Just a bit more EMG

…and then…

The Electroencephalogram

Announcements 3/4/13

- Electricity test – Everyone has now passed!
- Papers: 1 or 2 paragraph prospectus due no later than Monday March 25
- Lab Updates
- 3x5 time

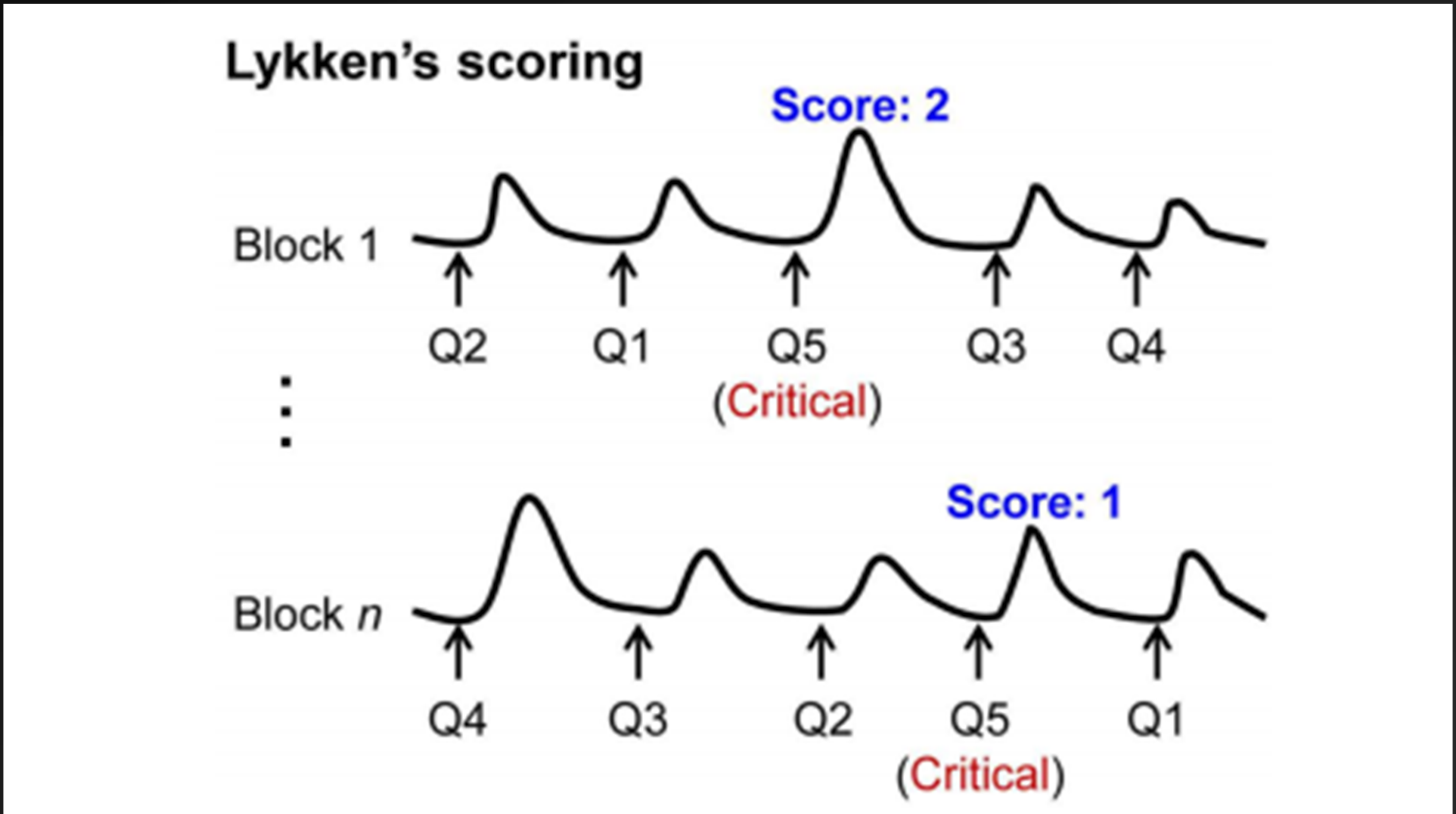
Lab Updates

- EKG-EMG lab (will cover during lecture)

Lab Updates

- SCR GKT lab
  - Should ignore first response in series and score remainder
  - How to make dichotomous verdict of guilty?
    - Lykken's scoring
    - Binomial Probability

Lykken Method



Binomial Probability

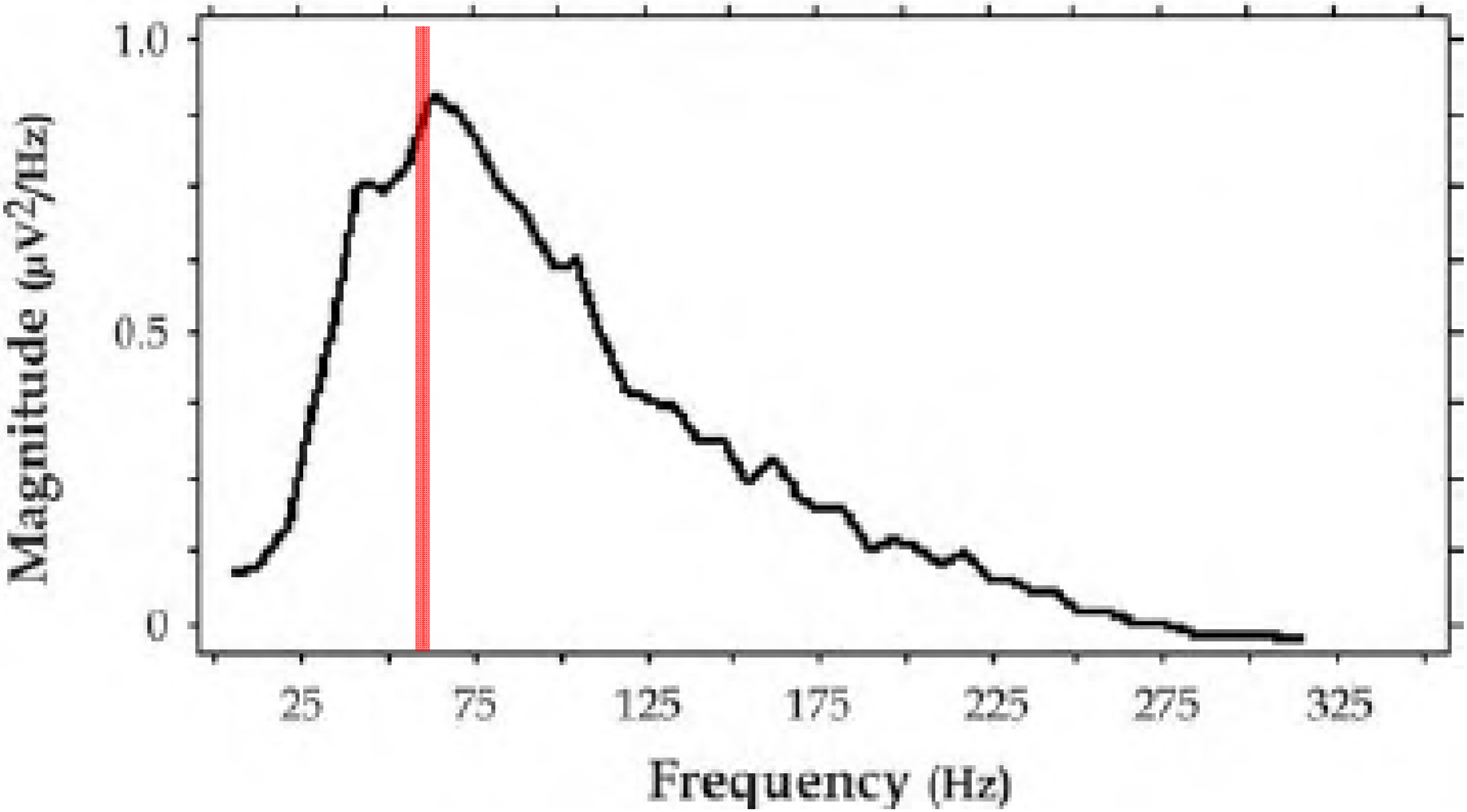
# with Max Response (N)	Probability of exactly N	Probability of N or fewer	Probability of N or More
0	0.17	0.17	1.00
1	0.34	0.50	0.83
2	0.29	0.80	0.50
3	0.15	0.94	0.20
4	0.05	0.99	0.06
5	0.01	1.00	0.01
6	0.00	1.00	0.00
7	0.00	1.00	0.00
8	0.00	1.00	0.00

Many Options…

- ✓ Excel: BINOM.DIST function
- ✓ R: binom.test function
- ✓ Matlab: binocdf function
- ✓ SPSS: Nonparametric tests, Legacy Dialogs, Binomial

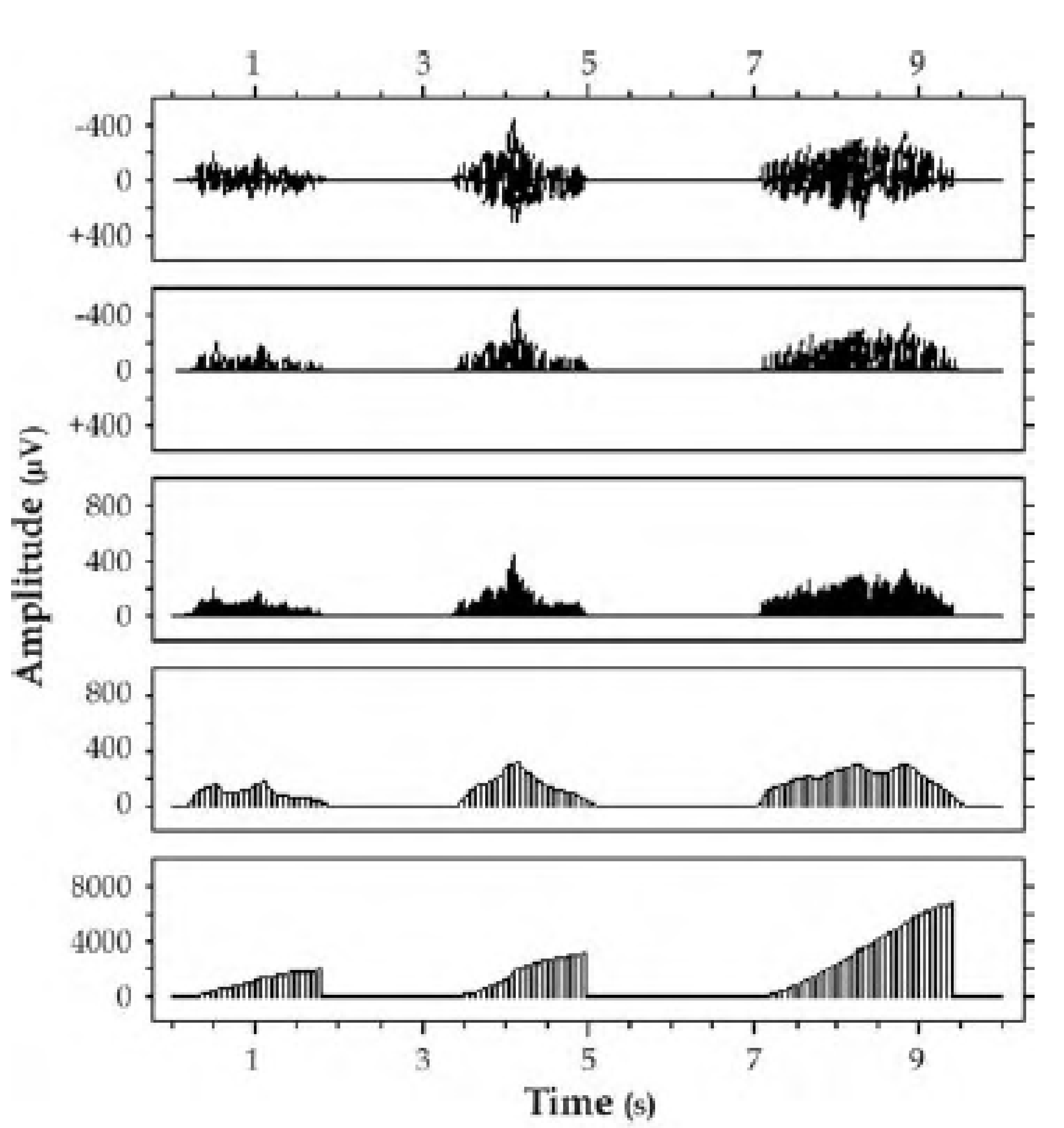
Returning to EMG….

EMG Power



Signal Recording (cont')

- Amplification
  - Differential amplifiers with common mode rejection
  - Actually double differential (ground)
- Amplify voltages 1000-20000 times
- May use on-line filter
  - Should pass 10-500 Hz
- Digitization (more in next lecture)
  - Fast, very fast
  - Or, slower, following on-line signal processing



Signal Transformations

Figure 12.5. Common alternative representations of the surface EMG signal. The top five smaller panels depict three distinct non-fatigued responses. Going from top to bottom: the first represents "raw" (amplified and band-pass filtered only) waveforms; the second, half-wave rectified waveforms; the third, full-wave rectified waveforms; the fourth, "smoothed" waveforms; and the fifth, true integrated waveforms. The larger bottom panel depicts what one of these responses might look like if represented in the frequency domain. (Modified from Figure 7 of Cacioppo et al., 1990c).

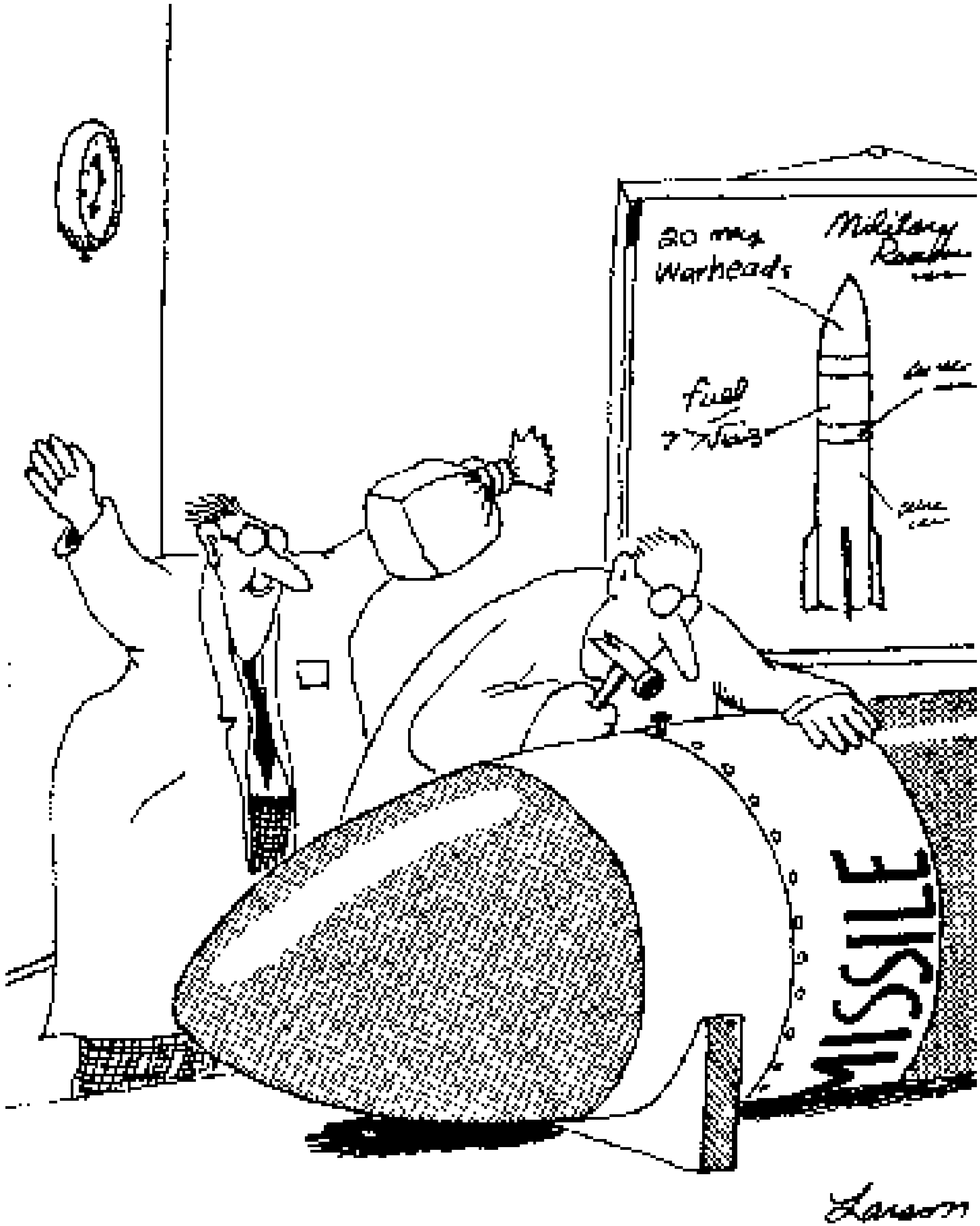
Lab Updates

- EKG-EMG lab
  - EKG – done in QRSTool and CMetX
  - EMG
    - Step 1 in Neuroscan Edit
      - Filter and Rectify signals

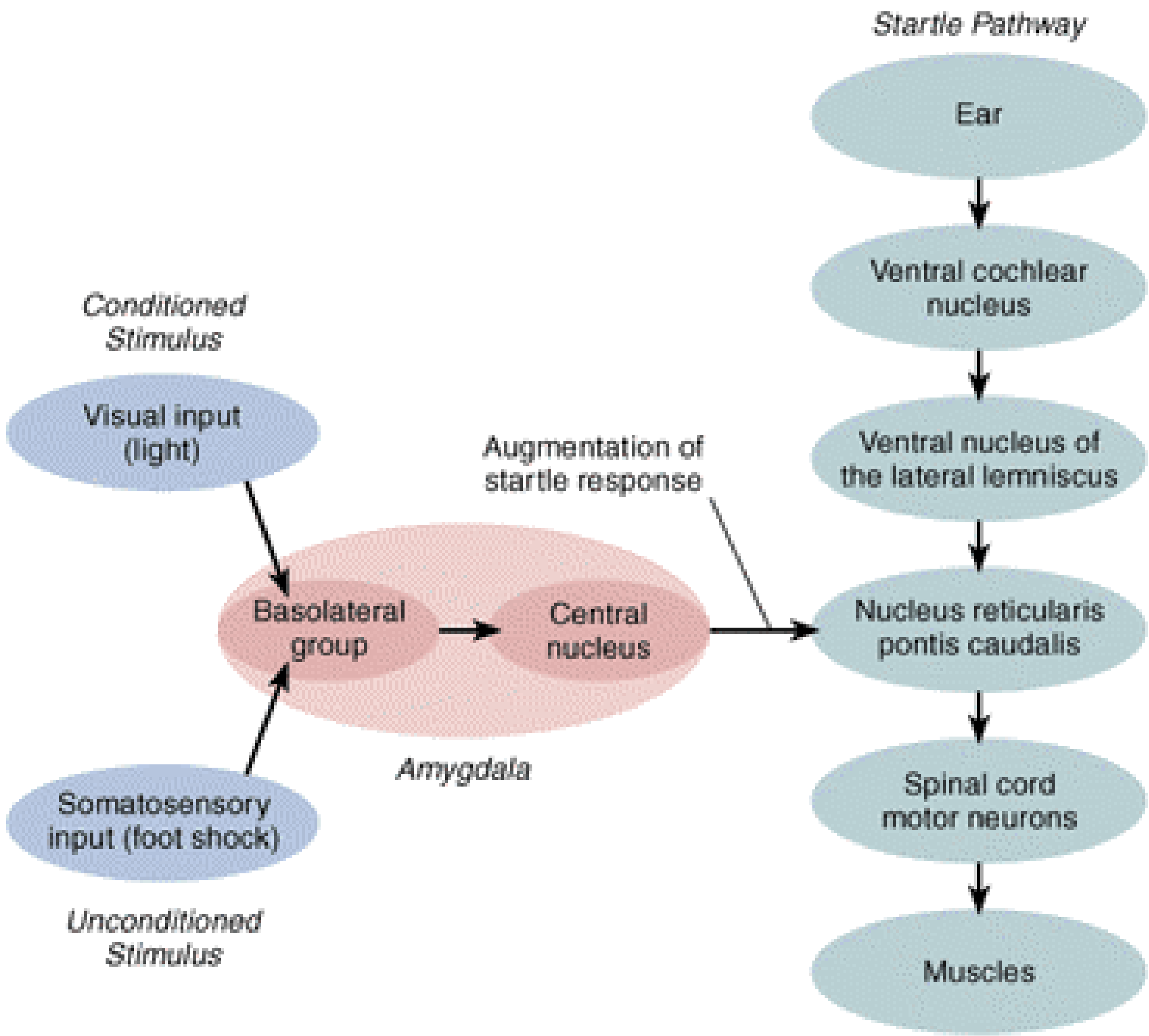
    - Step 2 in Matlab
      - Get mean for each condition
      - Convert to within-subject z-scores

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


20 meg
Warheads
Military
Fuel
MISSILE
Larson

► Neural Circuits Responsible for an Auditory Startle Response and for Its Augmentation by Conditioned Aversive Stimuli



Source: Adapted from Davis, M., *Trends in Pharmacological Sciences*, 1992, *13*, 35–41.

