Frequency-domain EEG applications and methodological considerations

Applications

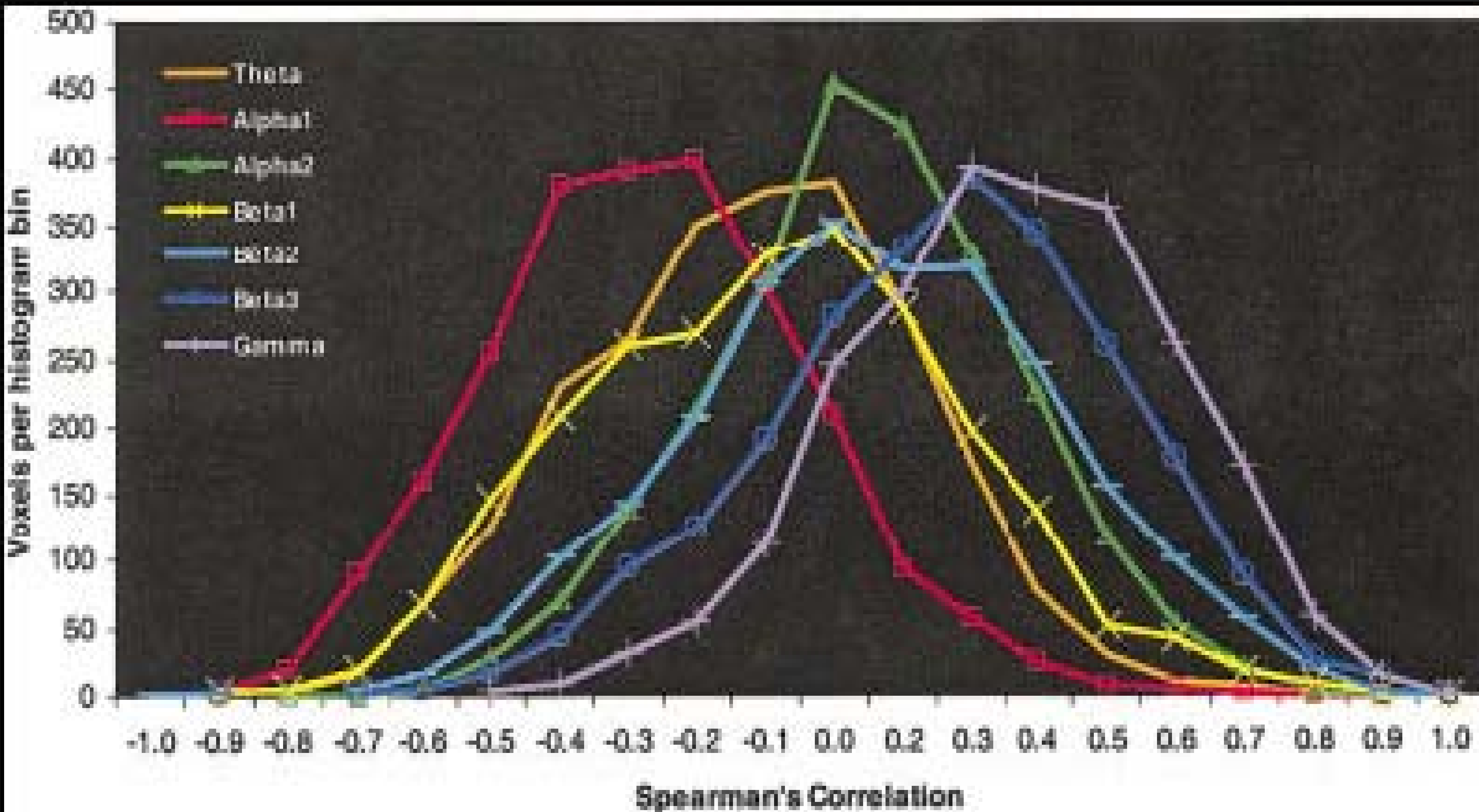
- Emotion Asymmetries
  - Lesion findings
    - Catastrophic reaction (LH)
    - RH damage show a belle indifference
  - EEG studies
    - Trait (50+ studies)
    - State (30 + studies)

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)

Alpha Vs Activity Assumption (AAA)



Oakes et al, 2004, *Human Brain Mapping*

Left Hypofrontality in Depression

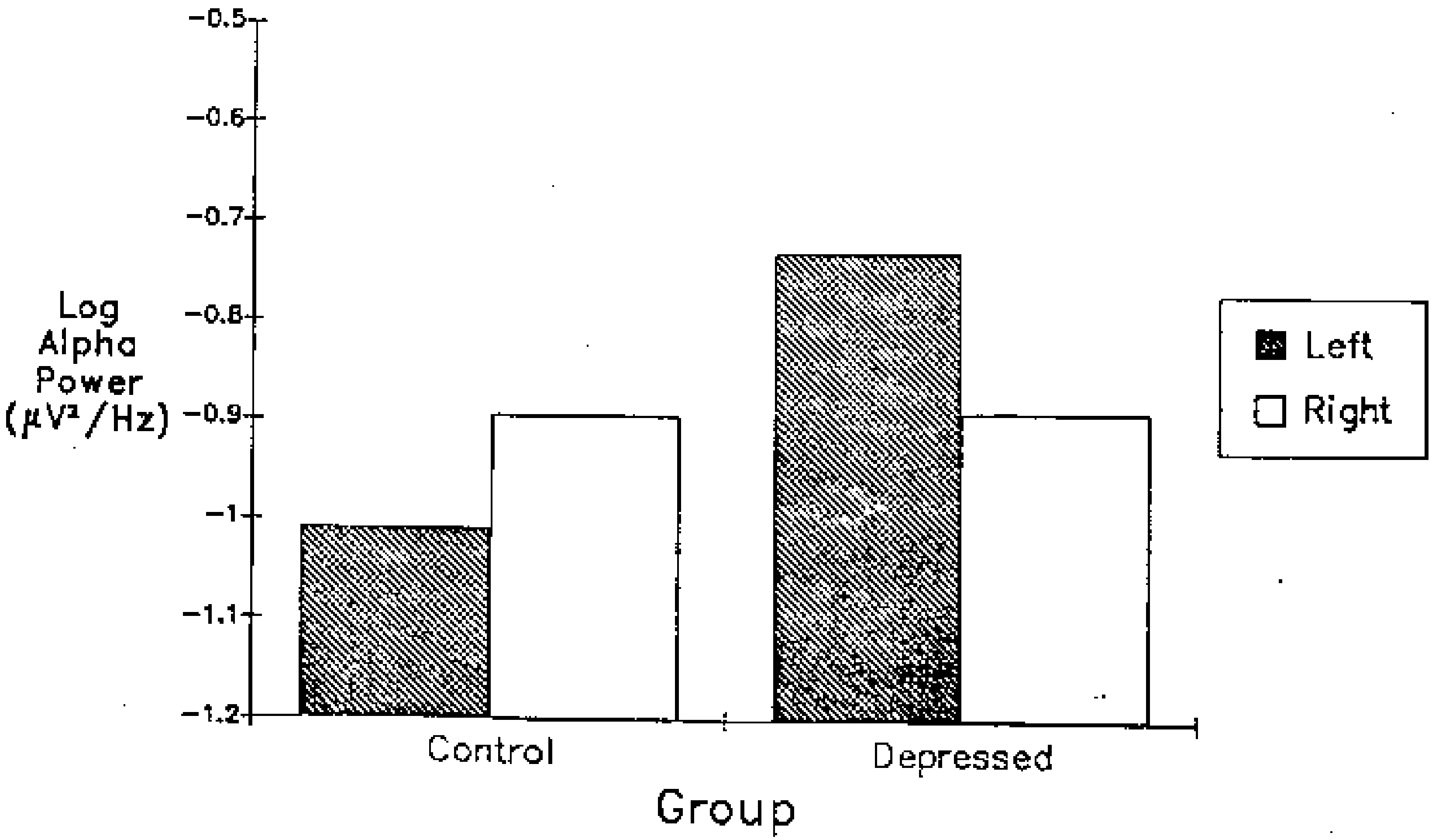
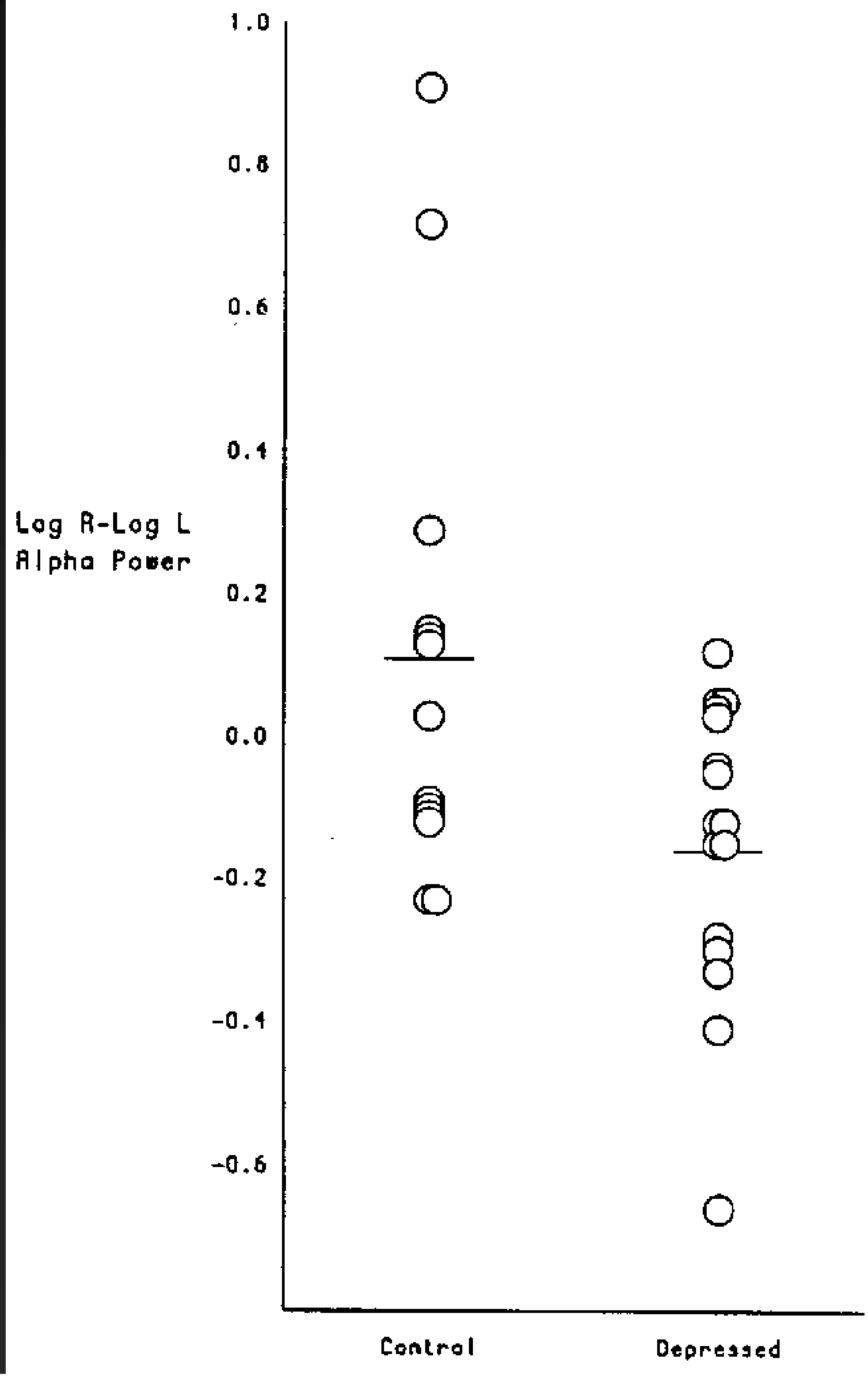


Figure 1. Mean log-transformed alpha (8–13 Hz) power (in $\mu V^2/Hz$) for Cz-referenced electroencephalograms (averaged across eyes-open and eyes-closed baselines), split by group and hemisphere, for the midfrontal region. (Decreases in alpha power are indicative of increased activation.)

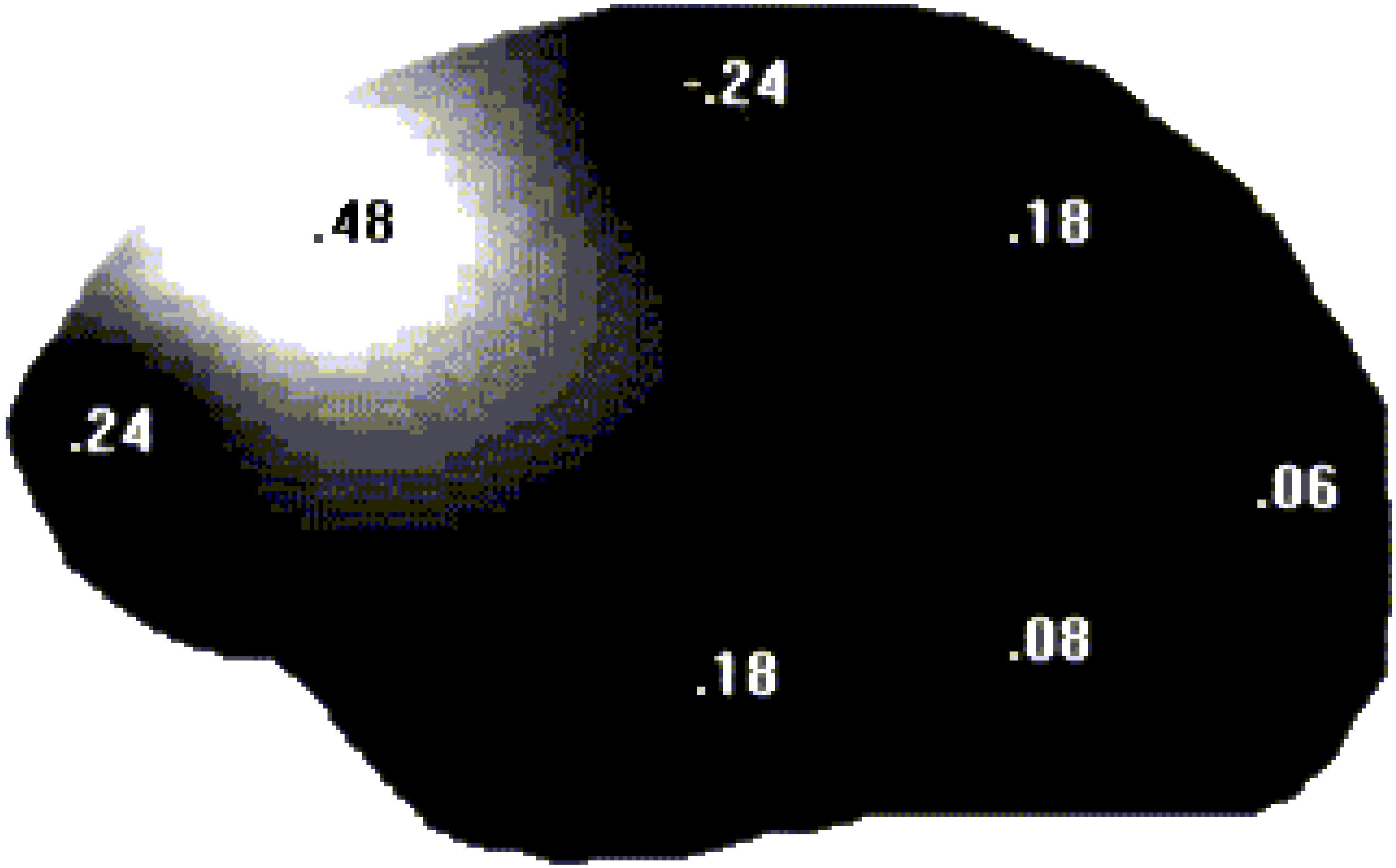
Henriques & Davidson (1991); see also, Allen et al. (1993), Gotlib et al. (1998); Henriques & Davidson (1990); Reid Duke and Allen (1998); Shaffer et al (1983)

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."

