EEG temporal–spatial transformer for person identification

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- Fundamentals of EEG Signal Processing
- Concept of Transformer in EEG analysis
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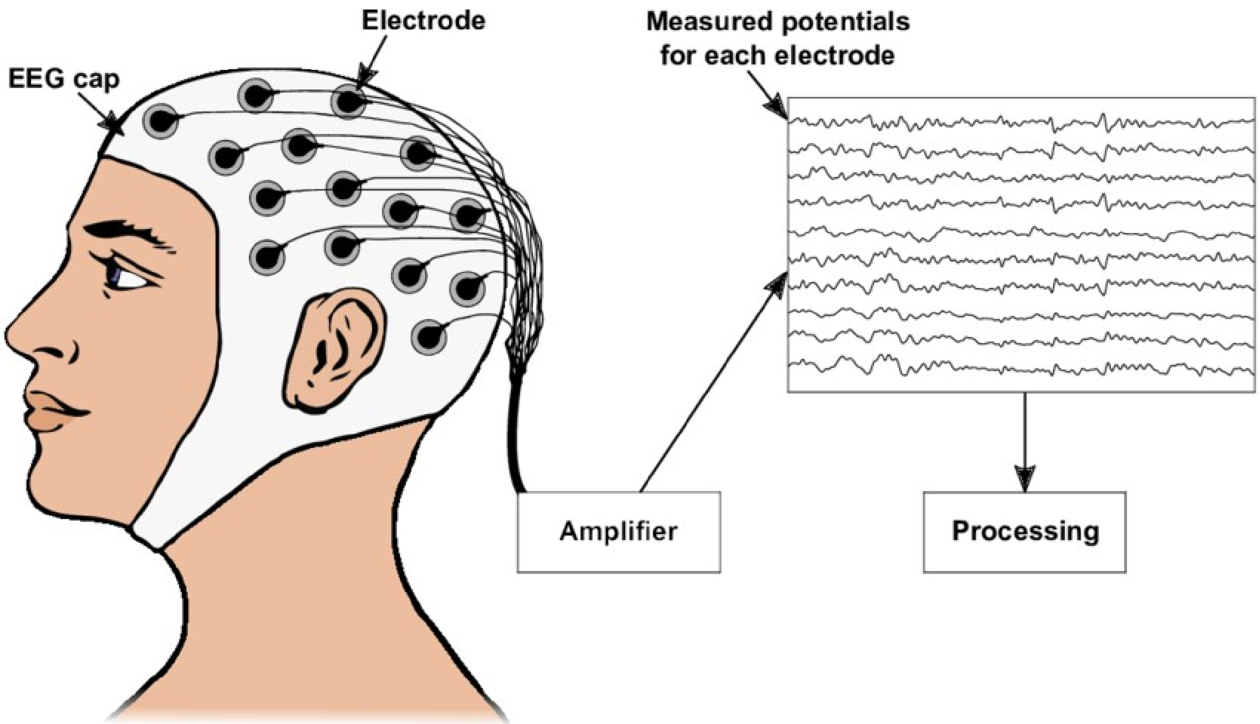
Introduction to EEG

