Lecture 3
Classification of Biosignals

Digital Signal Processing and Analysis in Biomedical Systems

Contents

- What and why biosignals?
- Classification of biosignals
- Examples

What are biosignals?

All types of biomedical systems either generate the signals to influence the human body, or analyze biosignals to extract useful information about functioning of human body.

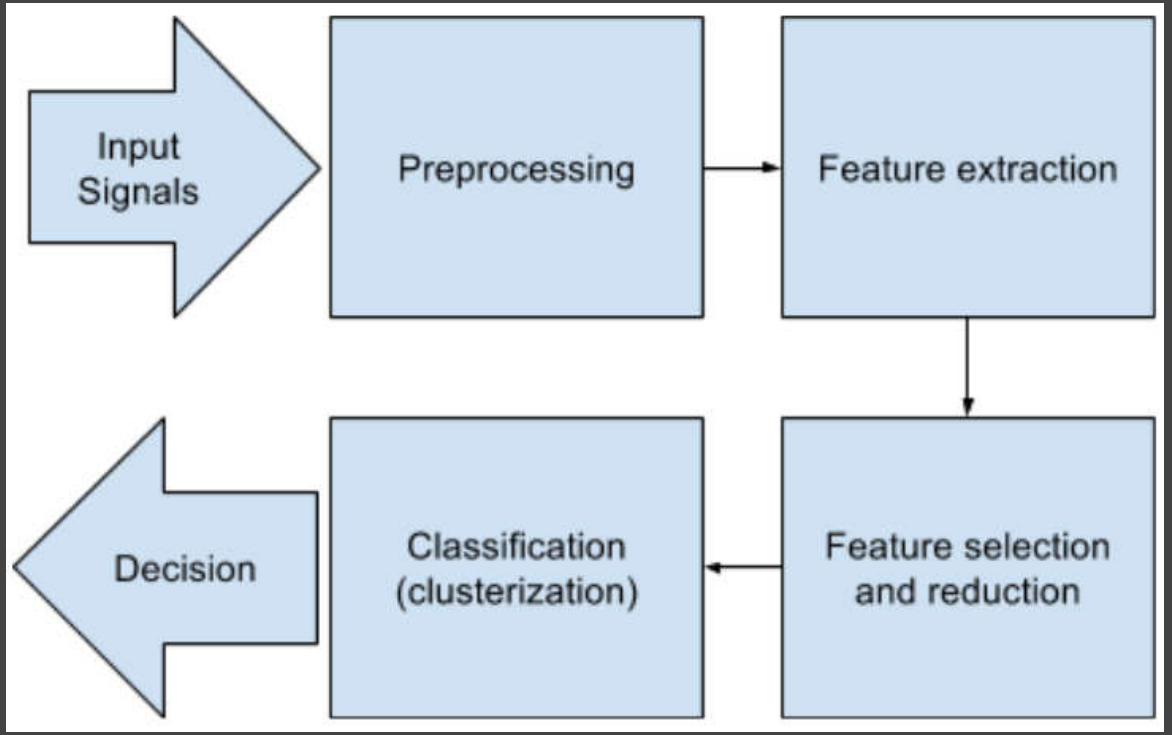
Signal – is the parameter that is observable from the object.

Biosignal is a description of physiological phenomenon of any nature.

Bio+Signal = “living object” + “function that carries information about the behavior or state”. Biosignals are the key objects in Biosystems.

Signal analysis

At the level of signals, the biomedical system for diagnosis is based on Machine Learning.



Why biosignals?

Biosignal carries all information about the living object. We analyze signals which are coming from the body (ECG, EEG etc.) or are connected to the body (X-ray images, ultrasonic images).