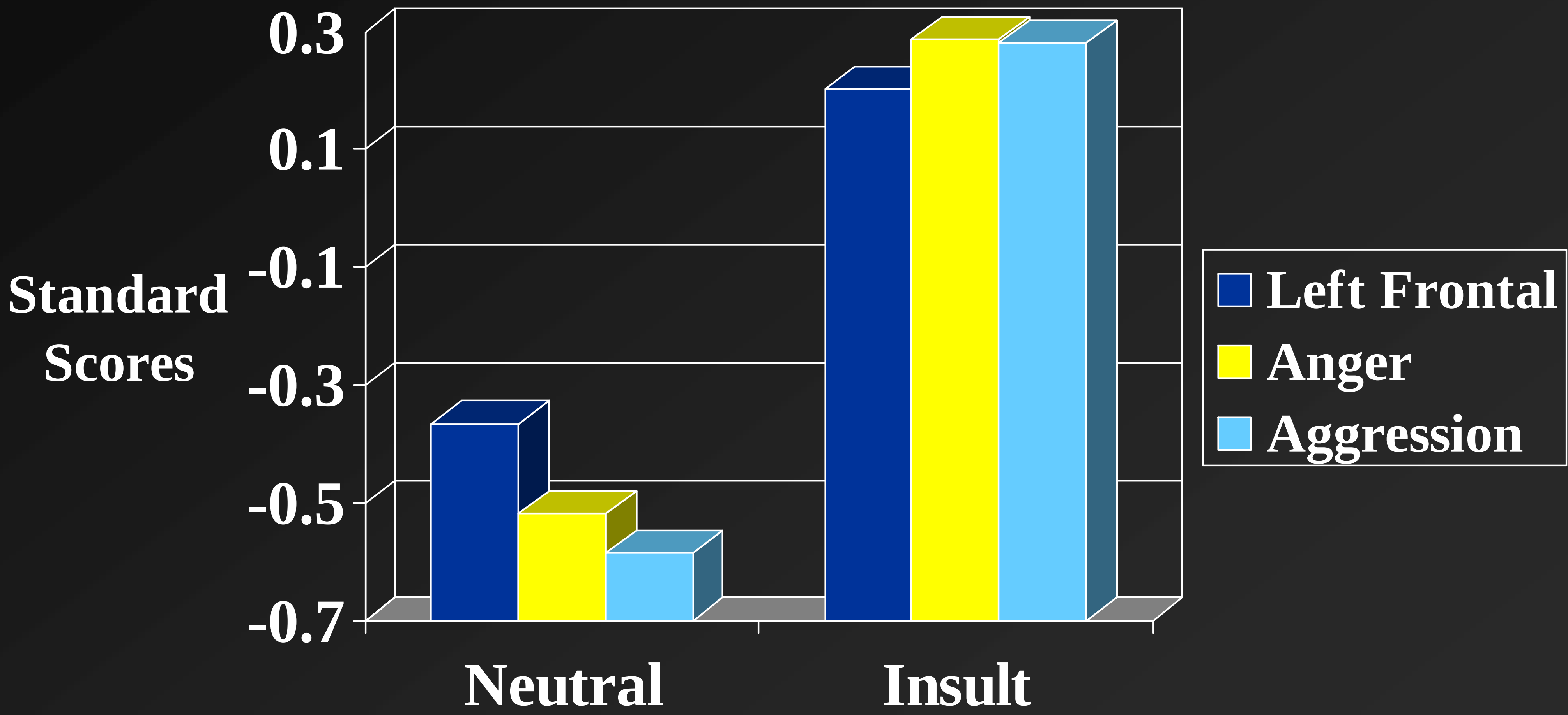
Harmon-Jones & Sigelman, *JPSP*, 2001

- 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

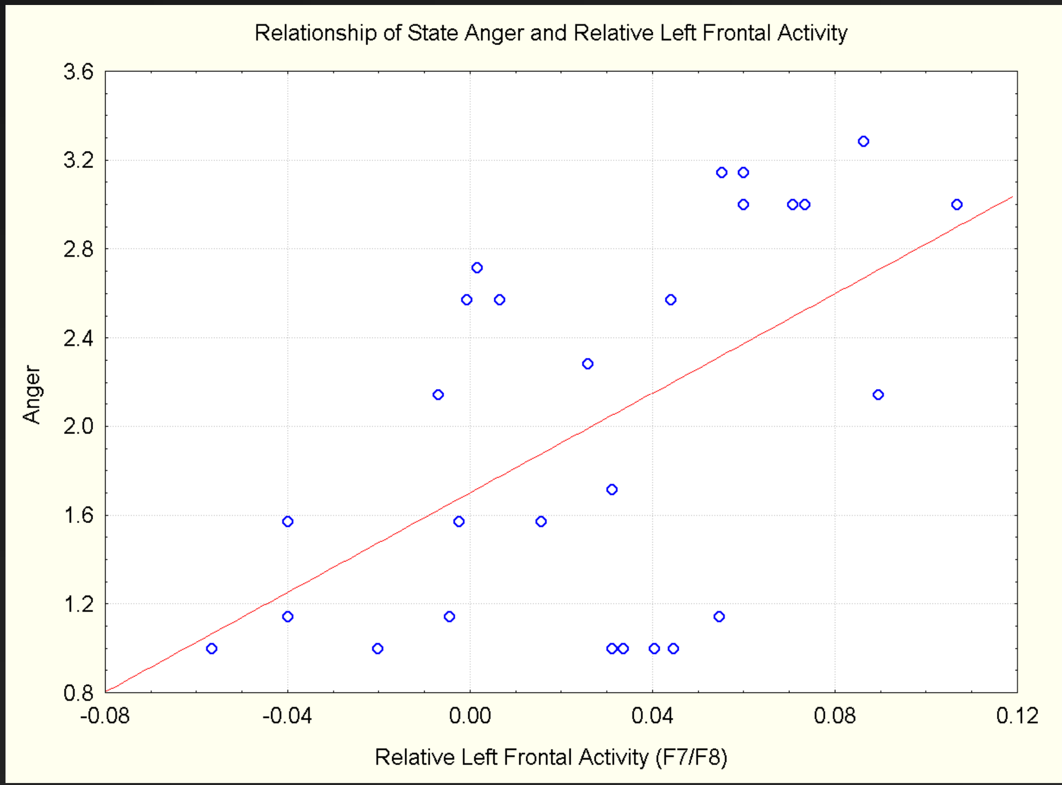
Relative Left Frontal, Anger, & Aggression as a Function of Condition



Harmon-Jones & Sigelman, *JPSP*, 2001

Frontal EEG asymmetry predicts Anger and Agression

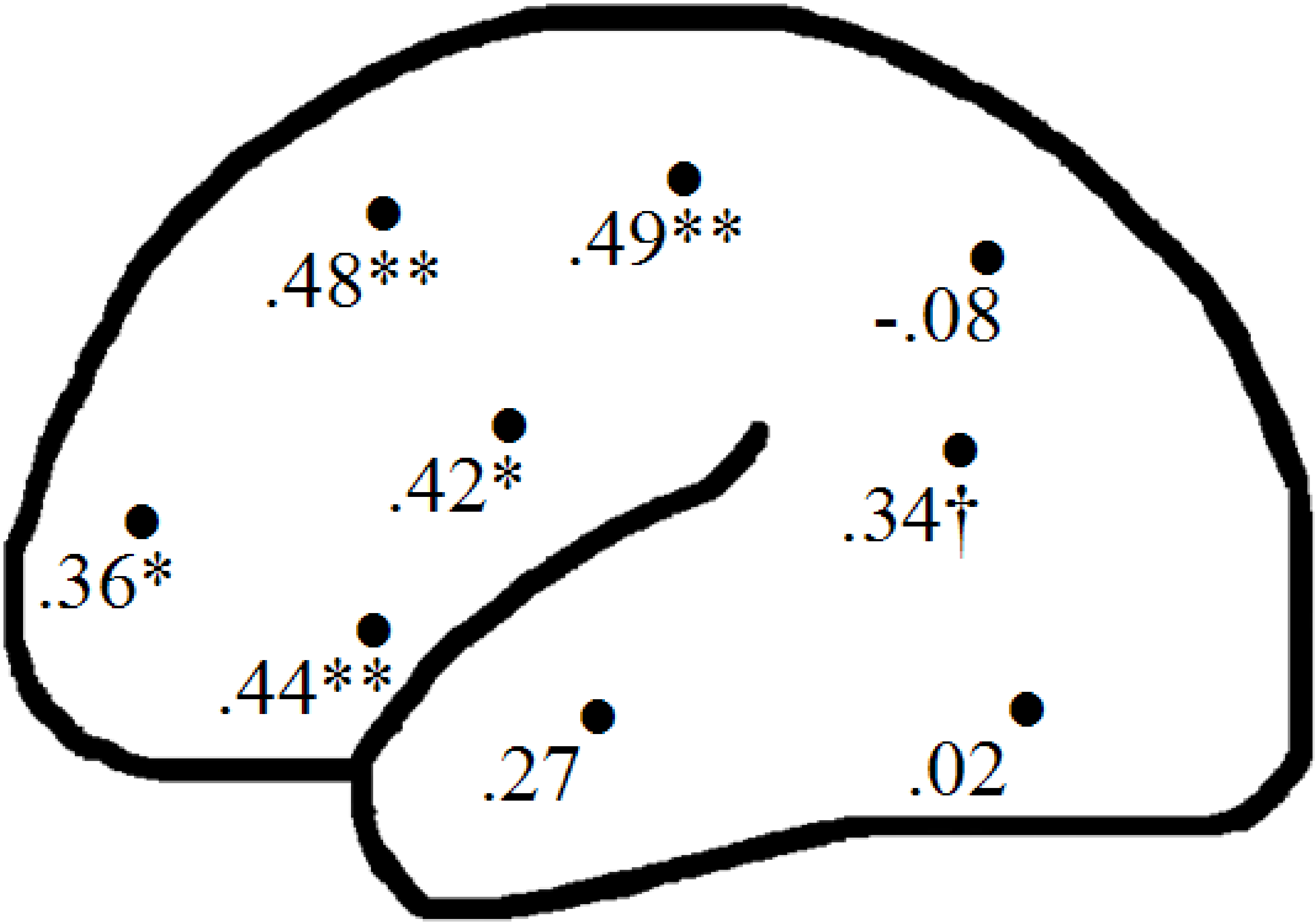
- Not in Neutral condition … no relationship
- Strongly in Insult condition
  - r = .57 for anger
  - r = .60 for aggression
  - Note: partial r adjusting for baseline indiv diffs in asymmetry and affect



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)

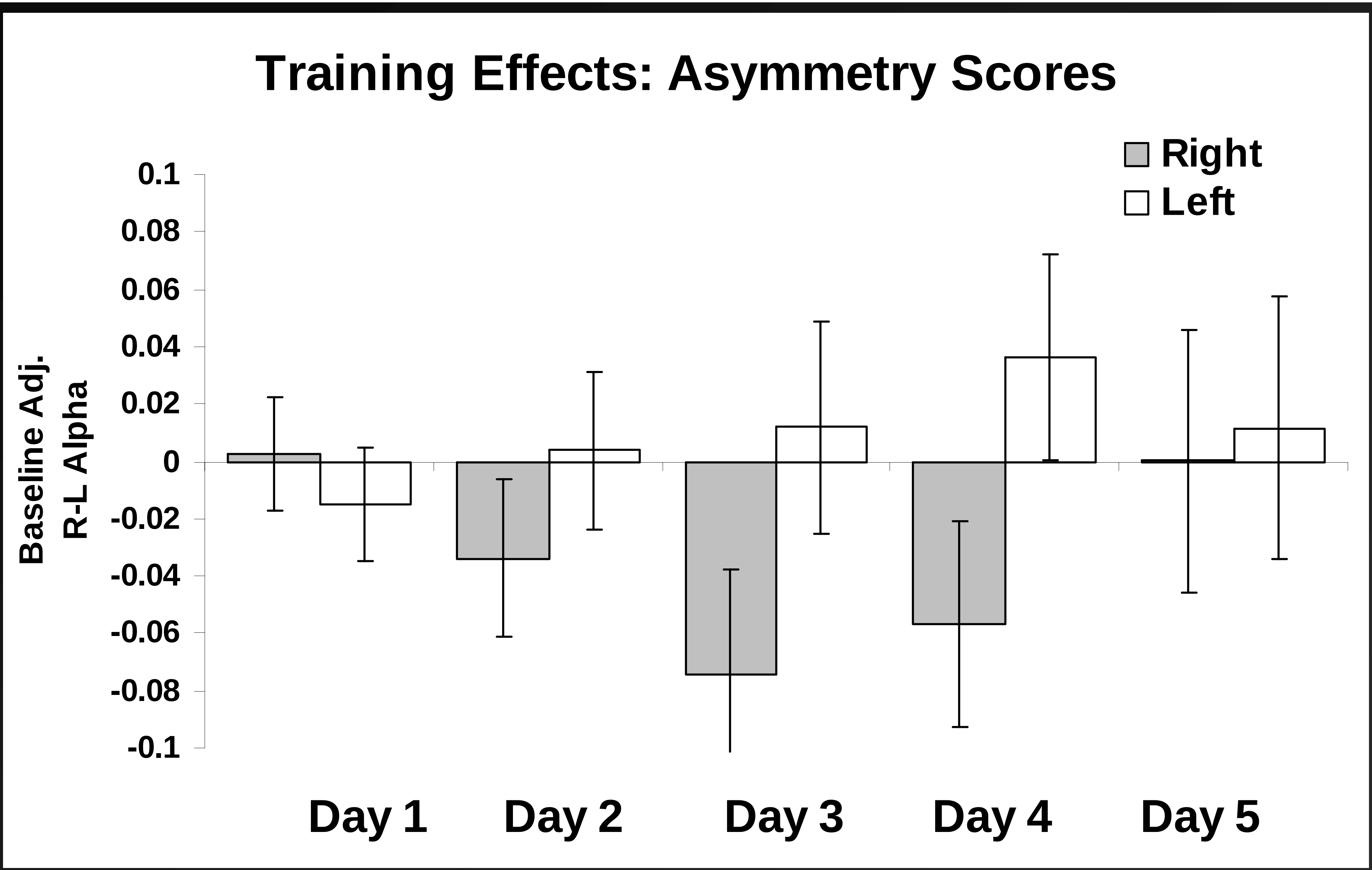
Correlations ≠ Causality

- 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

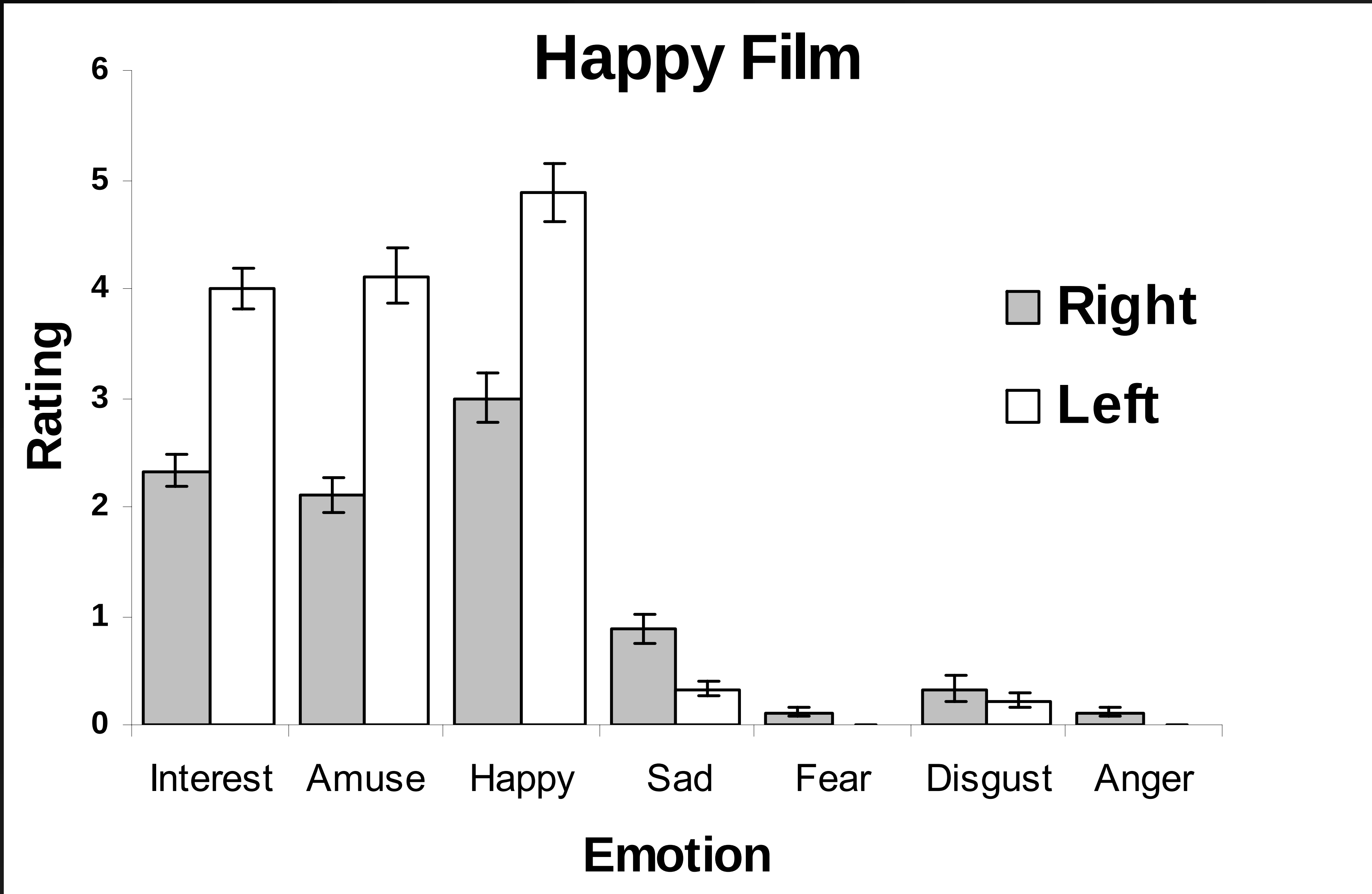
- Tones presented when asymmetry exceeds a threshold, adjusted for recent performance

- Films before first training and after last training



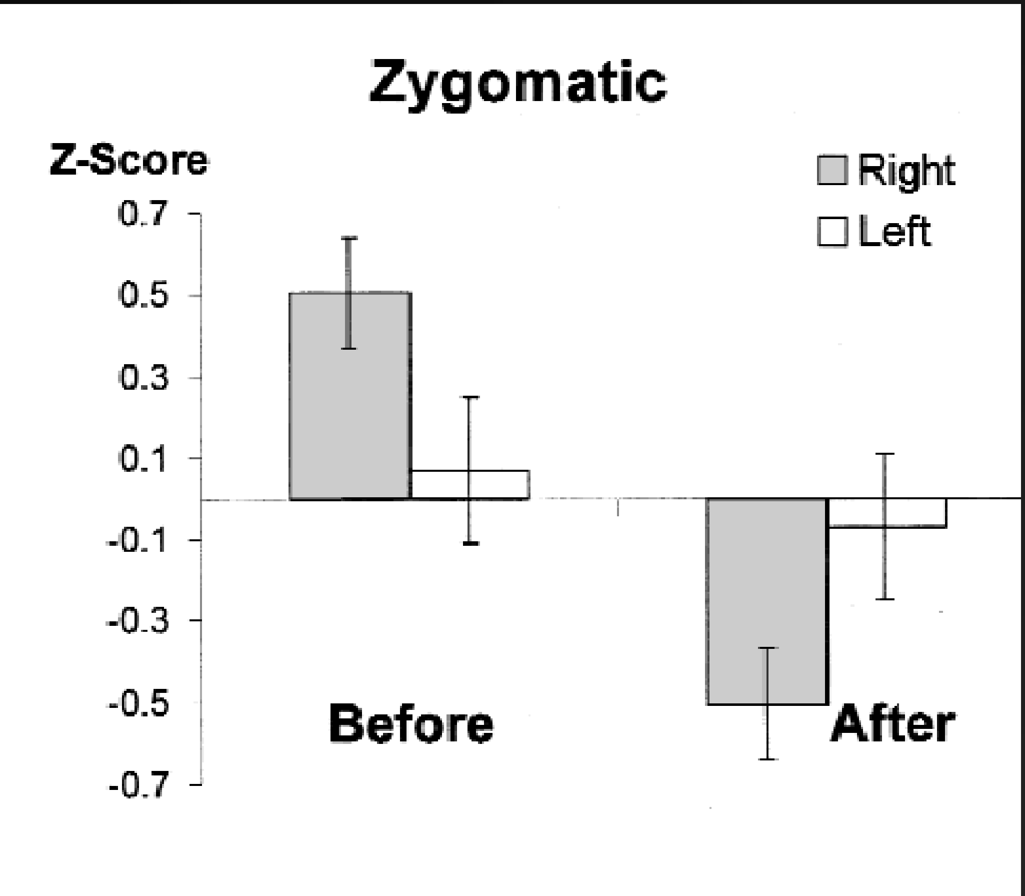
Manipulation of EEG asymmetry with biofeedback produced differential change across 5 days of training; Regression on Day 5

