A bit more on Frequency-domain EEG

and then...

The Event-related Brain Potential (Part 1)

Announcements

- Papers: 1 or 2 paragraph prospectus due a few minutes ago!
- Feedback coming soon if you’ve not received it already
- 3x5s

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)

Alpha Power time course over left central region during voluntary movements with right and left thumb
Event-related Synchronization and Desynchronization

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

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)
40 Hz Activity

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

Sheer work with Cats

- Learning paradigm
- Cat must learn
  - press to S_d (7cps light flicker)
  - not S- (3 cps light flicker)
- the hypothesis is that the synchronized 40 Hz activity represents the focused activation of specific cortical areas necessary for performance of a task

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

Lateraled 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 P4-02-T6 triangle).
- Results
  - greatest variability during baseline
  - smallest variability and greatest LH activation during verbal
  - no laterality effects in the 40Hz EMG bands
Laterality of 40 Hz

Controlling for EMG contributions

- Spydell & Sheer (1982)
  - used similar tasks and found similar results
  - using conservative controls for muscle artifact

Individual Differences

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

So this is exciting, why didn’t this work take off immediately?

- The EMG concern
  - The concern is likely over-rated (recall Table 3)
- Sheer died
- But not all is lost, as there is renewed interest…
Mukamel et al. Science 2005 recorded single unit activity and local field potentials in auditory cortex of two neurosurgical patients and compared them with the fMRI signals of 11 healthy subjects during presentation of an identical movie segment. The predicted fMRI signals derived from single units and the measured fMRI signals from auditory cortex showed a highly significant correlation.

Singer (1993)

- Revitalized interest in the field

The Binding Problem

- Potentially infinite number of things and ideas that we may attempt to represent within the CNS
- Cells code for limited sets of features
- These must somehow be integrated
- -- the so-called binding problem
- If there exists a cell for a unique contribution of attributes, then convergent information from many cells could converge on such a cell
- But there are a finite # of cells and interconnections
- And even the billions and billions of cells we have cannot conceivably handle the diversity of representations

The Functional Perspective

-- as yet merely a theory

- There is no site of integration
- Integration is achieved through simultaneous activation of an assembly of neurons distributed across a wide variety of cortical areas
- Neurons in such assemblies must be able to adaptively identify with other neurons within the assembly while remaining distinct from other neurons in other assemblies
- This association with other neurons is through a temporal code of firing (Synchronicity)
- This even allows for the possibility that a single neuron could be part of two active assemblies (via a multitasking procedure)

Implications

- Also allows for the possibility that there exists no direct neuronal connection between neurons within an assembly
- merely the fact that they are simultaneously activated that makes the unified experience of the object possible
- Yet what can synchronize these oscillations?

Implications – Alpha as a synchronization mechanism

Jensen et al. TICS, 2012
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)

The Event-Related Potential (aka the ERP)

Overview

Event-related potentials are patterned voltage changes embedded in the ongoing EEG that reflect a process in response to a particular event: e.g., a visual or auditory stimulus, a response, an internal event
The Classic View:
Time-locked activity and extraction by signal averaging

- Ongoing activity reflects "noise"
- Activity that reflects processing of a given stimulus "signal"
- The signal-related activity can be extracted because it is time-locked to the presentation of the stimulus
- Signal Averaging is most common method of extracting the signal
  - Sample EEG for ~1 second after each stimulus presentation & average together across like stimuli
  - Time-locked signal emerges; noise averages to zero
  - Signal to noise ratio increases as a function of the square root of the number of trials in the average

What does the ERP reflect?

- May reflect sensory, motor, and/or cognitive events in the brain
- Reflect the synchronous and phase-locked activities of large neuronal populations engaged in information processing

Component is a "bump" or "trough"

Nomenclature & Quantifying

- Most commonly label peaks and troughs by polarity (P or N) and latency at active recording site
- Quantifying
  - Amplitude
  - Latency
  - Area
  - "String" measure
  - Fancy stuff to be discussed in “advanced” topics

Making Meaning from the bumps

Poesy o'er the Cranial map with learned eyes,
Each rising hill and bumpy knoll decries
Here secret fires, and there deep mines of sense
His touch detects beneath each prominence.
Component is a "bump" or "trough"

Early Components
- Waves I-VI represent evoked activity in auditory pathways and nuclei of the brainstem
- Early components <60-100 msec
- Occur in obligatory fashion
- Are called Exogenous = determined "outside" organism
- Even subtle deviations in appearance may be indicative of pathology

Later ERP components
- Highly sensitive to changes in State of organism
- Meaning of stimulus (NOT physical characteristics)
- Information processing demands of task
- Therefore termed Endogenous = determined "within" organism

