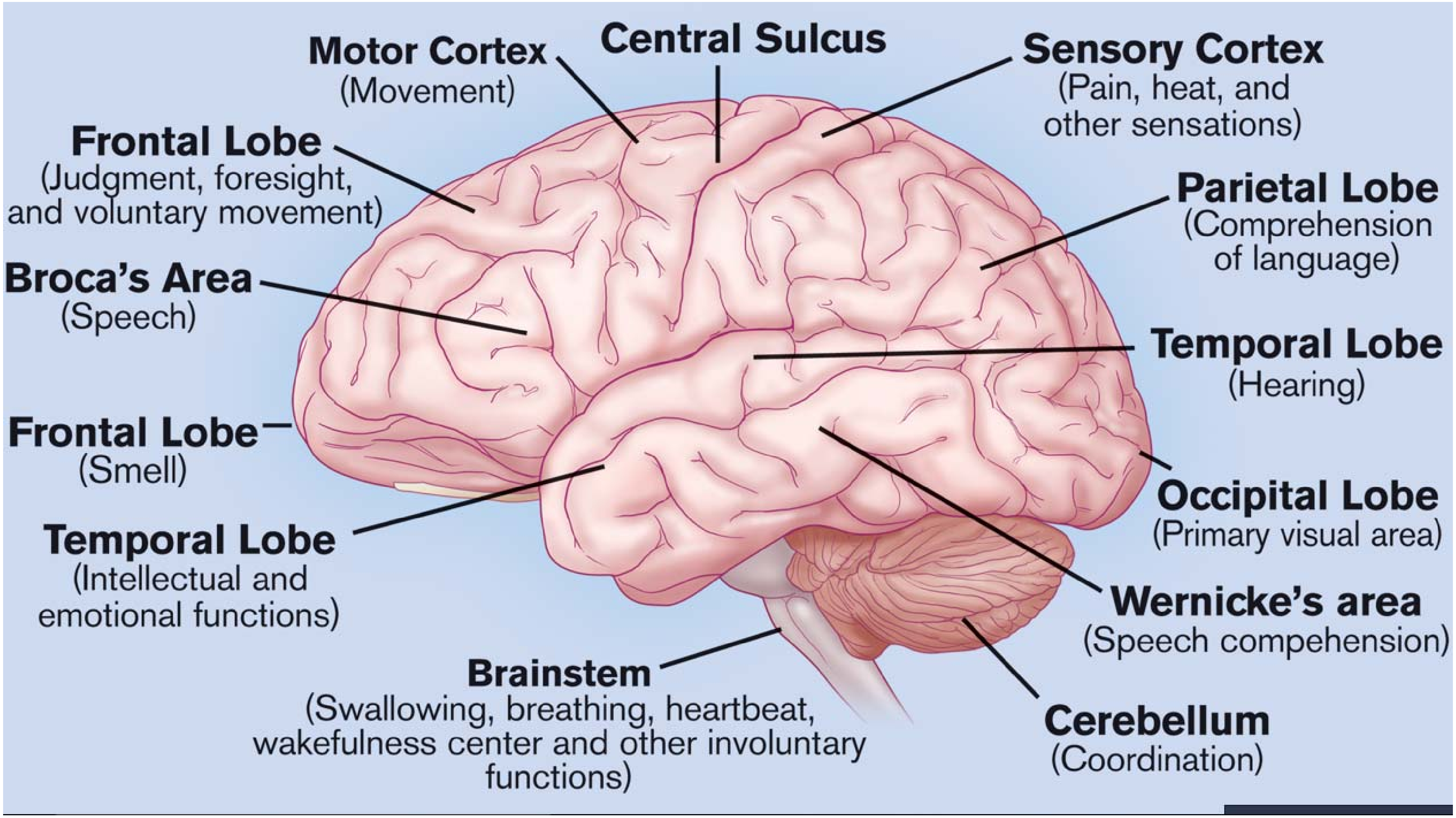
EE 4BD4 Lecture 11

The Brain and EEG

Brain Wave Recordings

- Recorded extra-cellularly from scalp (EEG)
- Recorded from extra-cellularly from surface of cortex (ECOG)
- Recorded extra-cellularly from deep structures (electroneurogram)

Brain Features



Cortical Fibres

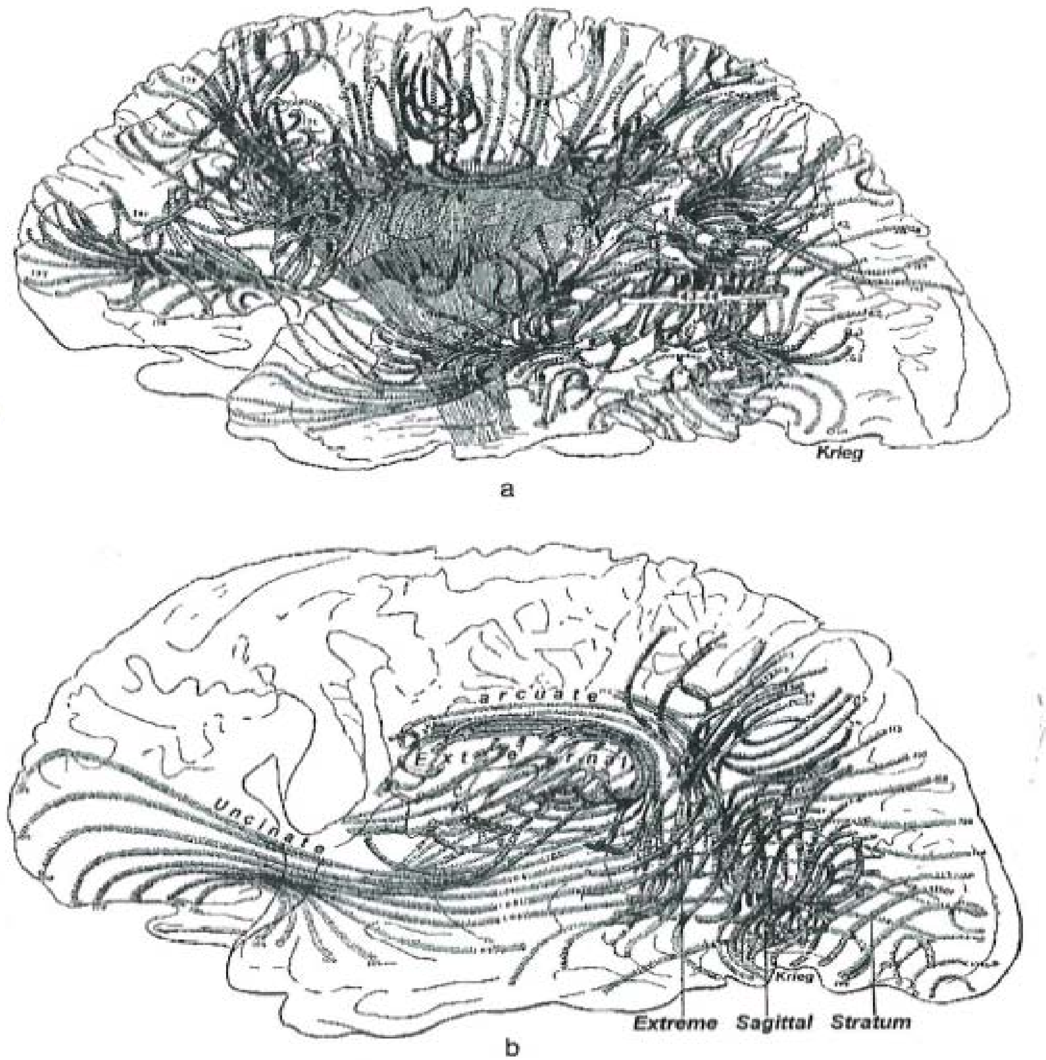


Figure 1-2 (a) Some of the superficial corticocortical fibers of the lateral aspect of the cerebrum obtained by dissection. (b) A few of the deeper corticocortical fibers of the lateral aspect of the cerebrum. The total number of corticocortical fibers is roughly 10^{10}, that is, for every fiber shown here, about 100 million are not shown. Reproduced with permission from Krieg (1963, 1973).

Overview (EEG)

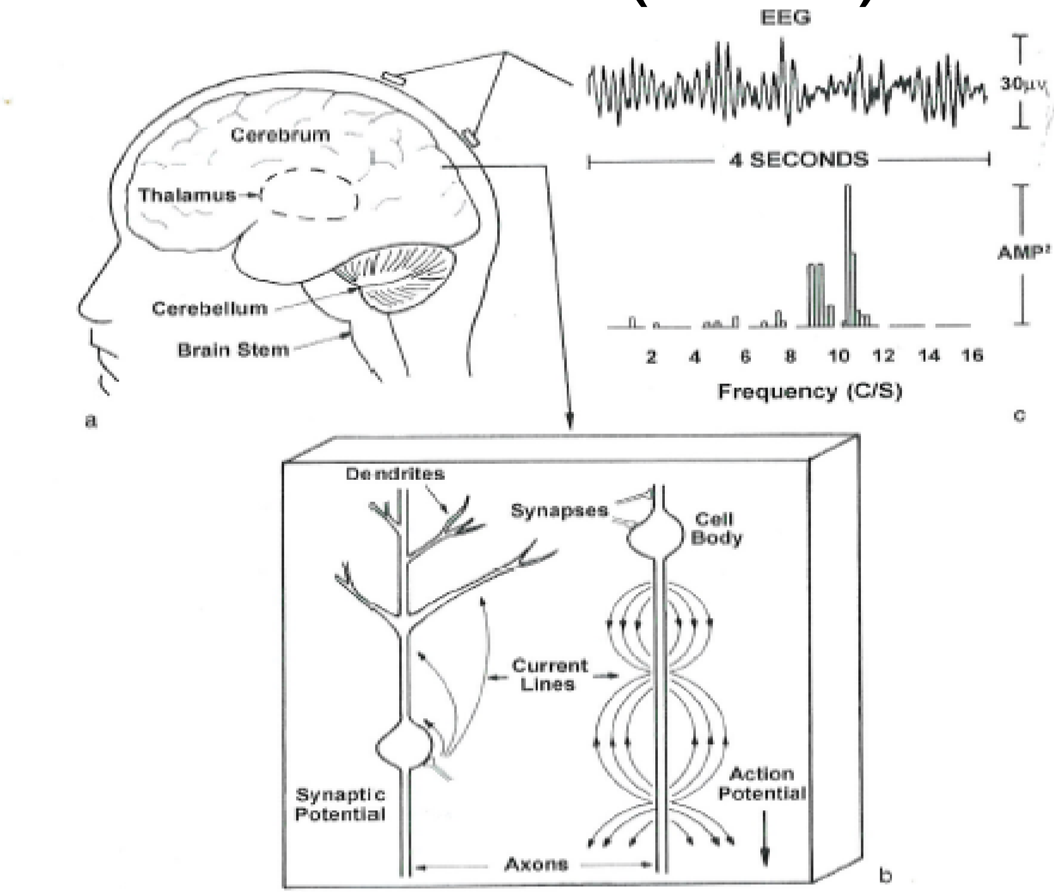


Figure 1-1 (a) The human brain. (b) Section of cerebral cortex showing microcurrent sources due to synaptic and action potentials. Neurons are actually much more closely packed than shown, about 10^5 neurons per mm^2 of surface. (c) Each scalp EEG electrode records space averages over many square centimeters of cortical sources. A four-second epoch of alpha rhythm and its corresponding power spectrum are shown.

