## Announcements 3/21/16

Today: The Electroencephalogram Papers: 1 or 2 paragraph prospectus due no later than Monday April 4
Lab Tomorrow (EEG!)

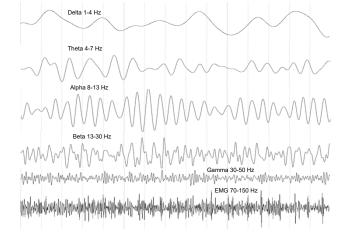
≻3x5 time

# 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

#### The Electroencephalogram

Basics in Recording EEG, Frequency Domain Analysis and its Applications

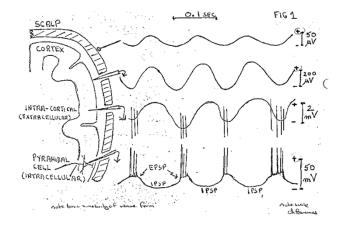


# Utility of EEG

- Relatively noninvasive
- Excellent time resolution

# Sources of scalp potentials

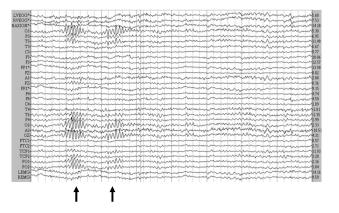
- Glial Cells minimal, some DC steady potentials
- ➤ Neurons
  - Action Potentials NO, brain tissue has strong capacitance effects, acting as Low Pass filter
  - ► <u>Slow waves</u>
    - Synaptic potentials YES, both IPSPs and EPSPs from functional synaptic units are major contributors
    - > Afterpotentials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

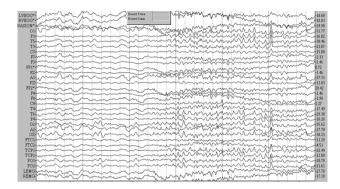


# Alpha and Synchronization

- ➢ Why Alpha?
  - ➤ It is <u>obvious</u> and hard to miss!
  - > Accounts for  $\sim 70\%$  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
  - Damage to thalamus DID disrupt cortical alpha rhythmicity
     Thalamic rhythmicity remains even in decorticate preparations
  - (Adrian, 1941)
  - > Removal of 1/2 thalamus results in ipsilateral loss of cortical alpha

Next

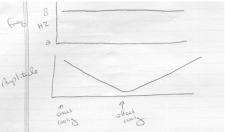




# Alpha and Synchronization

#### Andersen and Andersen (1968)

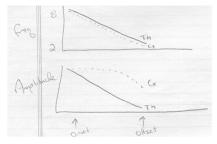
Cooling of Cortex resulted in change in amplitude but not frequency of Alpha



# Alpha and Synchronization

#### ➤ Andersen and Andersen (1968)

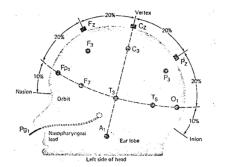
Cooling of Thalamus resulted in change in amplitude and frequency of Alpha at both thalamus and cortex

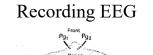


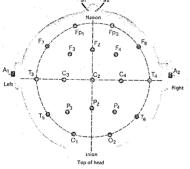
# Alpha and Synchronization

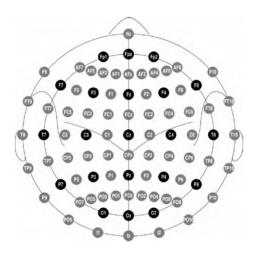
- In sum, Thalamus drives the alpha rhythmicity of the EEG
  - Cortex certainly does feedback to thalamus, but thalamus is responsible for driving the EEG
  - Particularly the Reticularis nucleus (Steriade et al. 1985)
- What causes change from rhythmicity to desynchronization?
  - Afferent input to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

