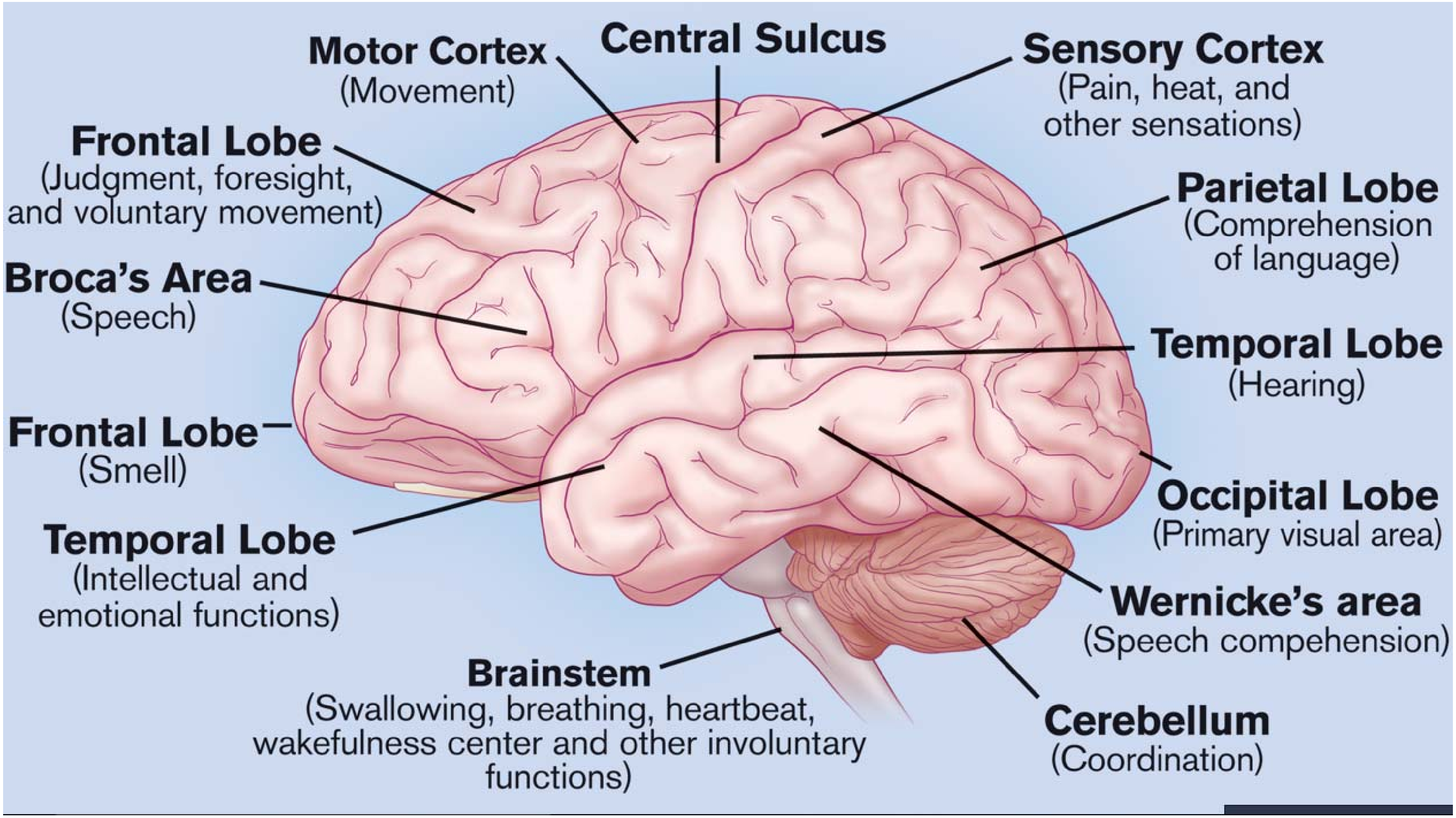
EE 791 Lecture 5

February 26, 2019

EEG Fundamentals

Brain Features



Brain Wave Recordings

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

Overview (EEG)

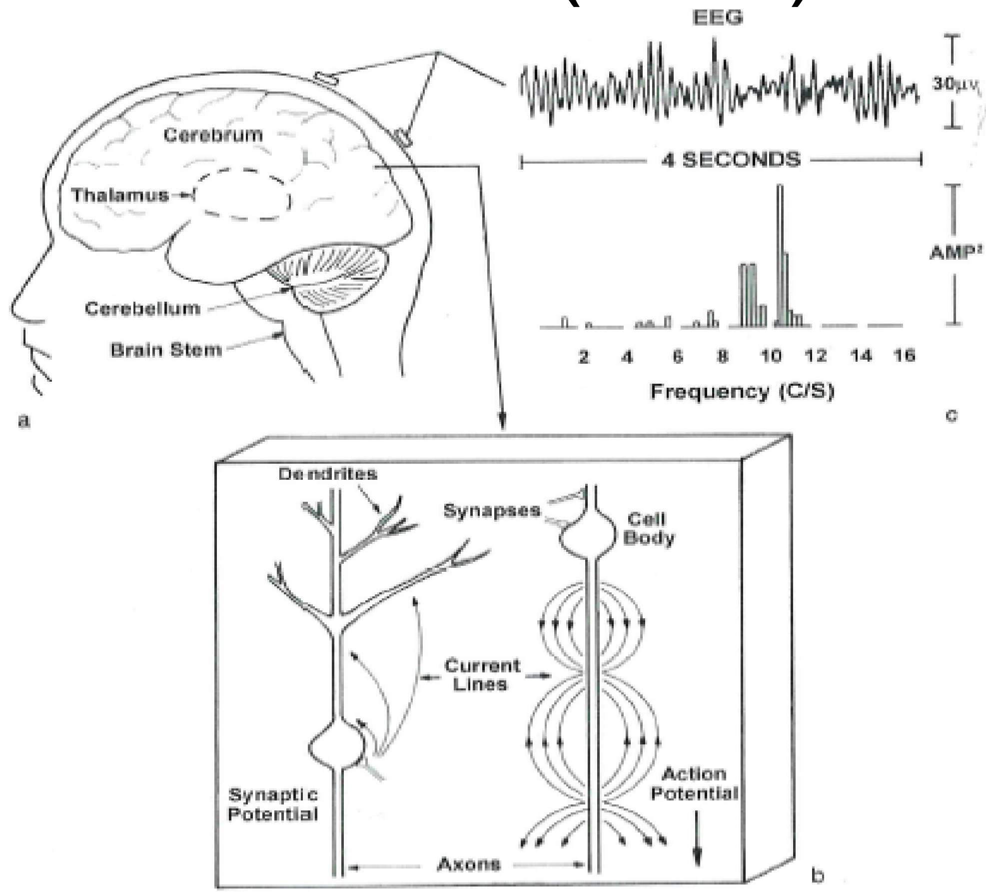


Figure 1-1 (a) The human brain. (b) Section of cerebral cortex showing microcurrent sources due to synaptic and action potentials. Neurons are actually much more closely packed than shown, about 10^5 neurons per mm^2 of surface. (c) Each scalp EEG electrode records space averages over many square centimeters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

Source of EEG Signal

- Only cerebral cortex contributes to ambient EEG
- Organized vertically in 6 layers (I to VI)
- Includes about 10^{10} neurons
- Individual action potentials travelling along neuron axons are too small to be measured on scalp
- Each neuron has 10's of thousands of synapse at its dendrites which are usually horizontally aligned
- Inward +ve current flow at excitatory synapses (EPSP)
- Outward +ve current flow at inhibitory synapses (IPSP)
- Viewed as current dipoles
- Sum of these flows creates synaptic fields

Cortical Contributions

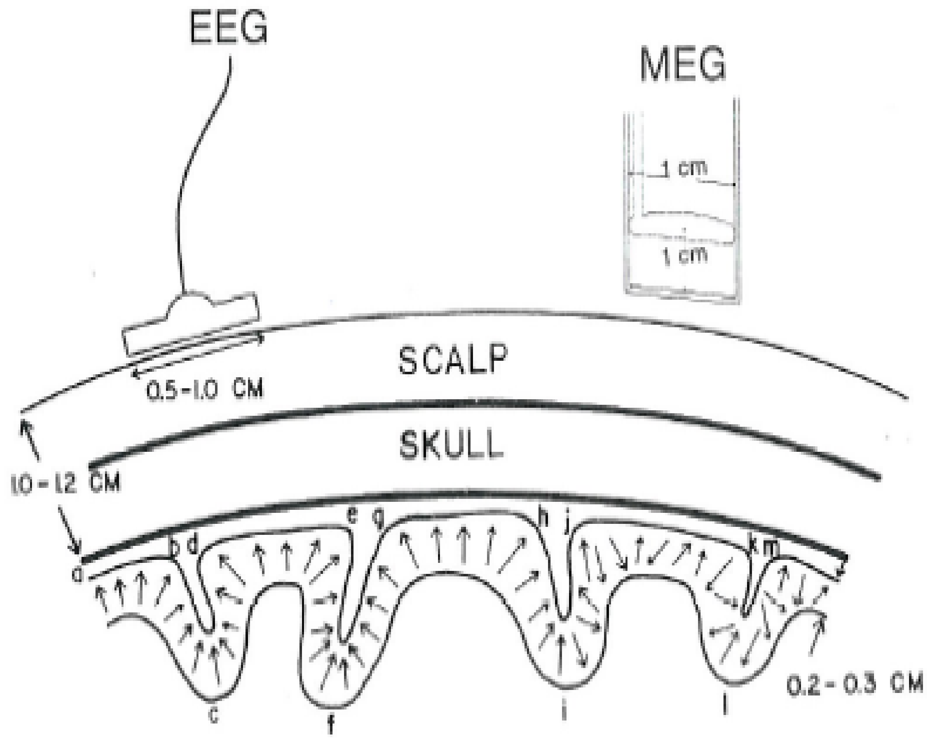


Figure 2-3 Neocortical sources can be generally pictured as *dipole layers* (or "dipole sheets," in and out of cortical fissures and sulci) with mesosource strength varying as a function of cortical location. EEG is most sensitive to correlated dipole layer in gyri (regions ab, de, gh), less sensitive 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).