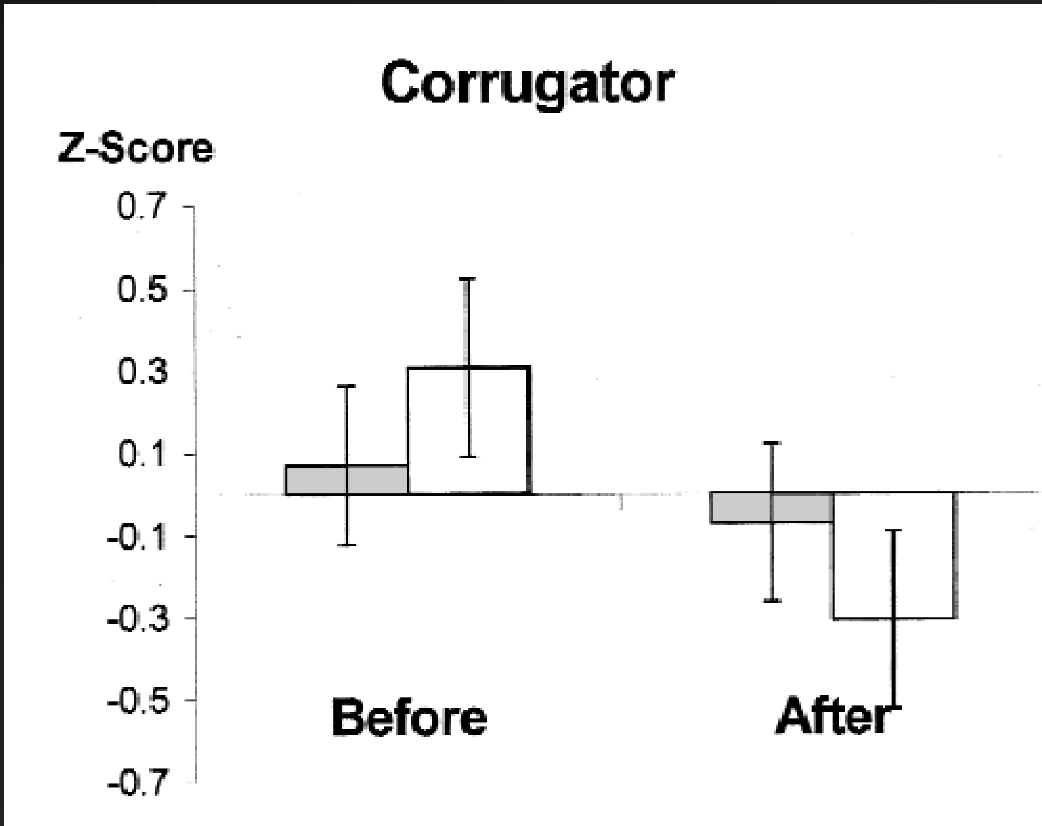
From Allen, Harmon-Jones, and Cavender (2001)



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)



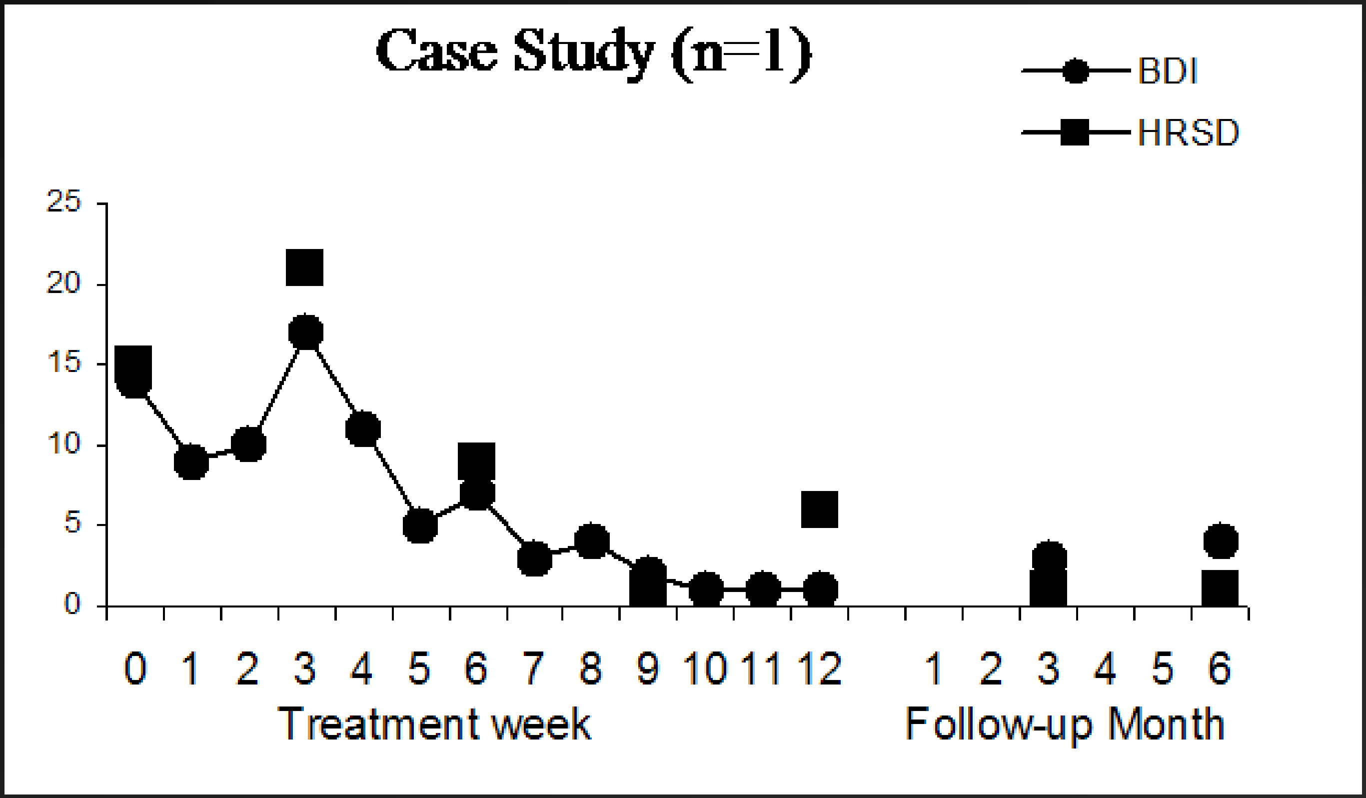


From Allen, Harmon-Jones, and Cavender (2001)

Manipulation of Asymmetry using Biofeedback

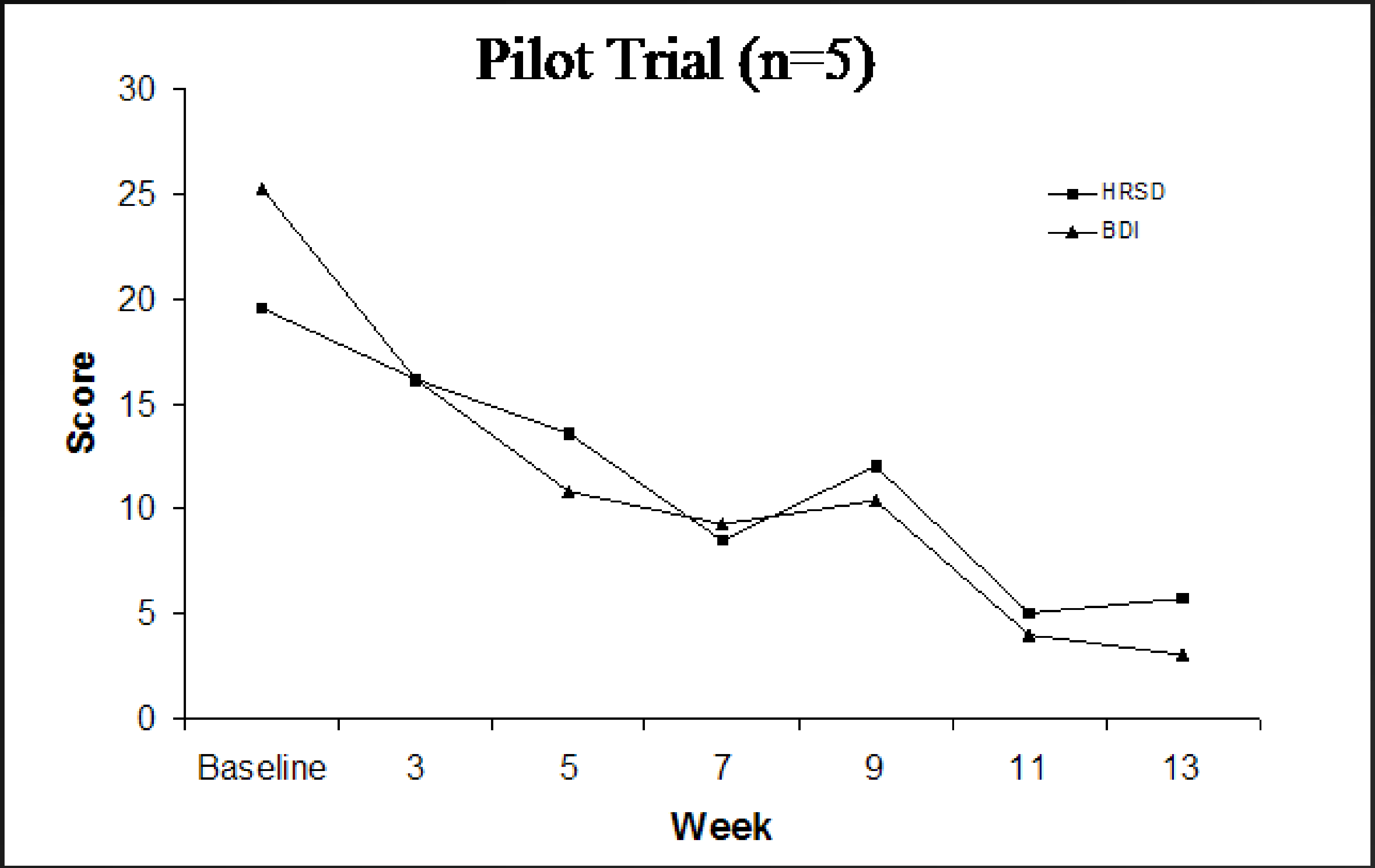
- Phase 1: Demonstrate that manipulation of EEG asymmetry is possible
- Phase 2: Determine whether EEG manipulation has emotion-relevant consequences
- Phase 3: Examine whether EEG manipulation produces clinically meaningful effects
- Phase 4: Conduct efficacy trial

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

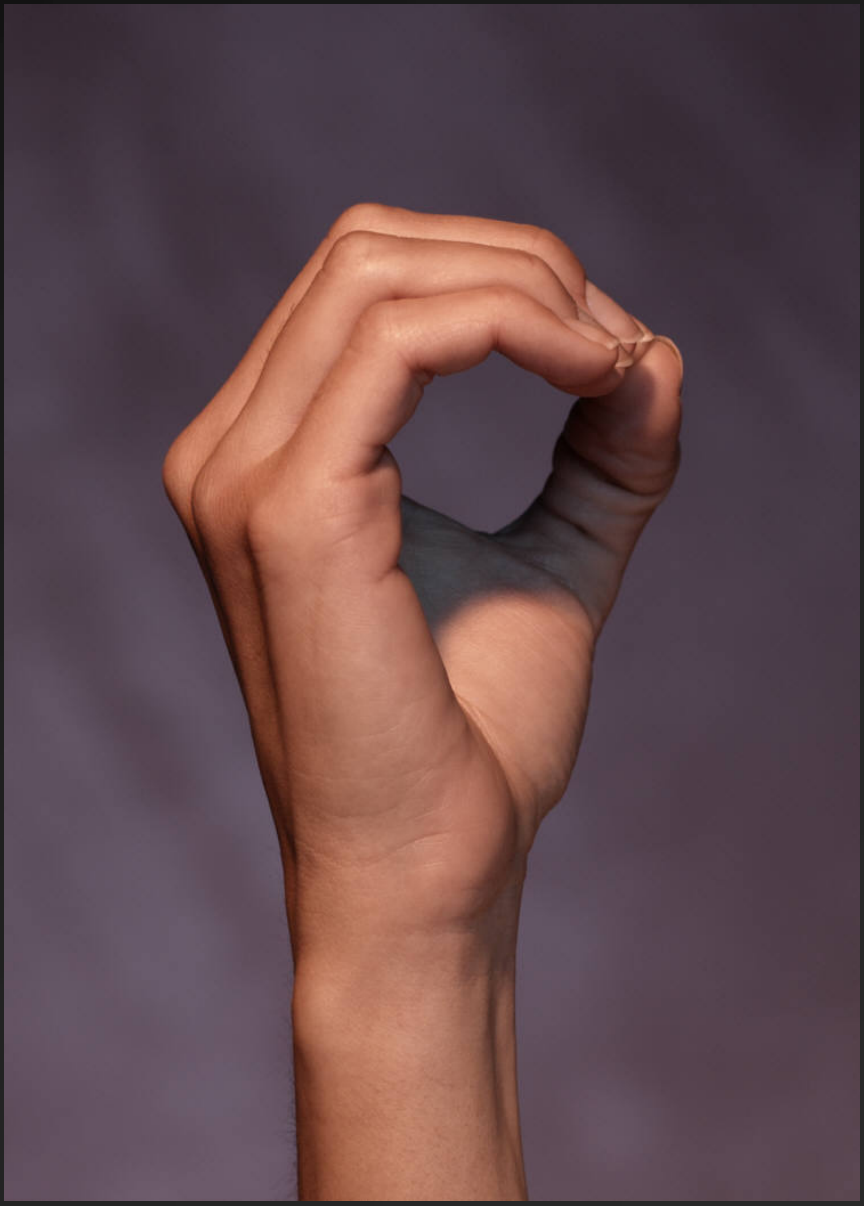
Phase 4: Randomized Control Trial

- 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

Results



A Different Manipulation

Peterson, Shackman, Harmon-Jones (2008)

- Hand contractions to activate contralateral premotor cortex
- Insult about essay (similar to Harmon-Jones & Sigelman, *JPSP*, 2001) followed by chance to give aversive noise blasts to the person who insulted them
- Hand contractions:
  - altered frontal asymmetry as predicted
  - Altered subsequent aggression (noise blasts)
- Asymmetry duruing hand contractions predicted aggression

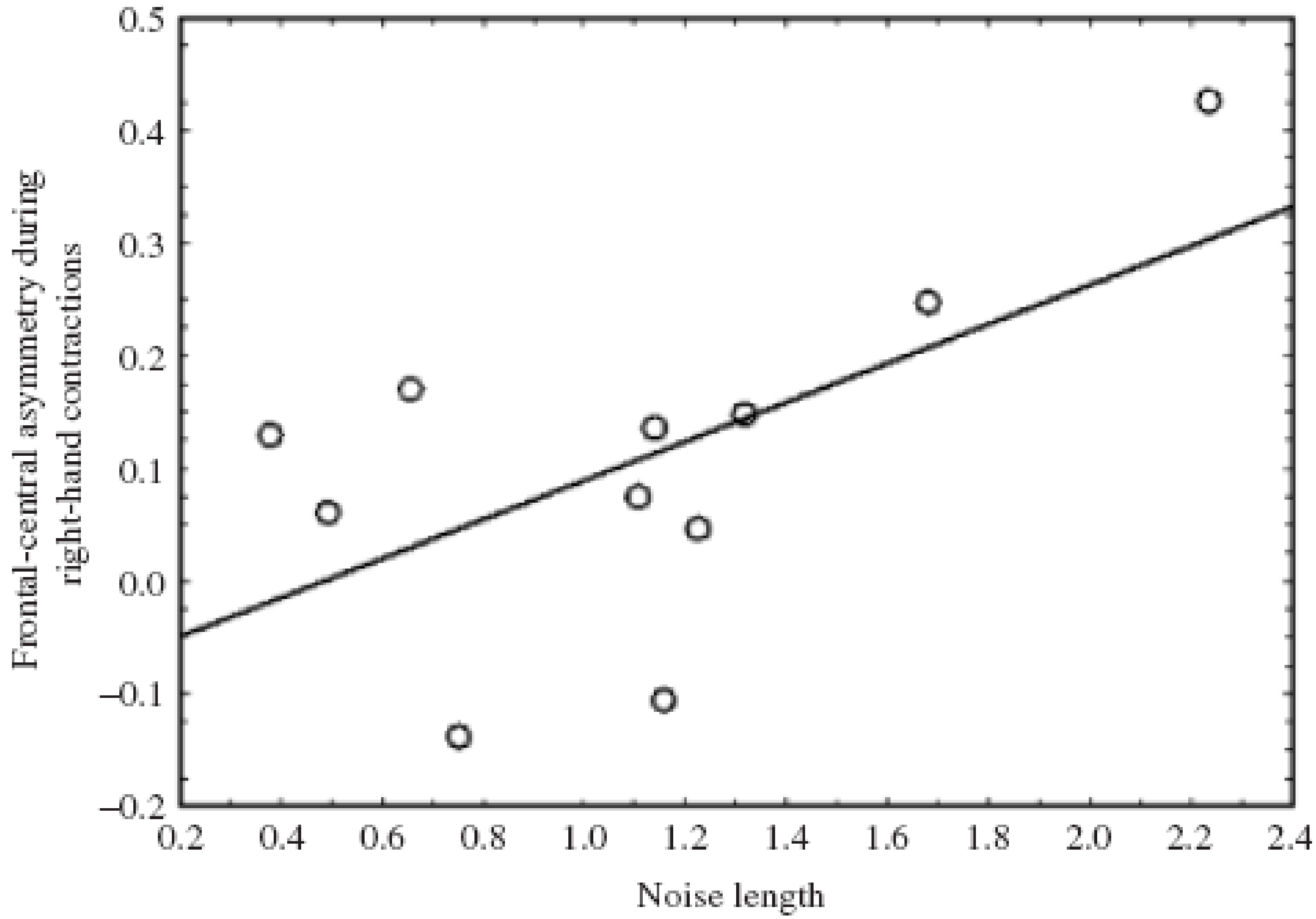


Figure 1. Relation between noise length and frontal-central asymmetry during right-hand contractions. Higher asymmetry scores indicate greater relative left than right activation.

