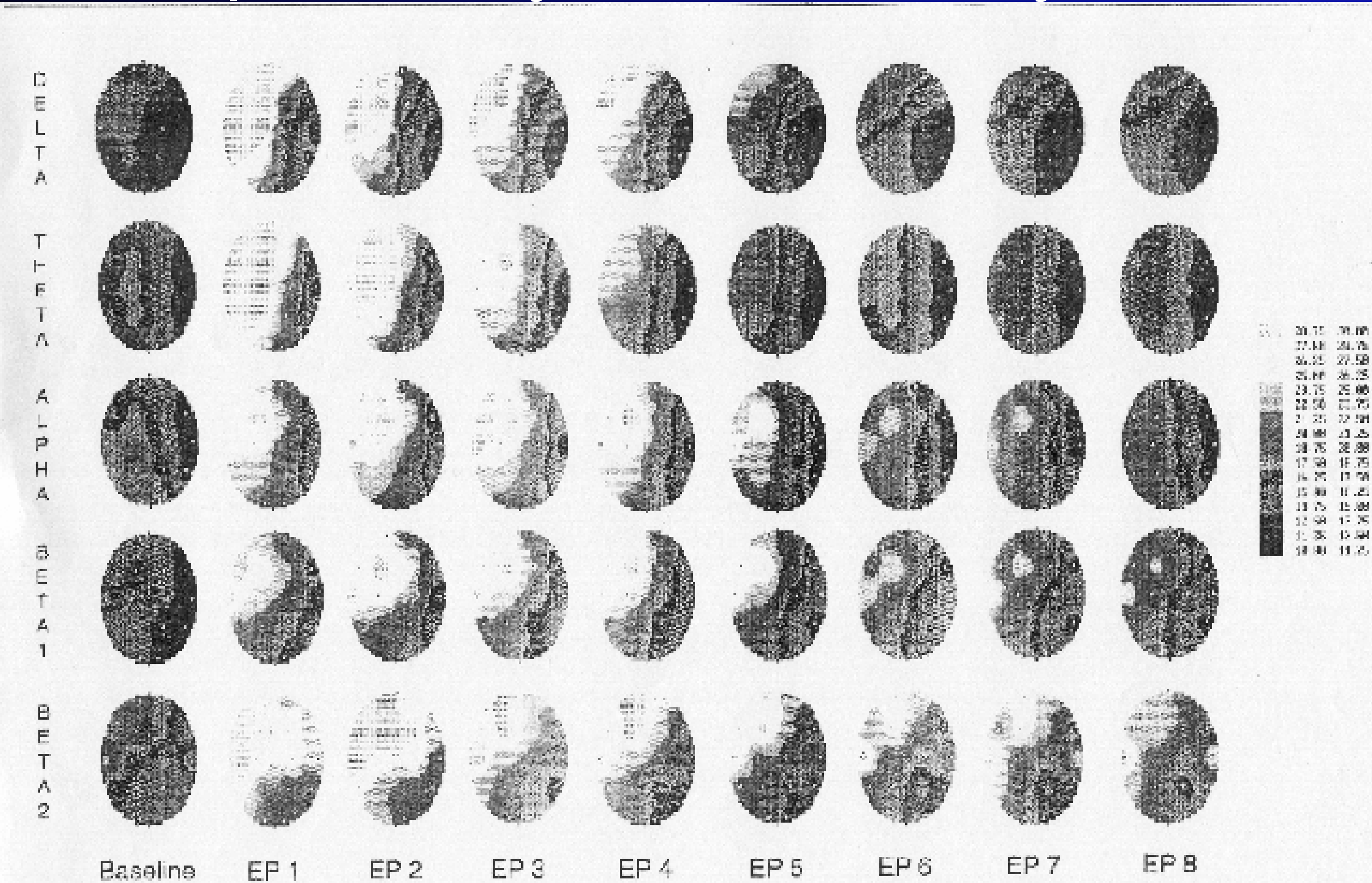


Alpha power time course during reading (upper) and voluntary finger movements (lower). Primary ERS is seen over electrodes overlying cortical areas not involved in the task.



Primary ERS seen over parietal and occipital leads during right finger movement. ERD is seen over cental electrodes, with earlier onset over hemisphere contralateral to movement.

If Alpha Desynchs, what Synchs?

