Today:
A wee bit of EMG and then….
The Electroencephalogram

Announcements 3/18/19

- Paper/Proposal <u>Guidelines</u> available on course webpage (link in D2L too)
  - Two paragraph prospectus due no later than Monday April 8
- 3x5 time

A few Applications

- Startle Probe
- Subtle affect
  - Mere Exposure
  - Subliminal effects
  - Mortality Salience
  - Biofeedback of EEG -- outcome measure
  - Emotion Regulation – outcome measure
  - Empathy – individual difference measure

Dimberg et al *Psychological Science* 2000

PSYCHOLOGICAL SCIENCE

Unconscious Facial Reactions

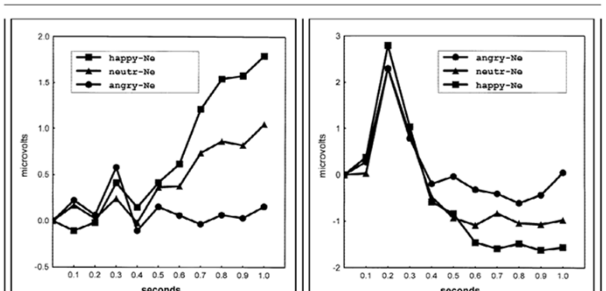

Fig. 1. Mean facial electromyographic response for the *zygomatic major* muscle, plotted in intervals of 100 ms during the first second of exposure. Three different groups of participants were exposed to identical neutral faces ("Ne"), preceded by unconscious exposure of happy, neutral ("neutr"), or angry target faces, respectively.

Fig. 2. Mean facial electromyographic response for the *corrugator supercilii* muscle, plotted in intervals of 100 ms during the first second of exposure. Three different groups of participants were exposed to identical neutral faces ("Ne"), preceded by unconscious exposure of angry, neutral ("neutr"), or happy target faces, respectively.

Dimberg et al *Psychological Science* 2000

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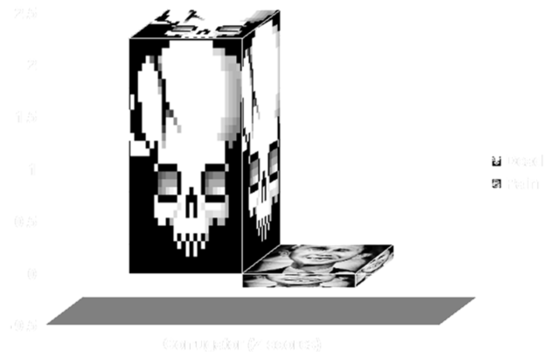

Another loose translation: Arndt, J., Allen, J.J.B., & Greenberg, J. (2001). Traces of terror: Subliminal death primes and facial electromyographic indices of affect. *Motivation and Emotion, 25*, 253-277.

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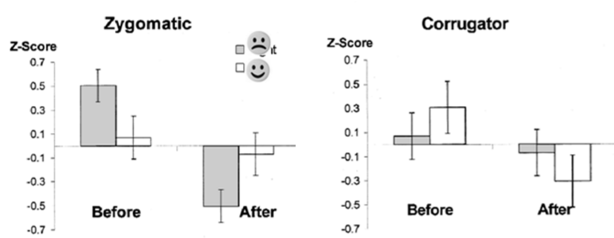

From Allen, Harmon-Jones, and Cavender (2001)

Allen, Cavender, Harmon-Jones, *Psychophysiology* 2001

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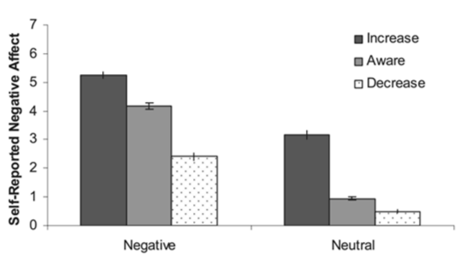

Figure 1. Self-reported negative affect on a 7-point Likert scale, where 0 = “not negative at all” and “7” = “strongly negative.”

Ray, McRae, Ochsner, & Gross, *Emotion*, 2010

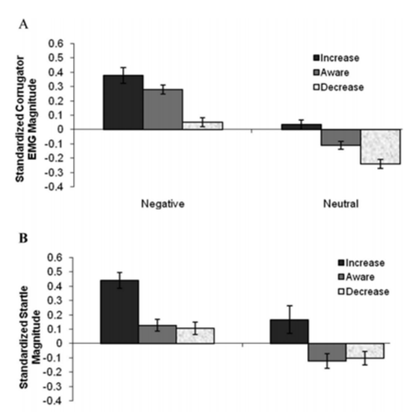

Figure 2. Standardized (A) corrugator EMG and (B) startle magnitude (averaged over Times 1 and 2).

Ray, McRae, Ochsner, & Gross, *Emotion*, 2010

A few Applications

- ➢ Startle Probe
- ➢ Subtle affect
  - ➢ Mere Exposure
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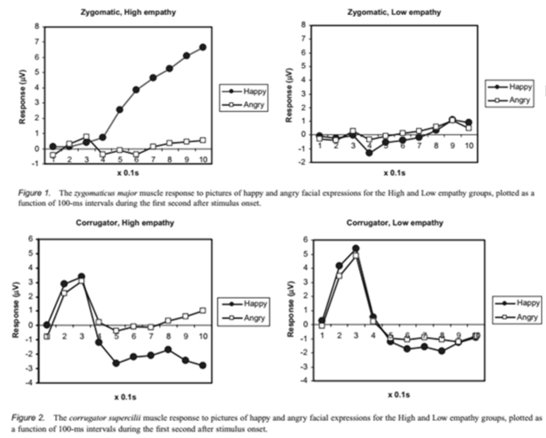


Faces

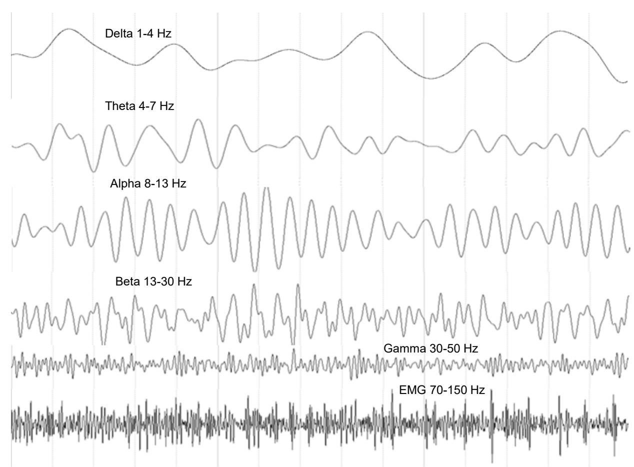
Dimberg & Thunberg (2012) *PsyCh Journal*