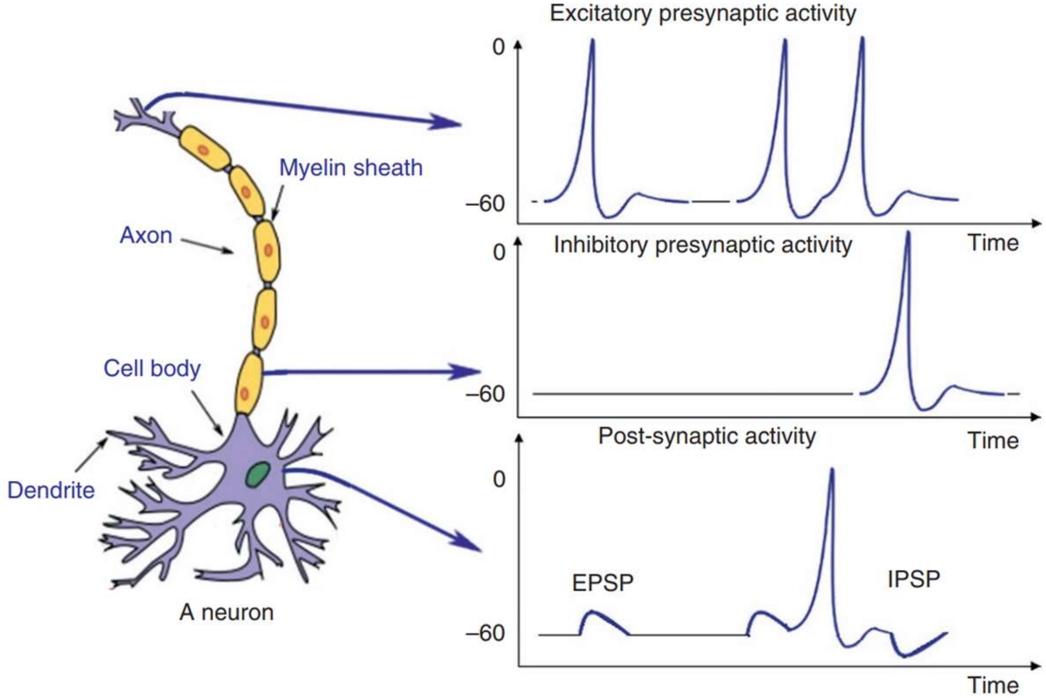
What is EEG

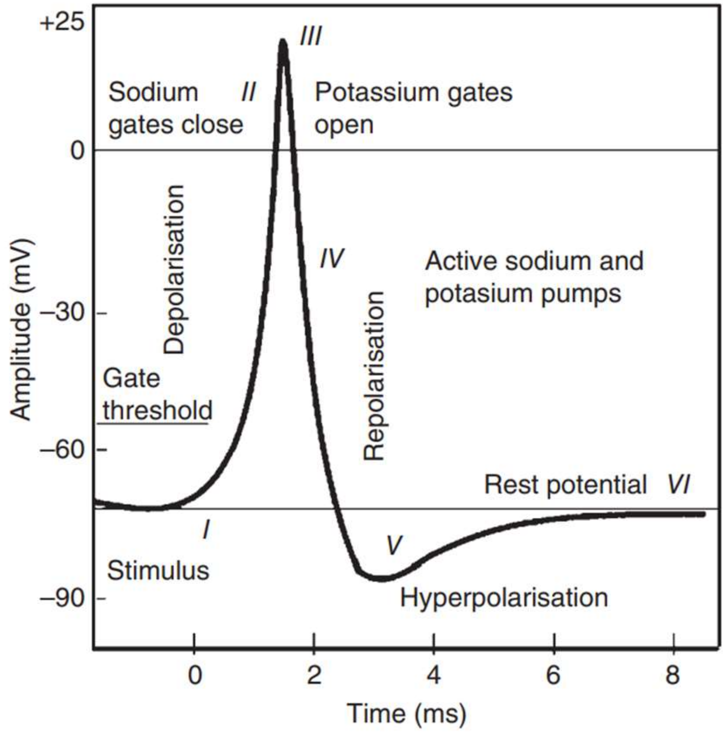
An electroencephalogram (EEG) is a test that measures electrical activity in the brain using small, metal discs (electrodes) attached to the scalp.

Brain cells communicate via electrical impulses and are active all the time, even during asleep. This activity shows up as wavy lines on an EEG recording.



Neural Activities





EEG generation
How can we measure neural activity

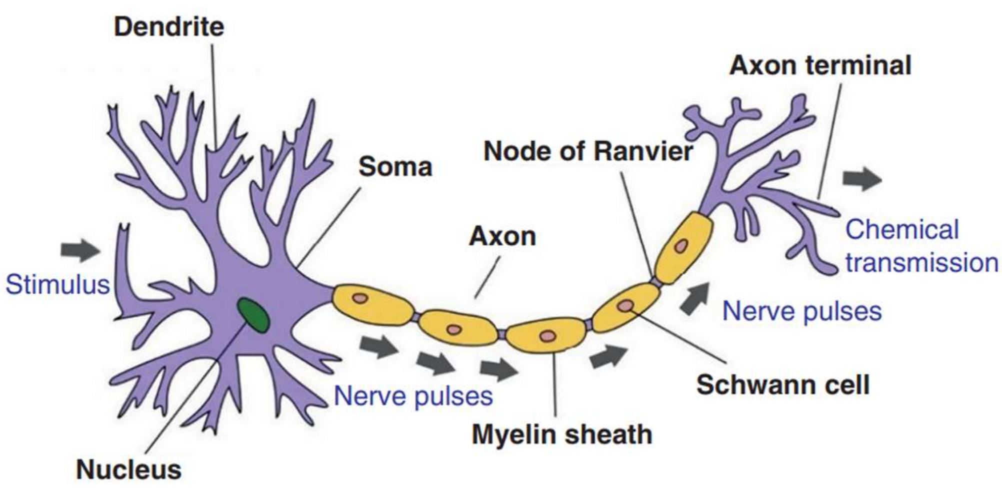
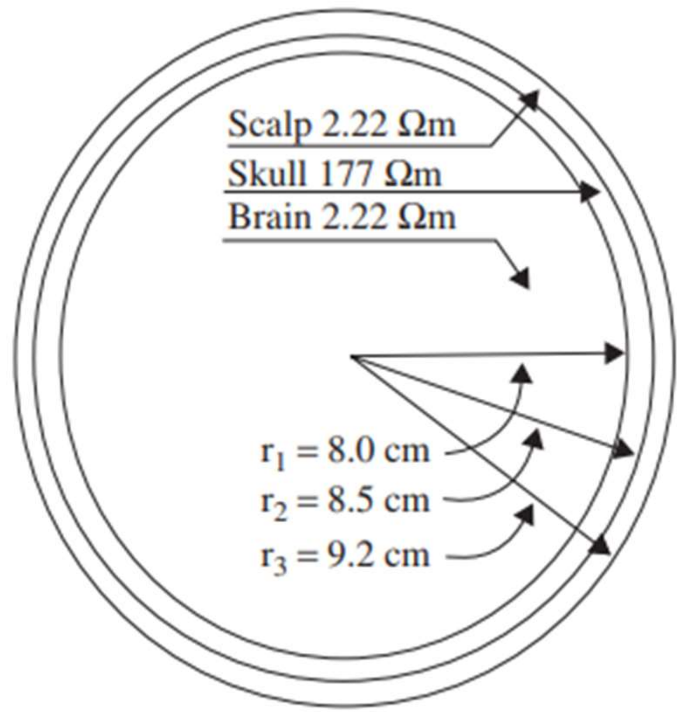