A few Applications

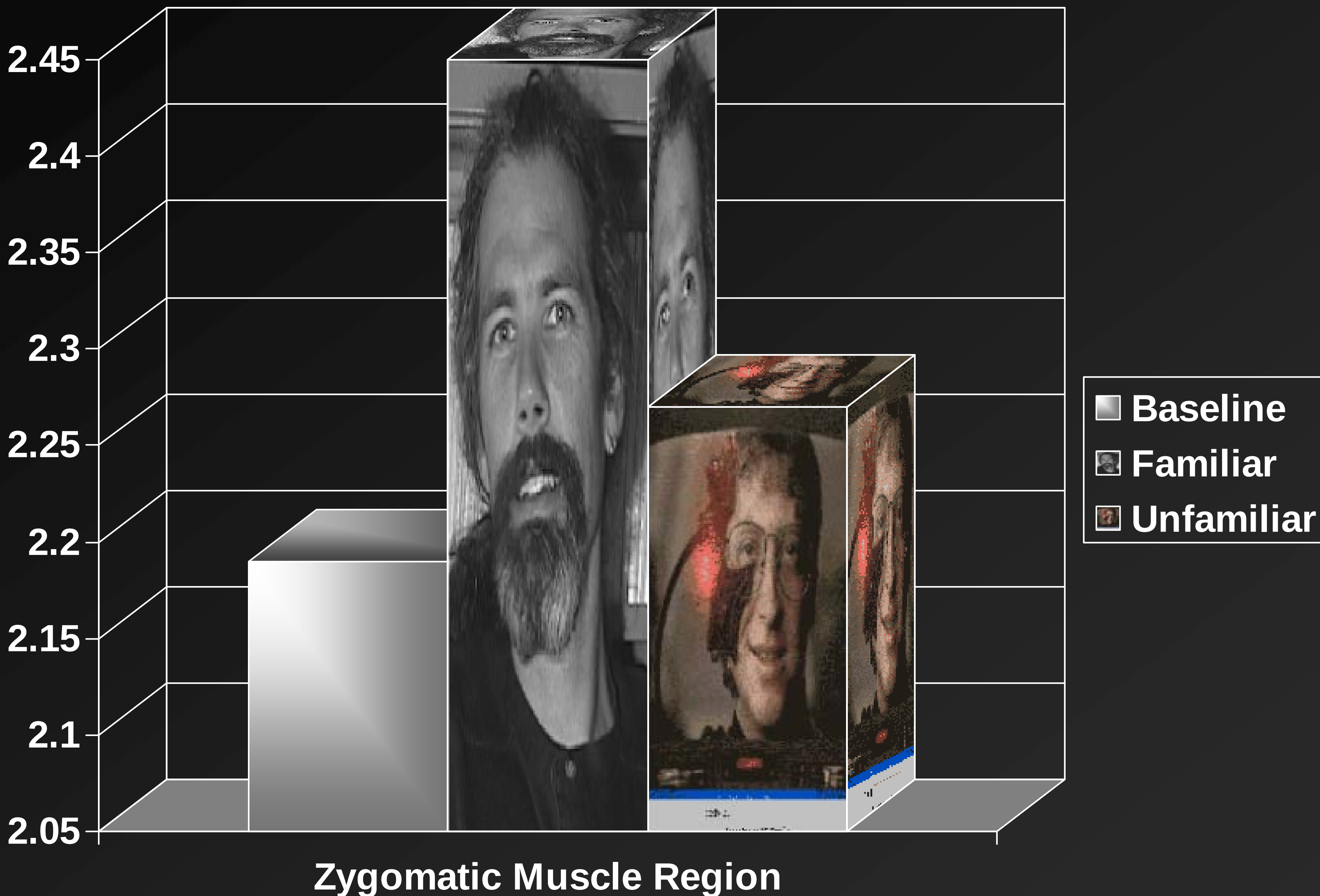
- Startle Probe
- Subtle affect
  - Mere Exposure
  - Subliminal effects
  - Mortality Salience
  - Biofeedback of EEG -- outcome measure
  - Emotion Regulation – outcome measure
  - Empathy – individual difference measure

The Phenomenon:

- People prefer stimuli to which they have been previously exposed to unfamiliar stimuli
- In absence of any reinforcement ("mere" exposure)
- Examples:
  - People we see incidentally in our routines
  - Songs
  - Scientific journal preferences
- Effect size r=.26 (Meta-analysis,Bornstein, 1989)

The logic:

- Evolutionary account Bornstein (1989)
  - it may be adaptive to prefer the familiar over the novel
  - novel objects could present a potential threat
  - organisms that had a fear of the strange and unfamiliar were more likely to survive, reproduce, and pass on genetic material
  - Preferring the familiar may thus be an adaptive trait that has evolved in humans and nonhumans
- Prediction:
  - unfamiliar as compared with familiar stimuli may be associated with more negative attitudes because of the unfamiliar stimuli's association with potential danger
  - Thus may see greater corrugator activity to novel than to familiar
  - No prediction for positive affect (Zygomaticus activity)



Loosely translated from Harmon-Jones & Allen, 2001

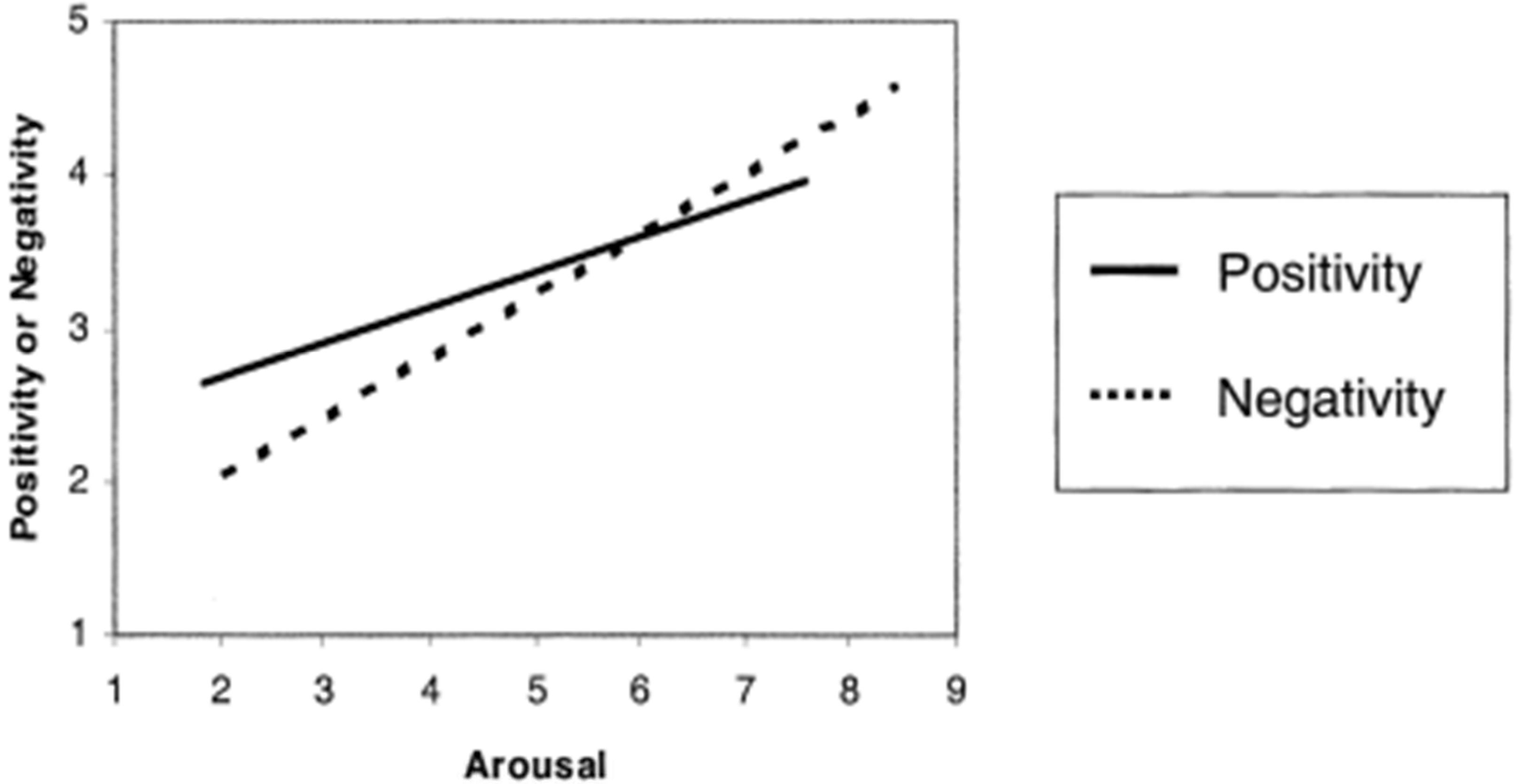


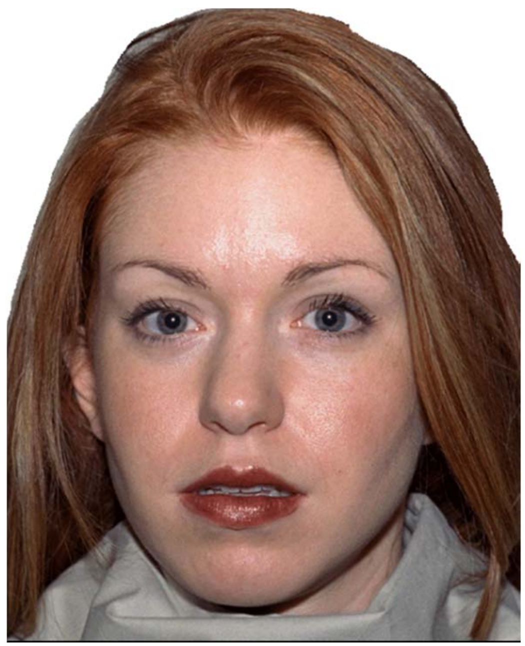
Figure 1. The positivity offset and negativity bias as seen in regression lines predicting mean positivity or mean negativity from mean arousal ratings of 256 positive and 216 negative items. For positivity, intercept = 2.20 and slope = 0.24. For negativity, intercept = 0.40 and slope = 1.19. (Adapted from: ''Eliciting Affect Using the International Affective Picture System: Trajectories Through Evaluative Space,'' by T. A. Ito, J. T. Cacioppo, and P. J. Lang, 1998, *Personality and Social Psychology Bulletin*, *8*, p. 872. Copyright 1998 by the Society for Personality and Social Psychology, Inc.)

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

30 ms

5 ms



Dimberg et al *Psychological Science* 2000

Unconscious Facial Reactions

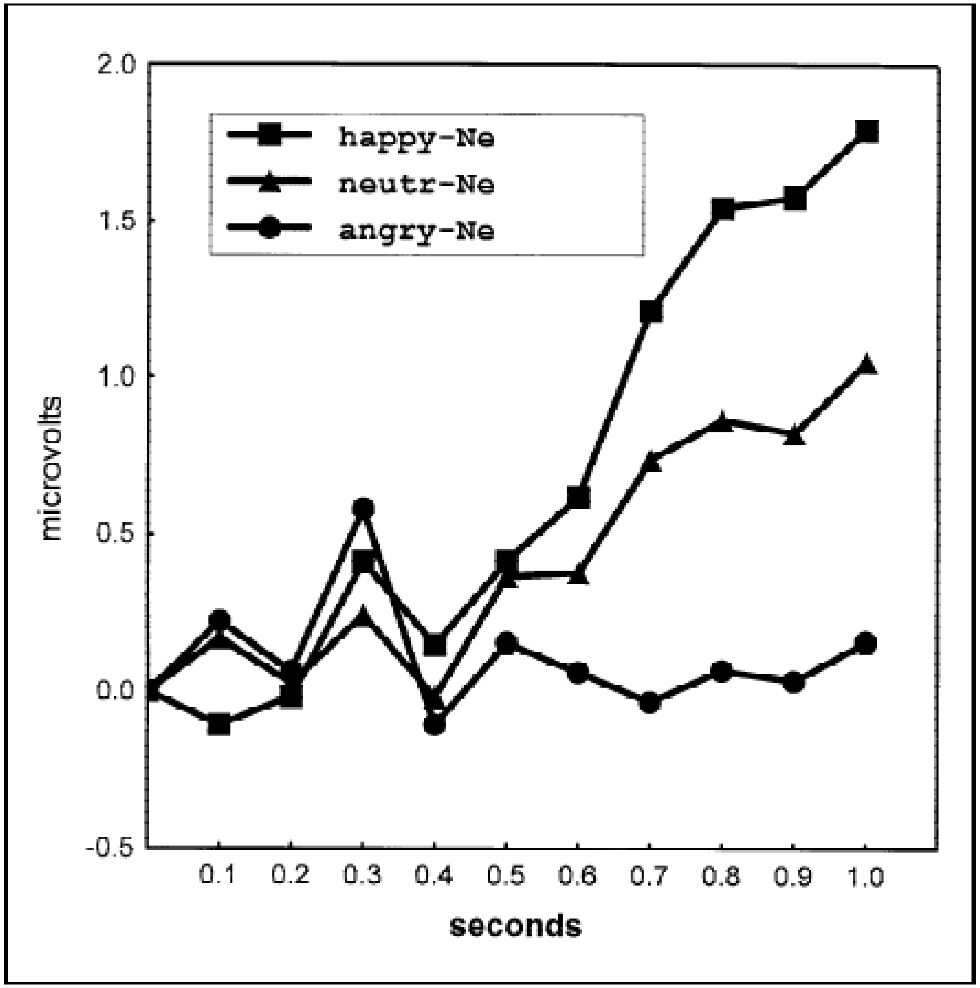


Fig. 1. Mean facial electromyographic response for the *zygomatic major* muscle, plotted in intervals of 100 ms during the first second of exposure. Three different groups of participants were exposed to identical neutral faces ("Ne"), preceded by unconscious exposure of happy, neutral ("neutr"), or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