The Electroencephalogram

Basics in Recording EEG, Frequency Domain Analysis and its Applications

Electroencephalogram (EEG)

- ➢ The EEG--an oscillating voltage recorded on scalp surface
  - ➢ Reflects Large # Neurons
  - ➢ Is small voltage
- ➢ Bands of activity and behavioral correlates
  - ➢ Gamma 30-50 Hz
  - ➢ Beta 13-30 Hz
  - ➢ Alpha 8-13 Hz
  - ➢ Theta 4-8 Hz
  - ➢ Delta 0.5-4 Hz
- ➢ Event-related activity (voltage: ERP; time-frequency)

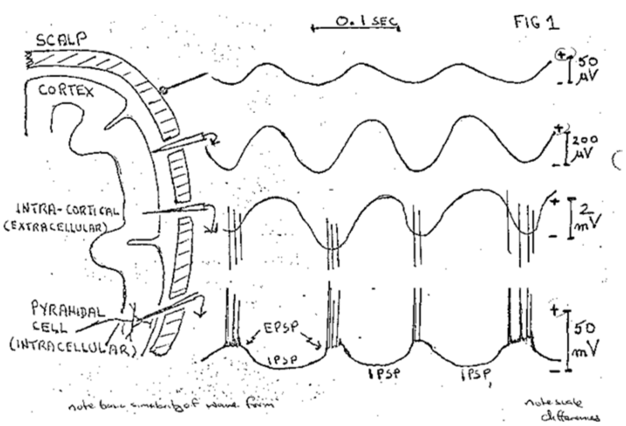


Utility of EEG

- *Relatively* noninvasive
- Excellent time resolution

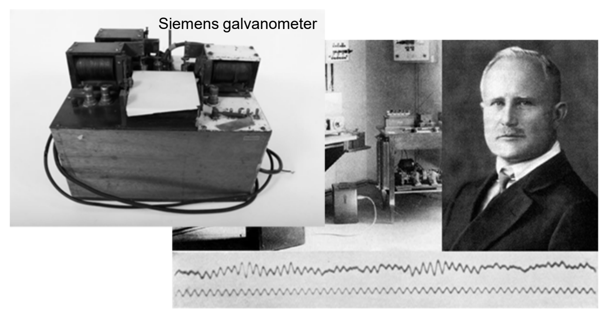
Sources of scalp potentials

- Glial Cells – minimal, some DC steady potentials
- Neurons
  - Action Potentials – NO, brain tissue has strong capacitance effects, acting as Low Pass filter
  - <u>Slow waves</u>
    - Synaptic potentials – YES, both IPSPs and EPSPs from functional synaptic units are major contributors
    - Afterpotentials – May contribute to a lesser extent



Brief history of EEG

- Hans Berger, 1929



Brief history of EEG

- Hans Berger, 1929
- 1930s Signal processing: capture on chart paper and analyze by visual inspection
- Alpha waves were first identified and anything higher was called beta!
  - Then frequencies described in the 1930s
  - Hoagland, Rubin, & Cameron (1936) delta waves
  - Jasper & Andrews (1936) claimed to have seen frequencies higher than 30 Hz and called them gamma waves but this was met with skepticism initially

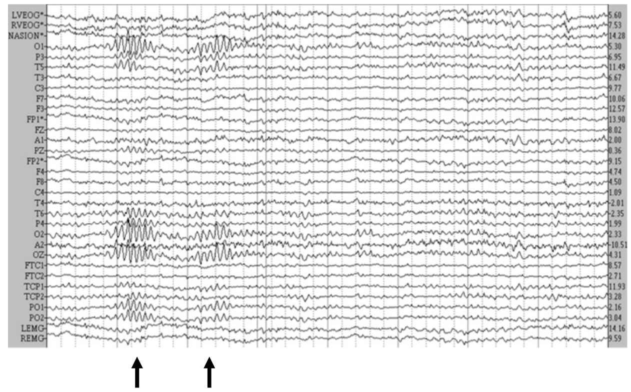
Brief history of EEG

- Mechanical Analyzers (Grey, 1935)
  - William Walter Grey (Roboticist)
  - Oscillators that functioned as mechanical band-pass filters
  - First model (1935) had four frequencies
  - By 1944, 10 frequencies!
  - Not till 1960s, with mainframe computers were computational approaches tractable
  - Cooley & Tukey (1965): Fast Fourier Transform (FFT)

Alpha and Synchronization

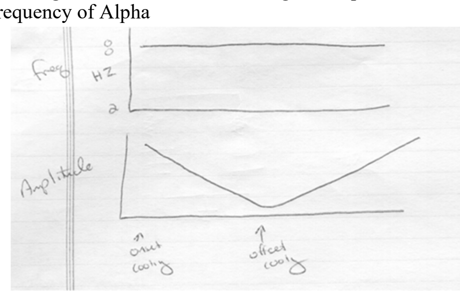
- Why Alpha?
  - It is <u>obvious </u>and hard to miss!
  - Accounts for ~70% of EEG activity in adult human brain
- From where, Alpha?
  - Historically, thought to be thalamocortial looping
  - Adrian (1935) demolished that theory
    - Recorded EEG simultaneously in cortex and thalamus
    - Damage to cortex did not disrupt thalamic alpha rhythmicity
    - Damage to thalamus DID disrupt cortical alpha rhythmicity
  - Thalamic rhythmicity remains even in decorticate preparations (Adrian, 1941)
  - Removal of ½ thalamus results in ipsilateral loss of cortical alpha

Next



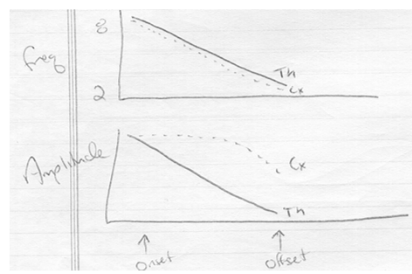
Alpha and Synchronization

- Andersen and Andersen (1968)
  - Cooling of Cortex resulted in change in amplitude but not frequency of Alpha



Alpha and Synchronization

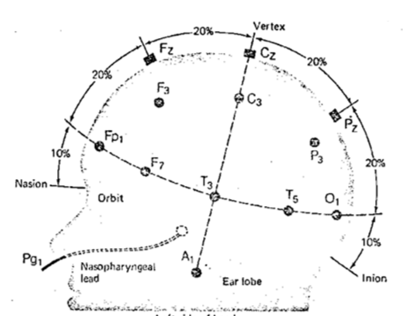
- Andersen and Andersen (1968)
  - Cooling of Thalamus resulted in change in amplitude and frequency of Alpha at both thalamus and cortex