EEG Subfields

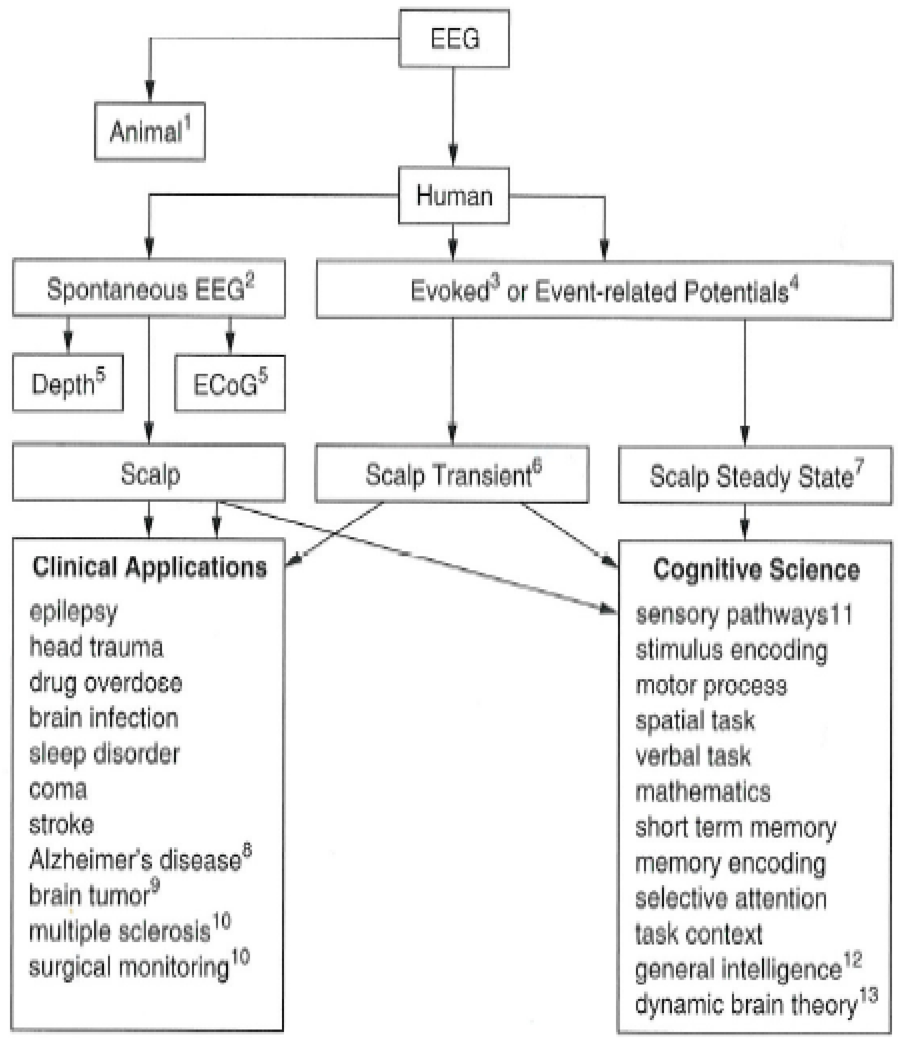


Figure 1-3 Common relationships between EEG subfields. Clinical applications are mostly related to neurological diseases. EEG research is carried out by neurologists, cognitive neuroscientists, physicists, and engineers who have a special interest in EEG. See text for a discussion of numbered superscripts. Reproduced with permission from Nunez (2002).

Neuronal Connections

- Most connections are short < 1mm
- Long distance pathways also exist (1 to 15 cm)
- Two hemispheres connected through corpus callosum 10^8 fibres
- Transmission times could be as little as 1 ms for short connections or 3 – 10 ms for longer.

Cortical Fibres

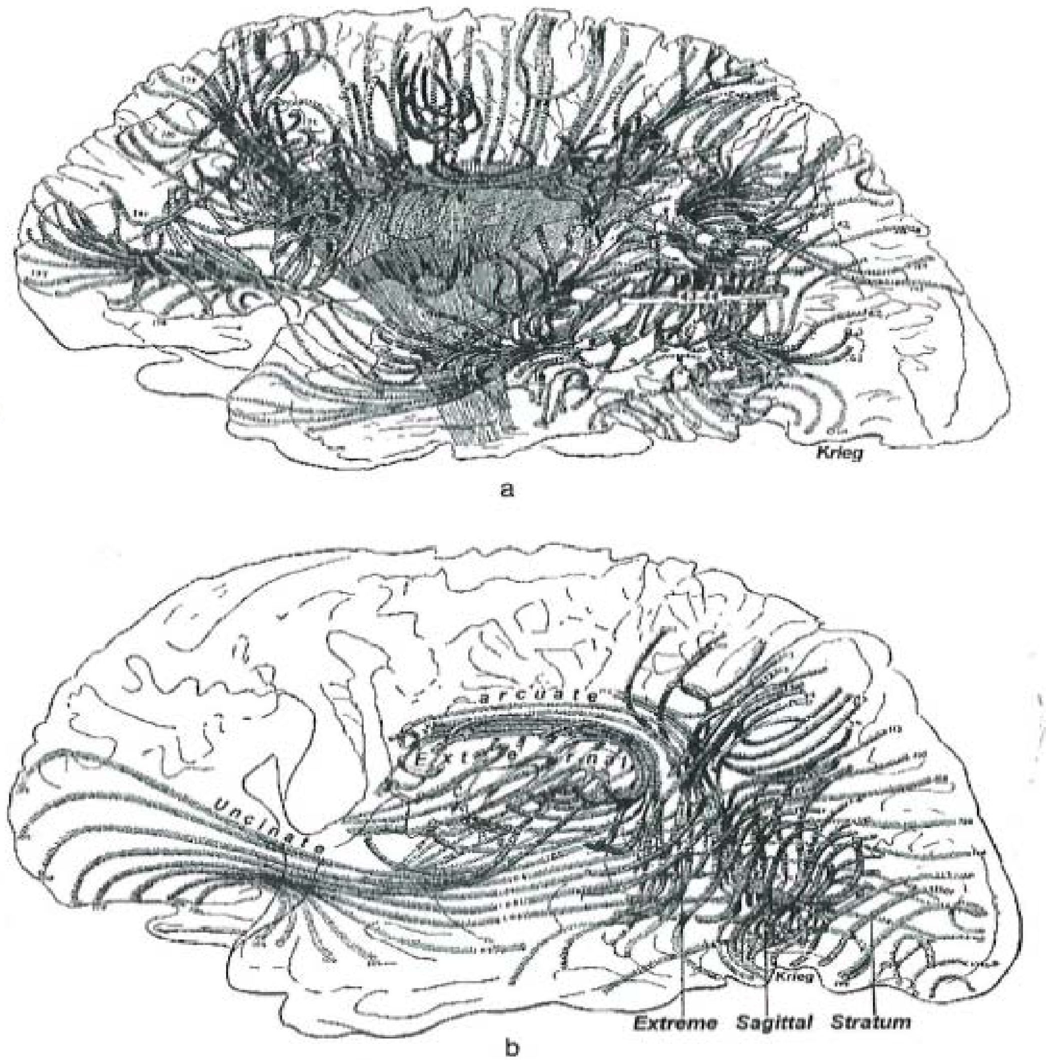
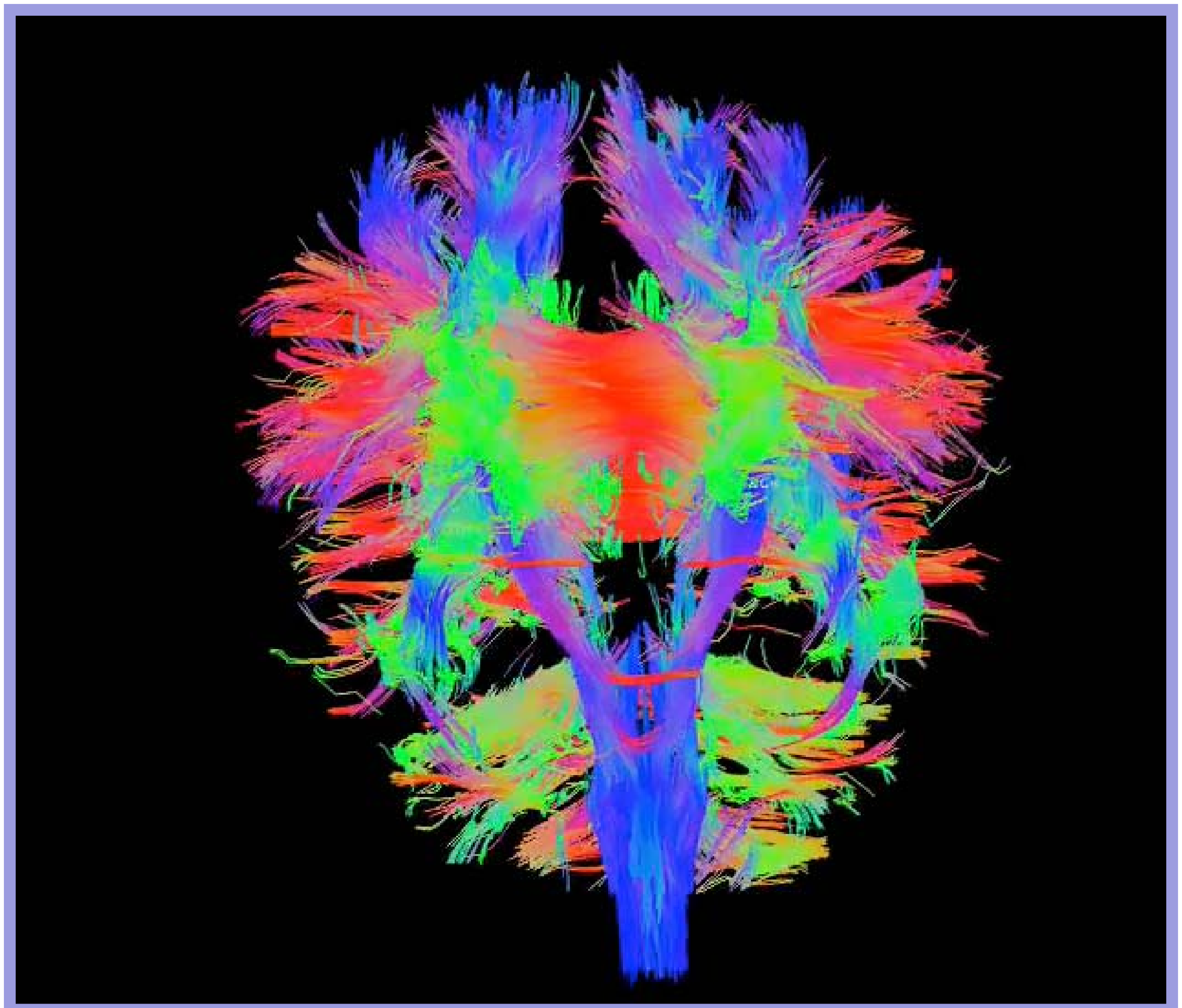


Figure 1-2 (a) Some of the superficial corticocortical fibers of the lateral aspect of the cerebrum obtained by dissection. (b) A few of the deeper corticocortical fibers of the lateral aspect of the cerebrum. The total number of corticocortical fibers is roughly 10^{10}, that is, for every fiber shown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

Diffusion Tensor Imaging



Alpha Predominance

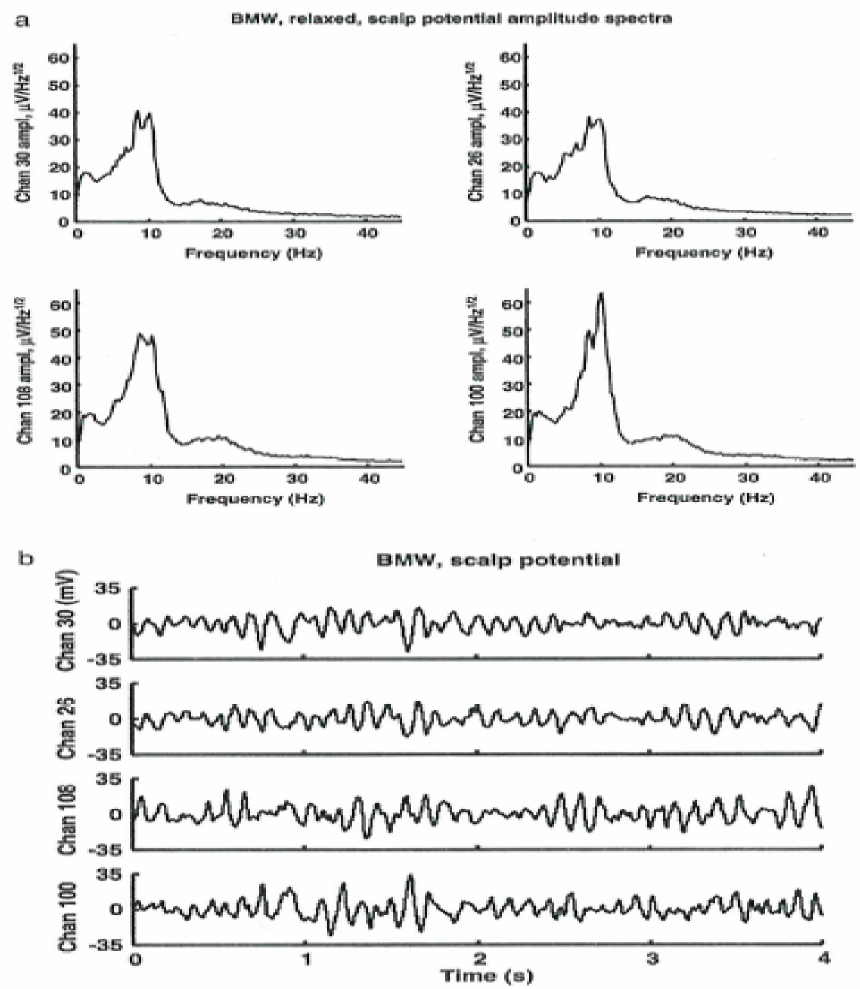


Figure 1-4 (b) Alpha rhythm recorded from a healthy 25-year-old relaxed male with eyes closed using a neck electrode as reference. Four seconds of data are shown from four scalp locations (left frontal-30; right frontal-26; left posterior-108; right posterior-100). Amplitudes are given in μV. (a) Amplitude 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

