Frequency-domain EEG applications and methodological considerations
Announcements 3/22/21

- Paper/Proposal Guidelines available on course webpage (link in D2L too)
  - Two paragraph prospectus due (on D2L) no later than Monday April 19
- Lab meets Wednesday!
- Class Feedback and Q&A
Frequency-domain EEG applications and methodological considerations
Time Domain

Frequency Domain
Figure 9: Constructing a complex signal from the superposition of sinusoids (top). The power spectrum of the signal show distinct peaks at the frequencies of the component sinusoids. A single sinusoid corresponds to a single peak in the power spectrum (bottom).
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.
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 (150+ 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)

For reviews:
Allen, Coan, & Nazarian 2004
Allen & Reznik, 2015
Reznik & Allen, 2018
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
Smith, Reznik, Stewart, & Allen, 2017
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
EIGHTEENTH ANNUAL MEETING
SOCIETY FOR PSYCHOPHYSIOLOGICAL RESEARCH

The Eighteenth Annual Meeting of The Society for Psychophysiological Research was held at The Concourse Hotel in downtown Madison, Wisconsin, September 15, 16, 17, and 18, 1978. Members of the Program Committee were: Rafael Klorman and Ted Weerts (Co-Chairmen), Michael Coles, Don Fowles, Linda Gannon, Arnold J. Rich, Jennings, Rathe Karrer, Michael Nelson, Arne Öhman, Leonard Salzman, and David Siddle.

As in recent years, the bulk of the research reports were given and discussed informally at Friday and Sunday evenings, September 15 and 17. In addition, research reports were presented at sessions on Saturday and Monday mornings, and others were included in the Display and Discussion Area, which ran in tandem with the meetings on Saturday from 8:30 to 5:00. Several symposia, workshops were also included in this year's program.

Following are the abstracts of research reports presented and discussed during the Paper Session, Display and Discussion poster session.
1978
"During positive affect, the frontal leads display greater relative left hemisphere activation compared with negative affect and vice versa."

3. Davidson, R. J. (State University of New York at Purchase), Schwartz, G. E. (Yale University), Saron, C., Bennett, J. (State University of New York at Purchase), & Goleman, D. J. Frontal versus parietal EEG asymmetry during positive and negative affect. A variety of data suggest that positive and negative affect may be differentially lateralized in the human brain. This report describes an experiment which explored the differential effect of positive versus negative affect on parietal and frontal brain regions. Seventeen right-handed subjects were exposed to portions of a television show judged to vary in emotional content. Subjects were asked to press down on a pressure-sensitive knob according to how much they disliked and to let up according to how much they liked the program, with hand use counterbalanced across subjects. These pressure changes, along with EEG filtered for 8–13 Hz recorded from F4, F3, P4, and P3 referenced to Cz, were digitized and printed every 30 sec. Two epochs representing the most positively and negatively rated affective conditions were averaged.
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

Henriques & Davidson (1991)
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.

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, JPS, 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 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 during 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 I think it will be fun.*
Motivational Styles and Depression

$r = .45$

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

$r = .00$

Harmon-Jones & Allen, 1997
Motivational Styles and Depression
Replications

Sutton & Davidson, 1997

Correlations with alpha asymmetry (ln[right]-ln[left]) and self-reported BAS scores (right) or BAS-BIS (left).

Positive correlations reflect greater left activity (less left alpha) is related to greater BAS scores or greater BAS-BIS difference

Coan & Allen, 2003
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 ≠ 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

Case Study ($n=1$)

Biofeedback provided 3 times per week for 12 weeks
“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

Dropout rate > 70%!
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)
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 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 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, 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 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.
Notes:
- Split Half
- 1000 Iterations
- Mean Fisher Z
- Spearman-Brown

Figure 1. Estimated internal consistency reliability ($r_{TT}$) of asymmetry scores for epoch set sizes $n$ ranging from 20 to 400, across average (black), online (grey), and linked-mastoids (dashed) reference derivations and all homologous electrode pairs. Graph markers and table insets indicate the epoch set size $n$ at which the estimated internal consistency reliability coefficient for each reference derivation was greater than or equal to .90.
Figure 2. Percentage of homologous electrode pairs in which estimates of internal consistency reliability ($r_{TT}$) of asymmetry scores were greater than or equal to .70 (white), .80 (light gray), and .90 (dark gray) as a function of epoch set size $n$ and reference derivation.