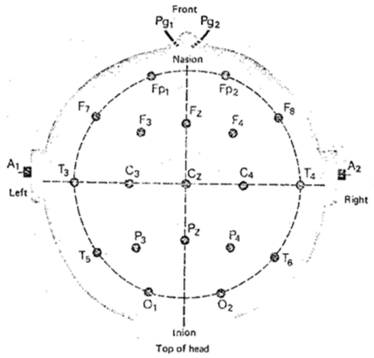
Alpha and Synchronization

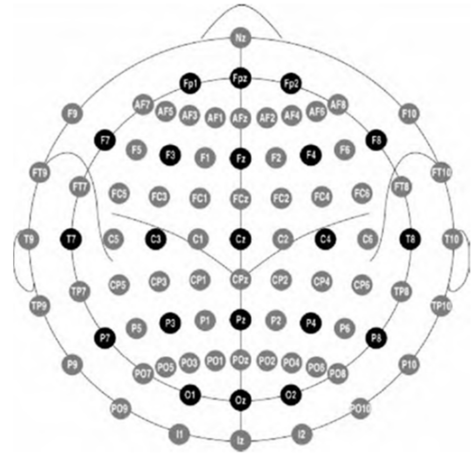
- In sum, Thalamus drives the alpha rhythmicity of the EEG
  - Cortex certainly does feedback to thalamus, but thalamus is responsible for driving the EEG
  - Particularly the Reticularis nucleus (Steriade et al. 1985)
- What causes change from rhythmicity to desynchronization?
  - Afferent input to thalamic relay nuclei
  - Mode-specific enhancement observed

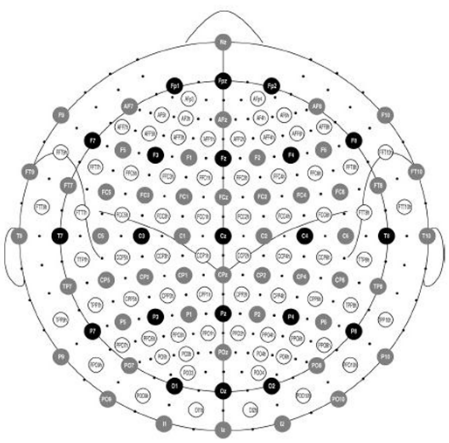
Recording EEG



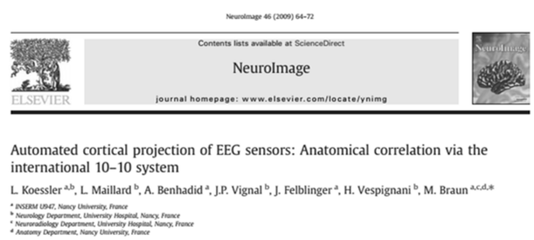
Recording EEG







Systems are surface-based, not anatomically-based


NeuroImage 46 (2009) 64–72

Contents lists available at ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/ynimg

ELSEVIER

Automated cortical projection of EEG sensors: Anatomical correlation via the international 10–10 system

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[d] Anatomy Department, Nancy University, France

Electrodes, Electrolyte, Preparation

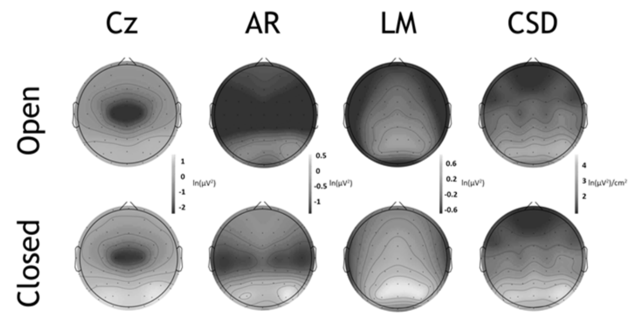
- Ag-AgCl preferred, Gold OK if slowest frequencies not of interest
  - Polarizing electrodes act as capacitors in series with signal
- Electrolyte: ionic, conductive
- Affixing
  - Subcutaneous needle electrodes (OUCH)
  - Collodion (YUCK)
  - EC-2 paste; lesser of the evils
  - Electrocap

Recording References

- Measure voltage potential differences
  - Difference between what and what else?
- “Monopolar” versus Bipolar
  - No truly inactive site, so monopolar is a relative term
  - Relatively monopolar options
    - Body – BAD IDEA
    - Head
      - Linked Ears or Mastoids
      - Tip of Nose
- Reference choice nontrivial as it will change your ability to observe certain signals

Recording References

- Bipolar recording
  - Multiple active sites
    - Sensitive to differences between electrodes
    - With proper array, sensitive to local fluctuations (e.g. spike localization)
- Off-line derivations
  - Averaged Mastoids
  - Average Reference (of EEG Leads)
    - With sufficient # electrodes and surface coverage, approximates inactive site (signals cancel out)
    - Artifacts "average in"
  - Current Source Density (more in advanced topics)

