Technical Details

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

Announcements

- Office Hours Monday/Friday 1-2pm
  - Or by appointment
  - CSB 161
- ???

Outline

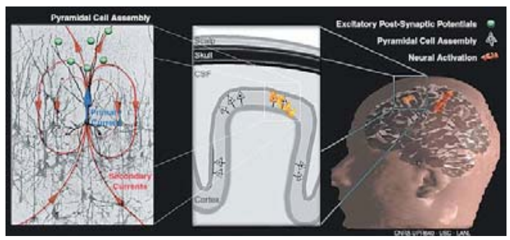
- Quick review from last time
- Ways of talking about waves
- Recording EEG
  - What equipment do you need?
  - What are some technical considerations?
- Analyzing EEG

Electroencephalogram (EEG)

- The EEG – an oscillating voltage recorded on scalp surface
  - Reflects Large # Neurons
  - Is small voltage

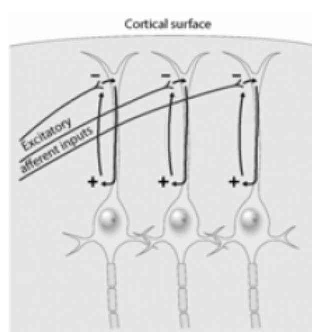
Sources of Scalp Potentials

- Action Potentials – NO, brain tissue has strong capacitance effects, acting as Low Pass filter
- Post-synaptic potentials – YES, both inhibitory and excitatory from functional synaptic units are major contributors



Questions

- If input to the cell is excitatory, why are there negative signs near the dendrites?
- What polarity would the signal be if the electrode was on the cortical surface?
- Assuming the scalp was directly over the cortical surface, what polarity would the scalp-recorded signal be?
- Why isn't it easy to infer whether activity is excitatory or inhibitory from the polarity of EEG activity?



Outline

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- **Ways of talking about waves**
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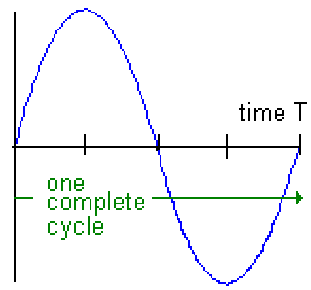
Ways of talking about waves

- Period
- Frequency
- Phase

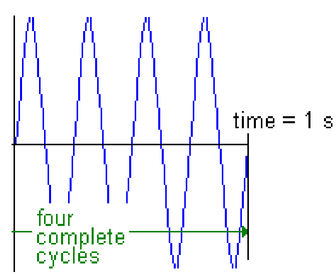
Period

- The period of a waveform is the time required for completing one full cycle.
- symbol: T
- Unit of measure: seconds (s)
- One period occupies exactly 360º of a sine waveform

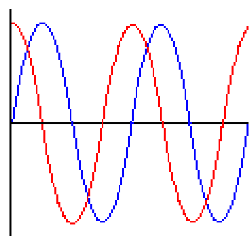


Frequency

- The frequency of a waveform is the number of cycles that is completed each second.
- symbol: f
- Unit of measure: hertz (Hz)
- This example shows four cycles per second (4 Hz)
- Conversions between period and frequency
- f = 1/T T = 1/f



Phase Angle



- The phase angle of a waveform is angular difference between two waveforms of the same frequency.
- Symbol: (theta)
- Unit of measure: degrees or radians

- Two waveforms are said to be *in phase* when they have the same frequency and there is no phase difference between them.

- Two waveforms are said to be *out of phase* when they have the same frequency and there is some amount of phase shift between them.

Bands of Activity

Delta 0.5-4 Hz

Theta 4-8 Hz

Alpha 8-13 Hz

Beta 13-30 Hz

Gamma 30-50 Hz

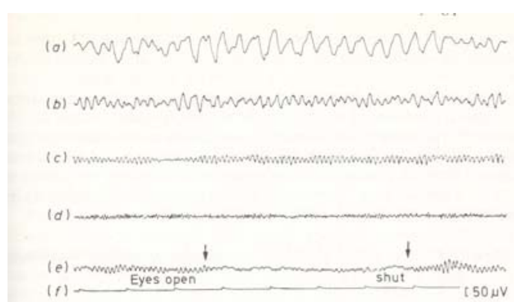


Figure 6.3 Examples of (a) delta, (b) theta, (c) alpha and (d) beta activity. (e) Blocking of the alpha rhythm by eye opening. (f) 1 s time marker

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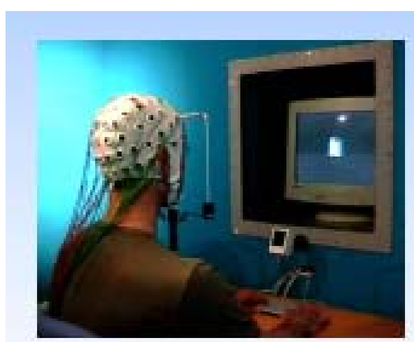
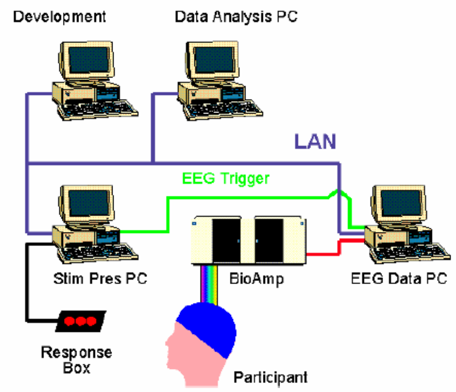
Recording EEG



What equipment do you need?

- Electrodes
- Amplifiers
- Analog to Digital Conversion device
- Output device (computer/plotter)
- Equipment for presenting stimuli

How do we record microvolt level EEG and ERPs?



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Electrodes, Electrolyte, Preparation

- Ag-AgCl Preferred (Tin typically used)
  - Inert
  - Nonpolarizable
- Electrolyte
  - Ionic
  - Conductive
  - NaCl
- Affixing
  - Subcutaenous needles (ouch)
  - Collodion (yuck)
  - EC-2 paste
  - Electrocap

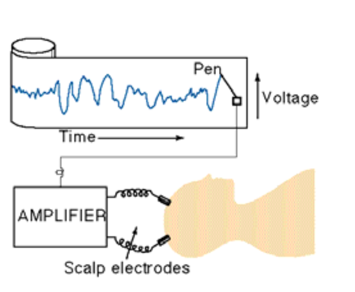
Measuring Voltage

- Have electrode on scalp
- Need ground
  - Ground lead in voltmeter
  - Safety function: connect subject to electrical ground of amplifier
- E1: potential at electrode
- B1:brain potential measured from scalp
- N: background noise
- E1=B1+N
- When N>B1, E1 reflects electrical activity in nearby flourescent lights, power cords, etc. but not much brain activity