Peterson, Shackman, Harmon-Jones (2008)

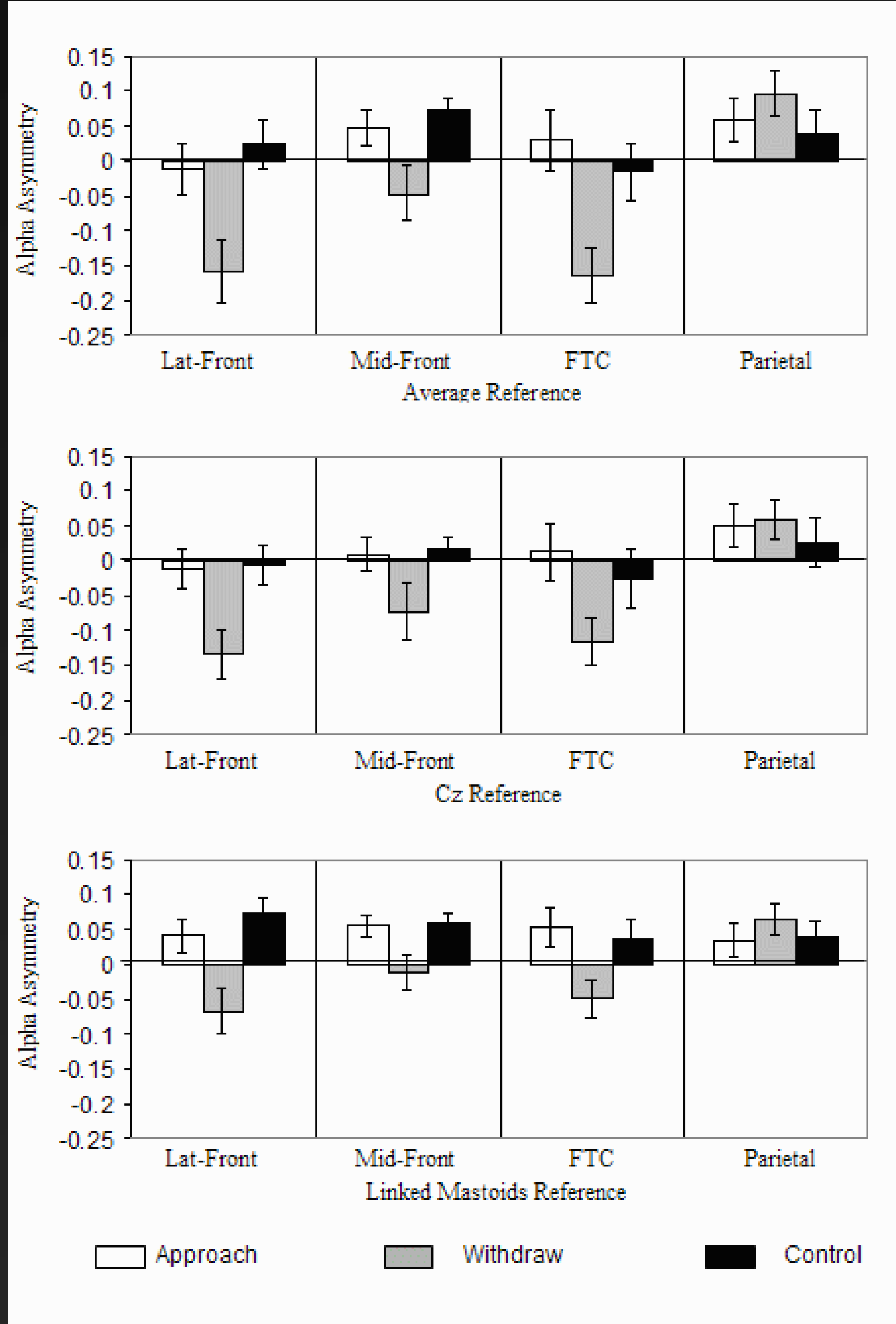
State Changes

- 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)

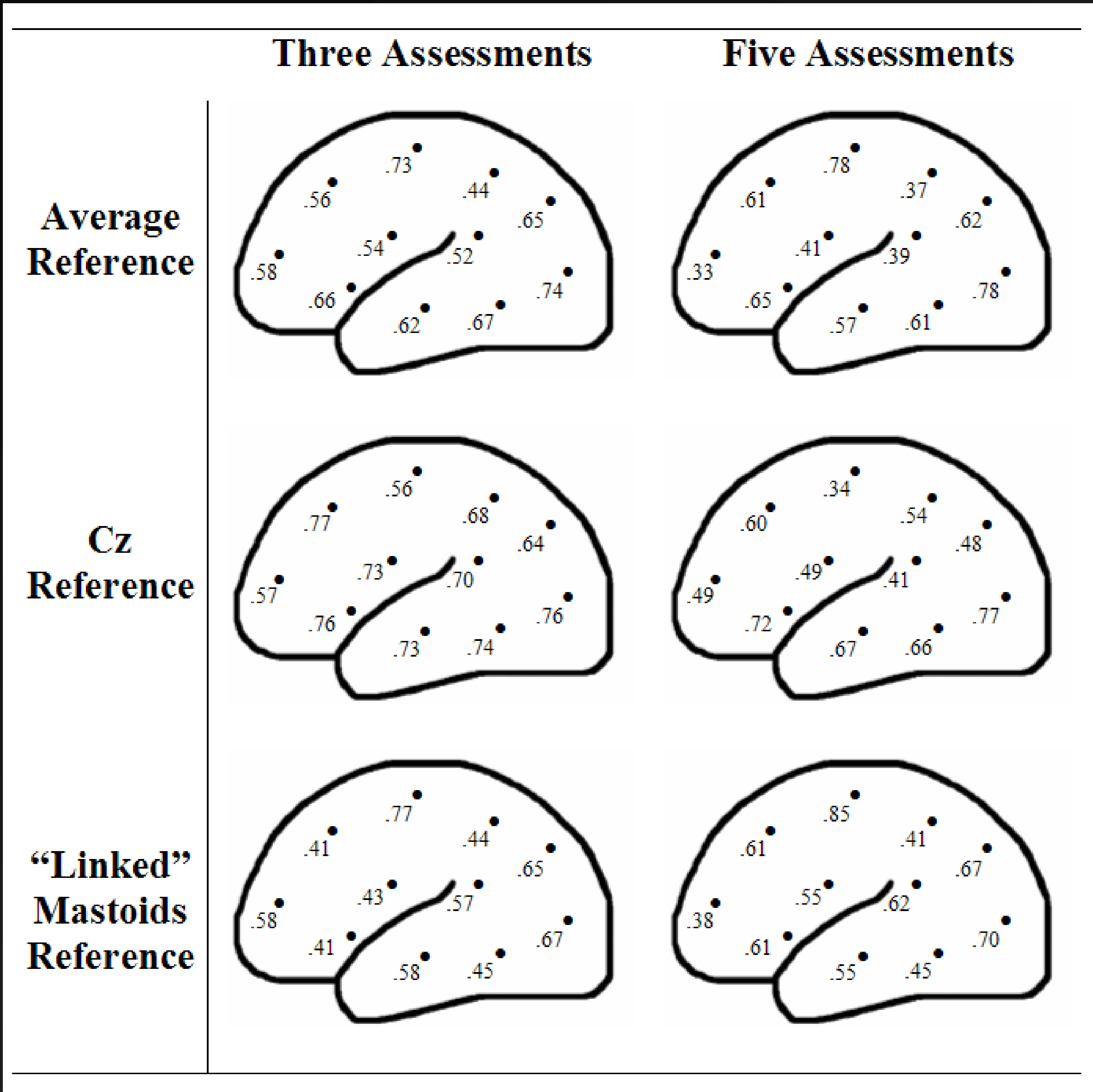
EEG responds to directed facial actions



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., 2004)
  - 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

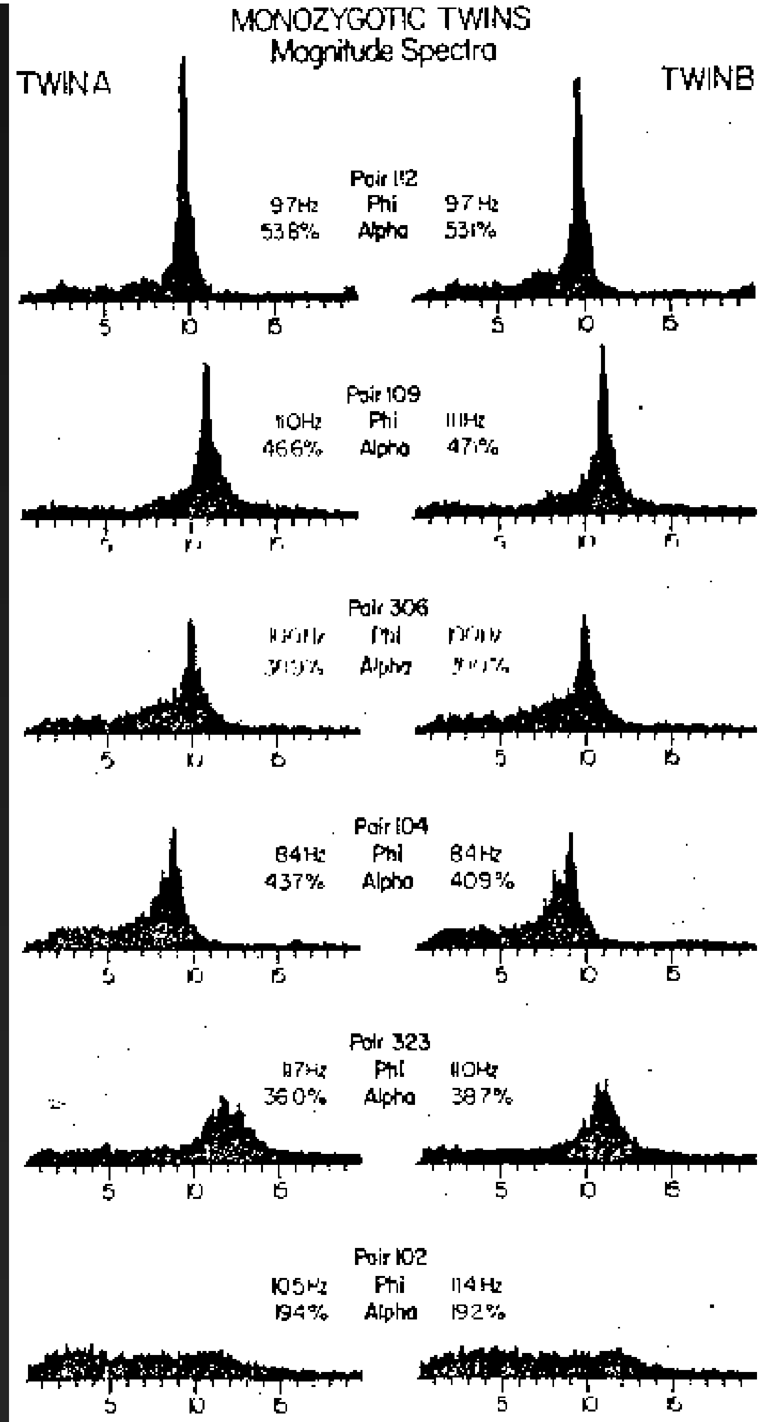


Figure 1. EEG spectra from 6 of the 39 monozygotic (MZ) twin pairs studied in 1974, selected to show the range of amount of alpha activity. Phi is the median frequency in a 3-Hz band centered on the central peak. All spectra are standardized to unit area. (Reprinted from Lykken, Tellegen, & Thorkelson,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

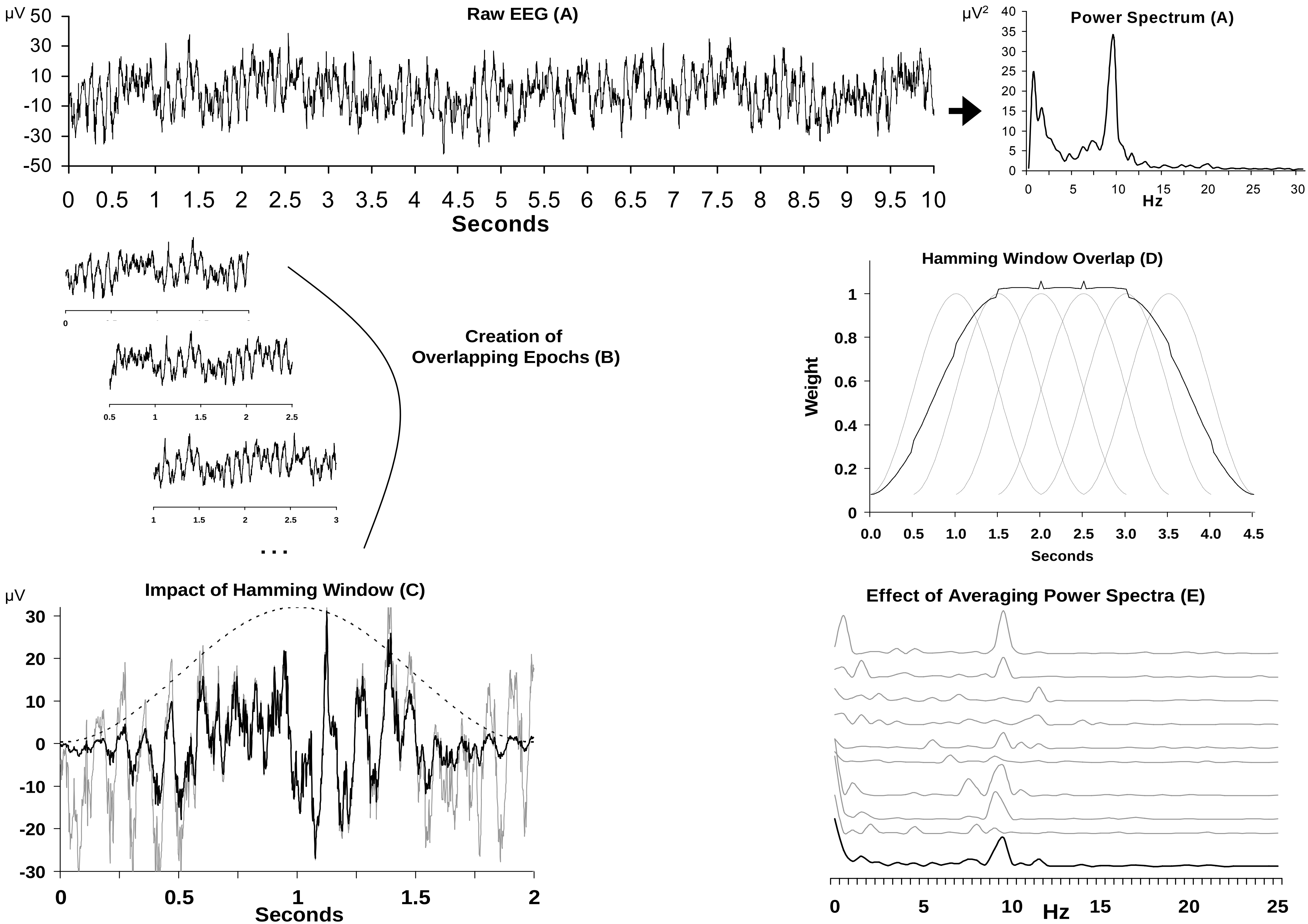
Trait, Occasion, and State variance

- 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 (2004)

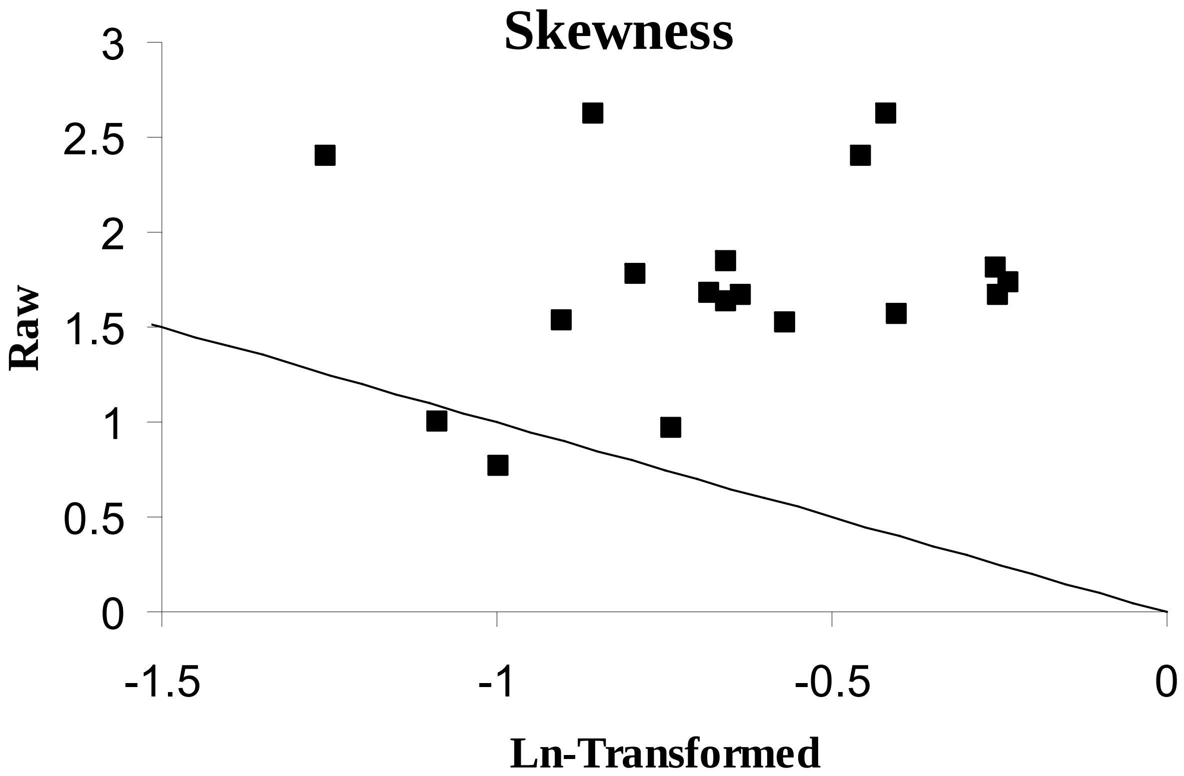

Raw EEG (A)
μV
Seconds
Power Spectrum (A)
μV²
Hz
Creation of
Overlapping Epochs (B)
Hamming Window Overlap (D)
Weight
Seconds
Impact of Hamming Window (C)
μV
Seconds
Effect of Averaging Power Spectra (E)
Hz