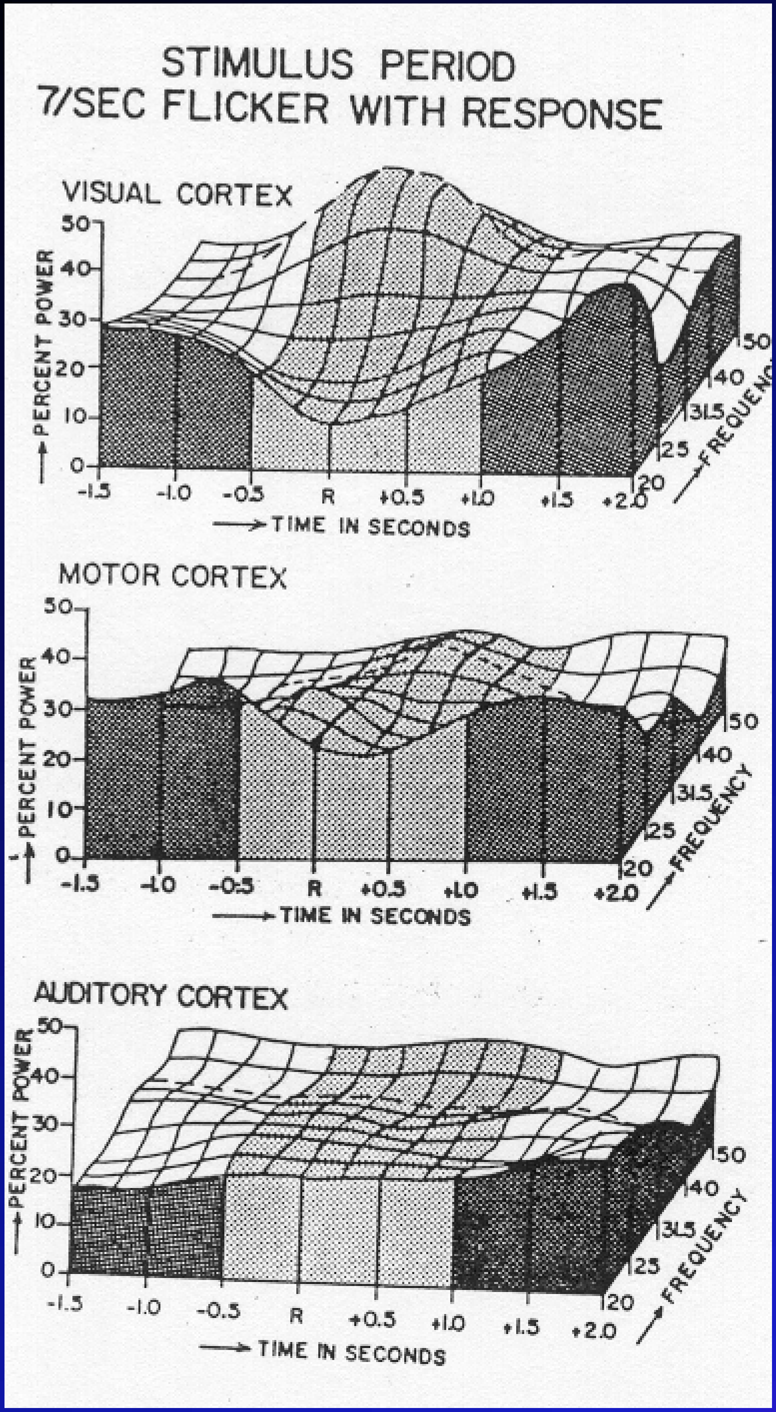


40 Hz Activity

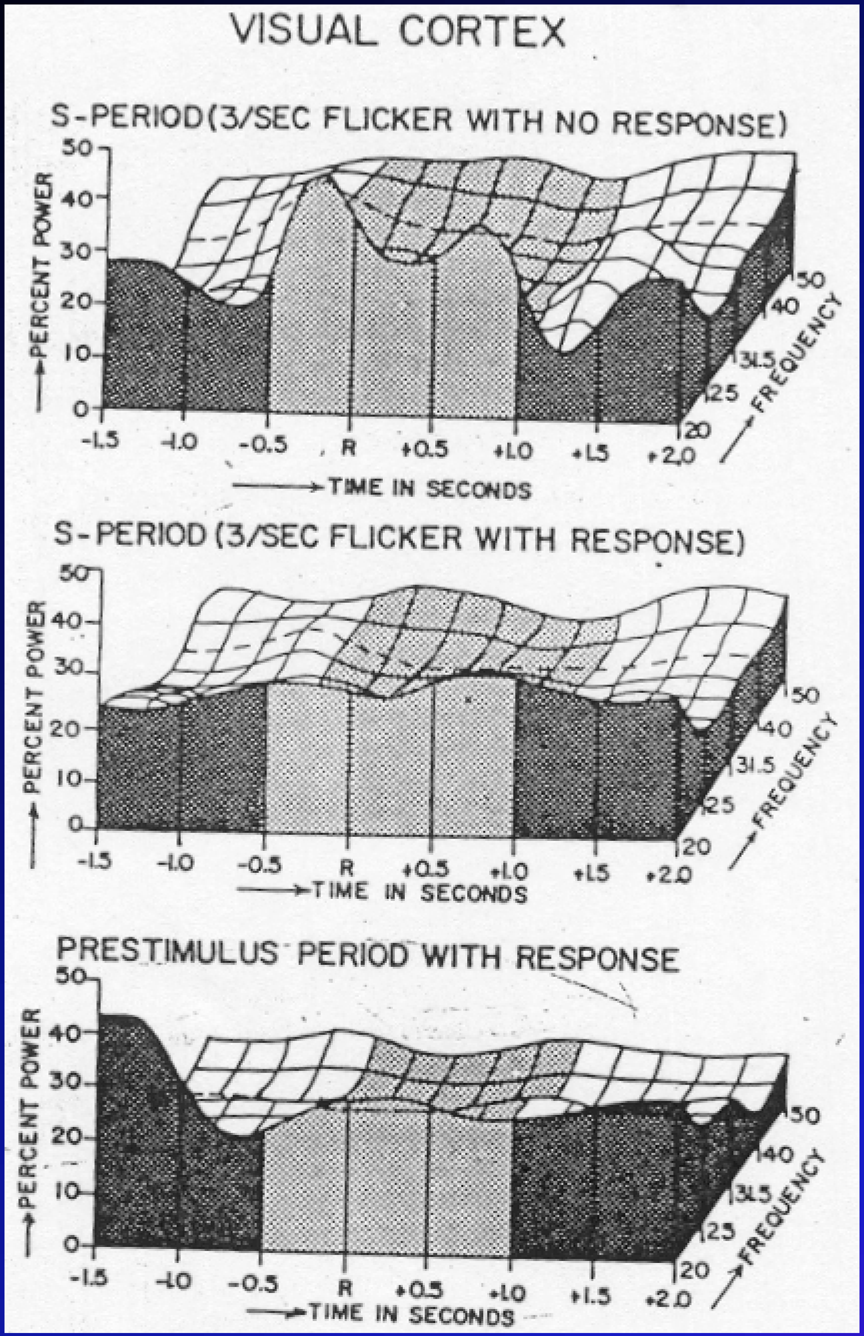
- First reports of important 40 Hz activity
- Sheer & Grandstaff (1969) review
  - pronounced rhythmic electrical bursting
- Daniel Sheer’s subsequent work until his death renewed interest in “40 Hz” phenomena

Sheer work with Cats

- Learning paradigm
- Cat must learn
  - press to S_D (7cps light flicker)
  - not S- (3 cps light flicker)
  - the hypothesis is that the synchronized 40 Hz activity represents the focused activation of specific cortical areas necessary for performance of a task



Note specificity of response, over visual cortex to discriminative stimulus, in 40-Hz range; Some hint of it later in the motor cortex. Note also decreased activity in slower bands during the same time periods.