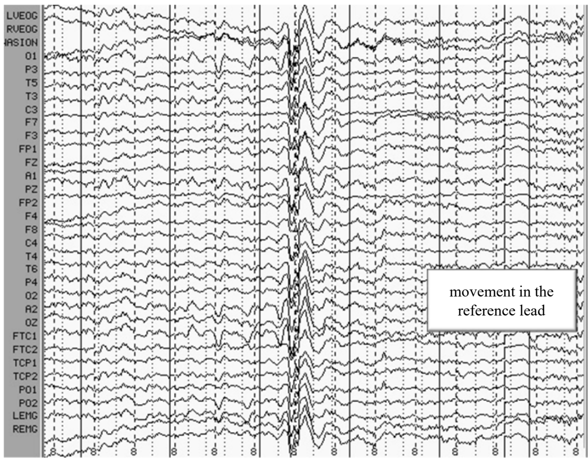


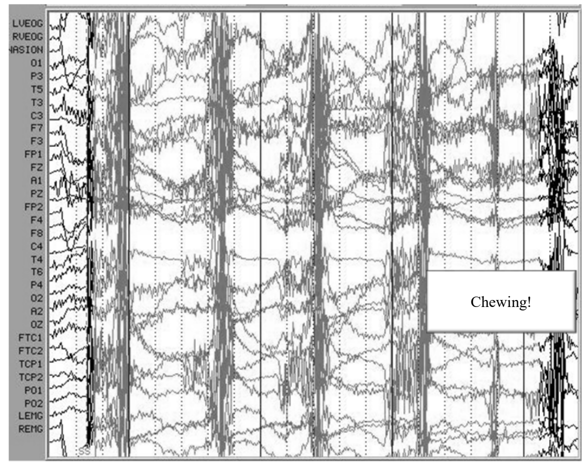
Electrode Placement

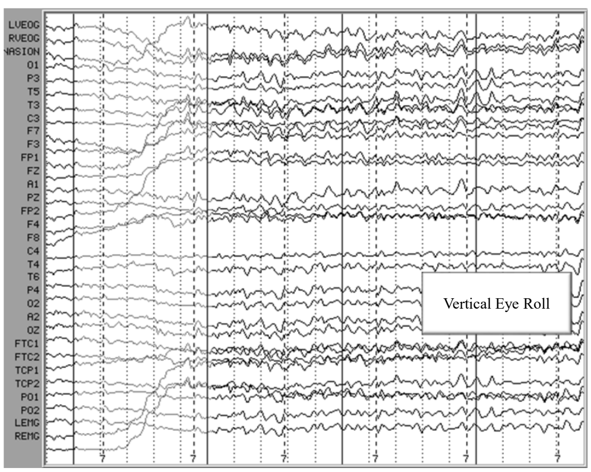
Dreaded Artifacts

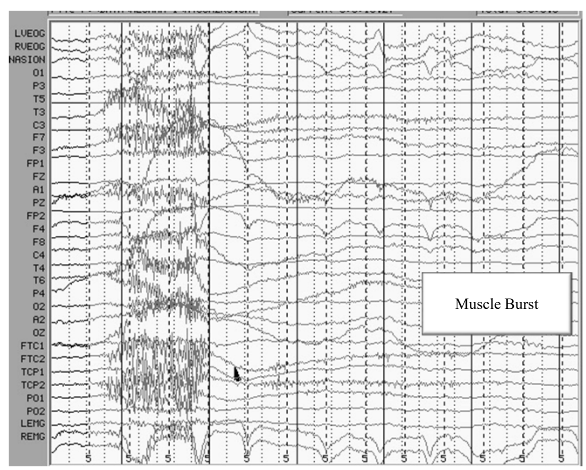
- Three sources
  - 60-cycle noise
    - Ground subject
    - 60 Hz Notch filter
  - Muscle artifact
    - No gum!
    - Use headrest
    - Measure EMG and reject/correct for influence
  - Eye Movements
    - Eyes are dipoles
    - Reject ocular deflections including blinks
    - Use correction procedure (more in advanced lecture)

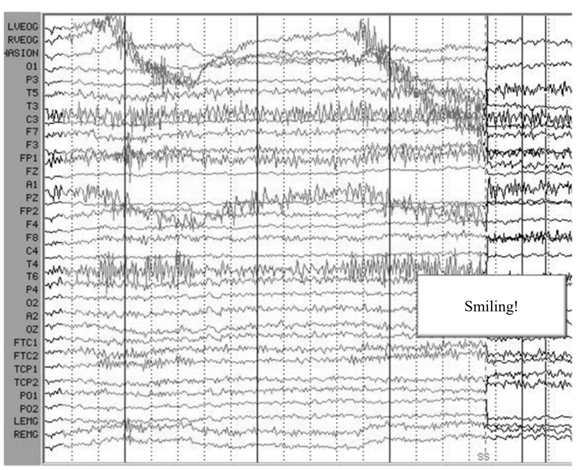
Name That Artifact!

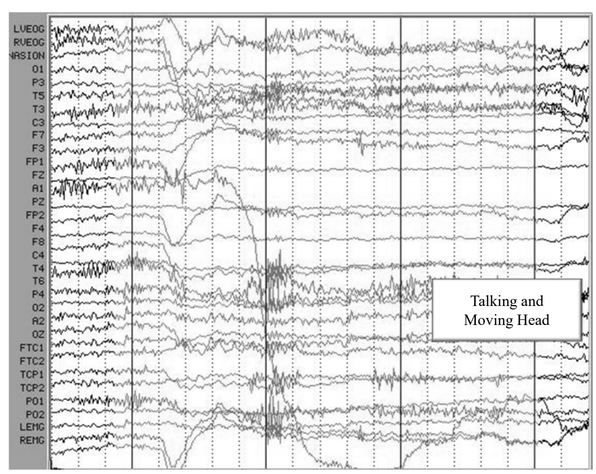

movement in the
reference lead

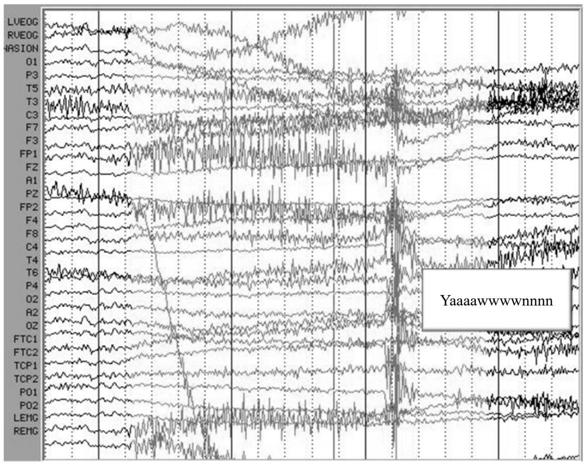

Chewing!

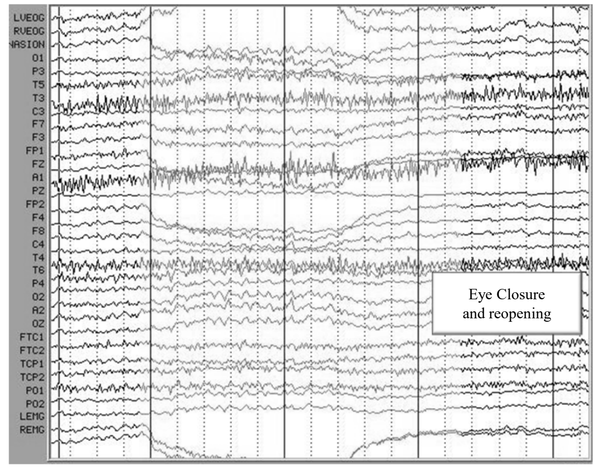

Vertical Eye Roll

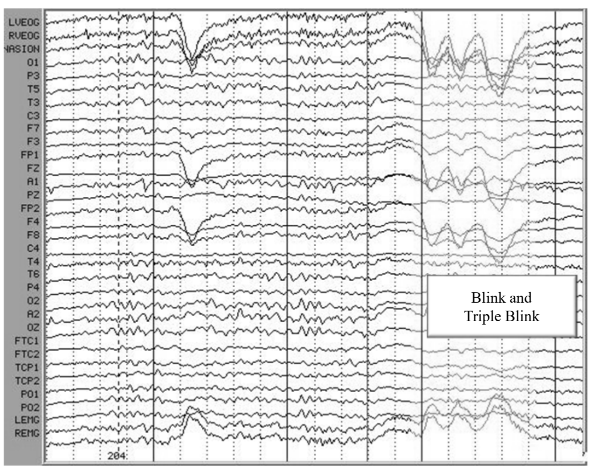

Muscle Burst


Smiling!


