EE 795 Lecture 9

Electroencephalography

Outline

- Origin
- Instrumentation
- Processing
- Applications
- Future

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)

EEG Subfields

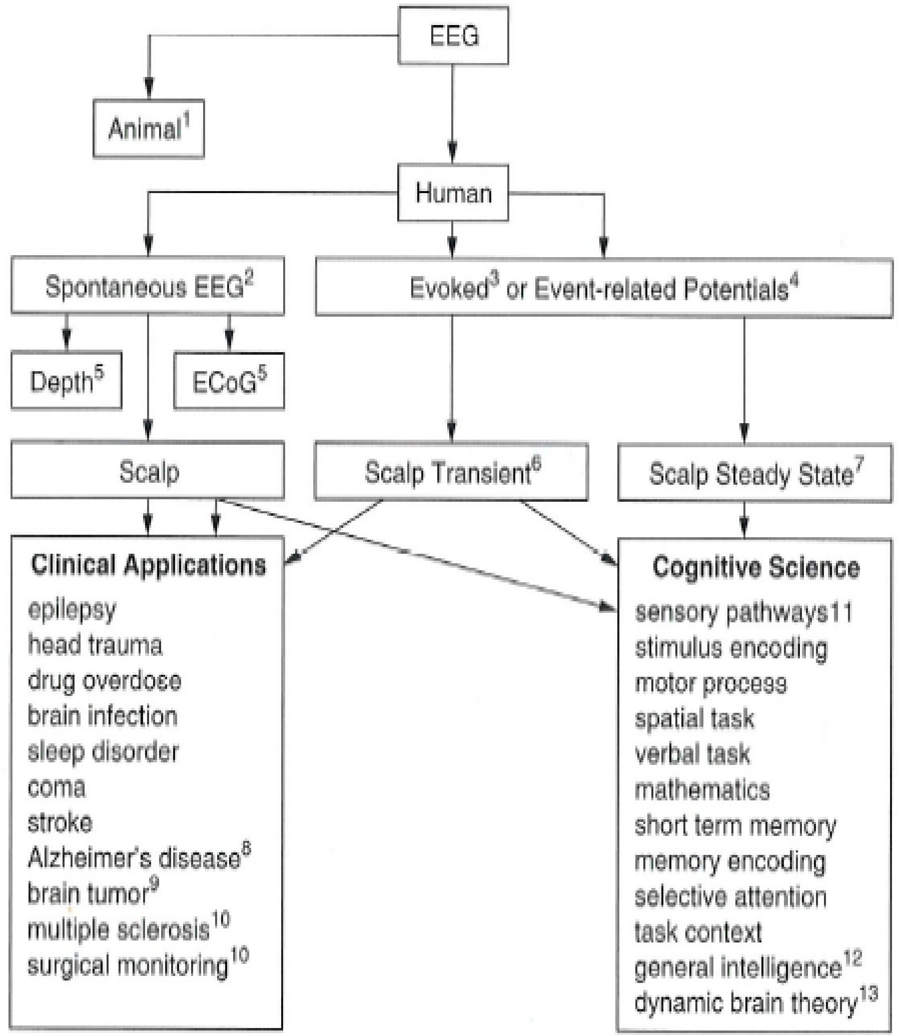


Figure 1-3 Common relationships between EEG subfields. Clinical applications are mostly related to neurological diseases. EEG research is carried out by neurologists, cognitive neuroscientists, physicists, and engineers who have a special interest in EEG. See text for a discussion of numbered superscripts.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

Structural Relationships

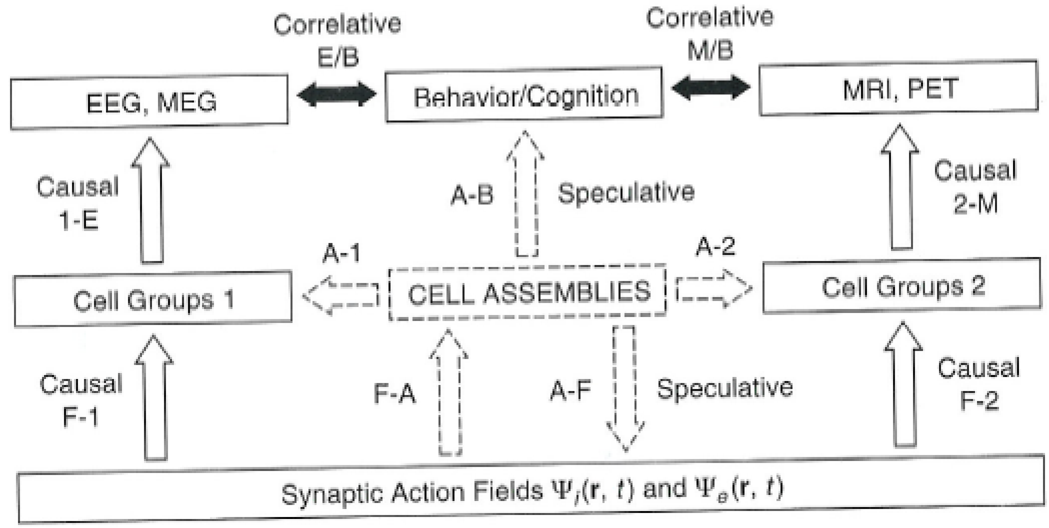


Figure 1-8 A conceptual framework for brain function. Double arrows (near top) indicate established correlative relationships between behavior/cognition and EEG, MEG, MRI, and PET. By definition, cell groups 1 generate EEG or MEG and cell groups 2 generate MRI or PET. Cell groups 1 and 2, which may or 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).

Cortical Fibres

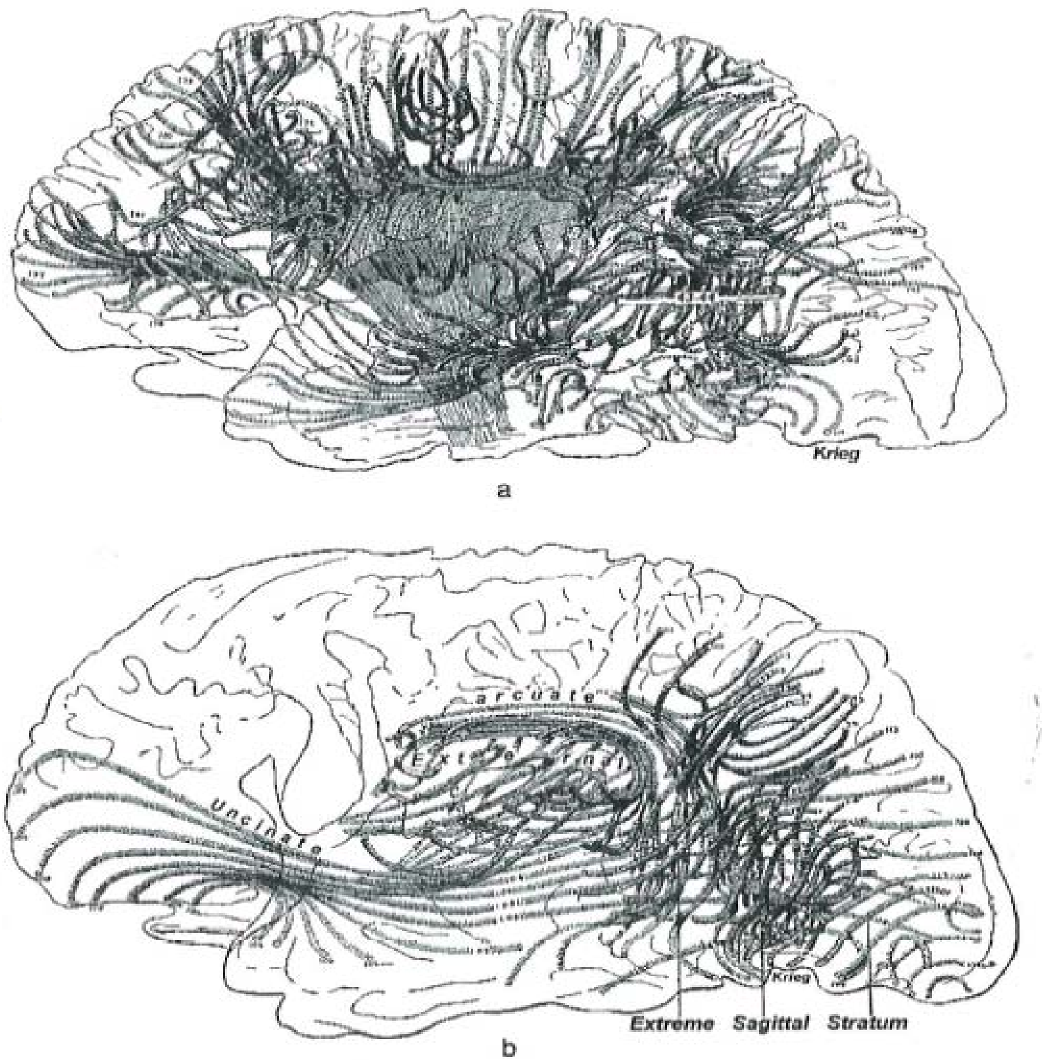


Figure 1-2 (a) Some of the superficial corticocortical fibers of the lateral aspect of the cerebrum obtained by dissection. (b) A few of the deeper corticocortical fibers of the lateral aspect of the cerebrum. The total number of corticocortical fibers is roughly 10^{10}, that is, for every fiber shown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

Overview (EEG)

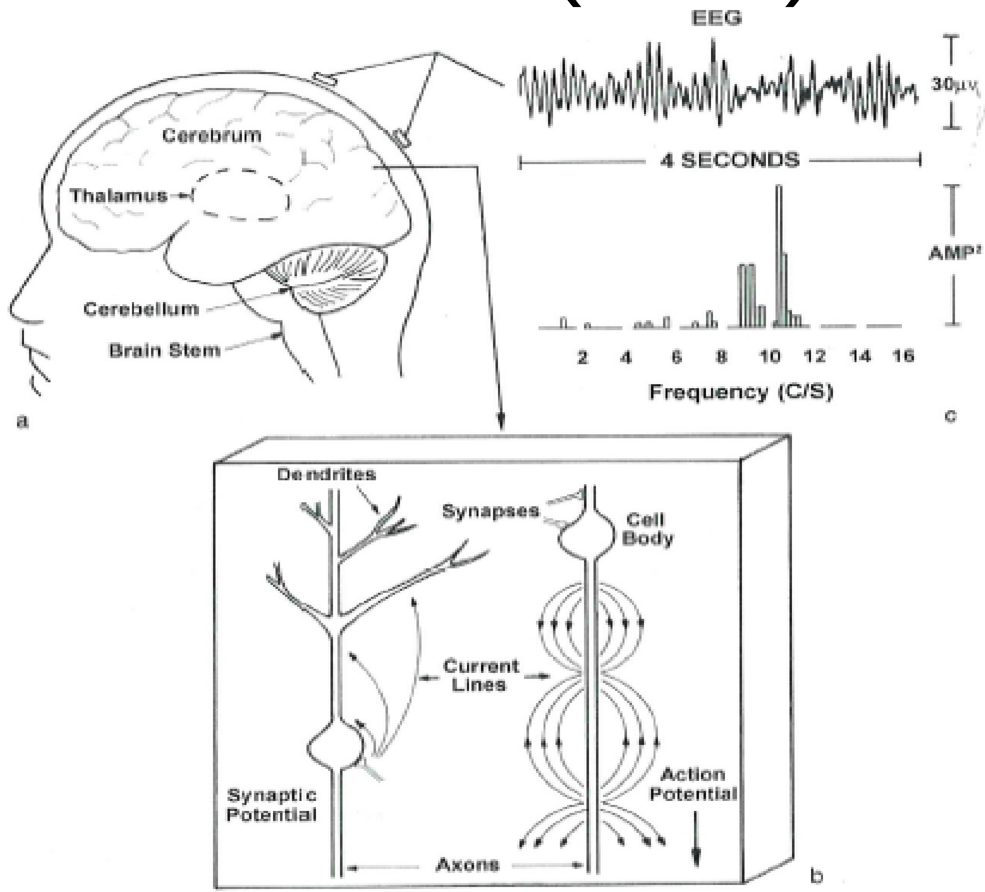


Figure 1-1 (a) The human brain. (b) Section of cerebral cortex showing microcurrent sources due to synaptic and action potentials. Neurons are actually much more closely packed than shown, about 10^5 neurons per mm^2 of surface. (c) Each scalp EEG electrode records space averages over many square centimeters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

Cortical Contributions

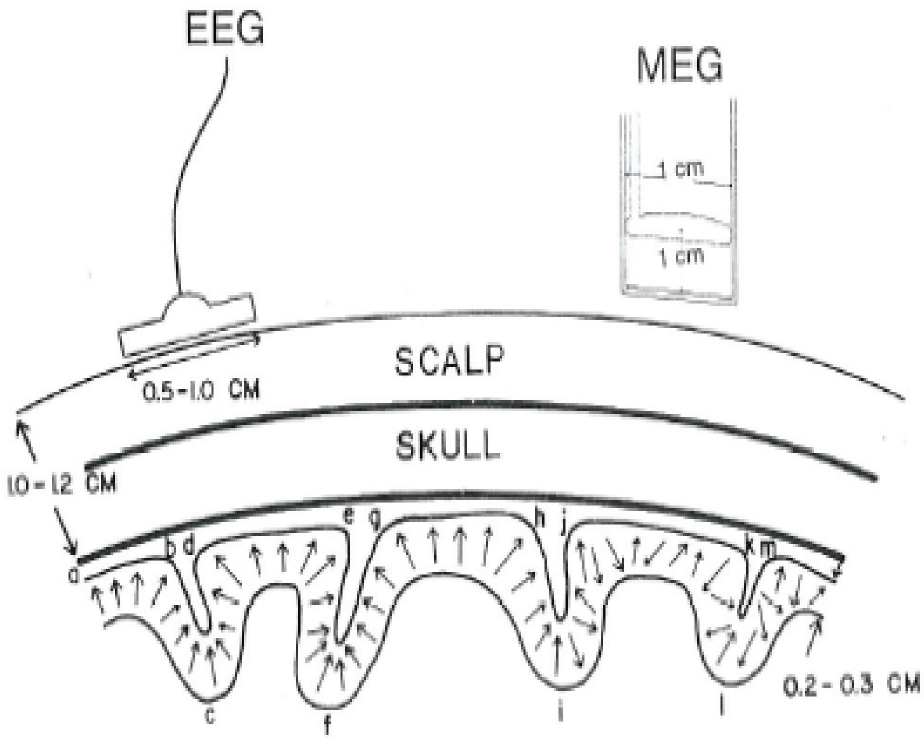


Figure 2-3 Neocortical sources can be generally pictured as *dipole layers* (or "dipole sheets," in and out of cortical fissures and sulci) with mesosource strength varying as a function of cortical location. EEG is most sensitive to correlated dipole layer in gyri (regions ab, de, gh), less sensitive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