Figure 3. Estimated internal consistency reliability ($r_{TT}$) of asymmetry scores for epoch set sizes of 120 and 200, with light gray numbers indicating $.85 \leq r_{TT} < .90$ and bold numbers indicating $r_{TT} \geq .95$ (the pair CR2-CBI was omitted).
State EEG in CIT!

Fig. 2. Grand average frontal EEG asymmetry scores for target, critical, and non-critical 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
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

World Disability Adjusted Life Years (Millions)

- Lower Respiratory Infections: 94.5
- Diarrhoeal Diseases: 62.6
- Unipolar Depression: 65.5
- Ischemic Heart Disease: 72.8
- HIV/AIDS: 58.5

World Health Organization, 2008
Middle Income Countries

World Disability Adjusted Life Years (Millions)

- 28.9 Lower Respiratory Infections
- 27.5 Road/Traffic Accidents
- 21.4 Ischemic Heart Disease
- 16.3 Cerebrovascular Disease
- 29.0 Unipolar Depression

World Health Organization, 2008
Upper Income Countries

World Disability Adjusted Life Years (Millions)

- 10.0 Unipolar Depression
- 7.7 Ischemic Heart Disease
- 4.8 Cerebrovascular Disease
- 4.4 Alzheimer's and Other Dementias
- 4.2 Alcohol Use Disorders

World Health Organization, 2008
Depression
Depression as a Heterogeneous Phenotype

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

Age at Select Percentiles for Onset of MDD

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

Figure 1. The relationship between the age at onset of major depression (MD) in an affected twin and the natural logarithm of the hazard ratio in the cotwin for MD (in open circles) and vascular disease (VD) (in filled-in circles). These results are obtained from a Cox proportional hazard model controlling for age, sex, and birth cohort. We fitted to these results piecewise models with a single inflection point using a grid search to find the single inflection point that maximized the model's -2 log likelihood.
Treating and Preventing Depression

- Identify those at risk
- Identify factors that place folks at risk
- Develop interventions to address those factors
Positive Affect and Mood
Behavioral Engagement
Approach Motivation
(including Anger)
High Behavioral Activation

Negative Affect and Mood
Behavioral Disengagement
Withdrawal Motivation
Low Behavioral Activation

\[ \ln(R) - \ln(L) \] Alpha
Hypothesized Findings

- MDD+
- MDD−
Frontal EEG asymmetry as risk marker for MDD

Several Desiderata...
Frontal EEG asymmetry as risk marker for MDD

Resting EEG asymmetry is a stable trait

- in clinical populations
  (Allen, Urry, et al., 2004; Jetha, Schmidt, & Goldberg, in press; Niemic & Lithgow, 2005; Vuga, et al., 2006)

- and nonclinical populations
  (Hagemann, Naumann, Thayer, & Bartussek, 2002; Jones, Field, Davalos, & Pickens, 1997; Papousek & Schulter, 1998, 2002; Tomarken, Davidson, Wheeler, & Doss, 1992; Tomarken, Davidson, Wheeler, & Kinney, 1992)
Allen, Urry, Hitt, & Coan (2004), *Psychophysiology*
Frontal EEG asymmetry as risk marker for MDD

Changes in clinical status are not associated with changes in resting EEG asymmetry
Frontal EEG asymmetry as risk marker for MDD

Resting EEG asymmetry is:

