

Introduction to EEG and Event Related Potentials

Shafali Spurling Jeste
Assistant Professor in Psychiatry and Neurology
UCLA Center for Autism Research and Treatment

Monday, August 2, 2010

Outline of Talk

- Basic definitions and neurophysiology
- Principles of EEG recording
- Types of EEG studies
 - Clinical EEG
 - qEEG/spectral analysis
 - Event related potentials
- Designing and implementing an ERP study

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Key points

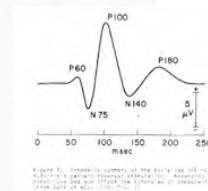
- EEG and ERP methodology promising in developmental populations
- Excellent temporal resolution
- Spatial resolution limited, requires inferences
- While post-acquisition data processing can be manipulated, rigorous study design critical in acquiring high quality data

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My path to EEG



Child Neurology Residency (2007)
Behavioral Child Neurology Fellowship (2008)



Post-doctoral training in developmental cognitive neuroscience with Dr. Charles Nelson (CHB) (2009)

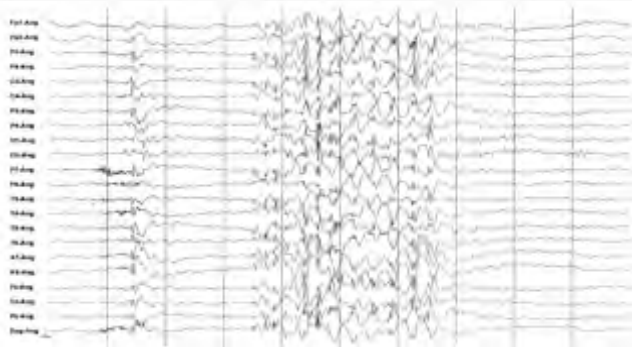
Moved to UCLA to establish an EEG program in the Center for Autism Research and Treatment (Jan 2010)



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Electroencephalography

- The recording of the brain's electrical activity produced by firing of neurons



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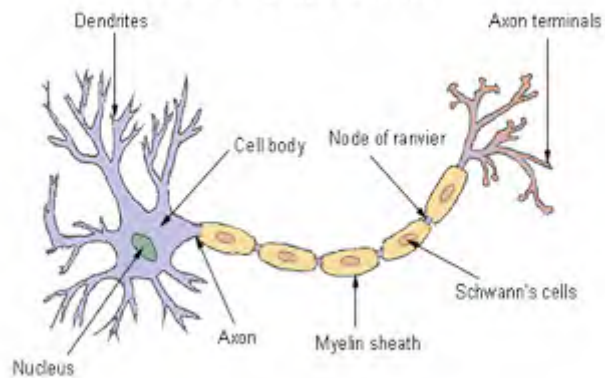
Electroencephalography

- Term *electroencephalogram* first coined by Hans Berger in 1924
- First to formally study human subjects
- First to describe different brain rhythms such as alpha and to associate them to normal vs. abnormal function



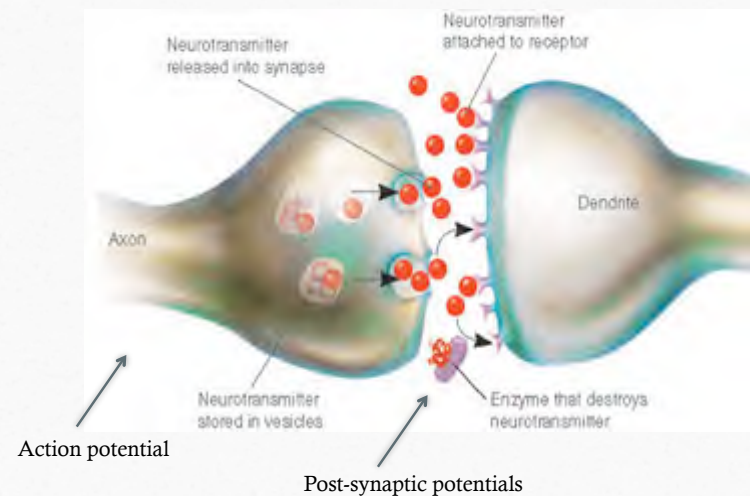
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Structure of a Typical Neuron



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Neuronal transmission

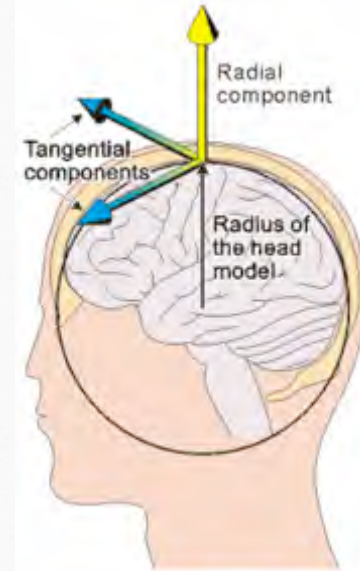
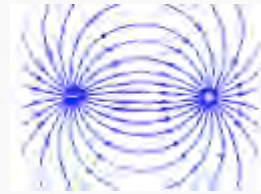


