

Inferences

<http://www.cogsci.ucsd.edu/~coulson/cogs179/>

Announcements

- Homework due next Thursday (not Tuesday)
- Course Reader?
 - Come up at the end of class
- Library Reserves – readings will be visible on Roger when they are available for check-out

Processing EEG data for ERPs

- Screen for artifacts
- Group trials together according to design of experiment
- **Average within a single subject**
- Rereference if necessary
- Digitally Filter, if necessary
- Create an across-subject average
- Visualize data
- Run statistics

Averaging

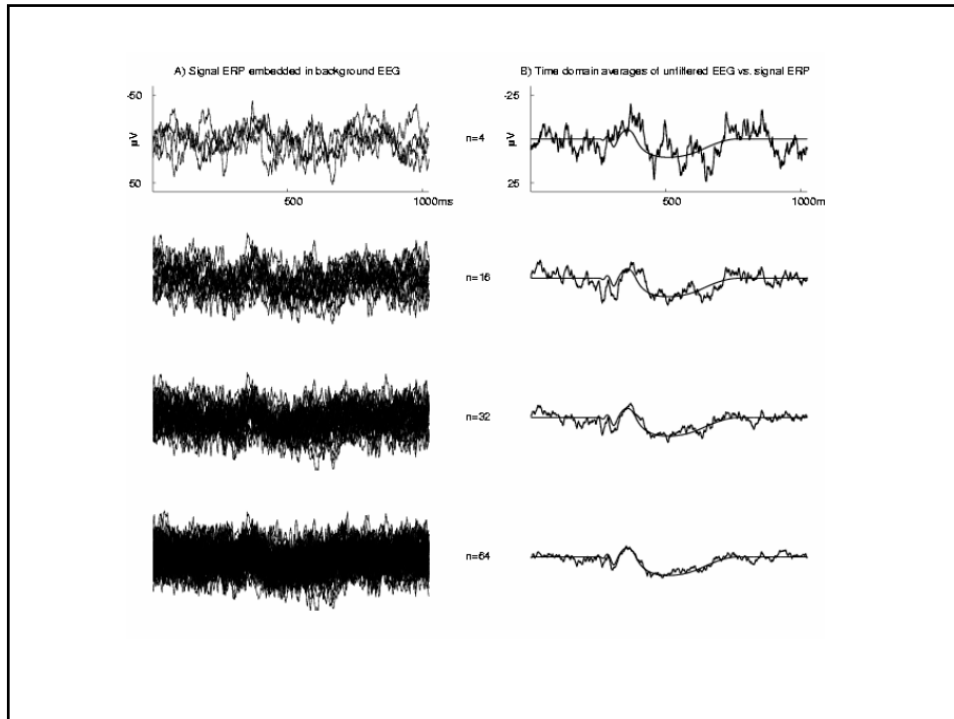
- Activity reflects both signal and “noise”
 - Signal: stimulus related processing
 - Noise: tonic background activity related to ongoing processes (level of arousal, etc)
- The signal-related activity can be extracted because it is time-locked to the presentation of the stimulus
- Signal averaging is 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

Assumptions of Averaging

- Signal and noise (in each epoch) sum linearly together to produce the recorded waveform for each epoch (not some peculiar interaction)
 - Safe assumption
 - Helmholtz Law (additivity)
- The evoked signal waveshape attributable solely to the stimulus is the same for each presentation
 - *No latency jitter*
 - (unlikely for cognitive tasks)
- The noise contributions can be considered to constitute statistically independent samples of a random process
 - Not always true...
 - Systematic blinking
 - Time-locked alpha (though this probably not “noise”)

Benefit of Averaging

- $S/N_{\text{ave } N} = \text{sqrt}(N) * S/N_{\text{single trial}}$
- P3 = 20 microvolts
- EEG = 50 microvolts
- $S/N = 20/50$
- If have thirty trials then
- $S/N = (5.5 * 20)/50 = 110/50$