Talking and
Moving Head







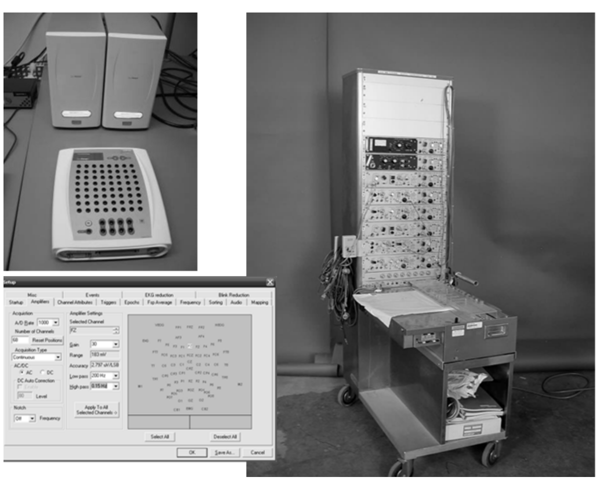
AC Signal Recording Options

- Time Constant/HP filter
  - Low frequency cutoff is related to TC by: $F = \dfrac{1}{(2\pi(TC))}$

Where F = frequency in Hz, TC = Time Constant in Seconds

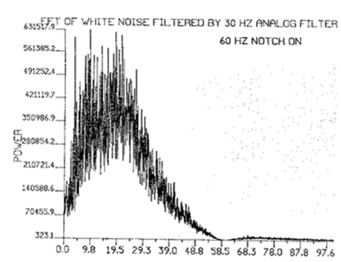
Applying formula:

Time Constant (sec)	Frequency (Hz)
10.00	.016
5.00	.032
1.00	.159
.30	.531
.10	1.592
.01	15.915



Hi Frequency/LP Settings

- Do not eliminate frequencies of interest
- Analog systems have broad roll-off characteristics
- Be mindful of digitization rate (more info soon!)



Digital Signal Acquisition

- Analog Vs Digital Signals
  - Analog
    - Continuously varying voltage as fxn of time
  - Discrete Time
    - Discrete points on time axis, but full range in amplitude
  - Digital
    - Discrete time points on x axis represented as a limited range of values (usally 2^x, e.g $2^{12} = 4096$)

A/D converters

- Schmidt Trigger as simple example
- The A/D converter (Schematic diagram)
  - Multiplexing (several channels); A/D converter is serial processor
    - Result is a vector [1 x n samples] of digital values for each channel ([x(t0), x(t1), x(t2),...,x(tn-1)]
  - 12 bit converters allow 212 = 4096 values
  - 16 bit converters allow 216 = 65536 values
- 12 bit is usually adequate for EEG
  - 4096 values allow 1 value for each ~0.02 µvolts of scalp voltage (depending upon sensitivity of amplifier, which will amplify signal ~20,000 times before polygraph output)
  - e.g.,
    - 2.1130 µvolts => 2481 D.U.'s (2480.74)
    - 2.1131 µ volts => 2481 D.U.'s (2480.76)
    - 2.1250 µ volts => 2483 D.U.'s (2483.20)

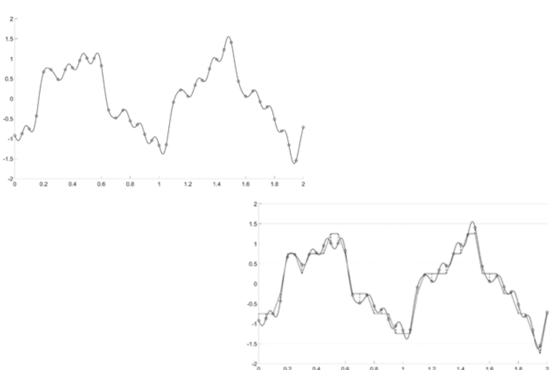


Figure 5: A signal sampled at 20 Hz. Discrete-time sampling (left panel) allows for continuous y-axis (µV) values, whereas digitally-sampled signals (right panel) must use a limited number of y-axis values. The three bit converter illustrated here (right panel) allows for 2^3=8 distinct values, providing only a course approximation of the signal voltage. The right panel depicts the discrete sample value (red circle) and the 3-bit digital equivalent (red line), and the discrepancy (dashed vertical black lines).

From: Curham & Allen (submitted)

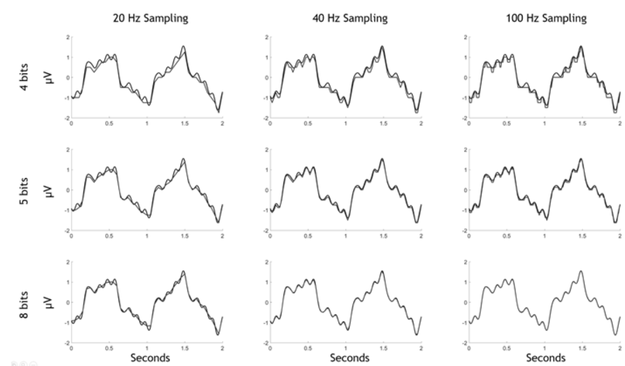


Figure 6: A comparison of a signal (black line) sampled (red line) at three sampling rates (20, 40, 100 Hz) and using three different converter resolutions (4-bit, 5-bit, and 8-bit) that allow for 16, 32, and 128 distinct µV values. Low bit-resolution was used here for illustrative purposes; commercial converters are typically 12-bit (4096 values) or 16-bit (65536 values).