Figure 1.6 Structure of a neuron.



Major parts of the brain

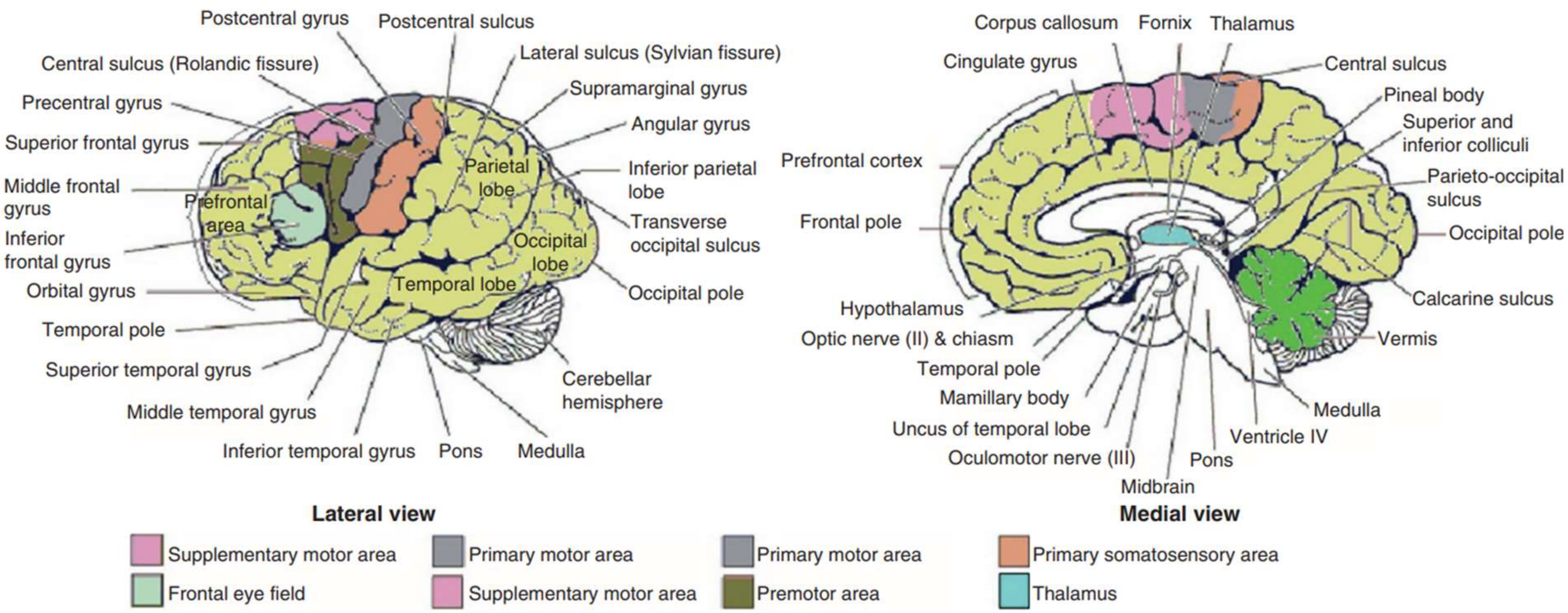
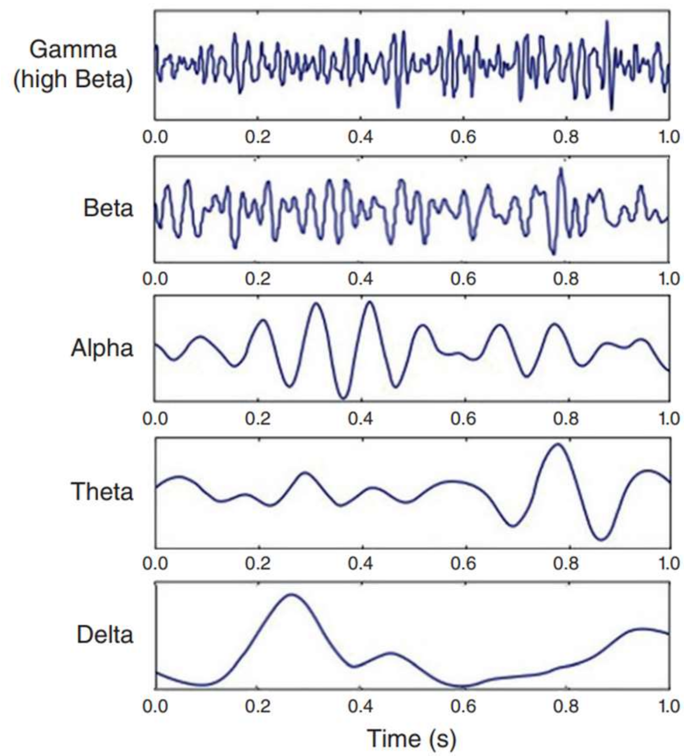