Limitation of Averaging

- The signal averaging method of reducing noise means that we do not have access to single trial data
- Therefore, it is difficult to look at within subject variation of ERP with other measures (e.g., behavior) using averaging techniques

Processing EEG data for ERPs

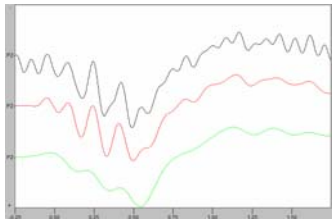
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Digital Filtering

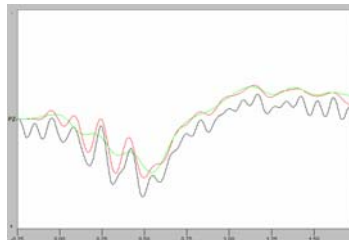
- Despite many trials and averaging, some noise may remain in the averaged waveform
- If you are only interested in later & slower components, then a low-pass filter may be of interest
- Unlike analog filtering, digital filtering need not distort signal
 - Low Pass
 - High Pass
 - Band Pass
- Can be used to zoom in on (brain) activity of particular interest to experimenter

Filtering

- *Low-Pass Filter*
- Black: 12.5 Hz
- Red: 8 Hz
- Green: 5 Hz



- Same ERPs overlaid
 - Note attenuation of positivity in green trace
 - Contribution of high frequency aspect of EEG

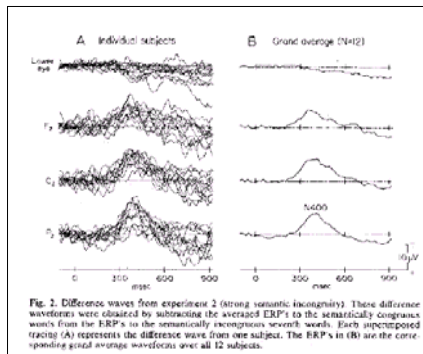


Processing EEG data for ERPs

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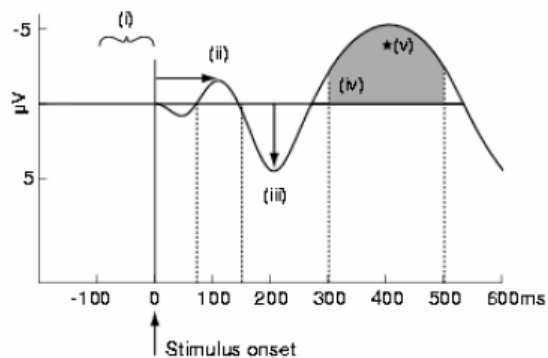
Visualization & Analysis

- Time x Voltage Plots (Time Domain Analysis)
- Each graph is data from 1 electrode
- Experimenters' eyes/brains very important for analysis
 - Identify patterns in the data
- Statistical characterization
 - Measurements
 - Significance tests
 - People also identify patterns in the clouds, so need reality check

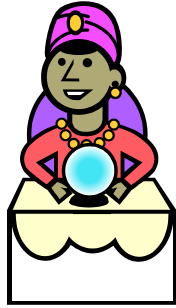


Selected ERP data reduction measures

- 100ms prestimulus baseline
- peak latency 75-150ms = 110ms
- peak amplitude 150 - 300ms = $4.50\mu\text{V}$
- area 300 - 500ms = $-648\mu\text{Vms}$
- mean amplitude 300 - 500ms = $\text{area}/\text{interval} = -4.24\mu\text{V}$



Inferences



- Inferences based on prior knowledge
 - functional significance of a particular ERP component
- Inferences *not* based on prior knowledge

No Prior Knowledge

- Timing
 - latency
- Degree of engagement
 - amplitude
- Functional Equivalence
 - scalp distribution



Simplest Inference

- ERPs to condition 1 differ from those to condition 2
- Cognitive processes associated with the two conditions differ in some respect
- Come on! Would that ever be useful information?