Not all components fit neatly into exogenous or endogenous categories
- Both Obligatory but modulated by psychological factors
- "Mesogenous"

Defining Components: aka how do I know one when I see one?
- By positive and negative peaks at various latencies and scalp locations
- By functional associations, covarying across subjects, conditions, or scalp locations in response to experimental manipulations
- By neuronal structures that plausibly give rise to them

Evoked Vs Emitted ERP's
- Evoked are most commonly studied: occur in response to a physical stimulus
- Emitted potentials occur in absence of a physical stimulus (e.g., omission of item in sequence)
- Evoked can have both exogenous and endogenous components; emitted usually have only endogenous

After Fabiani, Gratton, Federmeier, 2007
Comparison to other "windows on the brain"

- Very precise temporal resolution

At the surface, activity of many functional synaptic units recorded

ERP's generated only by groups of cells that are synchronously activated in a geometrically organized manner

After Lorente de Nó, 1947
Comparison to other "windows on the brain"

- Very precise temporal resolution
- Spatial localization is more difficult
  - At the surface, activity of many functional synaptic units recorded
  - ERP's generated only by groups of cells that are synchronously activated in a geometrically organized manner
- Synchronous activation may occur in one or more than one location
- Monopolar recording technique most often used
- Yet localization is not impossible in conjunction with other techniques

Caveat Emptor

- DO NOT interpret scalp distribution of ERP's as reflect cortical specialization
- Also, DO NOT interpret area of maximum amplitude to suggest that generator lies underneath

Correlate Vs substrate (Again)

- Late ERP components should not be taken to indicate the existence of a neurological substrate of cognitive processing
- Rather should be considered a correlate
- Constructs in search of validation; Process of validation:
  - Determine antecedent conditions under which the ERP component appears and also magnitude and latency of ERP component
  - Develop hypotheses concerning functional significance of the "subroutine" underlying the ERP component
  - Predict consequences of subroutine—validate empirically

Basic Signal Processing

Paradigms and acquisition

- Precise temporal control over stimulus presentation necessary
  - Requires discrete stimuli or responses
- Individual stimuli are presented numerous times; ERP's generally do not habituate, unlike peripheral measures
- Concurrent with each stimulus, a signal/pulse must be sent to the A/D converter to indicate time of stimulus onset
- Sampling epochs (legacy!) vs continuously
  - Considerations for sampling epochs
    - pre-onset samples (to provide a baseline for comparison)
    - epoch length
- Epochs for like stimuli averaged together to create ERP for that set of stimuli
Assumptions of Averaging methods

- Signal and noise (in each epoch) sum linearly together to produce the recorded waveform for each epoch (not some peculiar interaction)
- The evoked signal waveshape attributable solely to the stimulus is the same for each presentation
- The noise contributions can be considered to constitute statistically independent samples of a random process

Demo of Averaging

Filtering and its influence on the ERP

- Despite many trials and averaging, some noise may remain in the averaged waveform
- If you are only interested in later & slower components, then a low-pass filter may be of interest

Let’s ERP!

Same ERP filtered with 12.5 (black), 8 (red), and 5 (lime) Hz Low Pass FIR Filter

Same ERPs overlaid; note amplitude attenuation in P3 amplitude with stricter filters
Applications of Early Components

- Neurological evaluation of sensory function; e.g., evaluation of hearing in infants
- Tones of various dB intensities presented and V wave in auditory brainstem ERP examined
- Figure 10: 4000 individual trials per average

Prediction of recovery from coma

Inter-Hemispheric Transfer Time (IHTT)

- Hypothesized that interhemispheric transfer of information may be abnormal in various disorders (e.g., dyslexia)
- Reaction Time measures contain too much variability not related to Transfer Time
- ERP early components appear promising as a measure of time required to transfer information between hemispheres

IHTT Study (Saron)

- Checkerboards subtending < 1 degree of visual angle presented 2.9 degrees from center
- ERP’s recorded at O1 and O2
- Problem of lateralization and Paradoxical results possible: parfoveal regions on banks of calcarine fissure
- P100 wave latency examined; earlier latency in occiput contralateral to presentation
- Measured by peak picking procedure
- Also by cross-lagged correlation technique
- Both methods suggest ~15 millisecond IHTT; found to be in expected direction predicted by anatomy for over 90% of subjects
- Reaction time data from same task showed no reliable differences
P1, N1, and Attention

From Luck et al., TICS, 2000

More than Spatial Directed Attention

Taylor Clinical Neurophys 2002

P1 and Sleep

Note: P1 disappears in Stage 2 sleep, but reemerges in REM sleep

“These combined PET/ERP data therefore provide strong evidence that sustained visual spatial attention results in a preset, top-down biasing of the early sensory input channels in a retinotopically organized way.”