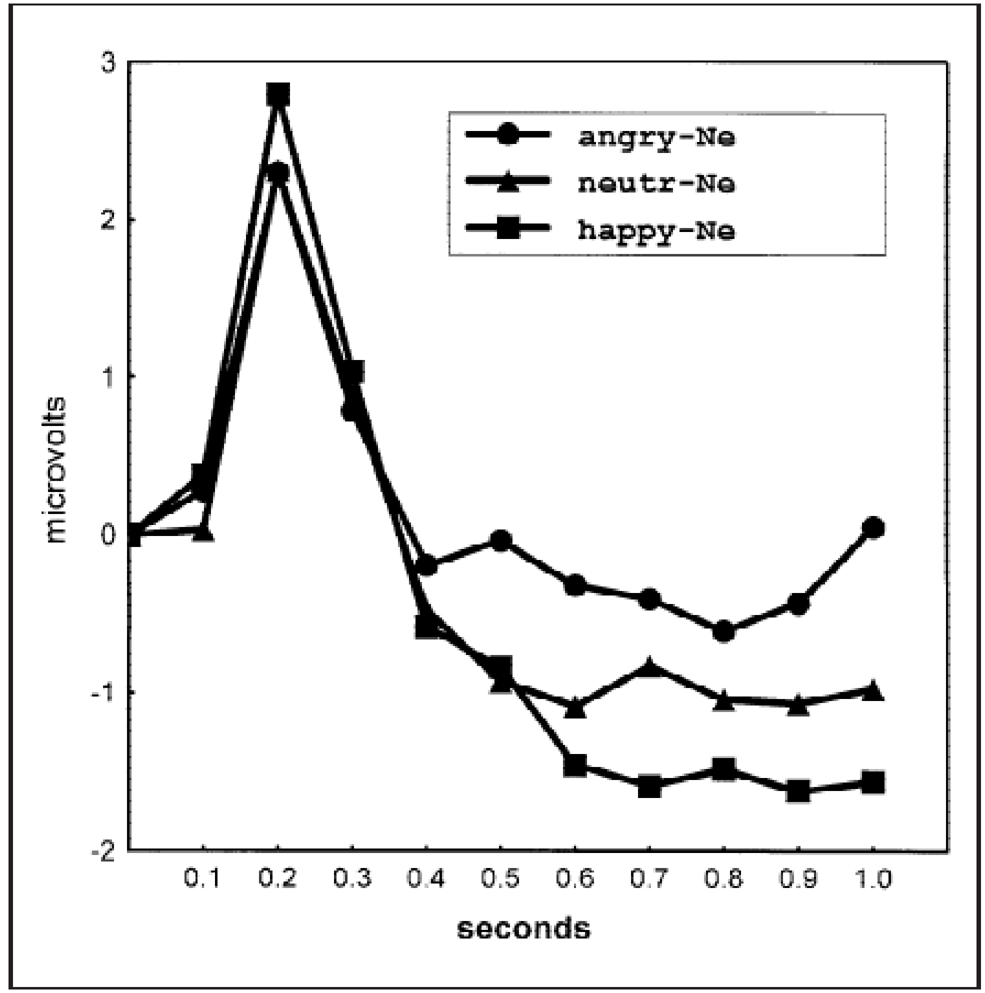
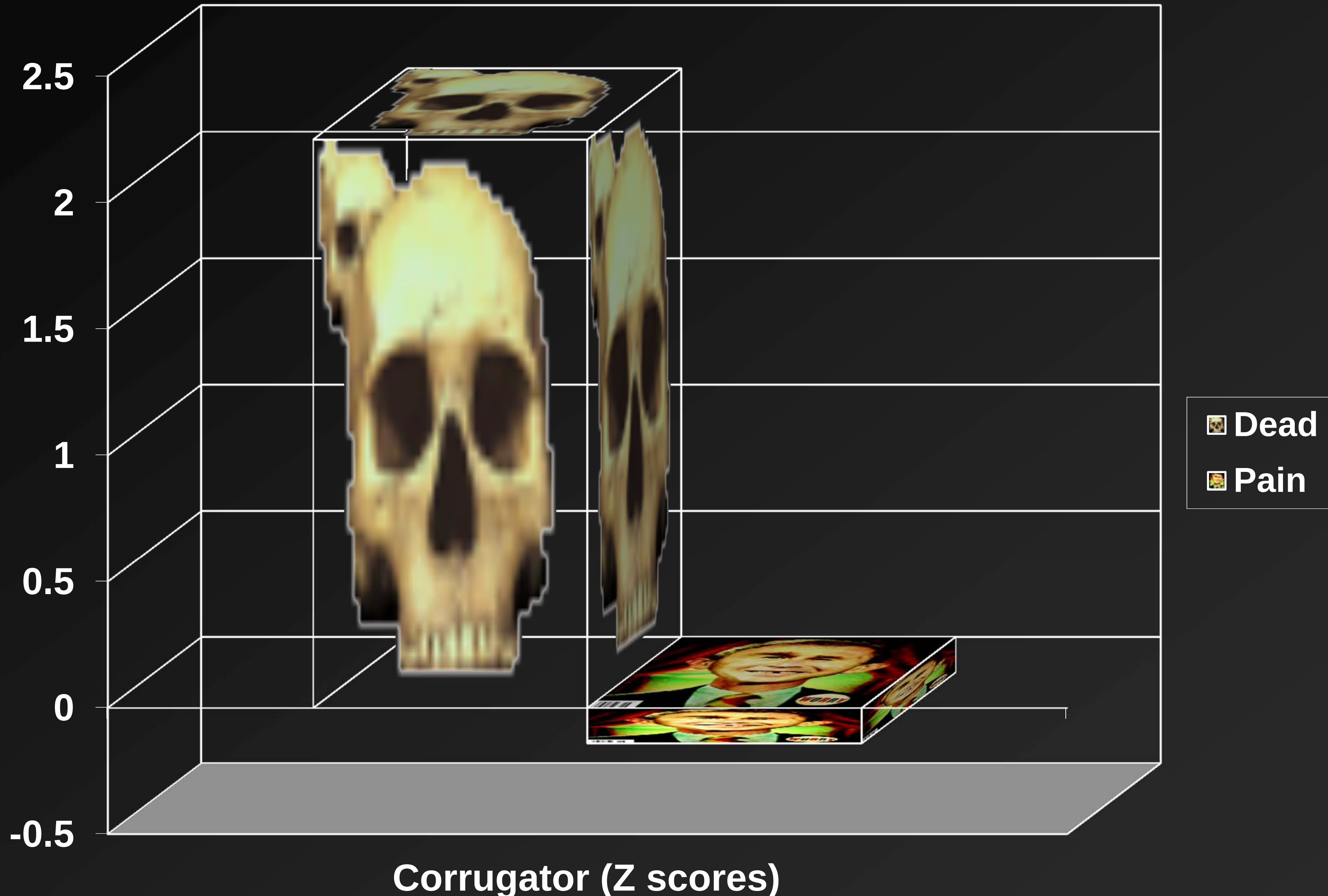


Fig. 2. Mean facial electromyographic response for the *corrugator supercilii* muscle, plotted in intervals of 100 ms during the first second of exposure. Three different groups of participants were exposed to identical neutral faces ("Ne"), preceded by unconscious exposure of angry, neutral ("neutr"),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

Dimberg et al *Psychological Science* 2000

A few Applications

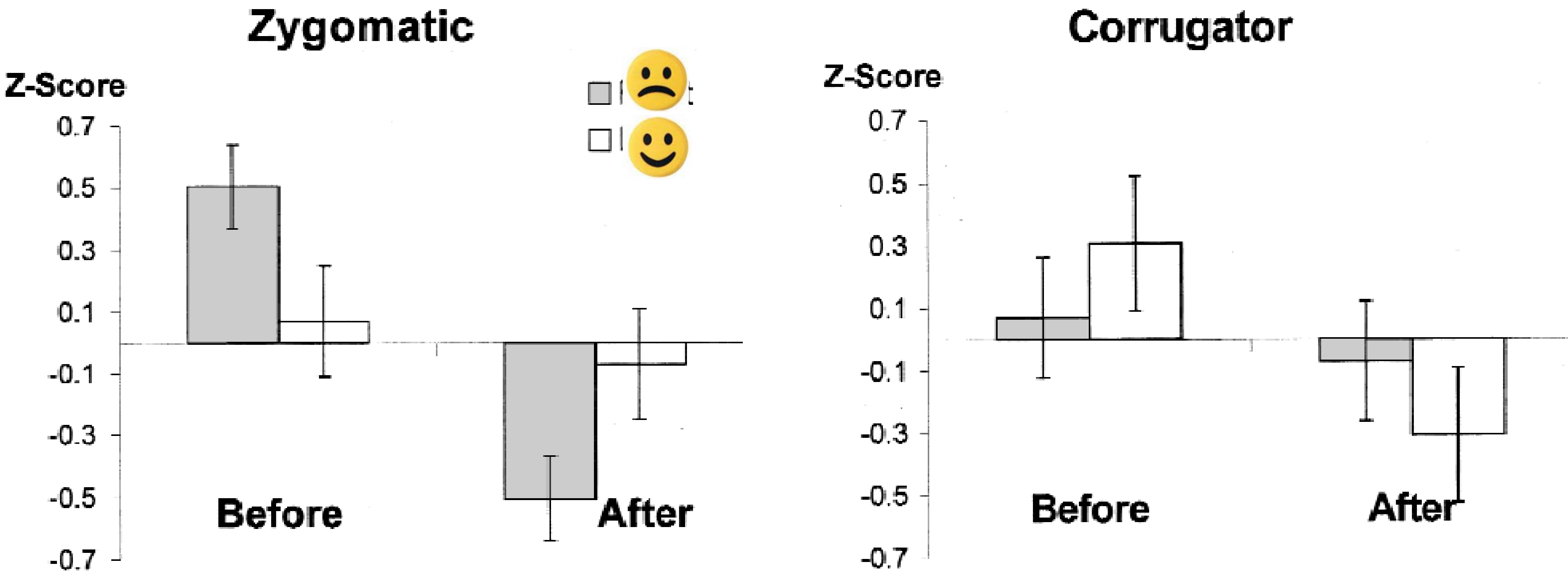
- Startle Probe
- Subtle affect
  - Mere Exposure
  - Subliminal effects
  - Mortality Salience
  - Biofeedback of EEG -- outcome measure
  - Emotion Regulation – outcome measure
  - Empathy – individual difference measure



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.

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



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

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

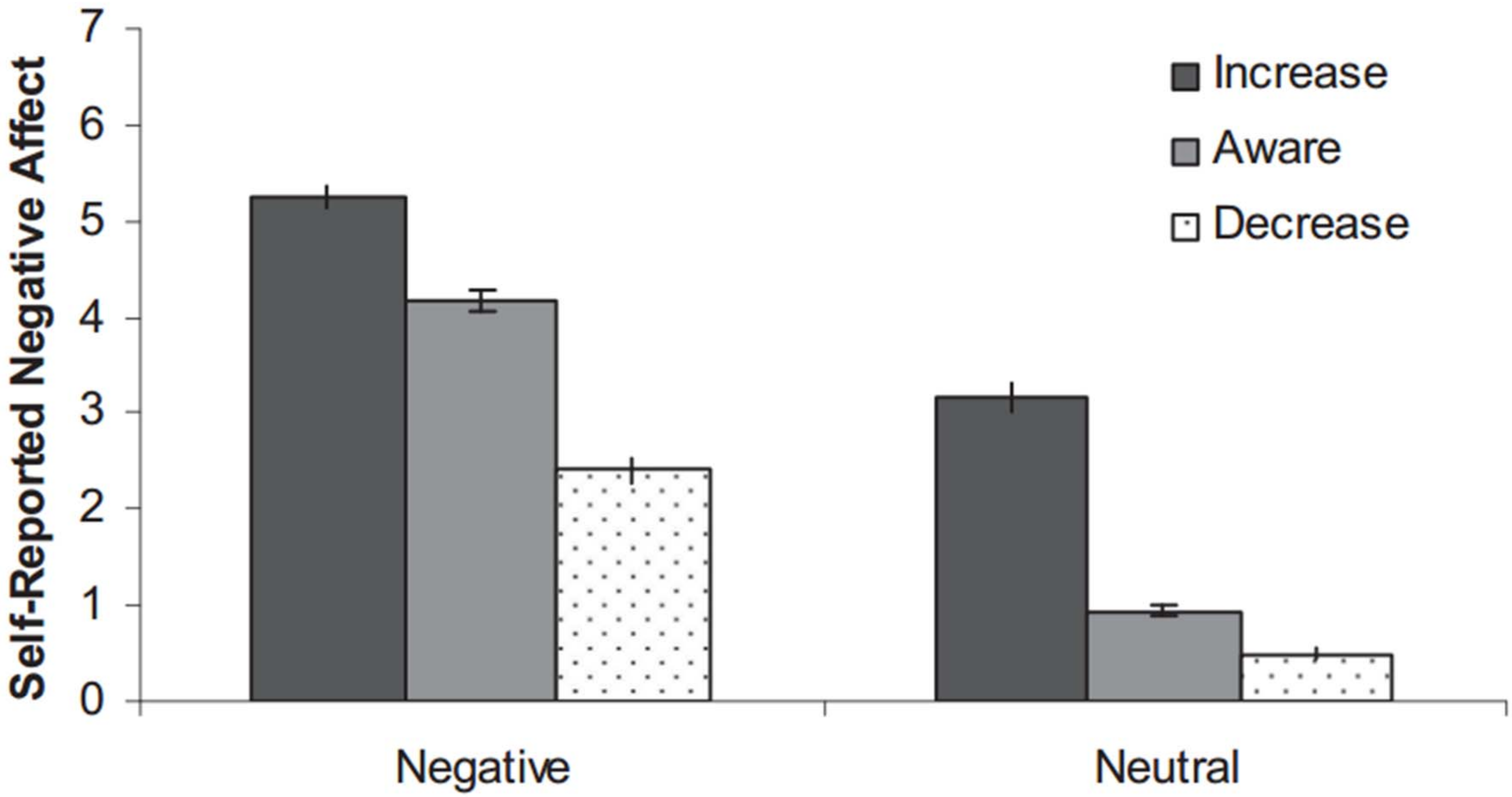


Figure 1. Self-reported negative affect on a 7-point Likert scale, where 0 = "not negative at all" and "7" = "strongly negative."

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

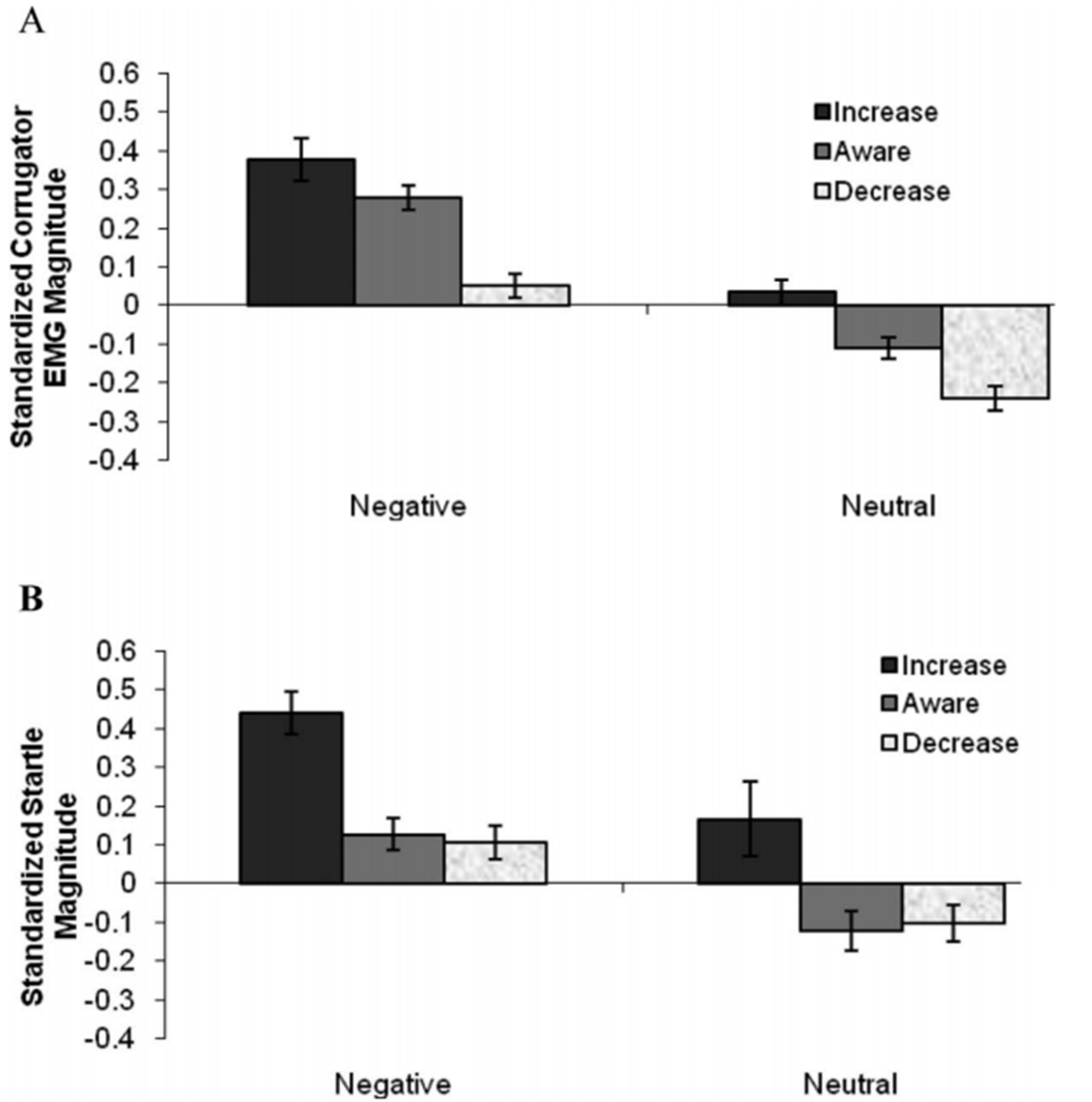


Figure 2. Standardized (A) corrugator EMG and (B) startle magnitude (averaged over Times 1 and 2).

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

A few Applications

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

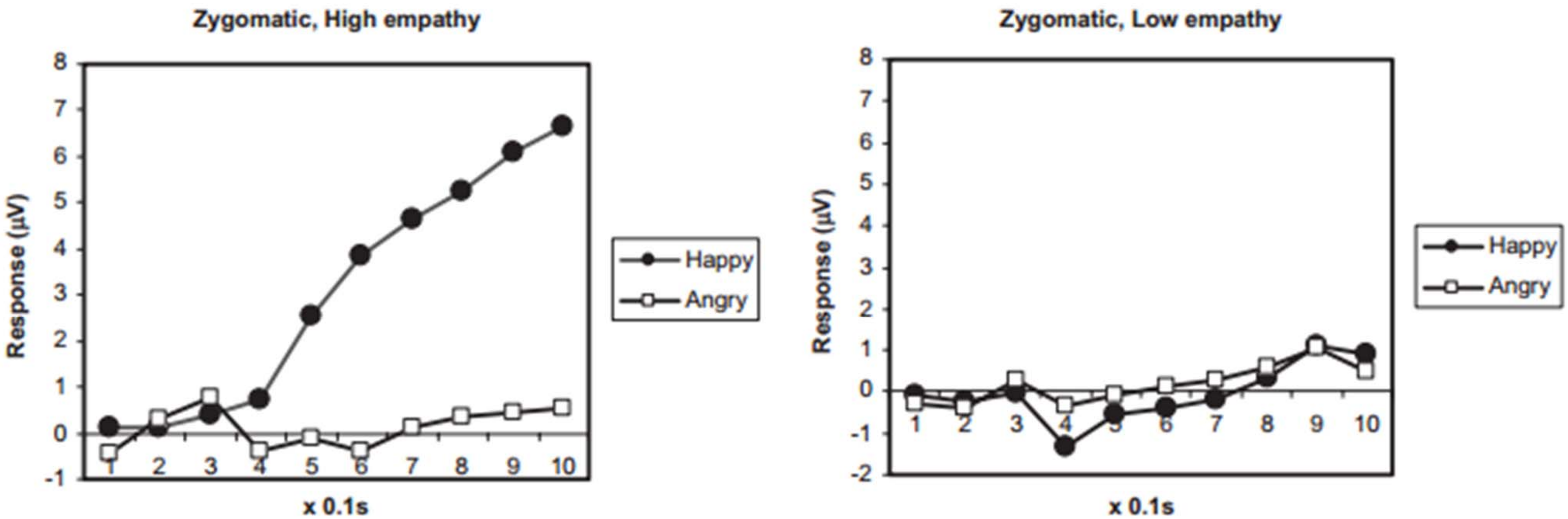


Figure 1. The *zygomaticus major* muscle response to pictures of happy and angry facial expressions for the High and Low empathy groups, plotted as a function of 100-ms intervals during the first second after stimulus onset.