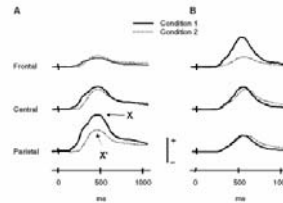


Figure 1.1
Hypothetical ERP waveforms elicited at three electrode sites in two experimental conditions in two experimental situations (A and B). The differences between the waveforms allow a number of functional interpretations. See text for details.

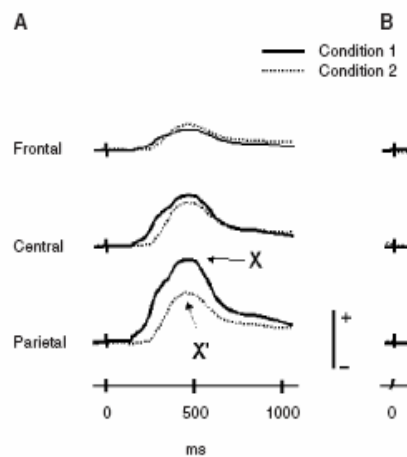
Is unattended information processed by the brain?

Otten, Rugg, & Doyle (1993)

- Record ERPs before, during, and after unattended stimuli
- Test whether manipulations of the information content of the unattended stimuli affects the waveforms they elicit
 - Compare ERPs to unattended words presented twice in a row
 - *ERP to first stimulus differs from ERP to second*
 - *ERPs to sequentially presented non-repeated stimuli do not differ*
 - Information in the first stimulus affects the processing of the second (repeated) occurrence
- Unattended visual information is processed to the level of its identity
 - Not necessarily its meaning

Timing Inferences

- Conditions 1 & 2 begin to differ at 250 ms post-event
- Cognitive/neural processes that differentiate the two conditions began by 250 ms
- When (pardon the pun) would we care about this sort of issue?



When do attentional processes engage?

Woldorff & Hillyard (1991)

- Compare ERPs elicited by stimuli that are attended versus unattended
- Waveforms differ as early as 50 ms after stimulus onset
- Attentional processes engaged within 50 ms

Dissociative Inferences

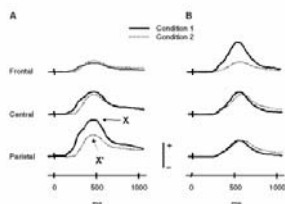


Figure 1.1
Hypothetical ERP waveforms elicited at three electrode sites in two experimental conditions in two experimental situations (A and B). The differences between the waveforms allow a number of functional interpretations. See text for details.

- Scalp distribution (topography) differs in A and B
 - Largest effect over Parietal site in A
 - Largest effect over Frontal site in B
- Different scalp distributions imply different patterns of underlying neural activity
- May support functional distinction between the conditions
 - Assumes neurophysiological distinction → functional distinction

Dissociative Inferences in Time

- Compare ERP effects in different conditions (A vs. B)
- ERP effects can also be compared at different time points in the waveform
- Different scalp distribution at different points in time (t1 vs. t2) suggests the neurocognitive processes invoked at t1 are distinct from those invoked at t2

Memory Processes

Rugg & Wilding (2000)

- Subjects see list of items (study)
- Subjects see list comprised of previously studied items and new items (test)
- Old items more positive than new items
 - Early: largest over posterior (parietal) sites
 - Late: largest over right anterior sites
- Task engaged different brain areas over time
 - Memory retrieval requires multiple, qualitatively different processes

Quantitative vs. Qualitative Differences

- What if the scalp distribution is the same for ERPs in 2 conditions, but the amplitude is greater for one than the other?
- Understood as quantitative (not qualitative) processing difference
- But null effects always tricky
 - Hard to draw too firm of conclusions from the absence of a difference
 - More on this later



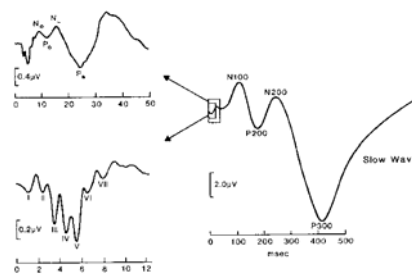
Inferences Based on Prior Knowledge

- Build on research by older (sometimes wiser) scientists
- Relies on the elicitation of an ERP component whose functional significance is agreed upon by cognitive neuroscientists



What is an ERP component?