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Generation of EEG signal

- Electrical potentials generated by a single neuron are too small to be detected by EEG
- Duration (<10 msec) and orientation of action potential difficult to detect at scalp
- Post-synaptic potentials 100 msec and are able to summate
- EEG recording is the summation of postsynaptic potentials of pyramidal cells in cerebral cortex and hippocampus
- Parallel networks are configured so that an electrical field summates to create a **dipolar field**

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- Intracellular ions move through and out the neuron, creating a source of the opposite charge (dipole)
- EEG detects the charge of the end of the dipole that is closer to scalp
- Direction and orientation of the dipole is critical for recording
- Radial vs. Tangential dipoles produce different recordings

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Volume Conduction

- Dipole conducted through a medium until it reaches the surface
- EEG signal spreads out laterally when it reaches high resistance of skull
- Hence scalp distribution can be distorted and does not accurately reflect exact location of neural sources

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Source localization

- Constrained by dipole orientations and volume conduction
- **Inverse problem:** determination of positions and orientations of dipoles (cortical and subcortical) on basis of observed scalp voltage distribution
- For any scalp distribution there are infinite number of possible sets of dipoles that could produce the distribution

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Key steps in EEG recording

- (1) Detection of scalp EEG
- (2) Amplification of signal
- (3) Filtration
- (4) Digitization of signal (from analog)

Goal is to maximize Signal to Noise Ratio

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Sources of Noise

Subject dependent

- Scalp impedance
- Physical movement of electrodes
- Chewing
- Blinking



Environmental

- AC line current
- Video monitors
- AC lights
- Pagers
- Cell phones etc etc

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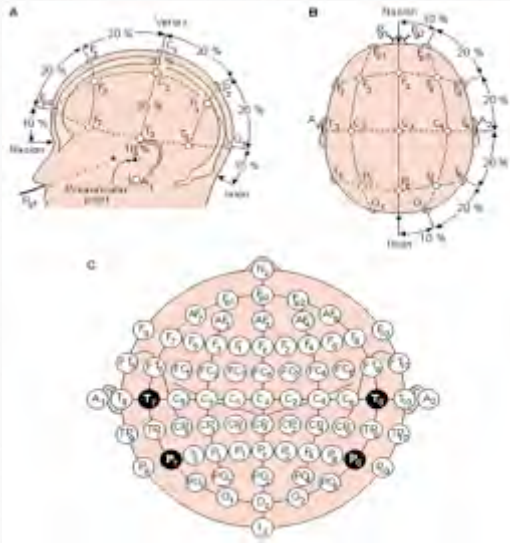
Step 1: Electrodes



- Small metal plates (Sn, Ag)
- Conductive gel
- Recordings are based on differences in voltage between the electrode of interest and a reference
- 10-20 system (Jasper, 1958)
- Montages:
 - Average reference
 - Bipolar
 - Referential

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10-20 system



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High-density electrode nets

- 64, 128, 256 leads
- Fast application
- Electrodes inside soft sponge
- High impedance
- Bridging between electrodes



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Step 1: Minimizing Noise

- Sources of impedance:
 - Hair
 - Hair products
 - Sweat and other scalp debris
- To minimize impedance:
 - Scalp abrasion
 - Application of conductive material such as salt

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Step 1: Minimizing noise

- Acoustically and electrically shielded
- Faraday cage
- Minimize environmental noise



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Step 2: Amplification

- Voltage fluctuations in scalp are tiny ($1/100,000^{\text{th}}$ of a volt)
- EEG must be amplified by factor of 10-50,000
- **Gain:** Amplification factor
- **Calibration:** Ensures that the gain in each electrode is the same (pass voltage of known size through system and measure output, then generate scaling factor for each channel)

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Step 3: Filtration

Filter settings based on the data of interest

High pass: attenuates low frequencies (0.01-0.1 hz)

Low pass: attenuates high frequencies (30-100 hz)

Bandpass: passes only intermediate frequencies

Notch: attenuates a narrow band (60 hz)

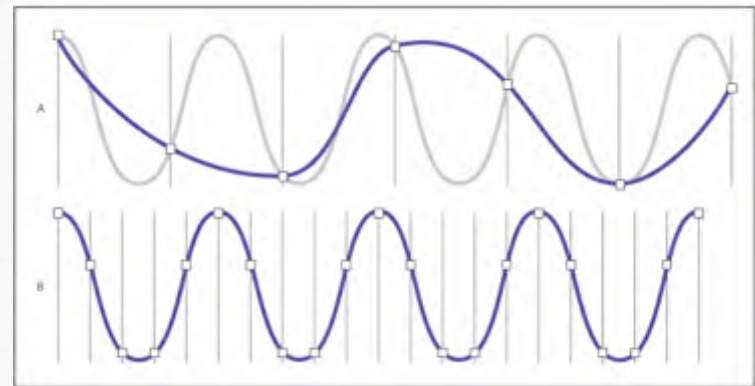
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Step 4: Digitization