Note very different pattern to S-. No 40-Hz change in visual cortex, and marked increase in lower frequencies at same time period.

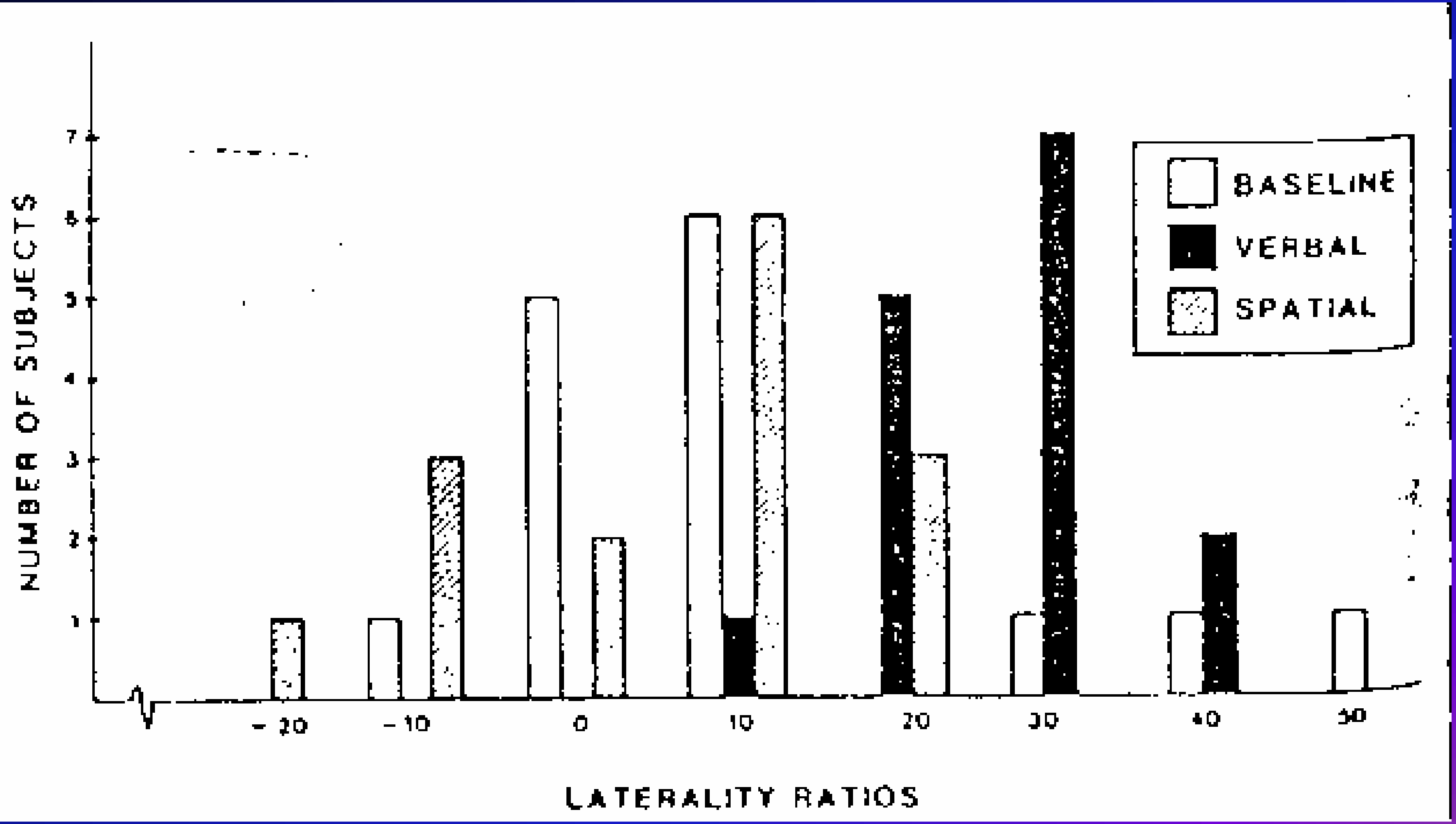
Human Studies

- Hypothesis is that 40 Hz activity correlates with the behavioral state of focused arousal (Sheer, 1976) or cortical activation
  - a "circumscribed state of cortical excitability" (Sheer, 1975)
  - Bird et al (1978)
    - biofeedback paradigm
    - increased 40 Hz activity is associated with high arousal and mental concentration
  - Ford et al., (1980)
    - subjects once trained to voluntarily suppress 40 Hz EEG are unable to maintain that suppression while simultaneously solving problems
    - concluded that problem solving and absence of 40 Hz are incompatible

Lateralized Task Effects

- Loring & Sheer (1984)
  - right-handed students
  - analogies task
  - spatial Task
- Results transformed into laterality ratios:
  - (L-R)/(L+R) 40 Hz
  - higher # => greater LH activity (P3-O1-T5 triangle vs P4-02-T6 triangle);
- Results
  - greatest variability during baseline
  - smallest variability and greatest LH activation during verbal
  - no laterality effects in the 40Hz EMG bands

Laterality of 40 Hz



Controlling for EMG contributions

- Spydell & Sheer (1982)
  - used similar tasks and found similar results
  - using conservative controls for muscle artifact

TABLE 1

Median changes in rate scores

	Median Rate Score Changes									
	Alpha		Beta II		40 Hz Total		40 Hz EEG		40 Hz EMG	
Problems	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Verbal	−36.7*	−52.4*	−20.1*	−20.2*	1.0*	0.1	1.2*	0.1	8.4*	10.6*
Rotation	−36.7*	−37.6*	−15.3*	−15.3*	0.7	1.0*	0.4	0.9*	13.9*	8.9*