- modestly heritable
  (Anokhin, Heath, & Myers, 2006; Coan, Allen, Malone, & Iacono, 2009; Smit, Posthuma, Boomsma, & De Geus, 2007)

- related to serotonergic candidate genes such as HTR1A allele variations
  (Bismark, et al., 2010)
Frontal EEG asymmetry as risk marker for MDD

Resting EEG asymmetry relates to internalizing disorders:

- MDD and depressive symptoms (Allen, Urry, et al., 2004; Bruder, et al., 2005; Debener, et al., 2000; Diego, Field, & Hernandez-Reif, 2001; Diego, Field, & Hernandez-Reif, 2001; Fingelkurts, et al., 2006; Ian H. Gotlib, Ranganath, & Rosenfeld, 1998; J. B. Henriques & Davidson, 1990; Jeffrey B. Henriques & Davidson, 1991; Mathersul, Williams, Hopkinson, & Kemp, 2008; Miller, et al., 2002; Pössel, Lo, Fritz, & Seeman, 2008; Schaffer, Davidson, & Saron, 1983; Vuga, et al., 2006);
Frontal EEG asymmetry as risk marker for MDD

Resting EEG asymmetry relates to internalizing disorders:

- Anxious arousal/somatic anxiety (Mathersul, et al., 2008; Nitschke, Heller, Palmieri, & Miller, 1999; J.L. Stewart, Levin-Silton, Sass, Heller, & Miller, 2008);
- Panic disorder (Wiedemann, et al., 1999);
- Comorbid anxiety/depression (Bruder, et al., 1997);
- Social phobia (R. J. Davidson, Marshall, Tomarken, & Henriques, 2000);
Frontal EEG asymmetry as risk marker for MDD

- Resting EEG asymmetry relates to internalizing disorders:
  - Premenstrual dysphoria (Accortt & Allen, 2006; Accortt, Stewart, Coan, Manber, & Allen, 2010);
PMDD

mood swings
marked anger
irritability depressed mood
appetite changes
difficulty concentrating fatigue
anxiety sleep difficulties
feeling out of control
physical symptoms
decreased interest
tension

Accortt & Allen, 2006
PMDD

Assessed at
- Late-Luteal
- Follicular

Accortt & Allen, 2006
Specificity or Spectrum: PMDD

Asymmetry by region

- **HIGHS**
- **LOWS**

Region:
- F7F8
- F3F4
- FTC12
- T3T4

Accortt & Allen, 2006
PMDD

- Larger Sample
- Diagnostic Interviews
- Matched for MDD

Accortt, Stewart, Coan, & Allen, 2010
PMDD

Accortt, Stewart, Coan, & Allen, 2010
Frontal EEG asymmetry as risk marker for MDD

Resting EEG asymmetry relates to internalizing disorders:

Childhood/adolescent internalizing psychopathology (anxiety, sadness, disappointment, low empathy and sociability, higher stress cortisol, and avoidant-withdrawn behavior (Baving, Laucht, & Schmidt, 2002; Buss, et al., 2003; R.J. Davidson, 1991; Forbes, Fox, Cohn, Galles, & Kovacs, 2005; N.A. Fox, Henderson, Rubin, Calkins, & Schmidt, 2001; Henderson, Marshall, Fox, & K.H., 2004; Schmidt, Fox, Schulkin, & Gold, 1999).
Frontal EEG asymmetry as risk marker for MDD

Resting EEG asymmetry identifies *family members* of those with internalizing disorders

Meta-Analysis: Depression, Anxiety

- Studies of resting frontal alpha asymmetry
- Measures of depression or anxiety
- Both adult and infant samples

Literature Sample:
- 31 papers
- 59 tests (studies, sites, reference)
- Adult samples predominantly female

Thibodeau, Jorgensen, & Kim, 2006
Mean Effect Sizes
- Adults $d=0.54$
- Infants $d=0.61$