Instrumentation (EEG Electrodes)

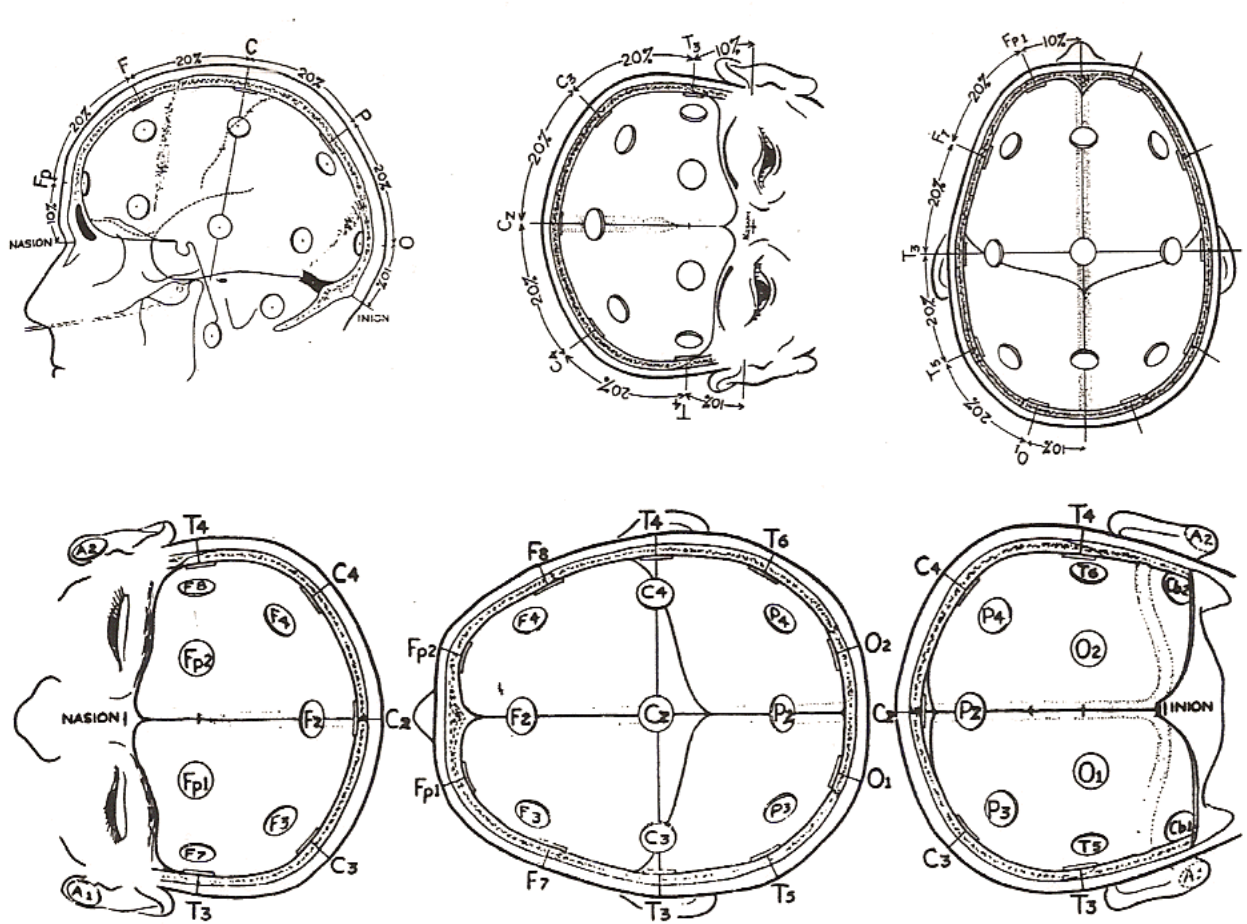
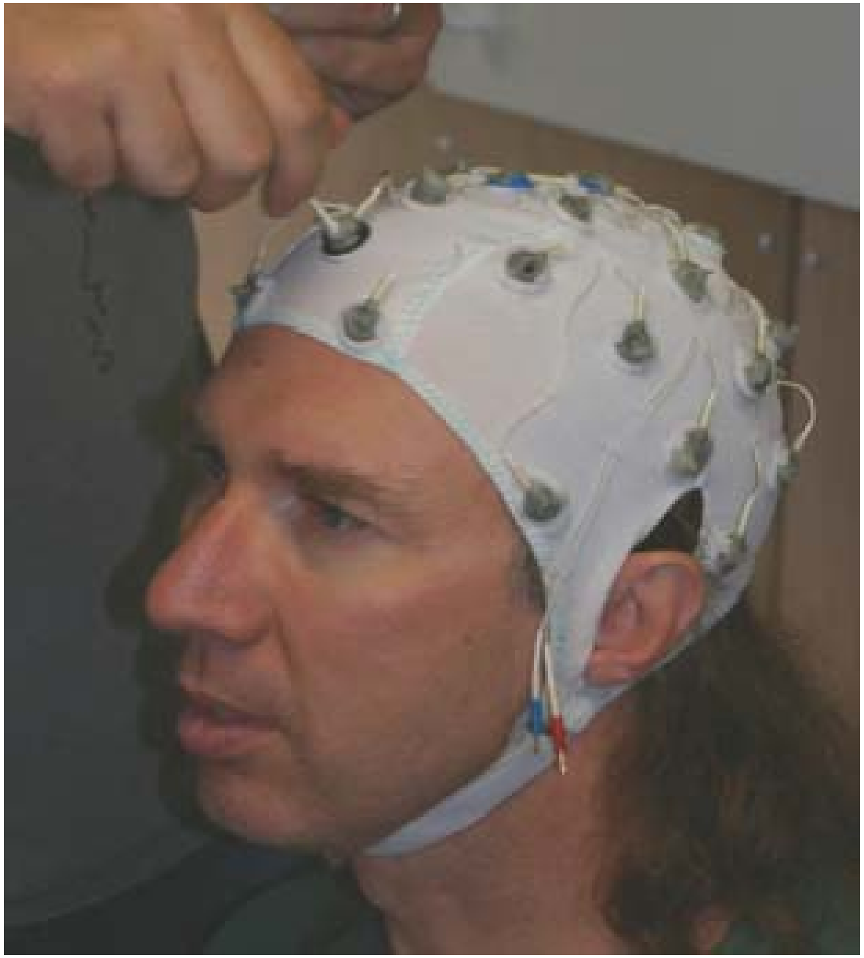


Figure 4.28 The 10-20 electrode system This system is recommended by the International Federation of EEG Societies. (From H. H. Jasper, "The Ten-Twenty Electrode System of the International Federation in Electroencepha-

Electrode Placement



Cortical Electrodes

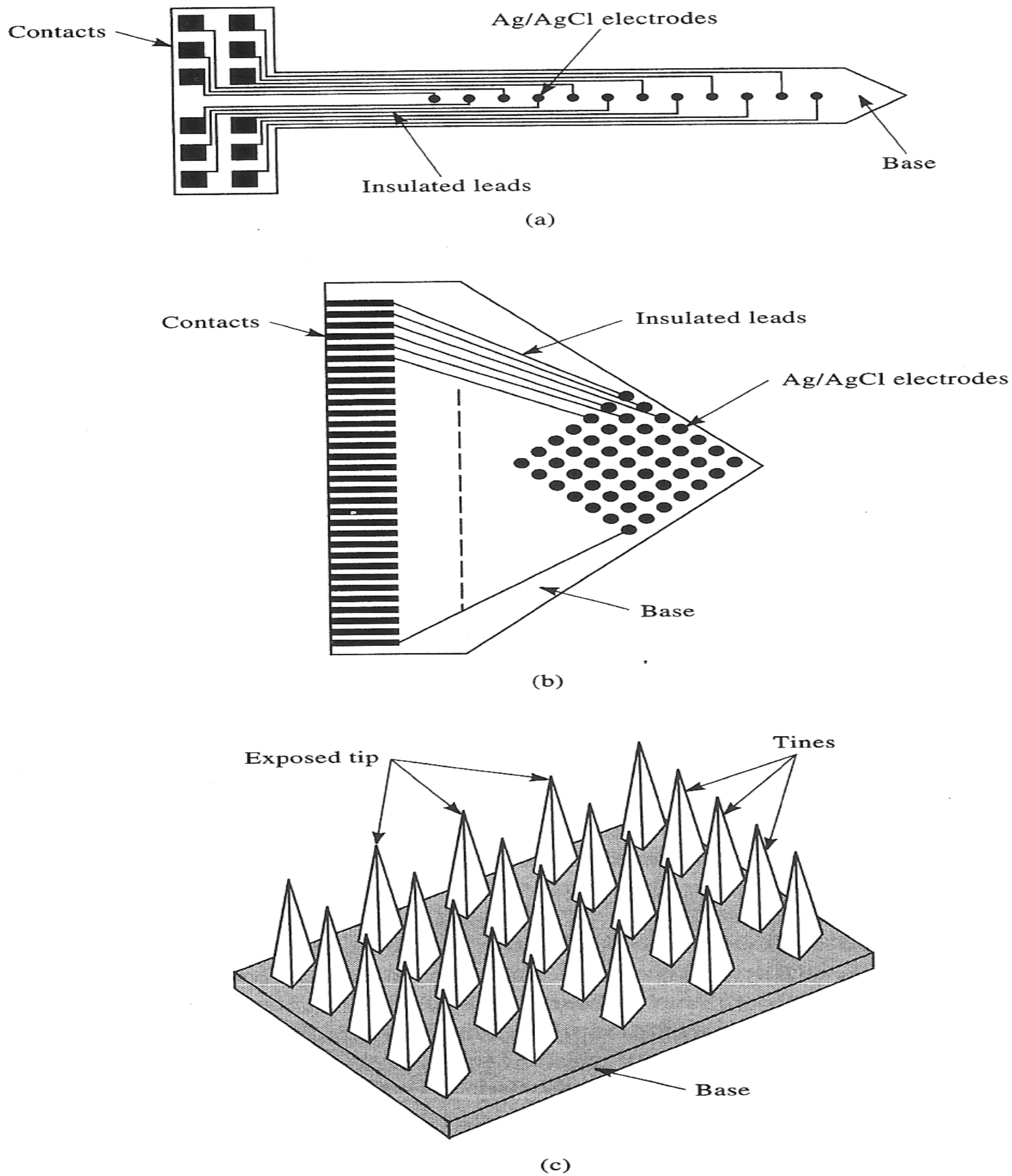


Figure 5.16 Examples of microfabricated electrode arrays. (a) One-dimensional plunge electrode array (after Mastrototaro *et al.*, 1992), (b) Two-dimensional array, and (c) Three-dimensional array (after Campbell *et al.*, 1991).

Amplifier Connections

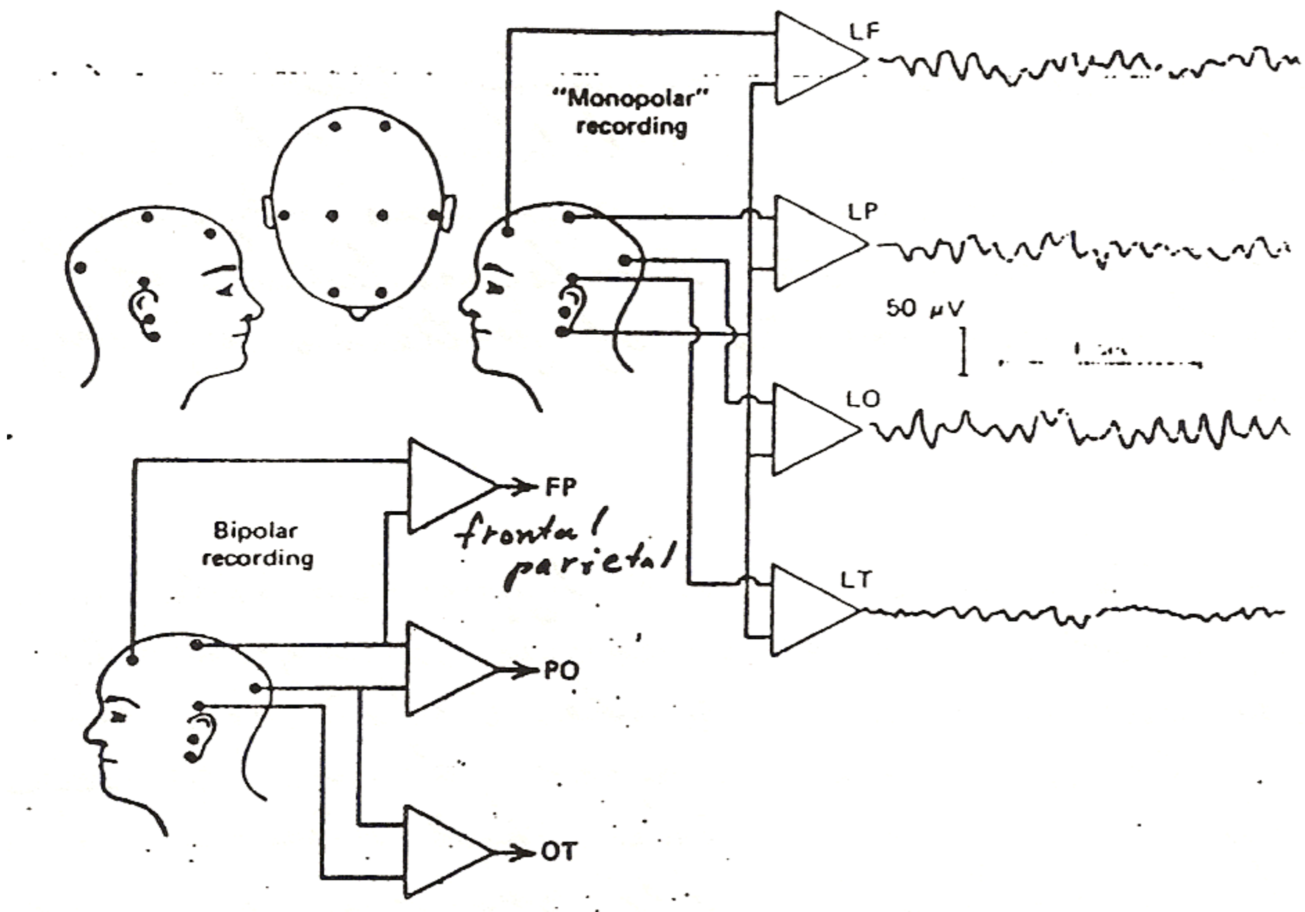


Figure 11-52. Method of connecting the recording channels for "monopolar" and bipolar recording. With "monopolar" recording, the reference electrode is on the earlobe, chin, or neck