Figure 1.8 Diagrammatic representation of the major parts of the brain.

Brain Rhythms

Rhythms	Description
alpha	occipital brain region when there is no attention
beta	frontally and parietally with low amplitude during attention and concentration
gamma	stressed brain under heavy workload
delta	infants and sleeping adults
theta	children and sleeping adults



EEG Recording and Measureme

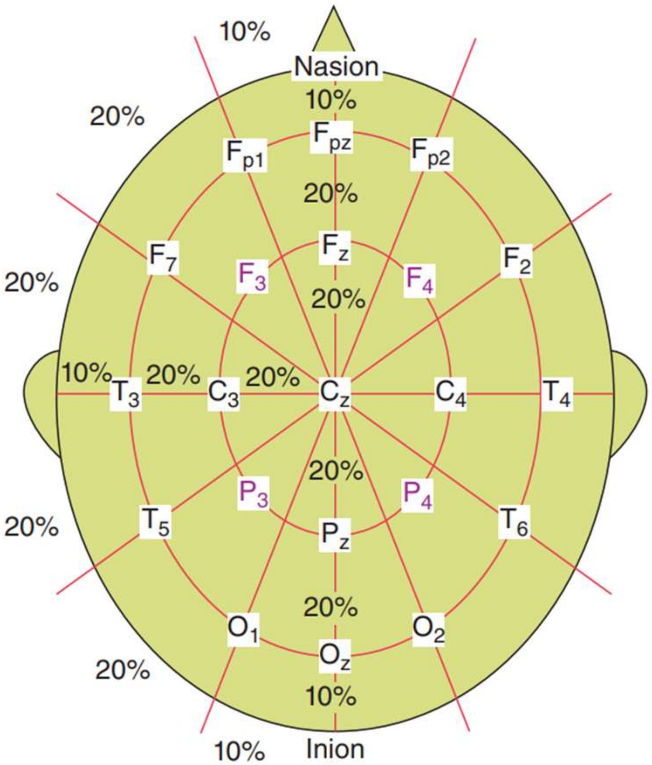


Figure 2.3 Conventional 10–20 EEG electrode positions for the placement of 21 electrodes.

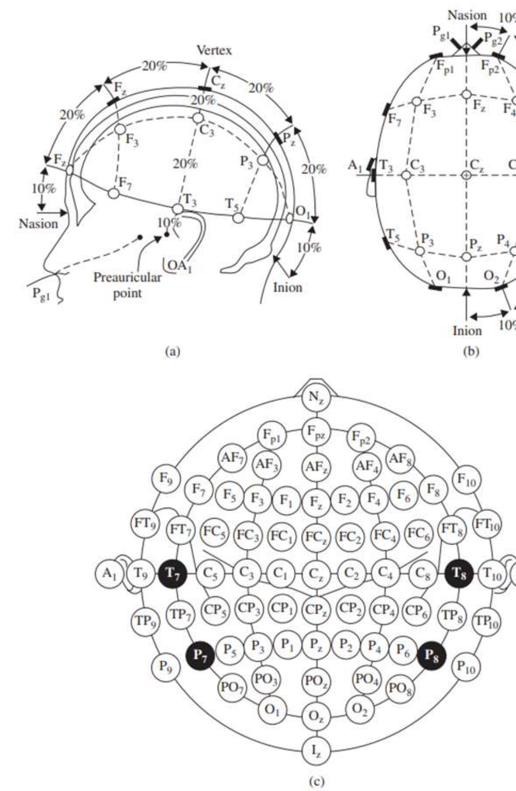


Figure 1.9 A diagrammatic representation of 10–20 electrode settings for 75 e
the reference electrodes: (a) and (b) represent the three-dimensional measures,
two-dimensional view of the electrode setup configuration