Cortical Contributions

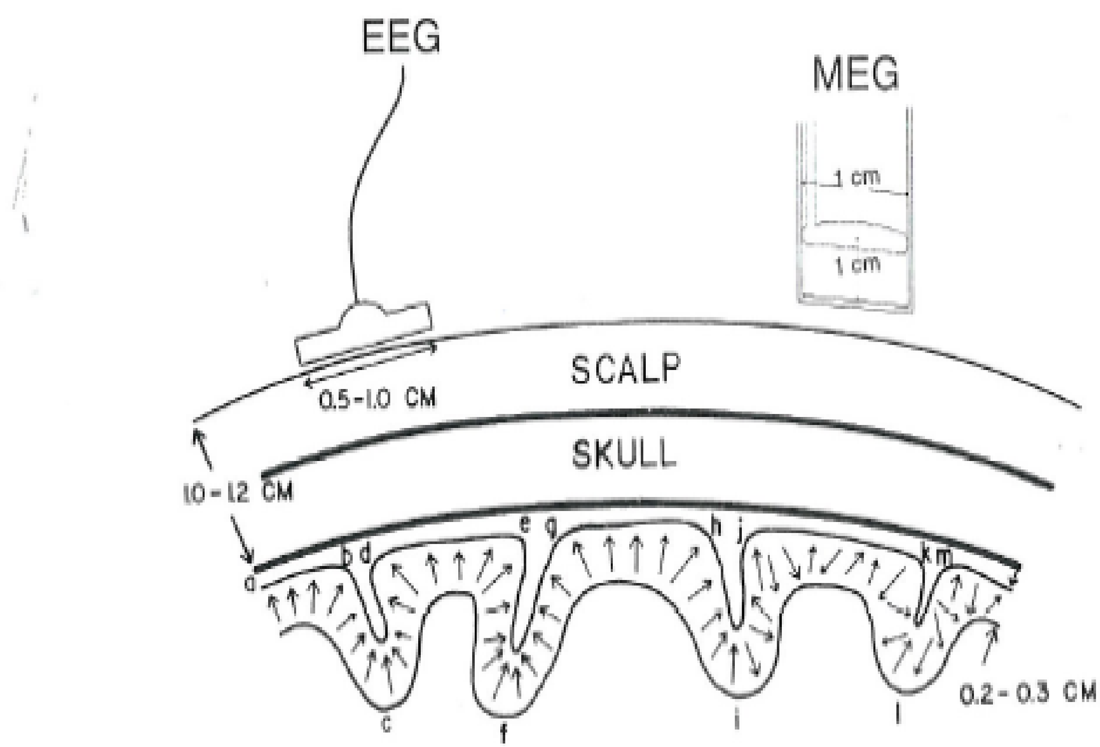
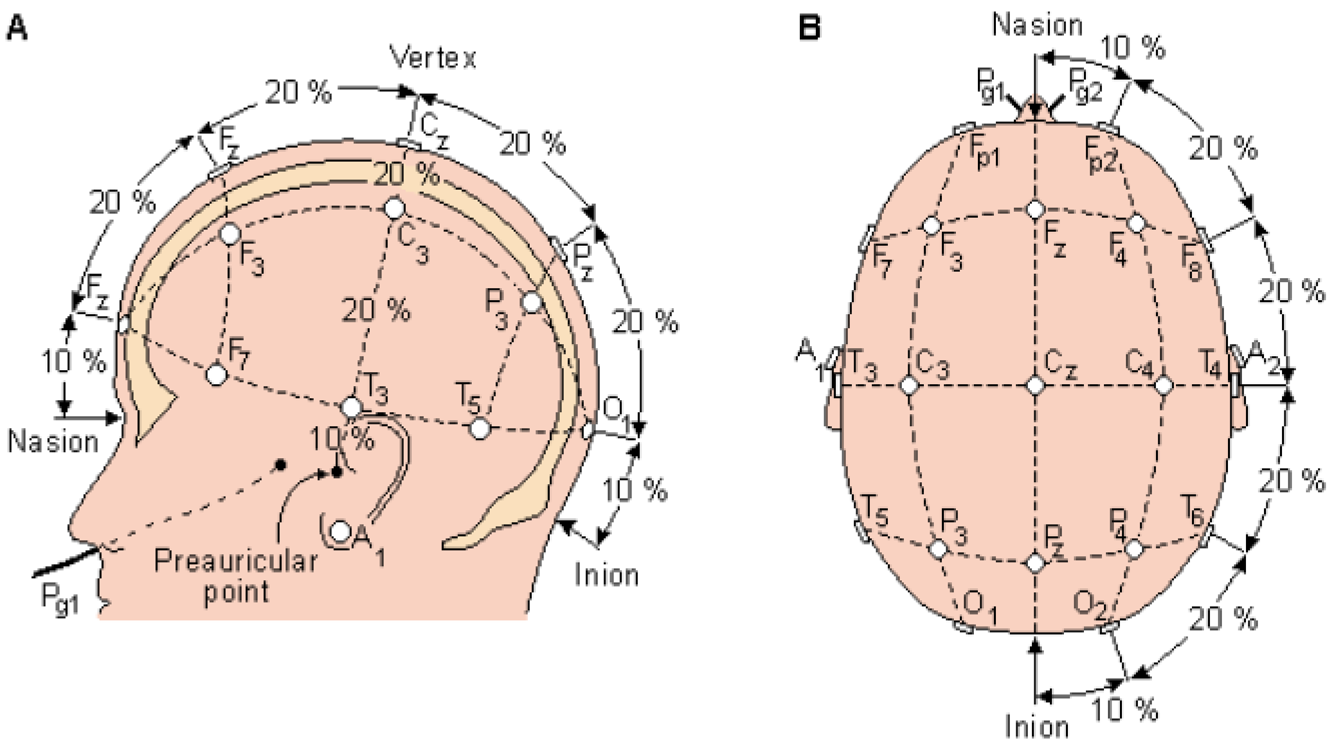


Figure 2-3 Neocortical sources can be generally pictured as *dipole layers* (or "dipole sheets," in and out of cortical fissures and sulci) with mesosource strength varying as a function of cortical location. EEG is most sensitive to correlated dipole layer in gyri (regions ab, de, gh), less sensitive to correlated dipole layer in sulcus (region hi), and insensitive to opposing dipole layer in sulci (regions bcd, efg) and random layer (region ijklm). MEG is most sensitive to correlated and minimally apposed dipole layer (hi) and much less sensitive to all other sources shown, which are opposing, random, or radial dipoles. Modified version reproduced with permission from Nunez (1995).

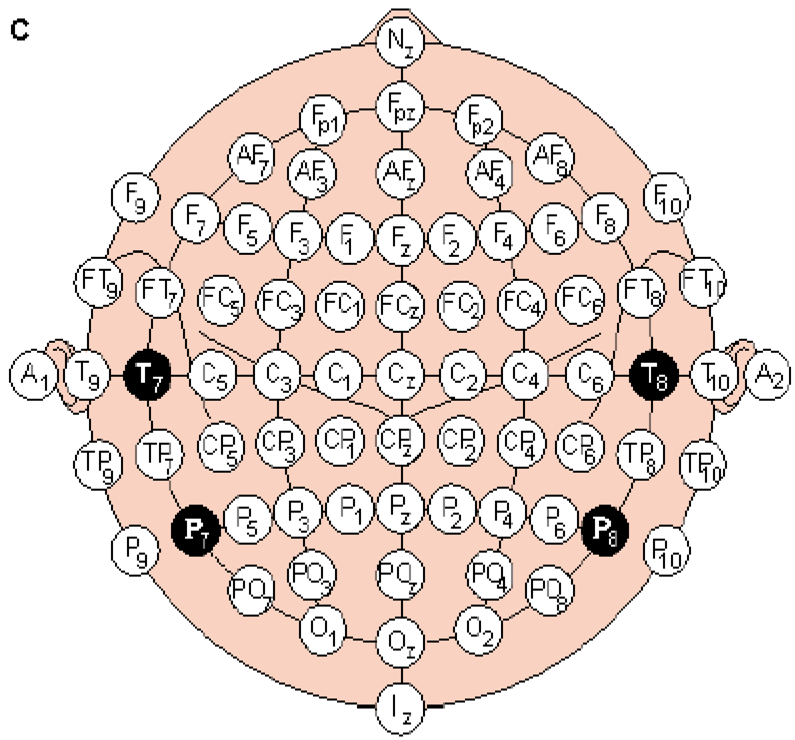
Electrode Placement

10 – 20 EEG Electrode placement

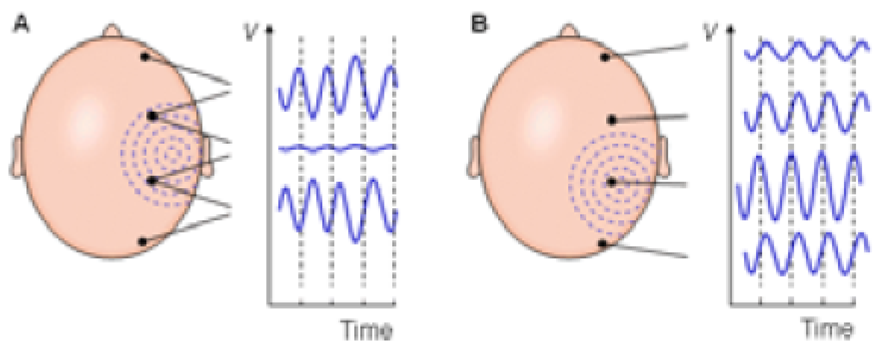


10% EEG Electrode placement

c



EEG Recording modes



- A) bipolar recordings
- B) unipolar recordings

Amplifier Connections

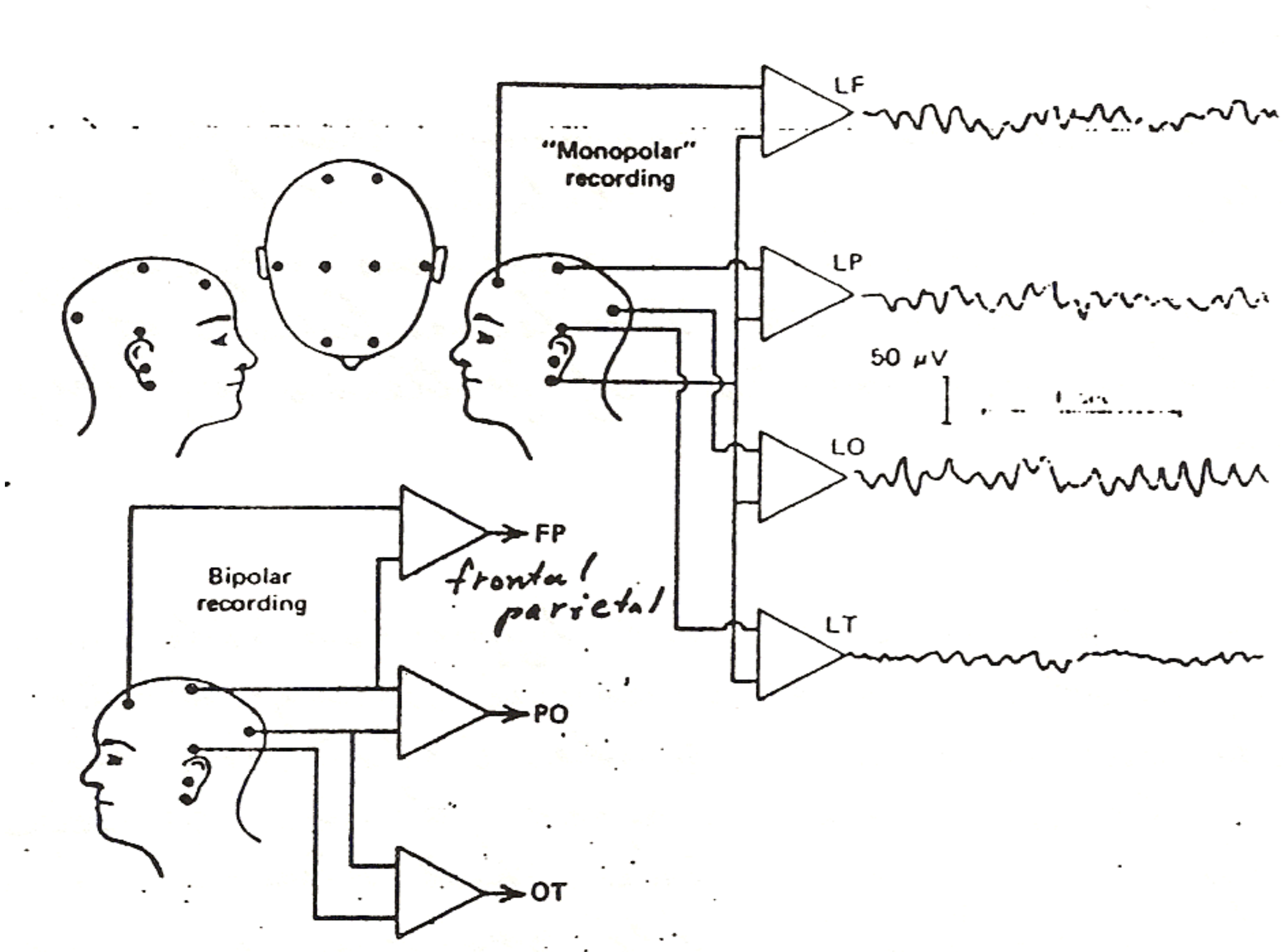
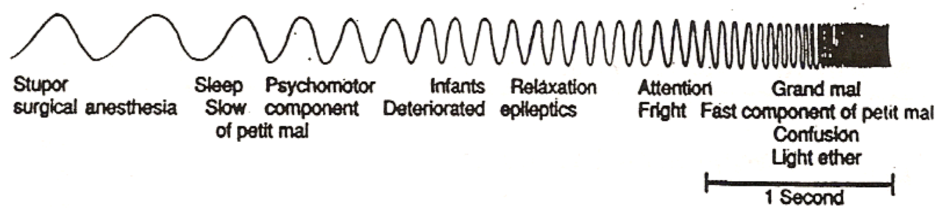


Figure 11-52. Method of connecting the recording channels for "monopolar" and bipolar recording. With "monopolar" recording, the reference electrode is on the earlobe, chin, or neck

Clinical Applications (Spontaneous EEG)

Figure 59–3. Effect of varying degrees of cerebral activity on the basic rhythm of the electroencephalogram. (From Gibbs and Gibbs: Atlas of Electroencephalography, 2nd Ed. Vol. I. Reading, Mass., Addison-Wesley, 1974. Reprinted by permission.)