- Analog-to-Digital Converter (ADC) converts EEG voltage fluctuations into numbers
- Most EEG systems have ADC resolution of 12 bits
 - Can code 2^{12} (4096) voltage values
- Set gain on amplifier to not exceed ADC range

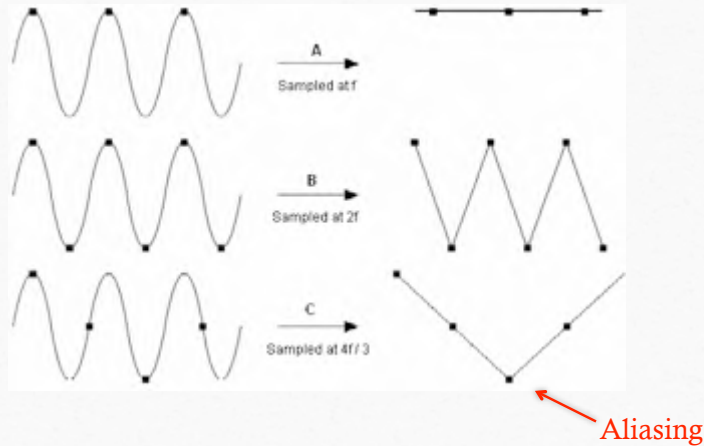
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Sampling Rate = # samples per second



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Nyquist Theorem (SR must be $\geq 2x$ highest frequency)



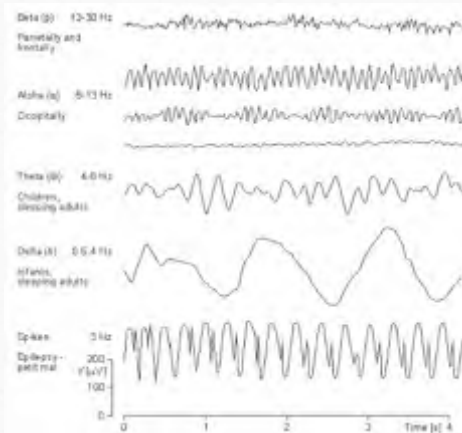
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Oscillations



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Clinical EEG

- Diagnosis and management of epilepsy
- Characterization of sleep
- Evaluation of coma
- Confirmation of brain death

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Clinical EEG



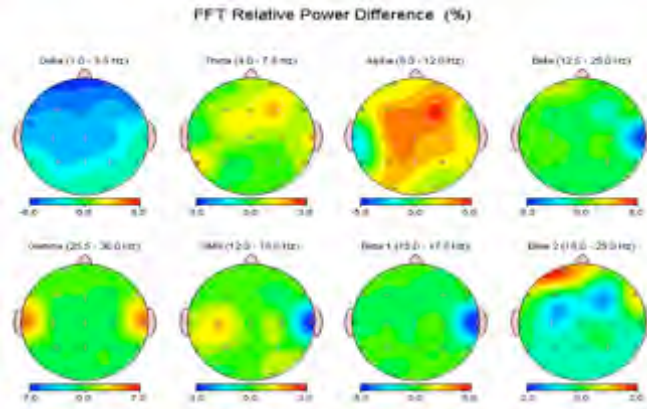
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Quantitative EEG

- Goal is to quantify spectral (frequency) components of EEG using Fast Fourier Transform (FFT) algorithm
- Adjust filtration based on frequencies of interest (ie to capture gamma, low pass filter ≥ 100 hz)
- Based on regions of interest, can cluster electrode placement
 - Example: prefrontal theta in depression

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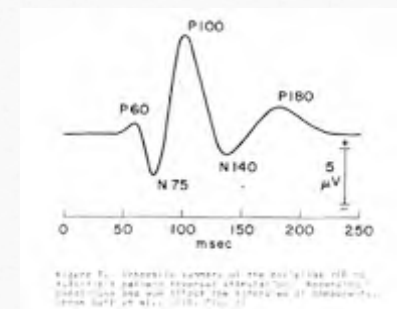
Quantitative EEG



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Event Related Potentials

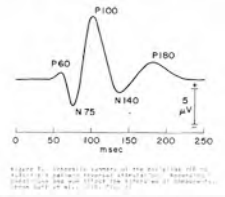
- Embedded within the EEG
- Neural responses time locked to specific sensory, cognitive, or motor events
- Can extract these responses from EEG through processing techniques
- 3 Dimensions
 - Latency
 - Amplitude
 - Topography (Spatial Location)



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ERP Components

- N for negative deflection
- P for positive deflection
- Number that follows is either
 - (1) Ordinal position in waveform (ie N1)
 - (2) Latency of component (ie N100)
- Early components (first 100 msec) are “endogenous” and reflect perception
- Late components (after 200 msec) are “exogenous” and reflect cognitive processing