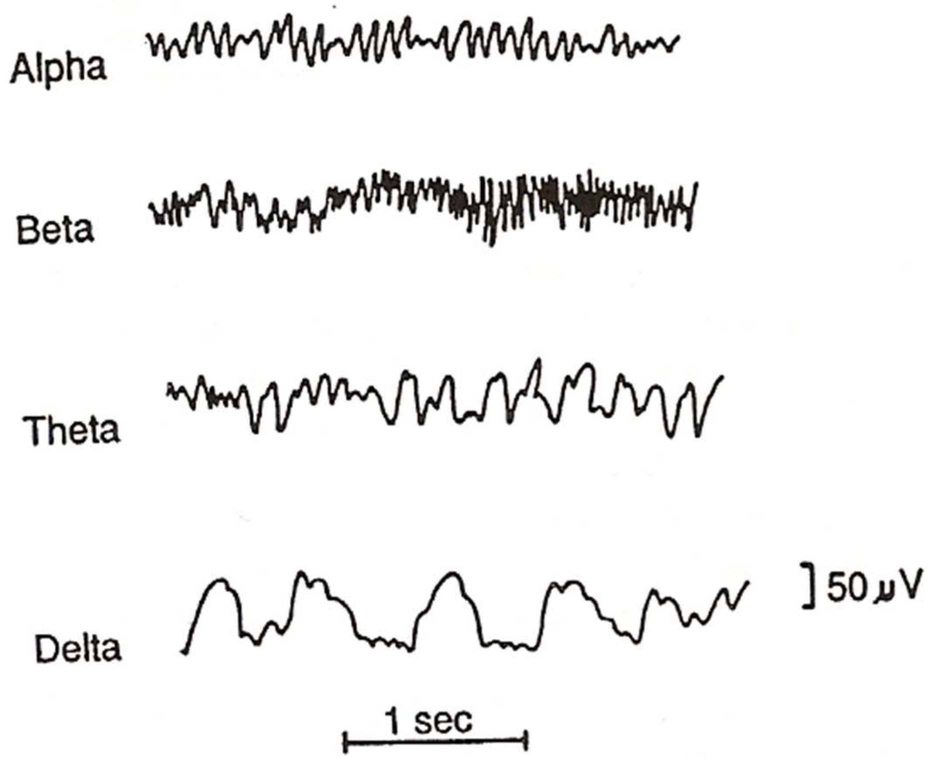


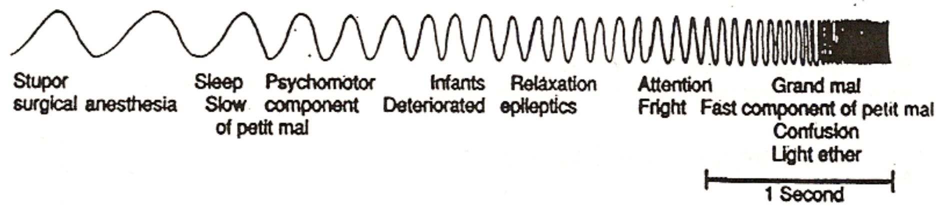
Figure 59–1. Different types of normal electroencephalographic waves.

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

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)

Structural Relationships

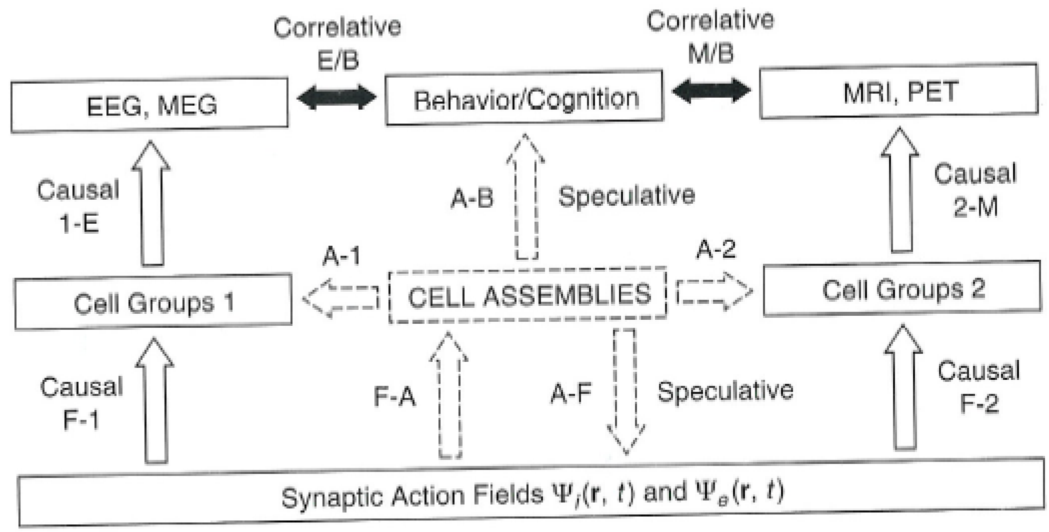


Figure 1-8 A conceptual framework for brain function. Double arrows (near top) indicate established correlative relationships between behavior/cognition and EEG, MEG, MRI, and PET. By definition, cell groups 1 generate EEG or MEG and cell groups 2 generate MRI or PET. Cell groups 1 and 2, which may or may not be part of neural networks (or cell assemblies), are embedded within the larger category (or "culture") of active synapses, the synaptic action fields $\Psi_e(\mathbf{r}, t)$ and $\Psi_i(\mathbf{r}, t)$. These excitatory and inhibitory synaptic action fields may be defined in terms of numbers of active synapses per unit volume or per unit of cortical surface area, independent of their functional significance. Cell assemblies and cell groups 1 and 2 may or may not overlap. Causal and correlative (may or may not be causal) interactions are indicated by hyphens and slashes, respectively. Reproduced with permission from Nunez and Silberstein (2000).

Cell Assemblies

- Can exist at different spatial scales and are dynamic
- Smallest are minicolumns .03 mm radius, 3 mm high and containing 100 pyramidal cells with 10^6 synapses
- If 10% of synapses active at any time and there are 60 X 10^6 neurons (6 cm^2 of surface) they can produce a few μvolts at scalp.
- Cell assemblies are mini to macro columns and change size depending on brain state

Development of EEG Signal

- The time varying cortical surface potential $\Phi(r_1,t)$ at location r_1
- $\Phi(r_1,t) \approx C_1 \Psi_i(r_1,t) – C_2 \Psi_e(r_1,t)$ where the Ψ_i are current sources and Ψ_e are current sinks, C_1 and C_2 are determined by distribution and volume conduction properties
- $V(r_1, r_2, t) = \Phi(r_1,t) - \Phi(r_2,t)$ is the differentially recorded EEG

The EEG Signal

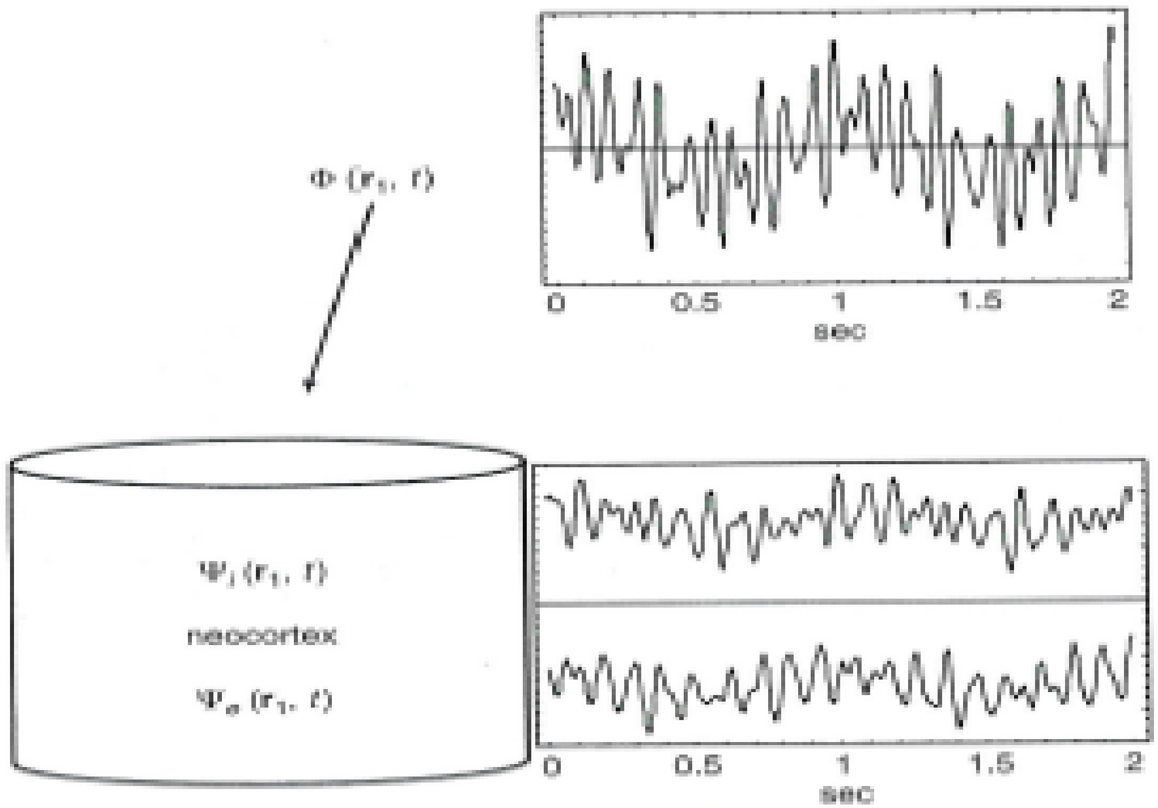


Figure 1-9 Modulations of inhibitory $\Psi_i(\mathbf{r}_1, t)$ and excitatory $\Psi_e(\mathbf{r}_1, t)$ synaptic action densities are imagined here to occur in superficial and deeper cortical layers, respectively. Each waveform shown here consists of five arbitrary frequency components in the delta, alpha, and beta ranges. The simulated cortical surface potential $\Phi(\mathbf{r}_1, t)$ is plotted as a linear combination of these synaptic field variables. A more realistic simulation might have excitatory synaptic action mainly in layers I and VI, and inhibitory synaptic action in layers II through V as indicated in fig. 11-4.