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

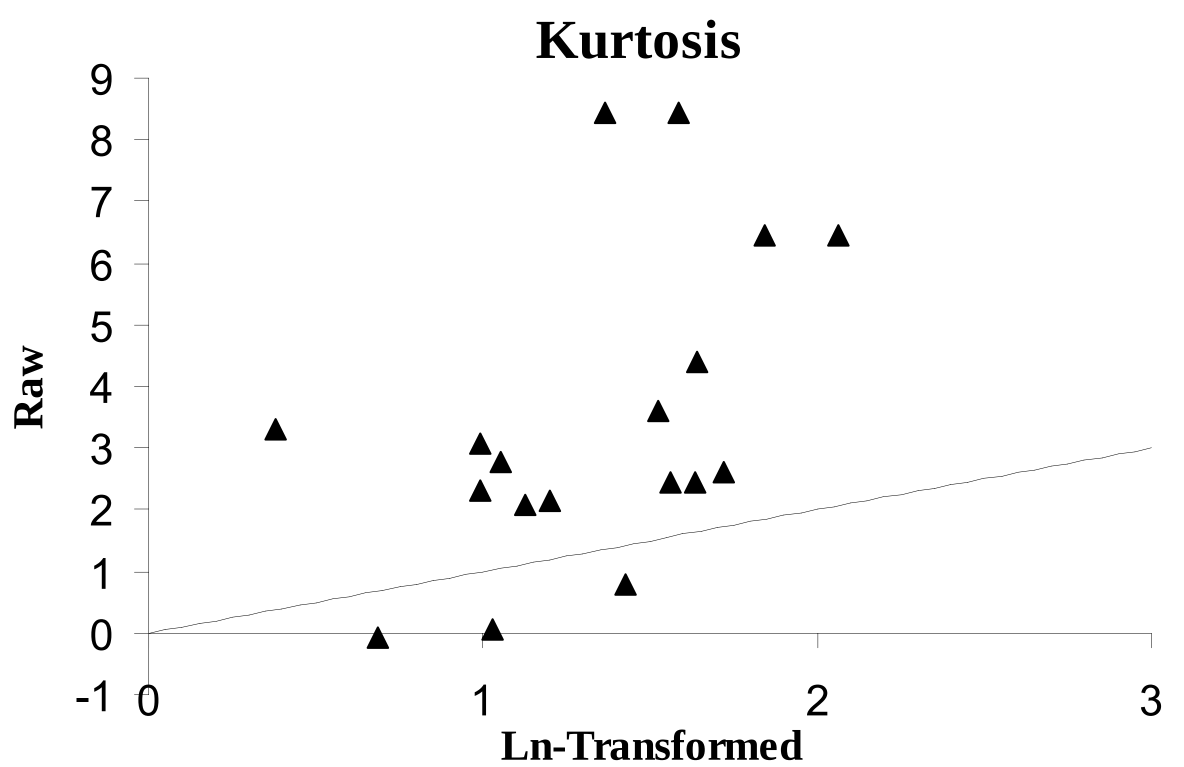
- Why?
  - Everyone is doing it!
  - Folks say power values are skewed



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

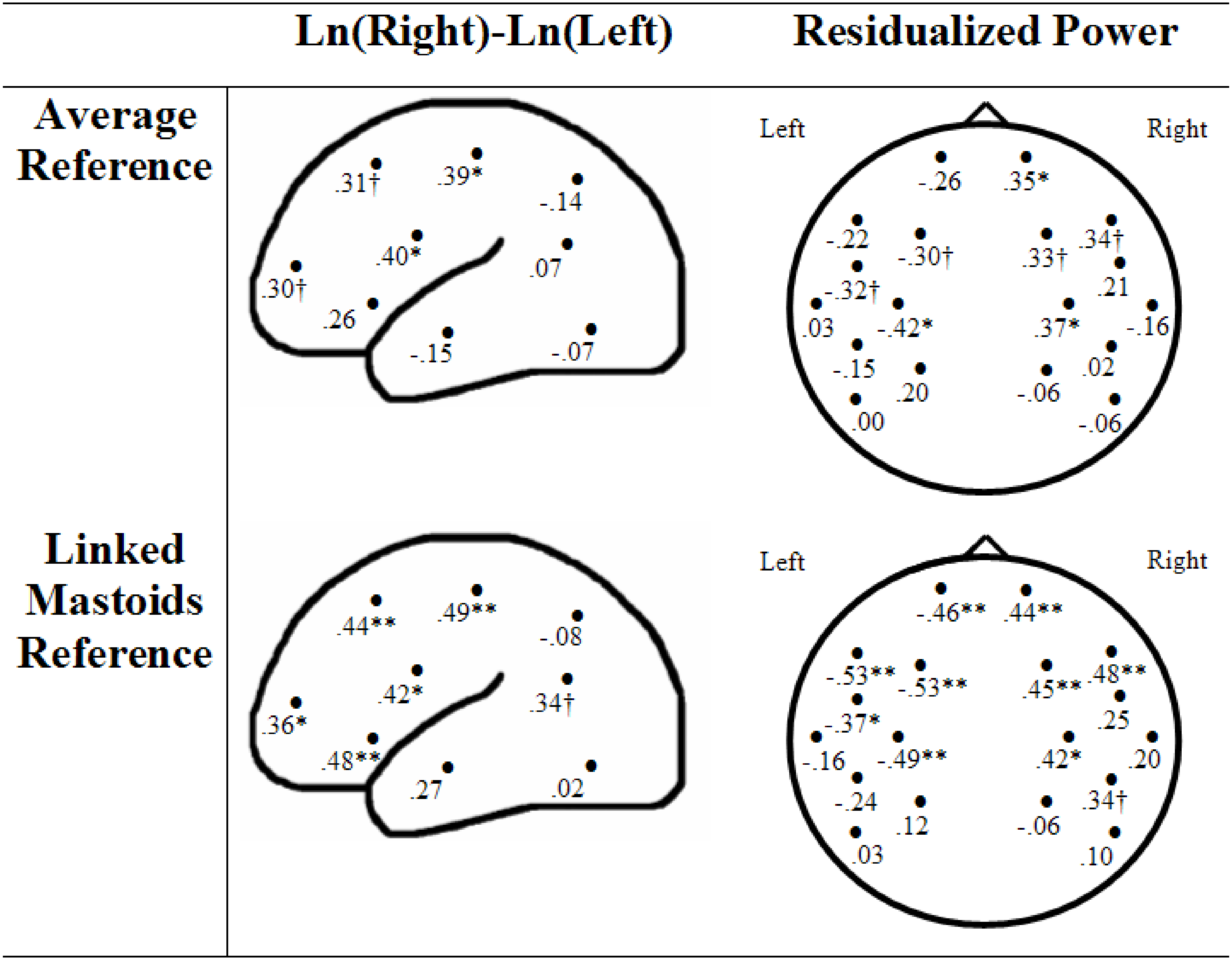
	Before Ln-Transform	After Ln-Transform
Skewness	67%	22%
Kurtosis	67%	33%

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
.31†
.39*
-.14
.40*
.07
.30†
.26
-.15
-.07
Left
Right
-.26
.35*
-.22
-.30†
.33†
.34†
-.32†
.21
.03
-.42*
.37*
-.16
-.15
.20
.02
-.06
.00
-.06
Linked Mastoids Reference
.44**
.49**
-.08
.42*
.34†
.36*
.48**
.27
.02
Left
Right
-.46**
.44**
-.53**
-.53**
.45**
.48**
.25
-.37*
-.16
-.49**
.42*
.20
-.24
.12
.34†
-.06
.03
.10

†$p < .10$; *$p < .05$; ** $p < .01$

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.

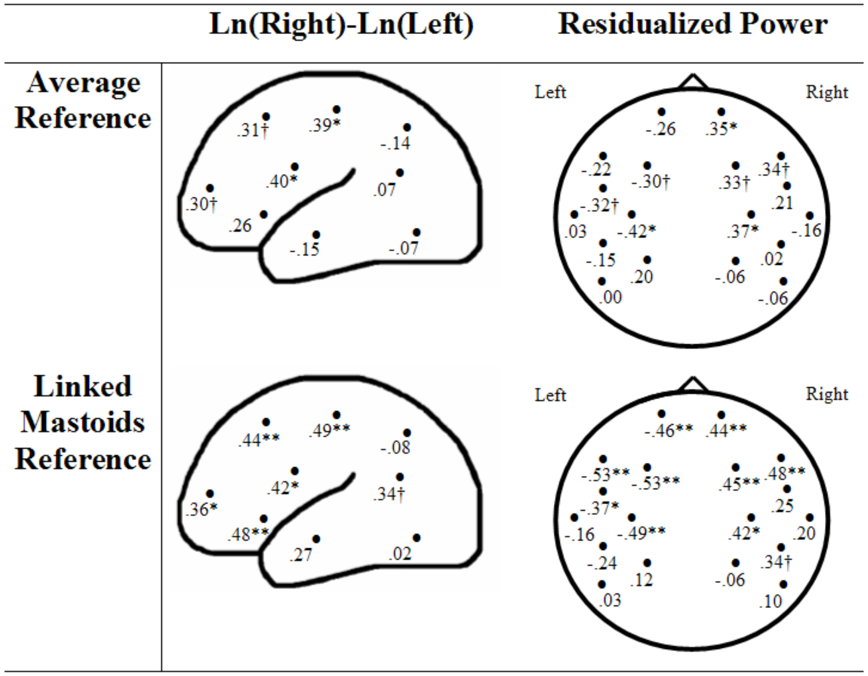
- Therefore, this procedure will make it appear that right hemisphere leads correlate with a criterion variable in the same direction and magnitude as the $R - L$ difference score, and that left hemisphere leads correlate with a criterion variable in the opposite direction but same magnitude as the $R - L$ difference score.

- Therefore, *don't do that!*

New Handout

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



†p < .10; *p < .05; ** p < .01

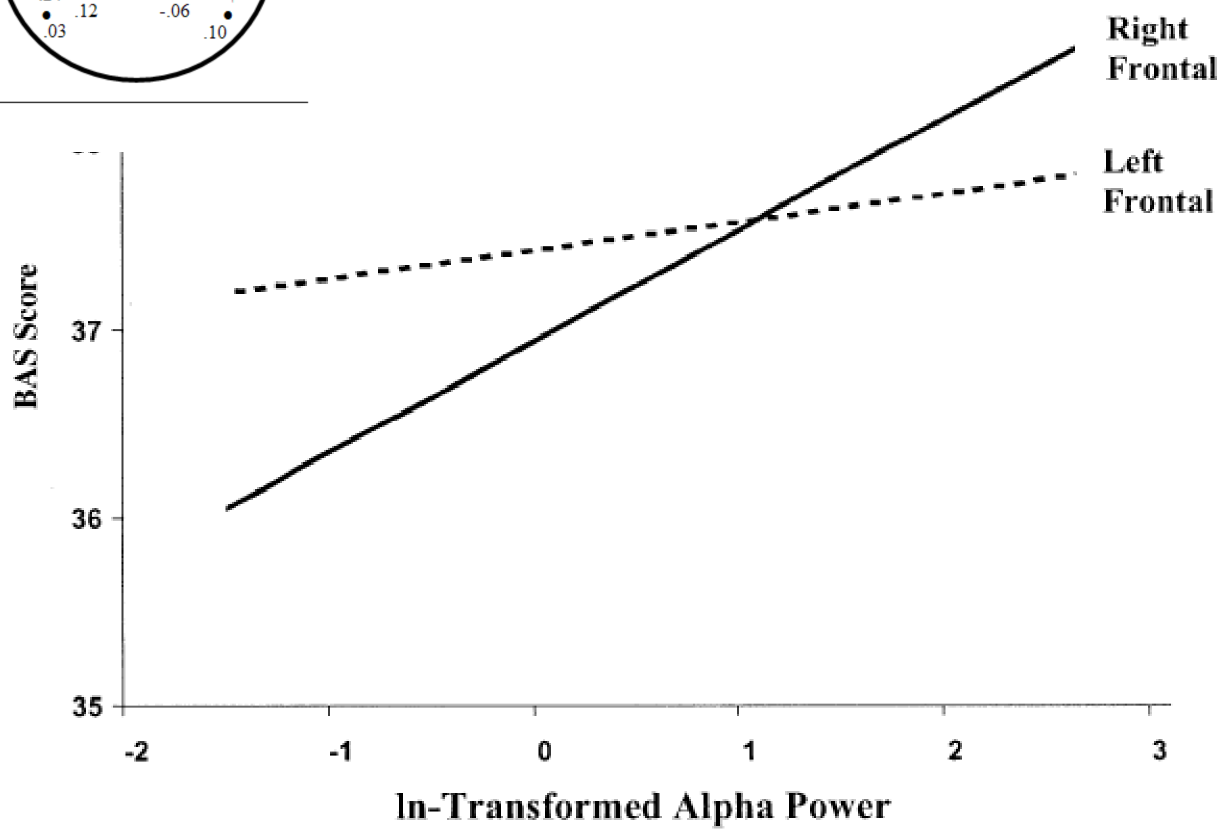
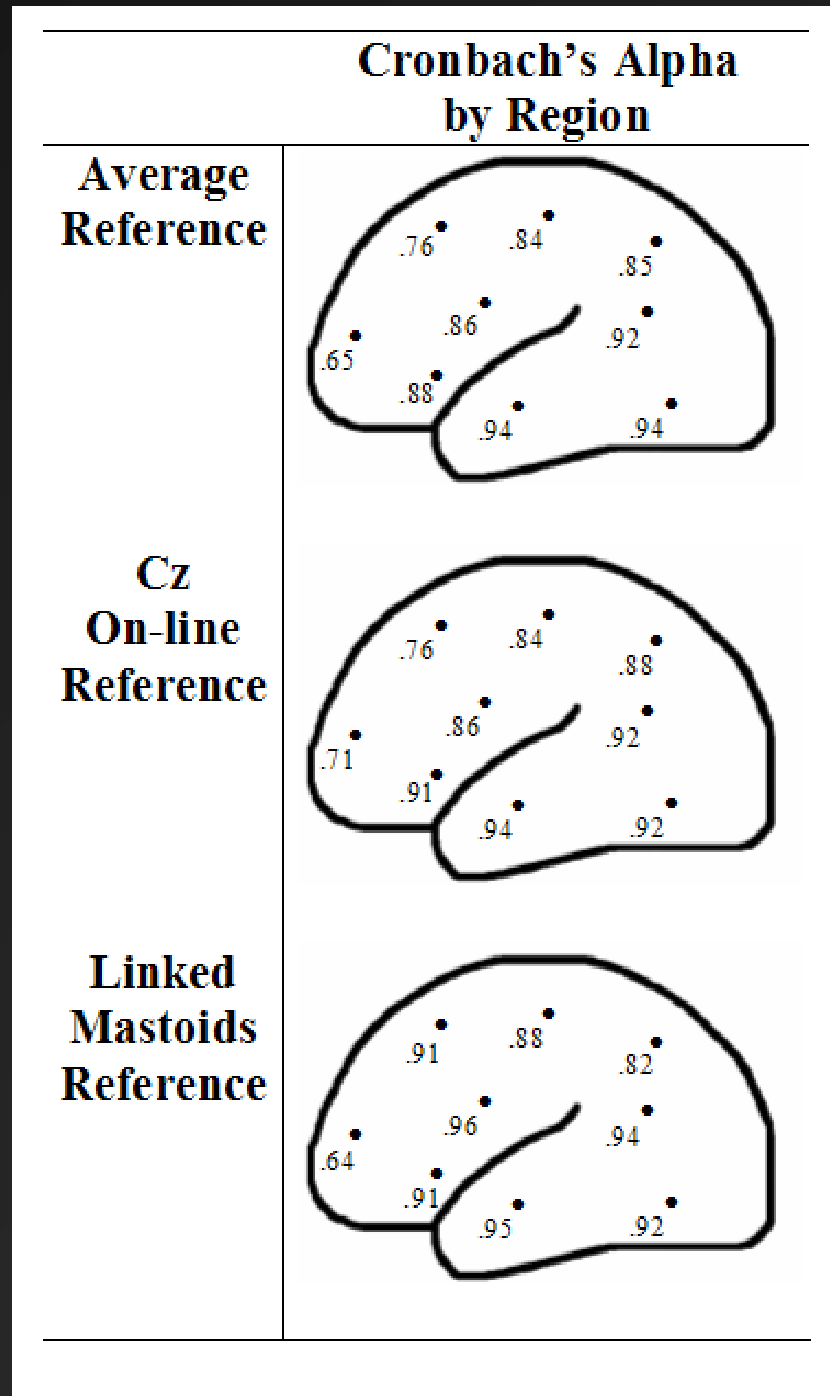
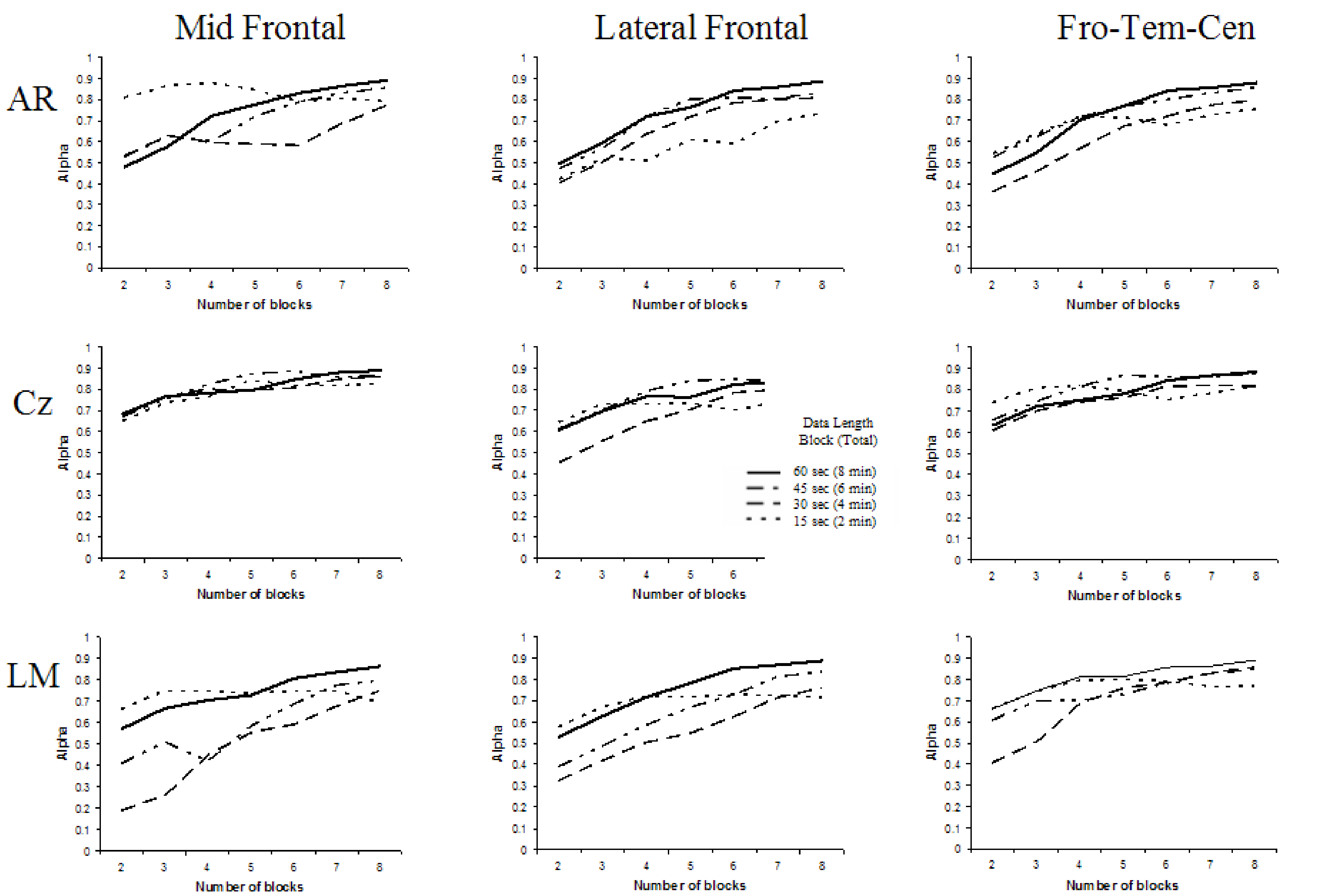


Figure 5. Regression lines for left and right frontal ln-transformed alpha power predicting BAS scores. The regression equations depicted are: BAS = (0.15) (Left) + 37.44; BAS = (0.60) (Right) + 36.98. Left includes ln-transformed power at F3 and F7, and right includes ln-transformed power at F4 and F8.