- Identify presence of lesions (historical)
- Diagnosis and monitoring of epilepsy (seizures)
- Sleep staging
- Estimation of depth of anesthesia
- Other organic brain disease
- Neuropsychiatry (depression, schizophrenia, Altzheimer)

Alpha Predominance

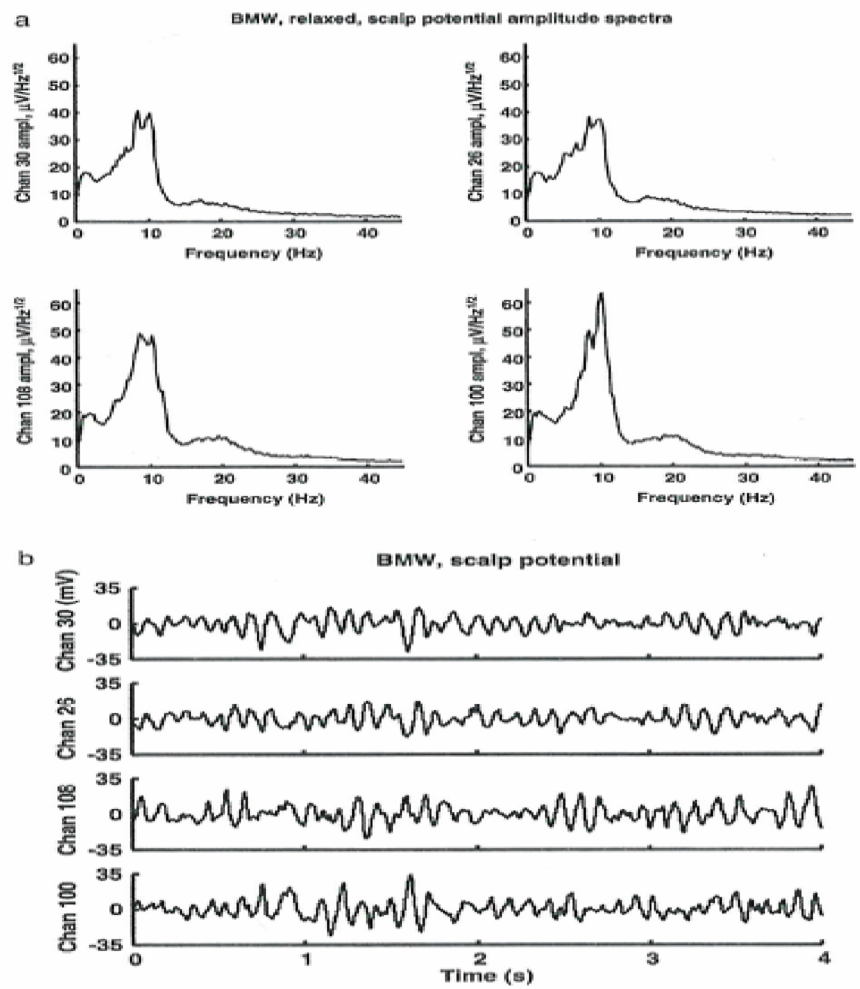


Figure 1-4 (b) Alpha rhythm recorded from a healthy 25-year-old relaxed male with eyes closed using a neck electrode as reference. Four seconds of data are shown from four scalp locations (left frontal-30; right frontal-26; left posterior-108; right posterior-100). Amplitudes are given in μV. (a) Amplitude spectra for the same alpha rhythms shown in (b) but based on the full five-minute record to obtain accurate spectral estimates. Amplitudes are given in μV per root Hz. Frequency resolution is 0.25 Hz. The double peak in the alpha band represents oscillations near 8.5 and 10.0 Hz. These lower and upper alpha band frequencies have different spatial properties and behave differently during cognitive tasks as shown in chapter 10.

General Bandwidths

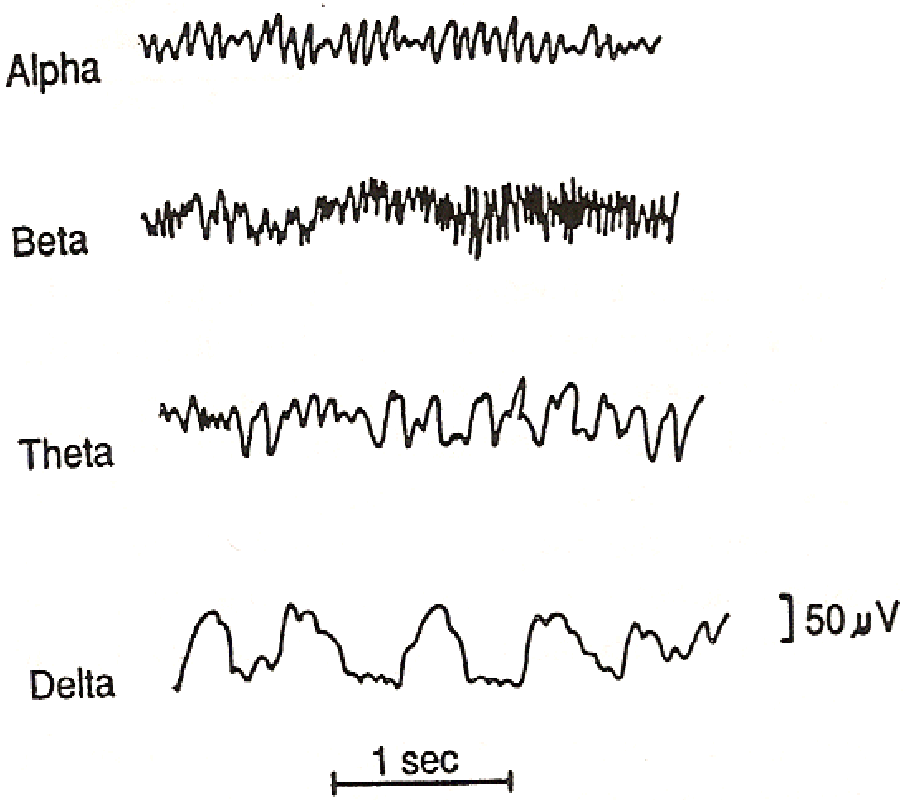


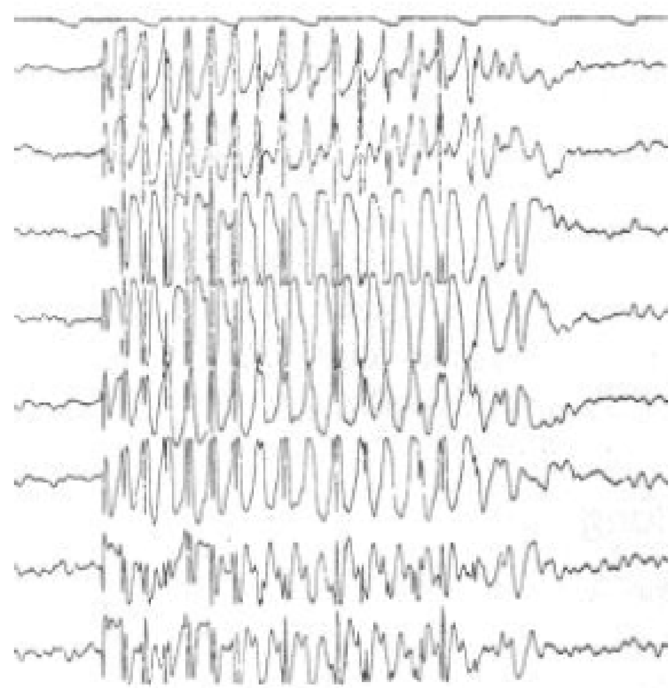
Figure 59–1. Different types of normal electroencephalographic waves.

Table 11-3 EEG Waveform Terminology

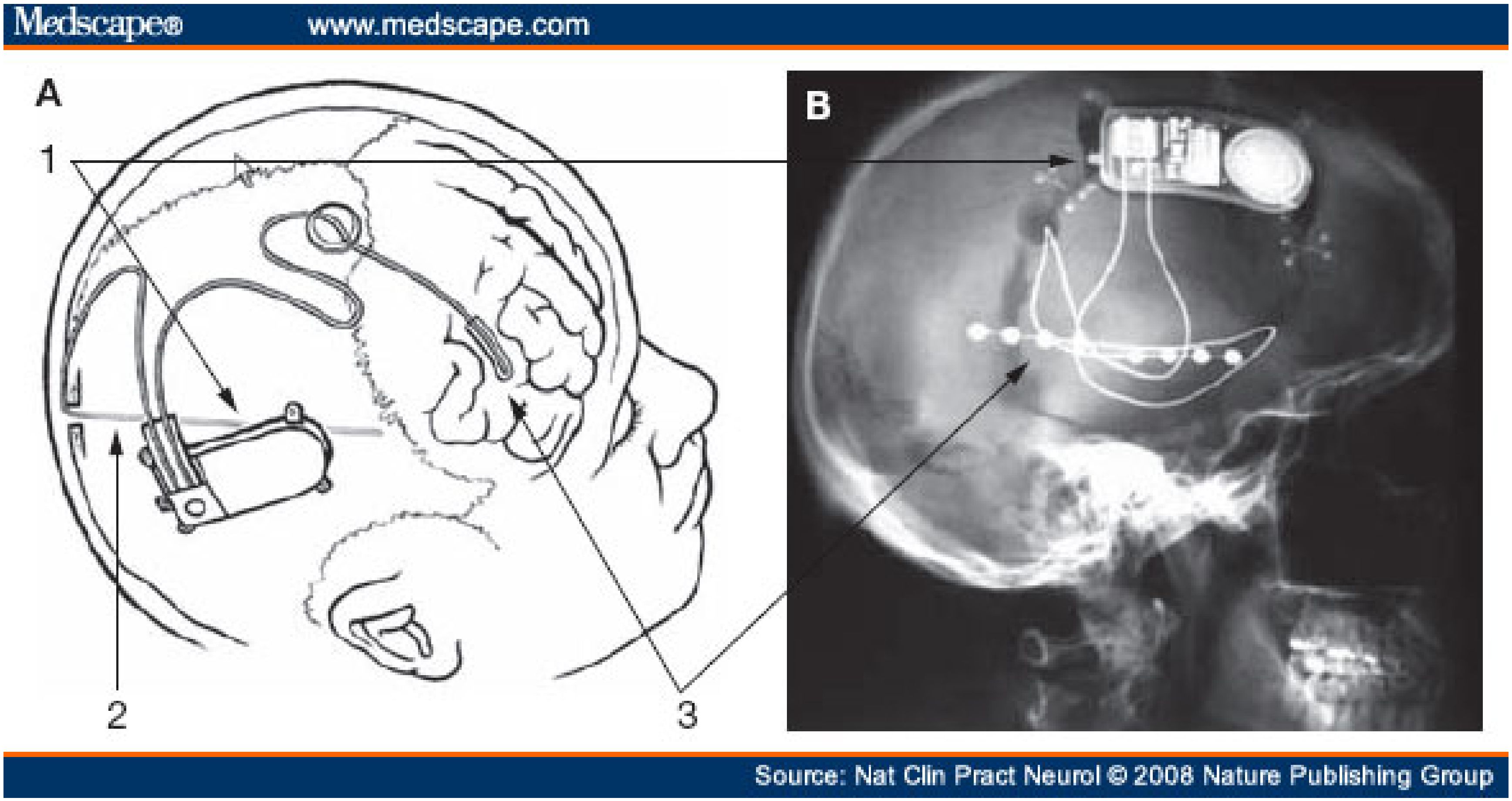
Waveform	Frequency (Hz)	Remarks
Alpha rhythm	8–12	Parietal-occipital; associated with the awake and relaxed subject; prominent with eyes closed
Beta rhythm low voltage	18–30	More evident in frontal-parietal leads; seen best when alpha is blocked
Delta	1–3.5	Associated with normal sleep and present in children less than 1 year old; also seen in organic brain disease
Theta	4–7	Parietal-temporal; prominent in children 2 to 5 years old