EEG Signal Processing

- Spontaneous EEG is one of few electrophysiological signals that has information primarily in frequency content
- Time-amplitude information in evoked EEG and spontaneous EEG
- Spontaneous processing includes Fourier (stationary) and Wavelet analysis (non stationary)

General Bandwidths

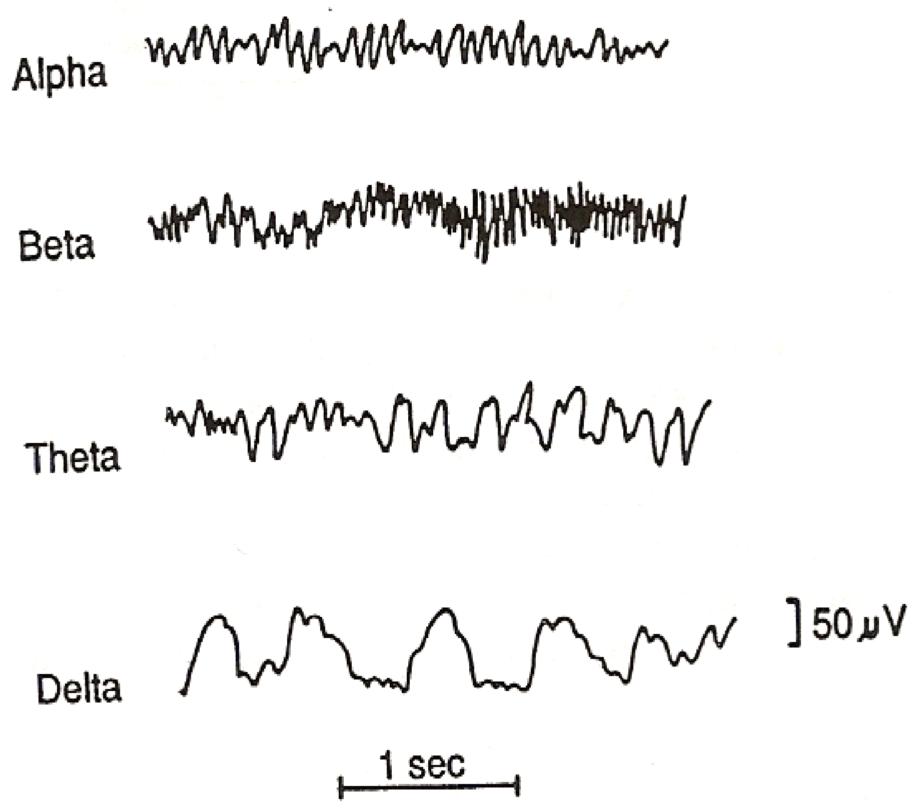


Figure 59–1. Different types of normal electroencephalographic waves.

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

Alpha Predominance

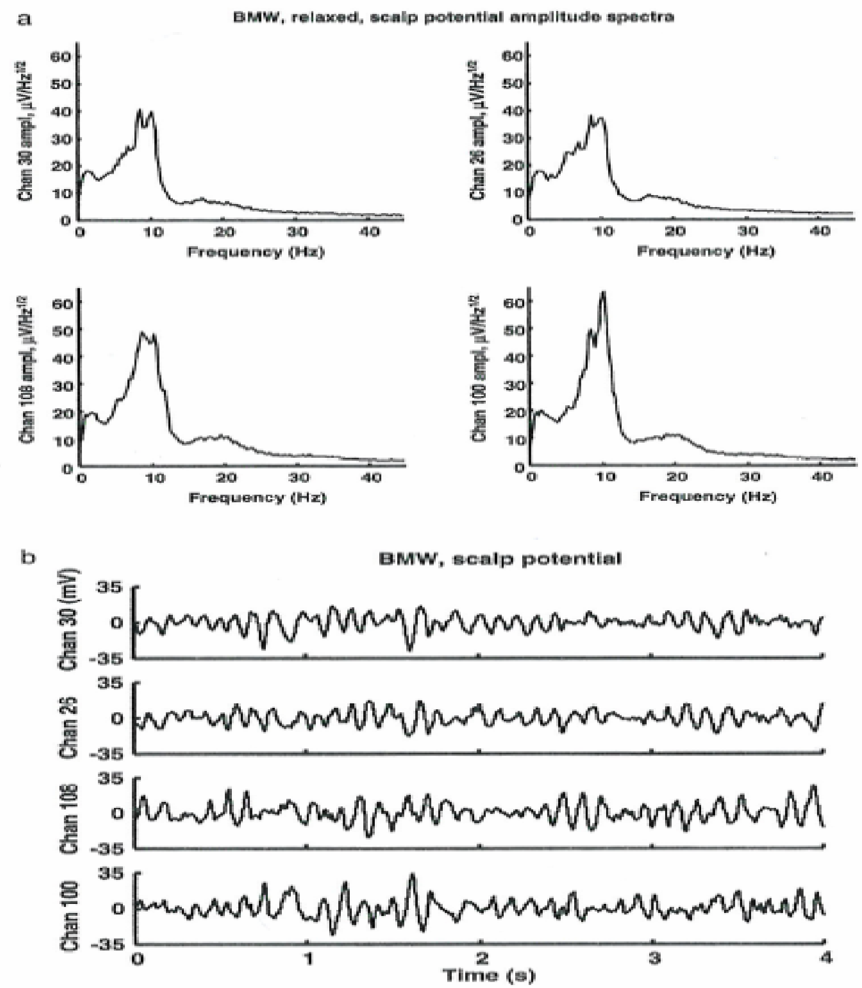


Figure 1-4 (b) Alpha rhythm recorded from a healthy 25-year-old relaxed male with eyes closed using a neck electrode as reference. Four seconds of data are shown from four scalp locations (left frontal-30; right frontal-26; left posterior-108; right posterior-100). Amplitudes are given in μV. (a) Amplitude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

Applications

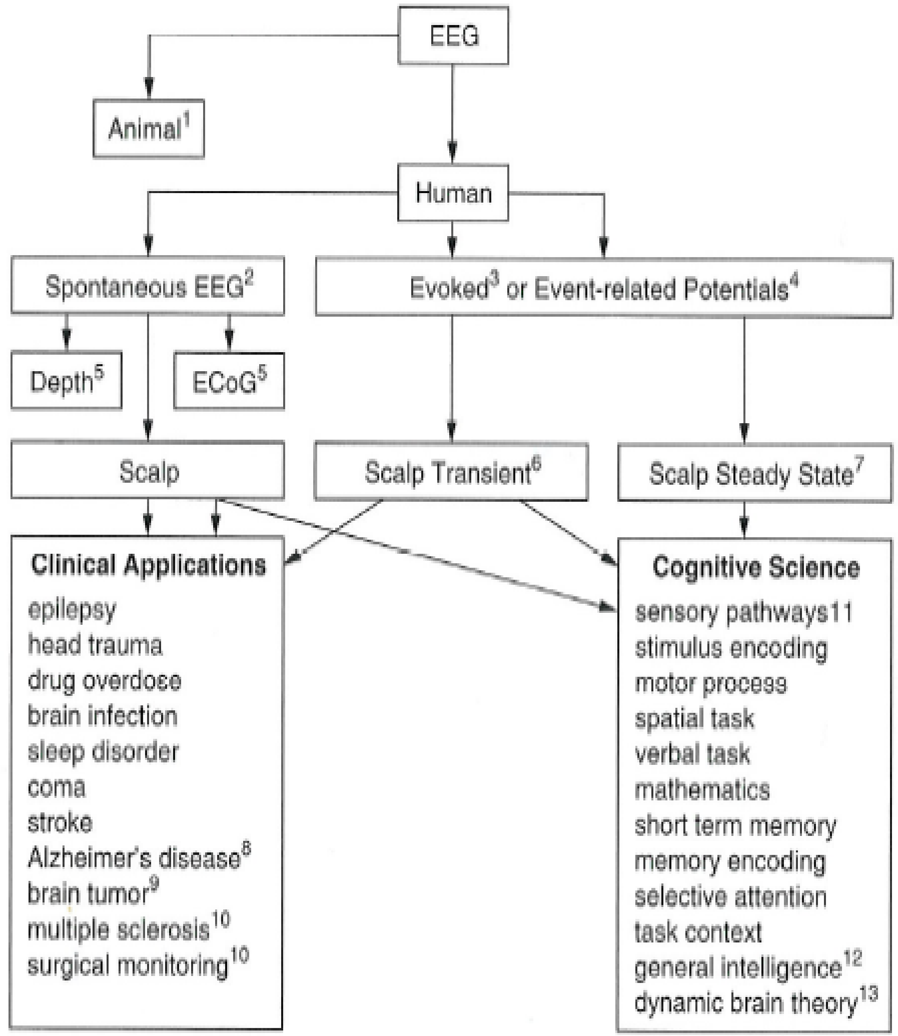
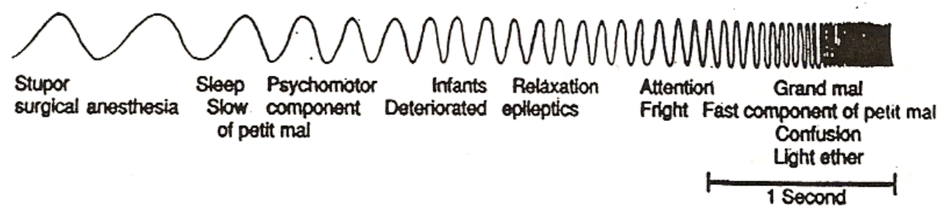


Figure 1-3 Common relationships between EEG subfields. Clinical applications are mostly related to neurological diseases. EEG research is carried out by neurologists, cognitive neuroscientists, physicists, and engineers who have a special interest in EEG. See text for a discussion of numbered superscripts.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

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)