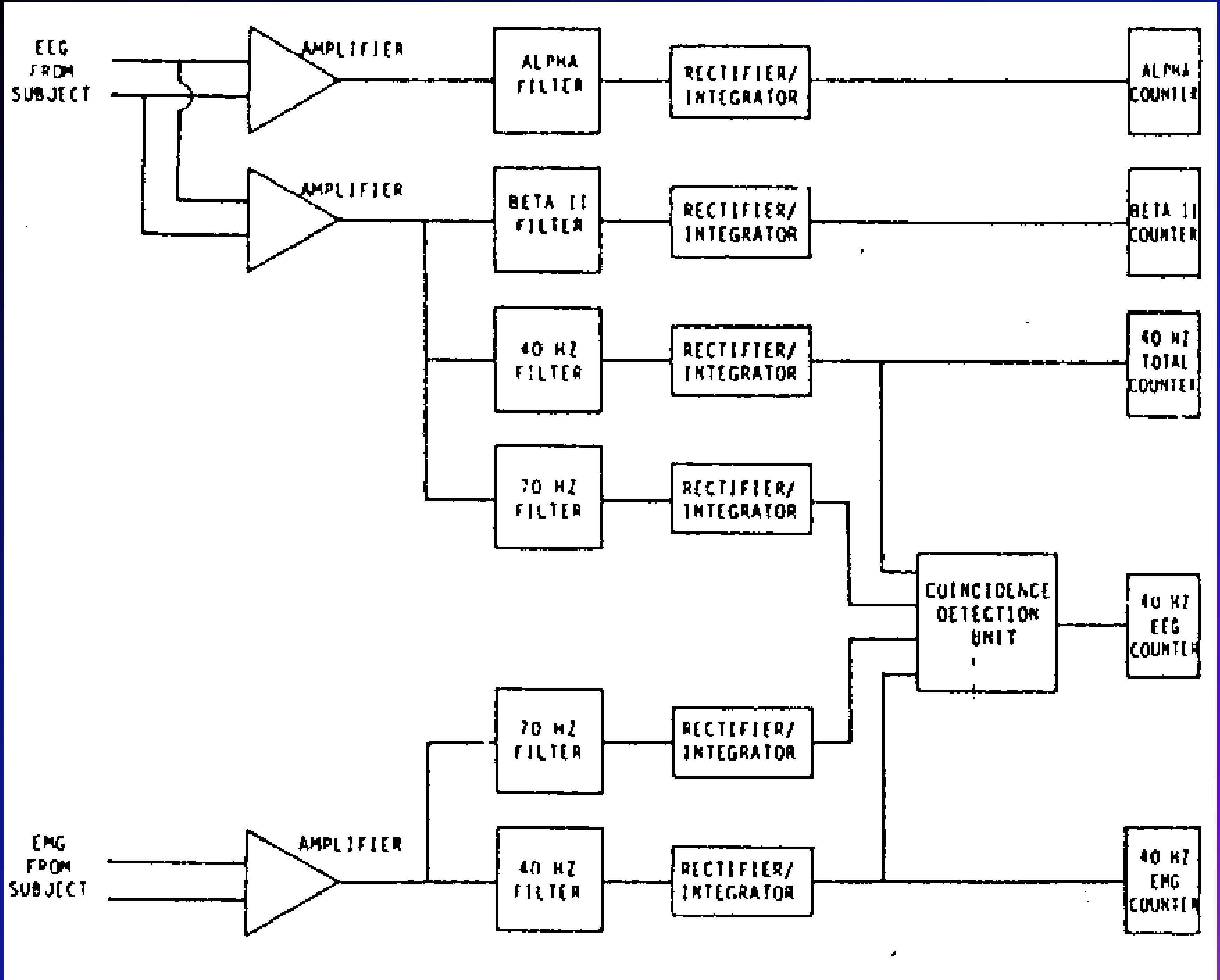
*$p < .05$.

TABLE 3

Spearman rank-order correlations between various 40 Hz activity measures

	Correlations							
	Verbal Left		Verbal Right		Rotations Left		Rotations Right	
40 Hz Measures	40 Total	40 EEG	40 Total	40 EEG	40 Total	40 EEG	40 Total	40 EEG
40 Hz EEG	.74*		.68*		.94*		.78*	
40 Hz EMG	.27	.28	.39	.05	.27	.35	.16	.25

*$p < .05$.



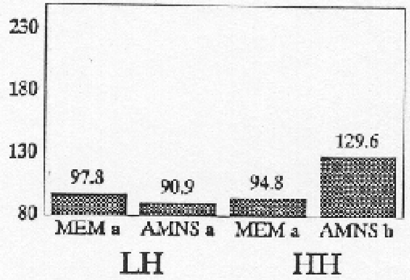
EEG FROM SUBJECT
AMPLIFIER
AMPLIFIER
ALPHA FILTER
BETA II FILTER
40 HZ FILTER
70 HZ FILTER
RECTIFIER/ INTEGRATOR
RECTIFIER/ INTEGRATOR
RECTIFIER/ INTEGRATOR
RECTIFIER/ INTEGRATOR
ALPHA COUNTER
BETA II COUNTER
40 HZ TOTAL COUNTER
COINCIDENCE DETECTION UNIT
40 HZ EEG COUNTER
70 HZ FILTER
RECTIFIER/ INTEGRATOR
EMG FROM SUBJECT
AMPLIFIER
40 HZ FILTER
RECTIFIER/ INTEGRATOR
40 HZ EMG COUNTER

Individual Differences

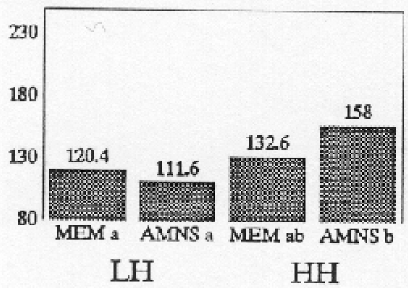
- Spydell & Sheer (1983), Alzheimers
  - controls showed task related changes in EEG with appropriate lateralization
  - Alz did not
- Schnyer & Allen (1995)
  - Most highly hypnotizable subjects showed enhanced 40 hz activity