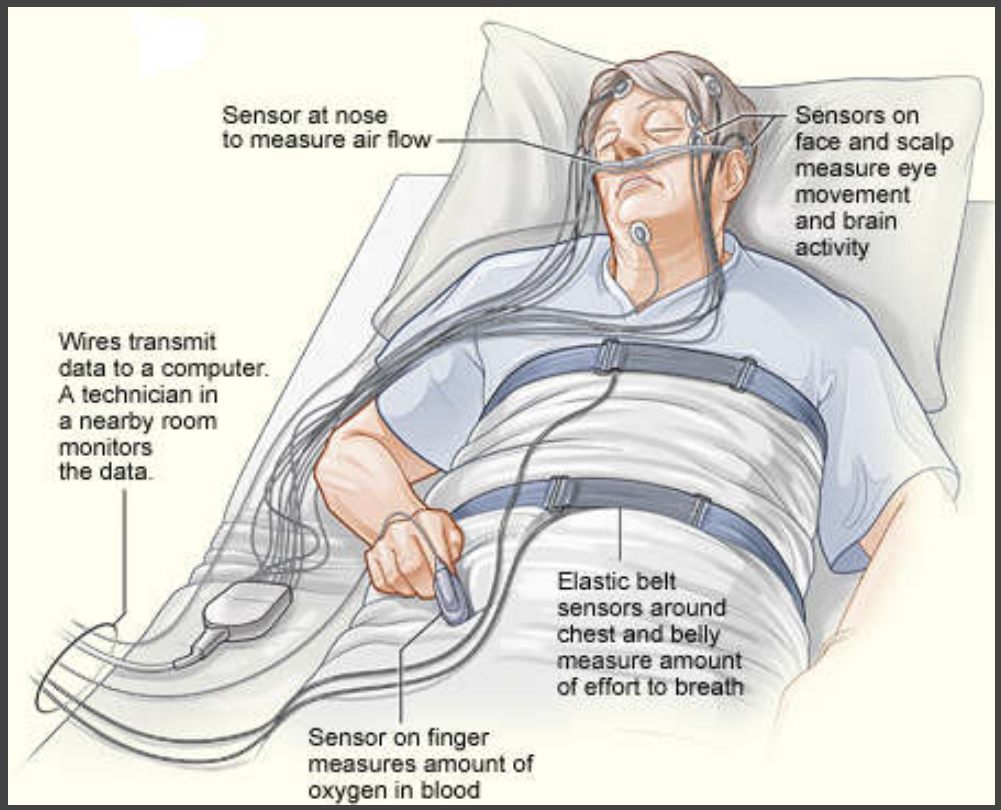
Biosignal can be used to understand the underlying physiological mechanisms of a specific biological event or system.

Biosignals through centuries

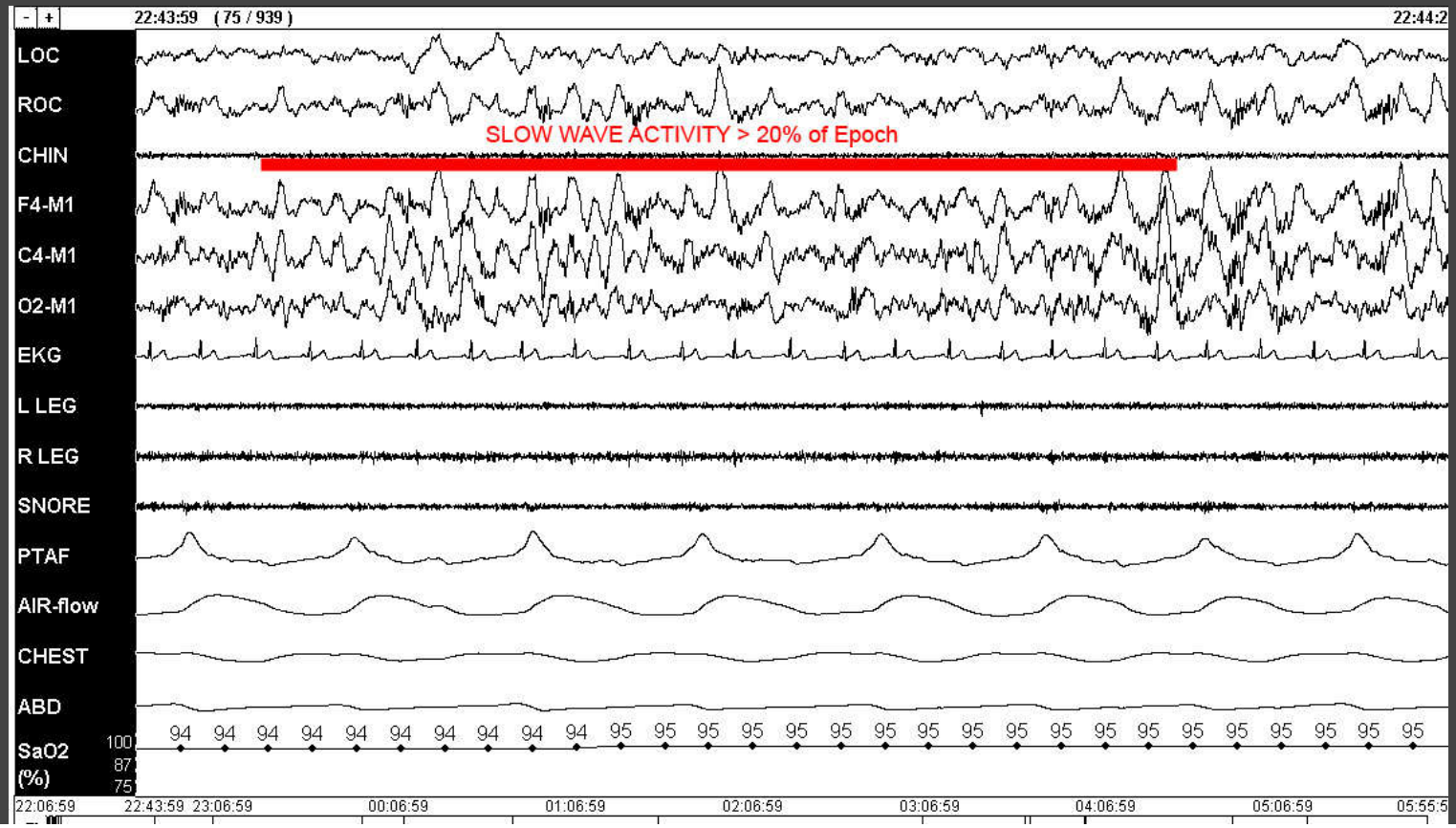
Hippocrates palpating a young patient (500 BC)