Basic Assumptions

- Sources are ideal current sources
- Current carriers +ve and –ve ions
- Volume conductor can be considered resistive at physiological frequencies
- Tissue in head is inhomogeneous and anisotropic
- Tissue at macroscopic scale can be considered linear so we can use principal of superposition

Instrumentation (EEG Electrodes)

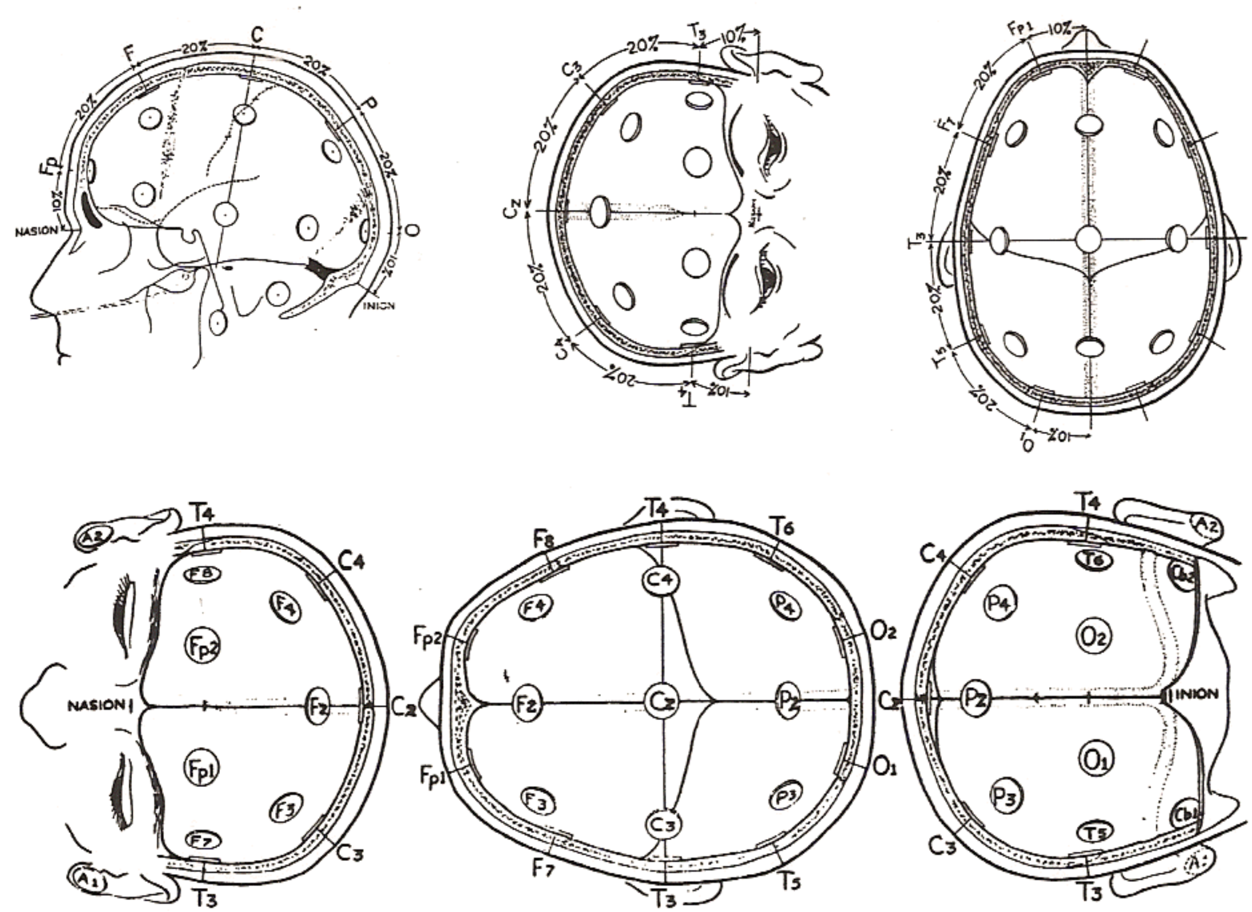


Figure 4.28 The 10-20 electrode system This system is recommended by the International Federation of EEG Societies. (From H. H. Jasper, "The Ten-Twenty Electrode System of the International Federation in Electroencepha-

Cortical Electrodes

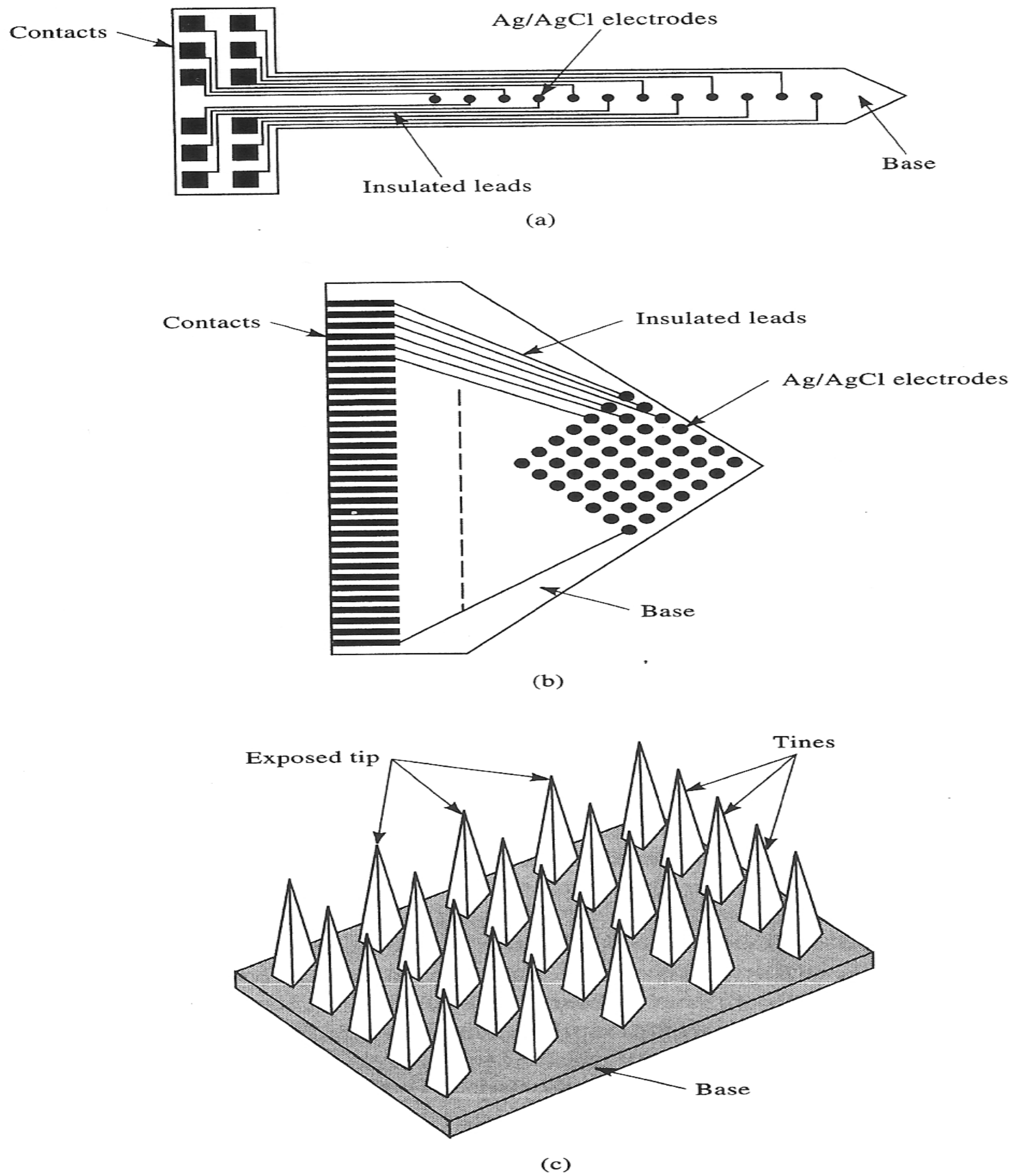


Figure 5.16 Examples of microfabricated electrode arrays. (a) One-dimensional plunge electrode array (after Mastrototaro *et al.*, 1992), (b) Two-dimensional array, and (c) Three-dimensional array (after Campbell *et al.*, 1991).

Amplifier Connections

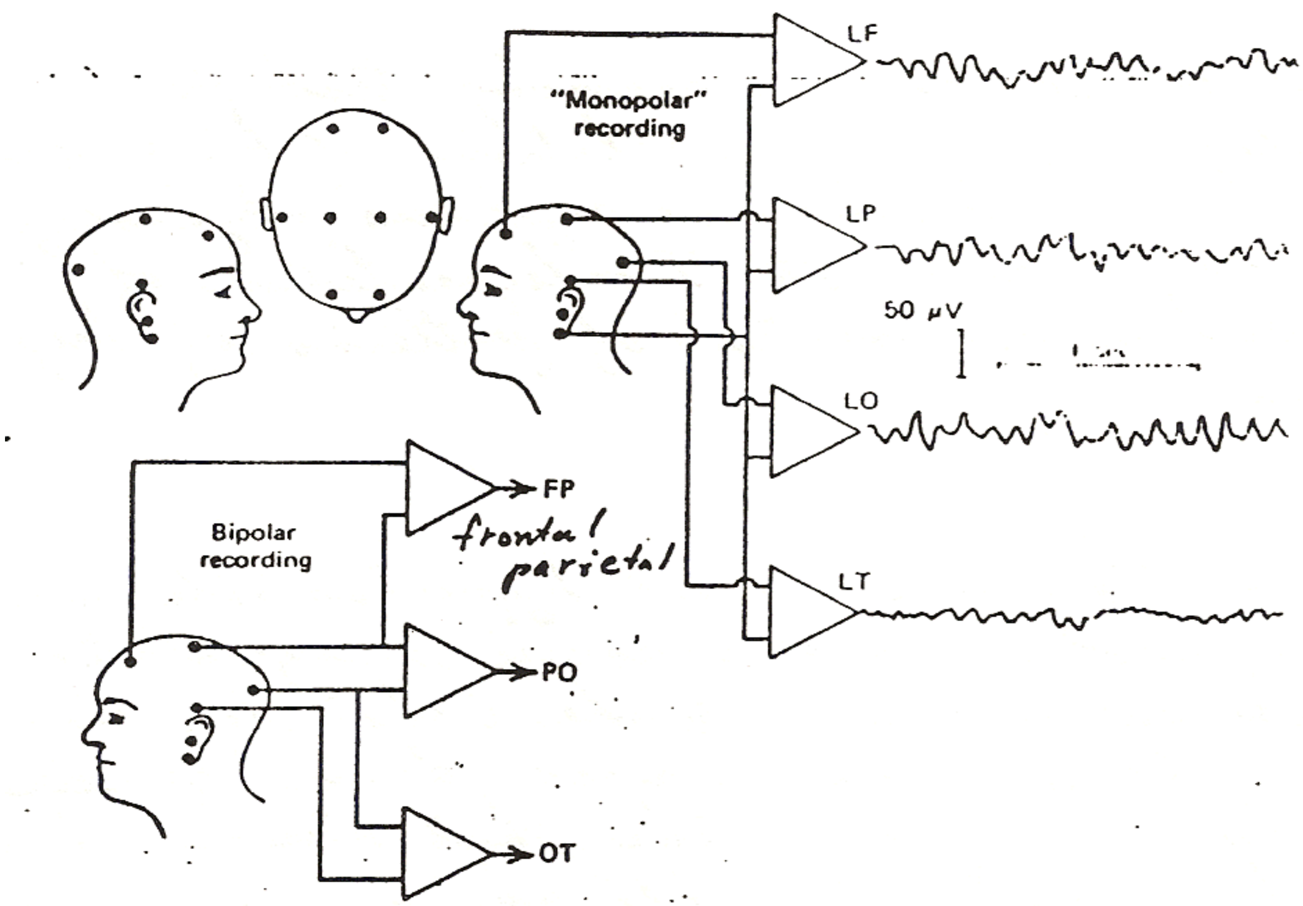
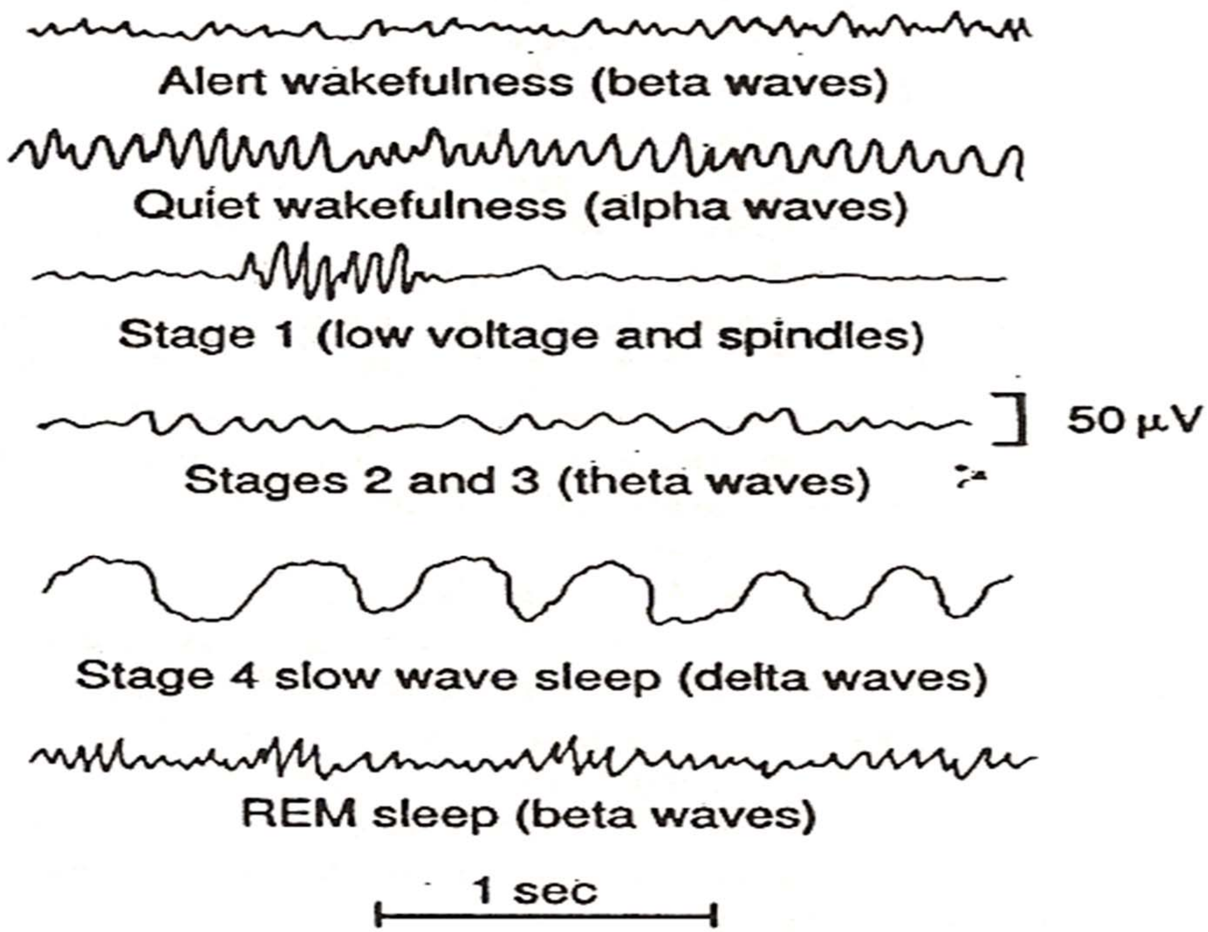