Reference Electrode

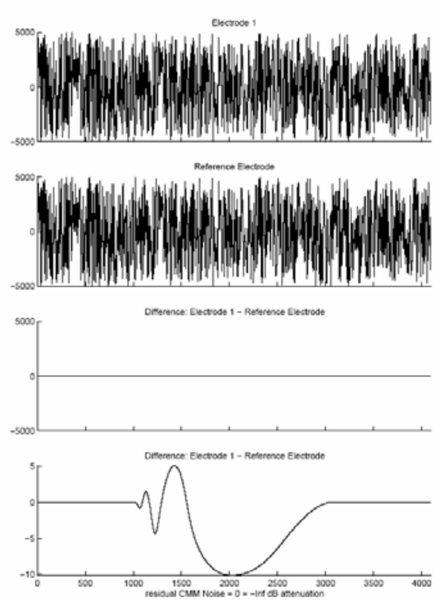
- Ambient noise looks similar at all scalp sites!
- E1: B1+N
- Reference: B2 + N
- Take difference between two inputs

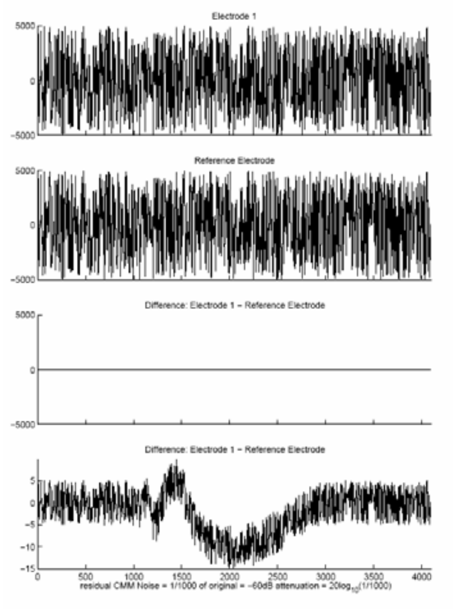
  (B1+N) – (B2+N)
- Common mode noise cancels out
- If activity at reference electrode is negligible, then B1-B2 will mostly reflect B1



Differential Amplification

- Permits extraction (and amplification) of difference between 2 sites
- Requires 2 signal electrodes
  - 1 at scalp location of interest
  - 1 at reference site
    - Same noise as scalp site, little or no brain activity
    - E.g. Mastoid bone, earlobe, nose tip
- Conceptually 2 pairs of electrodes
  - Pair 1: scalp site and ground
  - Pair 2: reference site and ground
- In practice, use same ground (3 electrodes)
  - E1: scalp location of interest
  - E2: reference electrode
  - G: ground electrode





Electrode Montages

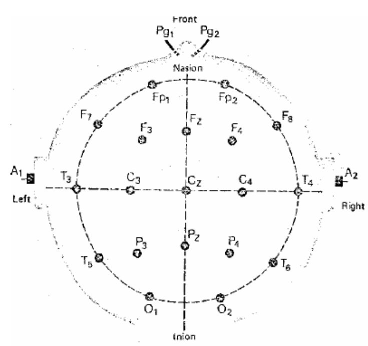
- Arrangement of electrodes over the scalp
- Things to decide:
  - How many electrodes?
  - How distributed over the head?
  - What will serve as the reference?

How Many Electrodes?

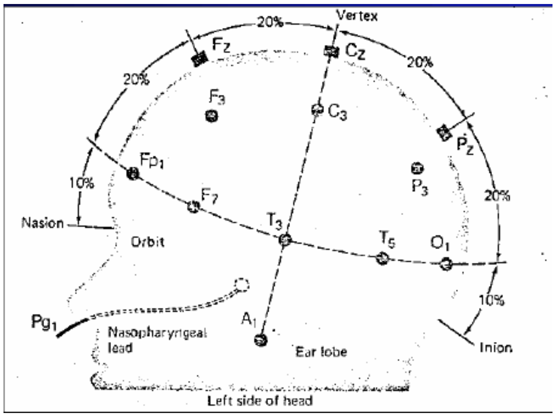
- Optimal spatial resolution is achieved with 256 electrodes
  - Between 30 and 100 typical for cognitive research
- Tradeoffs
  - Prep time
  - Technical difficulties

Layout

- Standardization
  - 10-20 System
- Dipole Fitting
  - Even spacing



10-20 System



High Density Recordings

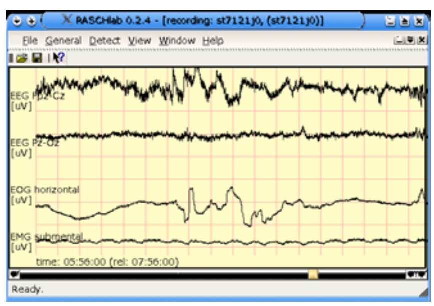
- Even spacing via geodesic tesselation
- Facilitates localization algorithms (dipole fitting)

Choice of Reference

- Bipolar recording
  - Multiple active sites
    - Sensitive to differences between electrodes
    - With proper array, sensitive to local fluctuations (e.g. spike localization)
    - Electro-Occulo-Gram (EOG)
    - For brain activity, want reference site w/negligible brain activity (mastoid, nose, etc.)
- Off-line derivations
  - Done on computer, after data collection finished
  - Averaged Mastoids
  - Average Reference (of EEG Leads)

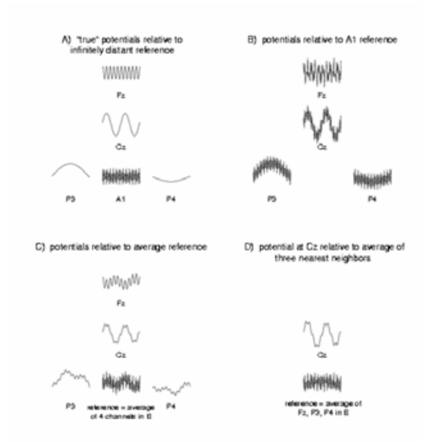
Bipolar Derivation

- EOG
  - Side of Left eye
  - Side of Right eye
- Horizontal eye (HE) movement left results in sudden change in voltage
- Fixation steady voltage
- HE movement right results in opposite voltage change



Offline Derivations

- Average Mastoids
  - Important if examining hemispheric differences
- Average Reference
  - With sufficient # electrodes and surface coverage, approximates inactive site (signals cancel out)
  - Good if you have lots of channels & noise is randomly distributed across sensors
  - Artifacts “average in”
  - Bad if noise is confined to a few electrode sites (as in c in the diagram)



What equipment do you need?

- Electrodes
- **Amplifiers**
- Analog to Digital Conversion device
- Output device (computer/plotter)
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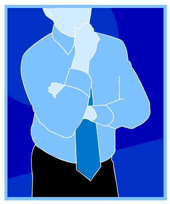
Amplification

- Brain signals very small at the scalp
  - Non-brain sources 50-500 microvolts
  - EEG 10-100 microvolts
  - ERP effects 1-10 microvolts
    - 10^-6 Volts=1 microvolt
- Amplifiers change data in 2 important ways
  - How much amplification?
  - What kind of frequency filtering?