Moderators
- Reference
- Recording length
- Co-morbidity

Publication Bias
- ↑ Effect Size
- Can’t account for full effects

Thibodeau, Jorgensen, & Kim, 2006
A “Definitive” Study

- Large (n=306), medication-free
  - Both men (n=95) and women (n=211)
  - Lifetime Depressed (n=143)
  - Never Depressed (n=163)
- Assessed for Family History
- No co-morbidity, medically healthy

Stewart, Bismark, Towers, Coan, & Allen, 2010
A “Definitive” Study

- Large (n=306), medication-free
- Assessed for Family History
- No co-morbidity, medically healthy
- Resting EEG
  - Two sessions per day
  - Four days
- Four Reference Montages
- Mixed Linear Models

Stewart, Bismark, Towers, Coan, & Allen, 2010
Completed BDI in Pre-Testing (N = 10,227)

Invited to Participate in Study Screening (N = 1904)

Invited for Interview (N = 520)
Did Not Respond (N = 863)
Excluded After Screening (N = 521)
- Epilepsy (N = 3)
- Unknown (N = 19)
- Did Not Schedule Interview (N = 65)
- Head Injury/LOC (N = 85)
- Psychotropic Medication (N = 104)
- Left-handedness (N = 245)

Excluded After Interview (N = 197)
- No Longer Interested (N = 9)
- Psychotropic Medication (N = 11)
- Unknown (N = 14)
- Did Not Show for Interview (N = 15)
- Subsyndromal Past MDD and No Current MDD (N = 18)
- Did not Meet targeted BDI severity range just prior to screening (N = 30)
- Head Injury/LOC (N = 33)
- Comorbid Axis I Diagnoses (N = 67)

Eligible and Enrolled in Study (N = 323)

Final Sample for Analysis (N = 306)
- Withdrew From Study Prior to EEG Recording (N = 10)
- Excluded for a diagnosis of Current Dysthymia without MDD (N = 7)

Anxiety Disorders
- PTSD (N = 1)
- Social Phobia (N = 2)
- Panic Disorder (N = 3)
- Anxiety NOS (N = 4)
- Specific Phobia (N = 6)
- OCD (N = 7)
- GAD (N = 11)

Substance Use
- Dependence (N = 13)
- Abuse (N = 33)

Psychotic Disorders
- Psychotic NOS (N = 1)
- Schizophrenia (N = 1)
- Bipolar Disorder (N = 4)

Eating Disorders
- Eating NOS (N = 4)
- Bulimia (N = 7)
- Anorexia (N = 8)

Other
- Hypochondriasis (N = 3)
- ADHD (N = 5)
Figure 2. Panel A shows frontal alpha asymmetry scores (8–13 Hz at F2–F1, F4–F3, F6–F5, F8–F7) by lifetime MDD status for each reference montage across all four frontal regions depicted on the head insert. Error bars reflect standard error. Panel B shows results of a follow-up assessment indicating that the relationship of lifetime MDD status to CSD-referenced asymmetry is not solely accounted for by current MDD status. The y-axis is ln μV² for AVG, Cz, and LM references, and ln μV²/cm² for CSD referenced data. MDD = major depressive disorder; AVG = average; CSD = current source density; CZ = Cz; LM = linked mastoid.
STICK WITH CSD...
Interim Synopsis: Endophenotype Desiderata

☑ Specificity: Associated with disorder
☑ Heritability
☑ State-independence: Primarily trait
☑ Familial Association: Seen in unaffected family members at rates higher than general population
☑ Predictive Power: predicts future disorder in unaffected individuals
Prospective Pilot Data

- Assessed never depressed (MDD-) individuals ~1 year after EEG
- Obtained 54 of 163 (representative)
- Completed BDI based on “worst month”
- BDI worst month residualized on BDI at EEG assessment
- Can EEG predict this worst month BDI score?
Prospective Pilot Data