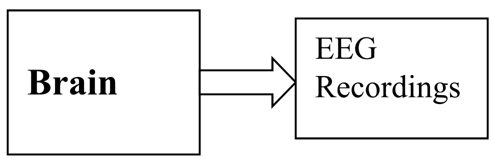
Figure 11-52. Method of connecting the recording channels for "monopolar" and bipolar recording. With "monopolar" recording, the reference electrode is on the earlobe, chin, or neck

Sleep Staging

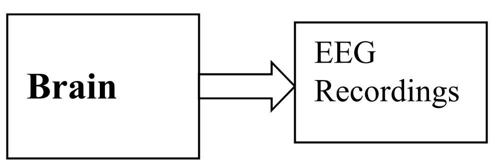


Evoked and Event Related Potentials

- Spontaneous recording (1 – 70 Hz), Fs = 200 Hz



- Evoked and Event Related (1 – 2500 Hz), Fs 200 to 50 kHz



Brain Stem Auditory Evoked Potential

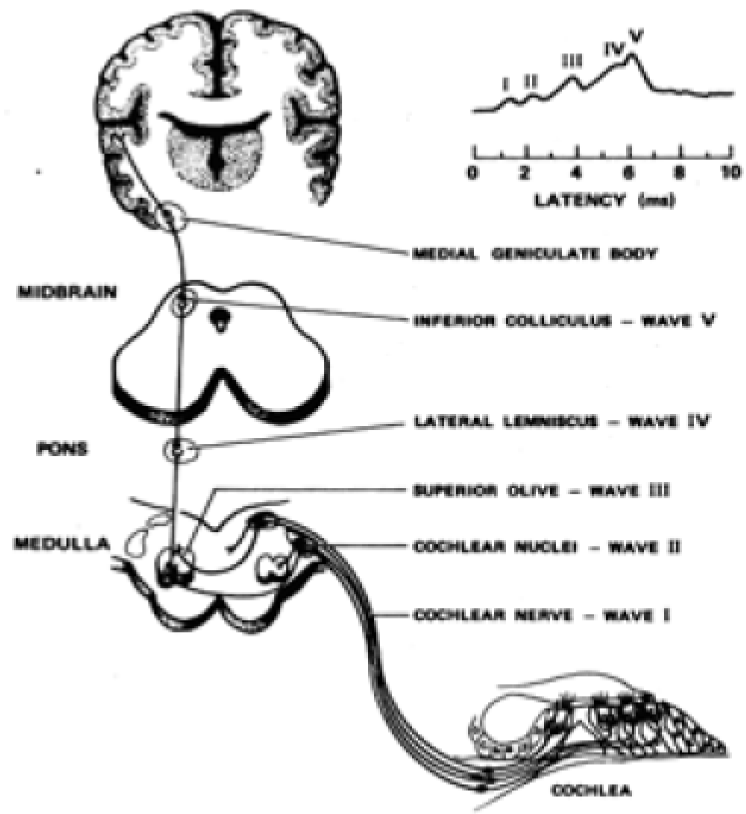
BSAEP Signal Pathway

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

  or certain tones.

- Normal evoked

  response ->



Complete Auditory Potential

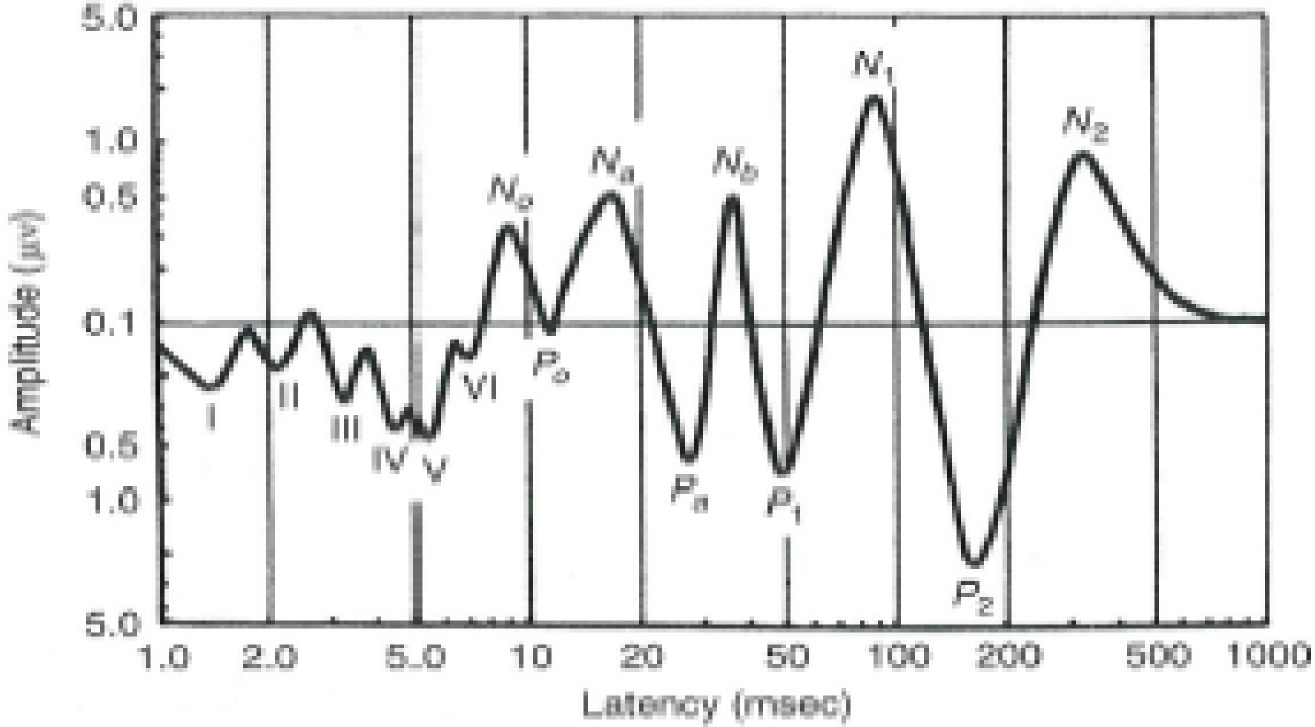
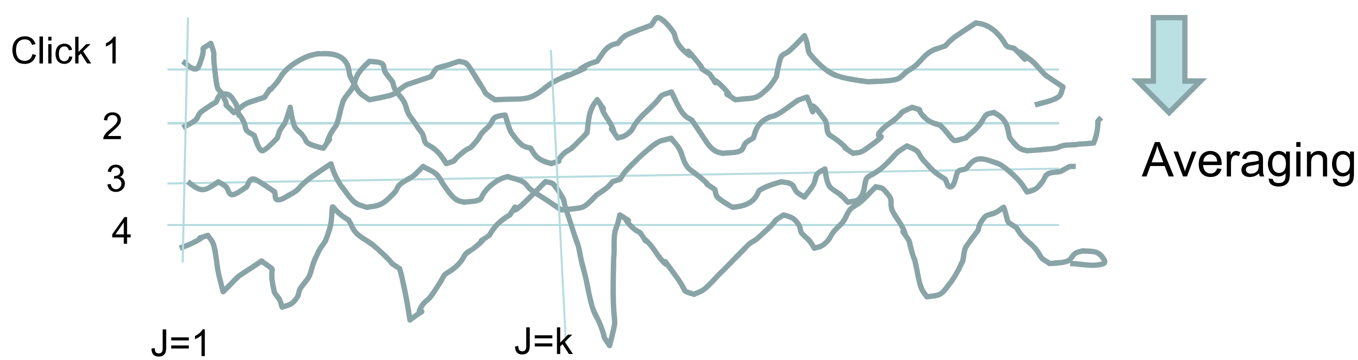


Figure 1-17 The auditory evoked potential waveform as recorded from the human scalp. A subject is presented with a series of up to several thousand tones or clicks and the time-locked EEG is averaged over the stimuli to remove the (much larger) spontaneous EEG. The first few ms of the waveform is also known as the brainstem averaged evoked response (BAER). Physiologists have assigned standard labels to each peak (N_1, P_2, and so forth). Reproduced with permission from Picton et al. (1974).