Epilepsy

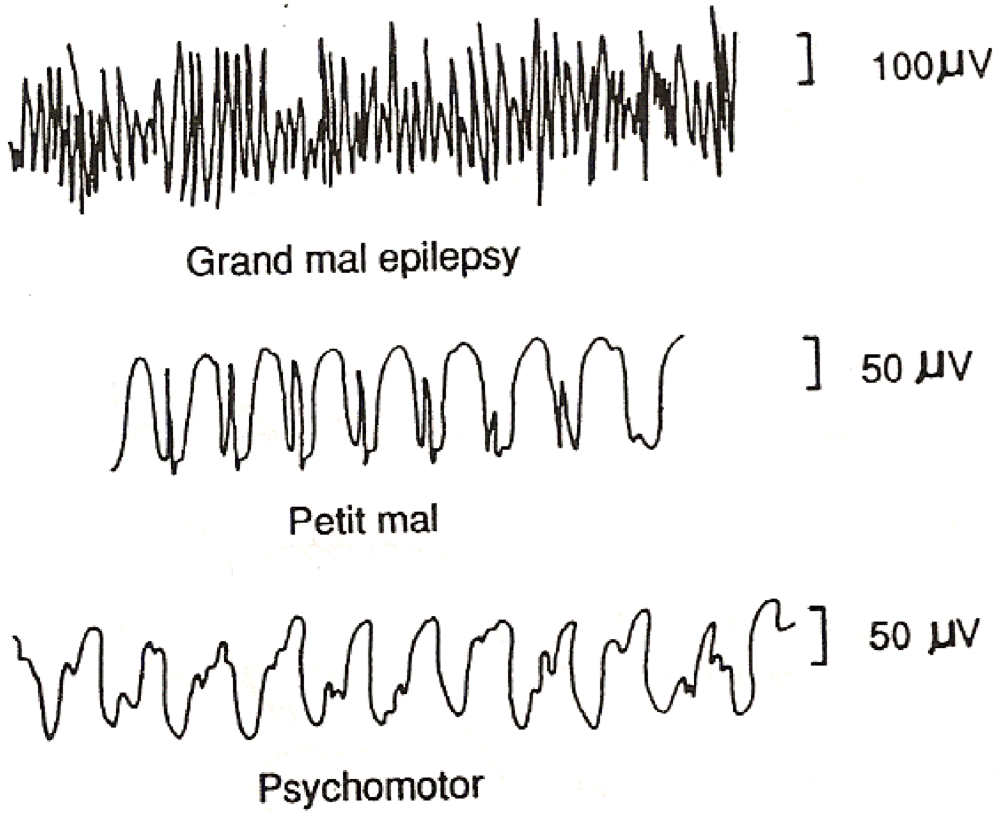
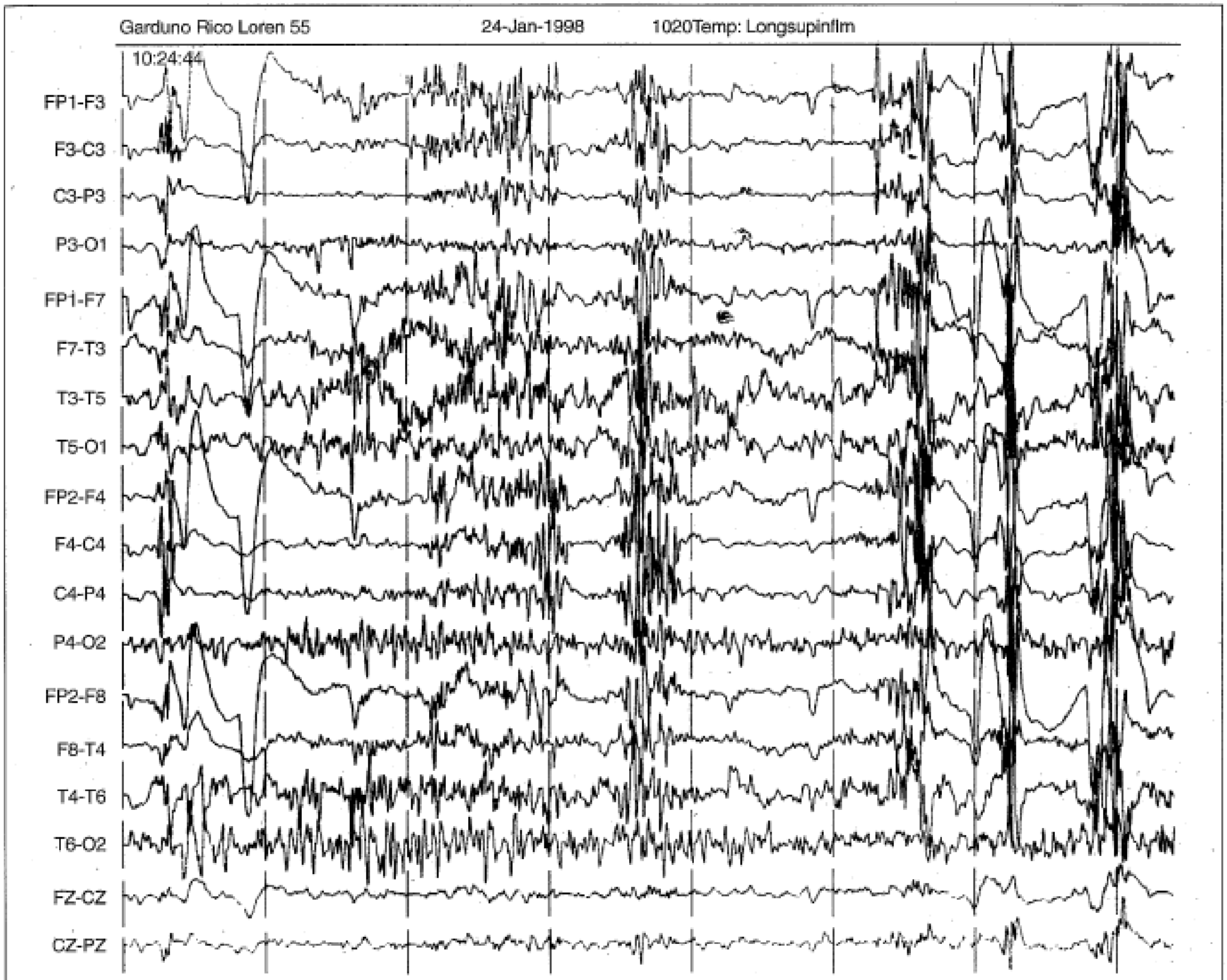


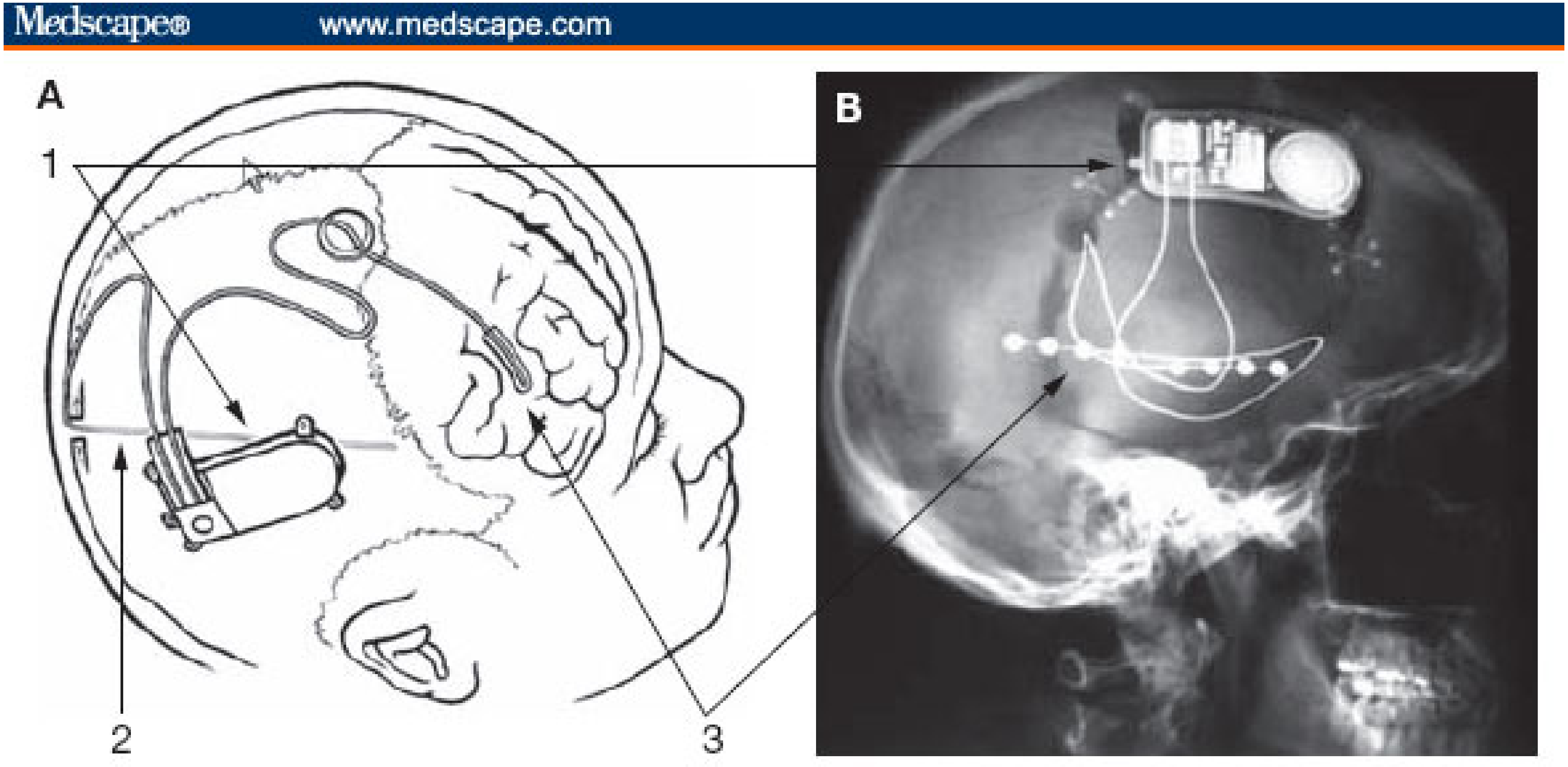
Figure 59–5. Electroencephalograms in different types of epilepsy.

Epilepsy EEG Signal



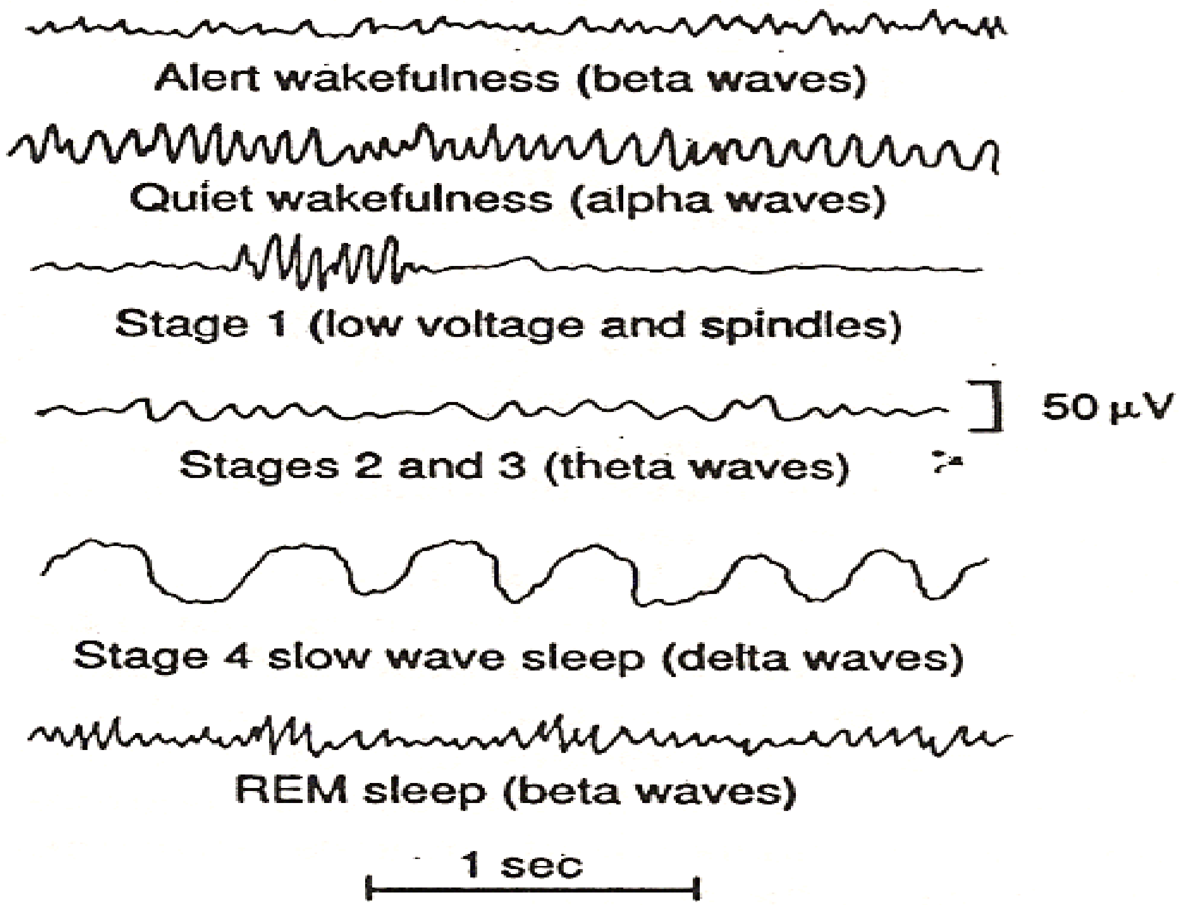
6. Record of a subject with seizure activity during sleep. The system detects the initial three spikes in 1 sec at the start of the sei-