EYES OPEN

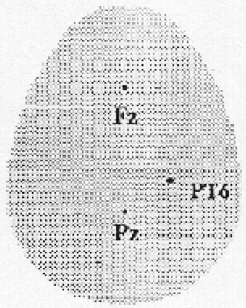
EYES CLOSED

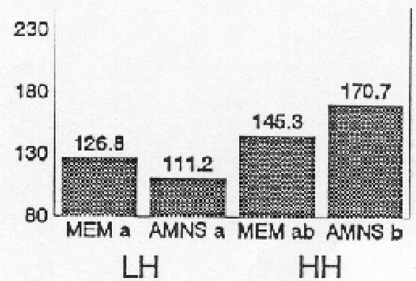


Site Fz, $\underline{F}[3, 37] = 4.72$, $\underline{p} < .01$

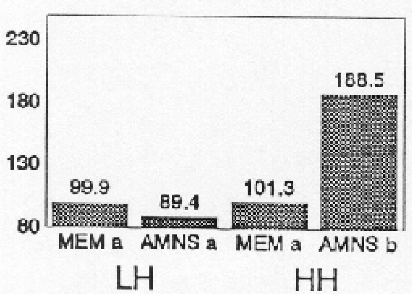


Site Pz, $\underline{F}[3, 37] = 4.73$, $\underline{p} < .01$

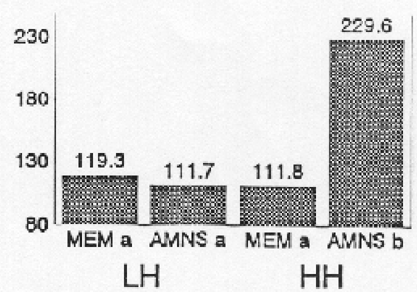




Site Pz, $\underline{F}[3, 37] = 6.46$, $\underline{p} < .01$



Site PT6, $\underline{F}[3, 37] = 10.82$, $\underline{p} < .001$



Site PT6, $\underline{F}[3, 37] = 5.30$, $\underline{p} < .001$

So this is exciting, why hasn't this work exploded?

- The EMG concern
  - The concern is likely over-rated (recall **Table 3**)
- Sheer died
- But not all is lost, as there is renewed interest…

Singer (1993)

- Revitalized interest in the field

The Binding Problem

- Potentially infinite number of things and ideas that we may attempt to represent within the CNS
  - Cells code for limited sets of features,
  - These must somehow be integrated
  - -- the so-called binding problem
- If there exists a cell for a unique contribution of attributes, then convergent information from many cells could converge on such a cell
  - But there are a finite # of cells and interconnections
- And even the billions and billions of cells we have cannot conceivably handle the diversity of representations

The Functional Perspective

- There is no site of integration
  - Integration is achieved through simultaneous activation of an assembly of neurons distributed across a wide variety of cortical areas
  - Neurons in such assemblies must be able to adaptively identify with other neurons within the assembly while remaining distinct from other neurons in other assemblies
  - This association with other neurons is through a temporal code of firing (Synchronicity)
    - This even allows for the possibility that a single neuron could be part of two active assemblies (via a multitasking procedure)

Implications

- Also allows for the possibility that there exists no direct neuronal connection between neurons within an assembly
  - merely the fact that they are simultaneously activated that makes the unified experience of the object possible
- This is most likely when there is an oscillatory regularity
  - If networks are tuned to a single frequency, they are easy to synchronize, but difficult to desynchronize – PROBLEM!
  - Therefore it may be adaptive to have a broader-band oscillator (centered on ~40 hz)
  - Cannot be too slow (e.g., alpha) since this would be inadequate to successfully bind percepts together efficiently
  - Cannot be much faster than gamma since the human nervous system cannot allow synchronization at frequencies much beyond gamma

Implications

- This view is a dynamic view
  - depends on experience
  - can change with experience
- Synchronously activated units more likely to become enhanced and part of an assembly that will subsequently become synchronously activated
- Singer concludes:
  - Points out the problem of looking for synchronous activation on the micro level, suggesting that a return to the EEG literature looking for task-dependent synchronization in the gamma (aka 40 Hz) band!
- Forty-Hz may indeed make a comeback!

Trujillo's Opus (2002)