How much amplification?

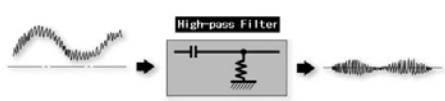
- Amplifiers increase the magnitude of input by a factor of up to 500,000x
- After amplification, signal should be on the order of +/- 1 V to be compatible with A/D converter on computer
- Gain depends on size of signal
  - ECG: 1 millivolt need 1000X
  - EEG: 50 microvolts need 20K
- Don't want to saturate amplifier and cause blocking
  - Channels close to eyes might be better with slightly smaller gain

What kind of frequency filtering?



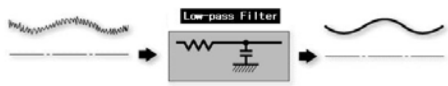
High Pass Filter

- Attenuates frequencies *below* chosen frequency
  - – Allows high frequencies to pass through



Low Pass Filter

- Attenuates frequencies *above* chosen frequency
  - – Allows low frequencies to pass through

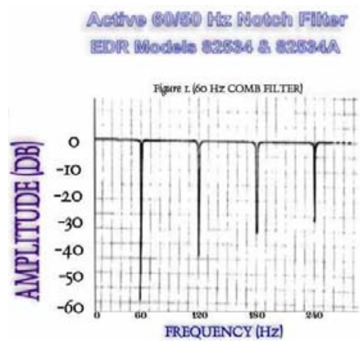


Time Constant

- Low pass filtering results in minimal distortion of the waveform
- BUT high pass filters can change shape of long-duration components
  - – Physical makeup of HP filter affects how low you can go
- Recording low frequency components depends on the AC coupling time constant of the filter
- Time it takes output to decay to 37%
- Time constant = 1 / 2piF
  - – F is low cutoff frequency
  - – 10 secs for .016 Hz
  - – 5 secs for .32 Hz

Notch Filter

- Attenuates activity at a particular frequency
- Line frequency
  - 60 Hz USA
  - 50 Hz Europe

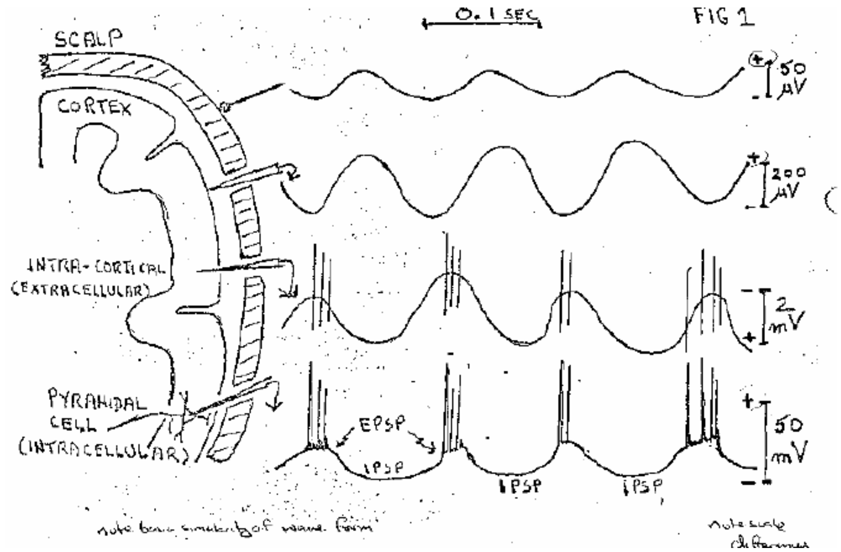


Analog Filter Considerations

- Ambient noise level
  - Notch vs. No notch
- Frequency range of interest
  - Brain activity present at very low frequencies
    - Go as low as possible
  - High frequency activity present in brain, but not much can be recorded at scalp (see next slide)
  - Brain activity (in EEG) ranges from 0 to 30 Hz
- Typical cut-offs

  0.01 to 100 Hz

  0.01 to 40 Hz



What equipment do you need?

- Electrodes
- Amplifiers
- **Analog to Digital Conversion device**
- Output device (computer/plotter)
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Analog to Digital Conversion

- Output of amplifier is analog
  - Continuous signal
- To store on a computer, must convert to digital format
  - Discrete pairing of time points and voltages
- Sample output of amplifier
  - Pick series of time points and measure voltage at each
  - Done with special I/O card on computer

A/D Card Issues

- What sampling rate?
- What resolution?

What sampling rate?

- How many samples per second?
- To properly represent a signal you must sample at a fast enough rate
  - else Aliasing
- Aliasing – when high frequency aspects of the waveform look slower due to undersampling

Aliasing

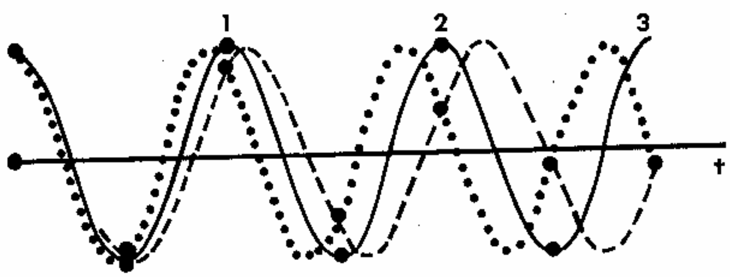
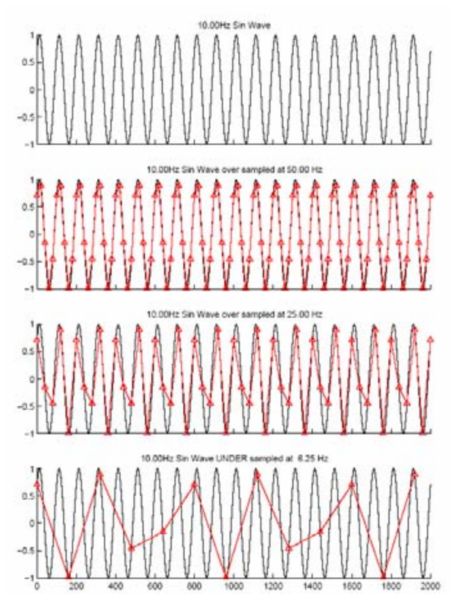


Fig. 3.1. A cosine wave of frequency F (solid line) sampled at its Nyquist rate. A higher frequency (dotted) wave, frequency F + a, is shown sampled at the same rate. At the sample times it is indistinguishable from a lower frequency (dashed) wave, frequency F − a.