Normal EEG

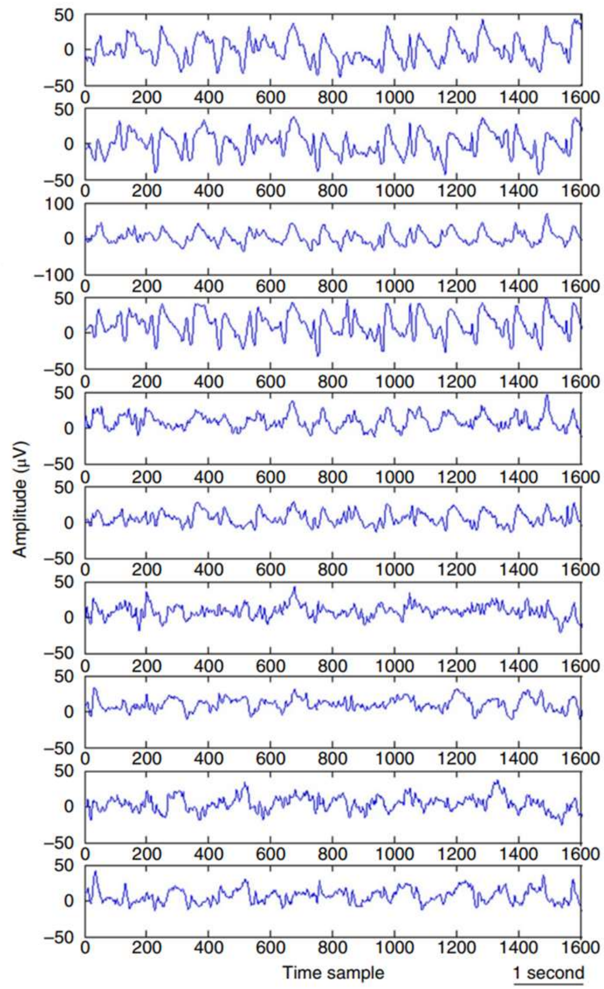


Figure 2.5 A typical set of EEG signals during approximately seven seconds of normal adult brain activity.

Normal EEG with eye blink artifact

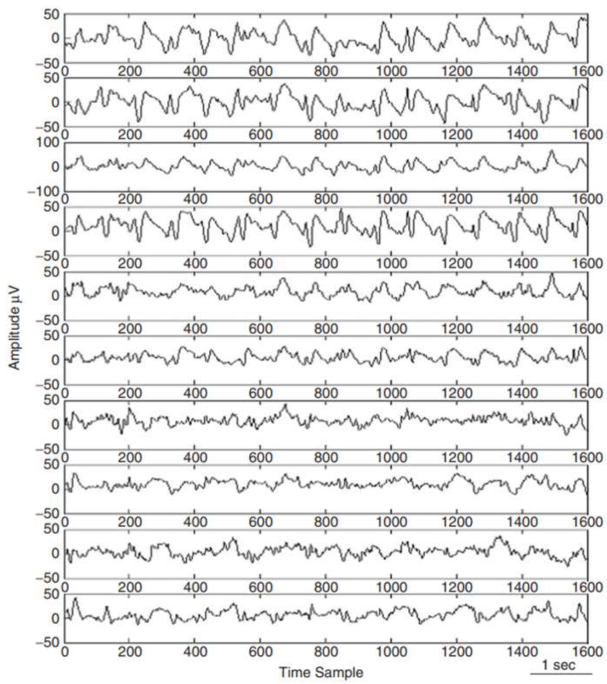


Figure 1.10 A typical set of EEG signals during approximately seven seconds of normal adult brain activity

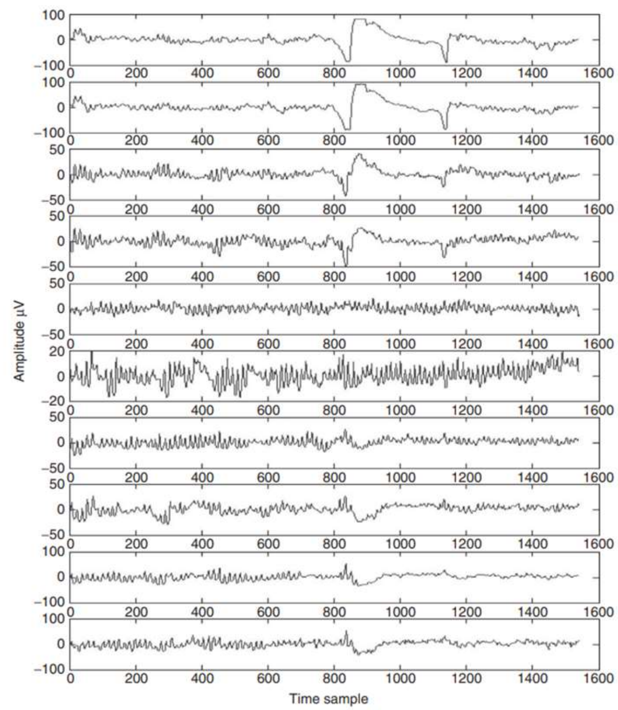


Figure 1.11 A set of normal EEG signals affected by the eye-blinking artefact

Abnormal EEG

Sharbrough divided the nonspecific abnormalities in the EEGs into three categories:

(i) widespread intermittent slow-wave abnormalities often in the delta wave range and associated with brain dysfunction

(ii) bilateral persistent EEG usually associated with impaired conscious cerebral reactions

(iii) focal persistent EEG usually associated with focal cerebral disturbance.