Closed Loop Epilepsy Treatment

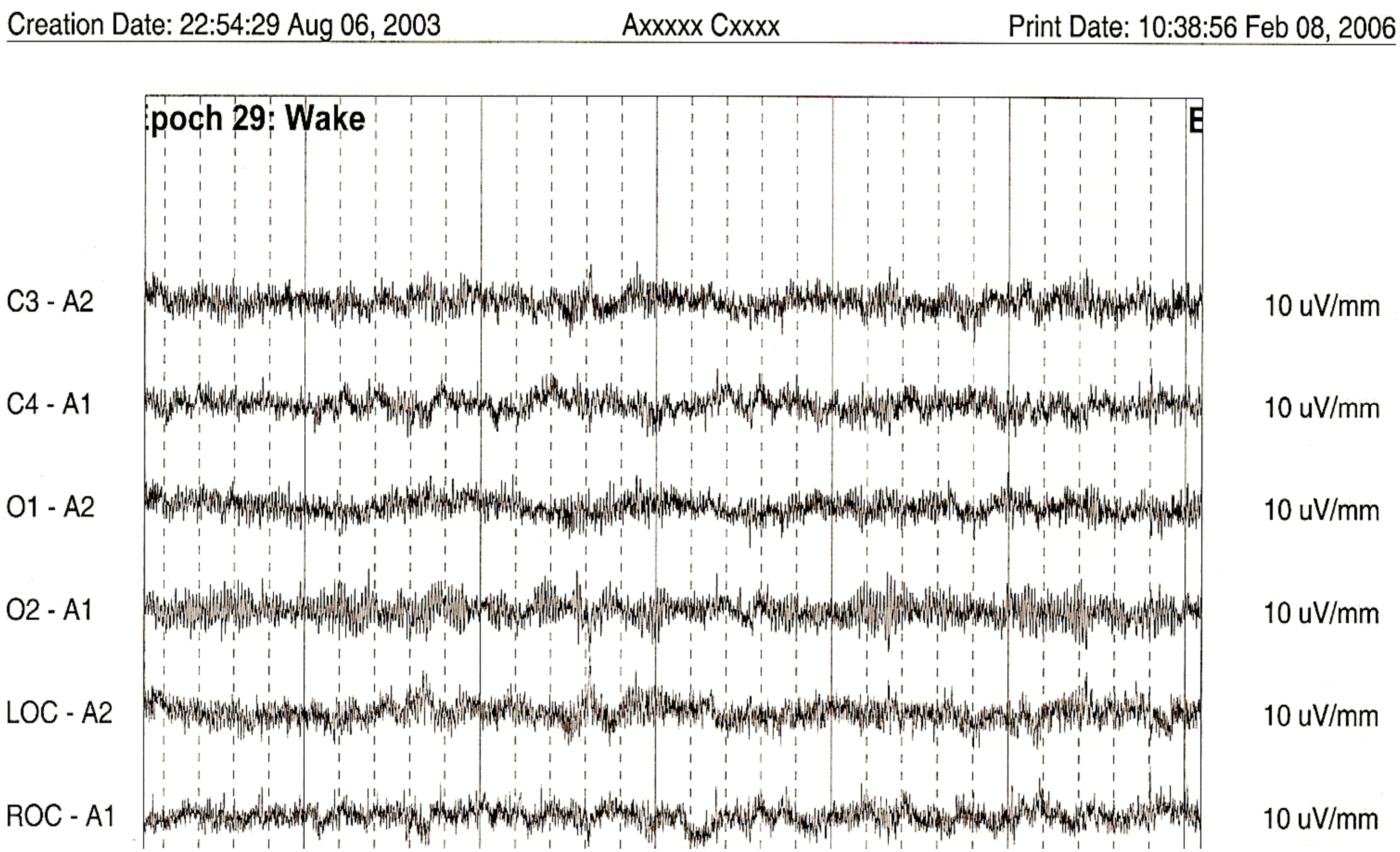


Source: Nat Clin Pract Neurol © 2008 Nature Publishing Group

Sleep Staging

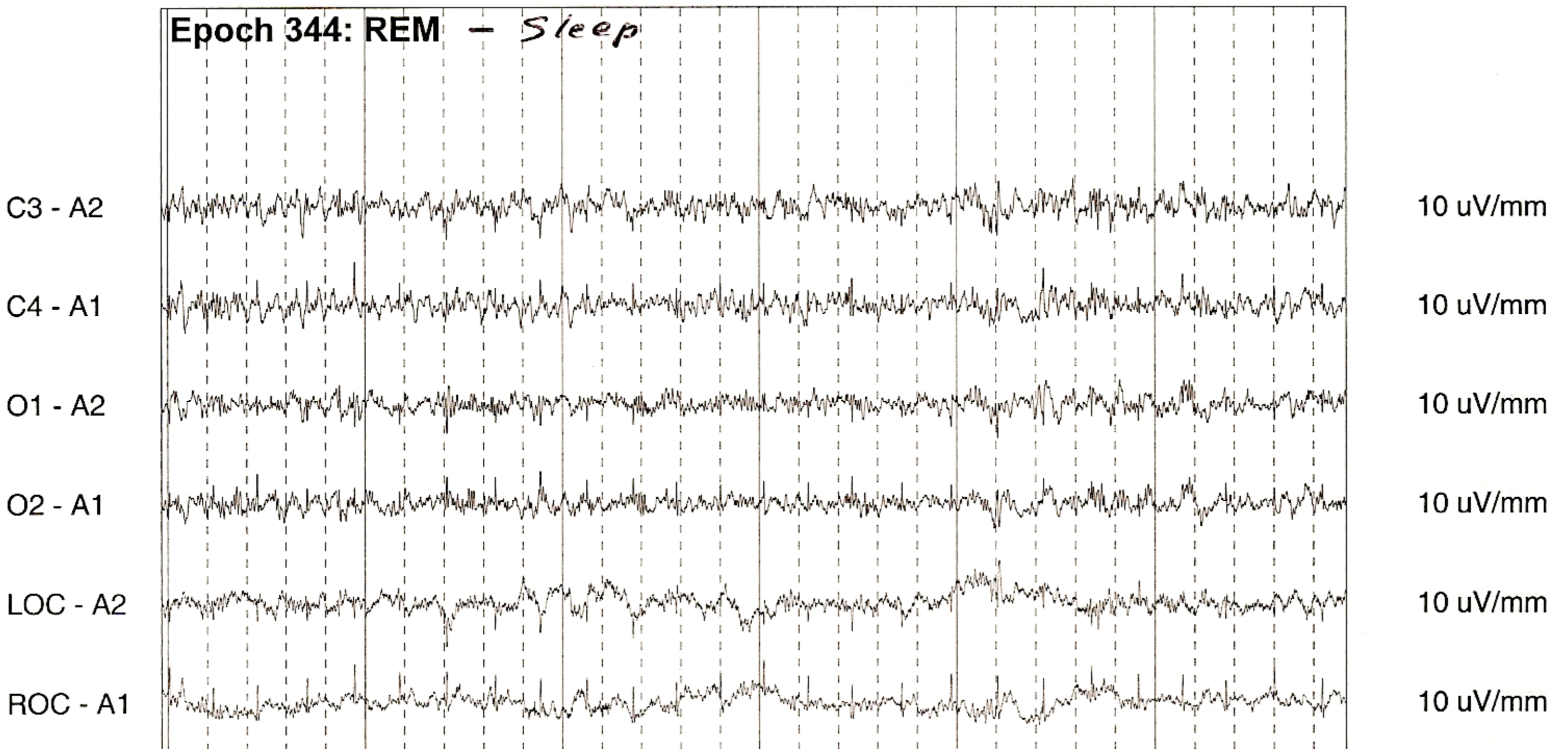


Awake



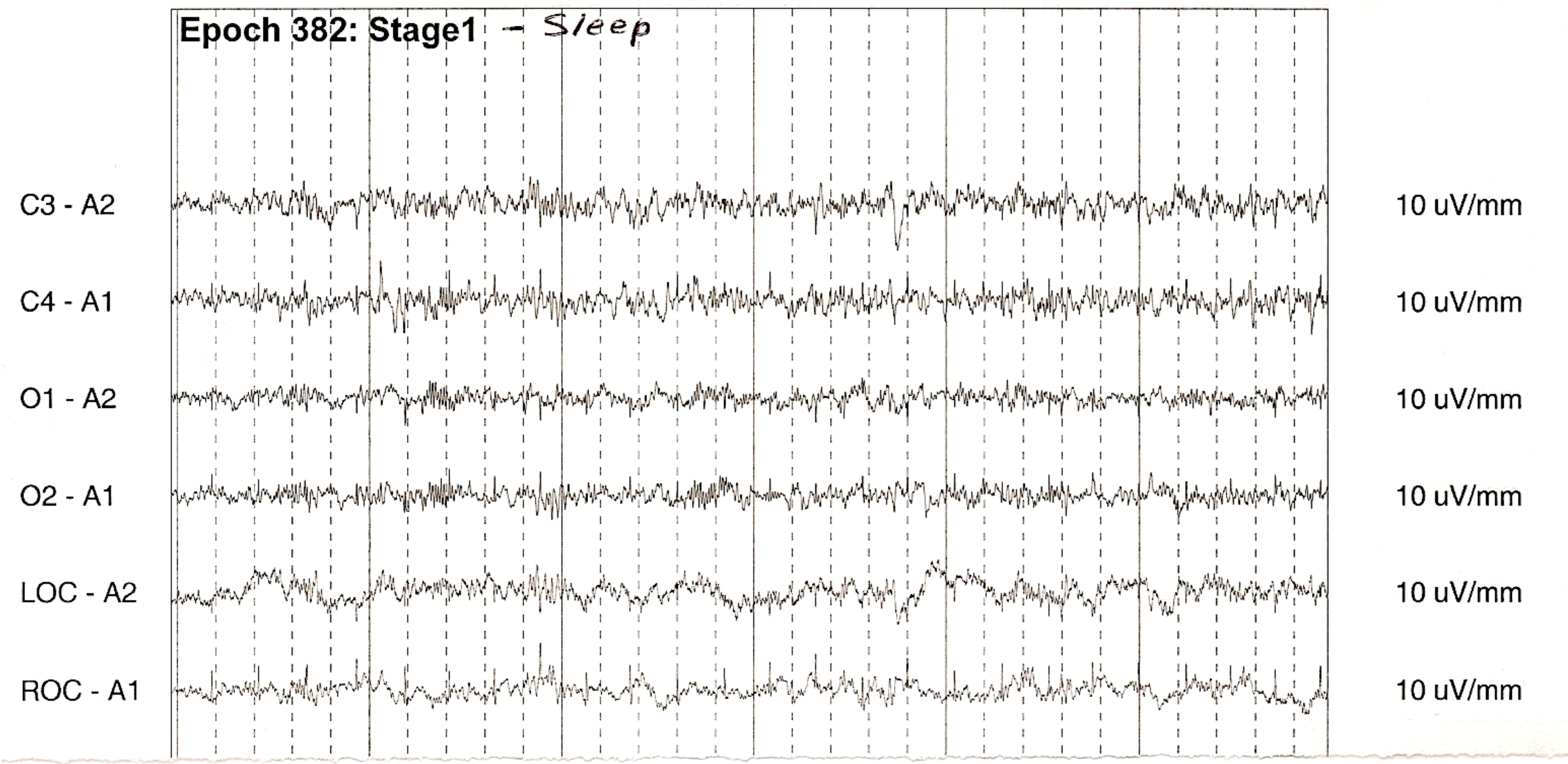
Creation Date: 22:54:29 Aug 06, 2003
Axxxxx Cxxxx
Print Date: 10:38:56 Feb 08, 2006
poch 29: Wake
C3 - A2
C4 - A1
O1 - A2
O2 - A1
LOC - A2
ROC - A1
10 uV/mm
10 uV/mm
10 uV/mm
10 uV/mm
10 uV/mm
10 uV/mm

REM



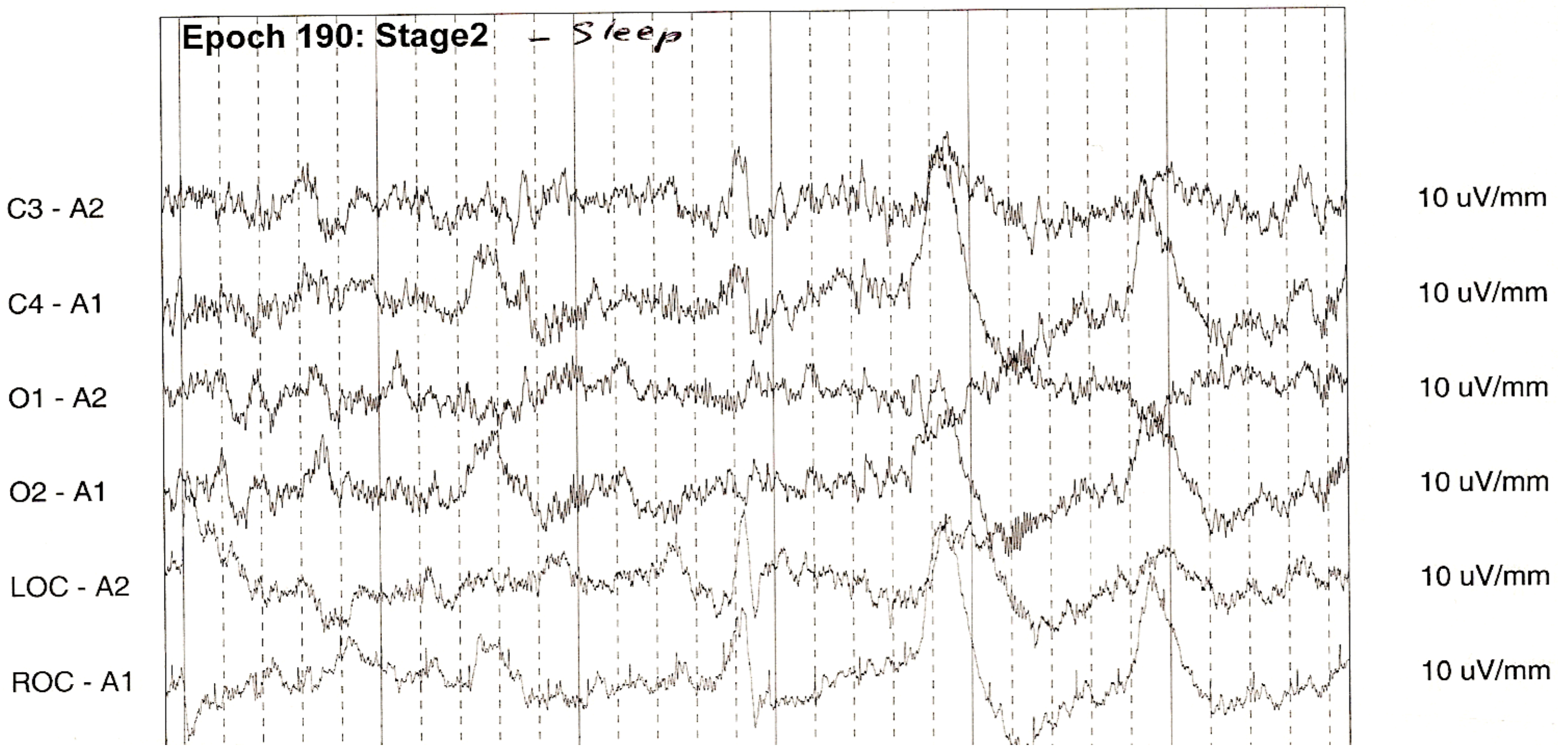
Epoch 344: REM — Sleep
C3 - A2
C4 - A1
O1 - A2
O2 - A1
LOC - A2
ROC - A1
10 uV/mm
10 uV/mm
10 uV/mm
10 uV/mm
10 uV/mm
10 uV/mm