EEG Asymmetry by BDI Follow-up

See also Nusslock et al., *J Abnormal Psychology*, 2011

Stewart & Allen, *Bio Psychology* 2018
Prospective Pilot Data: a wrinkle

CSD: Sex x Follow-Up BDI-II

- Men (n=16)
- Women (n=38)

Frontal Alpha Asym (R-In(L))

Follow-Up BDI-II (z-score)

Stewart & Allen, Bio Psychology 2018
Thus

- Frontal EEG asymmetry has promise as a risk indicator for MDD and other internalizing disorders

Need:
- Large-scale prospective study
- Links to underlying neural systems
Deconstructing the “resting” state:
Exploring the temporal dynamics of resting frontal brain asymmetry as an endophenotype for depression

Allen & Cohen, 2010
The Conventional Approach

- One number to summarize several minutes of resting data
- Good reliability, but...
  - Lacks temporal specificity
  - Confuses “more” with “more often”

$$\text{Asym} = \ln(\text{Right}) - \ln(\text{Left}) \text{ Alpha Power}$$
Three Central Questions

How do the novel peri-burst metrics of dynamic asymmetry compare to the conventional FFT-based metrics?

Do the peri-burst metrics adequately differentiate depressed and non-depressed participants?

What EEG dynamics surround the asymmetry bursts that are captured by the novel peri-burst metrics?
Three Central Questions

- How do the novel peri-burst metrics of dynamic asymmetry compare to the conventional FFT-based metrics?

- Do the peri-burst metrics adequately differentiate depressed and non-depressed participants?

- What EEG dynamics surround the asymmetry bursts that are captured by the novel peri-burst metrics?
Relationship of Peri-Burst Alpha Power with Conventional FFT-Derived Power

Allen & Cohen, 2010
Relationship of Peri-Burst Alpha Asymmetry at F6-F5 with Conventional FFT-Derived Alpha Asymmetry across the scalp

$\text{POS}$

$\text{NEG}$

$\text{COMBINED}$

$r^2 = .42 !$

$(1\%)$

Allen & Cohen, 2010
Three Central Questions

- How do the novel peri-burst metrics of dynamic asymmetry compare to the conventional FFT-based metrics?
- Do the peri-burst metrics adequately differentiate depressed and non-depressed participants?
- What EEG dynamics surround the asymmetry bursts that are captured by the novel peri-burst metrics?
Conventional Frontal EEG Alpha Asymmetry by MDD status

![Graph showing Conventional Frontal EEG Alpha Asymmetry by MDD status]

Stewart, Bismark, Towers, Coan, & Allen 2010, *J Abnormal Psychology*
Peri-burst Frontal EEG Alpha Power Asymmetry by MDD status

\[ \ln(R) - \ln(L) \]

Total Alpha Power

- **Current MDD**
- **Past MDD**
- **MDD-**

Allen & Cohen, 2010
Table 3. Effect sizes (Cohen’s $d$) comparing depressed groups to never depressed controls.

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Conventional</th>
<th>Peri-burst</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifetime MDD</td>
<td>.43</td>
<td>.38</td>
</tr>
<tr>
<td>Past MDD only</td>
<td>.43</td>
<td>.27</td>
</tr>
<tr>
<td>Current MDD (with or without Past MDD)</td>
<td>.35</td>
<td>.45</td>
</tr>
</tbody>
</table>
Prospective Pilot Data

A  EEG Asymmetry by BDI Follow-up

Right Activity  Left Activity

Frontal Alpha Asym (R–L)
Three Central Questions

- How do the novel peri-burst metrics of dynamic asymmetry compare to the conventional FFT-based metrics?
- Do the peri-burst metrics adequately differentiate depressed and non-depressed participants?
- What EEG dynamics surround the asymmetry bursts that are captured by the novel peri-burst metrics?
So?

- Novel peri-burst metrics account for substantial variance in conventional metrics (despite being just 1%)
- Peri-burst metrics differentiate depressed and non-depressed participants, similar to conventional metrics
So?