EEG of seizure activity

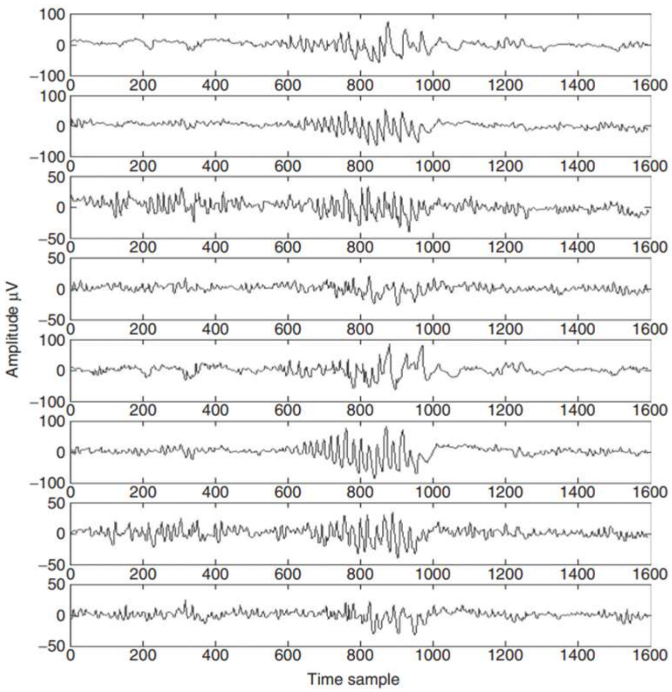


Figure 1.14 Bursts of 3–7 Hz seizure activity in a set of adult EEG signals

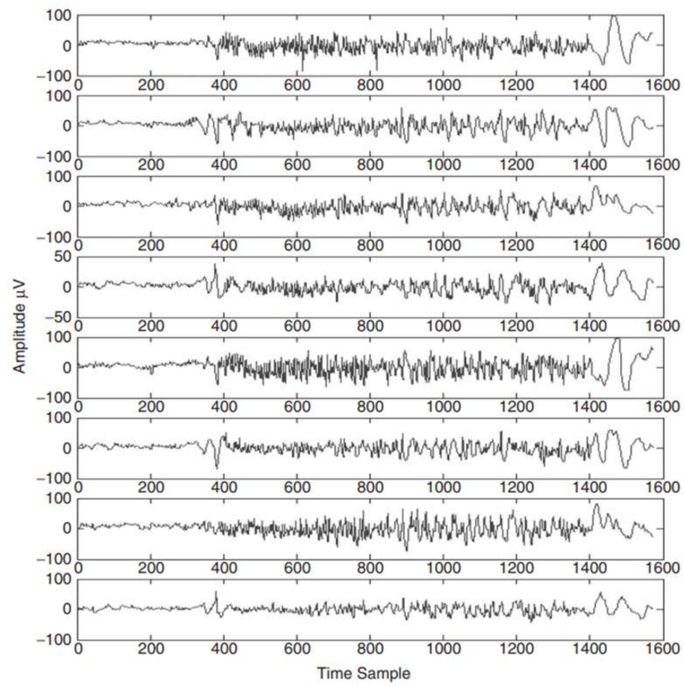
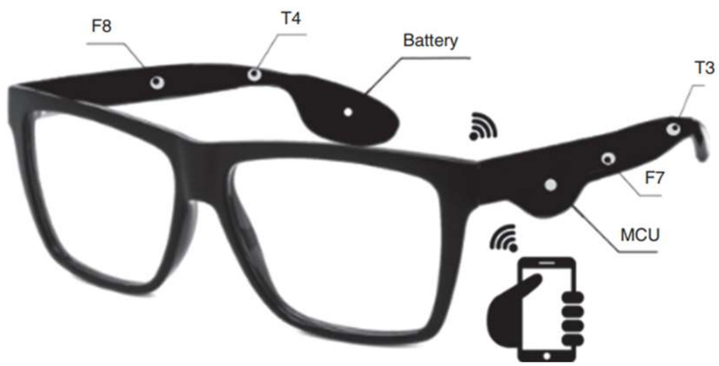
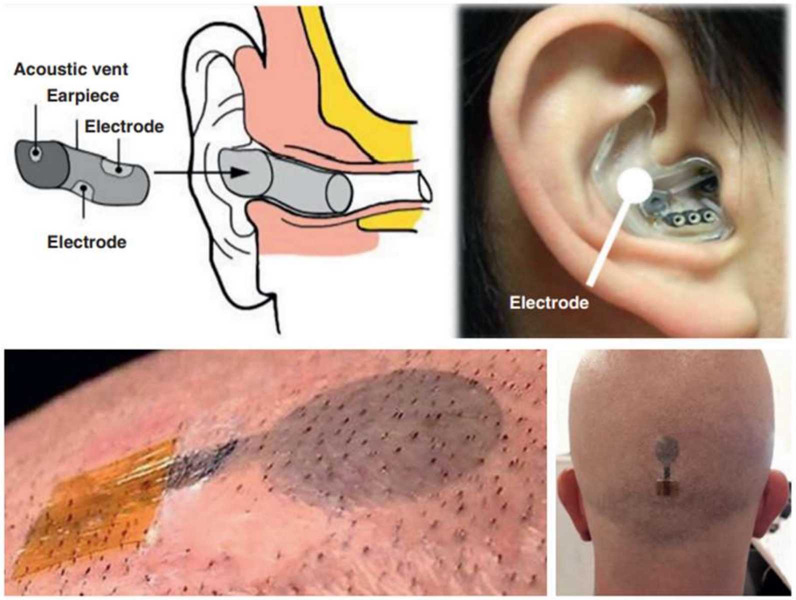


