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
    - 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

"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

Henriques & Davidson (1991)

Left Hypofrontality in Depression

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?

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.”

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

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

Harmon-Jones & Sigelman, *JPSP*, 2001

Harmon-Jones & Sigelman, *JPSP*, 2001

Harmon-Jones & Sigelman, *JPSP*, 2001

Harmon-Jones & Sigelman, *JPSP*, 2001

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

Manipulation of EEG
Peterson, Shackman, Harmon-Jones (2008)

- Hand contractions to activate contralateral premotor cortex
- Insult about essay (similar to Harmon-Jones & Sigelman, JSP, 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
Motivational Styles and Depression Replications

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.

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)

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, Schullkin, & Gold, 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

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)
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)

- 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)

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 estimates have underestimated the internal consistency reliability of asymmetry by disregarding EEG sessions into segments of equal duration (e.g., 1 trial and finding composite scores for each subject as “trials” to estimate internal consistency reliability) or by computing internal consistency reliability by using less than the number of distinct items available. Reliability estimates for scoring EEG data in the present study (204 subjects, 8 sessions) were obtained using mean split-half correlation with epoch alpha power as input estimate scores. Estimates of all scalp sites and reference schemes agreed with as for as 100 epochs, suggesting the internal consistency of frontal asymmetry is greater than 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


State EEG in CIT!

Matsuda, Nittono, & Allen, Neurosci Letters, 2013
Depression as a Heterogeneous Phenotype

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

Depression: Variable Age Onset

Identify those at risk
Identify factors that place folks at risk
Develop interventions to address those factors
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)

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; J. A. 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; Debenert, 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, 1999; Jeffrey B. Henriques & Davidson, 1991; Mathersdul, Williams, Hopkinson, & Kemp, 2008; Miller, et al., 2002; Pössel, Lo, Fritz, & Seeman, 2008; Schaffer, Davidson, & Saron, 1983; Vuga, et al., 2006);

  - Anxious arousal/somatic anxiety (Matthews, 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

- PMDD

  - Assessed at
    - Late-Luteal
    - Follicular

PMDD

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

Accortt & Allen, 2006
Specificity or Spectrum: PMDD

![Asymmetry by region graph]

Accortt & Allen, 2006

**PMDD**

- Larger Sample
- Diagnostic Interviews
- Matched for MDD

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

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

Reference Effects

- AR
- CSD
- LM
- Cz

Stewart, Bismark, Towers, Coan, & Allen 2010, J Abnormal Psychology
Reference Effects

Cz    AR    LM    CSD

Open  

Closed

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 53 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?

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 inset. 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 in μV² for AVG, Cz, and LM references, and in μV²/s/cm² for CSD referenced data. MDD = major depressive disorder; AVG = average; CSD = current source density; CZ = Cz; LM = linked mastoids.

Stewart, Bismark, Towers, Coan, & Allen, 2010

Stewart & Allen, in preparation
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

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)

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
Consider residualized left lead power when \( L \approx R \)

\[
L_{resid} = L - L
\]

In limiting case where \( r_{LR} \rightarrow 1.0 \)

\[
L = a + b(R)
\]

\[
L = 0 + 1(R) = R
\]

\[
L_{resid} = L - L = L - R
\]


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, \textbf{don’t do that!}

What to do?

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

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”

\[
\text{Asym} = \text{Ln(Right)} - \text{Ln(Left)} \text{ Alpha Power}
\]
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?

Relationship of Peri-Burst Alpha Power with Conventional FFT-Derived Power

<table>
<thead>
<tr>
<th>POS</th>
<th>NEG</th>
</tr>
</thead>
<tbody>
<tr>
<td>F5</td>
<td>F6</td>
</tr>
</tbody>
</table>

Relationship of Peri-Burst Alpha Asymmetry at F6-F5 with Conventional FFT-Derived Alpha Asymmetry across the scalp

\[ r^2 = .42 ! \] (1%)

Conventional Frontal EEG Alpha Asymmetry by MDD status

- Current MDD+
- Past MDD+
- MDD-

Stewart, Bismark, Towers, Coan, & Allen 2010, J Abnormal Psychology
Prospective Pilot Data

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)

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

If Alpha Desynchs, what Synchs?

Event-related Synchronization and Desynchronization

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

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  

Saueng Hoppe Klimesch Gerloff Hummel (2007)

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

Theta PLV  

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 Sd (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

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

  - 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-O2-T6 triangle)
- Results
  - greatest variability during baseline
  - smallest variability and greatest LH activation during verbal
  - no laterality effects in the 40 Hz 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

Individually 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

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…
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

Functional Role of Gamma Synchronization

- Feedforward coincidence detection
  - To summate effectively, signals must arrive at post-synaptic neuron from multiple sources within msec of each other (else decay)
  - Gamma-band synchronization can lead to temporal focusing of inputs from multiple and distributed pre-synaptic neurons
- Rhythmic Input Gain Modulation
  - Excitatory input is most effective when it arrives out of phase with inhibitory input and vice versa
  - Allows for precision and efficiency of signal transmission (or inhibition)

Fries, 2009
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 ± some range
  - Gamma! (Stay tuned during advanced topics)