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Advantages of ERPs

- Non-invasive
- Motion artifact less of an issue
- Feasible in challenging populations
- Excellent temporal resolution
- Can tease apart perceptual and cognitive processes
- *Can assess processing without an overt (behavioral) response and before an overt response*

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Pitfalls of ERPs

- Electrode placement takes time
- Single application nets can be uncomfortable
- Poor spatial resolution
 - Source localization?
- Potential for “fishing” for findings if no *a priori* hypothesis
- Not as much foundation for cognitive paradigms in young and developmental populations (ie we don't have a lot of prior data to build upon)

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 - Event related potentials
- **Designing an ERP study and ERP data processing**

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Infants at Risk for ASD

- At 12 months, differences in:
 - Initiation/response to referencing behaviors
 - Requesting
 - Language production and comprehension
 - Response to changes in another person's emotional state
- At 18 months, differences in:
 - Functional play acts
 - Repeated non-functional play acts
- **No behavioral predictors prior to age 12 months**

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Study Questions

- Are there pre-behavioral markers of ASD in high risk infants?
- Are there signs of cognitive and perceptual dysfunction in early infancy that correlate to later phenotypes (not just ASD)?
 - Particular interest in language acquisition
- Domains of interest:
 - **Joint attention (and learning from social cues)**
 - Statistical language learning
 - Face processing

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High density EEG system

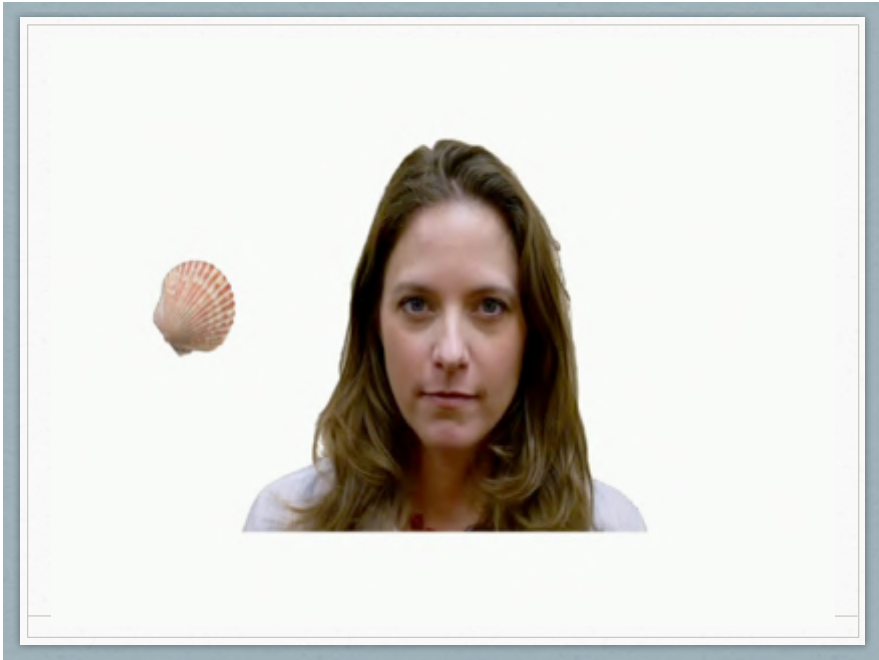
- EGI system (Electrical Geodesic Inc)
- 128 channel HCGSN nets (Hydrocel Geodesic Sensor Nets)
- Stimuli presented in eprime 2.0
- Stimuli "tagged" into EEG file to facilitate segmentation of data
- Netstation 4.4 software and waveform tools for data processing

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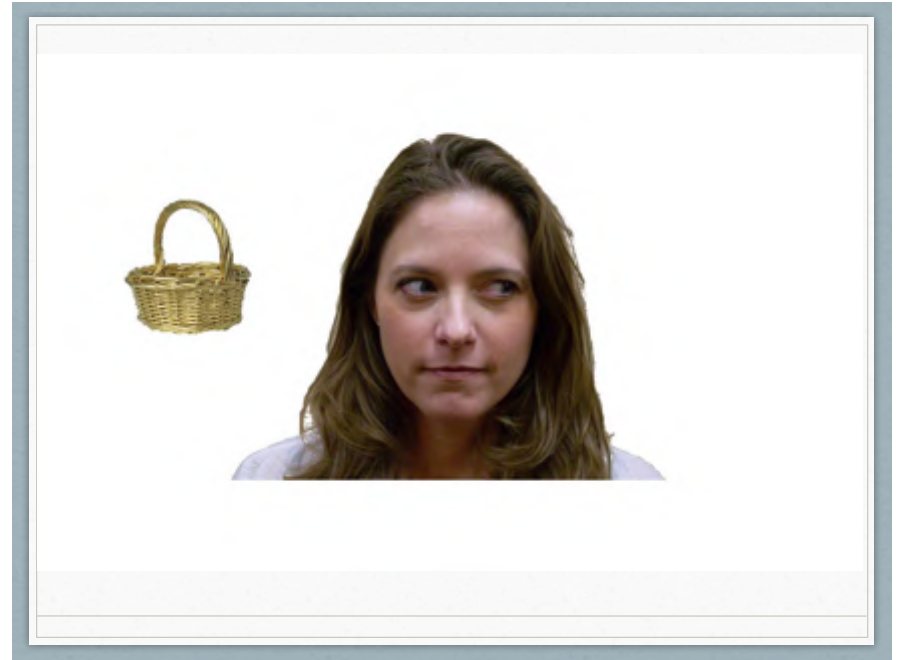
Joint Attention Paradigm