Figure 1.15 Generalized tonic–clonic (grand mal) seizure. The seizure appears in almost all of the electrodes

Unconventional and Special Purpose EEG Recording Systems





Invasive Recording of Brain Potentials

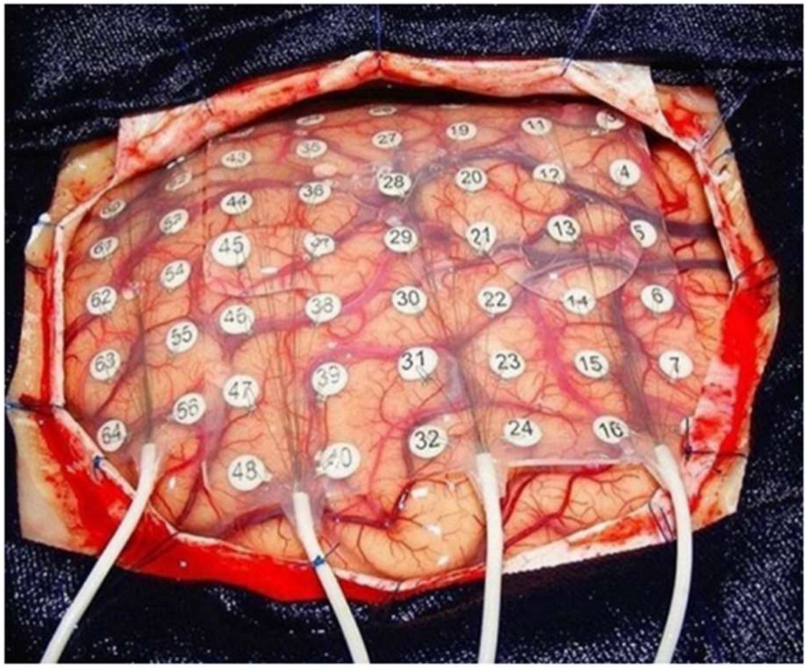


Figure 2.7 Electrocorticography.

Fundamentals of EEG Signal Processing

Fundamentals of EEG Signal Processing

There have been many algorithms developed so far for processing EEG signals.

Example operations:

- time-domain analysis
- frequency-domain analysis
- spatial-domain analysis
- multiway processing

Also, several algorithms have been developed to visualize the brain activity from images reconstructed from only the EEGs namely topographs.

Characteristics of EEG signal

Nonlinearity of the Medium

- Cause by the brain itself, EEG modeling, etc.

- Attractor dimension, and largest Lyapunov exponents (LLE) can characterize the nonlinear behavior of EEG signals

Non-stationarity

- Nonstationarity of the signals can be quantified by evaluating the changes in signal distribution over time.

- The change in the distribution of the signal segments can be measured in terms of both the parameters of a Gaussian process and the deviation of the distribution from Gaussian.

- The non-Gaussianity of the signals can be checked by measuring or estimating some higherorder moments such as skewness, kurtosis, negentropy, and Kullback–Leibler (KL) distance (aka KL divergence)

Signal Transforms

If the signals are statistically stationary it is straightforward to characterize them in either time- or frequency-domains.