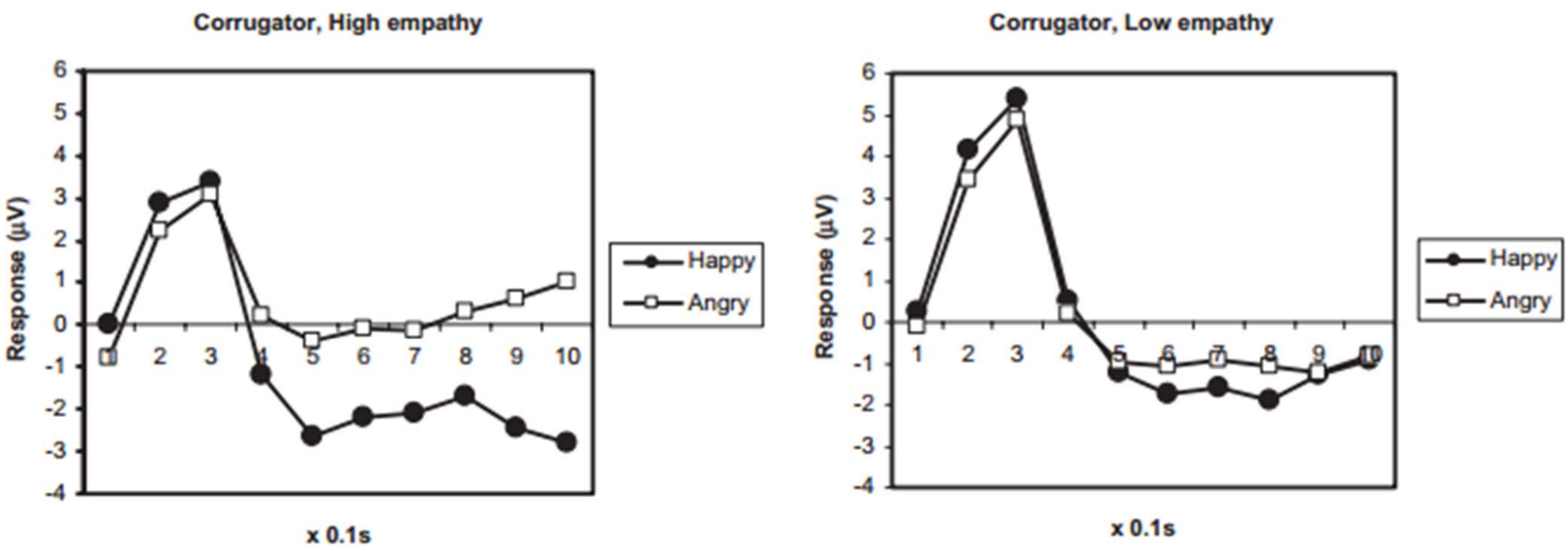


Figure 2. The *corrugator supercilii* muscle response to pictures of happy and angry facial expressions for the High and Low empathy groups, plotted as a function of 100-ms intervals during the first second after stimulus onset.

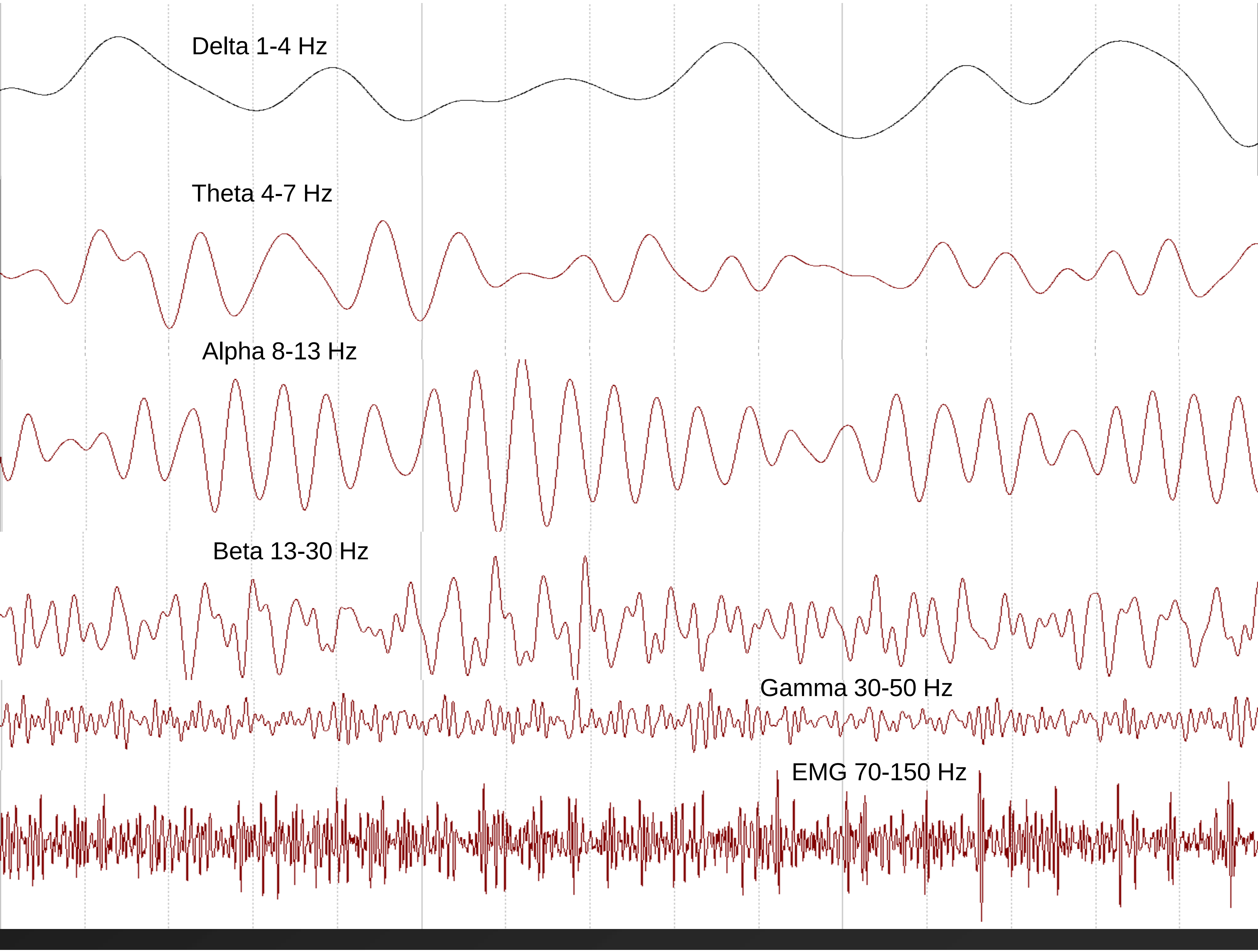
Dimberg & Thunberg (2012) *PsyCh Journal*

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


Delta 1-4 Hz
Theta 4-7 Hz
Alpha 8-13 Hz
Beta 13-30 Hz
Gamma 30-50 Hz
EMG 70-150 Hz

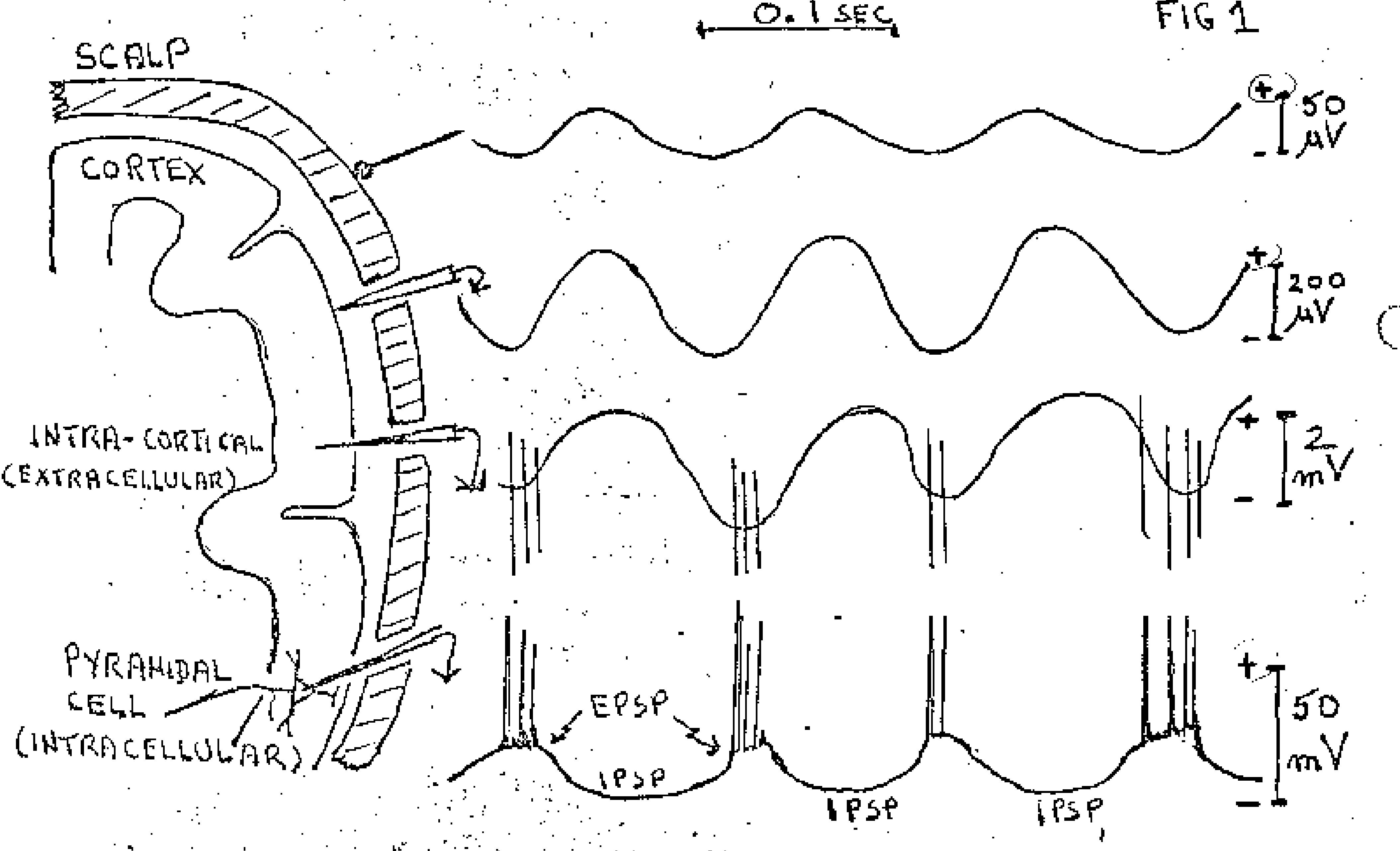
Utility of EEG

- *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
  - Slow waves
    - Synaptic potentials – YES, both IPSPs and EPSPs from functional synaptic units are major contributors
    - Afterpotentials – May contribute to a lesser extent

FIG 1



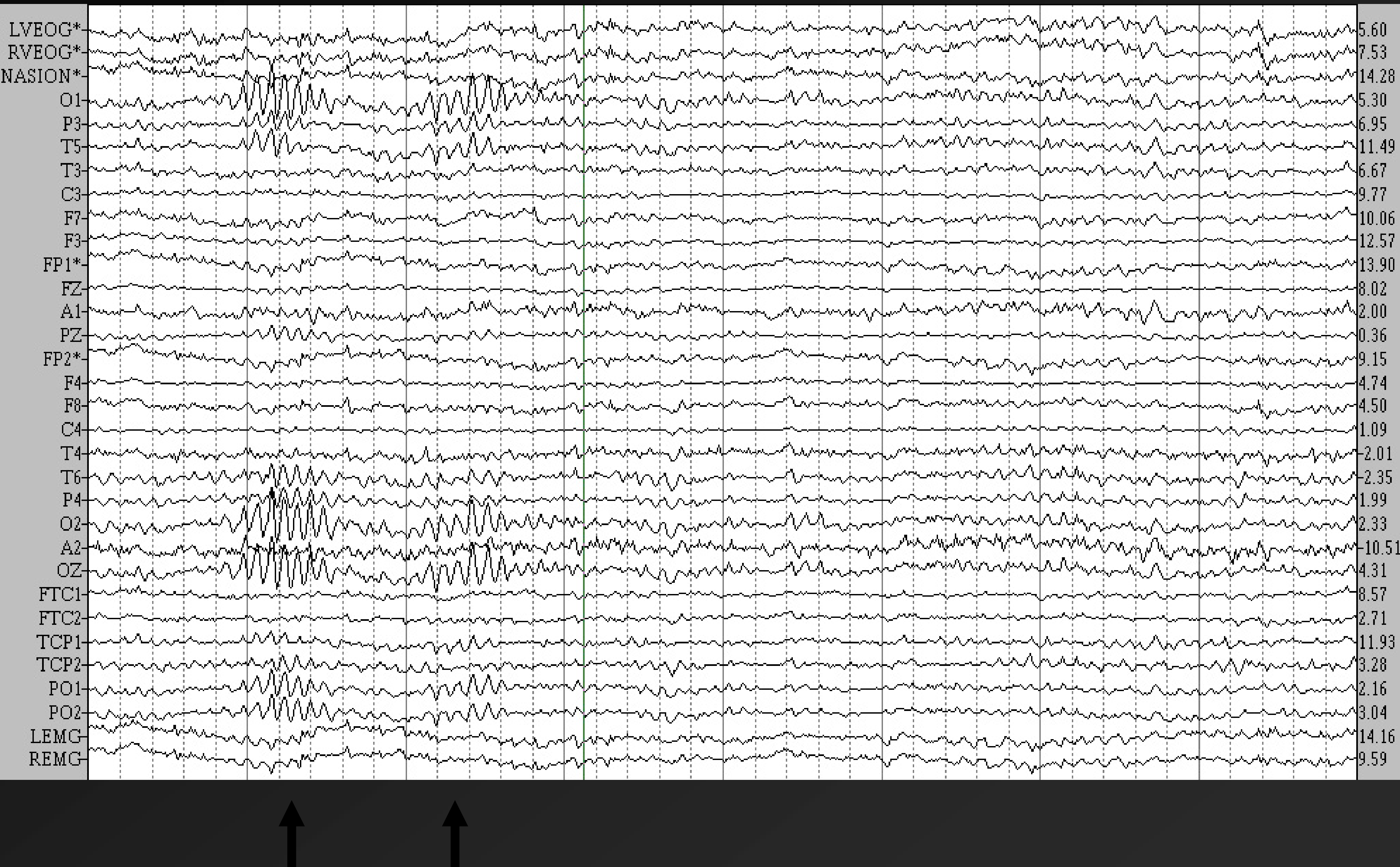
note basic similarity of wave form

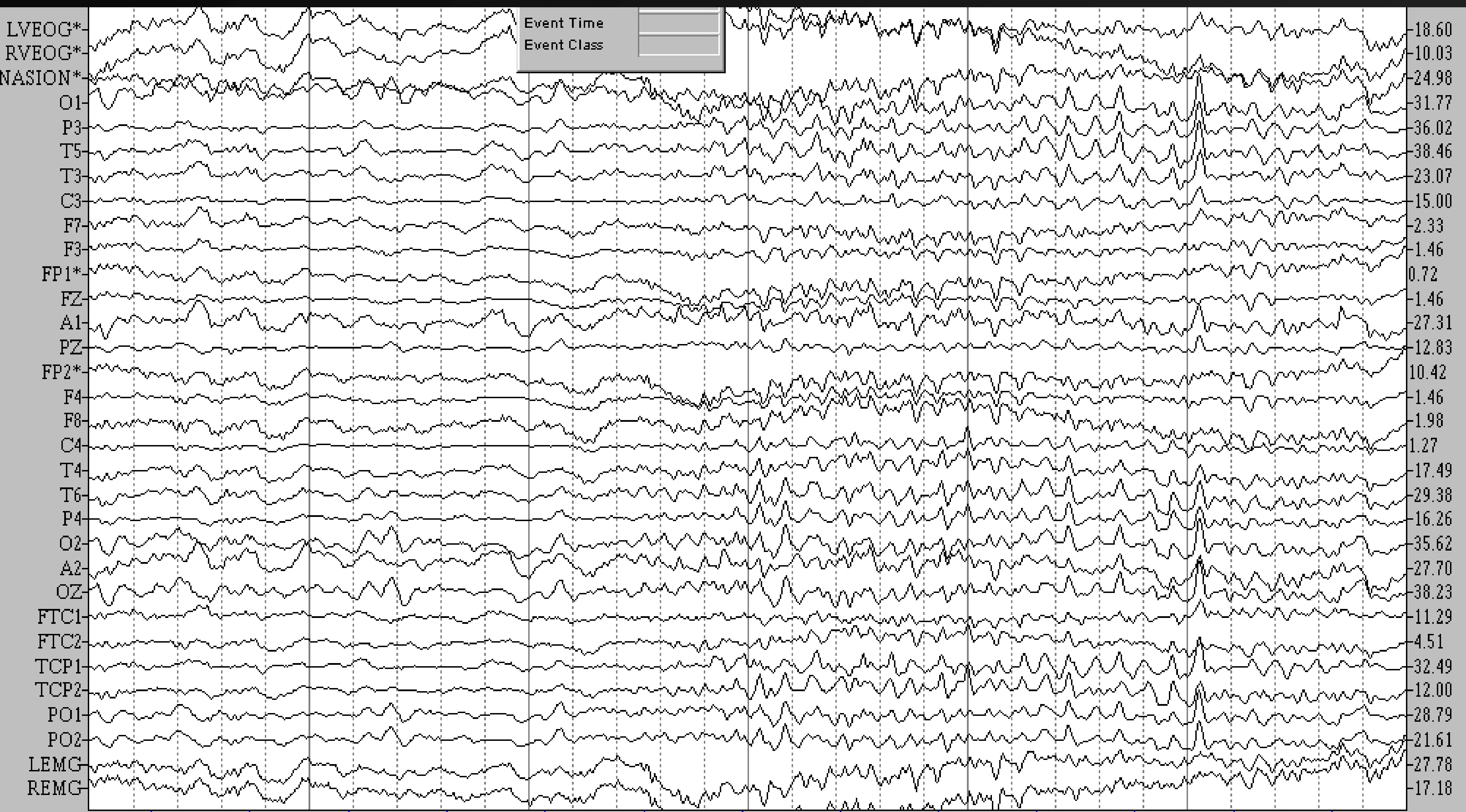
note scale differences

Alpha and Synchronization

- Why Alpha?
  - It is obvious 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