Perception of faces Vs Scrambled Faces

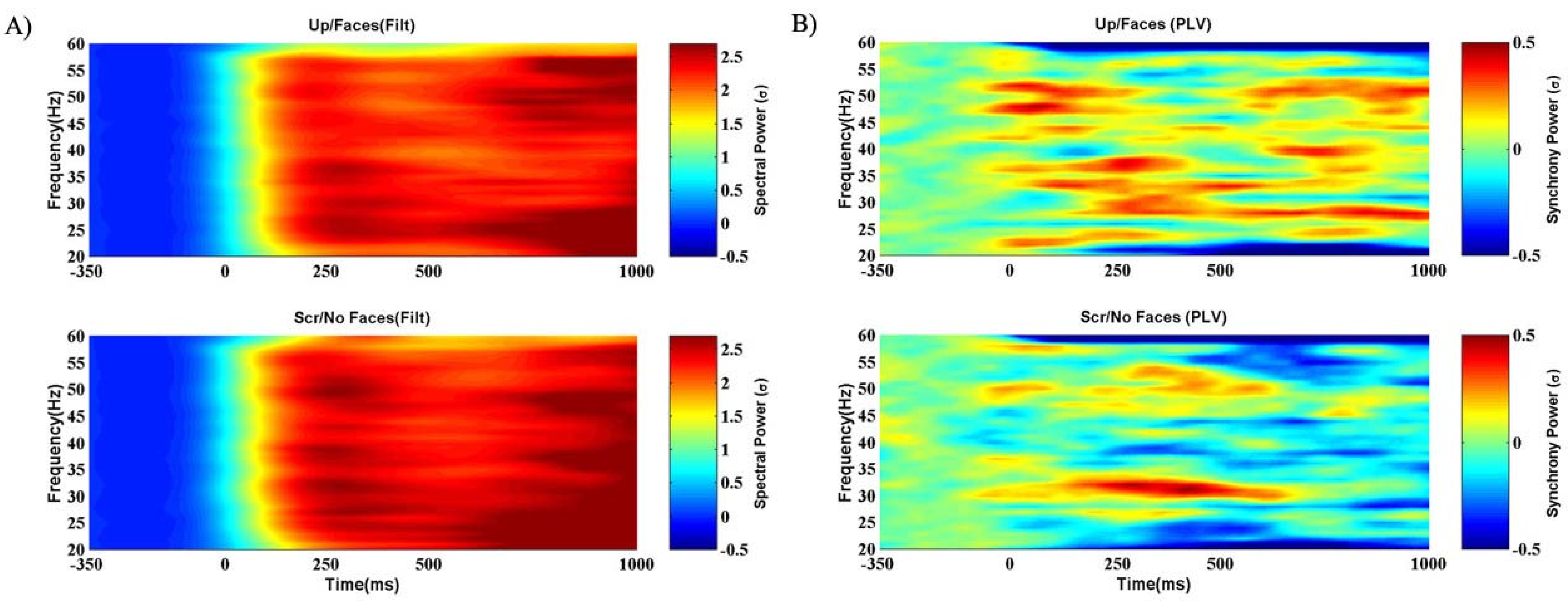


Figure 14. Time-frequency maps of average spectral and synchrony power averaged across electrodes, trials, and subjects. A). Average reference spectral power. B) Average reference phase synchrony power. Power values have been normalized with respect to a 250 ms pre-stimulus baseline; color scale shows regions of increase (yellow, red) and decrease (blue) indicated in standard deviations from the baseline.