Stage 1

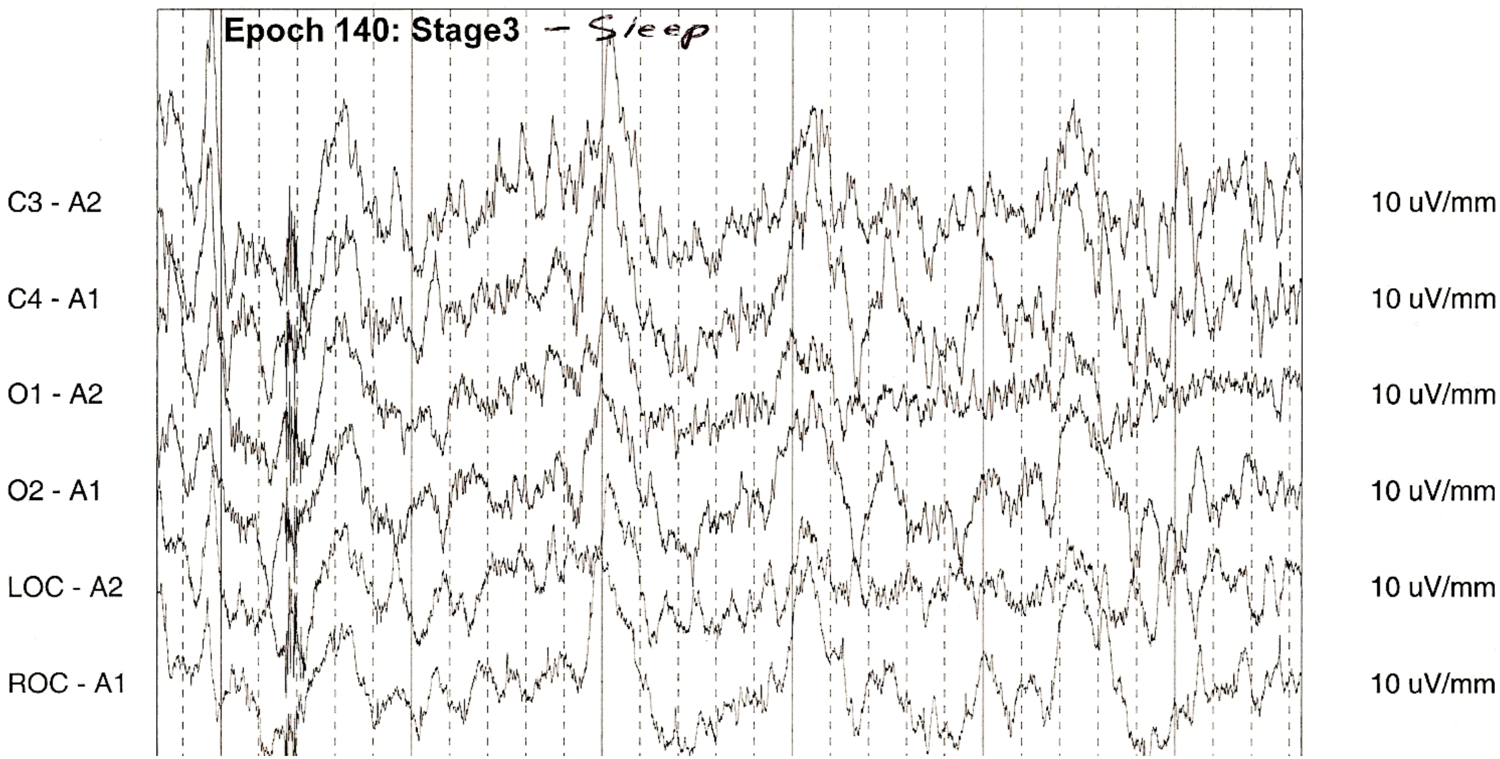


Epoch 382: Stage1 – Sleep
C3 - A2
C4 - A1
O1 - A2
O2 - A1
LOC - A2
ROC - A1
10 uV/mm
10 uV/mm
10 uV/mm
10 uV/mm
10 uV/mm
10 uV/mm

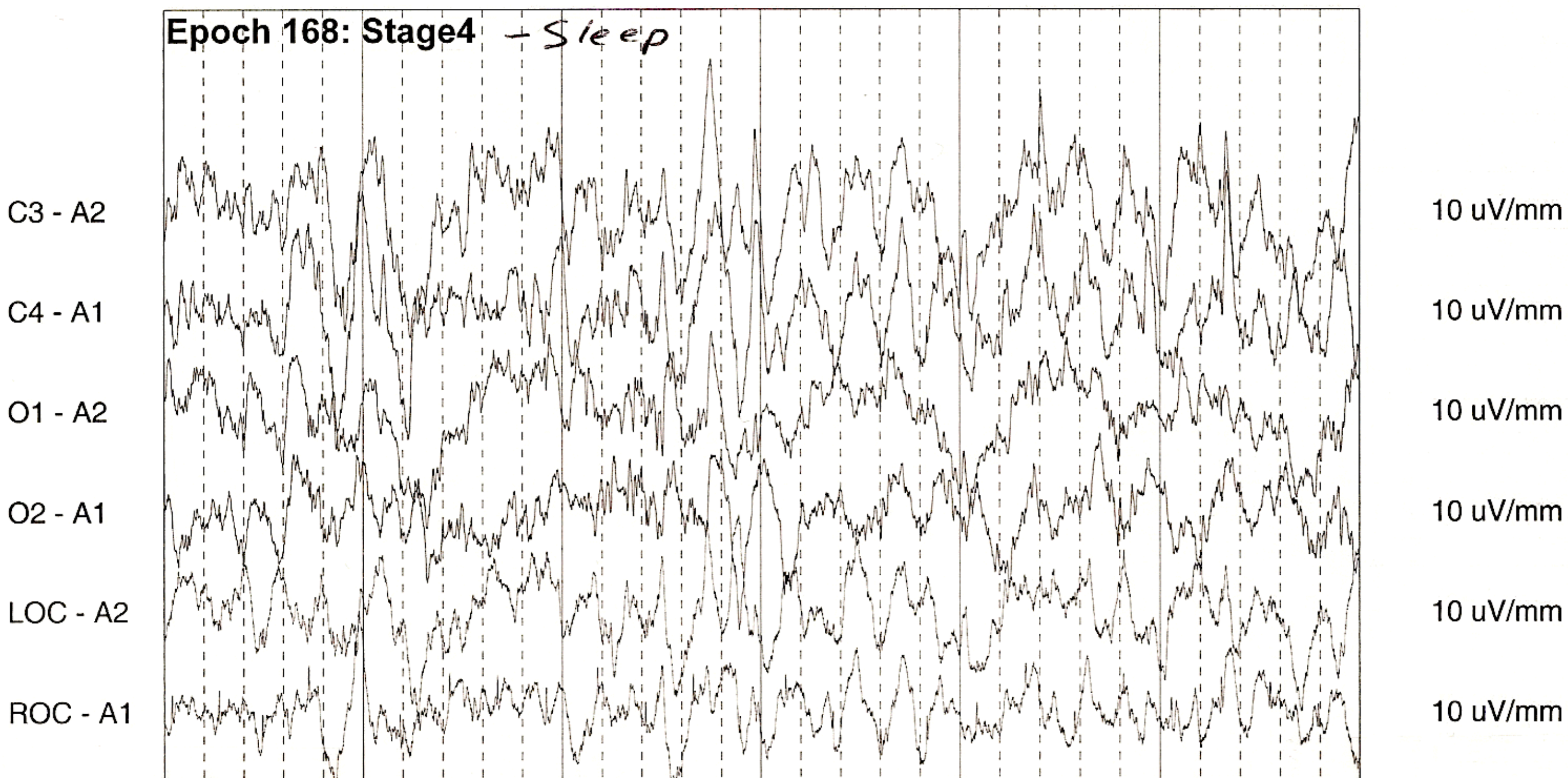
Stage 2


Epoch 190: Stage2 – Sleep
C3 - A2
C4 - A1
O1 - A2
O2 - A1
LOC - A2
ROC - A1
10 uV/mm
10 uV/mm
10 uV/mm
10 uV/mm
10 uV/mm
10 uV/mm

Stage 3

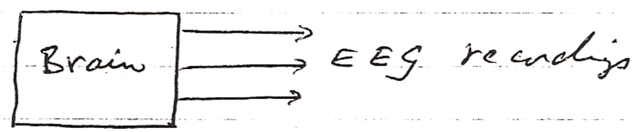

Epoch 140: Stage3 – Sleep
C3 - A2
C4 - A1
O1 - A2
O2 - A1
LOC - A2
ROC - A1
10 uV/mm
10 uV/mm
10 uV/mm
10 uV/mm
10 uV/mm
10 uV/mm

Stage 4

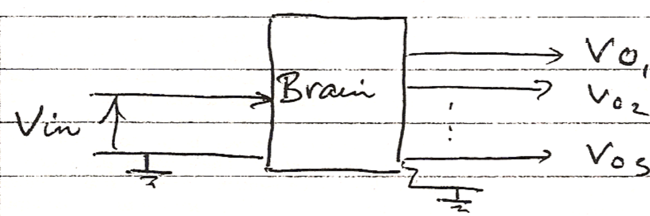

Epoch 168: Stage4 - Sleep
C3 - A2
C4 - A1
O1 - A2
O2 - A1
LOC - A2
ROC - A1
10 uV/mm
10 uV/mm
10 uV/mm
10 uV/mm
10 uV/mm
10 uV/mm

Brain Evoked Potentials

These are special uses of the EEG signal and are not limited to the bandwidth of normal EEG (1 → 40 Hz) recorded while the subject sits still. In engineering terms normal EEG is just monitoring the output of system with no control over input.



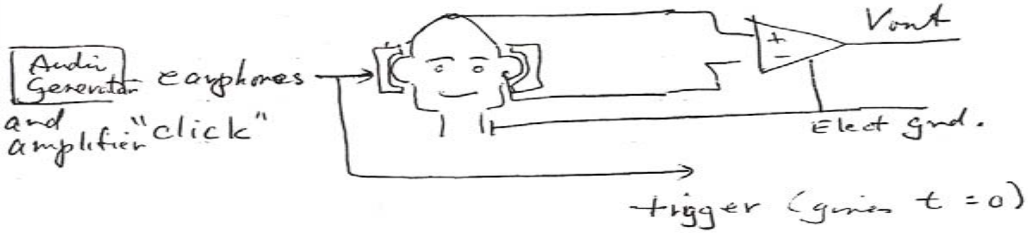
Evoked potentials use the more common approach where you determine the transfer function (characteristics) of a system by driving it with a known input. We can use the sensory input to the brain



Brain Stem Auditory Evoked Potentials BSAEP

Uses the auditory system input

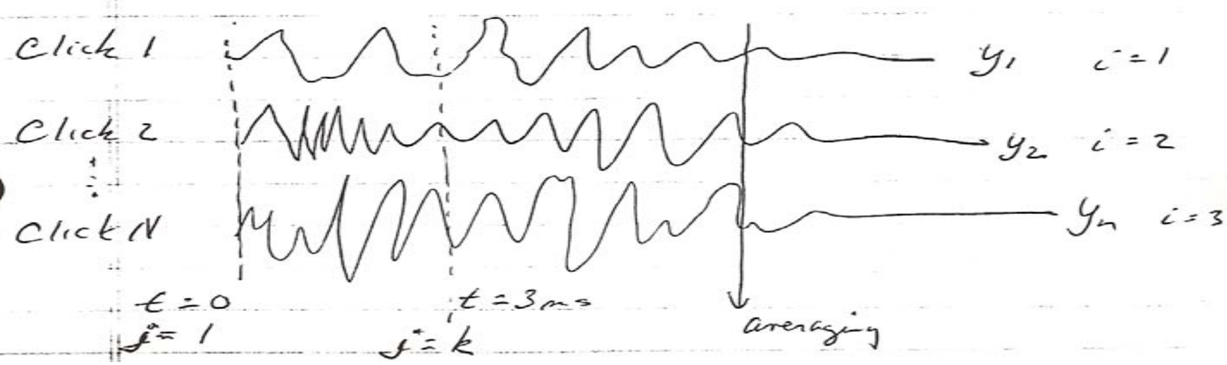
Brain Evoked Potentials - 2



Clicks are sent to the ear (at a certain db level) at the rate of 10 Hz.

For each click the ear sends signals down the auditory nerve to the auditory cortex and from there to the brainstem. This test can be used to determine the health of the auditory system but also the health of part of the brainstem which is deep in the brain

The evoked response is in the amplitude range hundreds of nanovolts to several μvolts and in (150 → 2500 Hz.



As for sensory nerve recordings in EMG

$$y_i = s_i + n_i$$

where s_i = desired brain response, n_i = noise for the ith click

$\therefore$ Synchronous averaging is used where

$$y_{i,j} = s_{i,j} + n_{i,j}$$

$y_{i,j}$ is the jth sample in the ith response.

Sample rate is typically 50KHz.

$$\therefore \sum_{i=1}^{N} y_{i,j} = \sum_{i=1}^{N} s_{i,j} + \sum_{i=1}^{N} n_{i,j}$$

If we assume that $s_{i,j}$ is deterministic and constant for any j and that $n_{i,j}$ is random zero mean, then

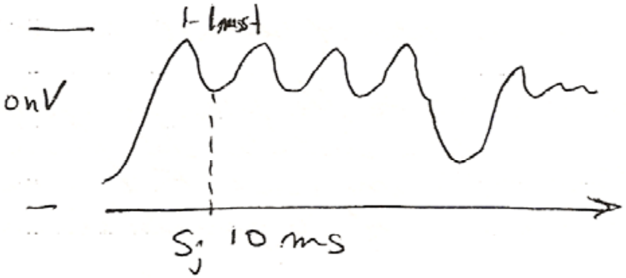
$$\sum_{i=1}^{N} s_{i,j} \longrightarrow N s_j$$

$$\sum_{i=1}^{N} n_{i,j} \longrightarrow 0$$

∴ To get the desired response average by N

$$\frac{1}{N}\sum_{i=1}^{N} y_{i,j} \rightarrow s_j$$

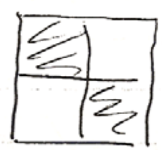
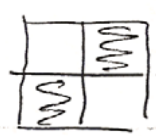
After typically 2048 clicks output y looks like



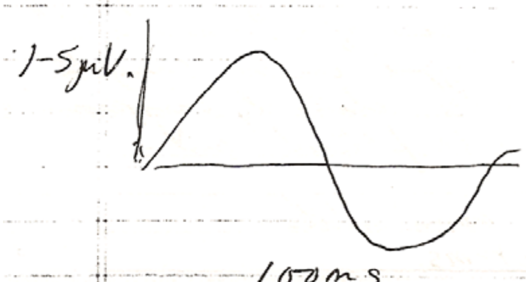
if noise is Gaussian (hardly ever the case)

SNR ratio improves by $\sqrt{2048} \approx 45$

The same can be done with the visual input to the brain.