Nyquist

- Nyquist’s theorem
  - Sample rate 2x as fast as highest signal frequency will capture signal perfectly
  - The highest frequency that can accurately be represented is ½ the sampling rate
  - This is known as the Nyquist frequency

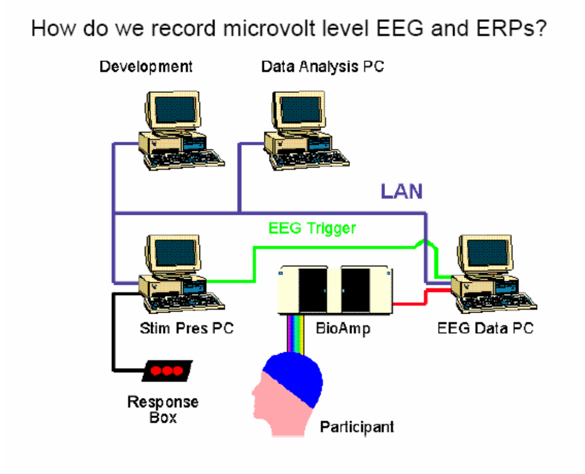
What resolution of voltages?

- How many bits for each number?
- 1 bit
  - Voltage high=1
  - Voltage low=0
- 12 bits
  - Can represent 4096 (2^12) distinct values
  - Good resolution for EEG

What equipment do you need?

- Electrodes
- Amplifiers
- Analog to Digital Conversion device
- **Output device (computer/plotter)**
- **Equipment for presenting stimuli**

Computers…



Outline

- Quick review from last time
- Ways of talking about waves
- Recording EEG
  - What equipment do you need?
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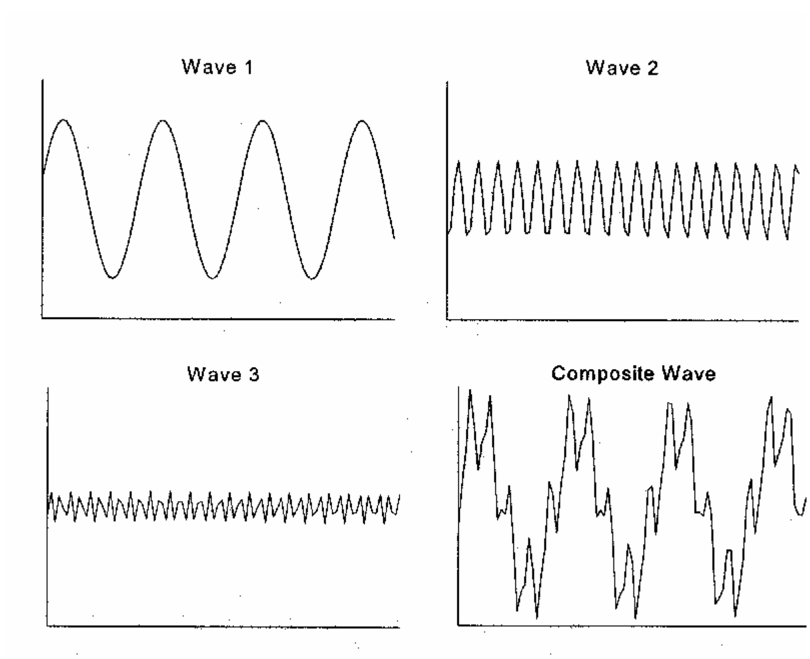
- **Analyzing EEG**
  - Time domain vs. Frequency Domain
  - How to process data to create ERPs

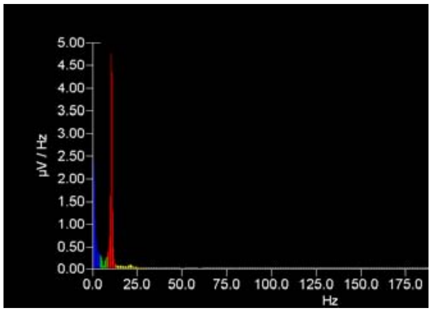
Time Domain Vs Frequency Domain Analysis

- Frequency Domain Analysis involves characterizing the signal in terms of its component frequencies
  - Assumes periodic signals
- Periodic signals (definition):
  - Repetitive
  - Repetitive
  - Repetition occurs at uniformly spaced intervals of time
- Periodic signal is assumed to persist from infinite past to infinite future



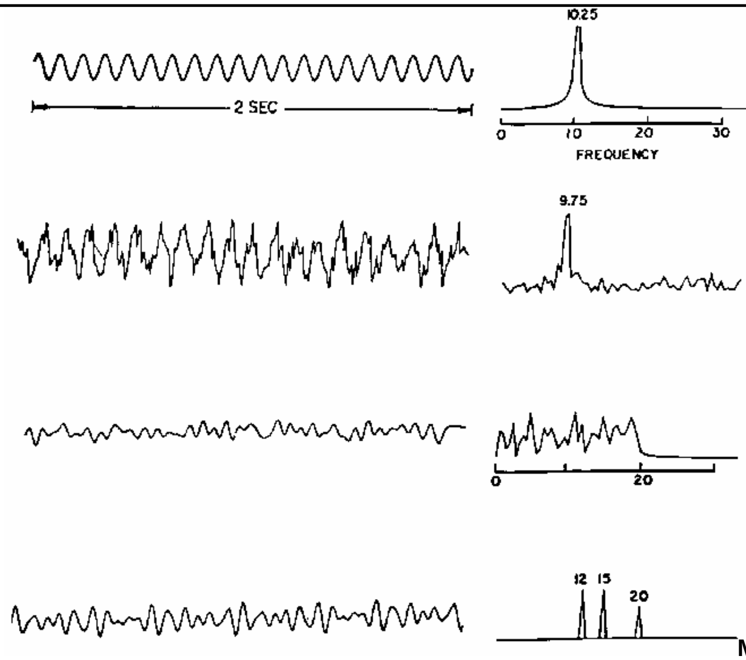
Fourier Series

- If a signal is periodic, the signal can be expressed as the sum of sine and cosine waves of different amplitudes and frequencies
- This is known as the Fourier Series Representation of a signal