From: Curham & Allen (submitted)

The Problem of Aliasing

- Definition
  - To properly represent a signal, you must sample at a fast enough rate.
  - Nyquist's (1928) theorem
    - a sample rate twice as fast as the highest signal frequency will capture that signal perfectly
    - Stated differently, the highest frequency which can be accurately represented is one-half of the sampling rate
    - This frequency has come to be known as the Nyquist frequency and equals ½ the sampling rate
- Comments
  - Wave itself looks distorted, but frequency is captured adequately.
  - Frequencies faster than the Nyquist frequency will not be adequately represented
  - Minimum sampling rate required for a given frequency signal is known as Nyquist sampling rate

Harry Nyquist

Aliasing and the Nyquist Frequency

- In fact, frequencies above Nyquist frequency represented as frequencies lower than Nyquist frequency
  - F_{Ny} + x Hz will be seen as F_{Ny} - x Hz
  - "folding back"
    - frequency $2F_{Ny}$ seen as 0,
    - frequency $3F_{Ny}$ will be seen as F_{Ny}
    - accordion-like folding of frequency axis

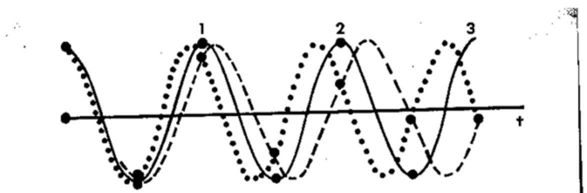


Fig. 3.1. A cosine wave of frequency F (solid line) sampled at its Nyquist rate. A higher frequency (dotted) wave, frequency F + a, is shown sampled at the same rate. At the sample times it is indistinguishable from a lower frequency (dashed) wave, frequency F − a.

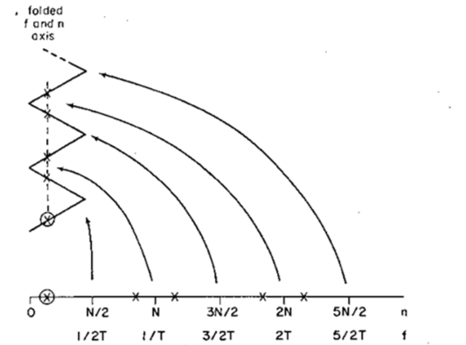
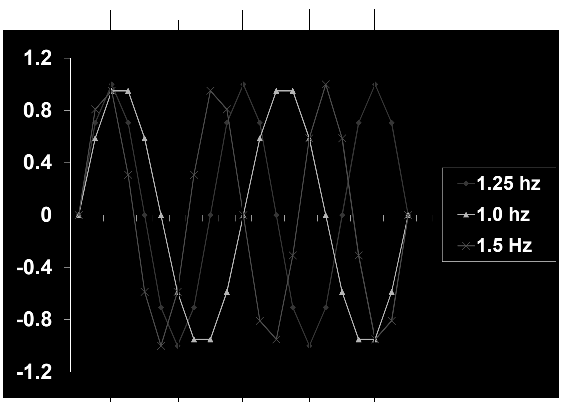
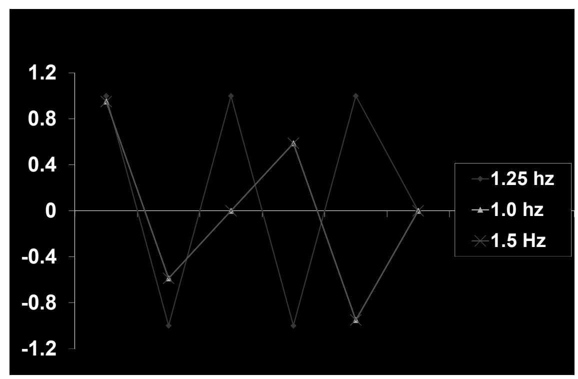


Fig. 3.2. The accordionlike folding of the frequency (or n) axis due to sampling of a continuous signal. Frequency components of the original signal marked with x's on the f axis are interpreted in the sampled version as belonging to the lowest frequency, an encircled x.

Aliasing Demo (Part 1, 10 Hz Sampling Rate)



Aliasing Demo (Part 2, 2.5 Hz Sampling Rate)



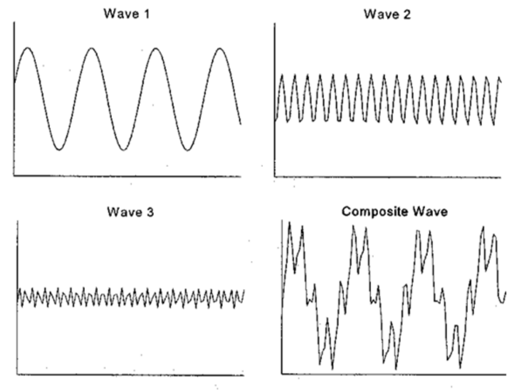
Matlab Demo of Aliasing

Solutions to Aliasing

- Sample very fast
- Use anti-aliasing filters
- KNOW YOUR SIGNAL!

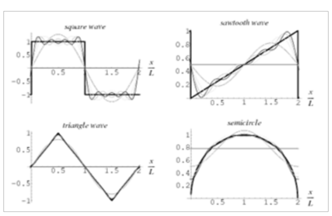
Time Domain Vs Frequency Domain Analysis

- 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 Representation

- 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



Interactive Fourier!

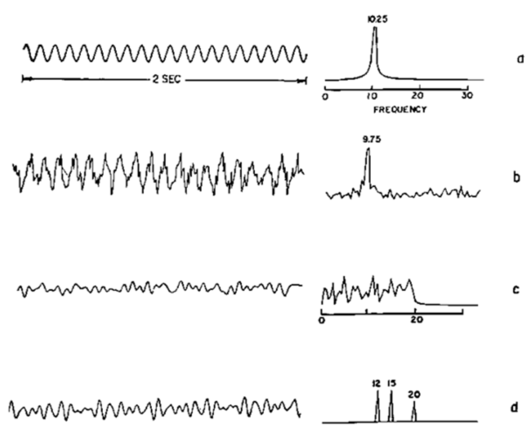
- Web Applet

Fourier Series Representation

- Pragmatic Details
  - Lowest Fundamental Frequency is 1/T
  - 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.
- Psychophysiologists often interested in amplitude component:
  - Power spectrum; for each frequency n/T

    $|Amp_{cos}^2 + Amp_{sin}^2|$
  - Amplitude Spectrum (may conform better to assumptions of statistical procedures); for each frequency n/T