Woldorff et al., Human Brain Mapping, 1997

"Increasing stimulus complexity results in more rapid early processing"

Note: Amplitude of P1 Latency of P1 Latency of N1

Taylor Clinical Neurophys 2002

More than Spatial Directed Attention

P1 and Occipital Origins

Woldorff et al., Human Brain Mapping, 1997

"These combined PET/ERP data therefore provide strong evidence that sustained visual spatial attention results in a preset, top-down biasing of the early sensory input channels in a retinotopically organized way.”

Woldorff et al., Human Brain Mapping, 1997

“Increasing stimulus complexity results in more rapid early processing"

Note: Amplitude of P1 Latency of P1 Latency of N1

Taylor Clinical Neurophys 2002

P1 and Sleep

Note: P1 disappears in Stage 2 sleep, but reemerges in REM sleep
Construct Validity of P300 (P3, P3b)

- First observed by Sutton, Braren, Zubin, & John (1965)
- P300 Amplitude; Johnson’s model is
  \[ \text{P300 Amplitude} = f[T \times (1/P + M)] \]
  where
  - \( P \) = probability of occurrence,
  - \( M \) = Stimulus meaning, &
  - \( T \) = amount of information transmitted

Aspects of the Model

- Rarity
  - The P300 is observed in variants of the "oddball paradigm"
  - The rare stimulus almost invariably elicits a P300: largest at parietal, then central, and then frontal sites
- Subjective probability
- Stimulus meaning
  - Actually composed of three dimensions
    - task complexity
    - stimulus complexity
    - stimulus value
- Information Transmission (proportion 0 to 1; example)
P3 Latency

- An index of processing time, independent of response requirements
- RT measures confounds the two
- McCarthy & Donchin (1981) experiment:
  - The words "RIGHT" or "LEFT" embedded in a matrix of letters of X's
  - Compatible condition: respond with hand indicated in matrix; Incompatible condition: respond with opposite hand (e.g., LEFT signals right hand response);
- Results:
  - P300 latency delayed when discriminability more difficult
  - Response compatibility had no effect on P300 latency
  - Note amplitude reduction as function of noise--information transmission)

Construct Validity?

- What, then, does the P300 mean in very general terms?
- A stimulus (or class of stimuli) is "important"; denotes information that is necessary or useful to the task
- Stimulus is meaningful, important, noticeable
- Evaluated within context of working memory? (cf. Donchin & Coles, 1988; Verlager 1988; Polich, 2007; Verlager, 2008)
- The P3a (Squires, Squires, and Hillyard, 1975): P3-like component with a frontal maximum and occurs to improbable stimuli in the "to-be-ignored" class of stimuli; a novelty response.

How Many P3s?

- The Classic P3/P300
- Parietal Central Maximum
- Largest when stimuli rare and task-relevant
- The P3a (Squires et al., 1975) or Novelty P3 (Courchesne et al., 1975)
  - More anterior scalp distribution
  - Slightly earlier latency
  - Responsive to rare, unexpected, unattended stimuli
Simons et al., 2001

• Squires Task was tones (two tones)
• Courchesne task was digitized speech (“me” “you” and collection of naturally occurring sounds
• In all cases subjects merely counted tones

P3a – Can you see it?

➢ Some inconsistencies in finding P3a following the initial Squires, Squires and Hilyard 1975 report
➢ Comerchero & Polich (1998) may have resolved the enigma
➢ P3a highly dependent on foreground discrimination

Note: Nontarget peak amplitude was earlier and larger at the frontal electrodes than those from the target stimuli, but especially when foreground discrimination is difficult

Synopsis

“...the manipulation of target-standard stimulus discriminability produced a stimulus environment in which the infrequently occurring nontarget engaged focal attention in a manner similar to that observed previously for ‘novel’ stimuli.”

“However, all stimuli in the present study were employed because of their ‘typical’ characteristics, so that the results imply that an anterior P3a component can be produced without using ‘novel’ stimuli per se.”

“If stimulus context is defined primarily by a difficult target-standard discrimination, attentional redirection to the nontarget would occur because of the frontal lobe activation that generates P3a.”

