Frequency-domain EEG applications and methodological considerations

Announcements

- Papers: 1 or 2 paragraph prospectus due no later than Monday March 25
- 3x5s

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 (usually 2^x, e.g. 2^12 = 4096)

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
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

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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

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.
- 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
    \[ |\text{Amp}_{\cos}^2 + \text{Amp}_{\sin}^2|^{1/2} \]

Preventing Spectral Leakage

- Use windows
  - not MicroSoft Windows
  - Hamming
  - Hanning
  - Cosine
  - Etc.

Hamming Demo

**Fig. 3.1.** Top, a periodized segment of a cosine wave. \( T \) is the observation time and \( 2\pi/T \) the period of the wave. Notice the discontinuities at 0 and \( T \). Bottom, a continuous and period-ic band-limited wave drawn through the sample points \( k = 7/16 \) sec 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

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
      - should be reversible and of relatively short duration

- **Unreliability of Measurement (small)**
  - Allen, Coan, & Nazarian 2004

Alpha Vs Activity Assumption (AAA)

EEG Asymmetry, Emotion, and Psychopathology
"During positive affect, the frontal leads display greater relative left hemisphere activation compared with negative affect and vice versa."

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 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.


**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
  - 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)

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 Aggression

- 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 diff 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 during hand contractions predicted aggression
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 I think it will be fun.*

Carver & White, 1994

Motivational Styles and Depression

\[ r = .45 \]

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, Schultkin, & Gold, 1999)
R>L Activity (L>R Alpha) characterizes:

- depressive disorders and risk for depression (e.g. Allen, Iacono, Depue, & Arbis, 1993; Gotlib, Fanaganath, & 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 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

State Changes

- Infants
  - Stranger/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)

States – how short can they be?

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

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Abstract

Frontal alpha asymmetry is typically assessed using alpha power averaged across many overlapping epochs. Previous research has examined the internal consistency reliability of asymmetry by dividing raw EEG measures into segments of equal duration (e.g., 1 min) and treating asymmetry scores for each segment as “items” to estimate internal consistency reliability using Cronbach’s alpha. Cronbach’s alpha partly depends on the number of items, and this approach may underestimate reliability by using less than the number of distinct items available. Reliability estimates for scoring EEG data in the present study (396 subjects), a measure was obtained using pairs with half correlations with scalp alpha power as treated as separate items. Estimates at all scalp sites and reference schemes approached .90 with as few as 100 epochs, suggesting the internal consistency of frontal asymmetry is greater than that previously reported.
Resting brain asymmetry as an endophenotype for depression

Endophenotypes

- Intermediate-level measure of characteristics related to risk for disorder
- Less complex phenotype for genetic association
- Can include, biochemical and imaging measures, among others
- Desiderata
  - Specificity
  - Heritability
  - State-independence
  - Familial Association
  - Co-segregation within families
  - Predicts development of disorder


Depression as a Heterogeneous Phenotype

- Variable Age of Onset
- Variable Symptom Presentation
- Variable Course
- Variable Response to Treatment

Depression: Variable Age Onset

Data from Kessler et al., Arch Gen Psychiatry, 2005, 62:593-602

Kendler, Fiske, Gardner, & Gatz, 2009, Biological Psychiatry