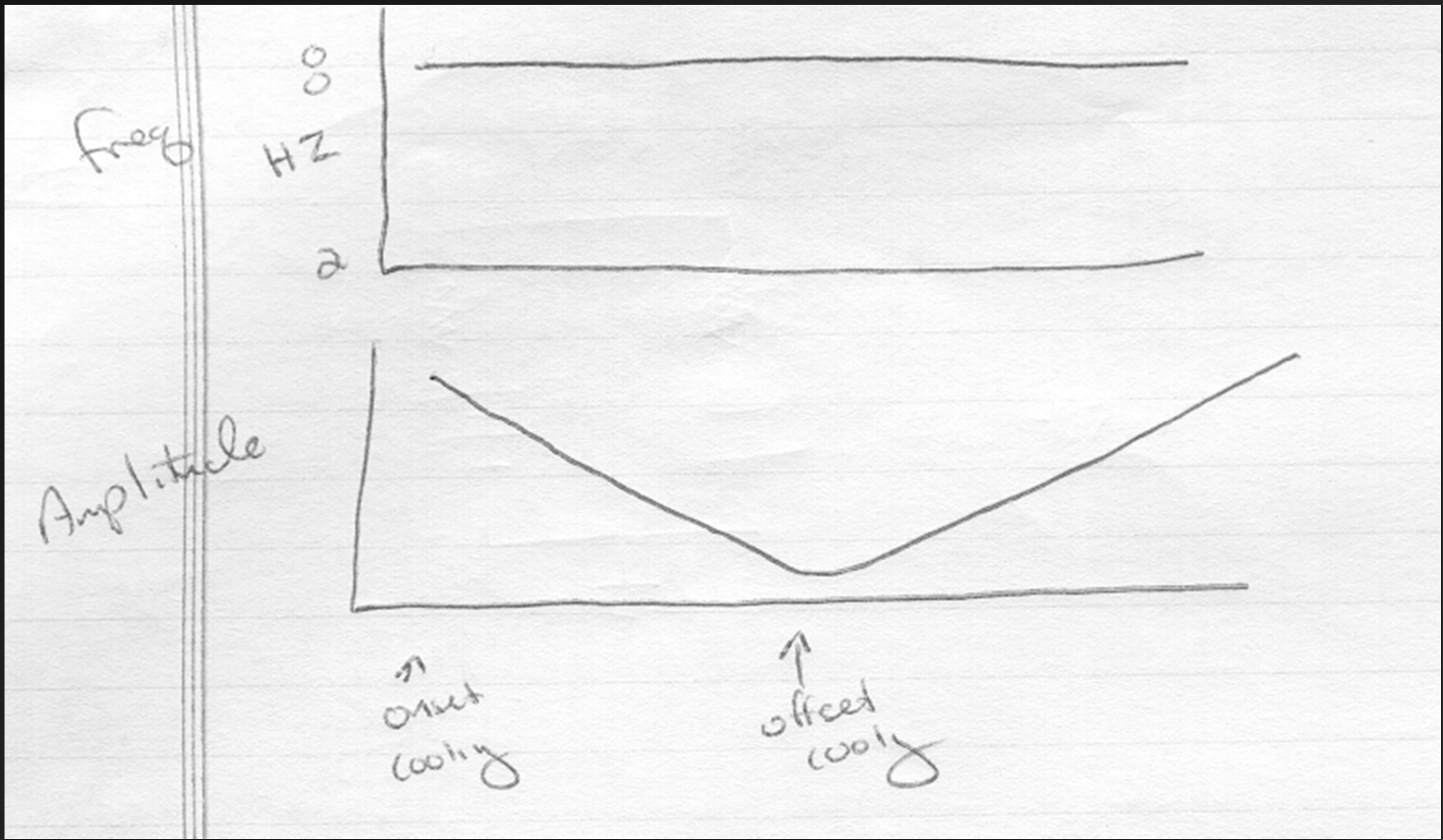
Next


LVEOG* 5.60
RVEOG* 7.53
NASION* 14.28
O1 5.30
P3 6.95
T5 11.49
T3 6.67
C3 9.77
F7 10.06
F3 12.57
FP1* 13.90
FZ 8.02
A1 2.00
PZ 0.36
FP2* 9.15
F4 4.74
F8 4.50
C4 1.09
T4 -2.01
T6 -2.35
P4 1.99
O2 2.33
A2 -10.51
OZ 4.31
FTC1 8.57
FTC2 2.71
TCP1 11.93
TCP2 3.28
PO1 2.16
PO2 3.04
LEMG 14.16
REMG 9.59


Event Time
Event Class
LVEOG* 18.60
RVEOG* 10.03
NASION* 24.98
O1 31.77
P3 36.02
T5 38.46
T3 23.07
C3 15.00
F7 2.33
F3 1.46
FP1* 0.72
FZ 1.46
A1 27.31
PZ 12.83
FP2* 10.42
F4 1.46
F8 1.98
C4 1.27
T4 17.49
T6 29.38
P4 16.26
O2 35.62
A2 27.70
OZ 38.23
FTC1 11.29
FTC2 4.51
TCP1 32.49
TCP2 12.00
PO1 28.79
PO2 21.61
LEMG 27.78
REMG 17.18

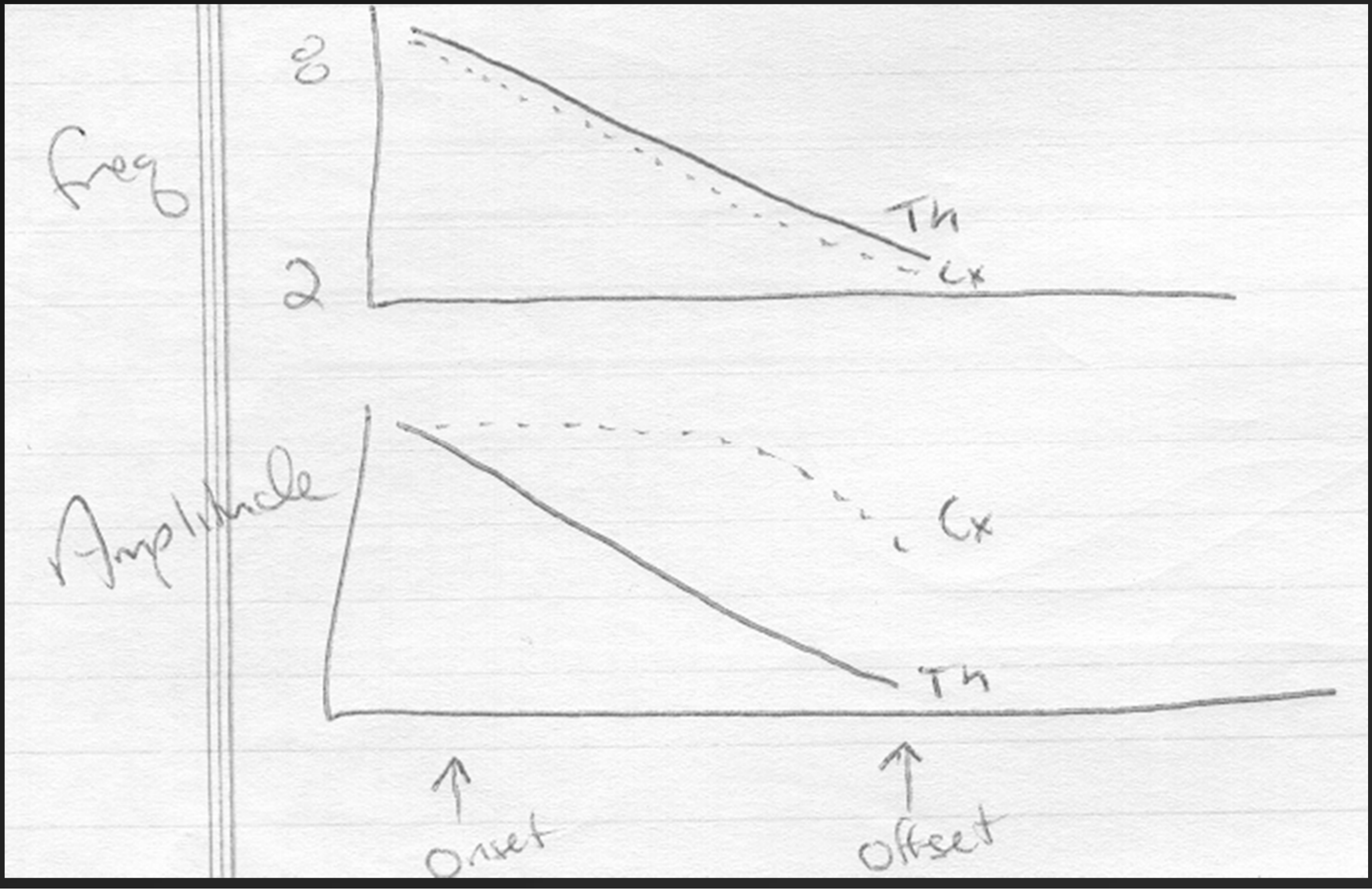
Alpha and Synchronization

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



Alpha and Synchronization

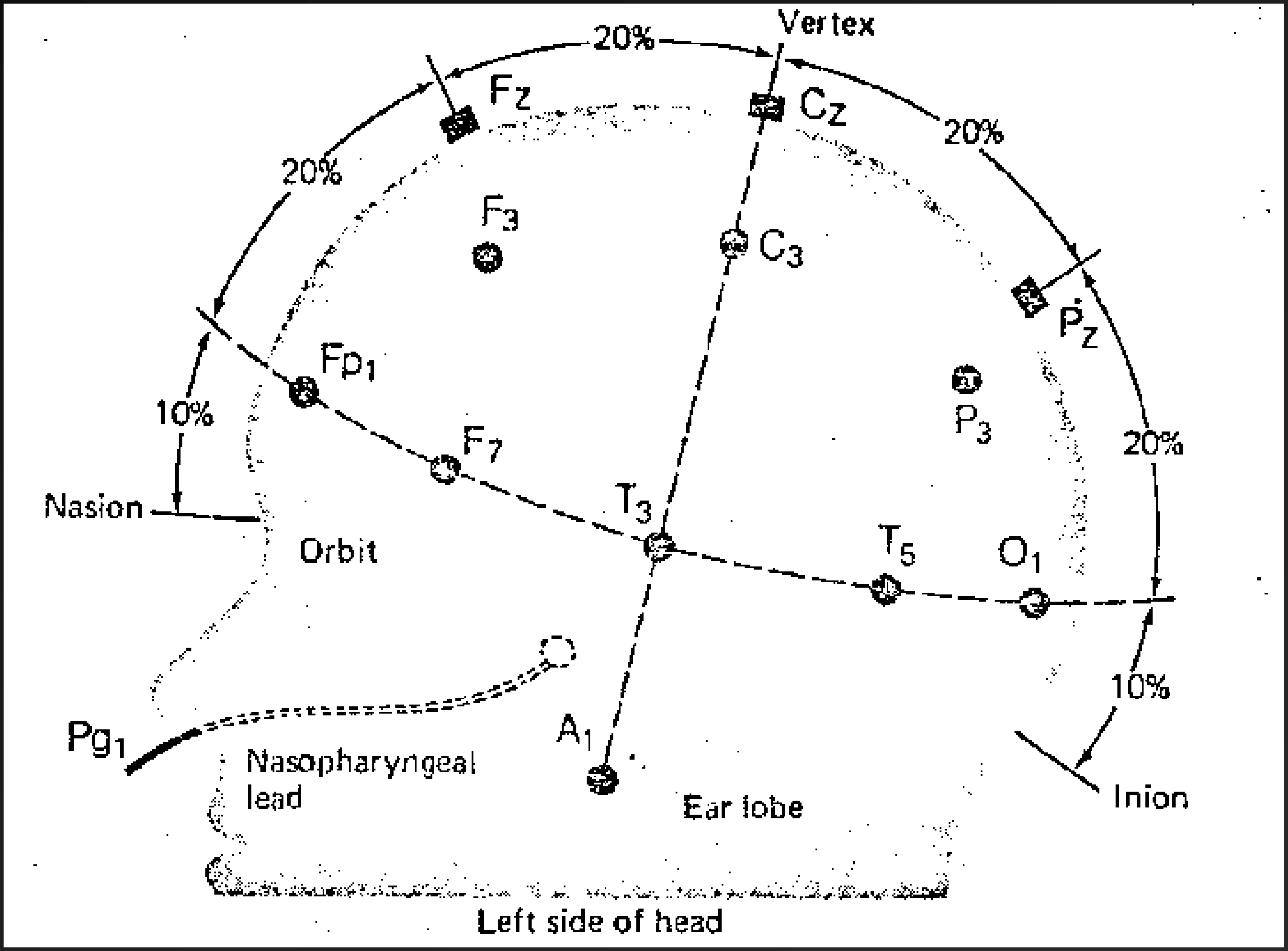
- Andersen and Andersen (1968)
  - Cooling of Thalamus resulted in change in amplitude and frequency of Alpha at both thalamus and cortex



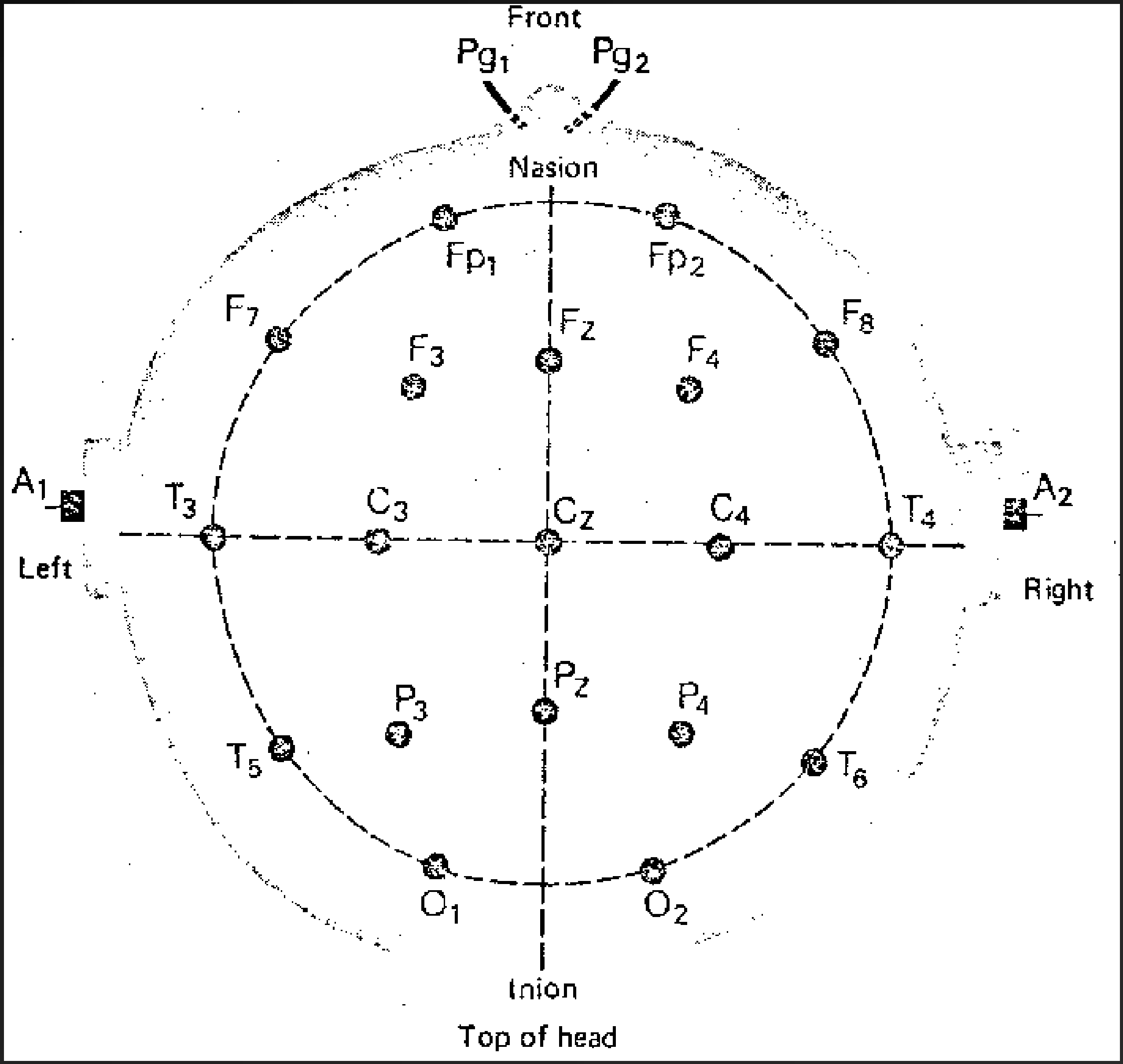
Alpha and Synchronization

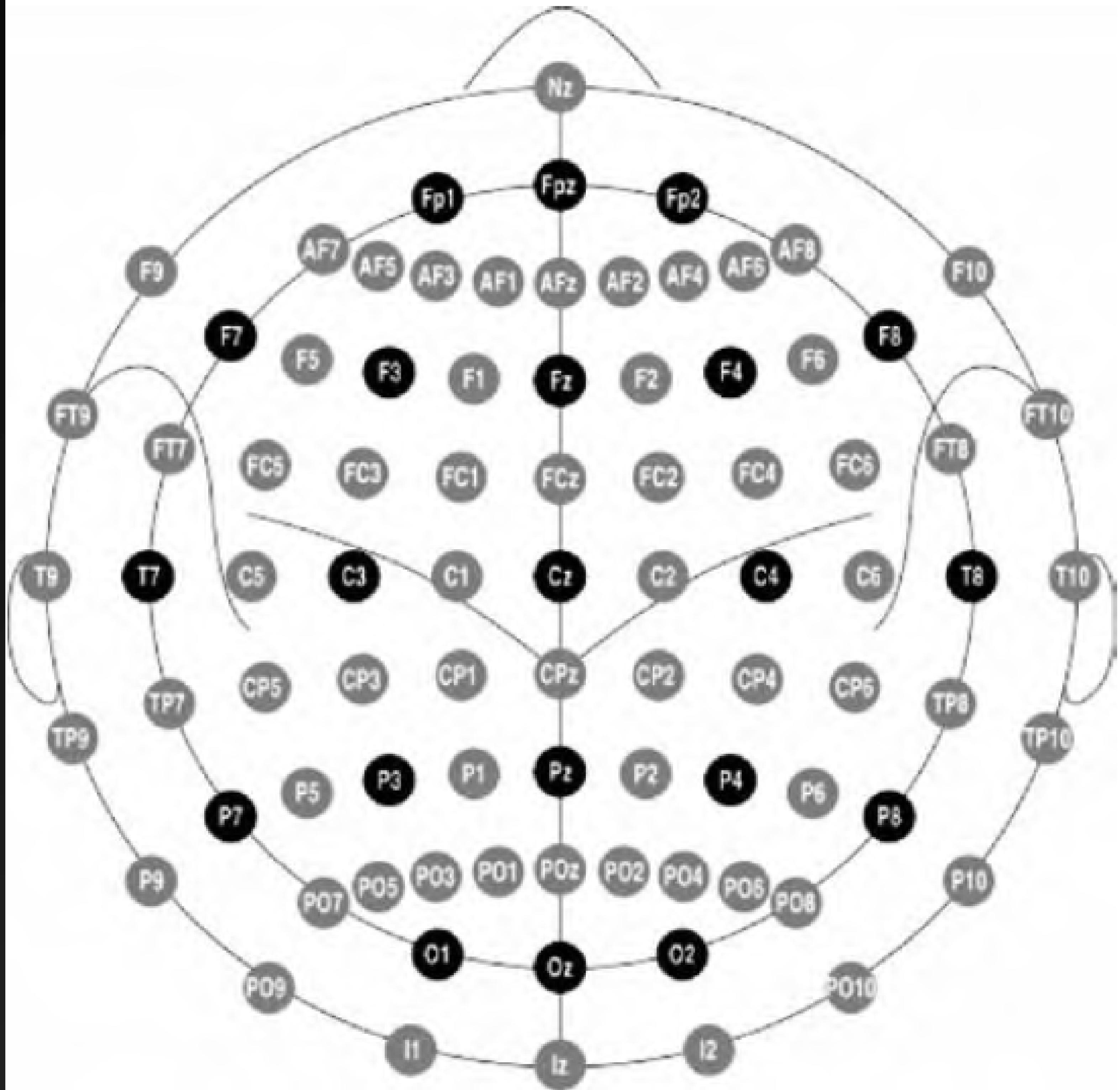
- In sum, Thalamus drives the alpha rhythmicity of the EEG
  - Cortex certainly does feedback to thalamus, but thalamus is responsible for driving the EEG
  - Particularly the Reticularis nucleus (Steriade et al. 1985)
- What causes change from rhythmicity to desynchronization?
  - Afferent input to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