Fourier Series Representation

- Pragmatic Details
  - Lowest Fundamental Frequency is 1/T
    - T=period sampled by the N samples
  - Resolution is 1/T
- Phase and Power
  - There exist a phase component and an amplitude component to the Fourier series representation
    - Using both, it is possible to completely reconstruct the waveform.
- Psychophysiologist usually only interested in amplitude component



a

Sine wave

b

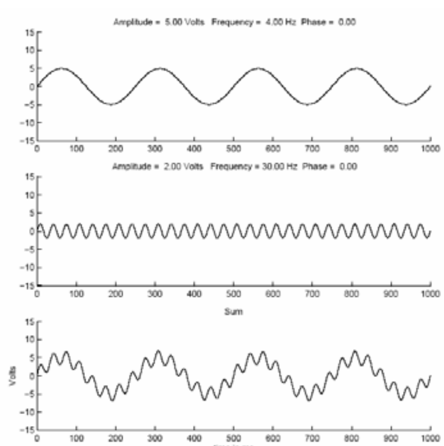
9.75 Hz wave with noise added

c

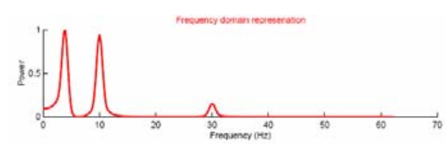
Noise Only < 20 Hz

d

Mixture of 3 waveforms



top



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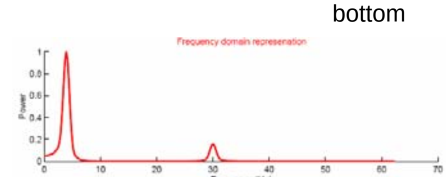
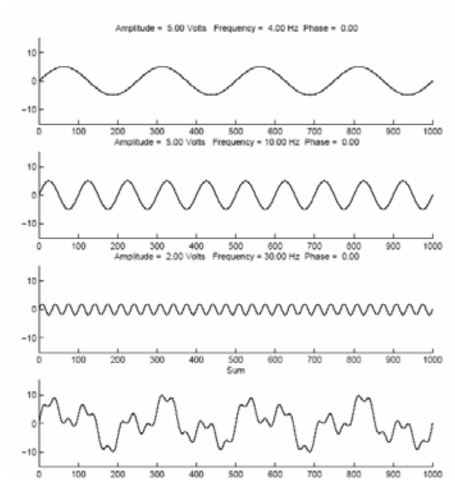


Which is the correct frequency domain representation for the composite waveform depicted on the bottom left?

Draw the Frequency Domain Representation for the composite waveform at the bottom



Time Domain Analysis

- Time Domain Analysis involves viewing the signal as a series of voltages as a function of time, [x(0), x(t1), x(t2),...,x(tn-1)]
  - e.g. event-related potential
  - Relevant dependent variables
    - latency of a particular response
    - amplitude of that response within the time window

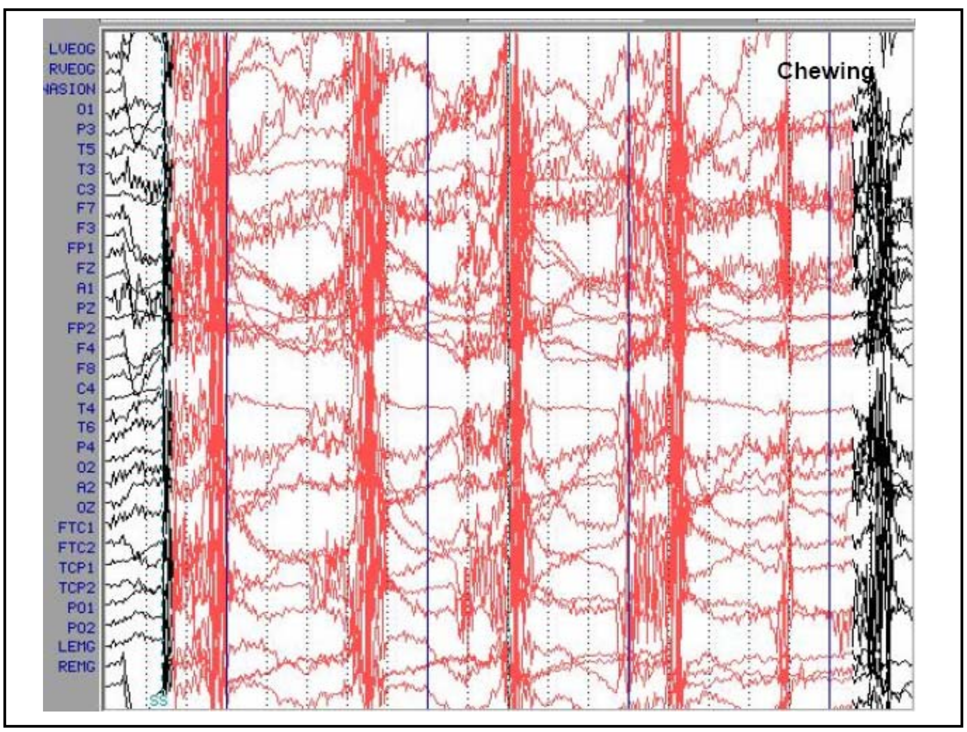
Processing EEG data for ERPs

- 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

Artifacts

- Reflection of non-brain activity
- Best cure is prevention
  - Record EEG in shielded environment
  - Instruct participants not to move, blink, etc. during important times during data collection
- Alternatively, artifact rejection
  - Identify artifacts in EEG
  - Remove from dataset
- Artifact correction (mathematical)
  - Blink correction
  - Eye movement correction


LVEOG
RVEOG
NASION
O1
P3
T5
T3
C3
F7
F3
FP1
FZ
A1
PZ
FP2
F4
F8
C4
T4
T6
P4
O2
A2
OZ
FTC1
FTC2
TCP1
TCP2
PO1
PO2
LEMG
REMG
Movement in reference lead


LVEOG
RVEOG
NASION
O1
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C3
F7
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FP1
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FP2
F4
F8
C4
T4
T6
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FTC1
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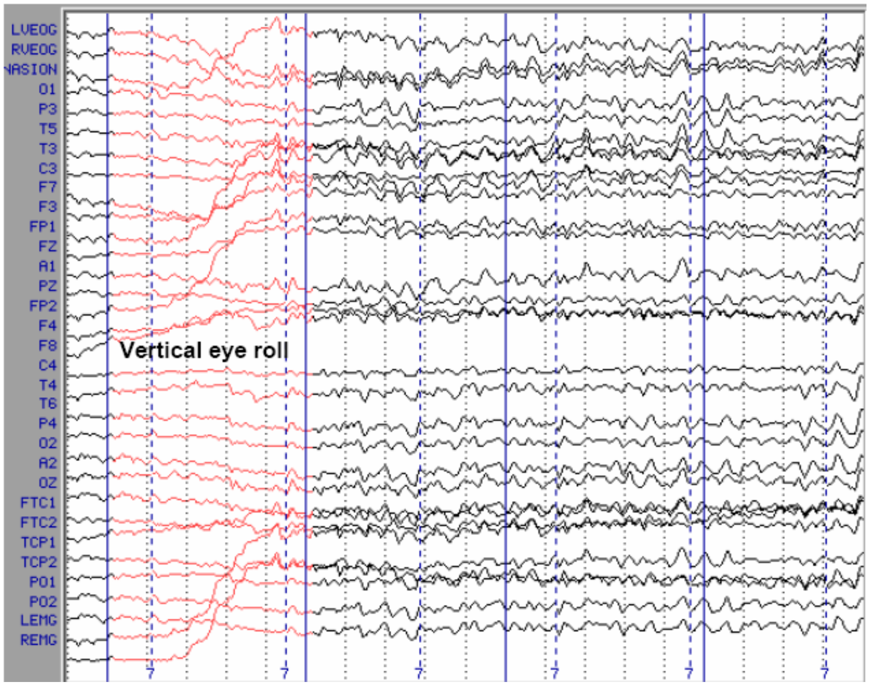
TCP1
TCP2
PO1
PO2
LEMG
REMG
Chewing