Bursts reflect …

- Transient lateralized alpha suppression that shows a highly consistent phase relationship across bursts
- Along with concurrent contralateral transient alpha enhancement that is less tightly phase-locked across bursts

Analogous to ERD/ERS (Pfurtscheller, 1992)?
So?

The fact that the alpha suppression is particularly tightly phase-locked across bursts raises the possibility that the lateralized alpha suppression may drive or regulate cortical processing.

Alpha has been shown to regulate gamma power (i.e., cross-frequency coupling, Cohen et al., 2009)
TIME AND SPACE
Multi-modal Imaging

- Tether EEG asymmetry to other measures neural systems known to be involved in MDD
- 23 subjects with simultaneous EEG and fMRI during resting state
Multi-modal Imaging

- Tether EEG asymmetry to other measures neural systems known to be involved in MDD

Mayberg et al., 2005
Multi-modal Imaging

Create RS-fMRI network with ACC seeds

Allen, Hewig, Miltner, Hecht, & Schnyer, in preparation
Remove Artifacts from Resting EEG
EEG Alpha Asymmetry is Negatively Correlated with IFG Connectivity in Two ACC-seeded Resting State Networks

Spatially-enhanced EEG asymmetry (using CSD transform) at sites F8-F7 is related to resting state connectivity between left inferior frontal gyrus and two ACC-seeded networks.

**Dorsal ACC-seeded Network**
Center of the depicted cluster is (x,y,z) -46, 28, -4 MNI coordinates. Largest correlation $r = -0.69$

**Subgenual ACC-seeded Network**
Center of the depicted cluster is (x,y,z) -54, 28, -4 MNI coordinates. Largest correlation $r = -0.71$

Allen, Hewig, Miltner, Hecht, & Schnyer, *in preparation*
EEG-fMRI Synopsis

Less relative left frontal activity (indexed by EEG) is related to increased connectivity of left IFG to two ACC-seeded RS networks

Consistent with:
- Hyper-connectivity in RSfMRI emotion networks in MDD (e.g., Grecius et al., 2007; Sheline et al., 2010)
- Frontal EEG asymmetry findings of less relative left frontal activity in risk for MDD.

Alpha power may regulate network connectivity

Note: Between vs Within Subjects
BETWEEN-SUBJECTS’ DATA DOES NOT NECESSARILY SUPPORT A WITHIN-SUBJECTS’ INTERPRETATION
Within Subjects’ Moderation of RSfMRI Connectivity

Calculate F8-F7 alpha asymmetry for each TR
- EEG leads TR by 4.096 seconds
- Median split into high (left) and low (right)
- Entered as moderator in PPI approach (cf. Friston et al., 1997)
  - Tests whether strength of connectivity to seed region varies as a function of the moderator
Within Subjects’ Moderation of RSfMRI Connectivity

Dorsal ACC Seed

Greater Connectivity with Less Left Frontal Alpha or Greater Left Frontal Alpha

Allen, Hewig, Miltner, Hecht, & Schnyer, in preparation
Within (red) and Between (blue)
Within-subject effects more extensive
Cognitive Control over Emotion

IFG has a key role in mediating the success of cognitive control over emotional stimuli.
Cognitive Control over Emotion

**Left IFG:**
Language and self-referential processing

**Right IFG:**
- Attentional control
  - behavioral inhibition
  - suppression of unwanted thoughts
  - attention shifting
  - efforts to reappraise emotional stimuli
Cognitive Control over Emotion

Left IFG:
Language and self-referential processing

Right IFG:
Attentional control
- behavioral inhibition
- suppression of unwanted thoughts
- attention shifting
- efforts to reappraise emotional stimuli

Working Hypothesis:
- Hyperconnected left IFG and emotion networks: rumination
- Hypoconnected right IFG: difficulty disengaging from emotion