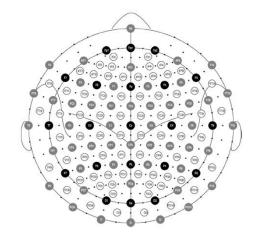
Recording EEG











# Systems are surface-based, not anatomically-based



Neurodinage

Automated cortical projection of EEG sensors: Anatomical correlation via the international 10–10 system L Koessler<sup>a,b</sup>, L Maillard<sup>b</sup>, A. Benhadid<sup>a</sup>, J.P. Vignal<sup>b</sup>, J. Felblinger<sup>a</sup>, H. Vespignani<sup>b</sup>, M. Braun<sup>a,cd,a</sup>

L KOESSIET \*\*, L Maillalt \*, A. Bernhadid \*, J.P. Vignal \* 808/B UB, Ange libering frame \* Normaling Department, University Hospital Nancy, France \* Normaling Department, University Hospital, Nancy, France \* #warmaning Department, University, France

## Electrodes, Electrolyte, Preparation

- Ag-AgCl preferred, Gold OK if slowest frequencies not of interest
  - $\succ$  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
- Reference choice nontrivial (more later) as it will change your ability to observe certain signals



## **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 advanced topics)

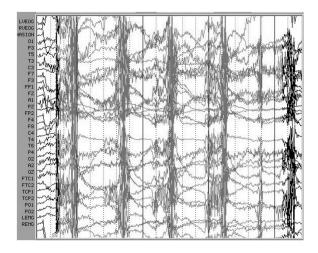
# Dreaded Artifacts

#### $\succ$ 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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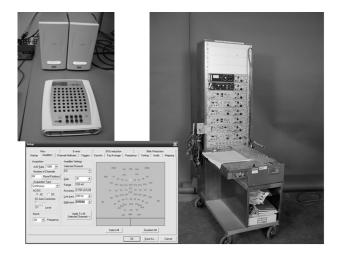
# AC Signal Recording Options

≻	Time	Constant/HP	filter
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Time Constant/HP filter > Low frequency cutoff is related to TC by:  $F = \frac{1}{(2\pi(TC))}$ 

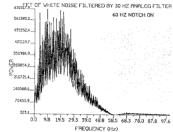
Where F = frequency in Hz, TC = Time Constant in Seconds

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!)

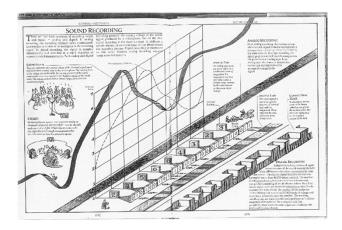


# **Digital Signal Acquisition**

- > 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)
    - $> 2.1250 \,\mu \text{ volts} => 2483 \text{ D.U.'s} (2483.20)$



#### 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 campling rate. sampling rate
- This frequency has come to be known as the Nyquist frequency and equals <sup>1/2</sup> the sampling rate ≻Comments
  - Wave itself looks distorted, but frequency is captured
- Wave itself looks distorted, but frequency is capture 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<sub>Ny</sub> + x Hz will be seen as F<sub>Ny</sub> x Hz
  - ➤ "folding back"
    - ➤ frequency 2F<sub>Ny</sub> seen as 0,
    - ≻ frequency 3F<sub>Nv</sub> will be seen as F<sub>Nv</sub>
    - ▶accordion-like folding of frequency axis

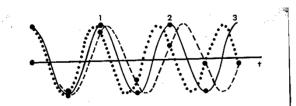


Fig. 3.1. A cosine wave of frequency F (solid line) sampled at its Nyquist rate. A higher frequency (dotted) wave, frequency F + a, is shown sampled at the same rate. At the sample times it is indistinguishable from a lower frequency (dashed) wave, frequency F - a.

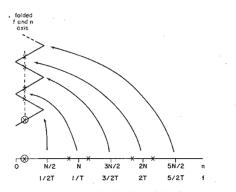
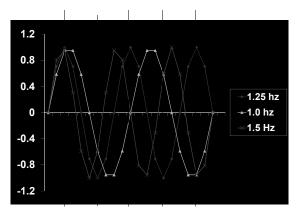
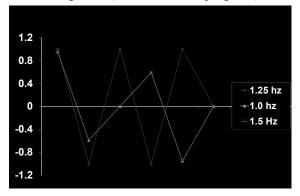


Fig. 3.2. The accordionlike folding of the frequency (or n) axis due to sampling of a continuous signal. Frequency components of the original signal marked with x's on the f axis are interpreted in the sampled version as belonging to the lowest frequency, an encircled x.