LVEOG
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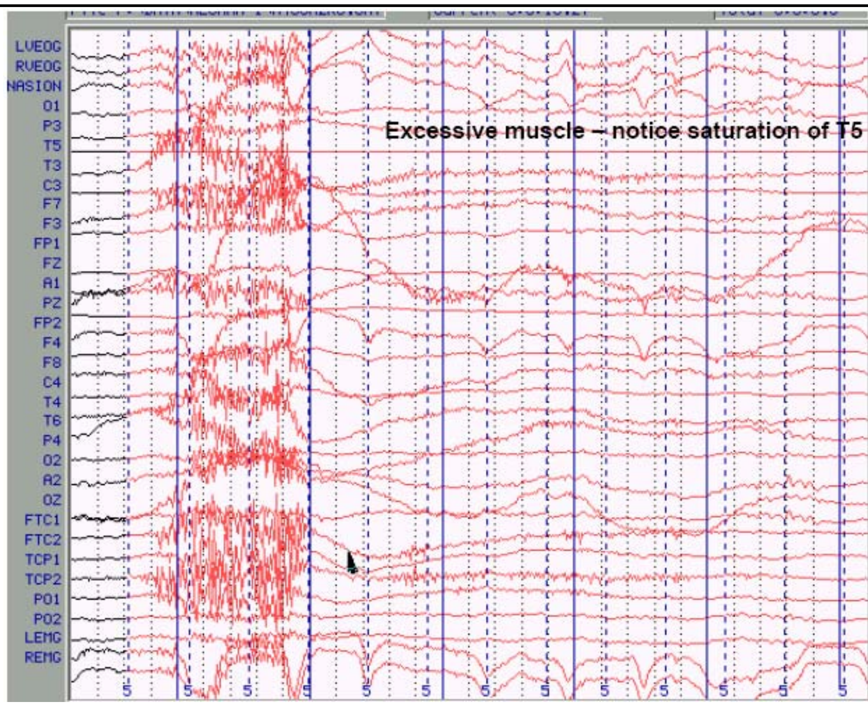
F8
C4
T4
T6
P4
O2
A2
OZ
FTC1
FTC2
TCP1
TCP2
PO1
PO2
LEMG
REMG
Vertical eye roll


LVEOG
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C4
T4
T6
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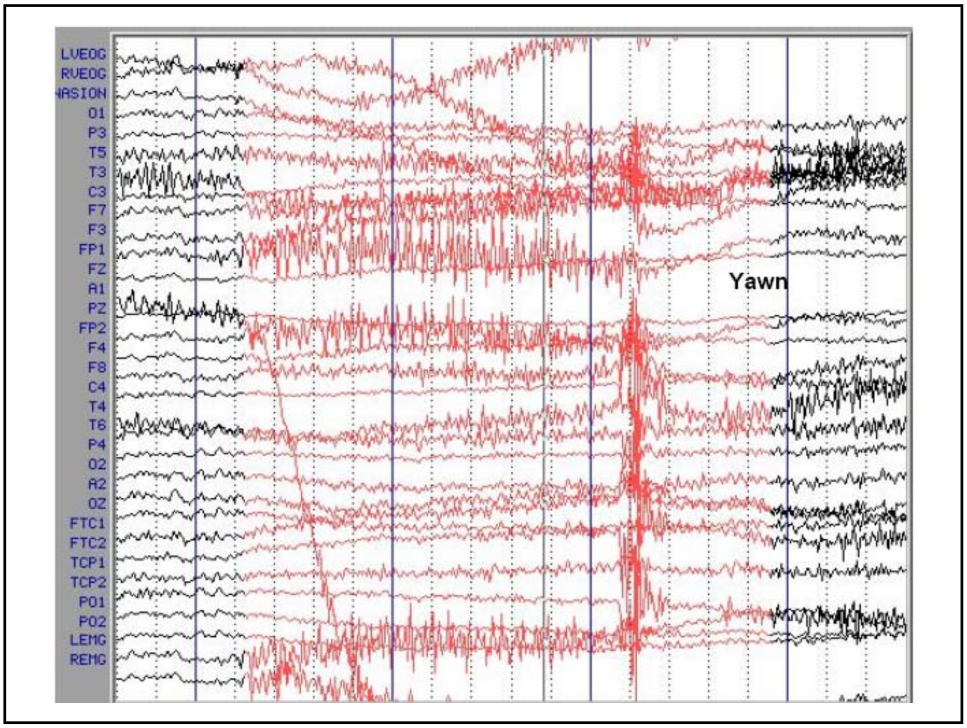
O2
A2
OZ
FTC1
FTC2
TCP1
TCP2
PO1
PO2
LEMG
REMG
Excessive muscle – notice saturation of T5