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"

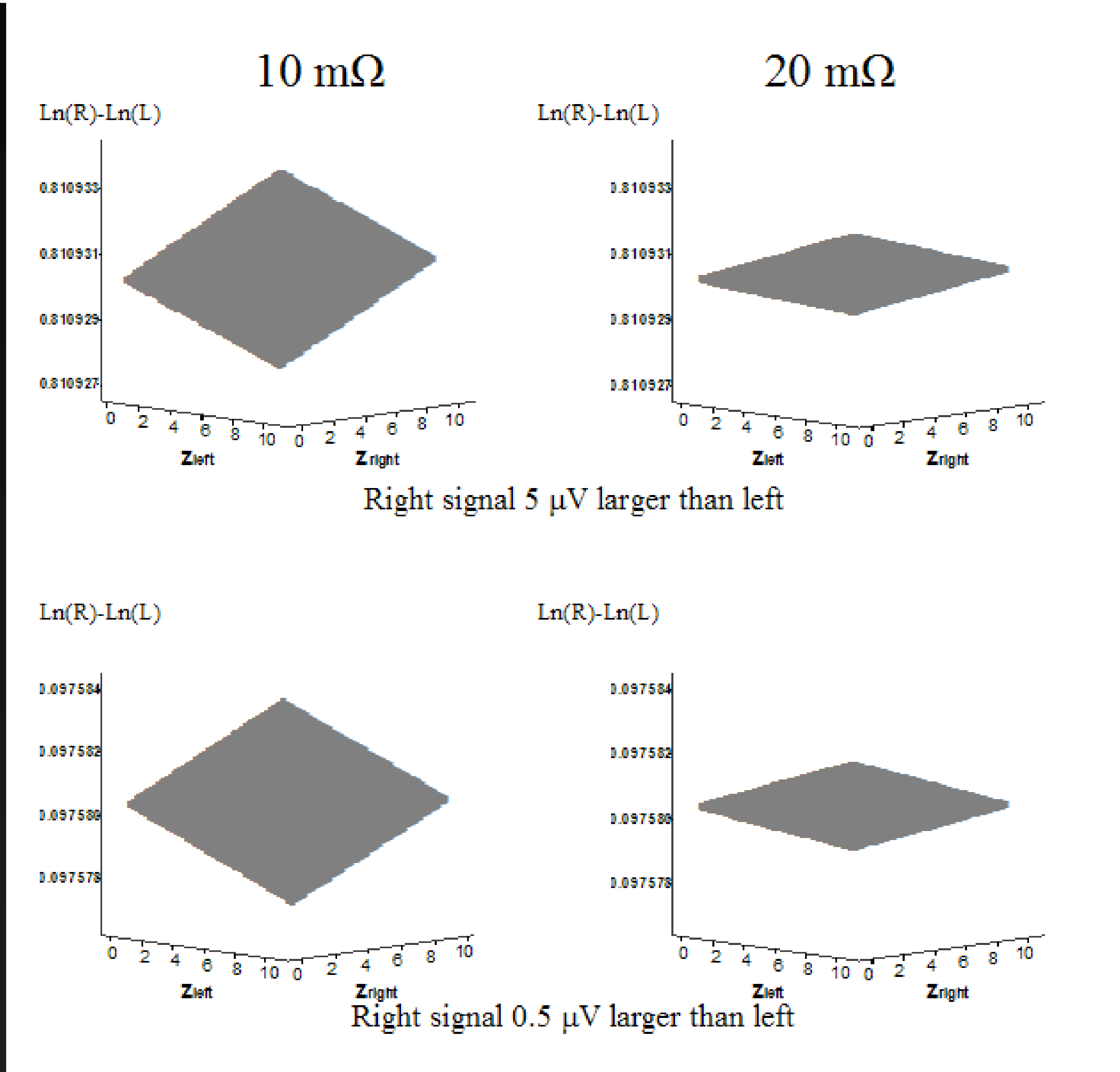




Mid Frontal
Lateral Frontal
Fro-Tem-Cen
AR
Cz
LM
Alpha
Number of blocks
Data Length
Block (Total)
60 sec (8 min)
45 sec (6 min)
30 sec (4 min)
15 sec (2 min)

Impedances

How important is it to match homologous impedances?



Answer:
Not that important

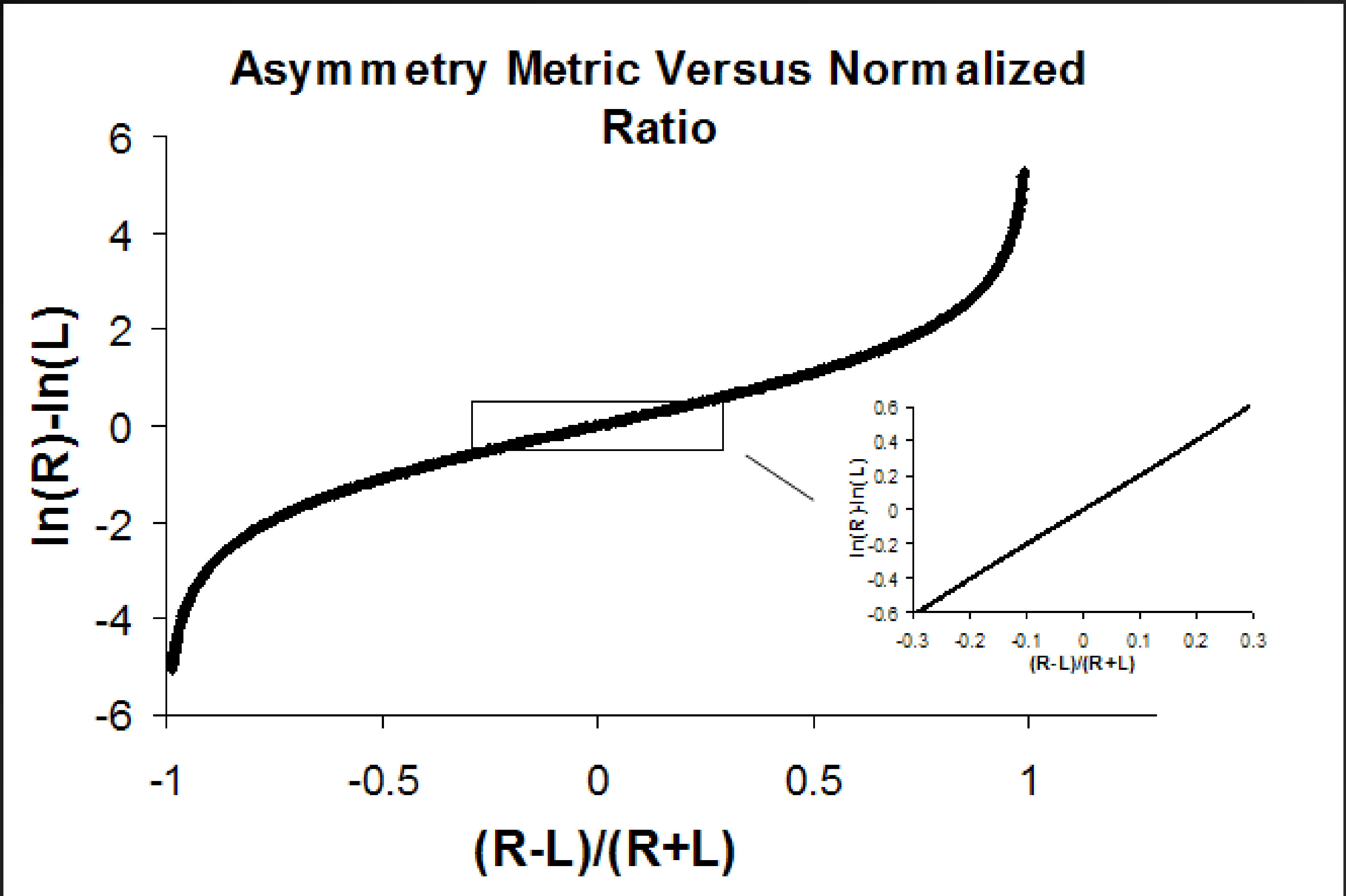
$$(V_E - V_R) = V_D\left(2 - \frac{Z_E + Z_R}{Z_{in}}\right) + V_C\left(\frac{Z_E - Z_R}{Z_{in}}\right) + O\left(\frac{1}{Z_{in}}\right)^2$$

Is 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?
    - Total alpha power (across sites) 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

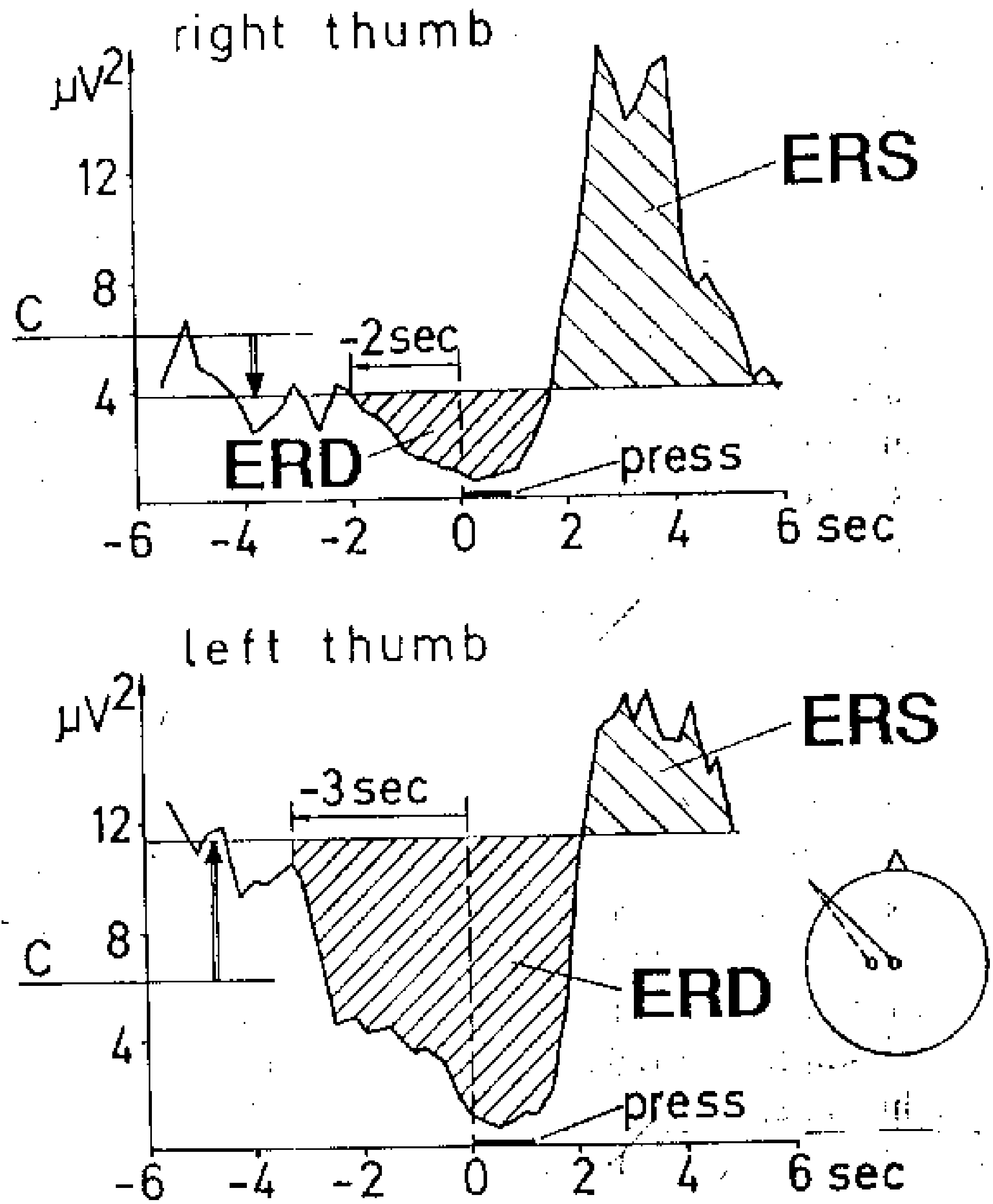
The optimist will see this as a testament to the robustness of the underlying systems reflected in frontal EEG asymmetry, and the curmudgeon will see this as representing considerable literature-wide alpha slippage due to the many permutations of data reduction and analysis.

Synchronization and Desynchronization

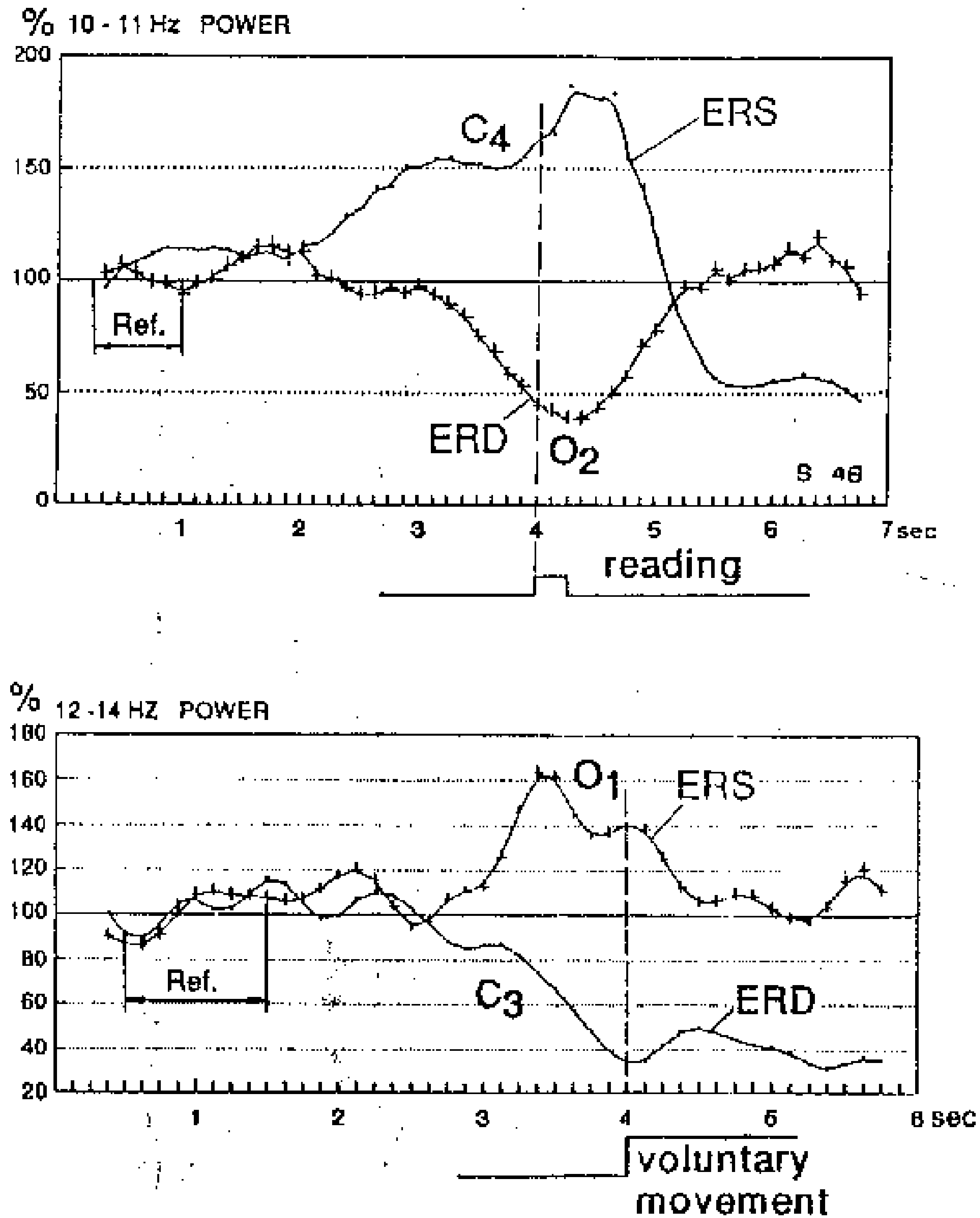
- Supposition that alpha blocking meant that the EEG had become desynchronized
  - Yet the activity is still highly synchronized -- not at 8-13 Hz
  - May involve fewer neuronal ensembles in synchrony