Aliasing Demo (Part 1, 10 Hz Sampling Rate)



Aliasing Demo (Part 2, 2.5 Hz Sampling Rate)



# Matlab Demo of Aliasing

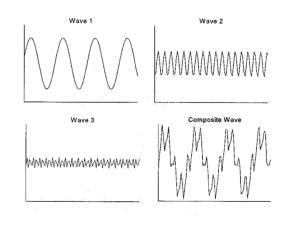


# Solutions to Aliasing

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

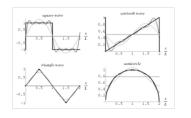
## Time Domain Vs Frequency Domain Analysis

- 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



## 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



# Interactive Fourier!

≻<u>Web Applet</u>



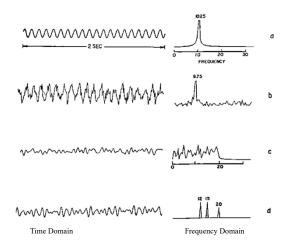
#### ➢ Pragmatic Details

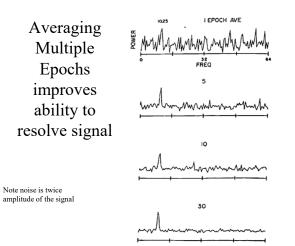
- Lowest Fundamental Frequency is 1/T
   Resolution is 1/T
- ➢ Phase and Power
  - There exist a phase component and an amplitude component to the Fourier series representation
    - > Using both, it is possible to completely reconstruct the waveform.
- Psychophysiologists often interested in amplitude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

 $|\text{Amp}_{\cos}^2 + \text{Amp}_{\sin}^2|$ 

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

 $|\text{Amp}_{\text{cos}}^2 + \text{Amp}_{\text{sin}}^2|^{1/2}$ 





# Lingering details

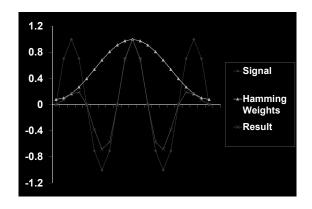
- In absence of phase information, it is impossible to reconstruct the original signal
  - Infinite number of signals that could produce the same amplitude or power spectrum
- Spectra most often derived via a Fast Fourier transform (FFT); a fourier transform of a discretely sampled band-limited signal 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

## Preventing Spectral Leakage

#### ≻Use windows

- ≻not Micro\$oft Windows
- ≻Hamming
- ≻Hanning
- ≻Cosine
- ≻Etc.





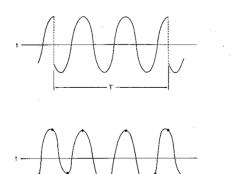


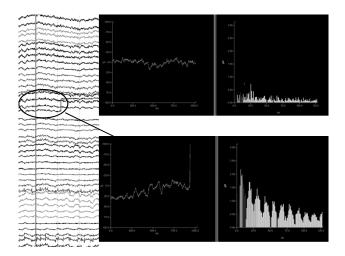
Fig. 3.3. Top, a periodicized segment of a cosine wave. I is the observation time and 3T/8 the period of the wave. Note the discontinuities at 0 and T. Bottom, a continuous and periodic band-limited wave drawn through the sample points  $\Delta = T/16$  see apart.

Matlab Demo of Hamming Window



# **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

Frequency-domain EEG applications and methodological considerations

# Applications

≻Emotion Asymmetries

#### ≻Lesion findings

- Catastrophic reaction (LH)
- ≻RH damage show a belle indifference
- ≻EEG studies
  - ≻ Trait (100+ studies)
  - State (oodles more studies)

# 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)

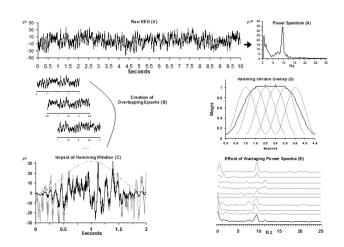
➤ State

> State EEG asymmetry covaries with current emotional state (e.g., self report, spontaneous emotional expressions)