Recording EEG

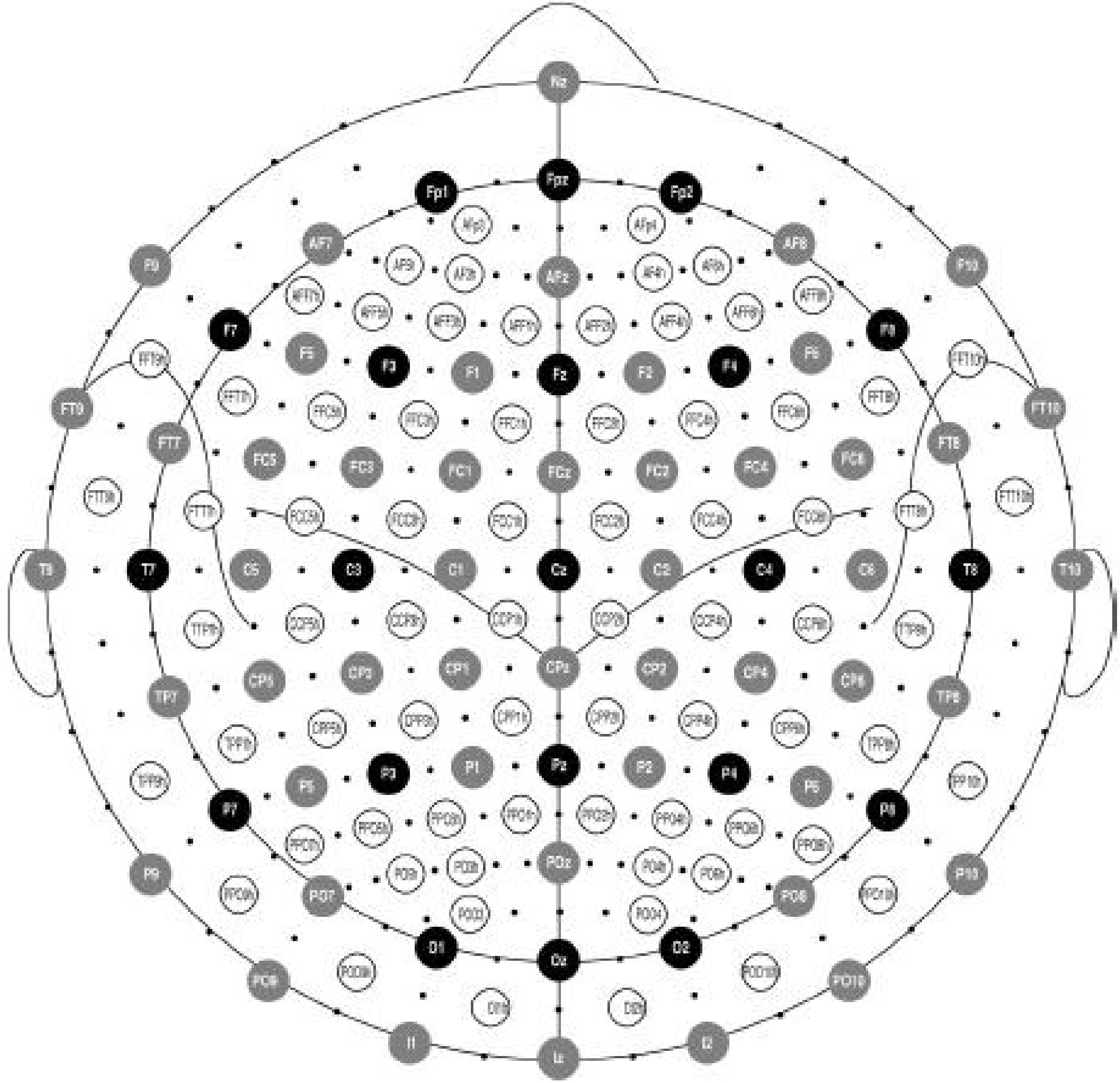


Recording EEG





Nz
Fp1
Fpz
Fp2
AF7
AF5
AF3
AF1
AFz
AF2
AF4
AF6
AF8
F9
F7
F5
F3
F1
Fz
F2
F4
F6
F8
F10
FT9
FT7
FC5
FC3
FC1
FCz
FC2
FC4
FC6
FT8
FT10
T9
T7
C5
C3
C1
Cz
C2
C4
C6
T8
T10
TP9
TP7
CP5
CP3
CP1
CPz
CP2
CP4
CP6
TP8
TP10
P9
P7
P5
P3
P1
Pz
P2
P4
P6
P8
P10
PO9
PO7
PO5
PO3
PO1
POz
PO2
PO4
PO6
PO8
PO10
O1
Oz
O2
I1
Iz
I2


Nz
Fpz
Fp1
Fp2
AF7
AF8
F9
F10
AFz
F7
F5
F3
F1
Fz
F2
F4
F6
F8
FT9
FT10
FT7
FT8
FC5
FC3
FC1
FCz
FC2
FC4
FC6
T9
T7
C5
C3
C1
Cz
C2
C4
C6
T8
T10
CP5
CP3
CP1
CPz
CP2
CP4
CP6
TP7
TP8
P7
P5
P3
P1
Pz
P2
P4
P6
P8
P9
P10
PO7
POz
PO8
O1
Oz
O2
PO9
PO10
I1
Iz
I2

Systems are surface-based, not anatomically-based

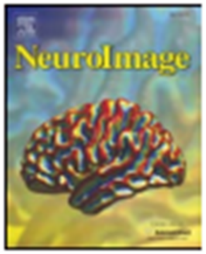
NeuroImage 46 (2009) 64–72

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

L. Koessler [a,b], L. Maillard [b], A. Benhadid [a], J.P. Vignal [b], J. Felblinger [a], H. Vespignani [b], M. Braun [a,c,d,*]

[a] *INSERM U947, Nancy University, France*
[b] *Neurology Department, University Hospital, Nancy, France*
[c] *Neuroradiology Department, University Hospital, Nancy, France*
[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 (more later) as it will change your ability to observe certain signals


E1-L Electro-Cap Large
58-62 cm - Blue
E1-M Electro-Cap Medi
54-58 cm - Red
E1-S Electro-Cap Small
50-54 cm - Yellow
E1-XS Electro-Cap X-S
46-50 cm - Green





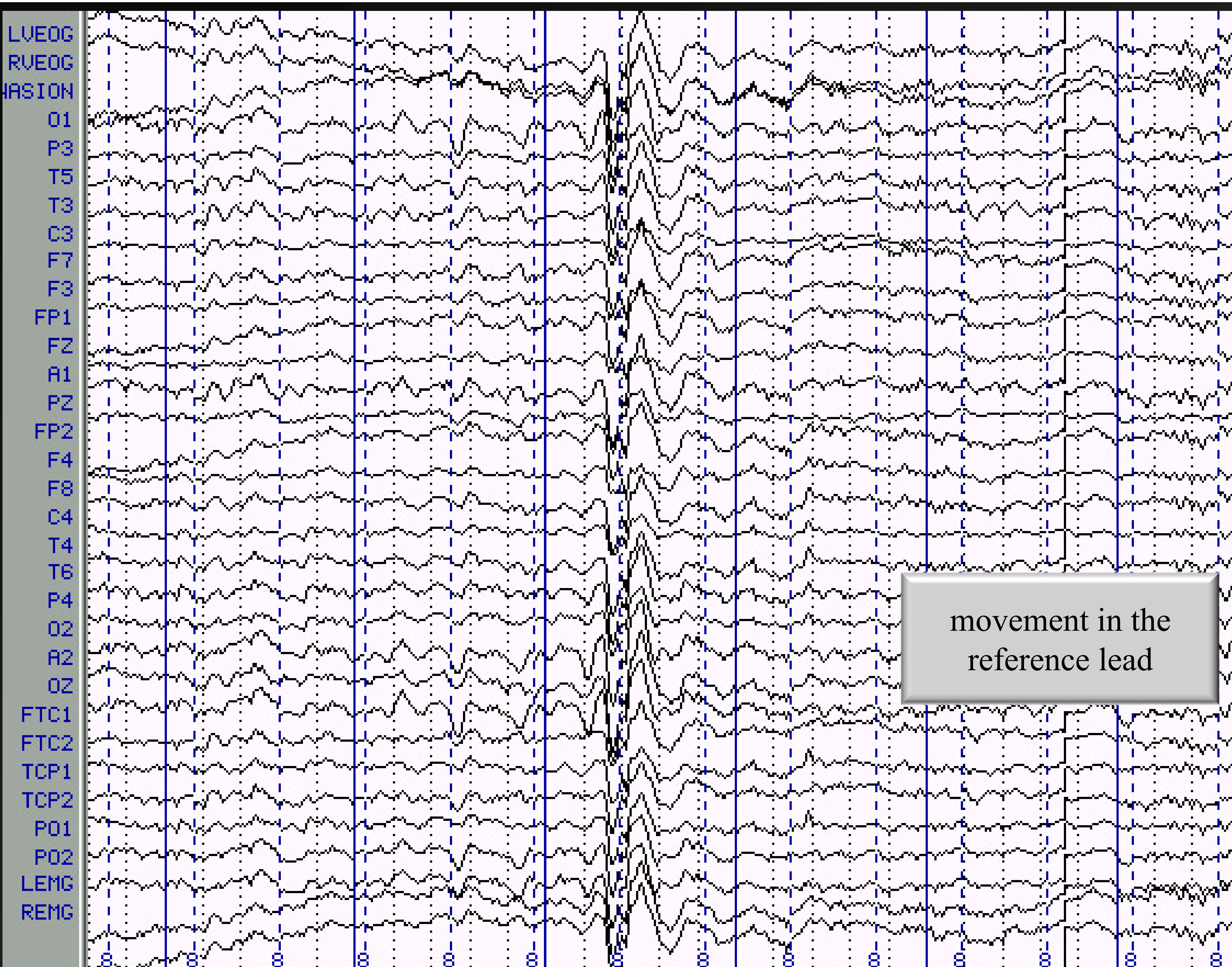
Recording References

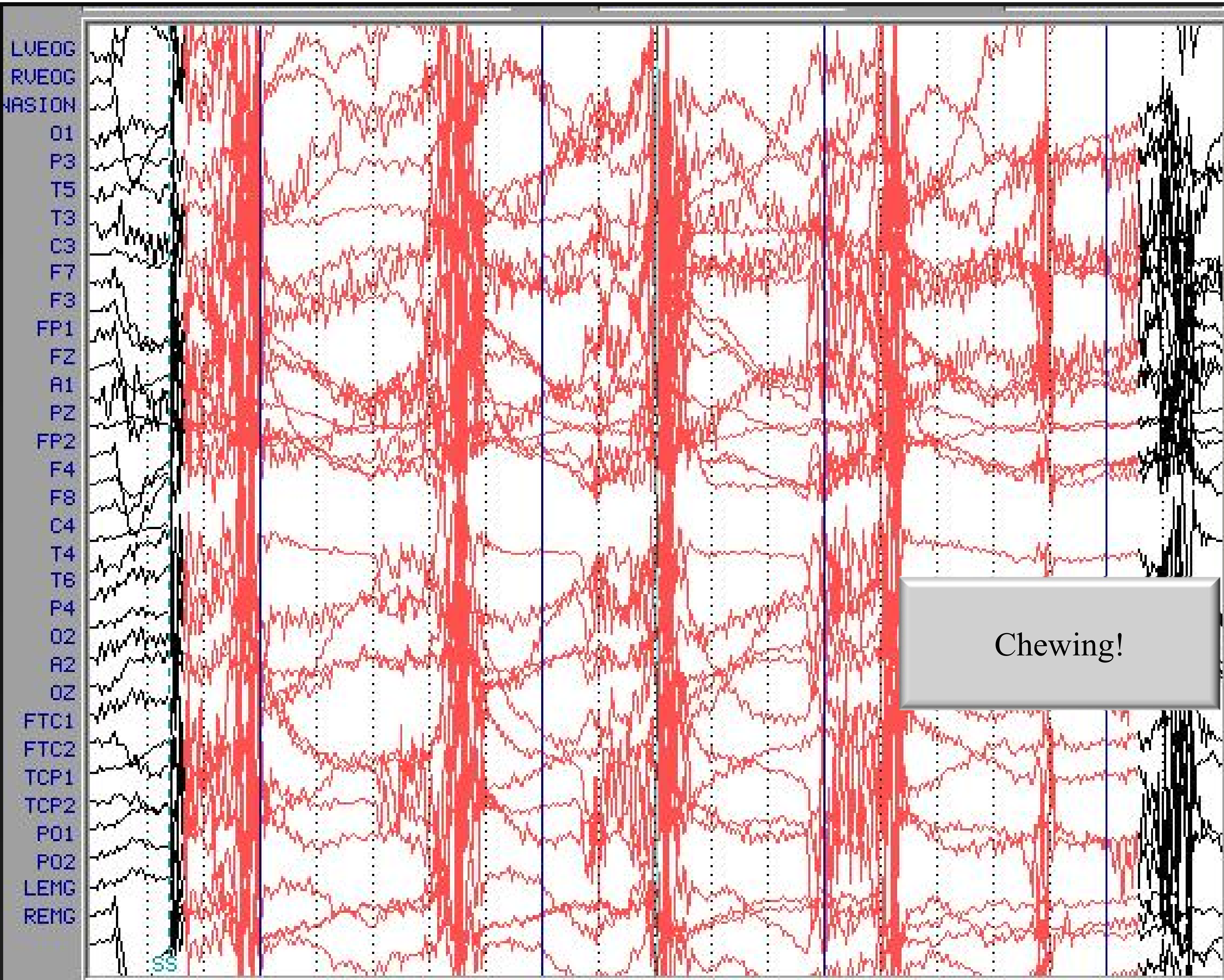
- Bipolar recording
  - Multiple active sites
    - Sensitive to differences between electrodes
    - With proper array, sensitive to local fluctuations (e.g. spike localization)
- Off-line derivations
  - Averaged Mastoids
  - Average Reference (of EEG Leads)
    - With sufficient # electrodes and surface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