LVEOG
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F8
C4
T4
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OZ
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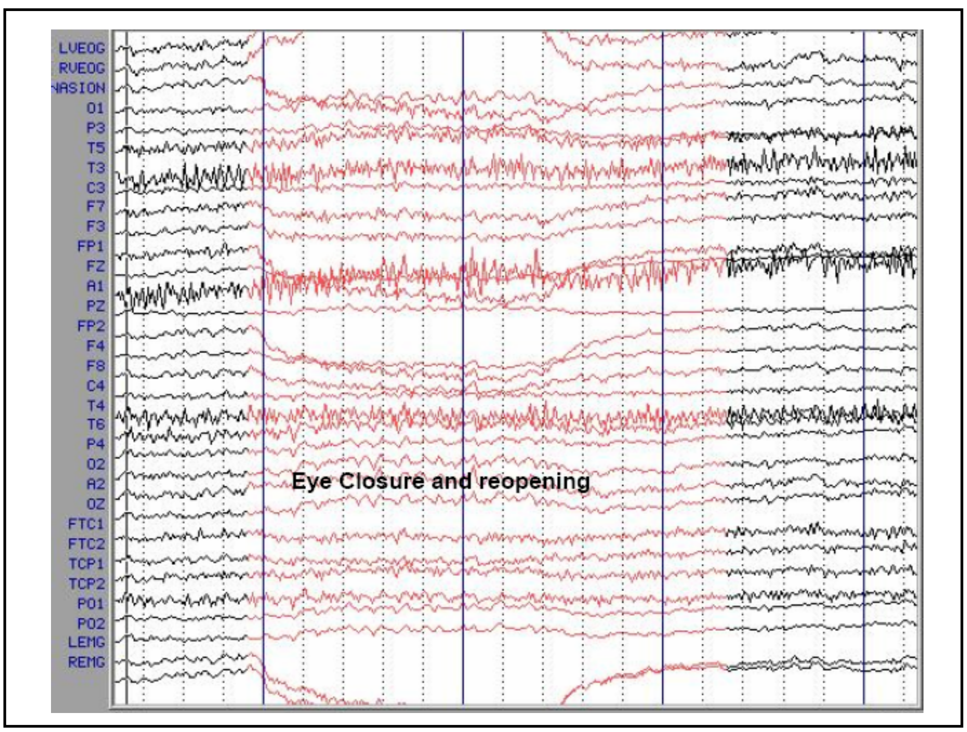
FTC2
TCP1
TCP2
PO1
PO2
LEMG
REMG
Yawn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C4
T4
T6
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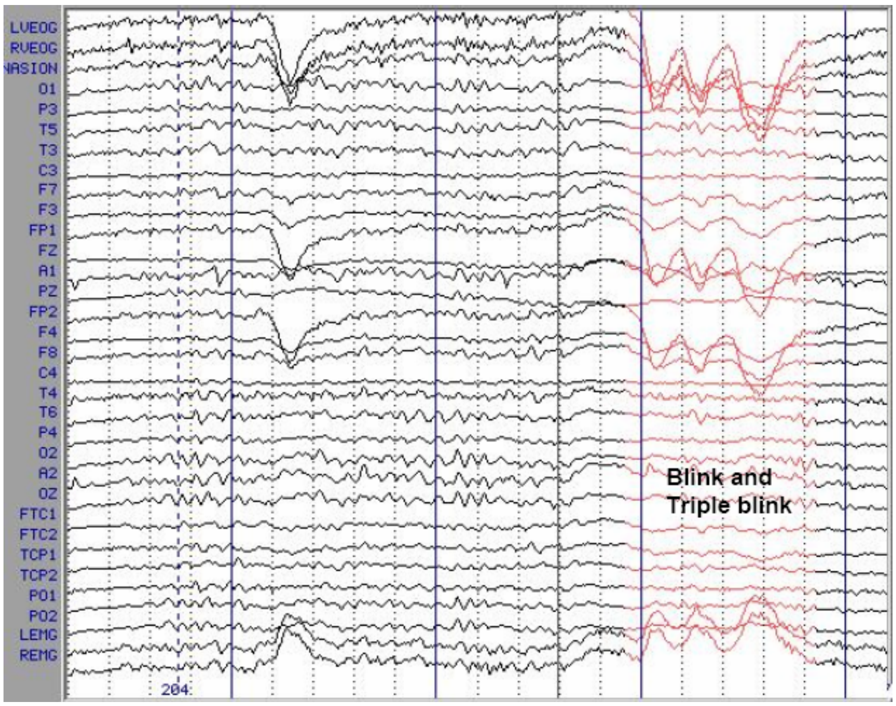
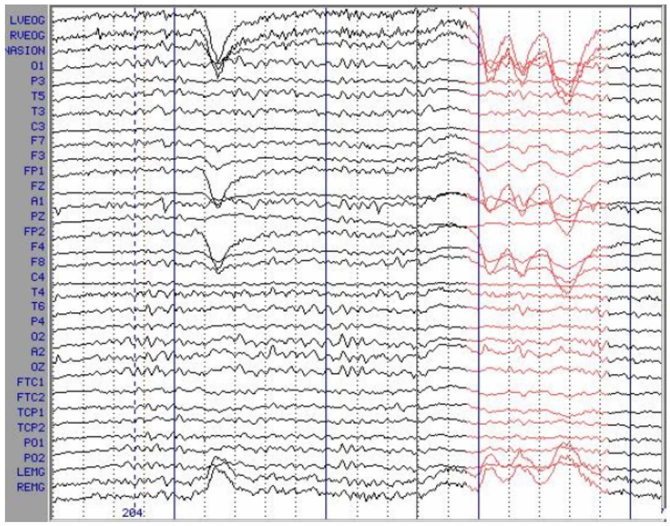
A2
OZ
FTC1
FTC2
TCP1
TCP2
PO1
PO2
LEMG
REMG
Eye Closure and reopening



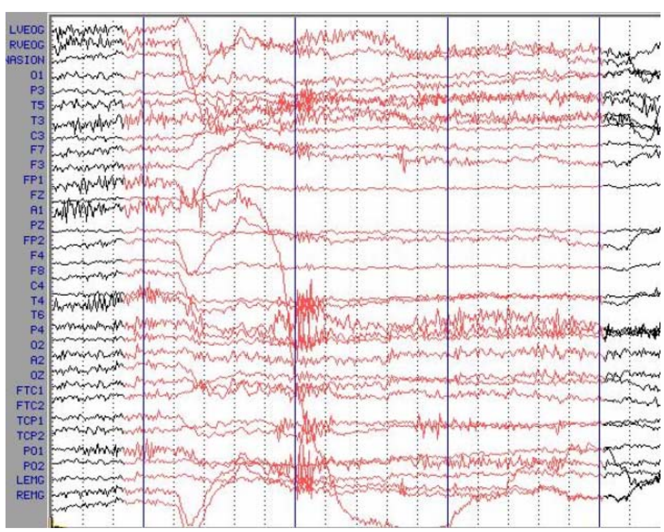
Dealing with Artifacts

- 60 cycle noise
  - Ground subject
  - 60 Hz Notch filter
- Muscle artifact
  - No gum
  - Use headrest
  - Measure EMG and correct for it
- Eye movements
  - Eyes are dipoles
  - Reject ocular deflections including blinks
  - Algorithms for blink and eye movement corrections

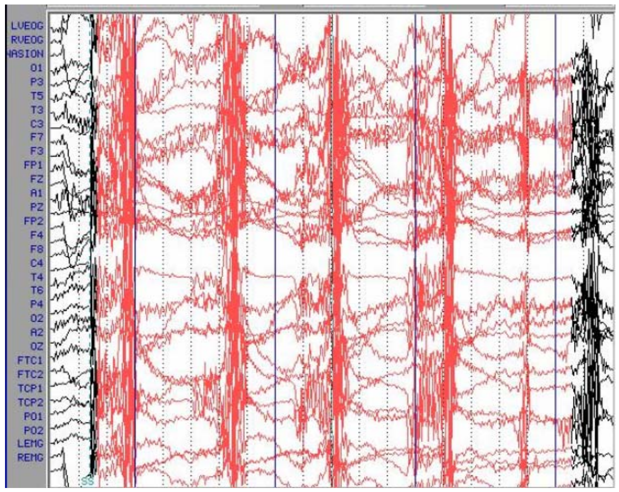
Name that artifact!