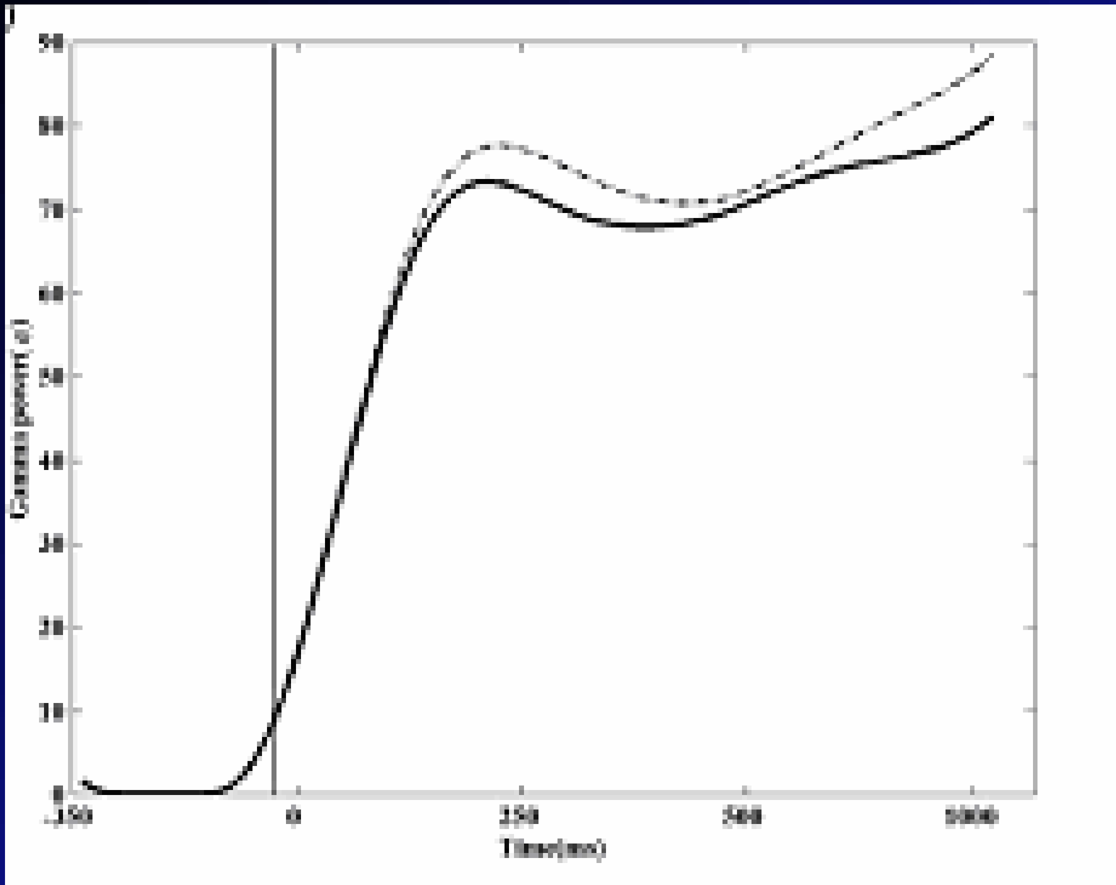
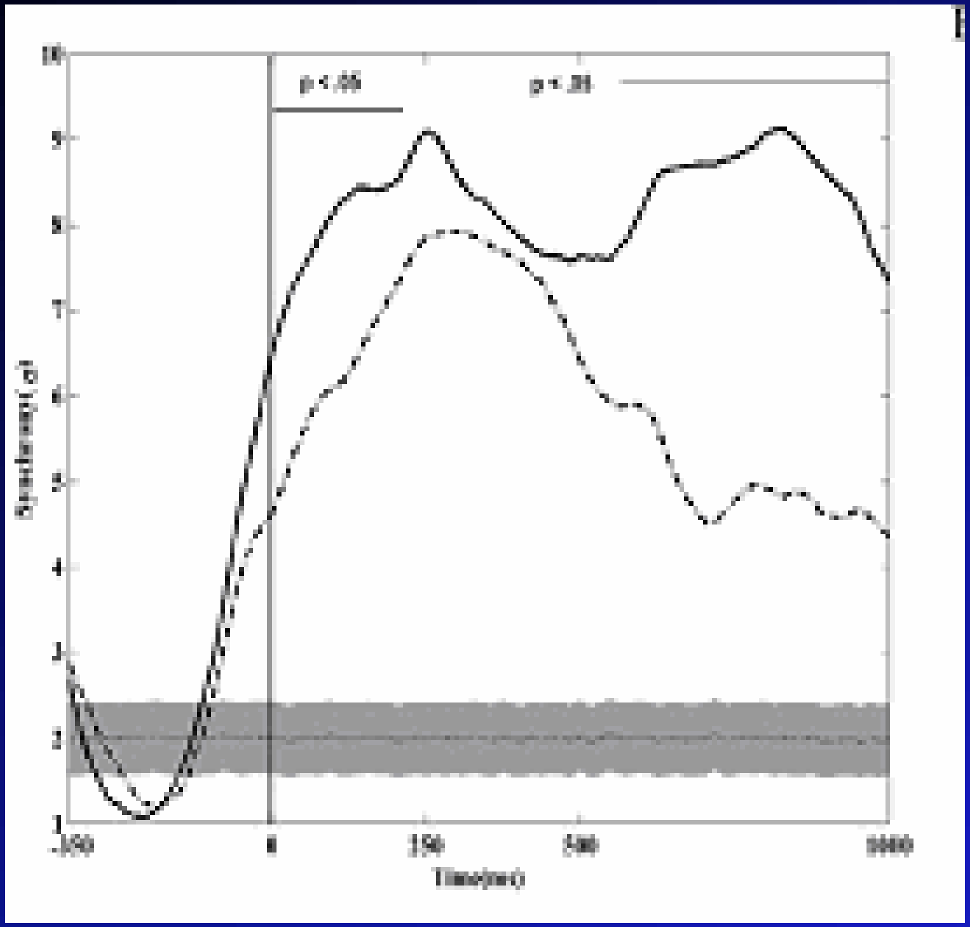
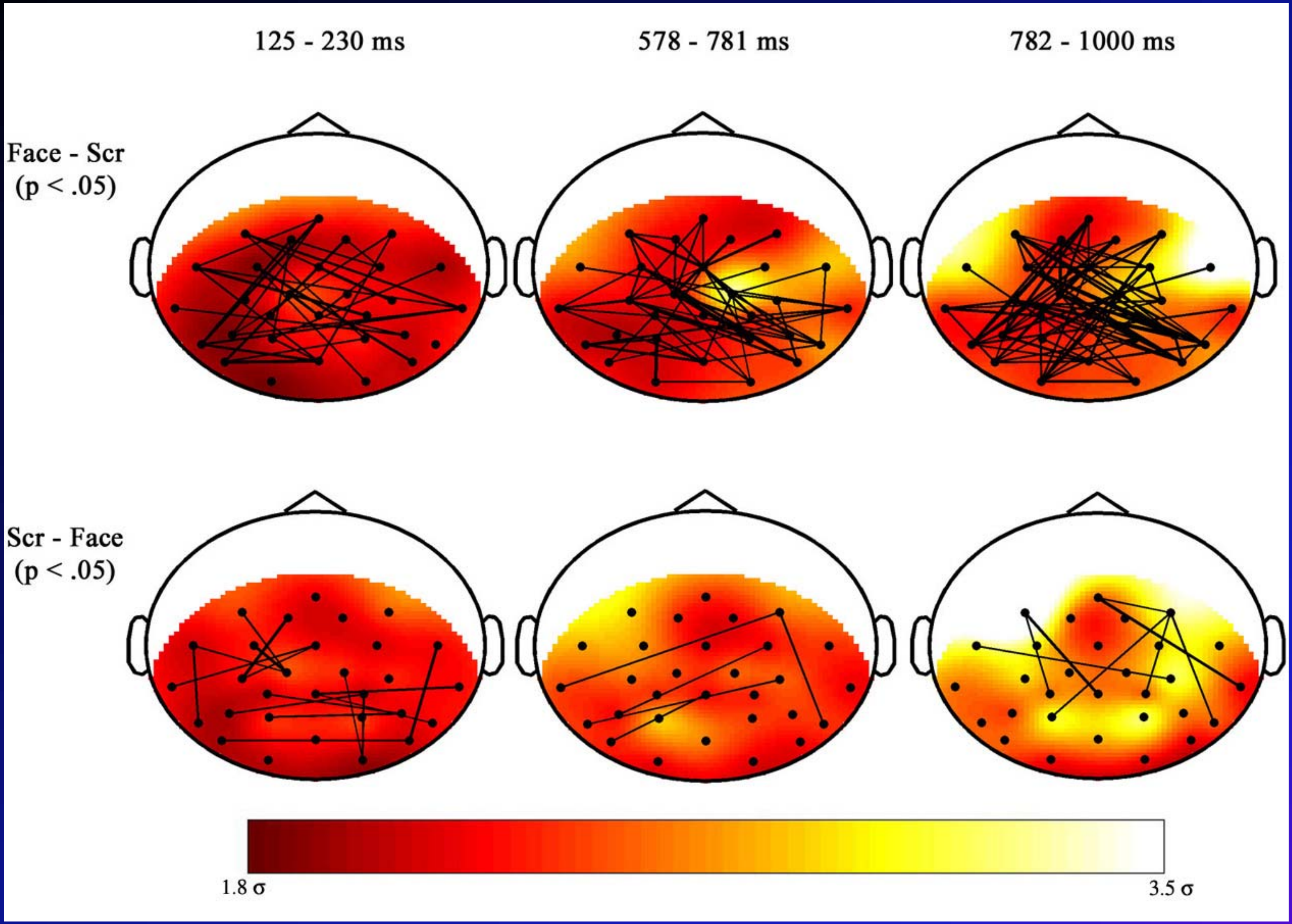