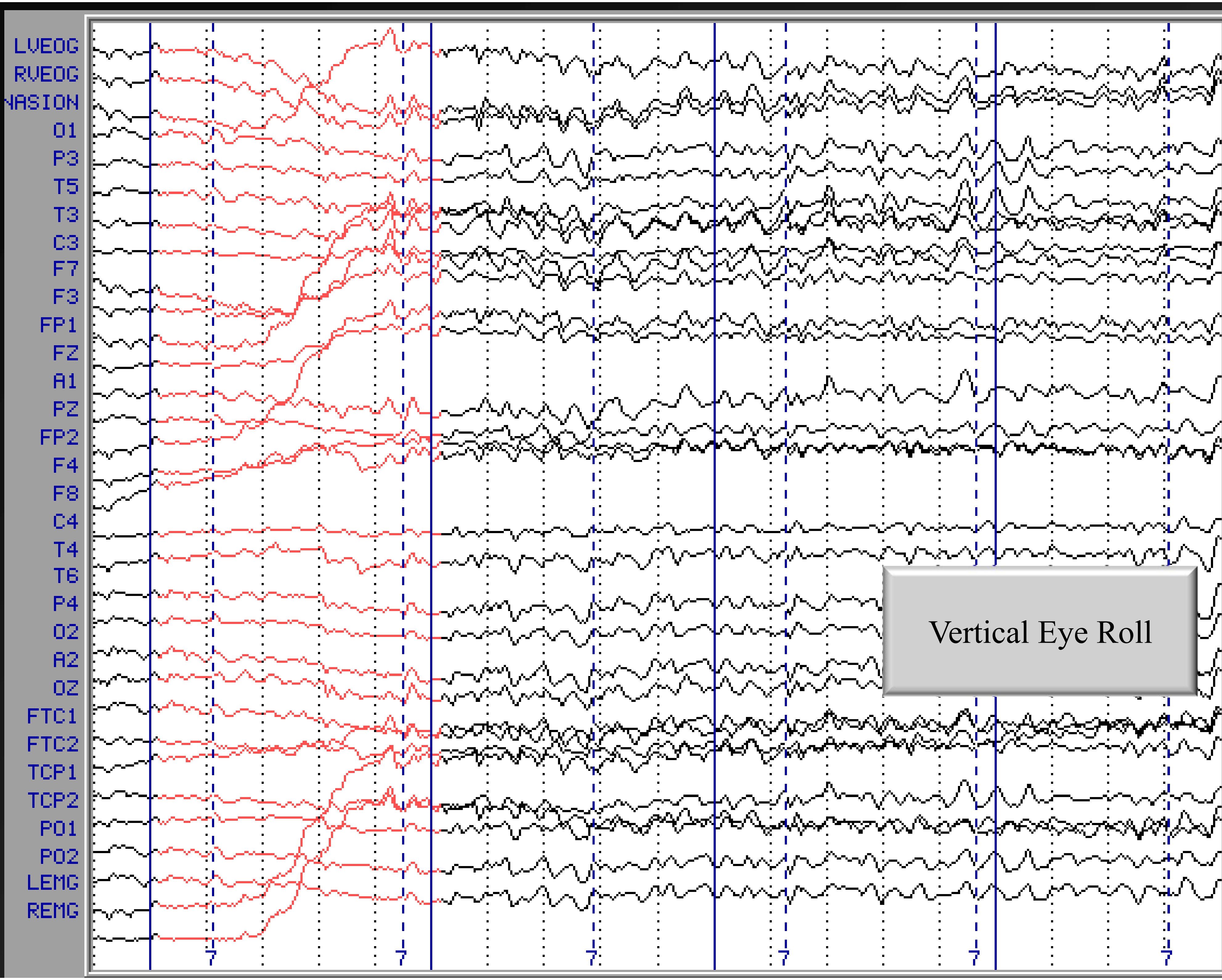
Dreaded Artifacts

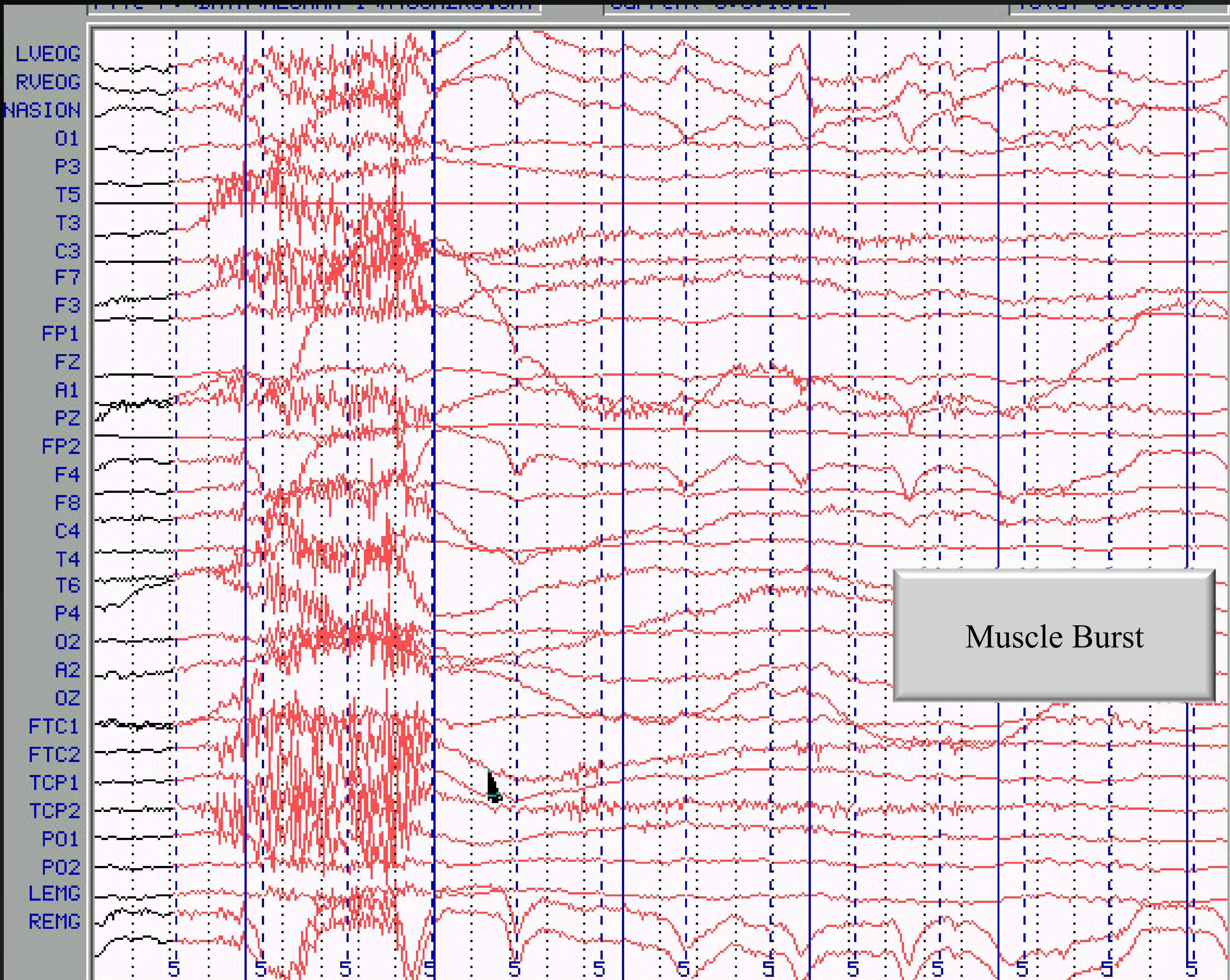
- Three sources
  - 60-cycle noise
    - Ground subject
    - 60 Hz Notch filter
  - Muscle artifact
    - No gum!
    - Use headrest
    - Measure EMG and reject/correct for influence
  - Eye Movements
    - Eyes are dipoles
    - Reject ocular deflections including blinks
    - Use correction procedure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

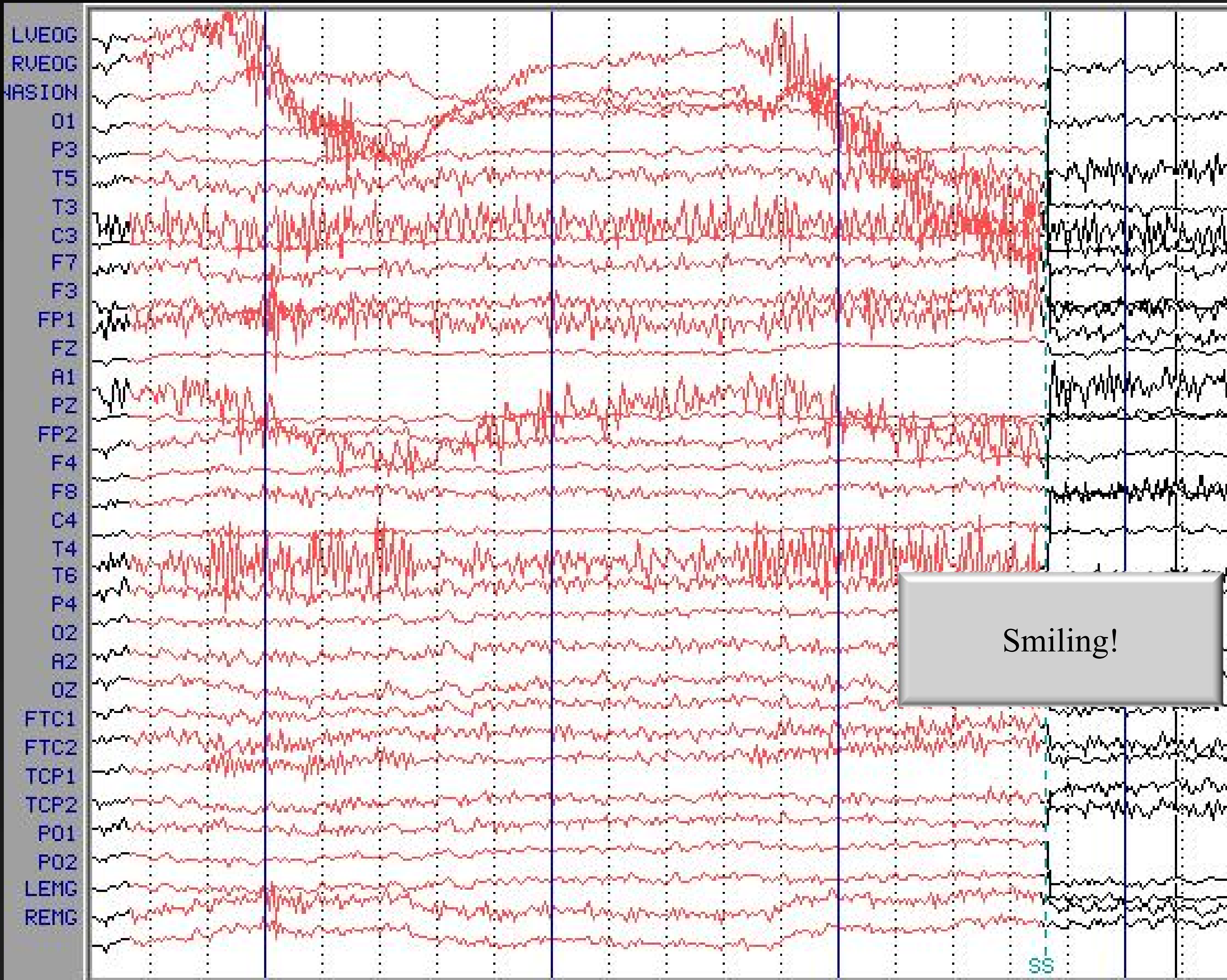
Name That Artifact!

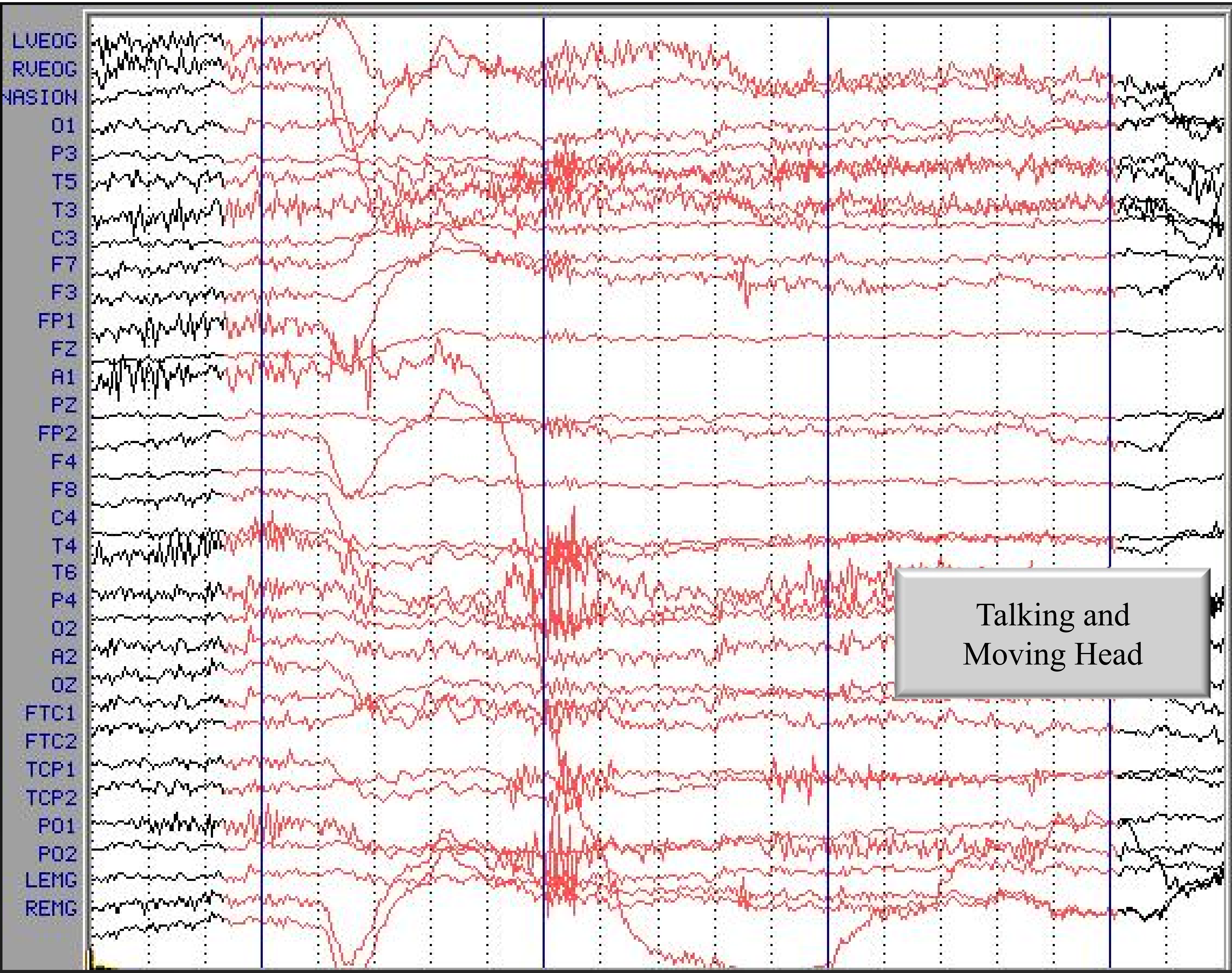

LVEOG
RVEOG
ASION
O1
P3
T5
T3
C3
F7
F3
FP1
FZ
A1
PZ
FP2
F4
F8
C4
T4
T6
P4
O2
A2
OZ
FTC1
FTC2
TCP1
TCP2
PO1
PO2
LEMG
REMG
movement in the reference lead

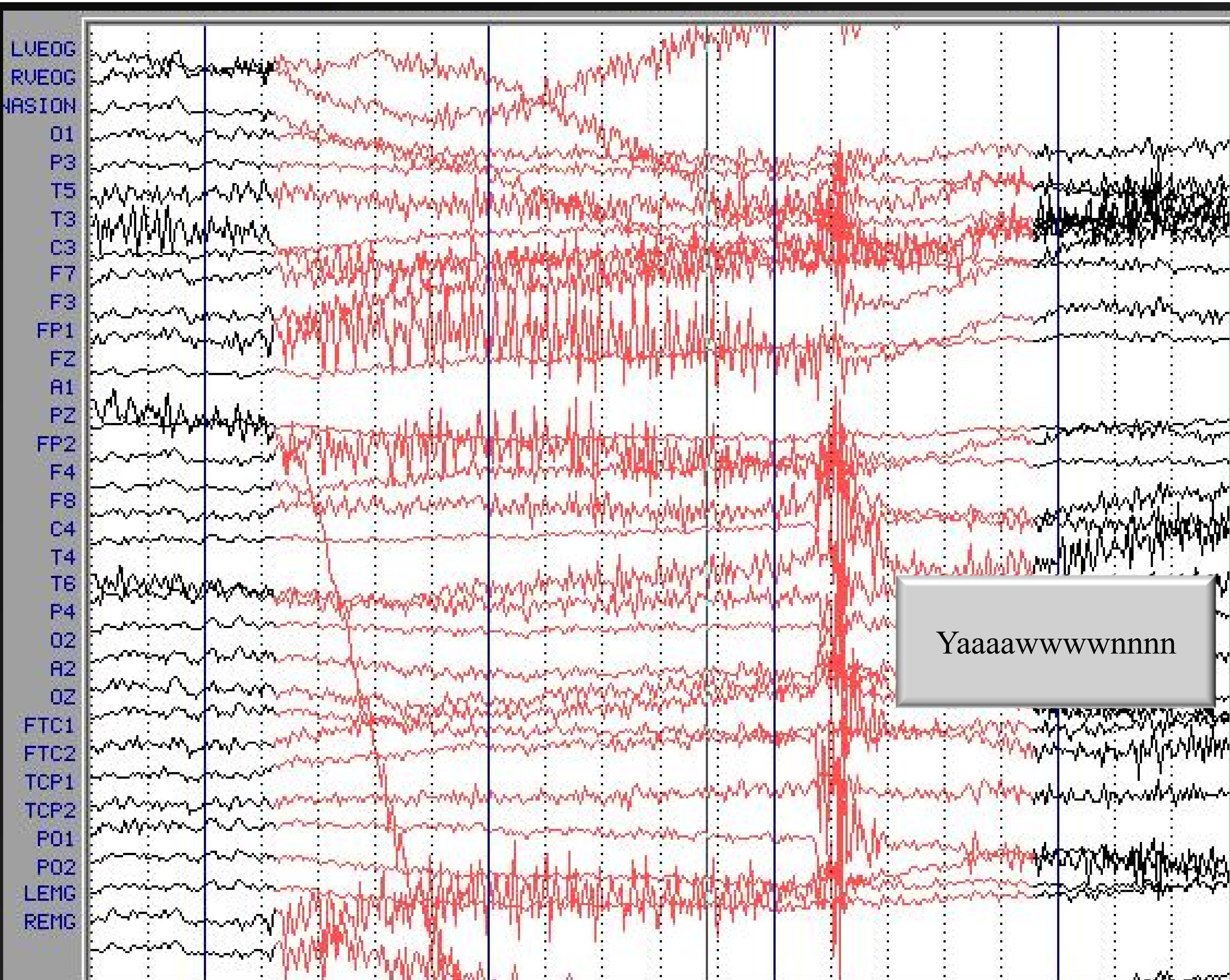

LVEOG
RVEOG
NASION
O1
P3
T5
T3
C3
F7
F3
FP1
FZ
A1
PZ
FP2
F4
F8
C4
T4
T6
P4
O2
A2
OZ
FTC1
FTC2
TCP1
TCP2
PO1
PO2
LEMG
REMG
SS
Chewing!

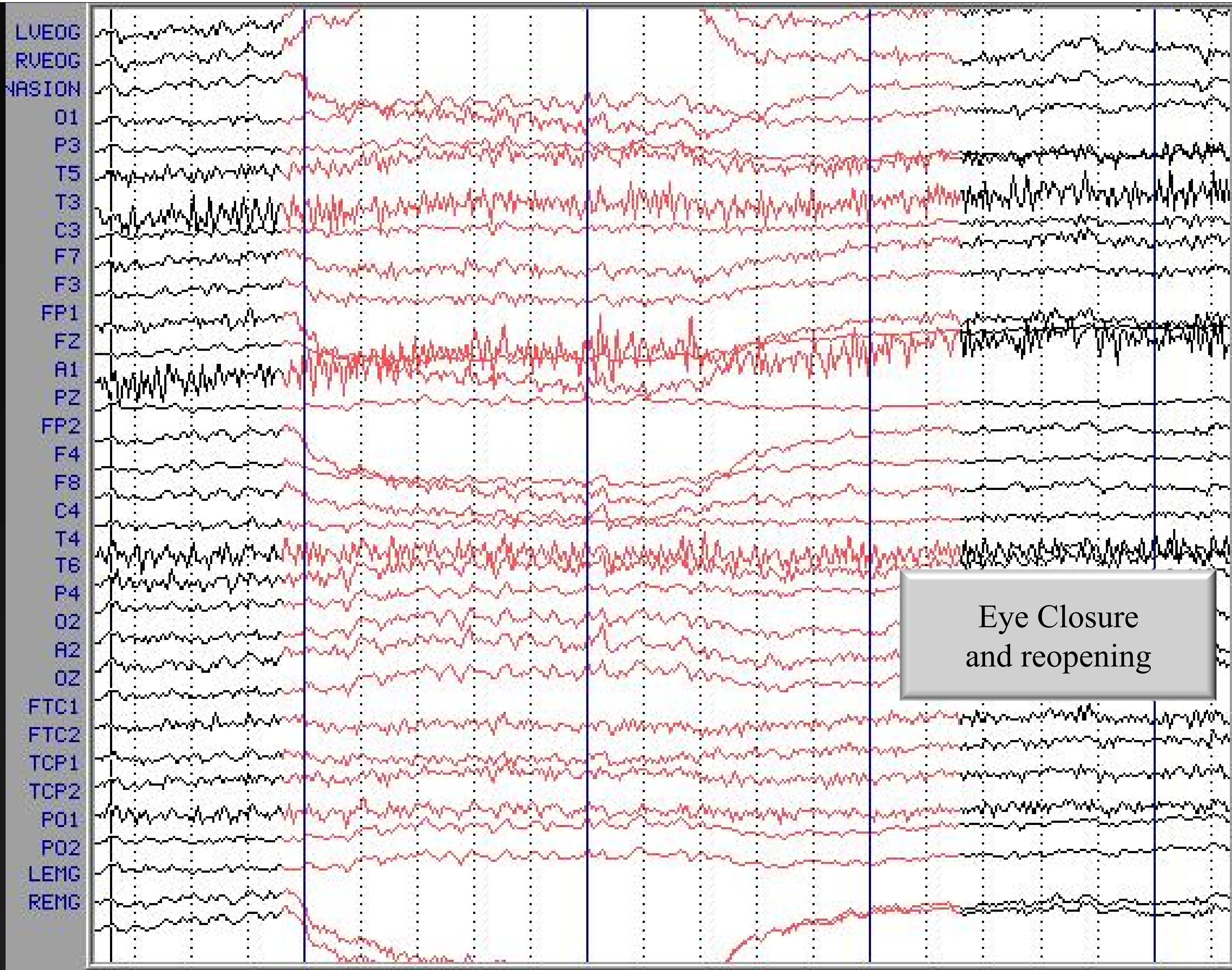

LVEOG
RVEOG
NASION
O1
P3
T5
T3
C3
F7
F3
FP1
FZ
A1
PZ
FP2
F4
F8
C4
T4
T6
P4
O2
A2
OZ
FTC1
FTC2
TCP1
TCP2
PO1
PO2
LEMG
REMG
Vertical Eye Roll