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

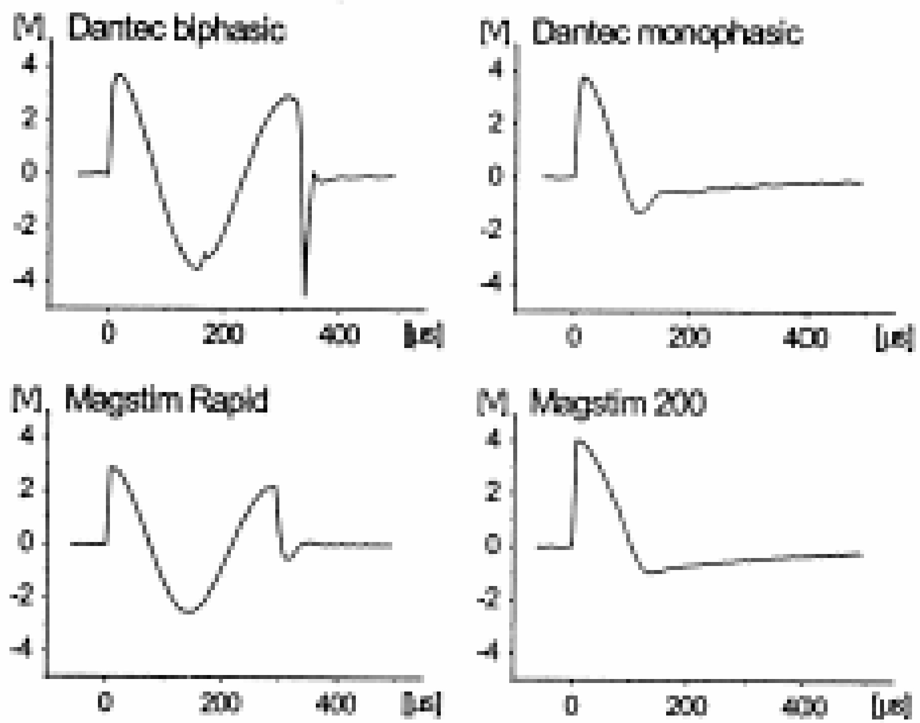
rTMS: Repetitive Trans-Cranial Magnetic Stimulation

- 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

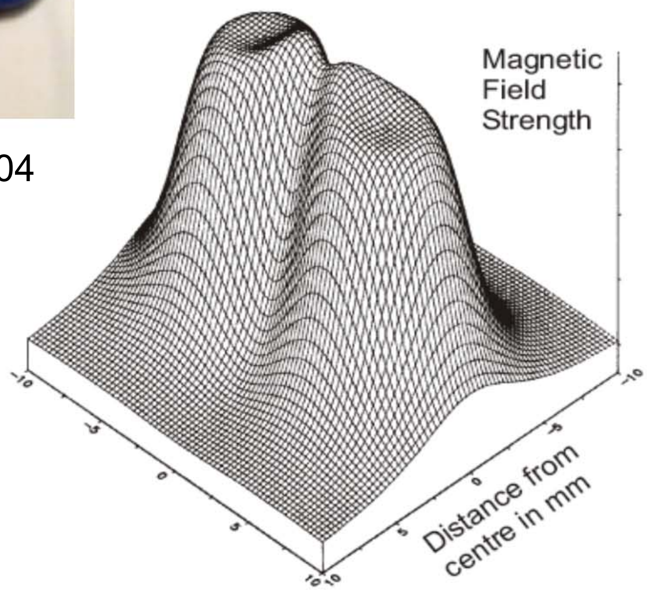
- Example Magstim

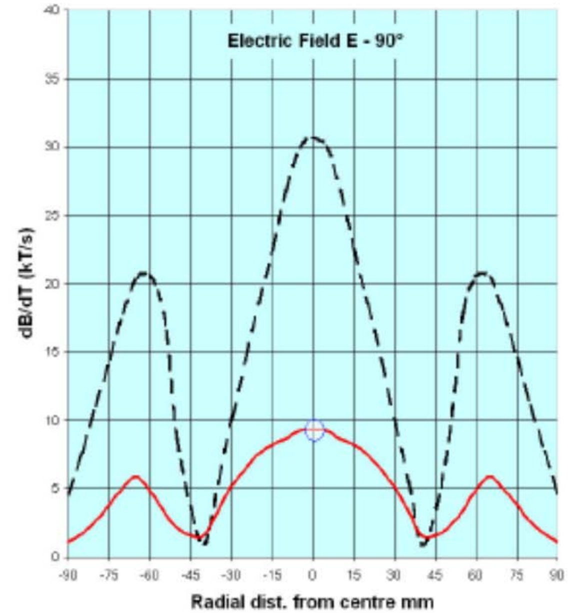
Stimulus Waveforms



Magnetic Field

Source: Medtronic, 2004





Source: Medtronic, 2004

Source: Medtronic, 2004

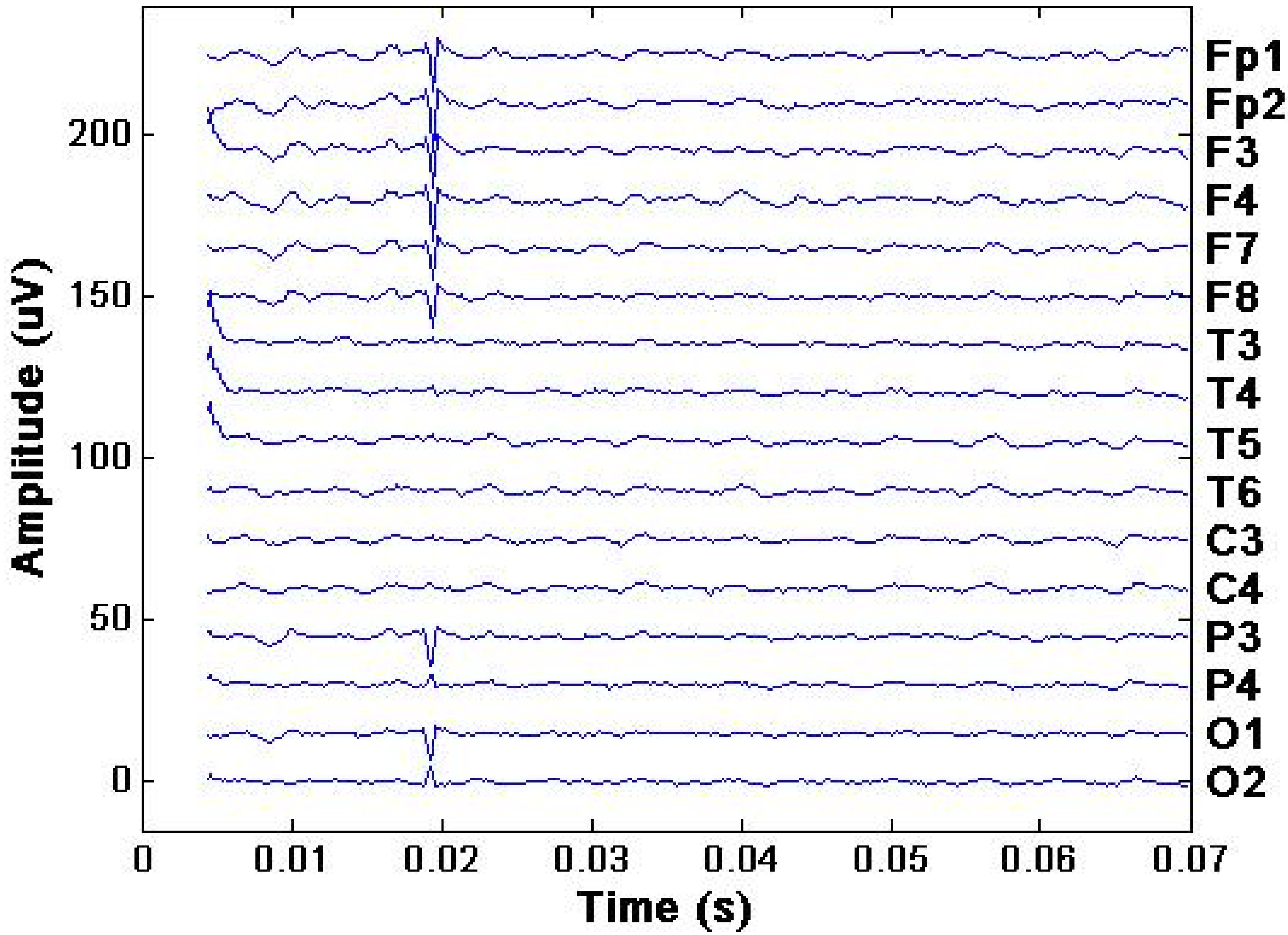
Research Challenges (Objectives)

- Develop quantitative method for predicting which patients will respond to rTMS (use pre treatment EEG parameters, QEEG)
- Develop quantitative method for determining best site of stimulation
- Determine effects of changing stimulus amplitude and frequency

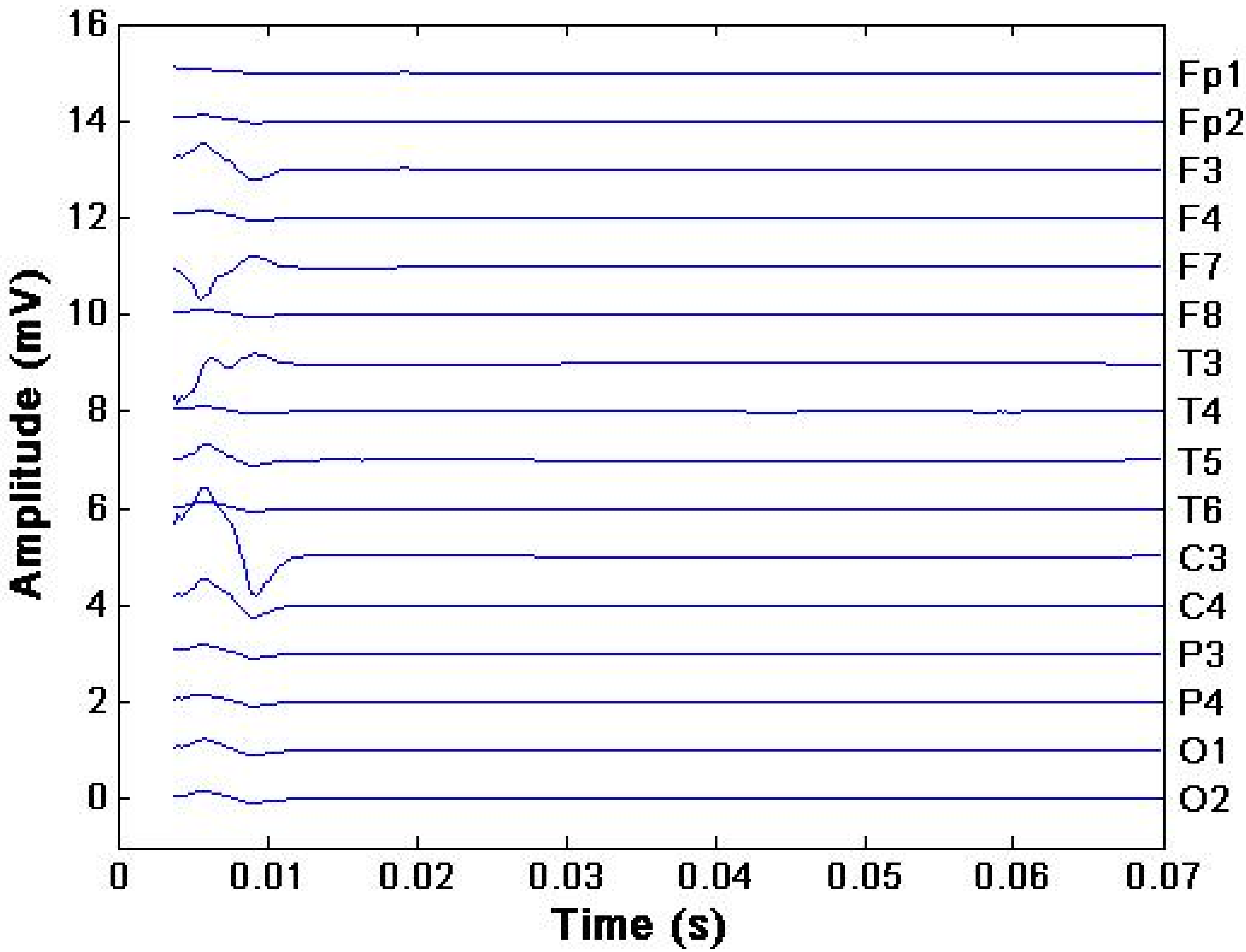
Left Side vs Right side Stimulation

- Only analyzing response in bandwidth 250 Hz - 2 KHz for short latency responses
- Series 1 is left side stimulation at 10 Hz for 8 sec at 110% MT
- Series 2 is right side stimulation at 1 Hz for 60 sec at 110% MT
- Ratio is True/Sham Response (avg signal power in 7.4 – 30 ms window) for left
- Right ratio corrected for residual background activity