- Portion of the ERP waveform that has been experimentally linked to a given neurocognitive process
- Physiological identification
 - Naatanen
 - Component defined in terms of its anatomical source/s
- Functional identification
 - Donchin
 - Component identified by functional process associated with its elicitation



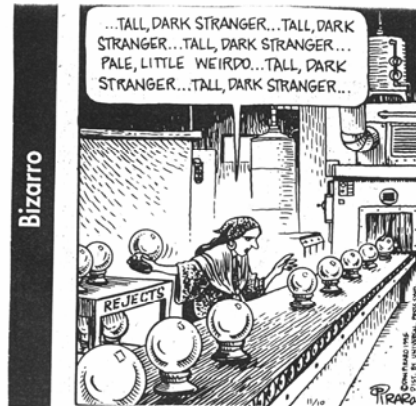
Early Components

- Waves I-VI represent evoked activity in auditory pathways in the brainstem
- “Exogenous”
 - Driven by factors *outside* the person
 - What are the features of the stimulus?
 - Reflect sensory processing

Later components

- P300, N400
- “Endogenous”
 - Driven by changes *inside* the subject
- Sensitive to the meaning of the stimulus
 - Not just its physical characteristics
- Sensitive to information processing demands

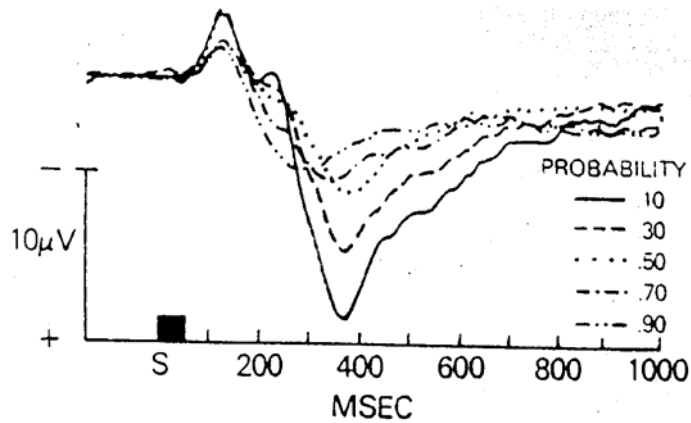
Oddball Paradigm



P300

- First observed by Sutton, Braren, Zubin, & John (1965)
- Thought to reflect
 - Stimulus evaluation
 - Stimulus categorization
 - “Context Updating”
- Probability
 - The P300 is observed in variants of the "oddball paradigm"
 - The rare stimulus almost invariably elicits a P3: largest at parietal, then central, and then frontal sites
 - Subjective probability
- Stimulus meaning
 - Actually composed of three dimensions
 - Task complexity
 - Stimulus complexity
 - Stimulus value