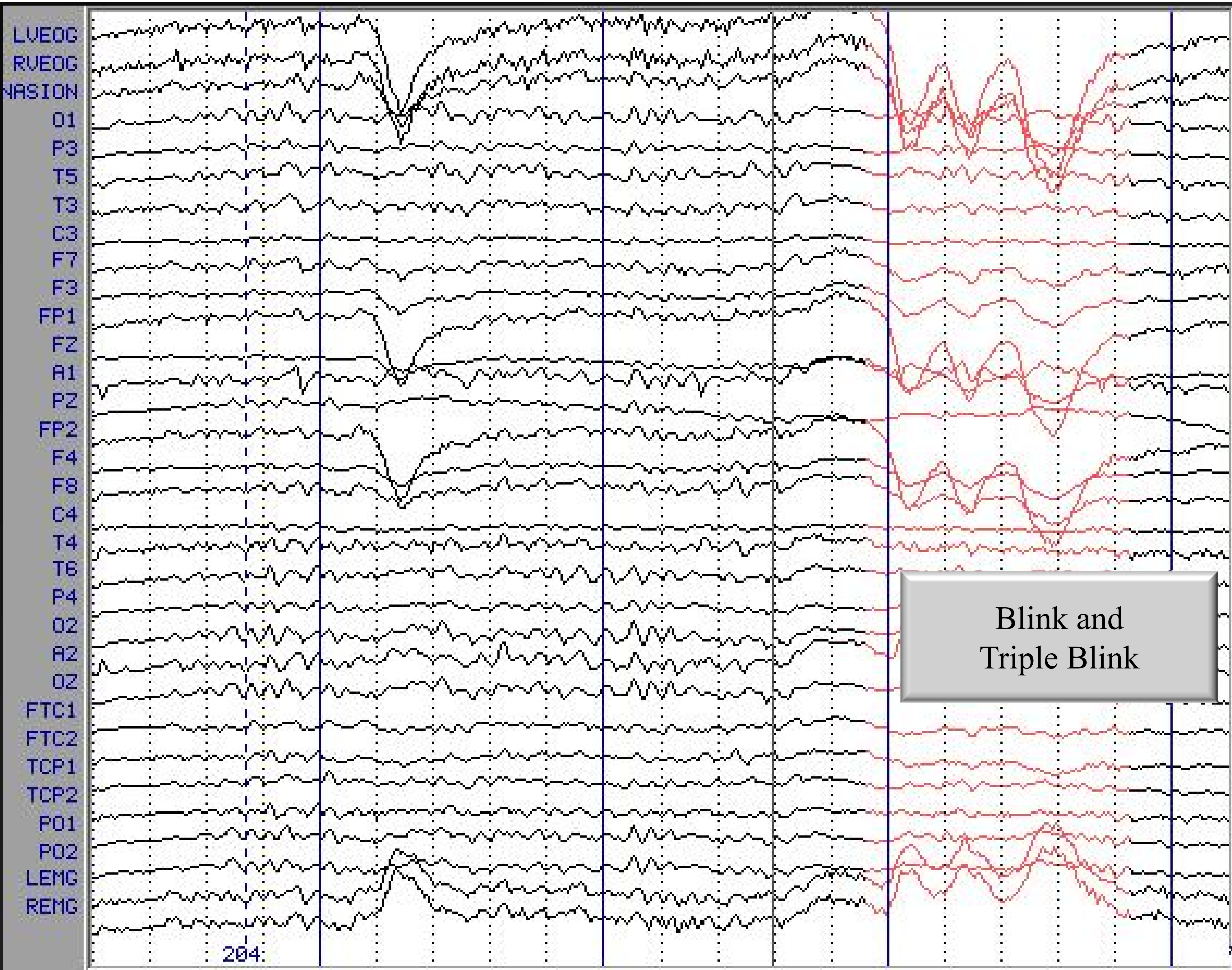

LVEOG
RVEOG
NASION
O1
P3
T5
T3
C3
F7
F3
FP1
FZ
A1
PZ
FP2
F4
F8
C4
T4
T6
P4
O2
A2
OZ
FTC1
FTC2
TCP1
TCP2
PO1
PO2
LEMG
REMG
Muscle Burst


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
SS
Smiling!


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
Talking and Moving Head


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
Yaaaawwwwnnnn


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
Eye Closure and reopening


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
204
Blink and
Triple Blink

AC Signal Recording Options

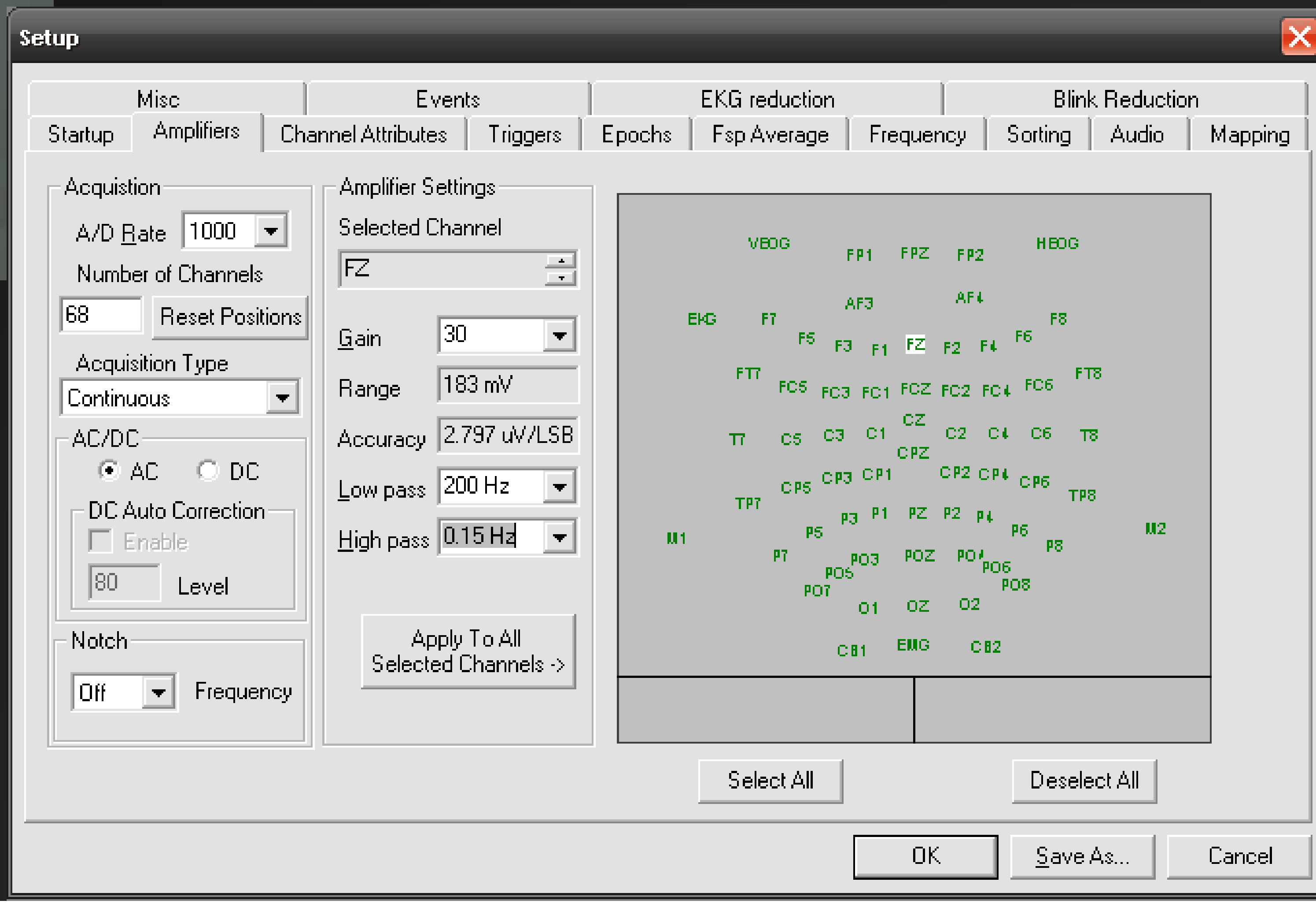
- Time Constant/HP filter
  - Low frequency cutoff is related to TC by:

$$F = \frac{1}{(2\pi(TC))}$$

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

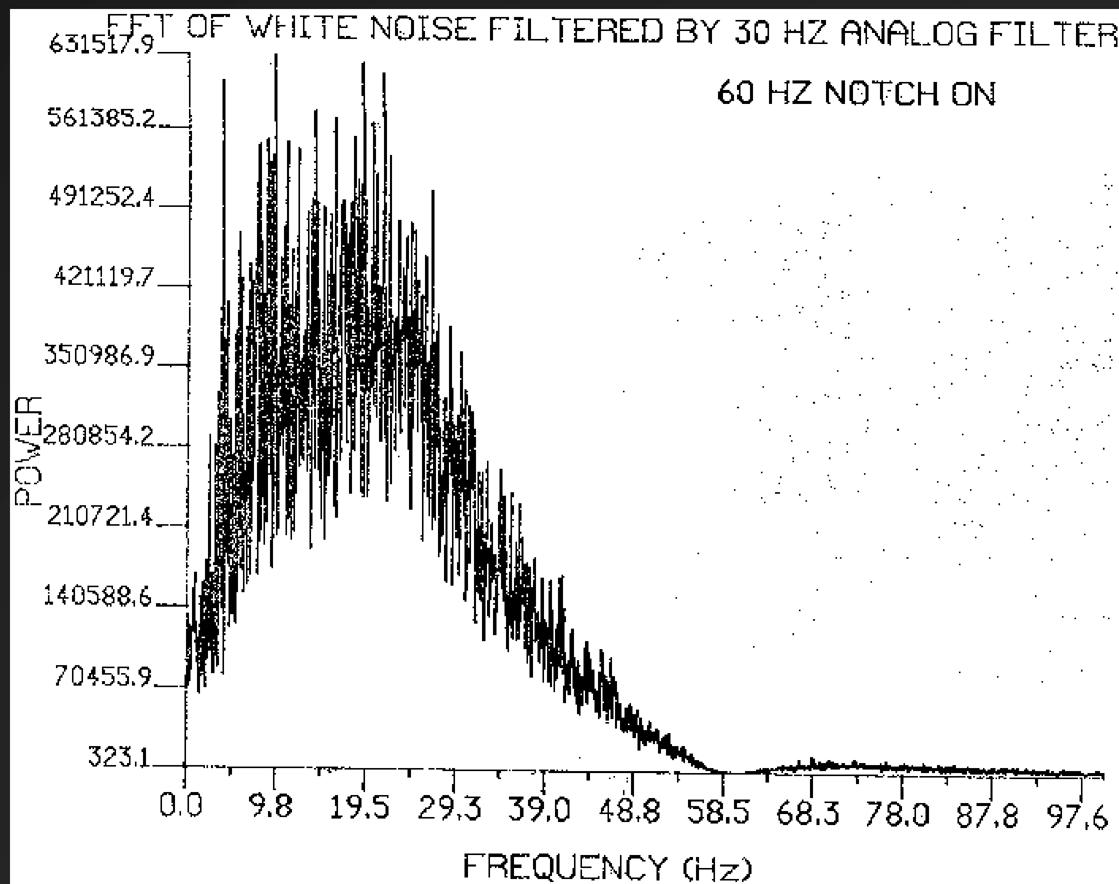
Applying formula:

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


Setup
Misc
Events
EKG reduction
Blink Reduction
Startup
Amplifiers
Channel Attributes
Triggers
Epochs
Fsp Average
Frequency
Sorting
Audio
Mapping
Acquisition
A/D Rate
1000
Number of Channels
68
Reset Positions
Acquisition Type
Continuous
AC/DC
AC
DC
DC Auto Correction
Enable
80
Level
Notch
Off
Frequency
Amplifier Settings
Selected Channel
FZ
Gain
30
Range
183 mV
Accuracy
2.797 uV/LSB
Low pass
200 Hz
High pass
0.15 Hz
Apply To All
Selected Channels ->
VEOG
FP1
FPZ
FP2
HEOG
AF3
AF4
EKG
F7
F8
F5
F3
F1
FZ
F2
F4
F6
FT7
FT8
FC5
FC3
FC1
FCZ
FC2
FC4
FC6
CZ
T7
C5
C3
C1
C2
C4
C6
T8
CPZ
CP3
CP1
CP2
CP4
CP6
CP5
TP7
TP8
P3
P1
PZ
P2
P4
M1
P5
P6
P8
M2
P7
PO3
POZ
PO4
PO6
PO5
PO7
PO8
O1
OZ
O2
CB1
EMG
CB2
Select All
Deselect All
OK
Save As...
Cancel

Hi Frequency/LP Settings

- Do not eliminate frequencies of interest
- Polygraphs 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 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)

SOUND RECORDING

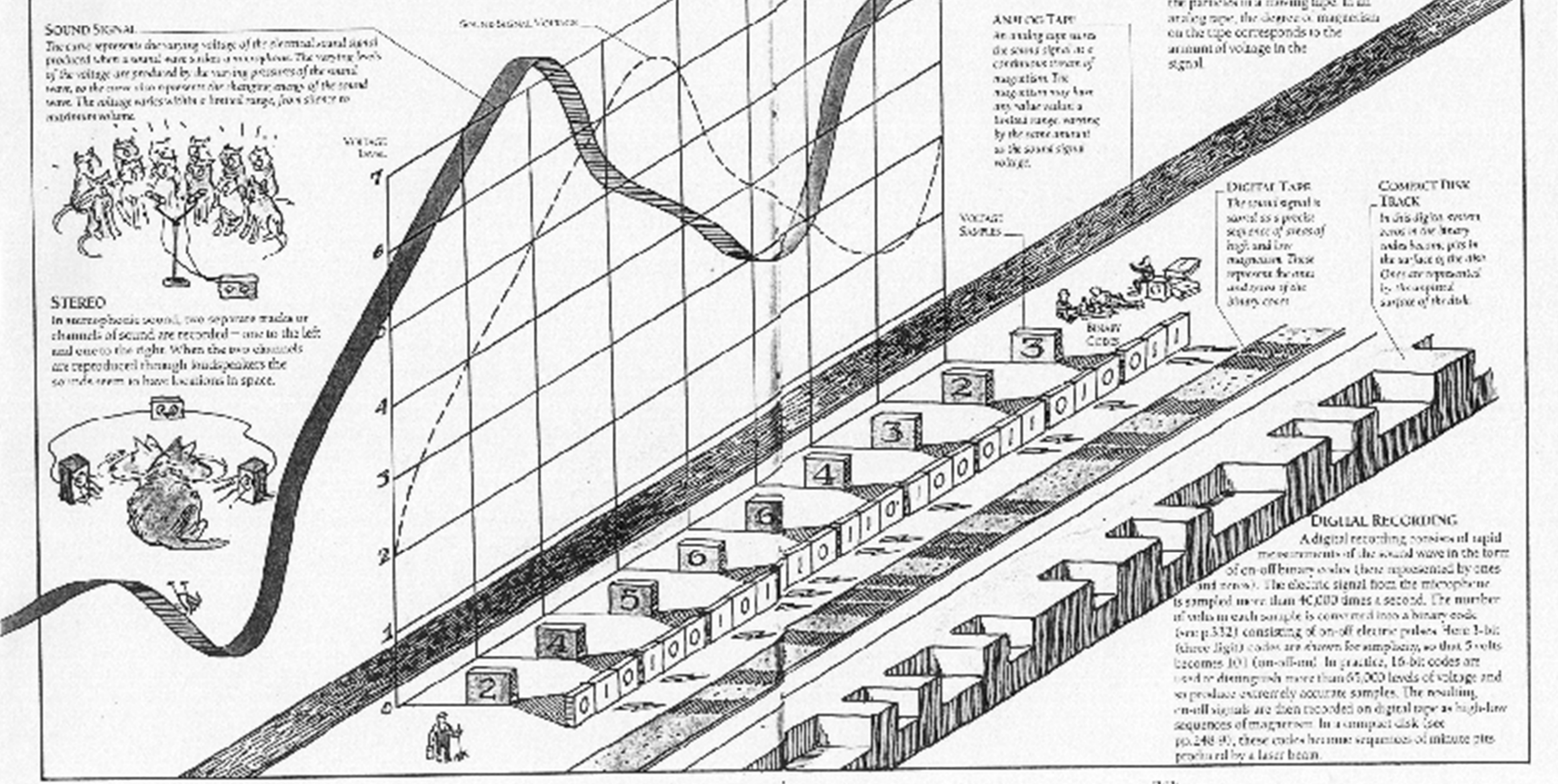
There are two basic methods of recording voices and music – analog and digital. In analog recording, the recording medium varies continuously in a way that is similar to or analogous to the incoming signal. In digital recording, the signal is sampled electronically and recorded as a rapid sequence of separate coded measurements. Both analog and digital recording preserve the varying voltage of the sound signal produced by a microphone, but of the two, digital recording is the more accurate. In addition, a certain amount of electrical noise or hiss always enters the recording process. Digital recording is insensitive to this noise, whereas analog recording requires noise reduction systems.

SOUND SIGNAL

The curve represents the varying voltage of the electrical sound signal produced when a sound wave strikes a microphone. The varying levels of the voltage are produced by the varying pressures of the sound wave, so the curve also represents the changing energy of the sound wave. The voltage varies within a limited range, from silence to maximum volume.

STEREO

In stereophonic sound, two separate tracks or channels of sound are recorded – one to the left and one to the right. When the two channels are reproduced through loudspeakers the sounds seem to have locations in space.



ANALOG RECORDING

In an analog recording, the varying voltage of the electric signal from the microphone is changed into another quantity that varies by the same amount. In a tape recording, the signal goes to a record head that magnetizes the particles in a moving tape. In an analog tape, the degree of magnetism on the tape corresponds to the amount of voltage in the signal.

ANALOG TAPE

An analog tape stores the sound signal as a continuous stream of magnetism. The magnetism may have any value within a limited range, varying by the same amount as the sound signal voltage.

DIGITAL TAPE

The sound signal is stored as a precise sequence of areas of high and low magnetism. These represent the ones and zeros of the binary codes.

COMPACT DISK TRACK

In this digital system, zeros in the binary codes become pits in the surface of the disk. Ones are represented by the original surface of the disk.

DIGITAL RECORDING

A digital recording consists of rapid measurements of the sound wave in the form of on-off binary codes (here represented by ones and zeros). The electric signal from the microphone is sampled more than 40,000 times a second. The number of volts in each sample is converted into a binary code (see p.332) consisting of on-off electric pulses. Here 3-bit (three digit) codes are shown for simplicity, so that 5 volts becomes 101 (on-off-on). In practice, 16-bit codes are used to distinguish more than 65,000 levels of voltage and so produce extremely accurate samples. The resulting on-off signals are then recorded on digital tape as high-low sequences of magnetism. In a compact disk (see pp.248-9), these codes become sequences of minute pits produced by a laser beam.