Abnormal Rythms

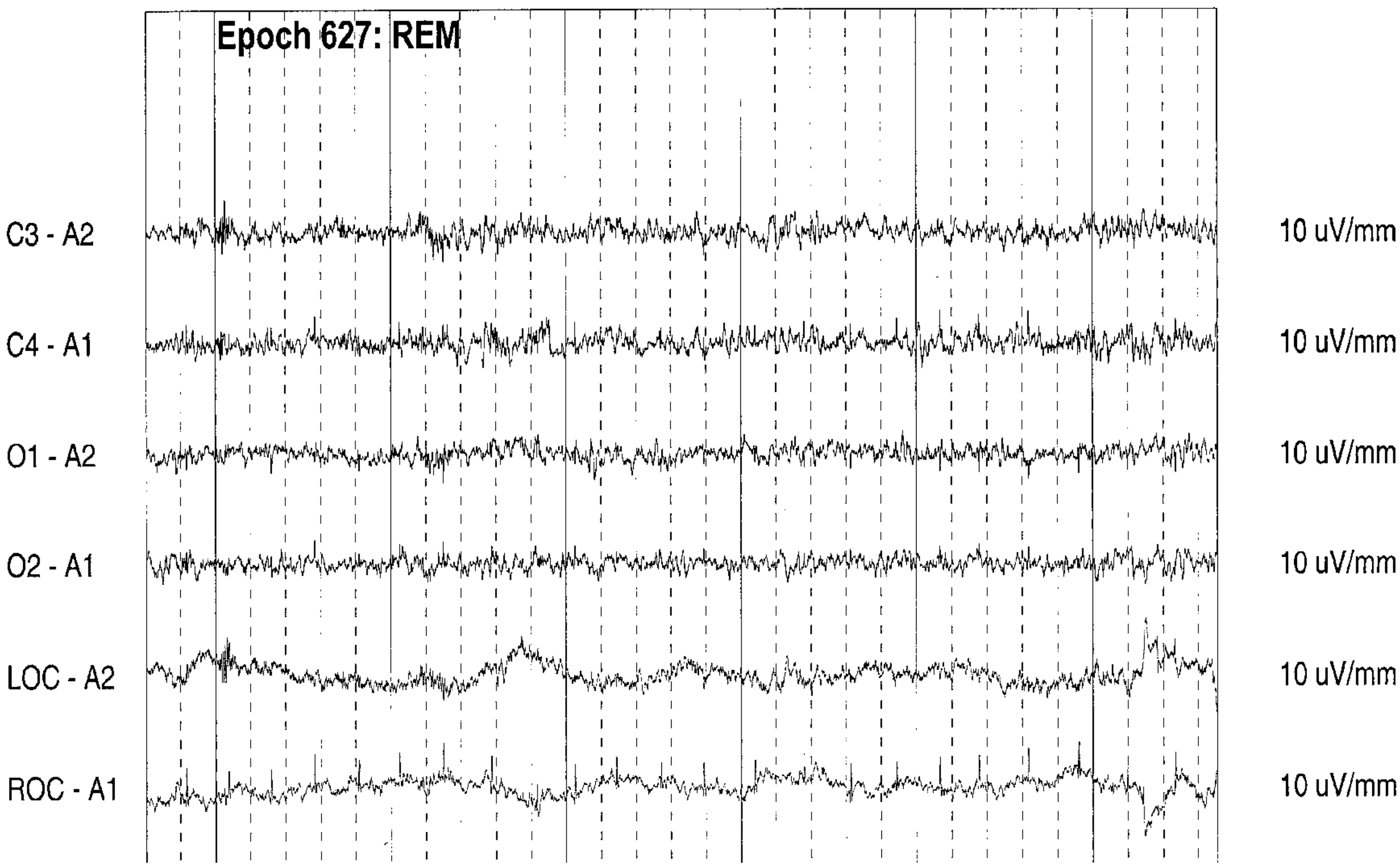
- Spikes
  - response to stimuli
  - Epileptic seizures
  - higher frequency content
  - Up to 100 Hz



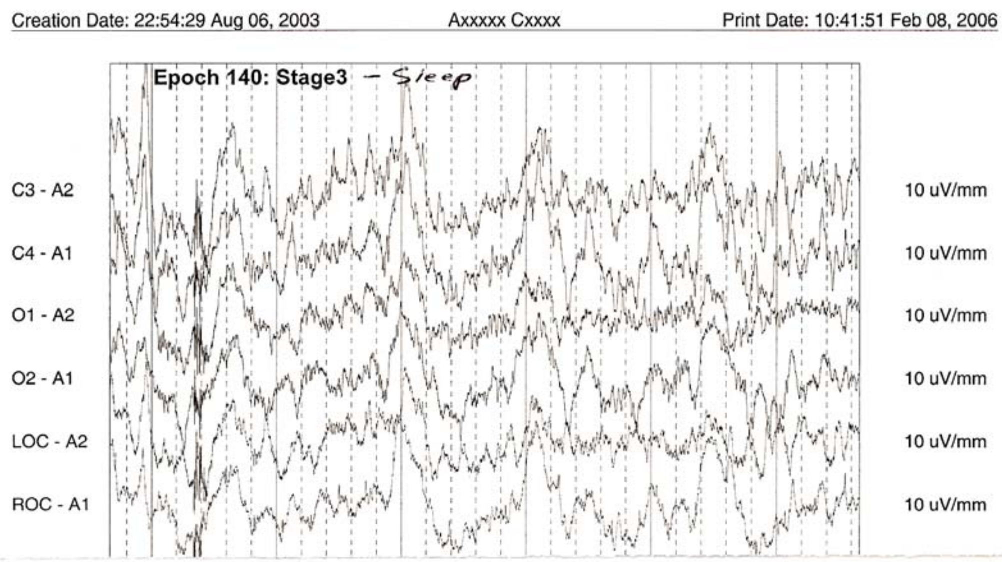
Closed Loop Epilepsy Treatment



EEG during REM Sleep



EEG during Stage 3 Sleep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Axxxxx Cxxxx
Print Date: 10:41:51 Feb 08, 2006
Epoch 140: Stage3 – Sleep
C3 - A2
C4 - A1
O1 - A2
O2 - A1
LOC - A2
ROC - A1
10 uV/mm
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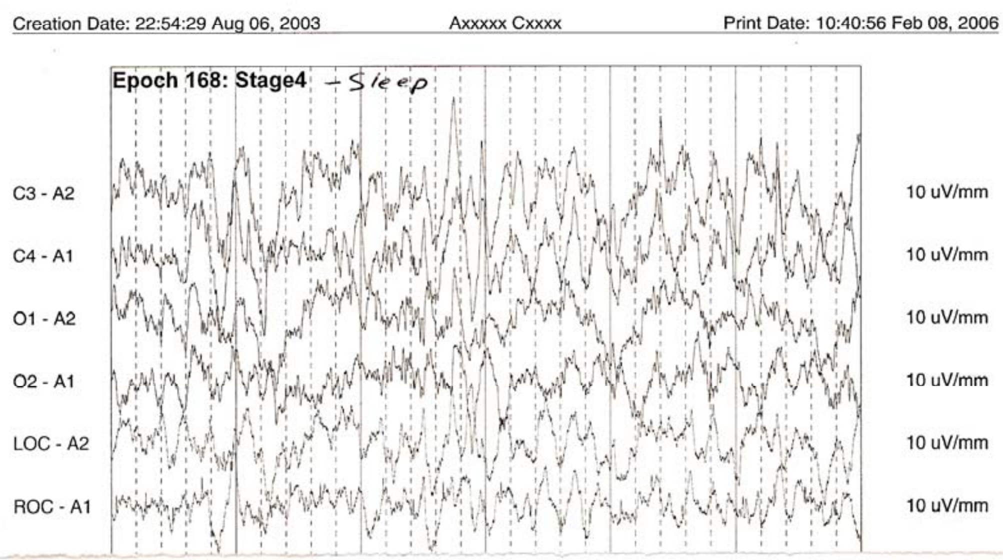
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Epoch 168: Stage4 – Sleep
C3 - A2
C4 - A1
O1 - A2
O2 - A1
LOC - A2
ROC - A1
10 uV/mm
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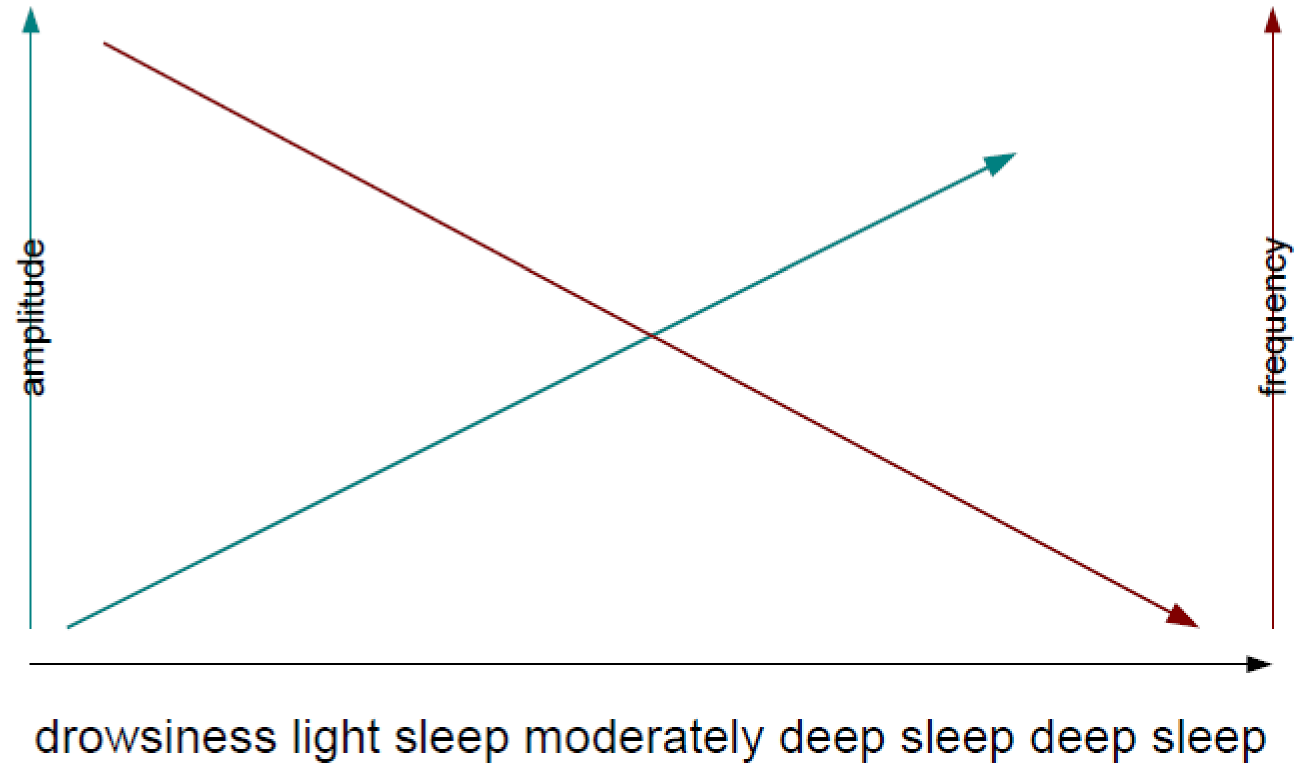
10 uV/mm

Applications of EEG
Sleep patterns analysis

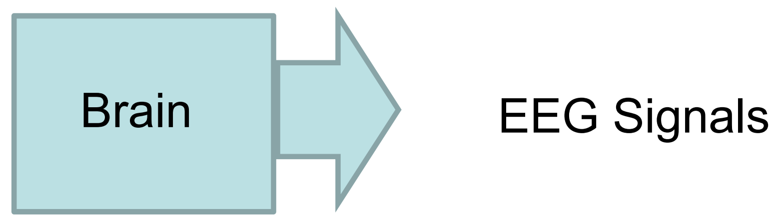


Additional Sleep Data Processing

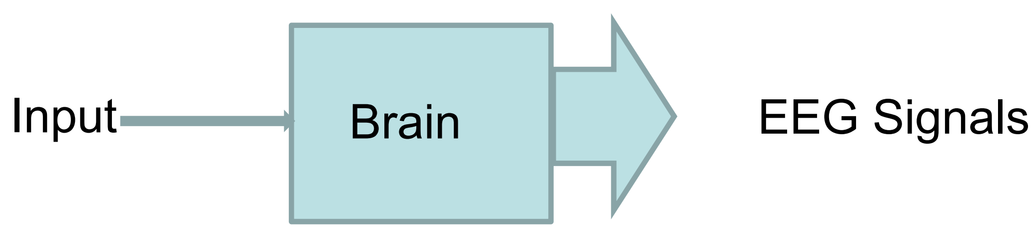
- Sleep spindles (modulated alpha periods) and K complexes in Stage 1 – 2
- Degree of correlation (time base) or coherence (frequency base) between different channels of EEG increases with depth of sleep.
- Higher level signal processing?
- Relate EEG to other recorded data (e.g. respiration rate, heart rate, SaO_2

Brain Evoked Potentials

- These are special applications of the EEG signal and are not limited to the usual bandwidth (1 – 40 Hz) of the quiet subject. In engineering terms ambient EEG is just the output of a system with no specific input.



- Evoked or event related potentials are the more common engineering approach when you determine the characteristics or transfer function of system by driving it with a known input, e.g. a sensory input to the brain.