1. Discrete Fourier Transform (DFT)
2. Parametric spectrum estimation methods such as those based on AR or autoregressive moving average (ARMA) modelling
(may suffer from poor estimation of the model parameters mainly due to the limited length of the measured signals)

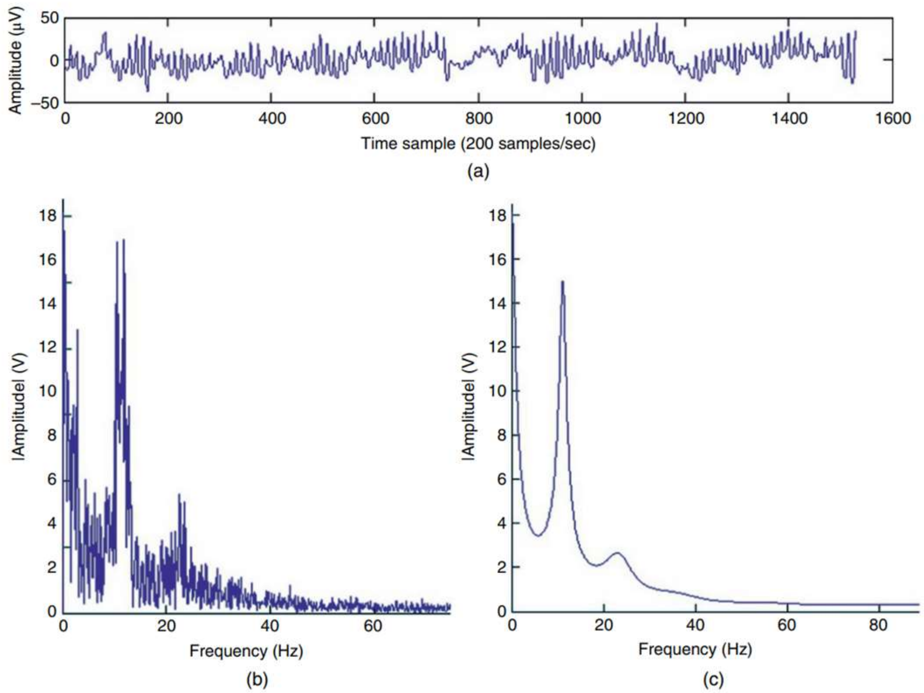


Figure 4.3 Single-channel EEG spectrum. (a) A segment of an EEG signal with a dominant alpha rhythm. (b) Spectrum of the signal in (a) using DFT. (c) Spectrum of the signal in (a) using a 12-order AR model.

EEG signal Decomposition

Single-channel source separation

Singular Spectrum Analysis

- Decomposition
- Reconstruction
- Aim: Separability, which characterizes how well different components can be separated from each other

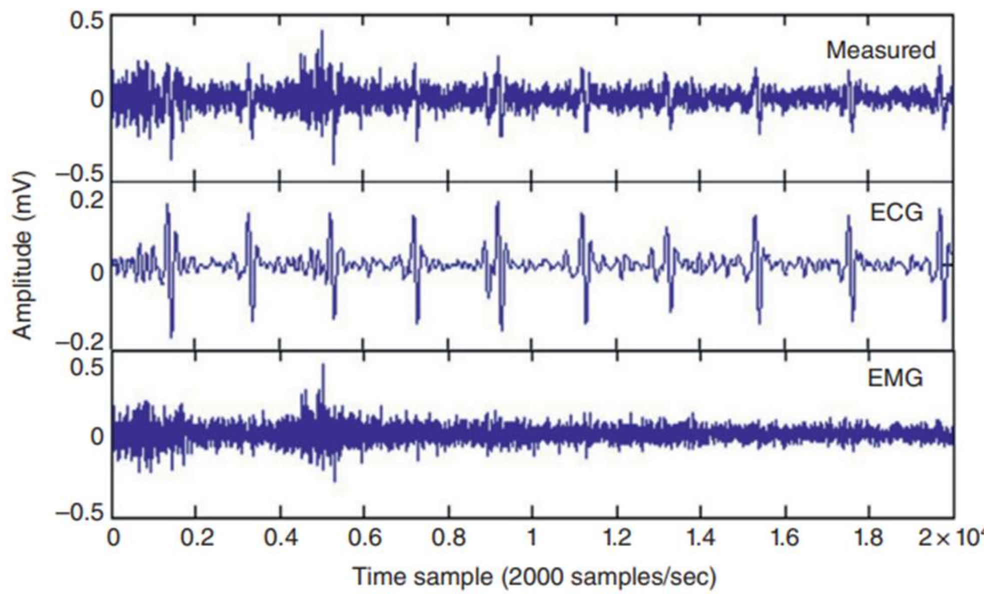


Figure 5.1 Separation of EMG and ECG using the SSA technique; top signal is the measurement, middle signal is the separated ECG, and the EMG signal can be viewed at the bottom.

EEG signal Decomposition

Multichannel EEG Decomposition

EEG signals are inherently multichannel in their normal recording formats. However, the number of channels can be as low as 16 or as high as 256 in conventional clinical EEG systems

In order to effectively separate the underlying sources from the electrode signals we should have more electrodes than source signals over any segment of time.

Independent Component Analysis

the constituent brain sources are independent from each other. In places where the combined source signals can be assumed independent from each other this concept plays a crucial role in separation and denoising the signals.