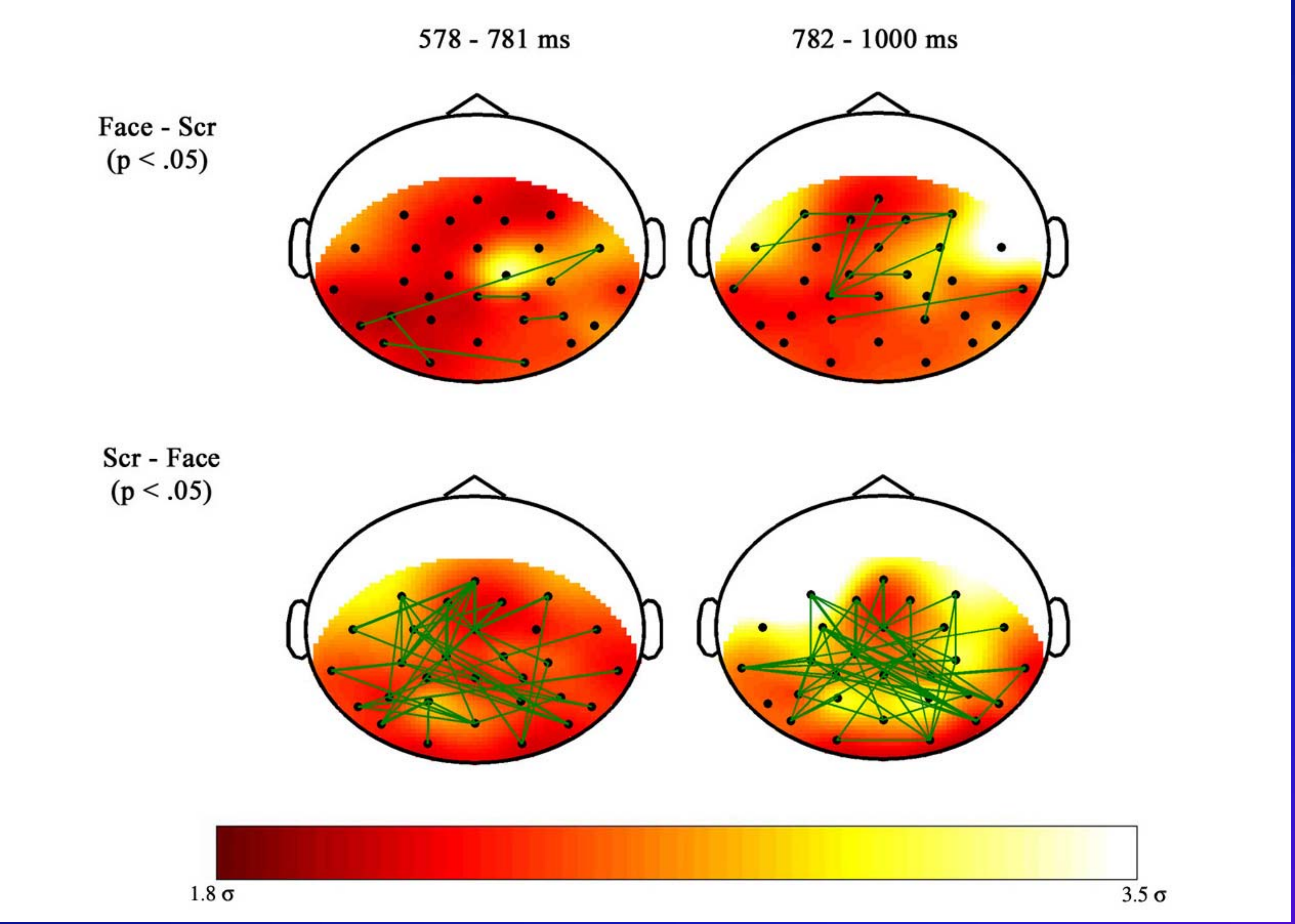
Figure 16. Time courses for spectral power indicated in standard deviations from the 250 ms pre-stimulus baseline. All graphs are grand averages over electrodes, trials, and subjects in the Up/No Faces (*thick line*) and Scr/No Faces (*dash-dot line*) conditions. No significant differences were found.



Time courses for phase synchrony over the central gamma range (25-55 Hz). All graphs are grand averages over electrodes, trials, and subjects in the Up/No Faces (*thick line*) and Scr/No Faces (*dash-dot line*) conditions



Average reference gamma-band power and synchrony power over the surface of the scalp. Spectral and synchrony power were averaged at each electrode/electrode pair over post-stimulus time bins in which significant differences were obtained between conditions in the global time course comparisons. The color scale indicates the magnitude of spectral power averaged across the frequency range 25 – 55 Hz. Lines between electrodes indicate significant phase synchrony, where a line is drawn only if there is a significant difference in synchrony (Wilcoxon t-test, one-tailed, $p < .05$) between comparison conditions. The thickness of the lines indicates the relative synchrony magnitudes, with thicker/thinner lines representing larger/smaller synchrony values. Face – Scr = Up/Faces – Scr/No Faces comparison; Scr – Face = Scr/No Faces – Up/Faces comparison.



Average reference gamma-band power and desynchrony power over the surface of the scalp. Spectral and desynchrony power were averaged at each electrode/electrode pair over post-stimulus time bins in which significant differences were obtained between conditions in the global time course comparisons. The color scale indicates the magnitude of spectral power averaged across the frequency range 25 – 55 Hz. Lines between electrodes indicate significant phase desynchrony, where a line is drawn only if there is a significant difference in desynchrony (Wilcoxon t-test, one-tailed, $p < .05$) between comparison conditions. The thickness of the lines indicates the relative synchrony magnitudes, with thicker/thinner lines representing larger/smaller synchrony values. Face – Scr = Up/Faces – Scr/No Faces comparison; Scr – Face = Scr/No Faces – Up/Faces comparison.