Brain Stem Auditory Evoked Potential

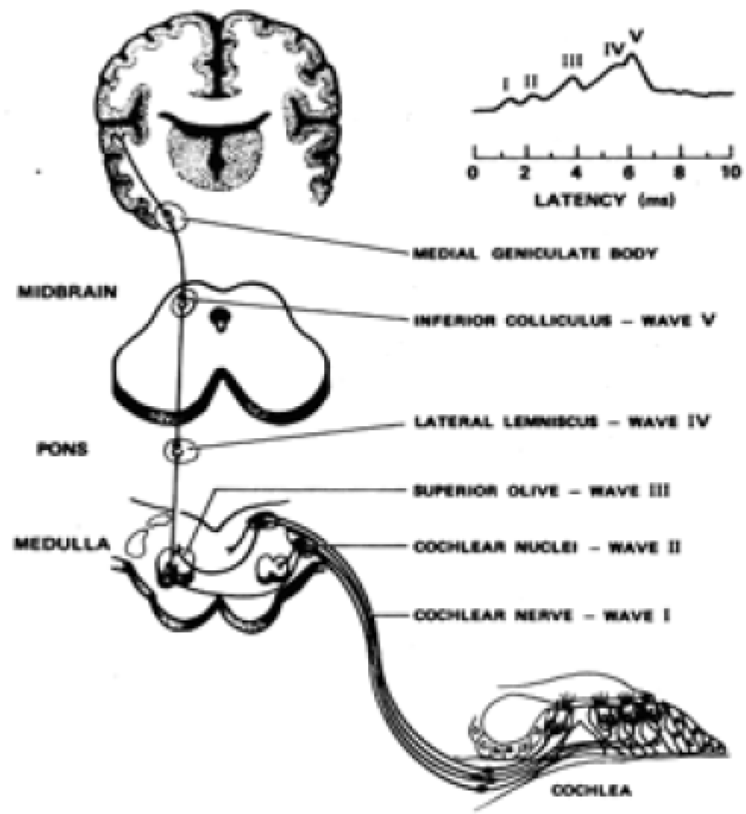
BSAEP Signal Pathway

- Measure the brain wave activity that occurs in response to clicks

  or certain tones.

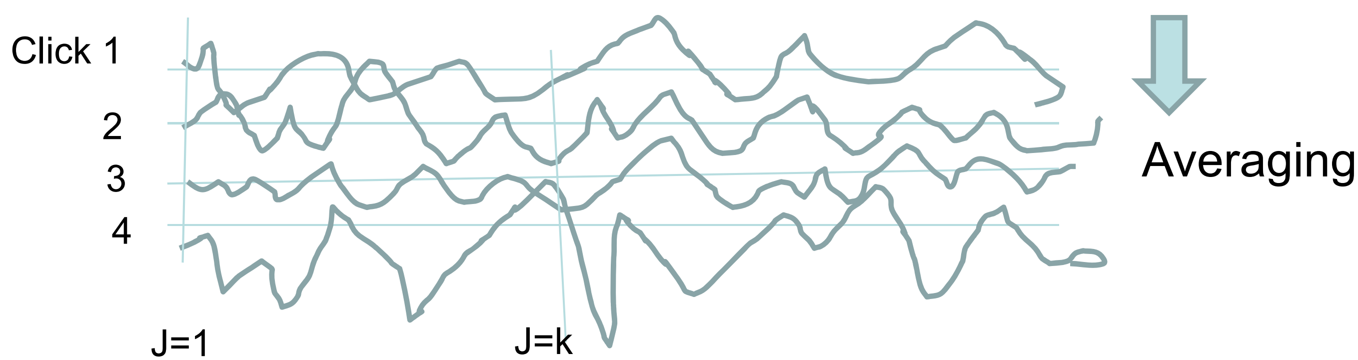
- Normal evoked

  response ->



Computer Processing of BSAEP

- Clicks are sent to the ear at a selected db level at 10 Hz rate
- Each click causes a response in the auditory pathway. The sequence of responses, y_i ,are recorded by the electrode at the vertex (top of the head) with low amplitude because brainstem and upper spinal cord are deep in the head. The evoked responses are in 100`s of nV to μV range with Bandwidth 100 to 2500 Hz



Synchronous Averaging

- Signal $y_i = s_i + n_i$ where s_i is the desired brain response (constant or deterministic) and n_i is the added noise for the i^{th} click. s_i is the same for every click while n_i is random from click to click and not correlated to the s_i
- $y_{i,j}$ is the j^{th} sample for the i^{th} response = $s_{i,j} + n_{i,j}$ with sample rate typically 50 KHz
- Averaging $\sum_{i=1}^{n} y_{i,j} = \sum_{i=1}^{n} s_{i,j} + \sum_{i=1}^{n} n_{i,j}$
- Since $s_{i,j}$ is deterministic and constant for any i, and $n_{i,j}$ is random for any i with mean = 0
- $\sum_{i=1}^{n} s_{i,j} = ns_j$ and $\sum_{i=1}^{n} n_{i,j} \rightarrow 0$, $\sum_{i=1}^{n} y_{i,j} \rightarrow ns_j$
- To get the desired signal average by n
- Note: No assumption was made about the noise or its distribution, so this technique works for all types of noise that is random and uncorrelated with the evoked response that is deterministic
-

Synchronous Averaging (cont`d)

- This a very reliable method of noise reduction but is not efficient. For the BSAEP with noisy amplifiers, the clinical standard is 2048 clicks, but that allows one to analyze signals < 1 µV
- If the noise has a Gaussian distribution, SNR improves with $\sqrt{n}$, i.e increases by a factor of ≈ 45
- If a noise spike occurs such as for movement or a muscle twitch, the amplitude of some samples in y_i will be several orders of magnitude larger than the background noise, requiring n to be much larger to eliminate this noise.
- The most efficient method is to have a threshold detector (hardware or software) which rejects any yi that exceeds the threshold before adding it to the sum.
- Modern instrumentation amplifiers such as the LT1920 have much lower noise, so n can be reduced from 2048 for the BSAEP

Other Evoked Potentials

rTMS: Repetitive Trans-Cranial Magnetic Stimulation

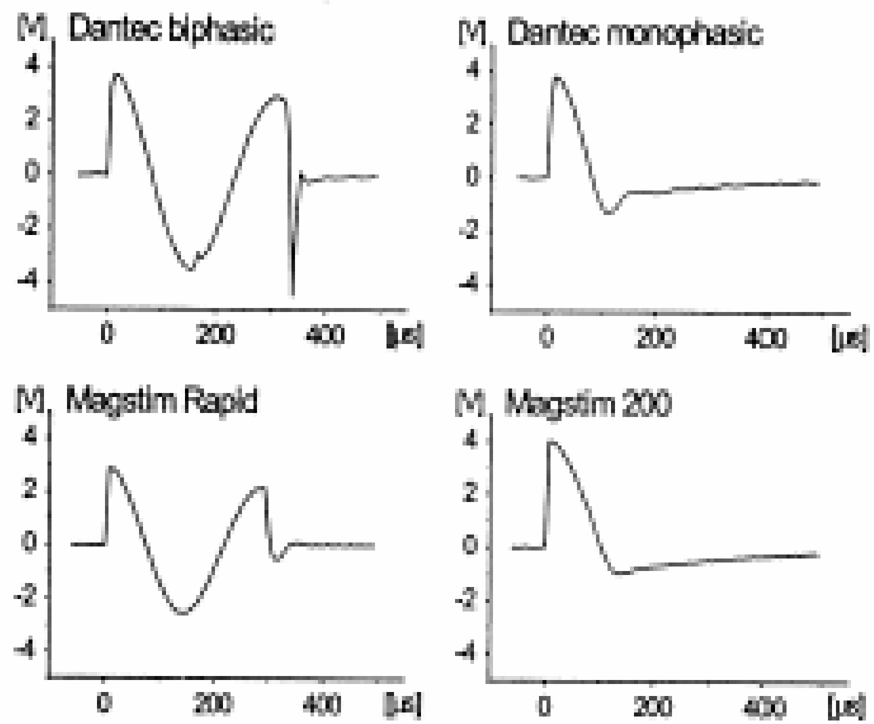
- Treat severely depressed patients who are resistant to pharmacology
- Alternative is periodic applications of electro-shock (ECT) treatment
- 30% of patients respond
- Would like to increase percentage of responders