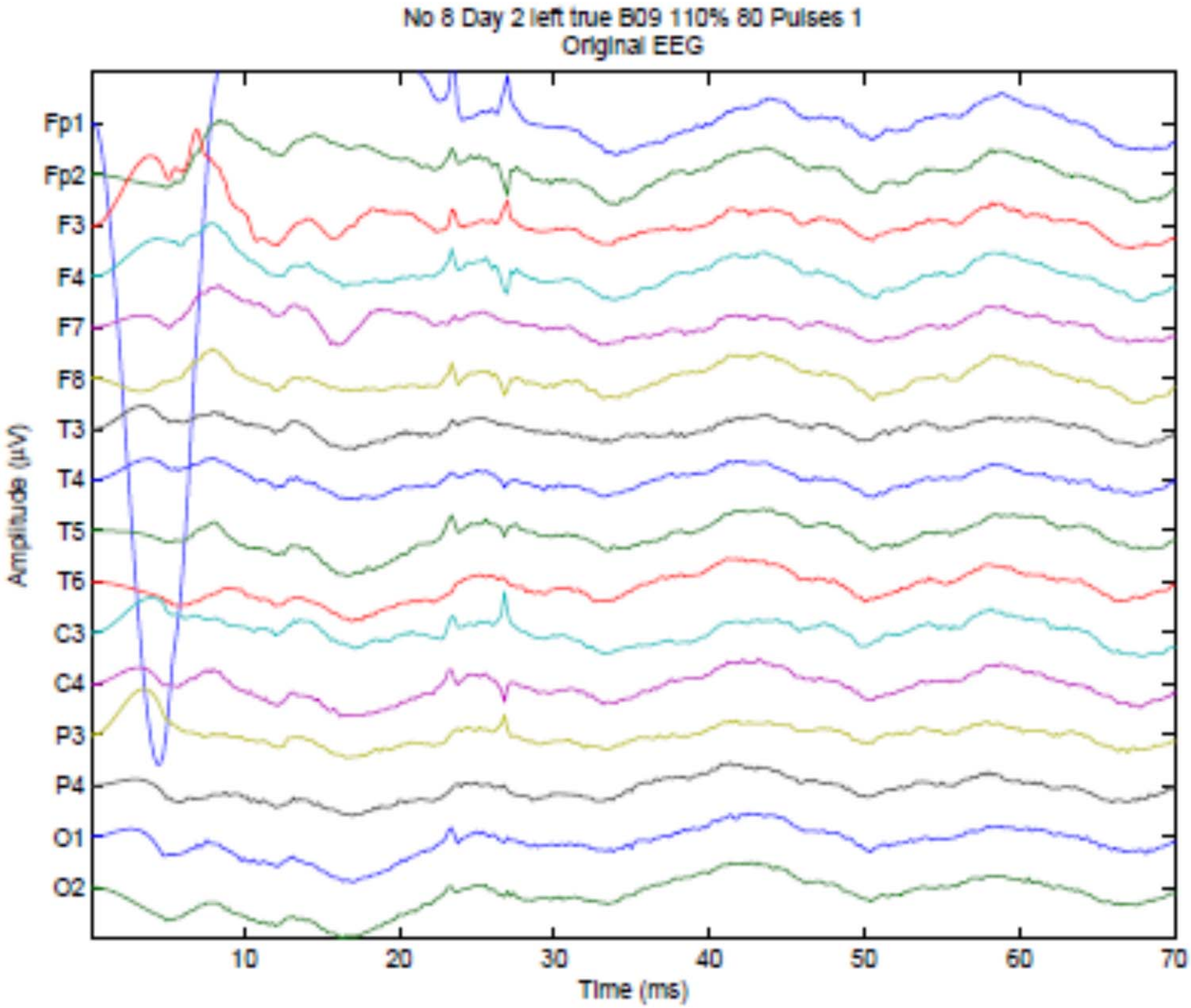
Sham Response to rTMS "Clicks"



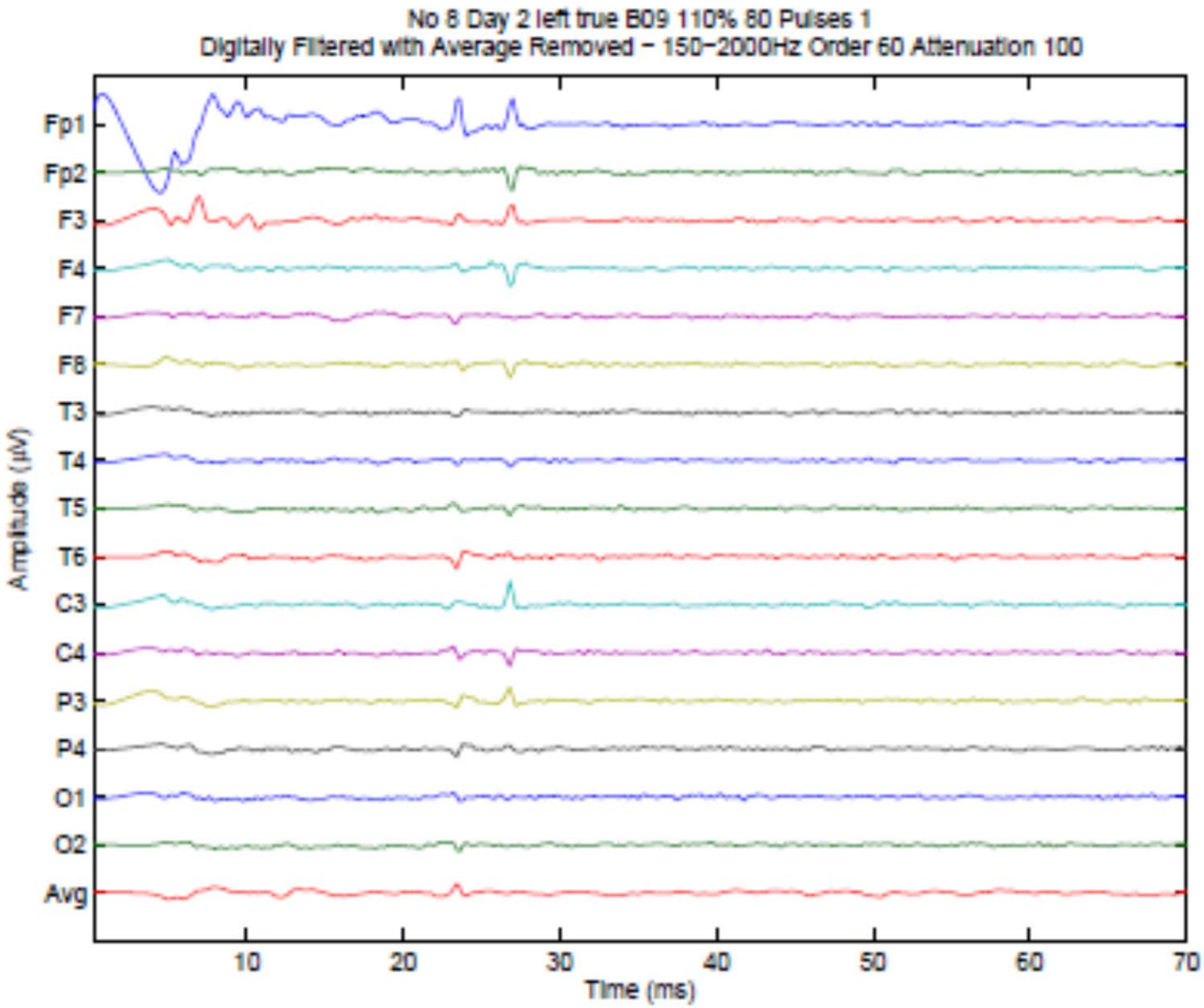
Muscle Responses during 10 Hz Left-sided Stimulation



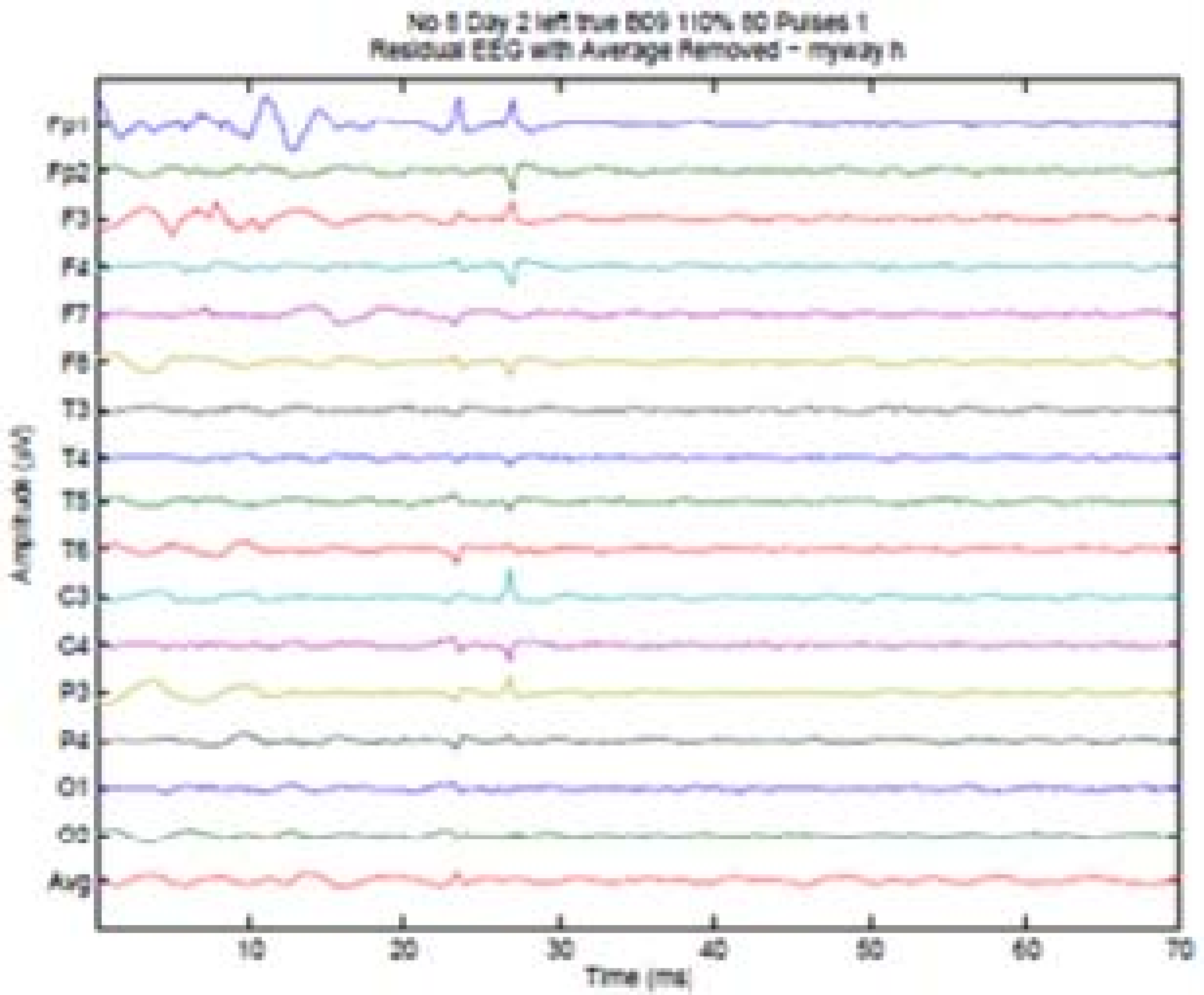
Results of Day 2 Position Study (Typical Subject)