Name that artifact



Name that Artifact



Averaging

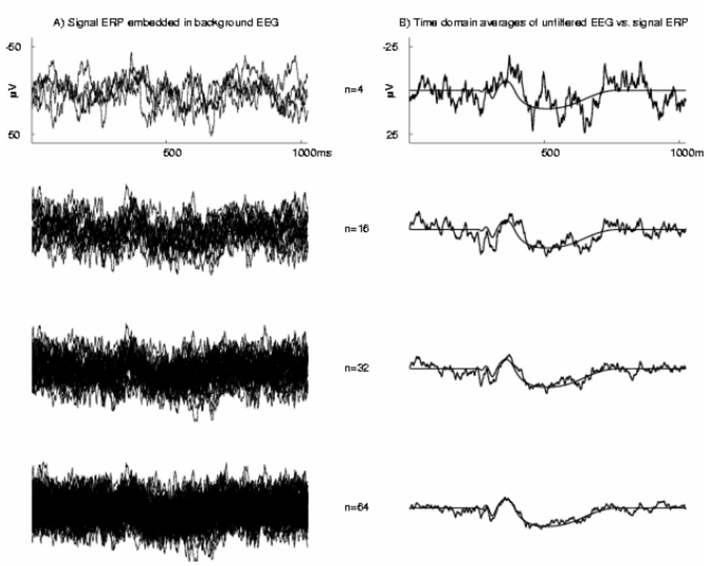
- Activity reflects both signal and “noise”
  - Signal: stimulus related processing
  - Noise: tonic background activity related to ongoing processes (level of arousal, etc)
- The signal-related activity can be extracted because it is time-locked to the presentation of the stimulus
- Signal averaging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

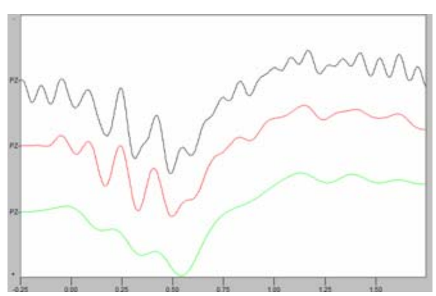
Benefit of Averaging

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



Digital Filtering

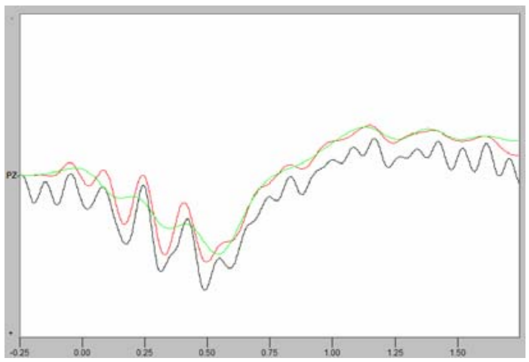
- Unlike analog filtering, digital filtering need not distort signal
- Can be used to zoom in on (brain) activity of particular interest to experimenter
- If you are only interested in later & slower components, then a low-pass filter may be of interest



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

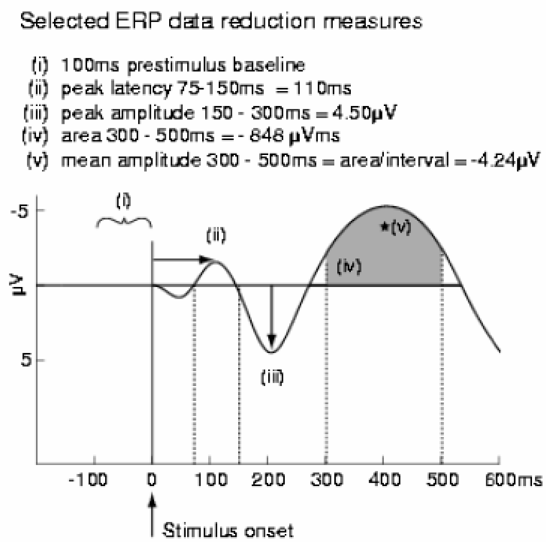
Filtering

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

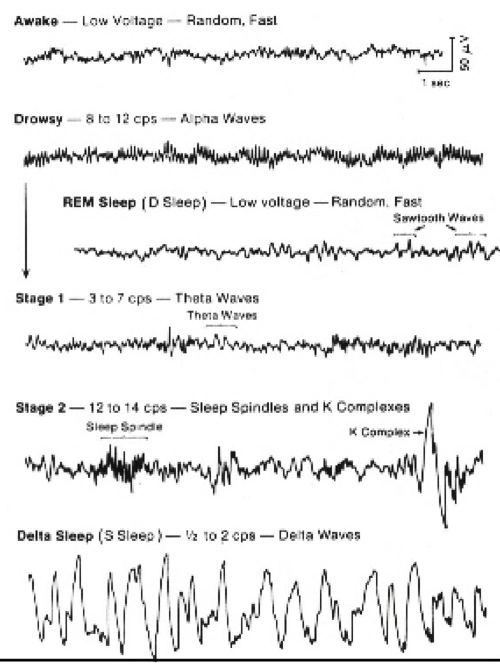


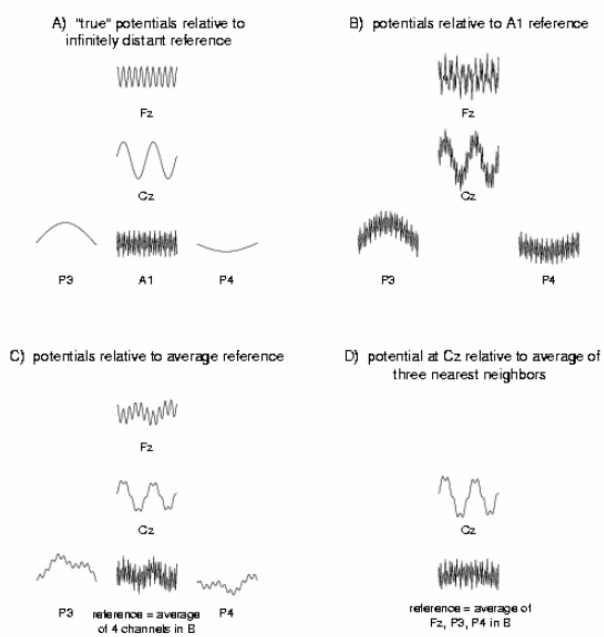
Visualization & Analysis

- Time x Voltage Plots
- 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



Next time: Inferences from ERPs


Awake — Low Voltage — Random, Fast
50 µV
1 sec
Drowsy — 8 to 12 cps — Alpha Waves
REM Sleep (D Sleep) — Low voltage — Random, Fast
Sawtooth Waves
Stage 1 — 3 to 7 cps — Theta Waves
Theta Waves
Stage 2 — 12 to 14 cps — Sleep Spindles and K Complexes
Sleep Spindle
K Complex
Delta Sleep (S Sleep) — ½ to 2 cps — Delta Waves


A) "true" potentials relative to infinitely distant reference
Fz
Cz
P3
A1
P4
B) potentials relative to A1 reference
Fz
Cz
P3
P4
C) potentials relative to average reference
Fz
Cz
P3
reference = average of 4 channels in B
P4
D) potential at Cz relative to average of three nearest neighbors
Cz
reference = average of Fz, P3, P4 in B