Current Commercial Machines

- Example Magstim

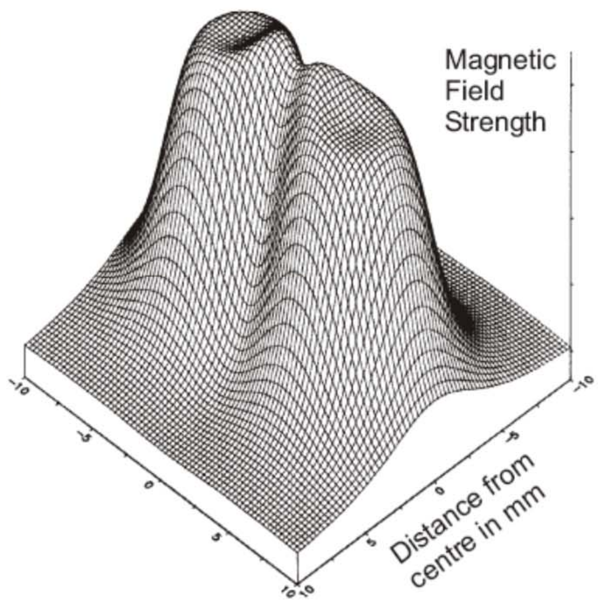
Clinical Treatment

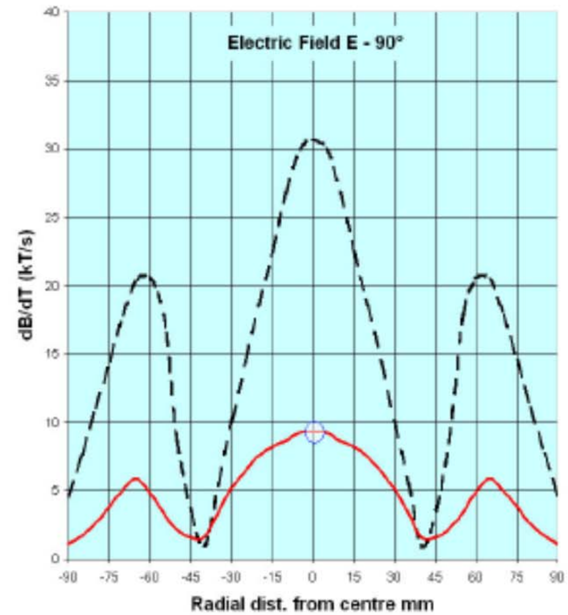
Stimulus Waveforms



Magnetic Field

Source: Medtronic, 2004





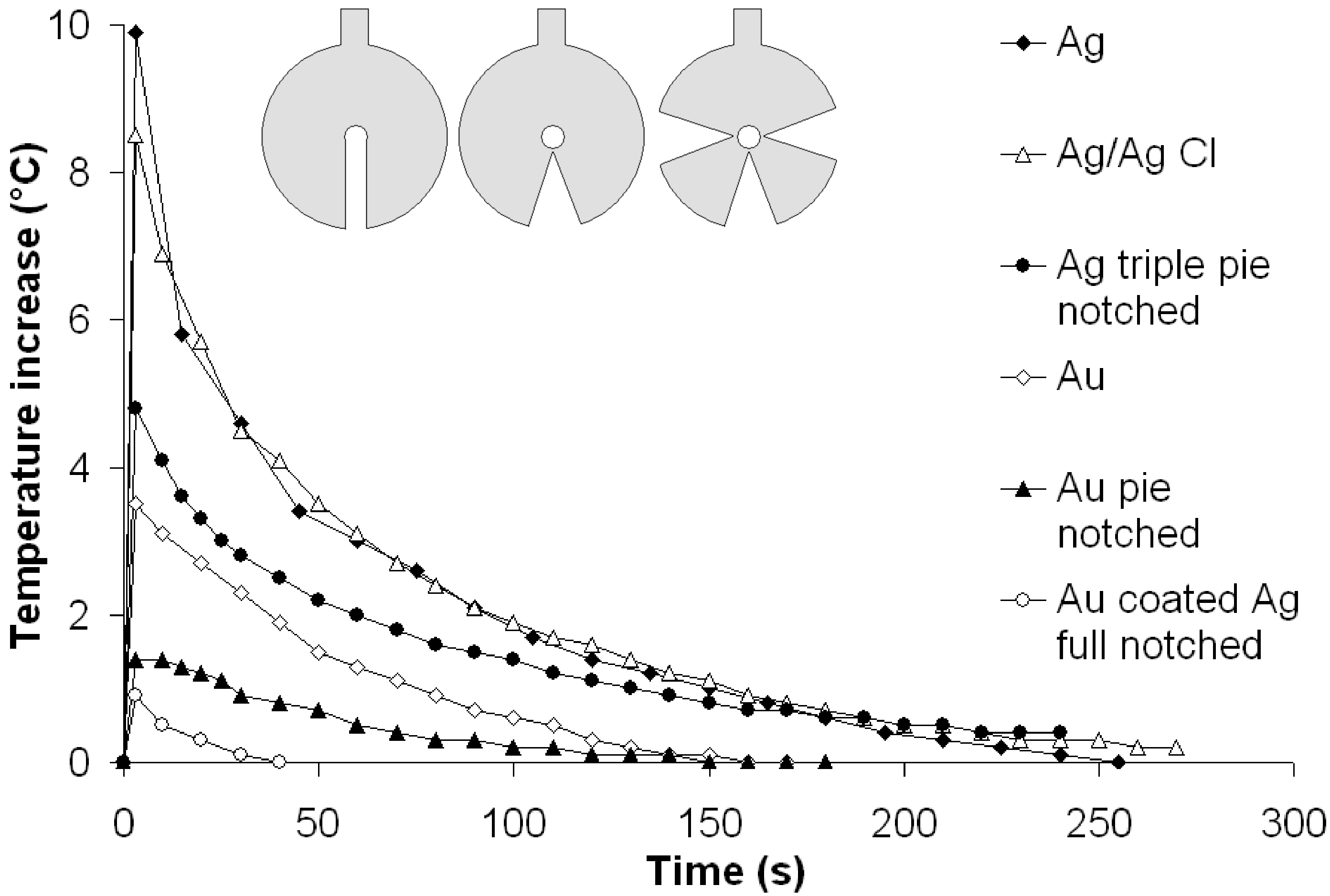
Source: Medtronic, 2004

Source: Medtronic, 2004

Instrumentation Challenges Recording Simultaneous Evoked Potentials

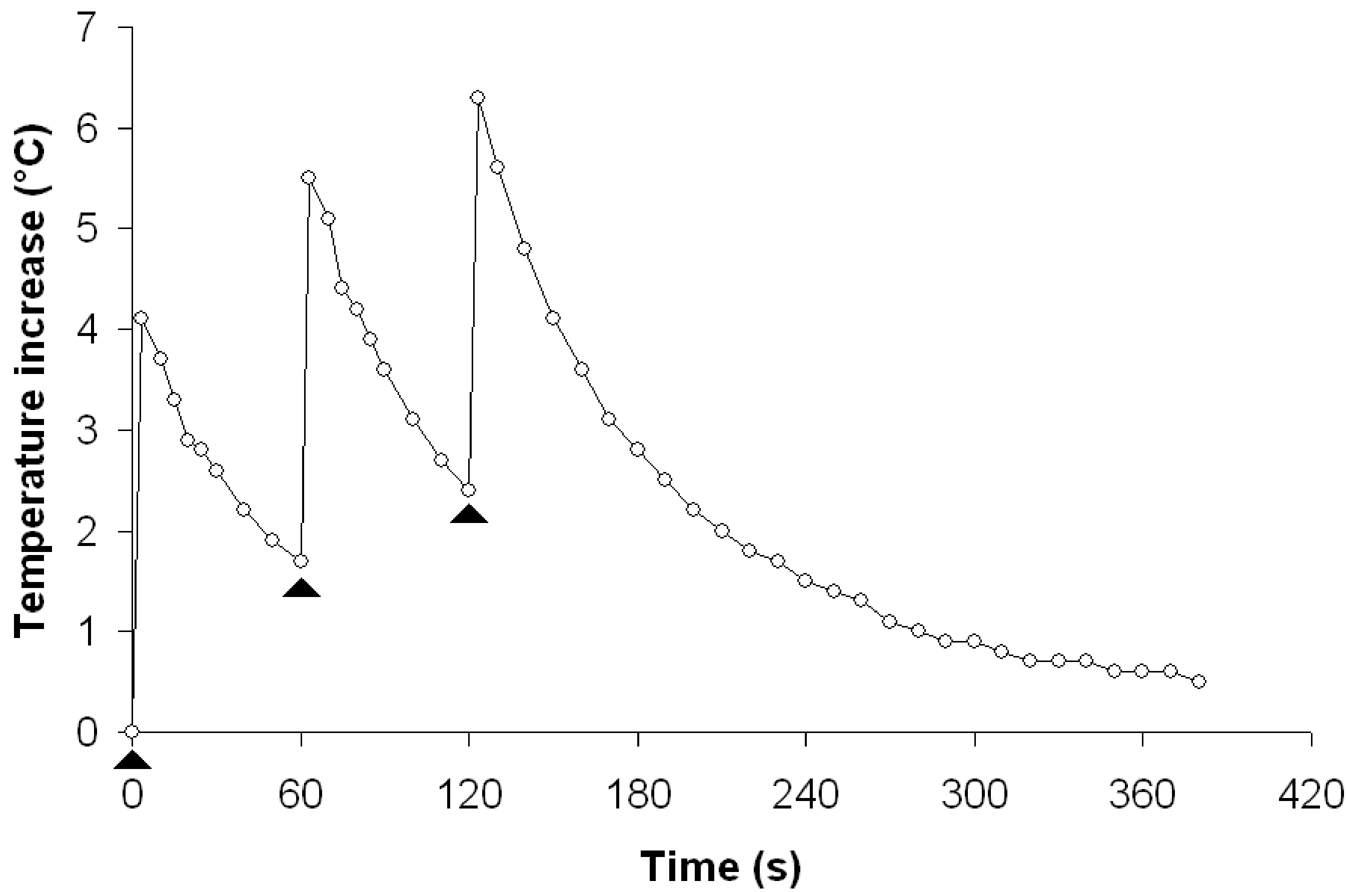
- Large magnetic field saturates electronics (coupling into electrode cable, amplifier inputs)
- Signals very small plus other background EEG, need repetitive stimulation for treatment and averaging
- Electrode heating during multiple stimuli
- Stimulation of scalp muscles (mV amplitudes phase locked to responses)
- Auditory “click” response