- Infants can distinguish direct from averted eye gaze
- Infants prefer to look at faces with directed eye contact
- By 4 months, infants will follow eye gaze and shift their attention to the direction of adult's eye gaze
- By 4 months infants learn best when taught in a joint attention format
- Are infants at high risk for ASD use social cues to learn?

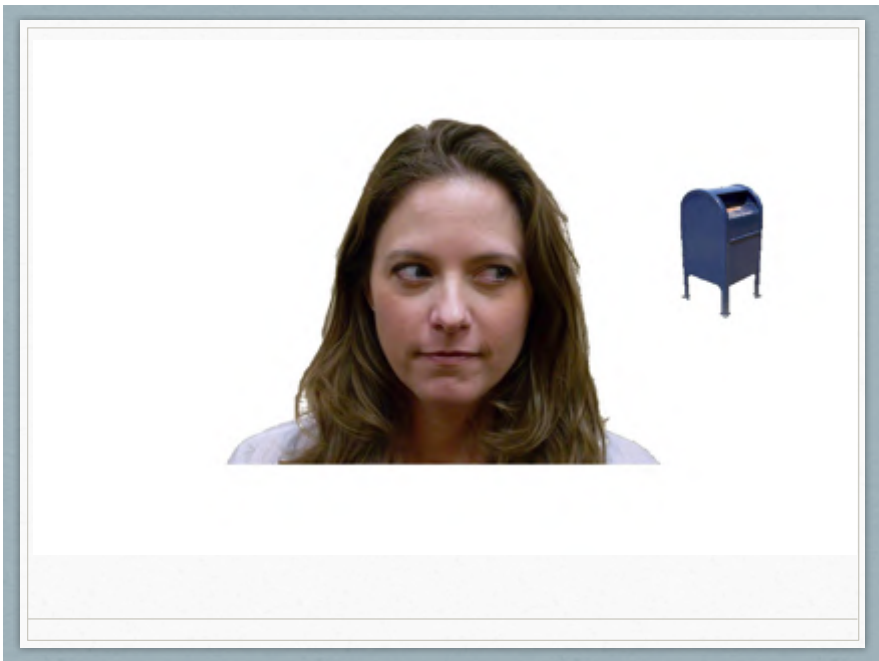
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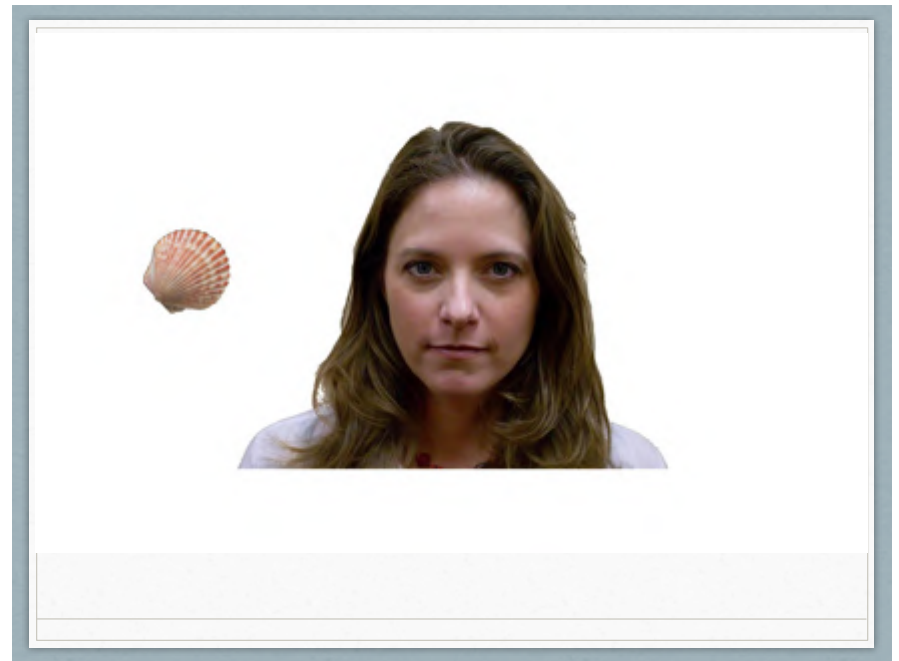
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Components of interest

- Nc: Marker of attention
 - Larger to unfamiliar than familiar stimuli
 - Negative component 350-650 msec after stimulus
 - Fronto-central
- PSW: updating of partially encoded information
 - Larger to less frequently presented stimuli
 - Positive component 700-1000 msec after stimulus
 - Fronto-central
- N290/P400 complex
 - Face processing
 - Modulated by gaze direction

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Considerations in study design

- (1) Timing of stimuli and ISI (jitter)
- (2) Enough trials to maximize signal, minimize noise
- (3) ...while still keeping subject's attention

Need to know what you are looking for before designing experiment!!