Event-related Synchronization and Desynchronization

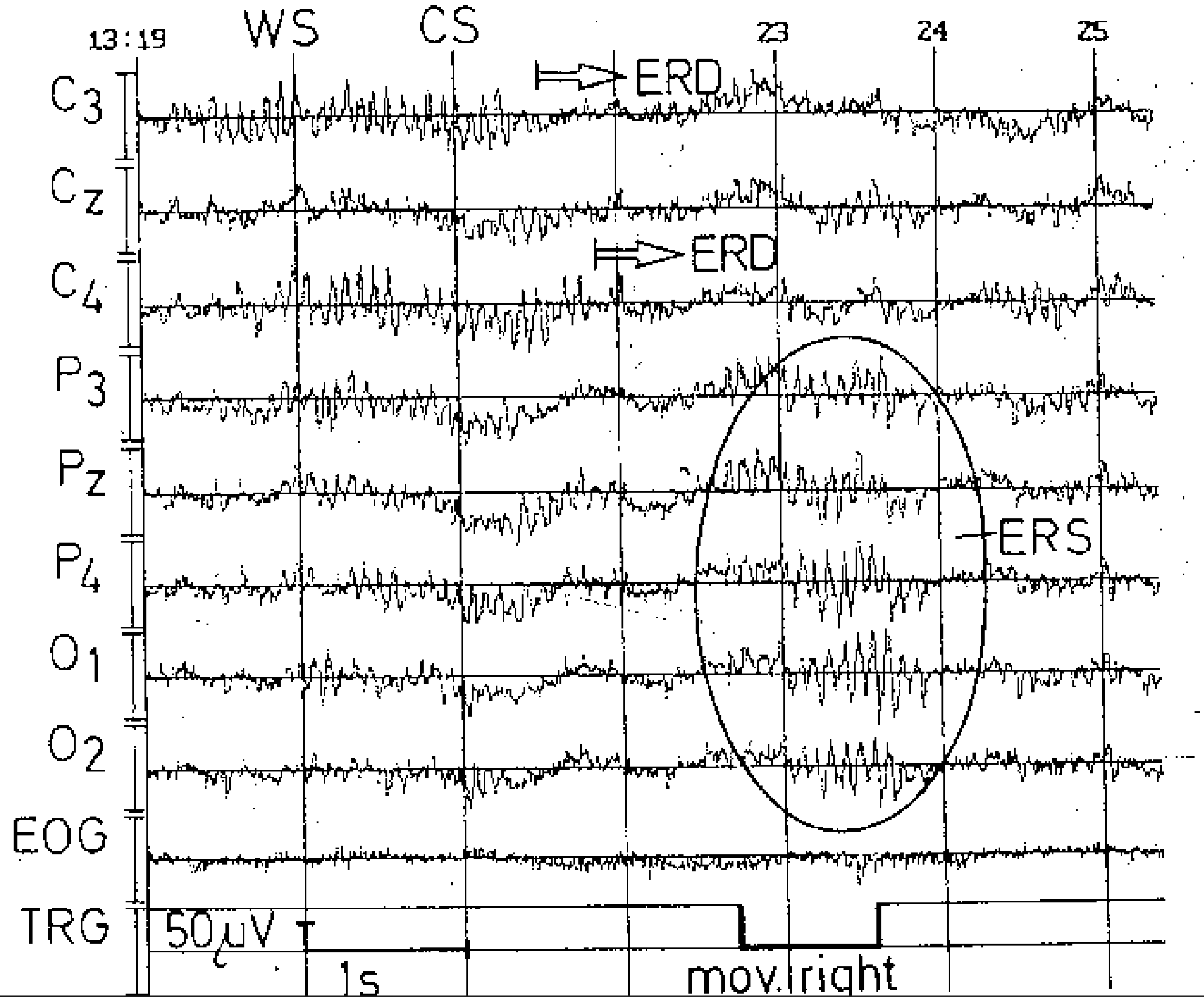
- Pfurtscheller (1992) -- Two types of ERS
  - Secondary (follows ERD)
  - Primary (**Figure 3 & Figure 4**)



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

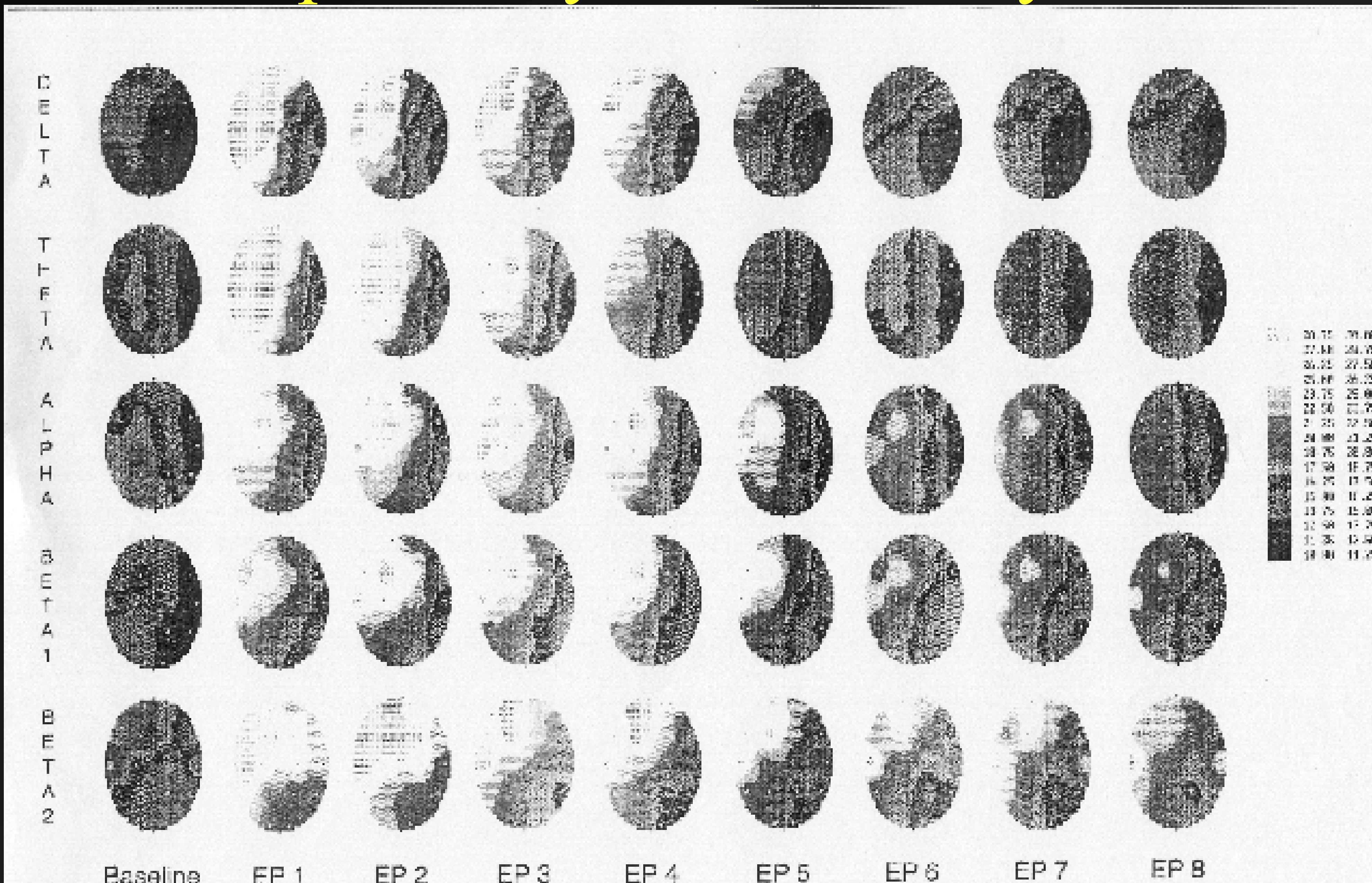


Alpha power time course during reading (upper) and voluntary finger movements (lower). Primary ERS is seen over electrodes overlying cortical areas not involved in the task.



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

If Alpha Desynchs, what Synchs?



Less drastic manipulations….

Frontal Midline Theta
(more later in advanced topics)

- Increased midline frontal theta during periods of high cognitive demand
- This is specifically under conditions in which cortical resources must be allocated for select cognitive processes
  - Attention
  - Memory
  - Error Monitoring

Saueng Hoppe Klimesch Gerloff Hummel (2007)

- Complex finger movement sequences
- Varied Task Difficulty, and Memory Load (2x2 design)
- Task-related Theta Power (4-7 Hz) computed for each condition relative to 5 min. resting baseline
- Phase coherence also examined across sites
  - Phase Locking Value (0-1)
  - Then expressed as percent increase over rest

Theta Power

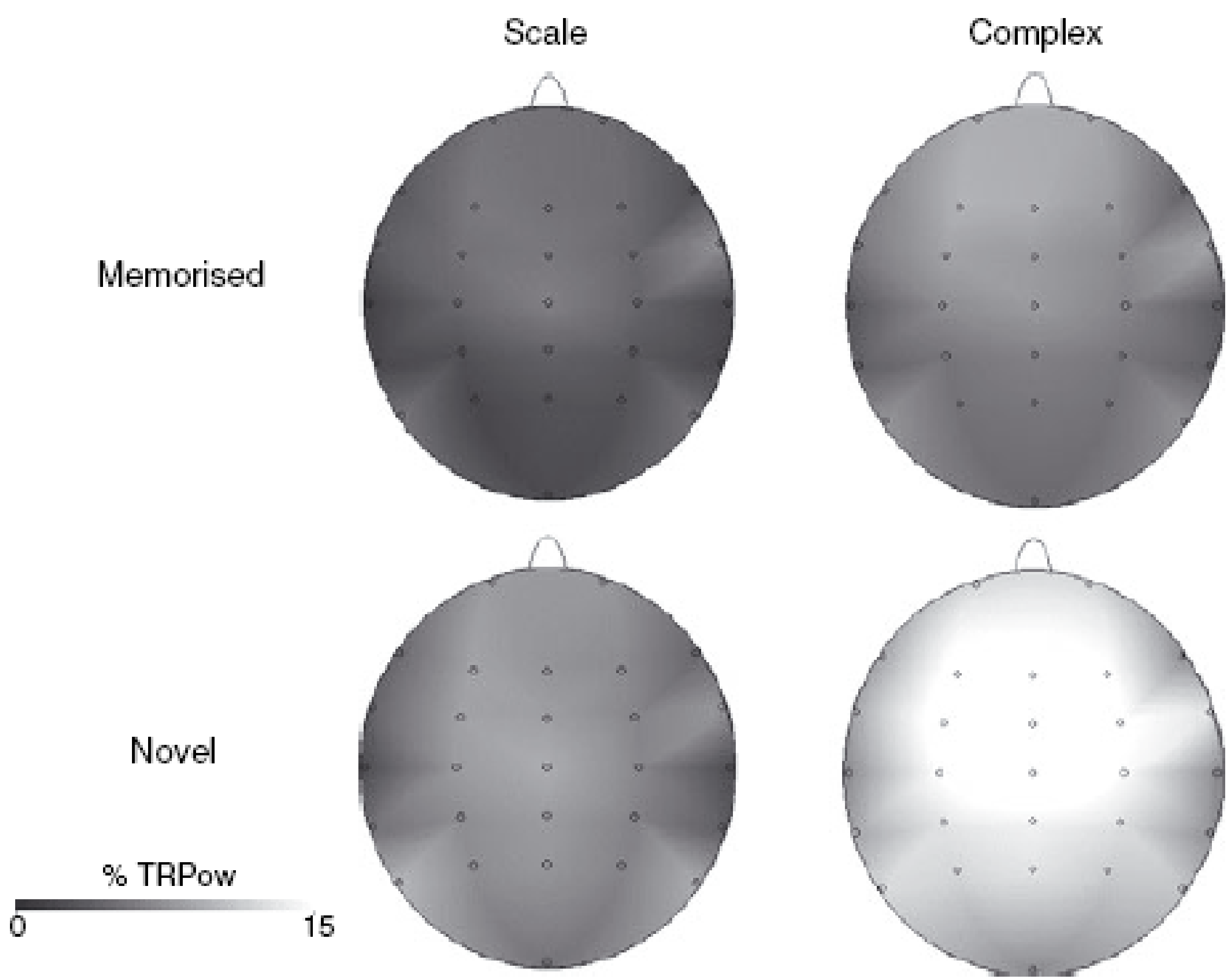
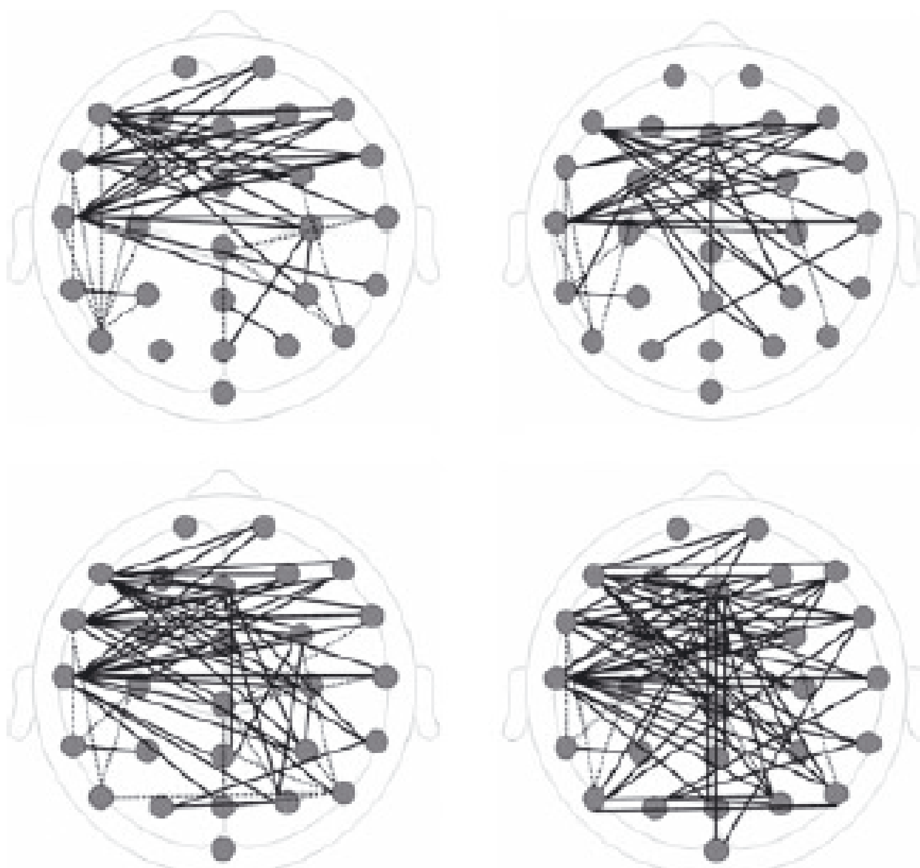


FIG. 1. Task-related theta (4–7 Hz) power increase. White indicates a strong task-related power increase compared with rest. Note that only during execution of novel and complex sequences is strong frontal-midline theta exhibited. This indicates that frontal theta activity reflects both memory load and sequence complexity.

Saueng Hoppe Klimesch Gerloff Hummel (2007)

Theta PLV



➢**Higher in Novel conditions, contrary to predictions**
➢**Speculate integration of visual with sensory-motor info**
➢**But, does theta=theta=theta? Fronto-central vs diffuse**

FIG. 3. Task-related theta phase coupling. Bold connections indicate a significant ($P < 0.005$) increase of theta phase coupling compared with rest, dotted lines indicate decrease of phase coupling. There are more significant electrode pairs during execution of novel sequences compared with performance of memorized ones. This effect is independent of task complexity. During both memorized and novel, there is no significant difference of the distributed theta network between scale and complex sequences.

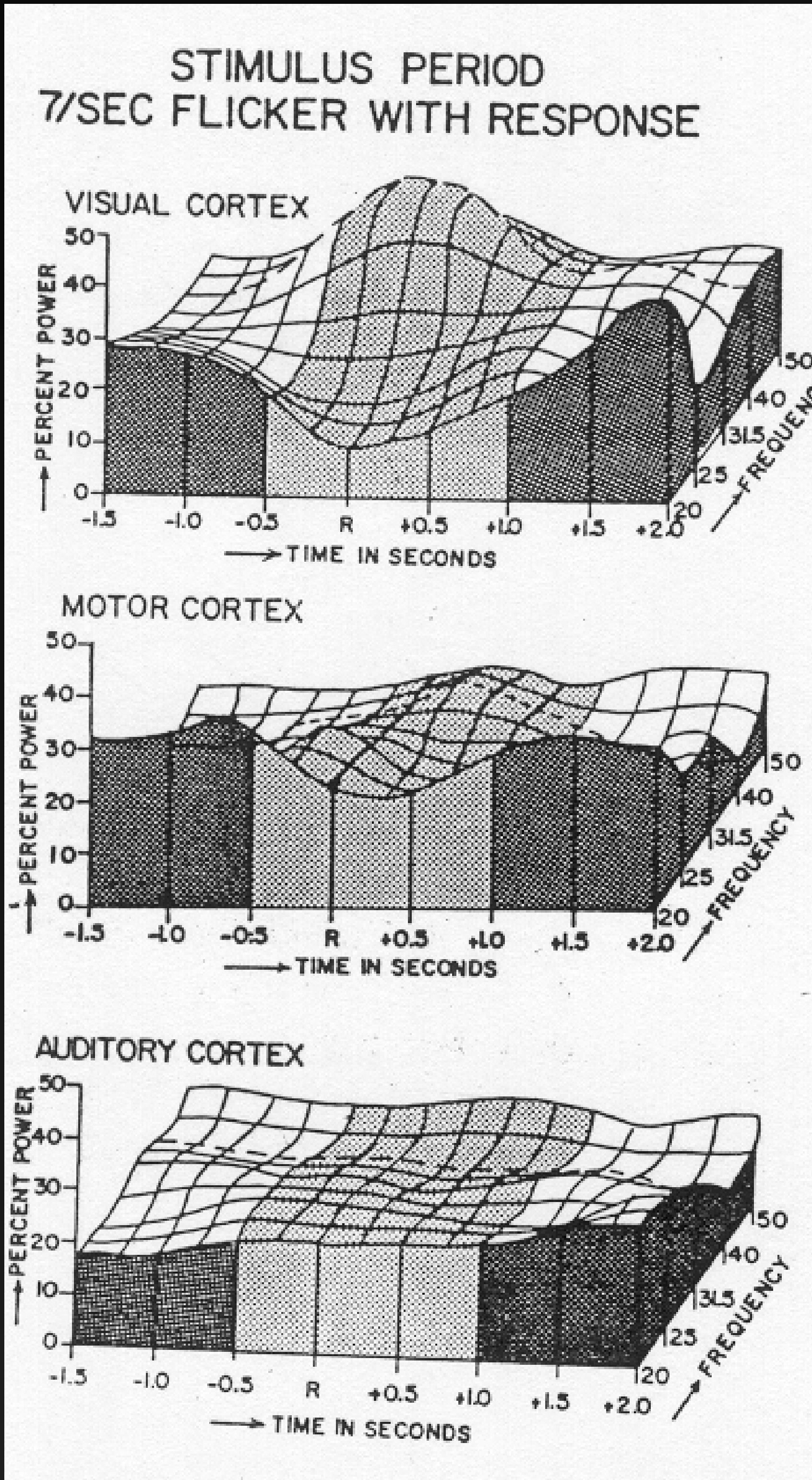
Saueng Hoppe Klimesch Gerloff Hummel (2007)