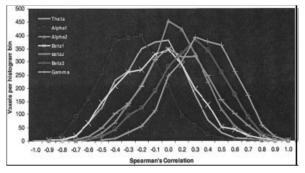
#### Trait, Occasion, and State variance

- > 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
      - experimental manipulations> should be reversible and of relatively short duration
- > Unreliability of Measurement (small)

Allen, Coan, & Nazarian 2004



#### Alpha Vs Activity Assumption (AAA)

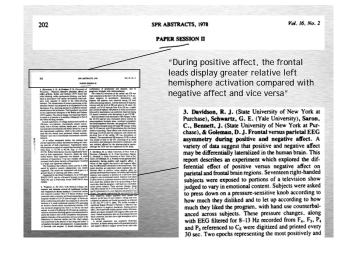


Oakes et al, 2004, Human Brain Mapping

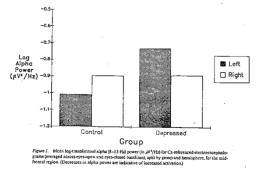
# Alpha and Activity

- ➤May be more apt to think of alpha as regulating network activity
- High alpha has inhibitory function on network activity (more in advanced topics)

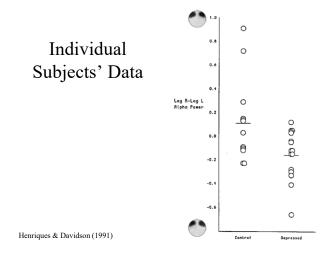
# EEG Asymmetry, Emotion, and Psychopathology



#### Left Hypofrontality in Depression



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)



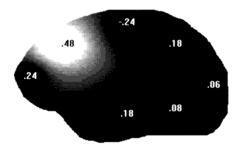
## Valence Vs Motivation

#### ➤ 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?

## 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
  - regative 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

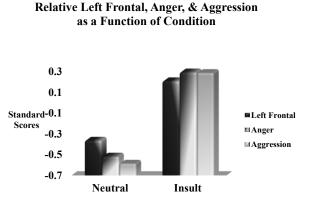
Harmon-Jones & Sigelman, JPSP, 2001

- ▶ 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



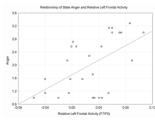
Harmon-Jones & Sigelman, JPSP, 2001



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

## Manipulation of EEG

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

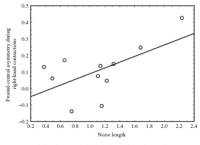


Figure 1. Relation between noise length and frontal-central asymmetry during right-hand contractions. Higher asymmetry scores indicate greater relative left than right activation.

Peterson, Shackman, Harmon-Jones (2008)

# 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)

#### Motivational Styles and Depression

#### Behavioral Activation Scale

Reward Responsiveness

When I see an opportunity for something I like, I get excited right away.

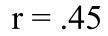
≻Drive

I go out of my way to get things I want.

- ➤Fun Seeking
  - I'm always willing to try something new if think it will be fun.

Carver & White, 1994

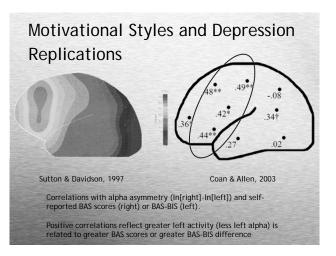
#### Motivational Styles and Depression



Mid-Frontal Asymmetry and BAS Scores Mid-Frontal Asymmetry and PA Scores

r = .00

Harmon-Jones & 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)

#### 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 $\neq$ 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

■ Right □ Left 0.1 0.08 0.06 0.04 Baseline Adj. R-L Alpha 0.02 0 -0.02 -0.04 -0.06 -0.08 -0.1 Day 5 Day 2 Dav 1 Day 3 Day 4

**Training Effects: Asymmetry Scores** 

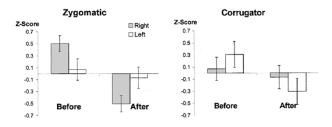
Manipulation of EEG asymmetry with biofeedback produced differential change across 5 days of training; Regression on Day 5

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



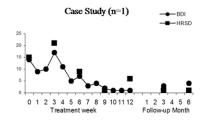
Despite no differences prior to training, following manipulation of EEG asymmetry with biofeedback subjects trained to increase left frontal activity report greater positive affect.