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Joint attention study design

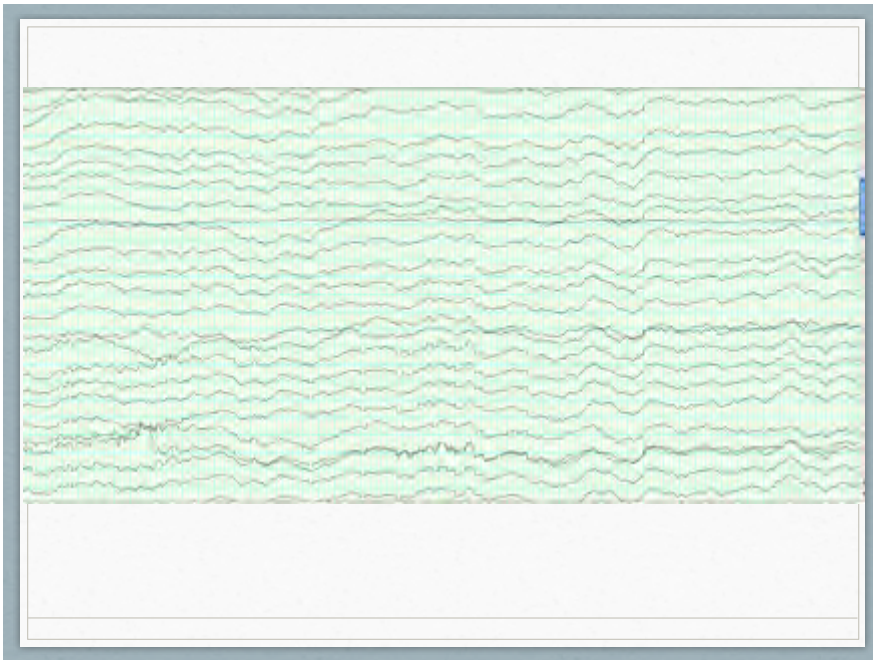
- Exposure phase: Stimulus presentation 1000 msec
- Test phase:
 - Stimulus presentation 500 msec
 - ISI 1000-1250 msec
- 200 test trials, randomized in blocks of 50
- Goal is to have >10 good trials per condition
- Components of interest: N290/P400 during exposure, frontal Nc and PSW during test

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Data processing: How to get an ERP from raw EEG?

- Filtering
- Segmentation
- Signal averaging
- Artifact detection and rejection

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Filtering

Filter settings based on the data of interest

High pass: attenuates low frequencies (0.1 hz)

Low pass: attenuates high frequencies (30 hz)

Bandpass: passes only intermediate frequencies

Notch: attenuates a narrow band, passes everything else

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Segmentation

- Defining parameters for time-locked segment of interest
- 100-200 msec of baseline prior to segment
- Segment length depends on components of interest
- Study design depends on segmentation

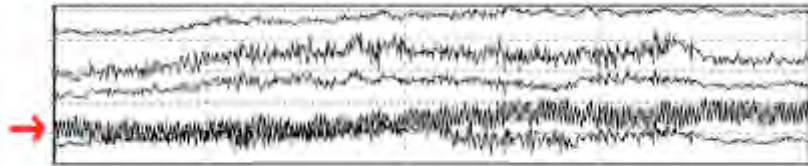
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Artifact detection

- Blinks, eye movements, muscle activity, skin potentials, electrical noise
 - Usually larger than the ERP, decrease S/N
 - Might be systematic rather than random, so may lead to wrong conclusions about data
- Automated artifact detection in adults (eye blinks, eye movements, bad channels)
- In child data, best to do manual artifact detection
 - But need to set an *a priori* threshold for rejection

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High frequency electrical noise