    $|Amp_{cos}^2 + Amp_{sin}^2|^{1/2}$

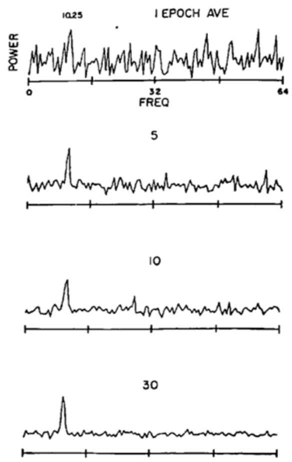


Time Domain

Frequency Domain

Averaging Multiple Epochs improves ability to resolve signal

Note noise is twice amplitude of the signal



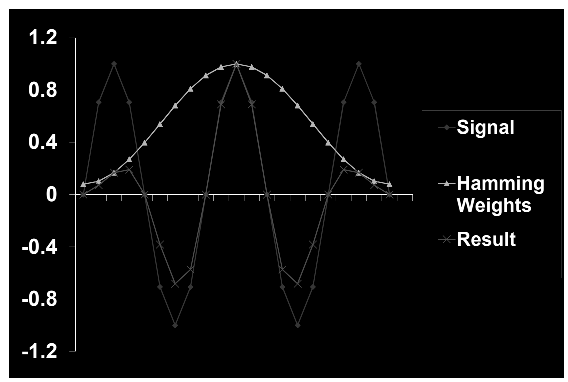
Lingering details

- In absence of phase information, it is impossible to reconstruct the original signal
  - **Infinite** number of signals that could produce the same amplitude or power spectrum
- Spectra most often derived via a **Fast** Fourier transform (FFT); a fourier transform of a discretely sampled band-limited signal with a power of 2 samples
- Sometimes **autocovariance function** is used (a signal covaries with itself at various phase lags; greater covariation at fundamental frequencies)
- Windowing: the Hamming Taper

Preventing Spectral Leakage

- Use windows
  - not Micro$oft Windows
  - Hamming
  - Hanning
  - Cosine
  - Etc.

Hamming Demo



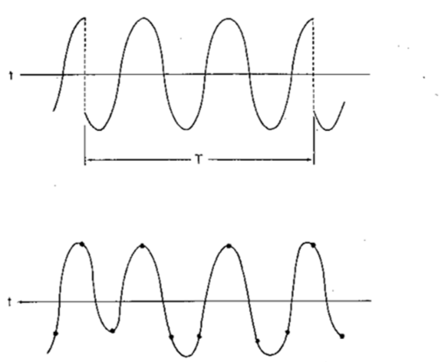
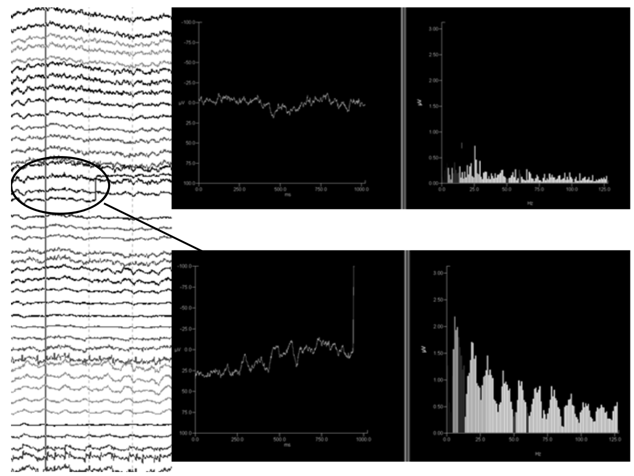


Fig. 3.3. Top, a periodicized segment of a cosine wave. T is the observation time and 3T/8 the period of the wave. Note the discontinuities at 0 and T. Bottom, a continuous and periodic band-limited wave drawn through the sample points Δ = T/16 sec apart.

Matlab Demo of Hamming Window

Pragmatic Concerns

- Sample fast enough so no frequencies exceed Nyquist
  - signal bandwidth must be limited to less than Nyquist
  - Violation = ERROR
- Sample a long enough epoch so that lowest frequency will go through at least one period
  - Violation = ERROR
- Sample a periodic signal
  - if subject engaging in task, make sure that subject is engaged during entire epoch
  - Violation = ??, probably introduce some additional frequencies to account for change



Demo of EEG Data

- CNT Data to Frequency Domain Representation

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)

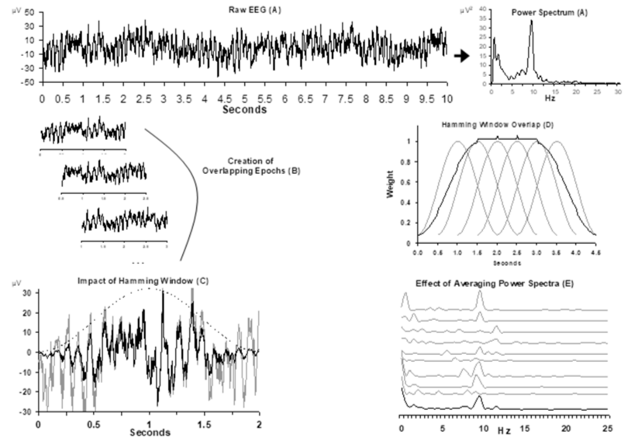
Types of Studies

- 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)

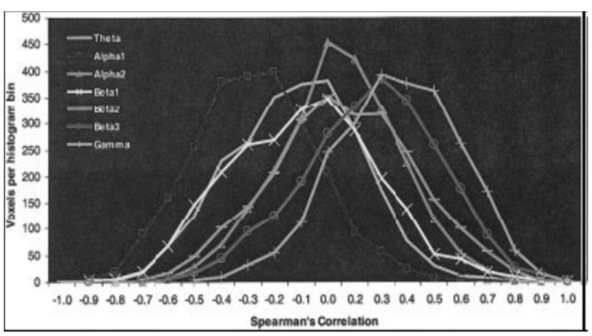
Trait, Occasion, and State variance

- 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)