Input =  changing to  many more squares.

checkerboard with all white squares going to black and all black to white at 1 Hz rate

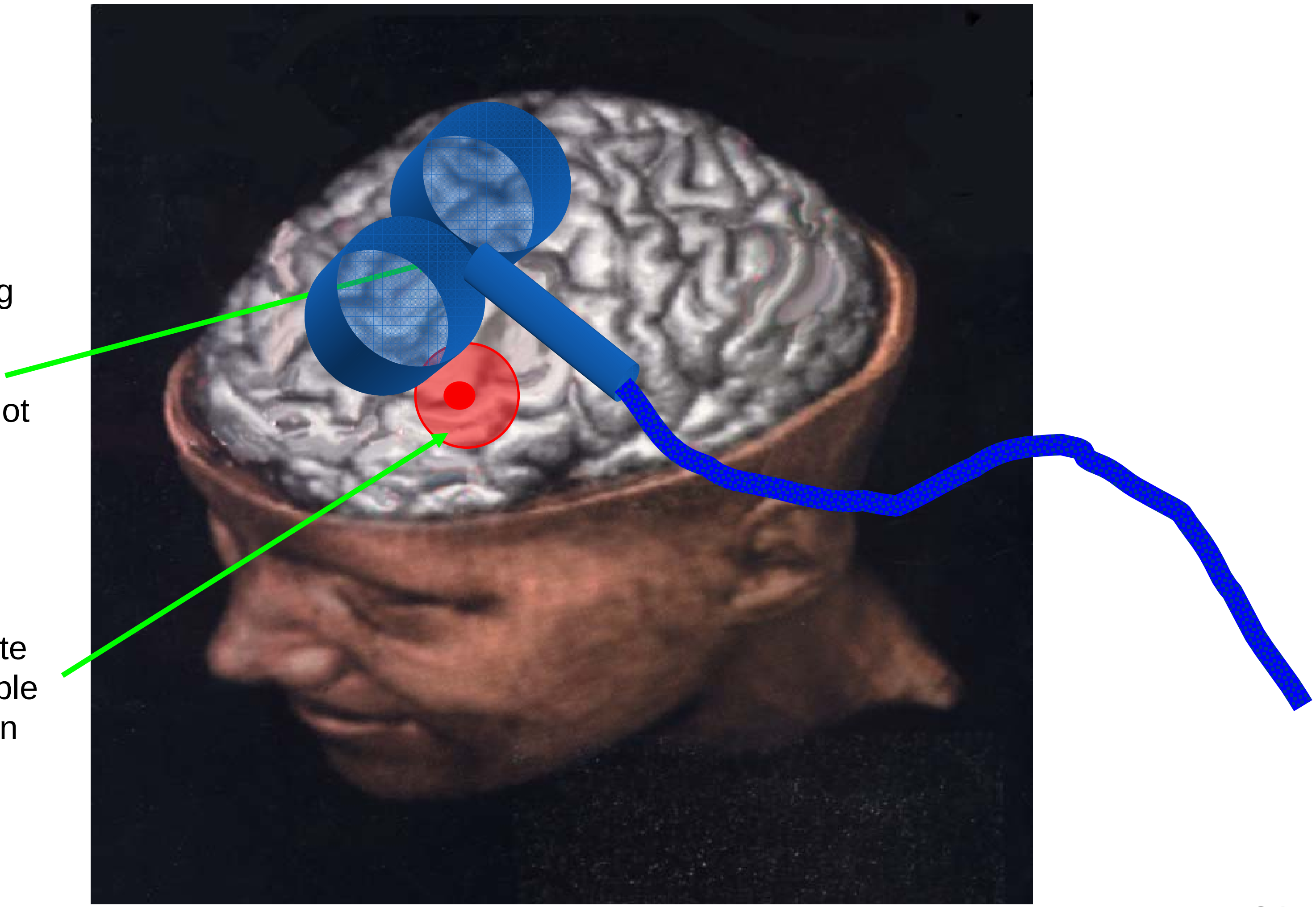


need about 64 → 128 to get rid of most noise

Future?

Clinical Treatment

Those with correctable pathophysiology may not respond as standard methods place the coil in the wrong spot (we are not very good at predicting RESPONSE using QEEG)



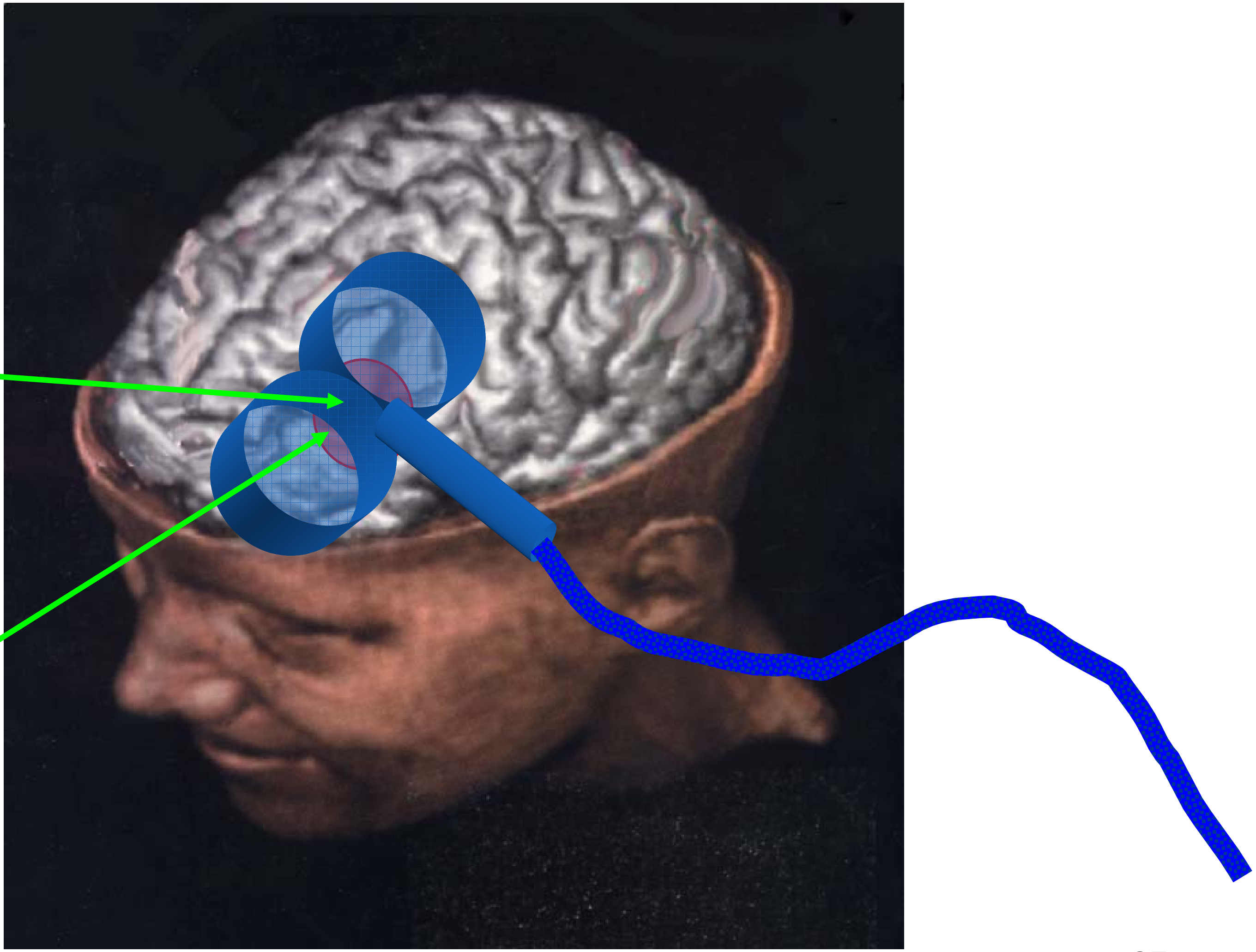
Standard positioning
Method incorrectly
Places coil here.
Magnetic energy is not
delivered to the
appropriate site

Possible site
Of correctable
dysfunction

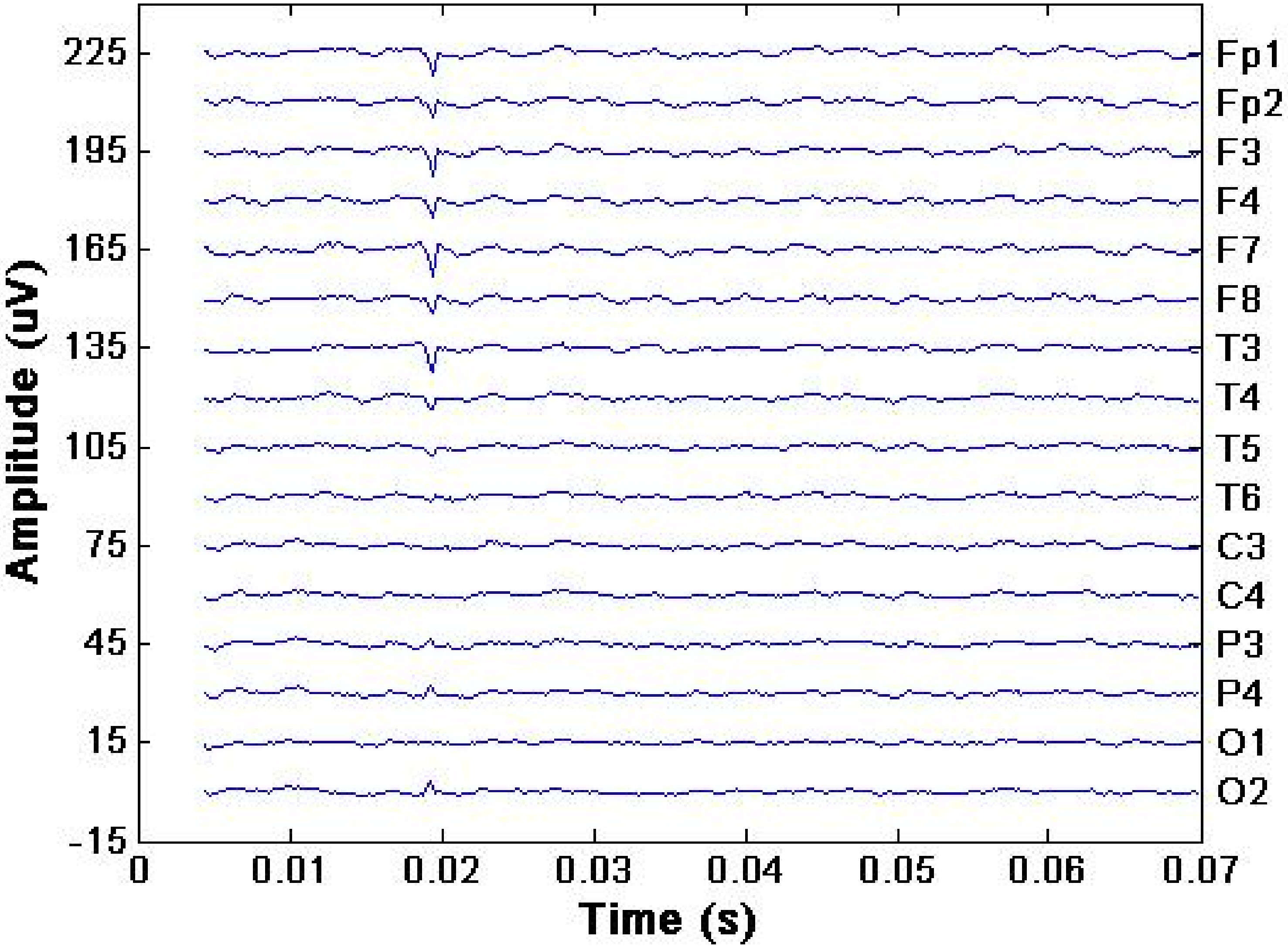
Stimulating over Correct Part of the Brain

Standard positioning method correctly places coil at the appropriate site to effect an antidepressant response