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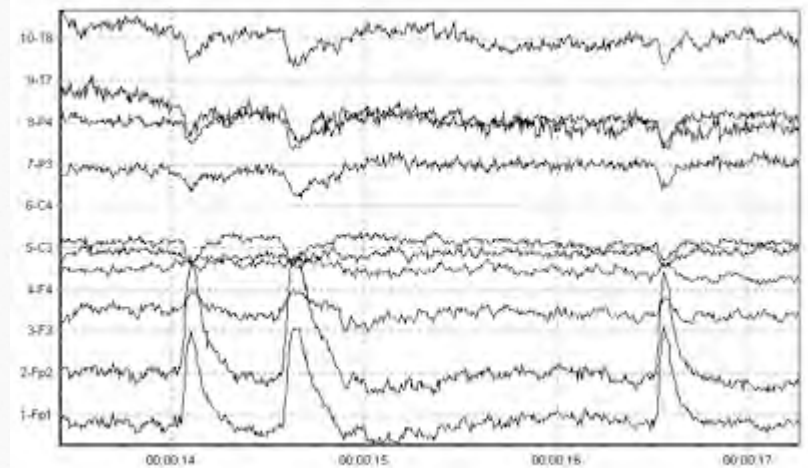
Blinks

- Electrical gradient in each eye
 - Positive in front, negative in back
- Blink causes monophasic deflection
- 50-100 μV , lasting 200-400 msec
- Opposite in polarity for sites above vs. below the eye
- How to reduce blinks:
 - Glasses over contacts
 - Short trials blocks
 - Give participant feedback during session

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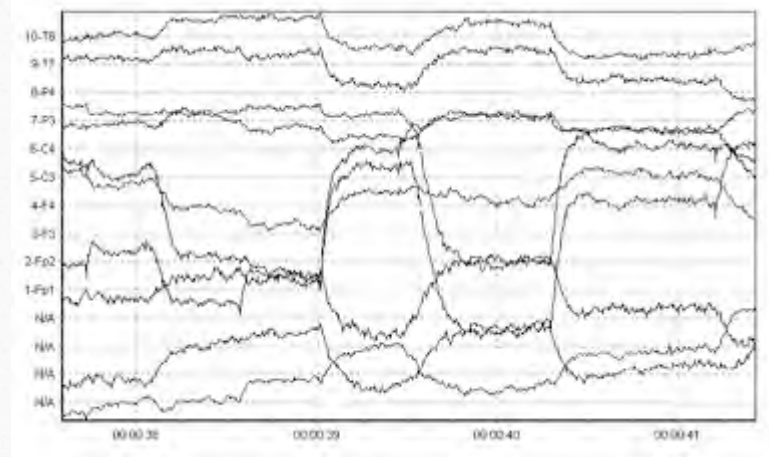


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Eye movements

- Voltage gradient on scalp changes when eyes move, more positive in location where eyes look
- Also have to look for saccade induced ERP response
- Boxcar shaped because saccade in one direction followed by another to return to fixation point
- Video helps

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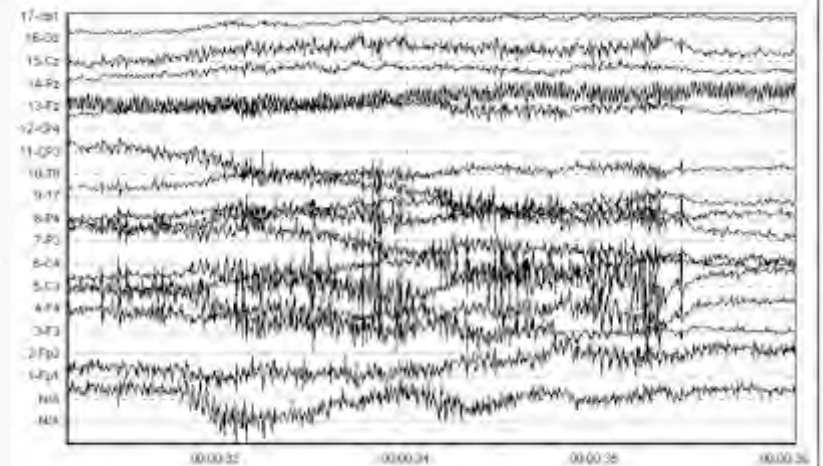


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EMG and EKG

- Muscle and heart activity
- EMG
 - High frequency
 - Usually eliminated by low pass filter
 - In kids often see chewing / sucking artifact
- EKG
 - Distinctive shape
 - Picked up by mastoids
 - 1 hz during entire recording session
 - Not a big deal, just decreases S/N

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Slow voltage shifts “drift”

- Change in skin impedance
 - Sweat causes decrease in impedance
- Slight changes in electrode position (movement)
 - Major issue in little kids/infants
 - High pass filter can help this
- Can cause amplifier to saturate, causing EEG to look flat (“blocking”)
 - Use lower gain on amplifier