Comerchero & Polich 1998, p. 47
ERPs and Memory

- Sensitive to both Recognition
- Likely episodic recollection
- Sensitive to Encoding

Repetition Priming Effects

- Robust effect that repeated items produce an enhanced late positivity across a broad latency range
- Magnitude of effect related to strength of memory trace

Repetition Priming

- Are there repetition effects that do not depend on the subjective awareness of the subject?
- Can use Masked Priming to examine (Schnyer, Allen, Forster, 1997)
Memory Encoding

- Words subsequently remembered show enhanced positivity at encoding
- Strategy interacts, however

Indirect Assessments of Recognition

- Can the ERP detect recognition, independent of subjects’ overt responses?
- Two applications
  - Clinical Malingering
  - Forensic Assessment
ERP Memory Assessment Procedures

- Learn a list of words
- Learn a second list of words
- Task: Concealed (1st list) and Nonconcealed (2nd list) words appear infrequently

<table>
<thead>
<tr>
<th>Item Type</th>
<th>Probability</th>
<th>Response</th>
<th>P3 Amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonconcealed</td>
<td>1/7</td>
<td>&quot;Yes&quot;</td>
<td>Large</td>
</tr>
<tr>
<td>Concealed</td>
<td>1/7</td>
<td>&quot;No&quot;</td>
<td>Large if Recognized</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Small if not Recognized</td>
</tr>
<tr>
<td>Unlearned</td>
<td>5/7</td>
<td>&quot;No&quot;</td>
<td>Small</td>
</tr>
</tbody>
</table>

- Similar to procedures by Rosenfeld et al, Farwell & Donchin

Motivational Variations

- Conceal
  - "YES" for words JUST learned, "NO" for all others
  - Try to hide the fact that you learned the first list of words I taught you

- Lie
  - "YES" for words learned
  - Lie about words from the first list I taught you
  - $5.00 incentive

The Challenge

To provide statistically supported decisions for each and every subject, despite considerable individual variability in ERP morphology

Bayesian Combination of ERP Indicators:
Probability that an ERP was elicited by Learned Items

<table>
<thead>
<tr>
<th>List</th>
<th>Learned</th>
<th>Unlearned</th>
</tr>
</thead>
<tbody>
<tr>
<td>U1</td>
<td>0.999</td>
<td>0.000</td>
</tr>
<tr>
<td>U2</td>
<td>0.000</td>
<td>1.000</td>
</tr>
<tr>
<td>U3</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>U4</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>U5</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Note: Only trials in which subjects did not acknowledge concealed items included
The Claim

- Brain Fingerprinting can determine “scientifically whether a suspect has details of a crime stored in his brain”

- Thus these ERP-procedures should be able to identify memories in laboratory studies

- Two tests of the robustness of this procedure:
  - False recollections
  - Virtual Reality Mock Crime

A Laboratory Paradigm for False Recollections: DRM

- Subjects presented with 15 words highly associated with an omitted critical item

  - Bed, rest, awake, tired, dream, wake, snore, nap, peace, yawn, drowsy
  - Sleep
Reported Rates of Recognition

Forced Choice Likert Confidence

Allen and Mertens (in press)

The Box Score Blues

<table>
<thead>
<tr>
<th>Ground Truth</th>
<th>Test Verdict</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actually Learned</td>
<td>Recognized 56%</td>
</tr>
<tr>
<td>Critical Lure</td>
<td>Recognized 72%</td>
</tr>
<tr>
<td>Unlearned</td>
<td>Recognized 4%</td>
</tr>
</tbody>
</table>

- Highlights the need to have memorable items in the test
- Suggests limited utility in substantiating disputed memories; e.g., claims regarding recovered memories
- Still has low false positive rate when person denies knowledge

Virtual Reality Mock Crime

- Subjects received email detailing their “Mission”
- Sneak into graduate student office to break in to virtual apartment
- Apprehended and interrogated using ERP-based procedure
- Some subjects given details about utilizing countermeasures
- Innocent subjects tour the same virtual apartment, but with different objects and details.
Results of Mock Crime Brainwave Procedure

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Guilty</th>
<th>Innocent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guilty</td>
<td>15</td>
<td>47%</td>
<td>53%</td>
</tr>
<tr>
<td>Guilty (countermeasure)</td>
<td>45</td>
<td>17%</td>
<td>83%</td>
</tr>
<tr>
<td>Innocent</td>
<td>15</td>
<td>6%</td>
<td>94%</td>
</tr>
</tbody>
</table>

Note: Using Bootstrapping approach, Guilty detection drops to 27%, but innocent subjects classified correctly in 100% of cases. Allows indeterminate outcomes.

ERPS and Affective Processing

- IAPS = International Affective Picture System
- Pleasant, Neutral, Unpleasant
- Vary in Arousal: Pleasant and Unpleasant tend to be more arousing
- Predict more significant stimuli produce larger P3

ERPS and Implicit Affective Processing

- Ito & Cacioppo (2000) *JESP*
- Evaluative Processing (positive vs negative)
- Nonevaluative (people vs no-people)
Ito & Cacioppo (2000) JESP