40 Hz Activity

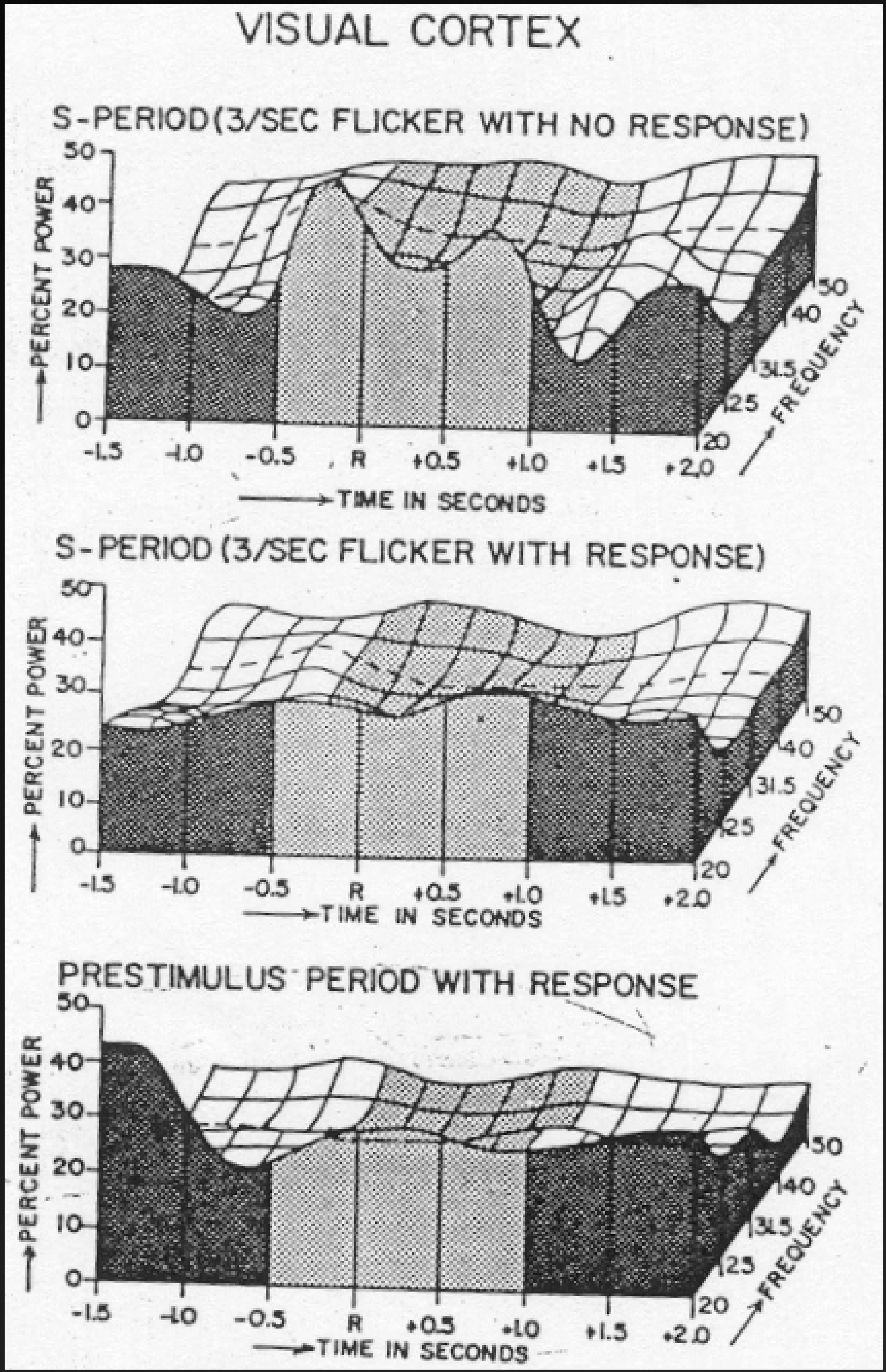
- First reports of important 40 Hz activity
- Sheer & Grandstaff (1969) review
  - pronounced rhythmic electrical bursting
- Daniel Sheer's subsequent work until his death renewed interest in "40 Hz" phenomena

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 to S_D, 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.

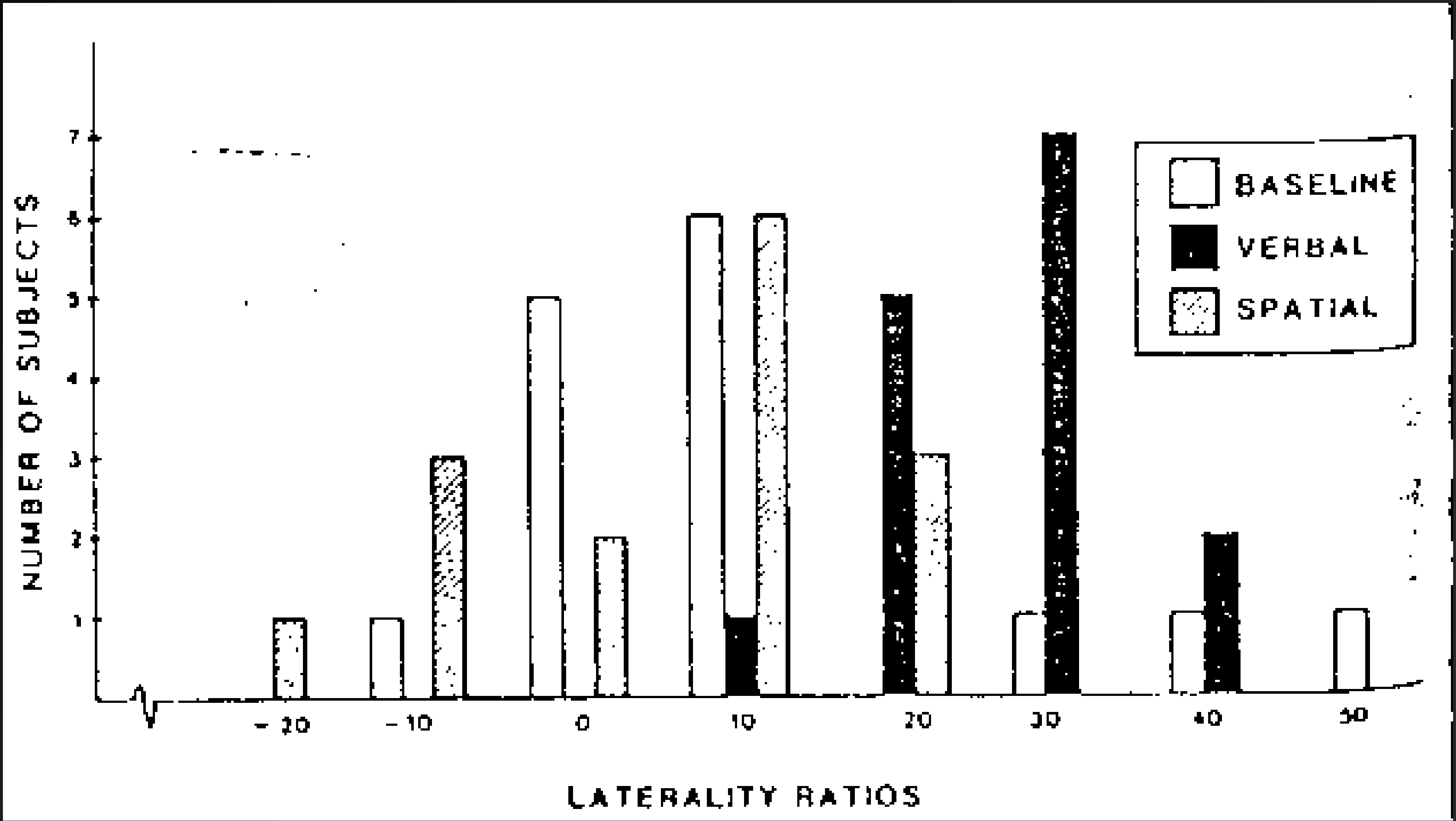
Human Studies

- 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*

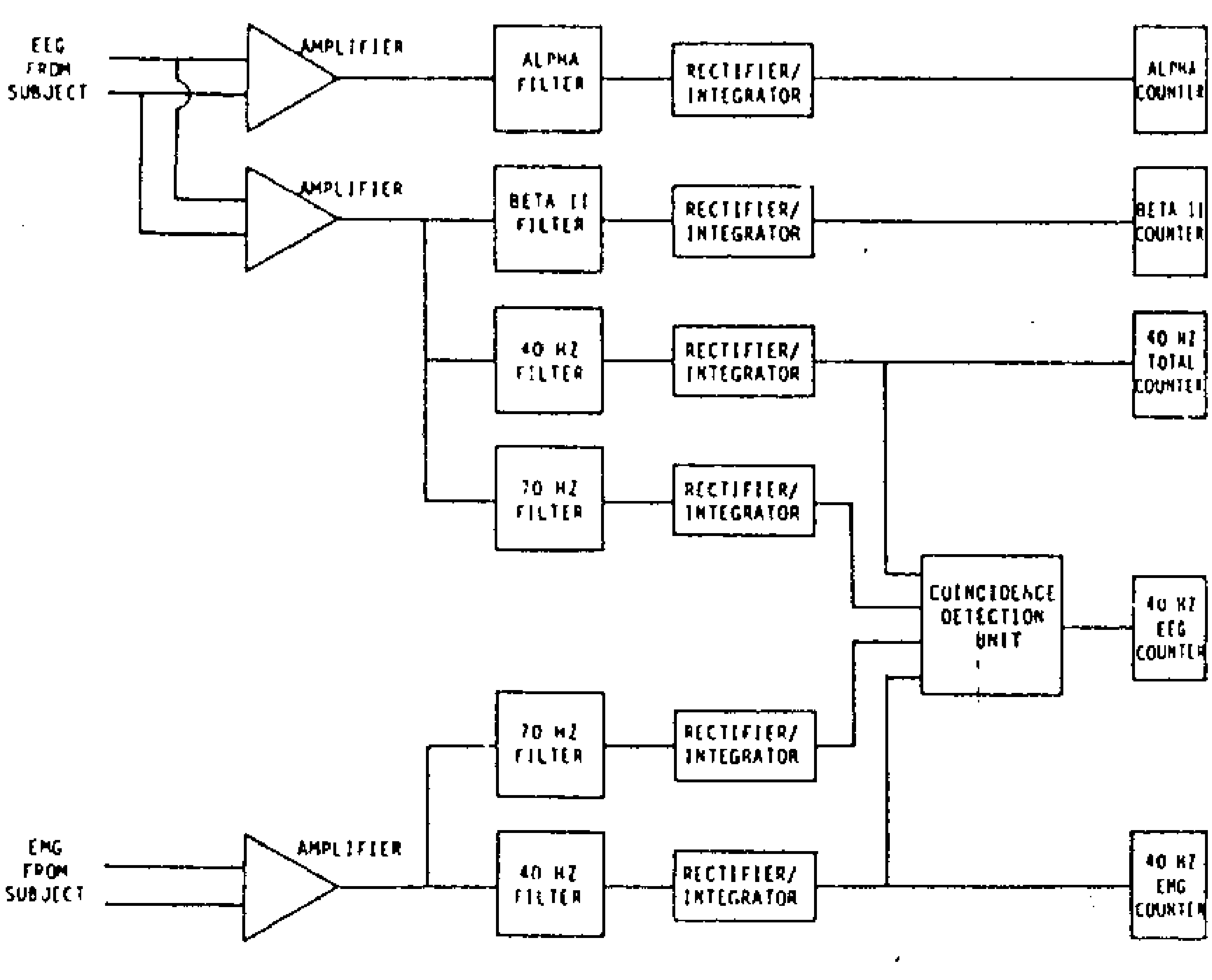
*$p<.05$.

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

*$p<.05$.

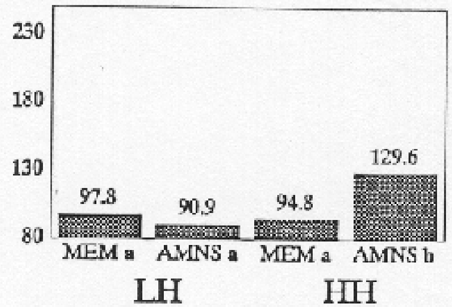

EEG FROM SUBJECT
AMPLIFIER
AMPLIFIER
ALPHA FILTER
BETA II FILTER
40 HZ FILTER
70 HZ FILTER
RECTIFIER/ INTEGRATOR
RECTIFIER/ INTEGRATOR
RECTIFIER/ INTEGRATOR
RECTIFIER/ INTEGRATOR
ALPHA COUNTER
BETA II COUNTER
40 HZ TOTAL COUNTER
COINCIDENCE DETECTION UNIT
40 HZ EEG COUNTER
70 HZ FILTER
RECTIFIER/ INTEGRATOR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

Individual Differences

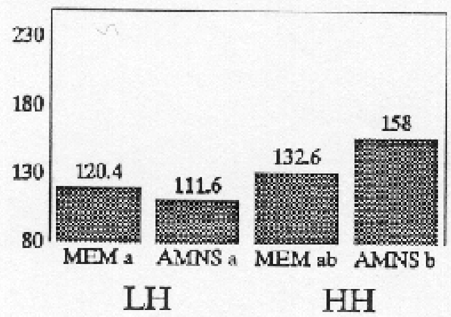
- Spydell & Sheer (1983), Alzheimers
  - controls showed task related changes in EEG with appropriate lateralization
  - Alz did not
- Schnyer & Allen (1995)
  - Most highly hypnotizable subjects showed enhanced 40 hz activity

EYES OPEN

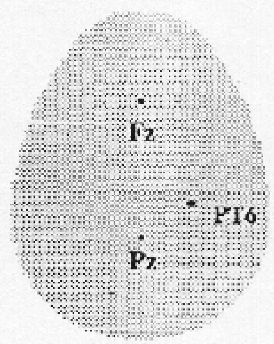
EYES CLOSED

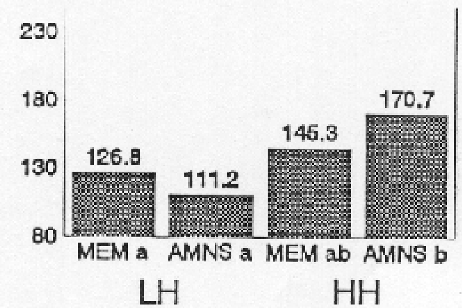


Site Fz, F[3, 37] = 4.72, p < .01

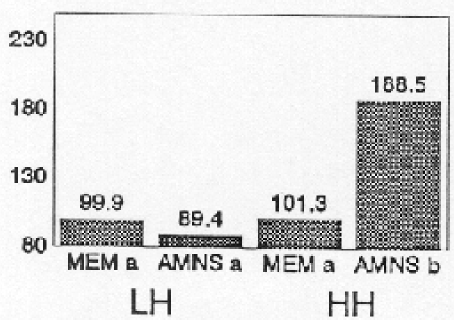


Site Pz, F[3, 37] = 4.73, p < .01

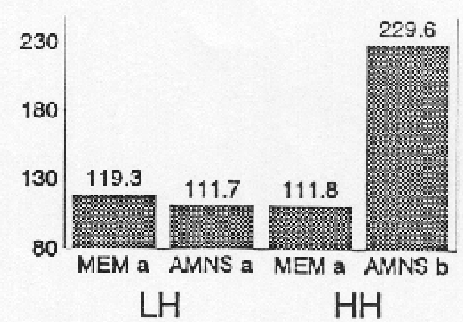




Site Pz, F[3, 37] = 6.46, p < .01



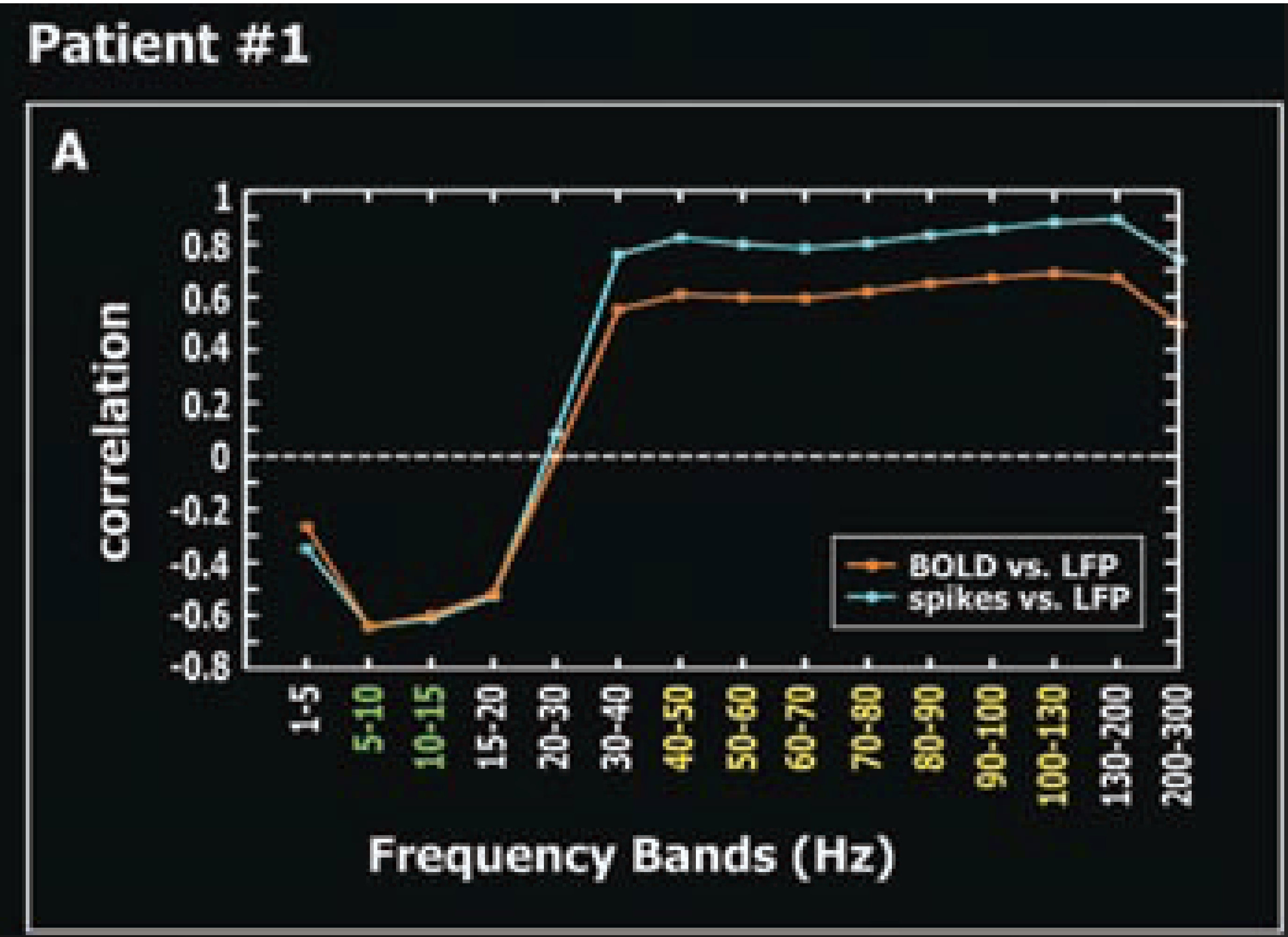
Site PT6, F[3, 37] = 10.82, p < .001



Site PT6, F[3, 37] = 5.30, 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…



Mukamel et al *Science* 2005
recorded single unit activity and local field potentials in auditory cortex of two neurosurgical patients and compared them with the fMRI signals of 11 healthy subjects during presentation of an identical movie segment. The predicted fMRI signals derived from single units and the measured fMRI signals from auditory cortex showed a highly significant correlation.

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 -- as yet merely a theory

- 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!
  - "Forty" = 40 $\pm$ some range
  - Gamma! (Stay tuned during advanced topics)