P300 & Probability



Local Probability

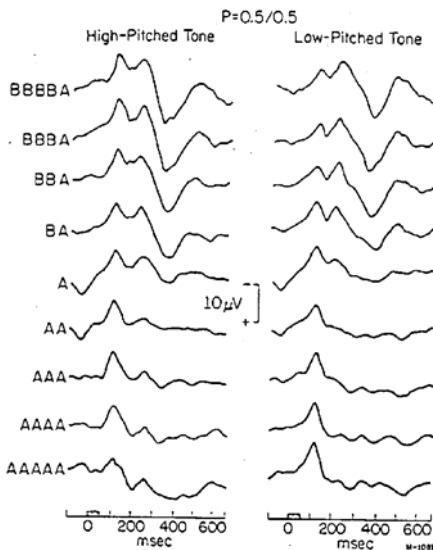


Figure 12-1. The ERPs in each column were elicited by the same physical tone; high-pitched tones were used for the left column and low-pitched tones for the right column. Both were presented in a Bernoulli series in which the probability of the two stimuli were equal. In the middle of each column (labeled "A") is the ERP elicited by all the presentations of the stimulus. The curve labeled "AA" was obtained by averaging together all the tones of one frequency that were preceded on the previous trial by tones of the same frequency. On the other hand, the curves labeled "BA" were elicited by stimuli preceded on the previous trial by the tones of different frequency. Similar sorting operations were applied to all other curves in this figure. It can be seen that the same physical tone elicited quite different ERPs, depending on the events that occurred on the preceding trials. Whenever a tone terminated a series of tones from the other category, a large P300 was elicited, and its magnitude was a function of the length of the stimulus series. (From "Effect of Stimulus Sequence on the Waveform of the Cortical Event-Related Potential," by K. C. Squires, C. D. Wickens, N. K. Squires, and E. Donchin. *Science*, 1976, 193, 1142-1146. Copyright 1976 by the AAAS.

Stimulus Meaning

- Stimulus Complexity
 - Complex (interesting?) visual stimuli produce larger P3
 - [e.g., Verbaten, Roelofs, Sjouw, & Slangen, 1986]
 - Words elicit larger P3 than more simple visual stimuli
 - [Johnson, Pfefferbaum, & Kopell, 1985; Kutas et al., 1977]
- Stimulus Value
 - Stimuli associated with reward [Jenness, 1972; Johnston, 1979]
 - Target status
 - Stimuli associated with punishment [Curtin et al., 2001]
 - Interesting [Homberg, Grumewald, and Netz, 1984]
- Task Complexity
 - Count vs. passive listen
 - Predict vs. count

P300 bigger when stimuli are important to the subject

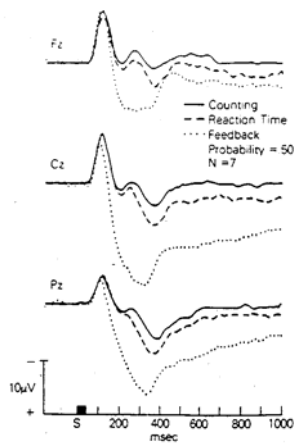


Figure 2. Grand-mean waveforms ($N = 7$) from F_z , C_z , and P_z from three different tasks. The ERPs elicited in an oddball paradigm run under two different task conditions, Counting (solid line) and Reaction Time (dashed line), are superimposed on the ERP elicited when the same stimulus signified correct performance in a feedback paradigm (dotted line). The waveforms were all elicited by a 1000 Hz, 50dB SL tone ($p = .50$).

P300 Component

- ERP component sensitive to probability and/or importance of stimulus
- Reflects stimulus evaluation and categorization
- Reflects updating model of world in memory
 - Orient to novel or important stimuli
 - Keep track of how often such stimuli occur

Characterizing ERP Components

- Polarity
 - Negative or Positive
- Latency
 - Point in time at which a wave typically peaks
 - Range of time during which component evident
- Scalp Distribution
 - Where on scalp wave is largest vs. smallest?
 - Very important in defining an ERP component
- Sensitivity to experimental manipulations
 - What makes it larger or smaller?
 - Very important in defining an ERP component
- (physiological & functional concerns BOTH relevant)

Components, Shcomponents...

- Provide way of communicating across experiments
- Serve as basis for integrating ERP data with other measures of brain activity
- Serve as physiological markers for specific cognitive processes
 - Requires general agreement on the functional significance of a given ERP component

Exploiting ERP Components

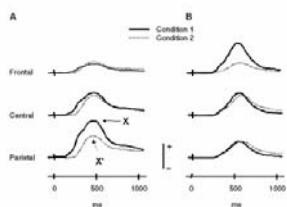


Figure 3.1
Hypothetical ERP waveforms elicited at three electrode sites in two experimental conditions in two experimental situations (A and B). The differences between the waveforms allow a number of functional interpretations. See text for details.