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



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

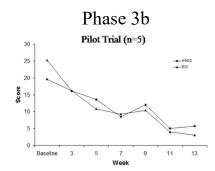
Phase 3a



Biofeedback provided 3 times per week for 12 weeks

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



"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

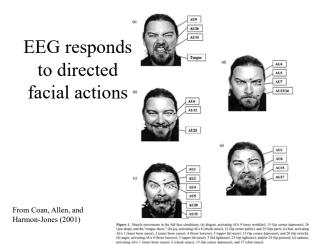


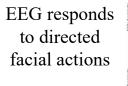
#### State Changes

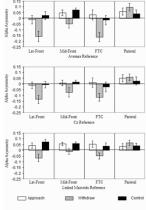
- ➤ Infants
  - Stanger/Mother paradigm (Fox & Davidson, 1986)
  - Sucrose Vs water (Fox & Davidson, 1988)
  - ➢ Films of facial expressions (Jones & Fox, 1992; Davidson & Fox, 1982)
- Primates
  - Benzodiazepines increases LF (Davidson et al., 1992)

## 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)







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

States – how short can they be?

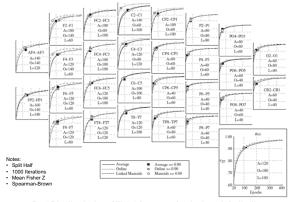
Psychophysiology, 46 (2009), 132–142. Wiley Periodicals, Inc. Printed in the USA. Copyright © 2008 Society for Psychophysiological Research DOI: 10.1111/j.1469-8986.2008.00759.x

A better estimate of the internal consistency reliability of frontal EEG asymmetry scores

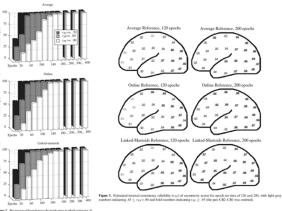
DAVID N. TOWERS AND JOHN J.B. ALLEN

#### Abstract

Fornial alpha asymmetry is typically computed using alpha power averaged across many overlapping epochs. Previous reports have estimated the internal consistency reliability of asymmetry by dividing resting EEG sessions into segments of equal duration (e.g., 1 min) and treating asymmetry soces for each segment as "items" to estimate internal consistency reliability using Cronbach's alpha. Cronbach's alpha partly depends on the number of items, such that this approach may underestimate reliability by using less than the number of distinct items available. Reliability estimates for resting EEG data in the present study (204 subjects, 8 sessions) were obtained using mean split-half correlations with epoch alpha power as treated as separate items. Estimates at all assign bies and reference schemes approached 90 with a few as 100 epochs, suggesting the internal consistency of frontal asymmetry is greater than that previously reported.



"igner 1. Estimated internal consistency reliability  $(r_{PI})$  of asymmetry scores for epoch set uise *n* ranging from 2010 e000, across verage (bick), online (gray), and linked-massish (stabular) ference derivations and all homologous destrote pairs. Graph markers and table insets indicate the epoch set size *n* at which the estimated internal consistency reliability coefficient for each effected entries that was grater than or equal to .90.



repert 2. Prevenue of the interval of the interval of the interval consistency relability (rgr) of asymmetry scores were greate than or equal to .70 (white), .80 (light gray), and .90 (dark gray) as i function of epoch set size n and reference derivation.

# State EEG in CIT!

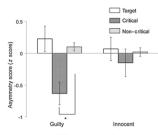


Fig. 2. Grand average frontal EG asymmetry scores for target, critical, and noncritical items in the guilty and innocent condition. Asymmetry score + ln[F4 alpha power] – ln[F3 alpha power]. Bars depict standard errors, \*p < .05.

Matsuda, Nittono, & Allen, Neurosci Letters, 2013