Electrode Materials



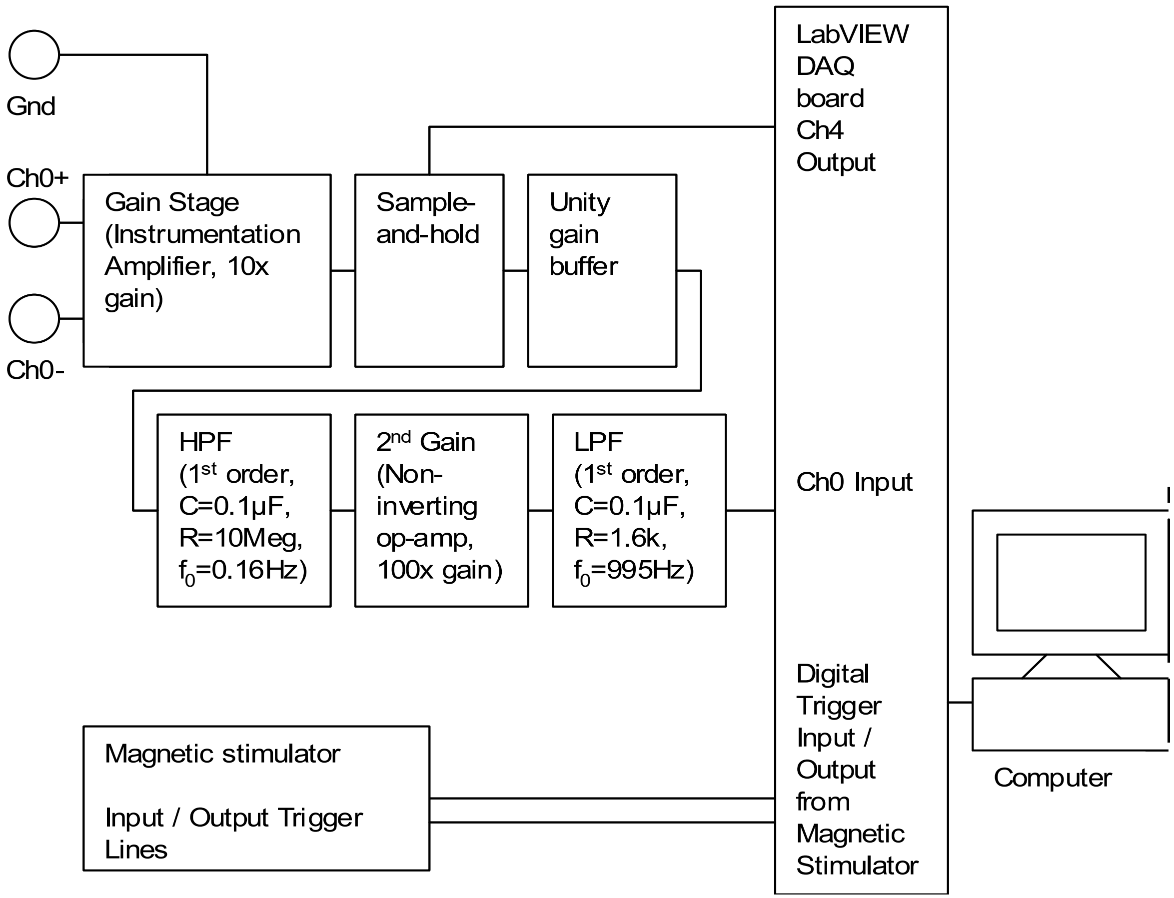
3s at 20Hz at 85% intensity, r = -30mm

rTMS Trains of Stimuli

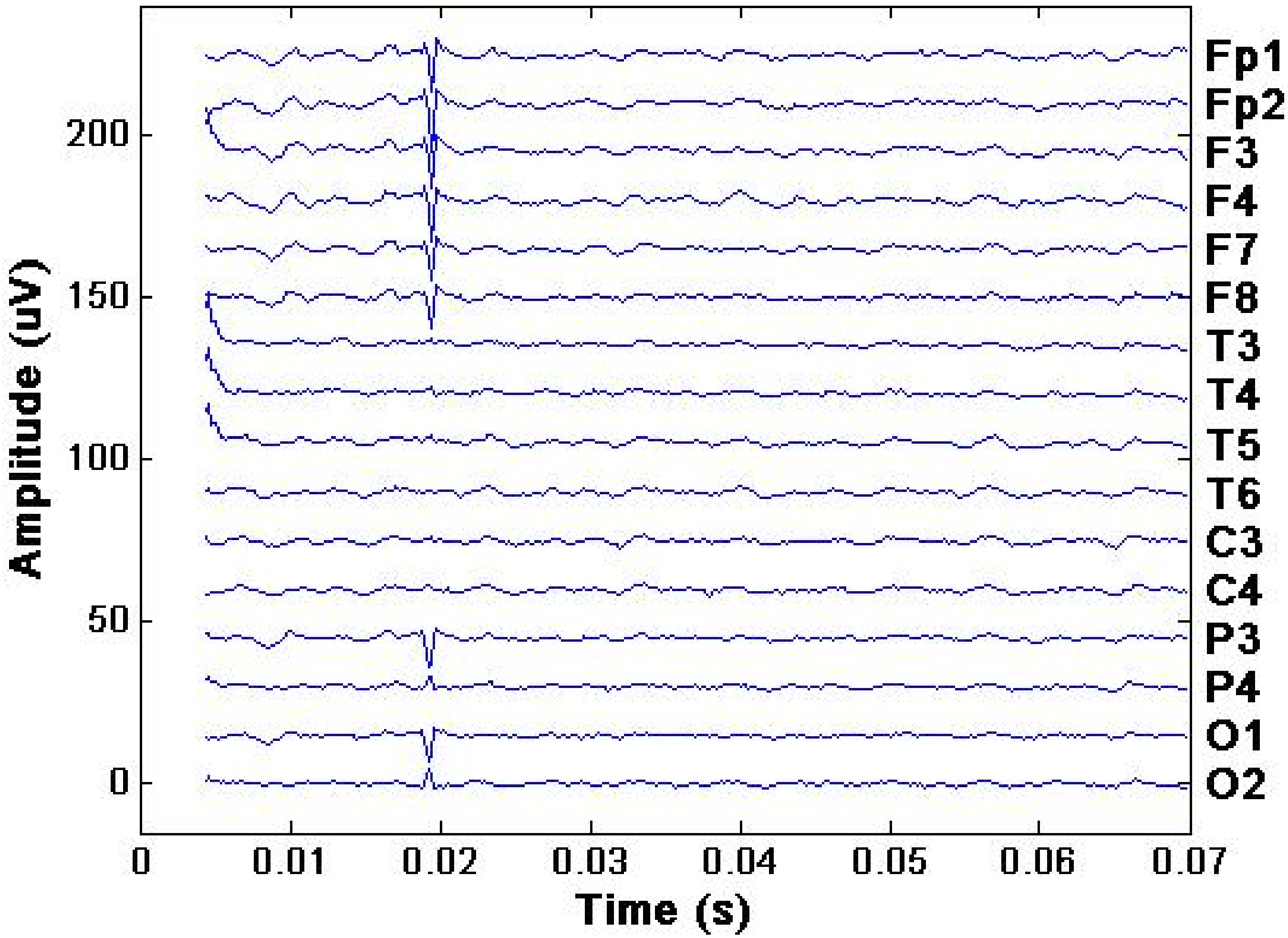


Au electrode, 3s at 20Hz at 85% intensity, trains at 0, 60, 120s

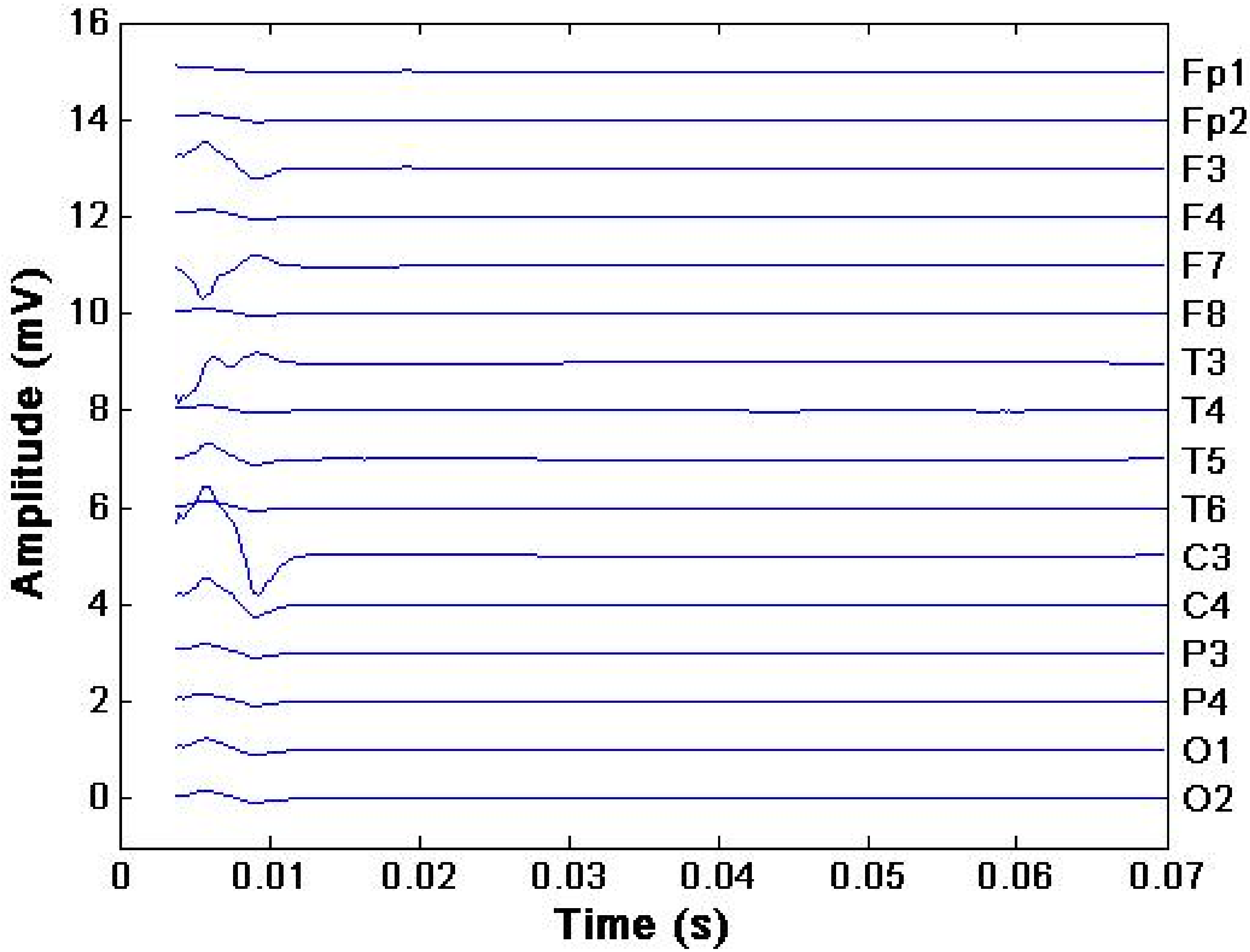
Systems Approach



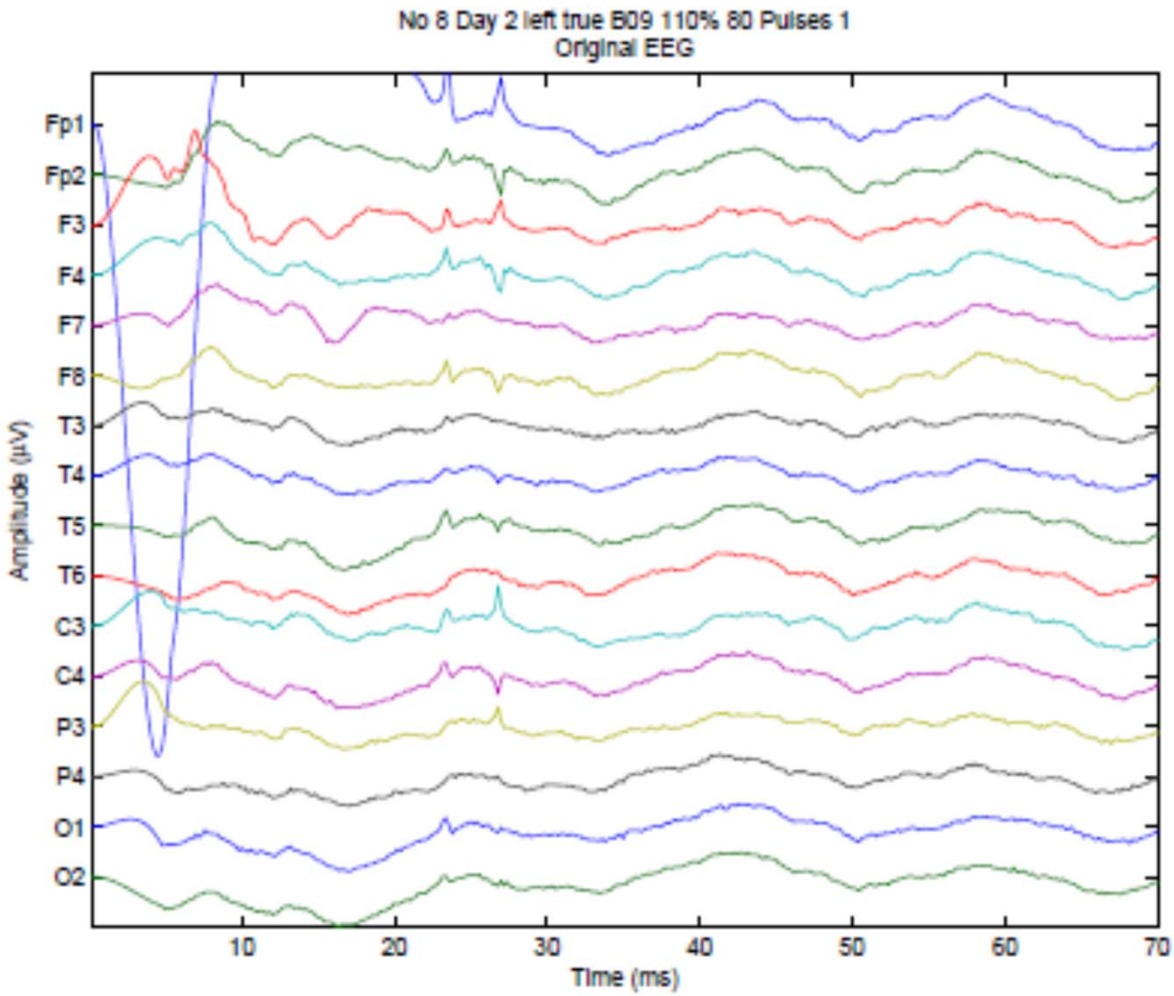
Sham Response to rTMS "Clicks"



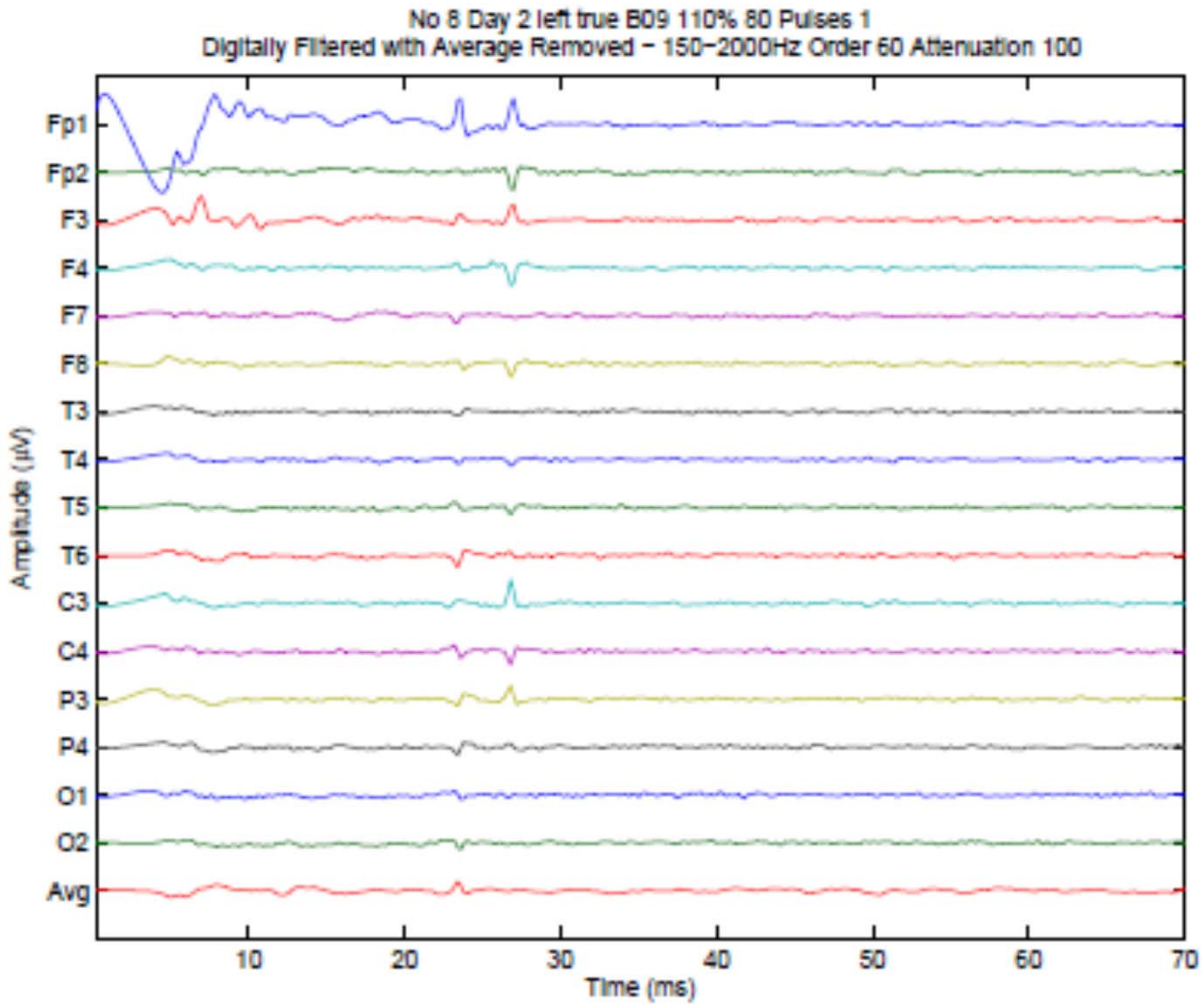
Muscle Responses during 10 Hz Left-sided Stimulation



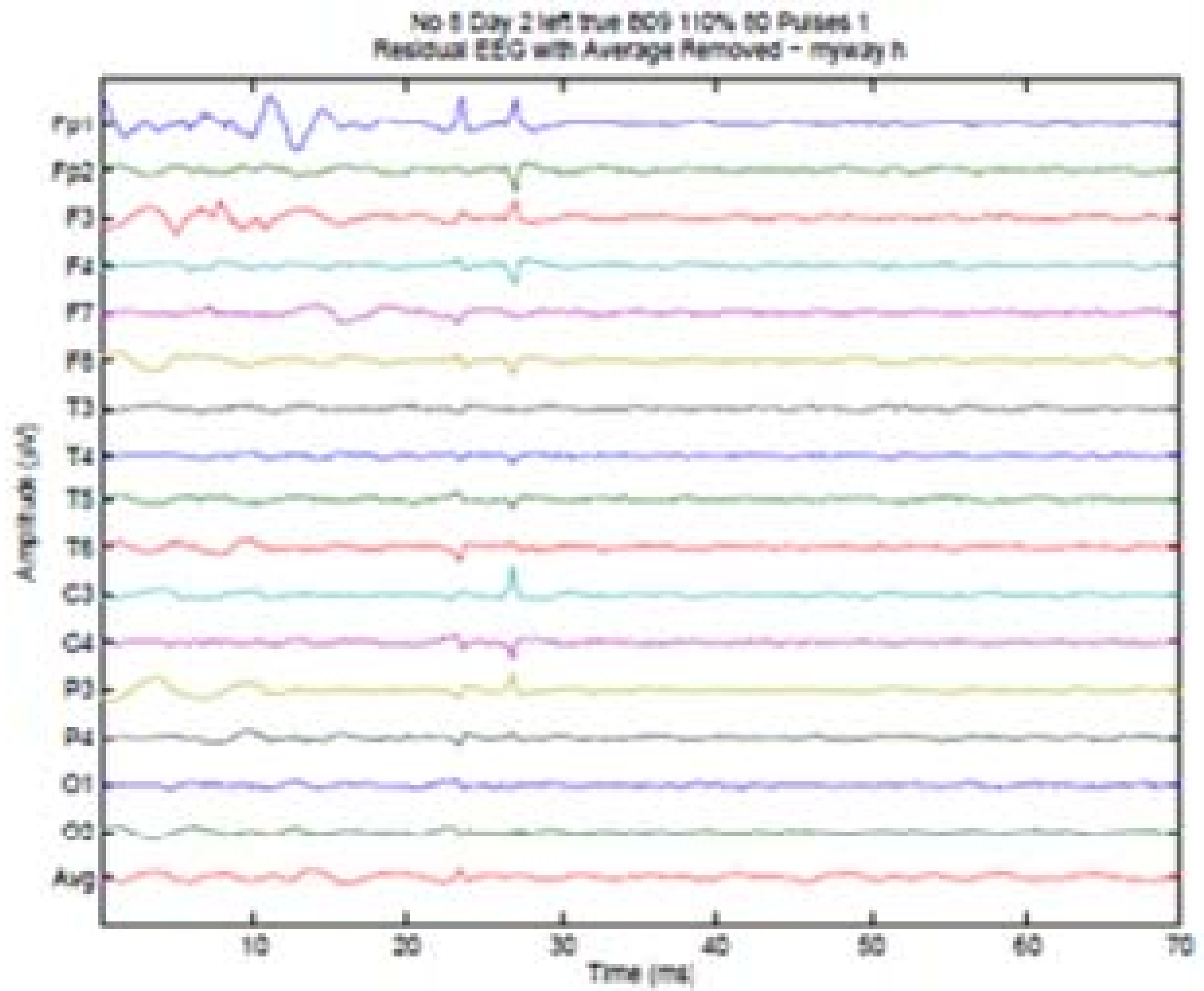
Results of Day 2 Position Study (Typical Subject)