- Assume positivity at X (relative to X') is known ERP component associated w/a specific cognitive process *P*
- Inference about the time course of *P* in conditions 1 and 2
 - Onset
 - Peak latency
 - Rise time
 - Duration
- Inferences about the degree of engagement of *P* in conditions 1 and 2
 - Amplitude
- Rely on well-designed experiments
 - Motivate initial connection between amplitude modulations and engagement of *P*
 - Motivate initial connection between latency modulations and engagement of *P*
 - Interpret observed modulations in terms of *P*

Inferential Limitations

- Null Results
- Scalp Distribution
- Polarity
- Intracerebral Sources
- Amplitude
- Time Course
- Correlation vs. Causation
- Interdomain Mapping



Null Results



- Failure to find an effect could arise for a number of reasons
 - There is actually no difference between the conditions
 - Design is not (statistically) powerful enough to reveal the difference between the conditions
 - Quantification of ERPs suboptimal
 - ERPs only represent a subset of brain activity
- Topographic differences ALWAYS imply underlying neural differences
- But *same* scalp distribution could result from multiple different configurations of neural sources
 - Inverse Problem...

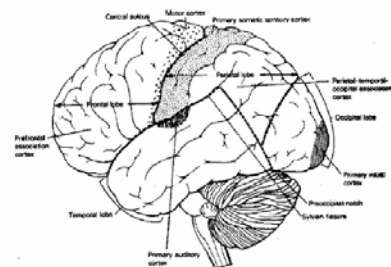
Scalp Distribution

- “Scalp distribution differences can only come about when the patterns of neural activity generating the distributions differ across conditions or time.” Otten & Rugg p. 10
- Many reasons distributions differ
- Engagement of anatomically distinct generators
- Differences in relative contributions of different generators in a network (relative strength or time course of engagement)

Causes of Scalp Distribution Differences

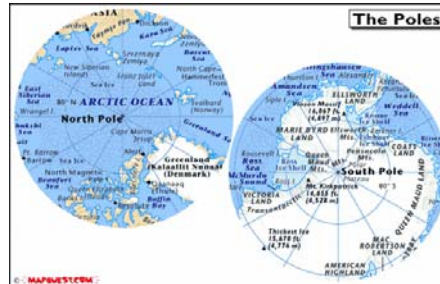
- Totally different brain areas active in the two conditions
 - Visual vs. Auditory Cortex
- Difference in relative contribution of areas in a network
 - Frontal & Motor cortex both active in A & B
 - Frontal stronger in A
 - Motor stronger in B
 - Qualitative or Quantitative?
- Difference in time course of engagement of areas in a network
 - Frontal & Motor cortex both active in both A & B
 - Increased frontal activity begins earlier in A than it does in B
 - Quantitative or Qualitative?

Lobes of the cerebral hemispheres



Polarity

- Polarity of ERP effect depends on many factors
 - Location and orientation of intracerebral sources
 - Location of reference electrode
 - Baseline against which it is compared



Intracerebral Sources

- Location of scalp activity not transparently related to underlying brain activity
- Effect largest over frontal sites not necessarily generated in frontal cortex
 - Each electrode detects summation of fields
 - Depends on strength and orientation of dipoles as well as distance between source and sensor
- But scalp activity not completely irrelevant either

Amplitude

- Typically interpreted as reflecting strength of activity
- But amplitude differences can also arise when violations of assumptions behind averaging occur
- Assume temporal invariance of signal
 - But latency jitter can introduce apparent amplitude differences between two conditions that differ only in the degree of latency variability
- Assume signal identical across trials
 - Possible signal present on some trials but not others
 - Amplitude differences across conditions would then indicate the *probability* of the engagement of a particular process rather than the *degree* of engagement of a particular process