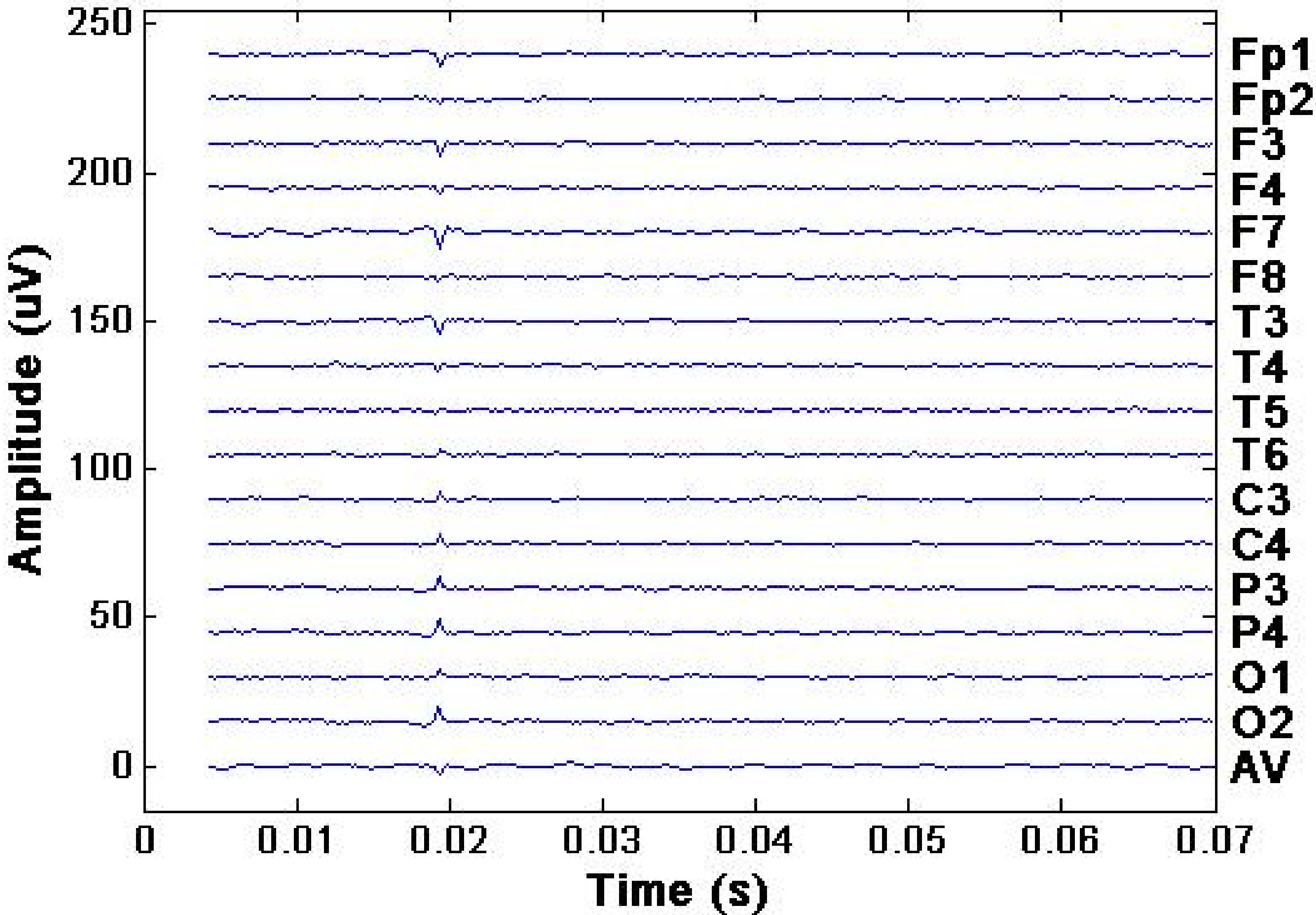
Possible site of correctable dysfunction



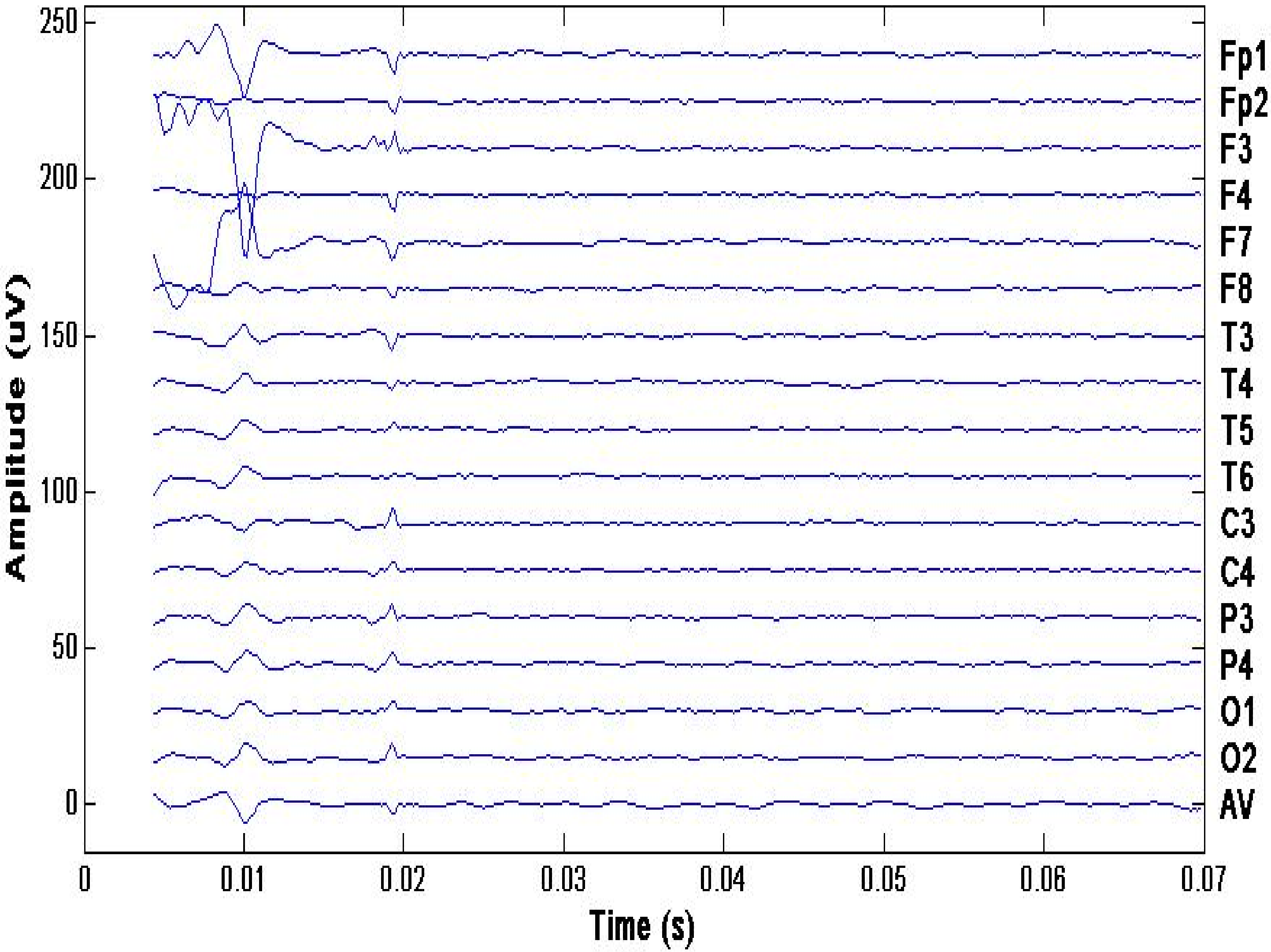
Sham (Acoustic Response)



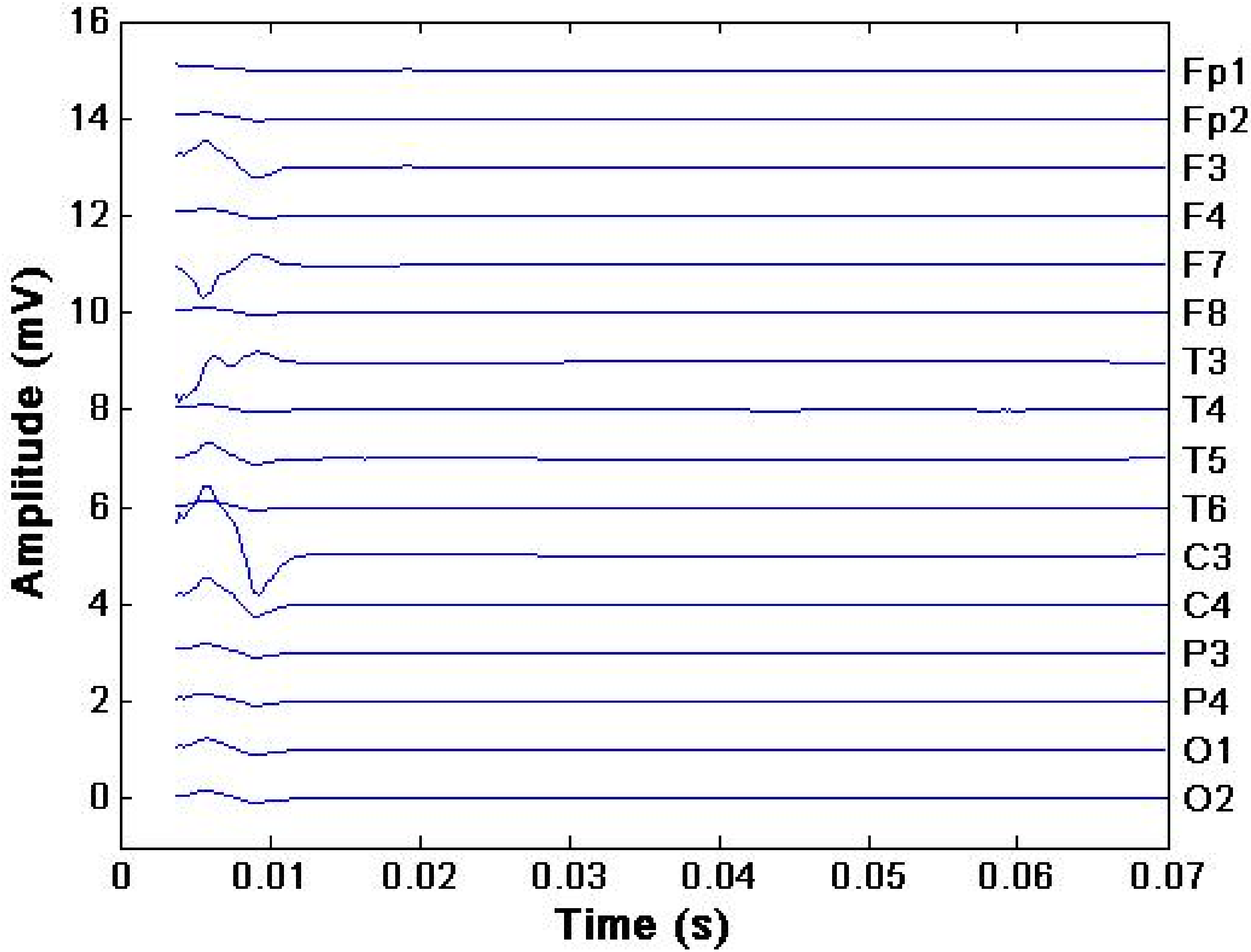
Sham (Acoustic –Averaged)



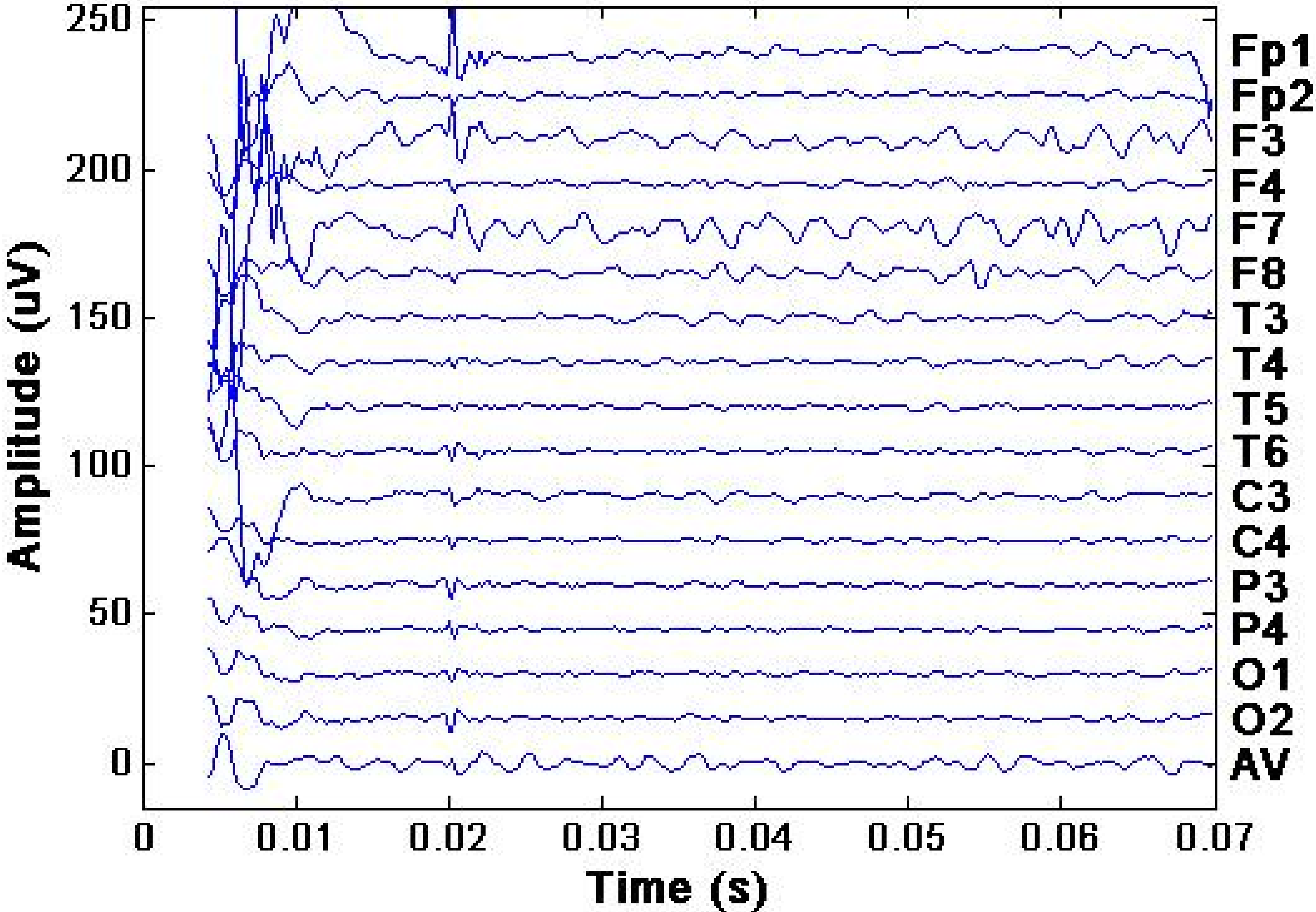
True Response Left B09



Scalp Muscle Response



True Response Subject 2 B10



New Advances in EEG

- Brain patterns very complex
- Use mathematical processing (machine learning) to analyse patterns to predict:
- Which drug to use for Schizophrenia
- Which drug to use for treating major depression
- Will rTMS work?
- Diagnose neuropsychiatric disease?