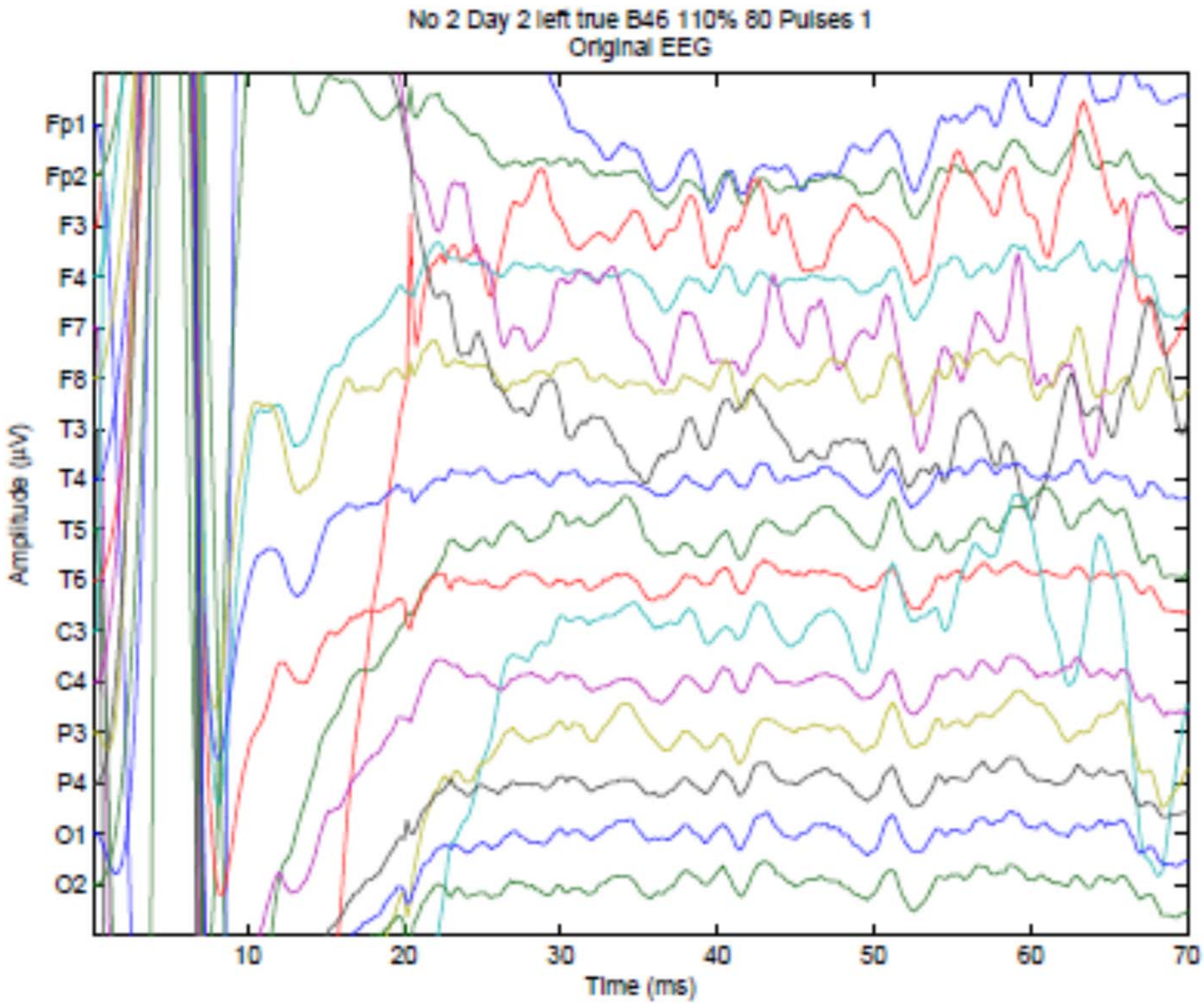
Using Digital Filtering



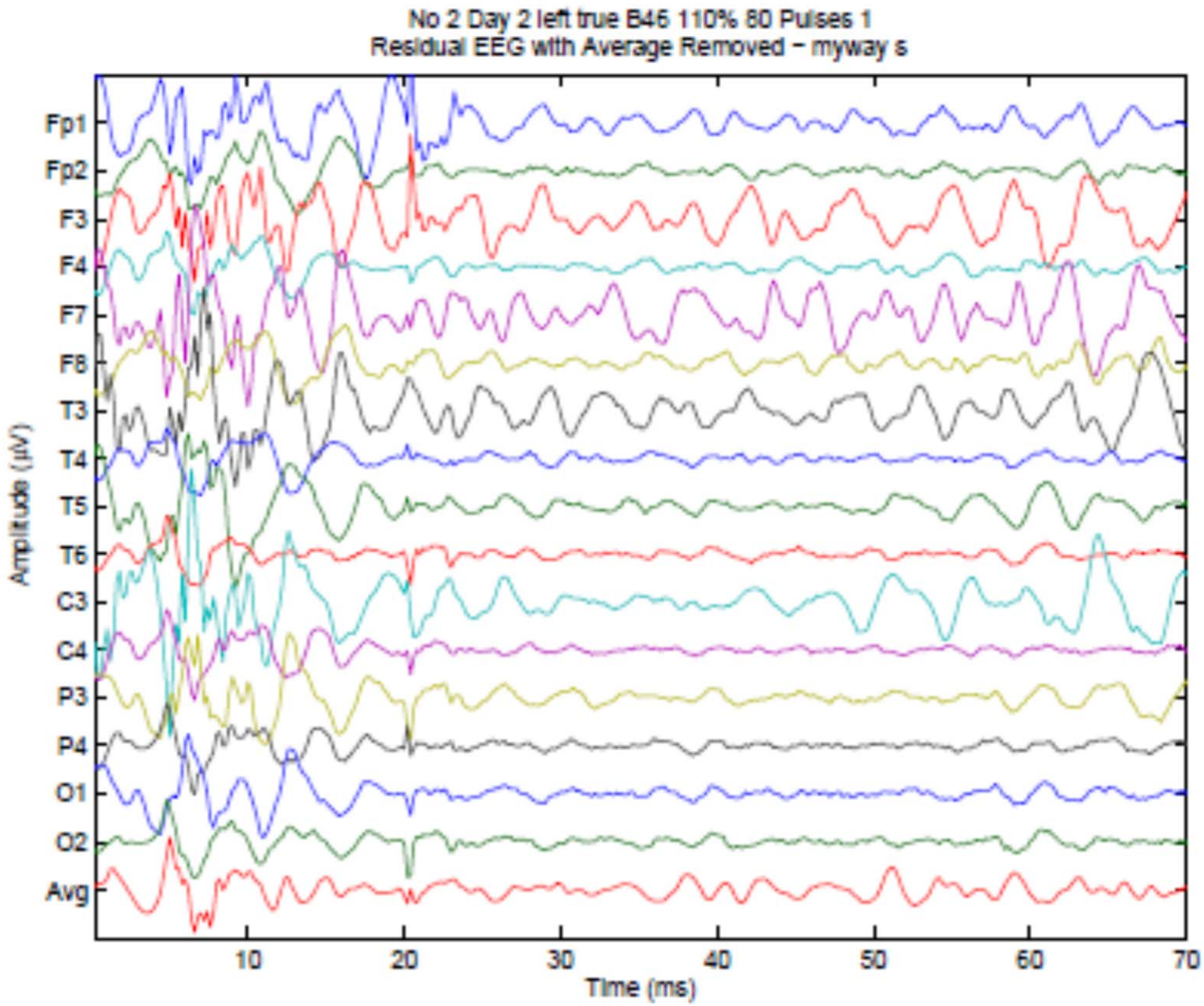
Using Wavelet Denoising



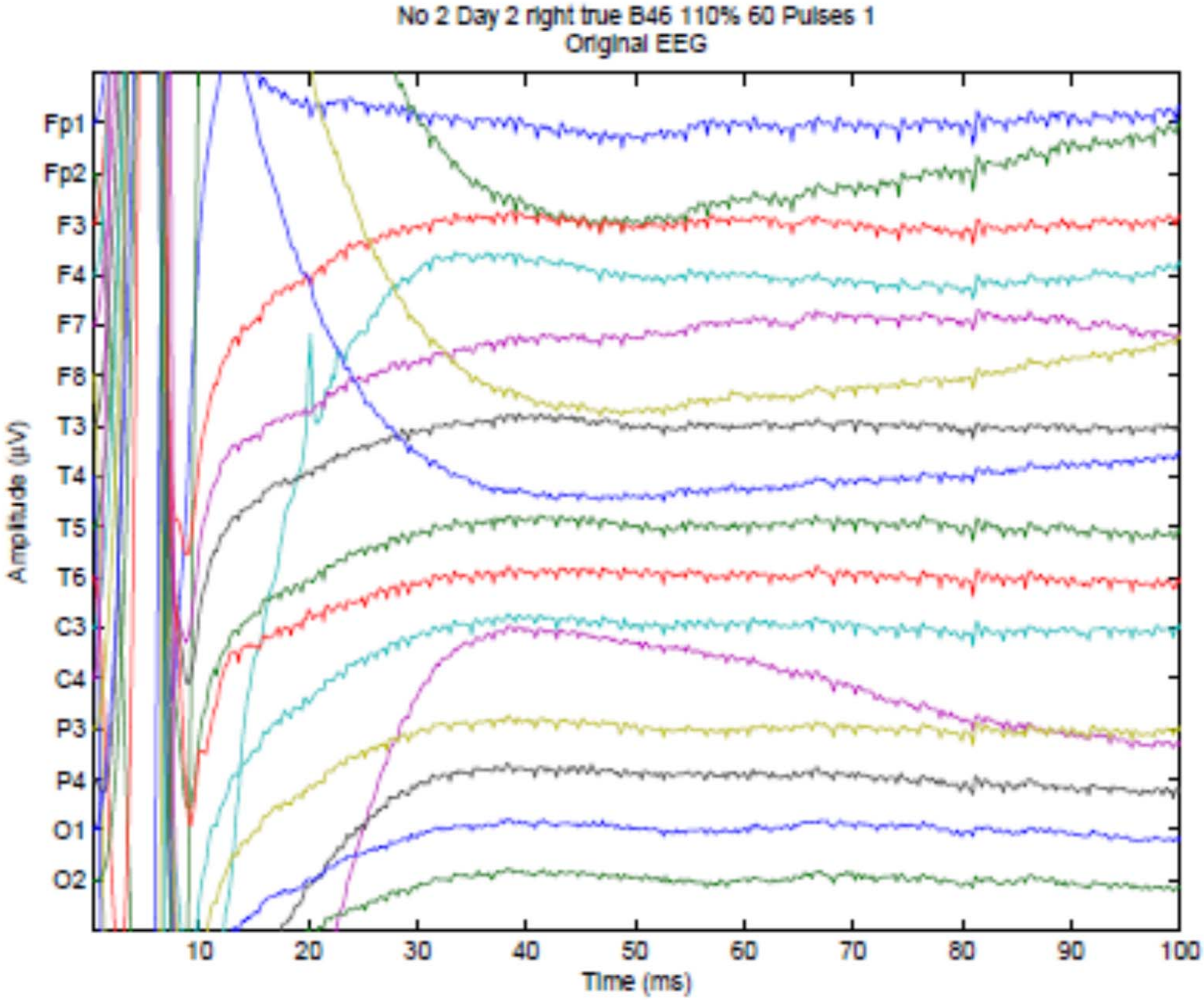
Brain Response for Sensitive Subject



Wavelet Denoised Response



Right side 1 Hz Response



Right Side Denoised Response