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Signal Averaging

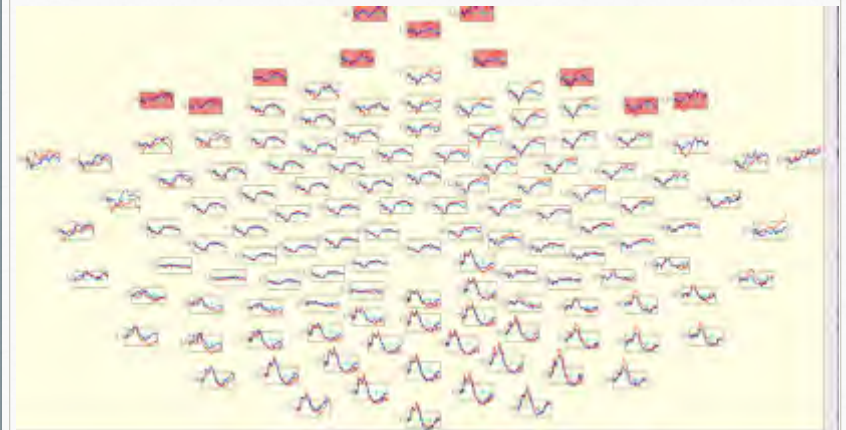
- Average segmented data across all trials, per condition and then across subjects
- EEG data from single trial assumed to contain ERP waveform + random noise
- ERP waveform assumed to be same in each trial, whereas noise varies
- Averaging trials reduces noise, increases S:N ratio

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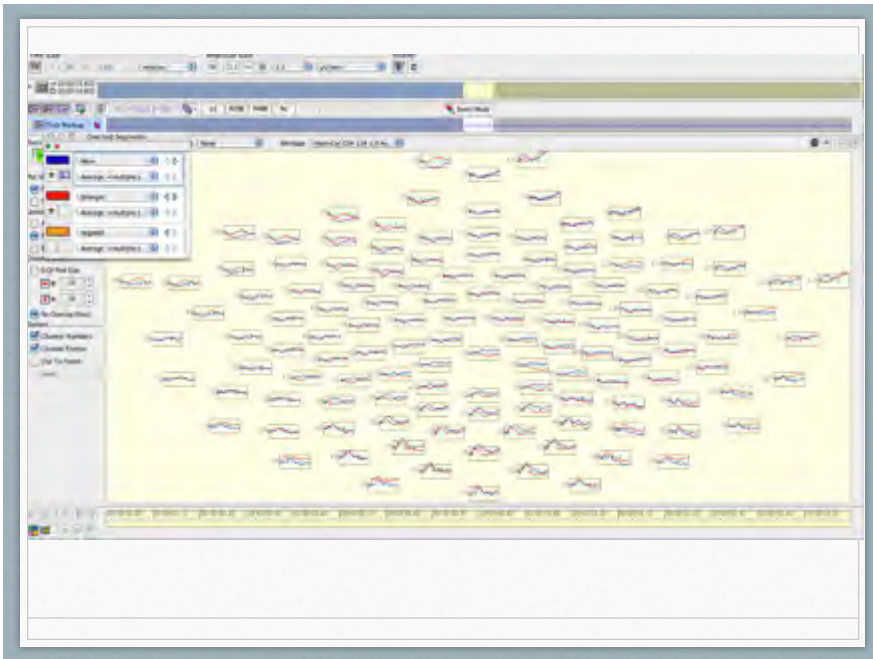
Data processing

- Filtering
- Segmentation
- Signal averaging
- Artifact detection and rejection

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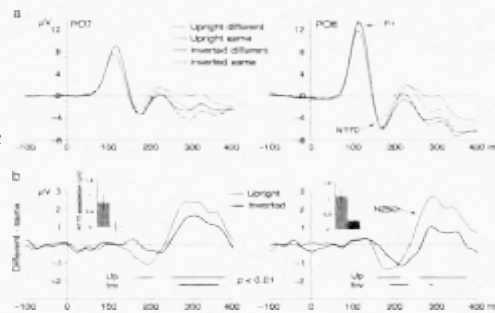
Measurement, plotting, analysis

- Variables of interest: Latency, Peak vs. mean amplitude
 - Depends on component of interest
- Need to establish baseline (100-200 msec) but realize that pre-stimulus interval (ISI) may not be completely neutral
- Amplitude directly affected by latency
- Plot in excel
- Analysis in SPSS, using ANOVA's

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Plotting ERP waveforms

- Need to include voltage and time scale
- Superimpose different conditions/groups
- Show prestimulus baseline (100-200 msec)



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What do differences in waveforms mean?

- Reliably different waveforms can be linked to different activity in the nervous system
- Need a theoretical framework linking biological states and functional states
- Ideally, need apriori hypothesis of nature and source of differences
- Findings then need to be replicated

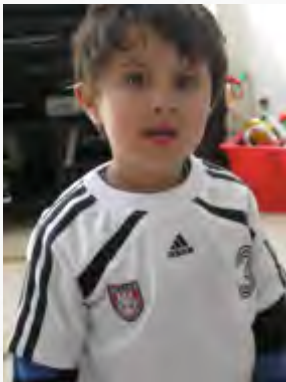
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Key points

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- Excellent temporal resolution
- Spatial resolution limited, requires inferences
- While post-acquisition data processing can be manipulated, rigorous study design critical in acquiring high quality data

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Questions?



sjeste@mednet.ucla.edu

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