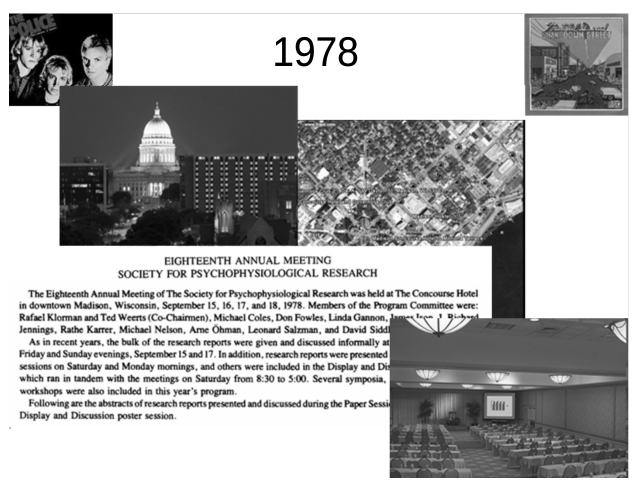


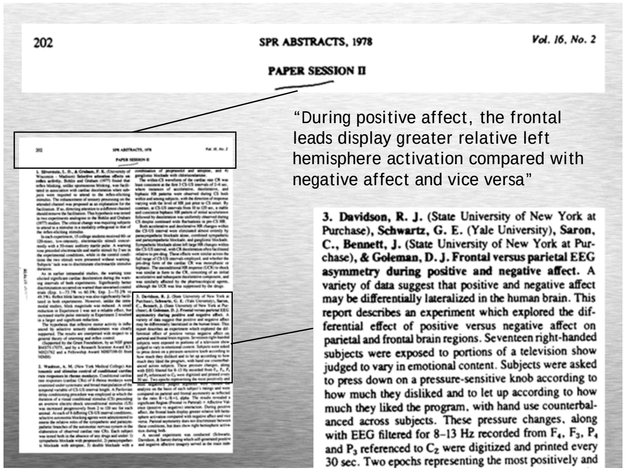
Oakes et al, 2004, *Human Brain Mapping*

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





202 SPR ABSTRACTS, 1978 *Vol. 16, No. 2*

PAPER SESSION II

"During positive affect, the frontal leads display greater relative left hemisphere activation compared with negative affect and vice versa"

3. Davidson, R. J. (State University of New York at Purchase), **Schwartz, G. E.** (Yale University), **Saron, C., Bennett, J.** (State University of New York at Purchase), **& Goleman, D. J. Frontal versus parietal EEG asymmetry during positive and negative affect.** A variety of data suggest that positive and negative affect may be differentially lateralized in the human brain. This report describes an experiment which explored the differential effect of positive versus negative affect on parietal and frontal brain regions. Seventeen right-handed subjects were exposed to portions of a television show judged to vary in emotional content. Subjects were asked to press down on a pressure-sensitive knob according to how much they disliked and to let up according to how much they liked the program, with hand use counterbalanced across subjects. These pressure changes, along with EEG filtered for 8–13 Hz recorded from F_4, F_3, P_4 and P_3 referenced to C_Z were digitized and printed every 30 sec. Two epochs representing the most positively and

Left Hypofrontality in Depression

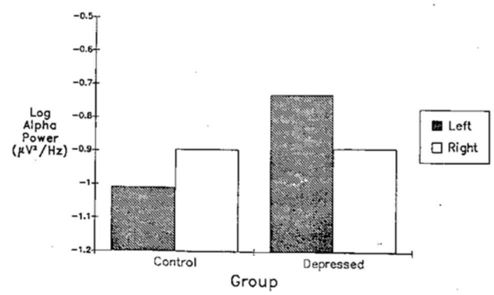
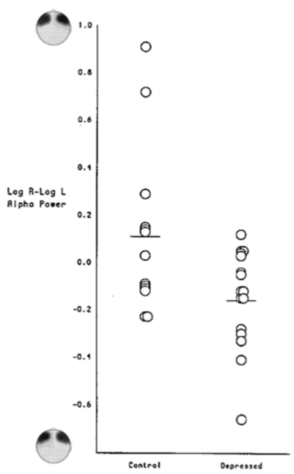


Figure 1. Mean log-transformed alpha (8–13 Hz) power (in µV²/Hz) for Cz-referenced electroencephalograms (averaged across eyes-open and eyes-closed baselines), split by group and hemisphere, for the mid-frontal region. (Decreases in alpha power are indicative of increased activation.)

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)

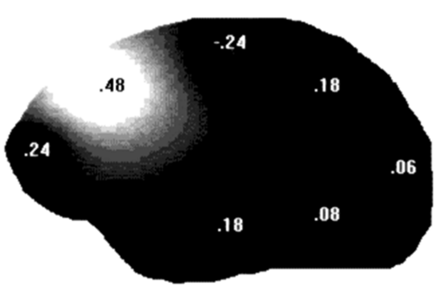
Individual Subjects' Data



Henriques & Davidson (1991)

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.

After Harmon-Jones and Allen (1998).

State Anger and Frontal Asymmetry

- Would situationally-induced anger relate to relative left frontal activity?

Harmon-Jones & Sigelman, *JPSP*, 2001

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.”

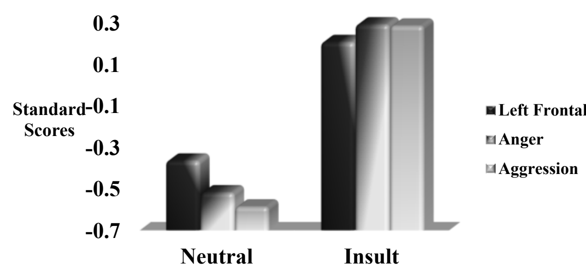
Harmon-Jones & Sigelman, *JPSP*, 2001

- 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

Harmon-Jones & Sigelman, *JPSP*, 2001

Harmon-Jones & Sigelman, *JPSP*, 2001

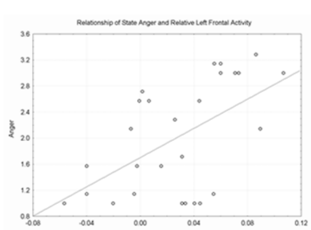
Relative Left Frontal, Anger, & Aggression as a Function of Condition



Harmon-Jones & Sigelman, *JPSP*, 2001

Frontal EEG asymmetry predicts Anger and Agression

- 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 diffs in asymmetry and affect



Harmon-Jones & Sigelman, *JPSP*, 2001

Manipulation of EEG

Peterson, Shackman, Harmon-Jones (2008)

- Hand contractions to activate contralateral premotor cortex
- Insult about essay (similar to Harmon-Jones & Sigelman, *JPSP*, 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 duruing hand contractions predicted aggression

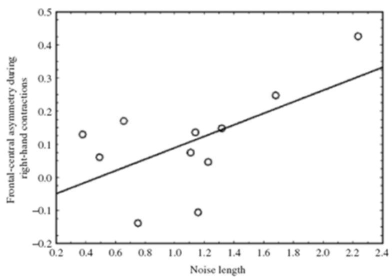


Figure 1. Relation between noise length and frontal-central asymmetry during right-hand contractions. Higher asymmetry scores indicate greater relative left than right activation.

Peterson, Shackman, Harmon-Jones (2008)