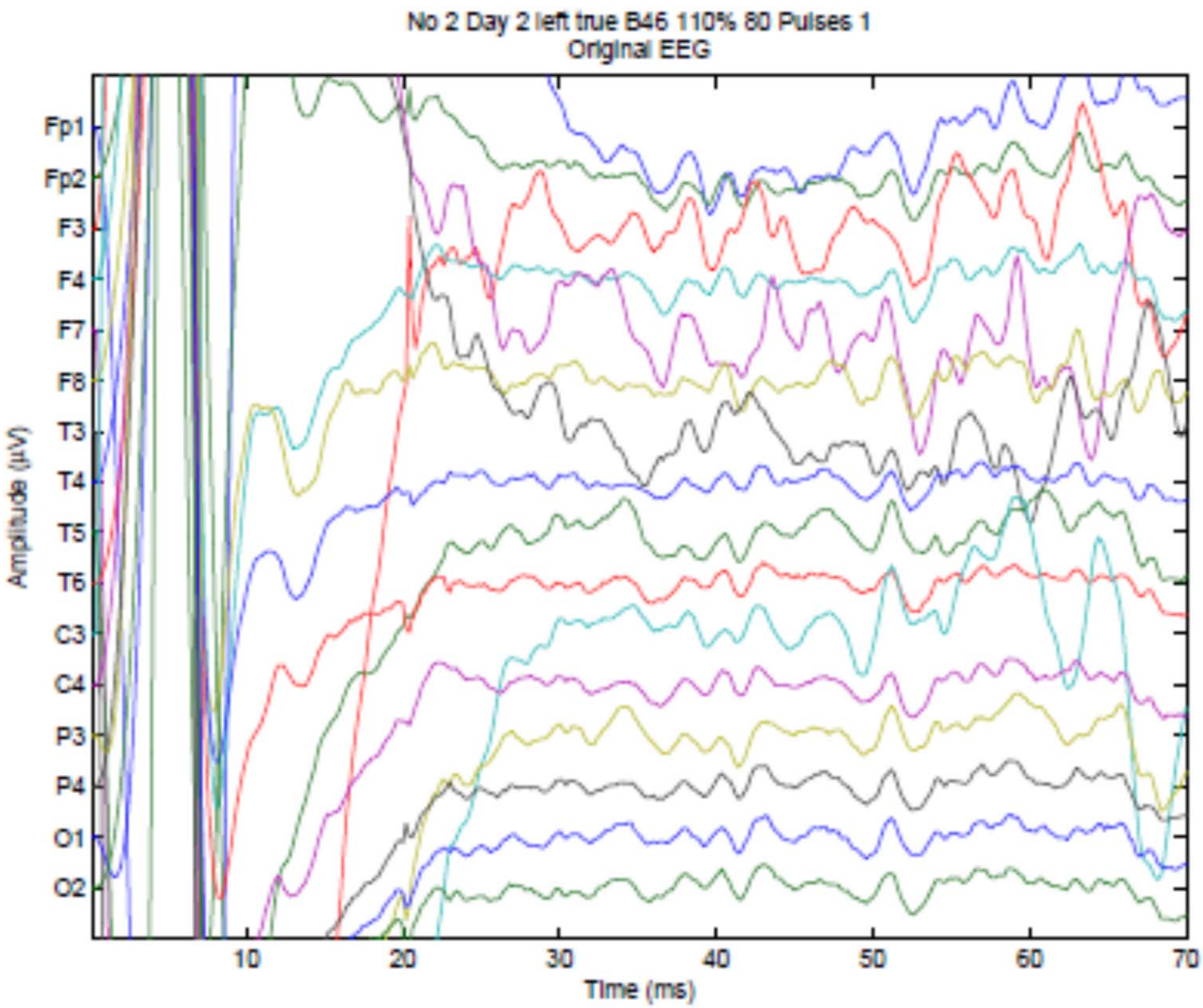
Using Digital Filtering



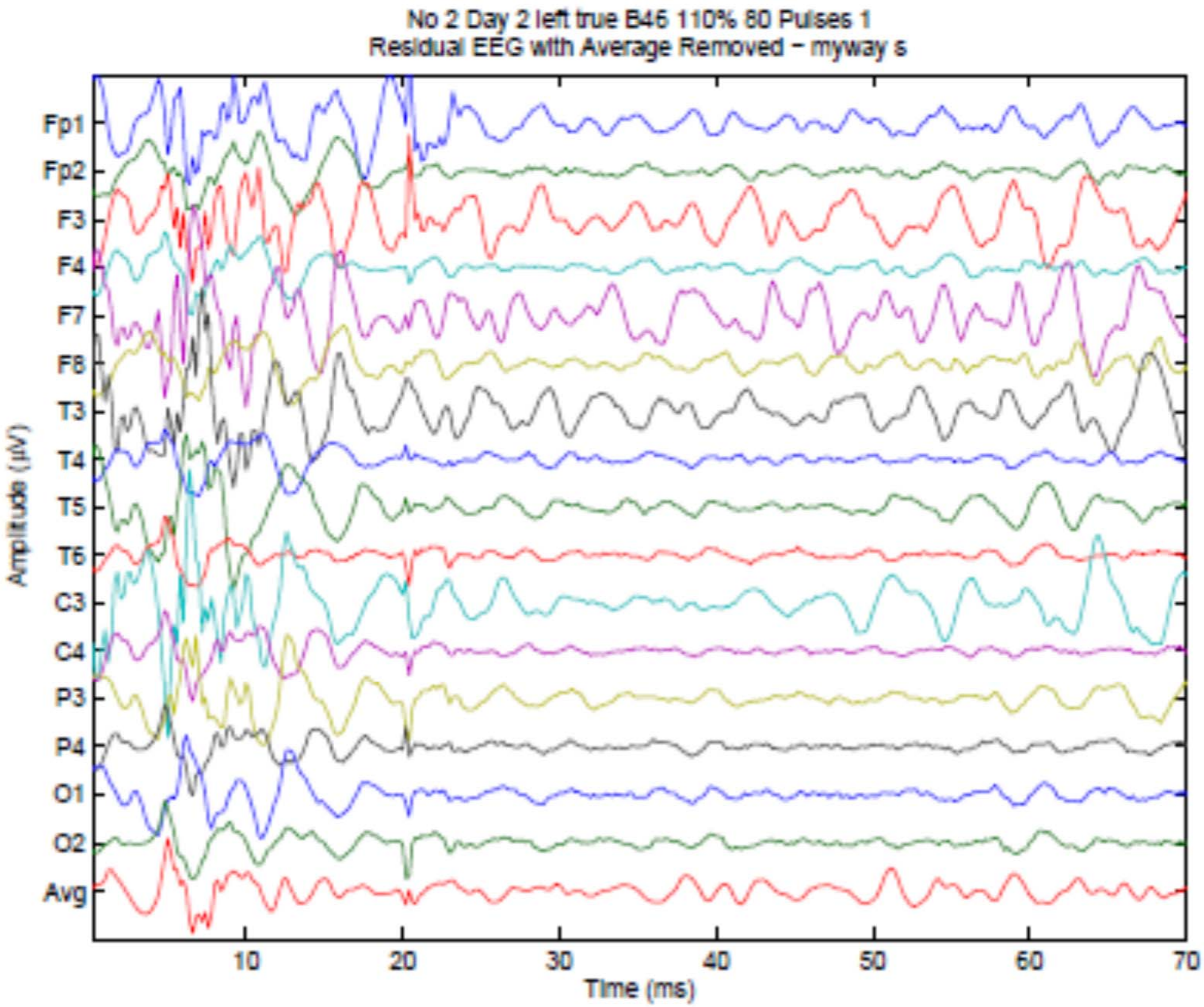
Using Wavelet Denoising



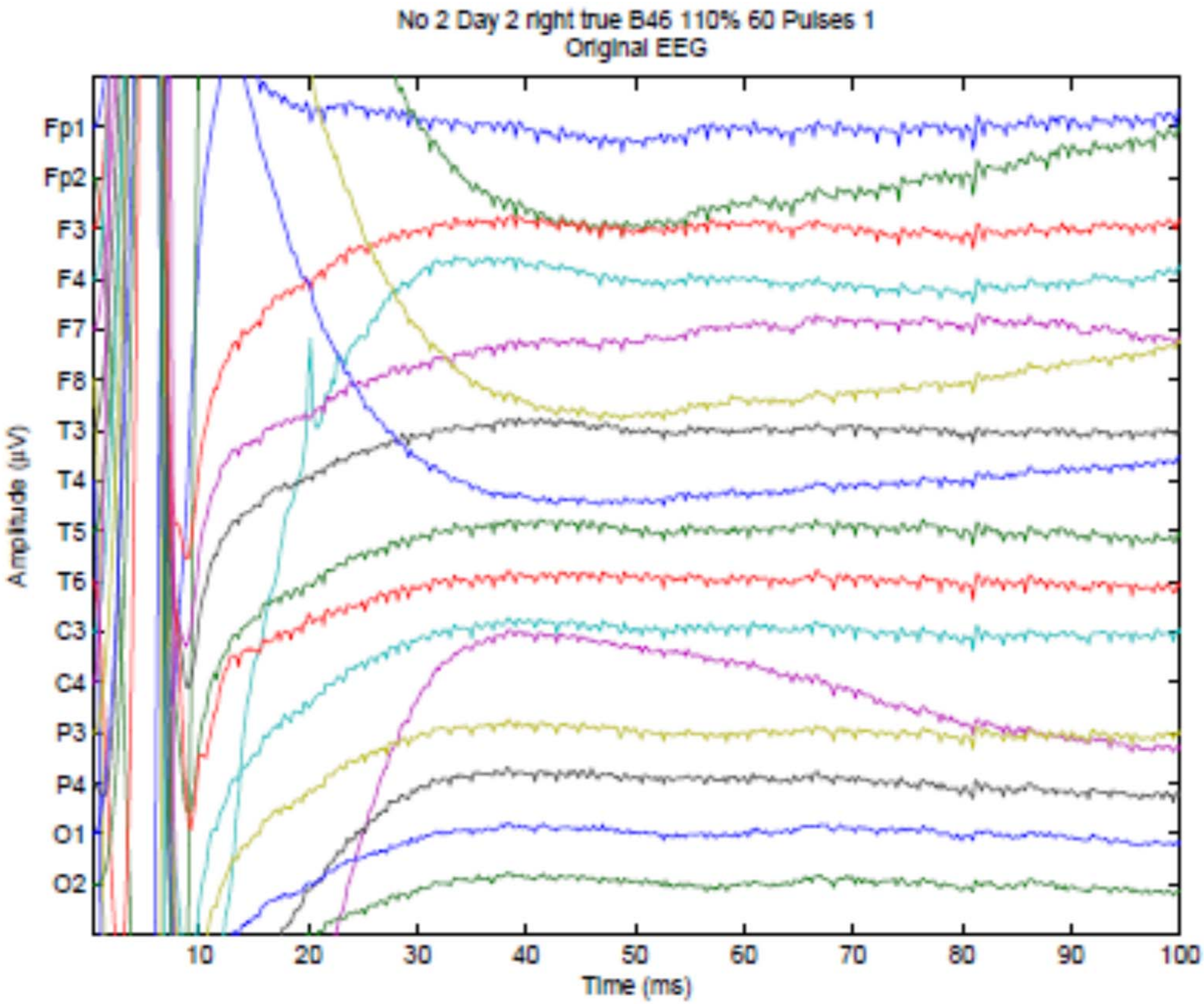
Brain Response for Sensitive Subject



Wavelet Denoised Response



Right side 1 Hz Response



Right Side Denoised Response