ICU in modern hospital (2016 AD)

Example - Polysomnogram



PSG signal


22:43:59 (75 / 939)
22:44:2
LOC
ROC
CHIN
SLOW WAVE ACTIVITY > 20% of Epoch
F4-M1
C4-M1
O2-M1
EKG
L LEG
R LEG
SNORE
PTAF
AIR-flow
CHEST
ABD
SaO2 (%)
100
87
75
94 94 94 94 94 94 94 94 94 94 95 95 95 95 95 95 95 95 95 95 95 95 95 95 95 95 95 95
22:06:59
22:43:59
23:06:59
00:06:59
01:06:59
02:06:59
03:06:59
04:06:59
05:06:59
05:55:5

Classification of biosignals - 1

According to the physical **nature** of biosignals

- Electric
- Magnetic
- Chemical
- Mechanical (acoustic)
- Optical
- Thermal

Classification of biosignals - 2

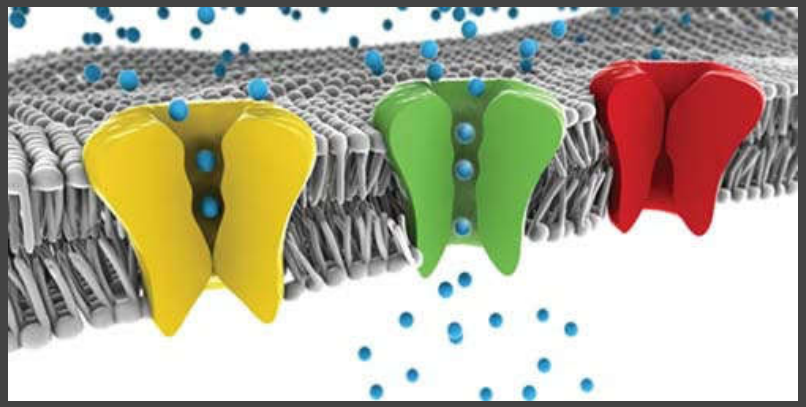
According to the **system of origin** of biosignals

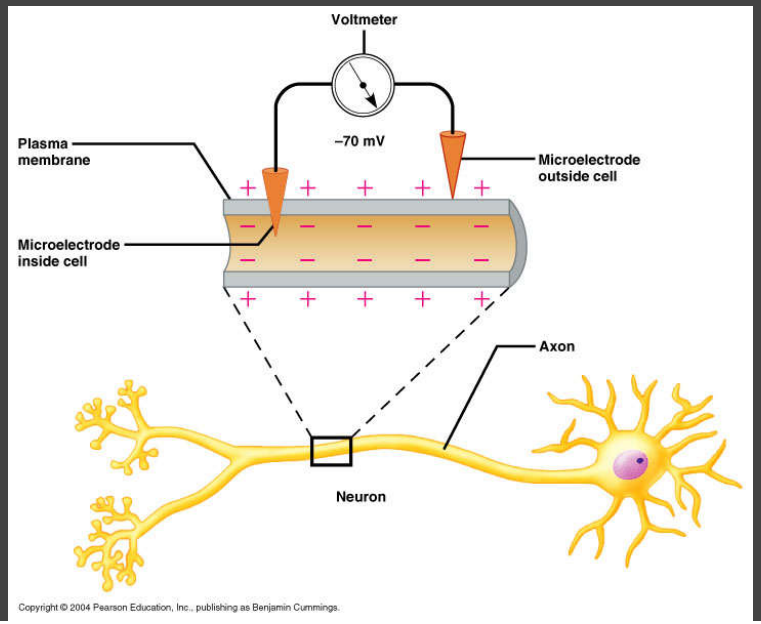
- Endocrine system
- Nervous system (Central and Peripheral)
- Cardiovascular system
- Vision system
- Auditory system
- Musculoskeletal system
- Respiratory system
- Gastrointestinal System
- Blood system

Classification according to the physical nature of signal

Electric signals

Electric field is generated in cells (nerve and muscle) and organs because of intra- and extracellular ionic currents. They are the results of electrochemical processes in the single ionic channels.





Action potential generation

Types of electrical signals

Neural cells

ENG – electroneurogram

EEG – electroencephalogram

ERG – electroretinogram

Muscle cells

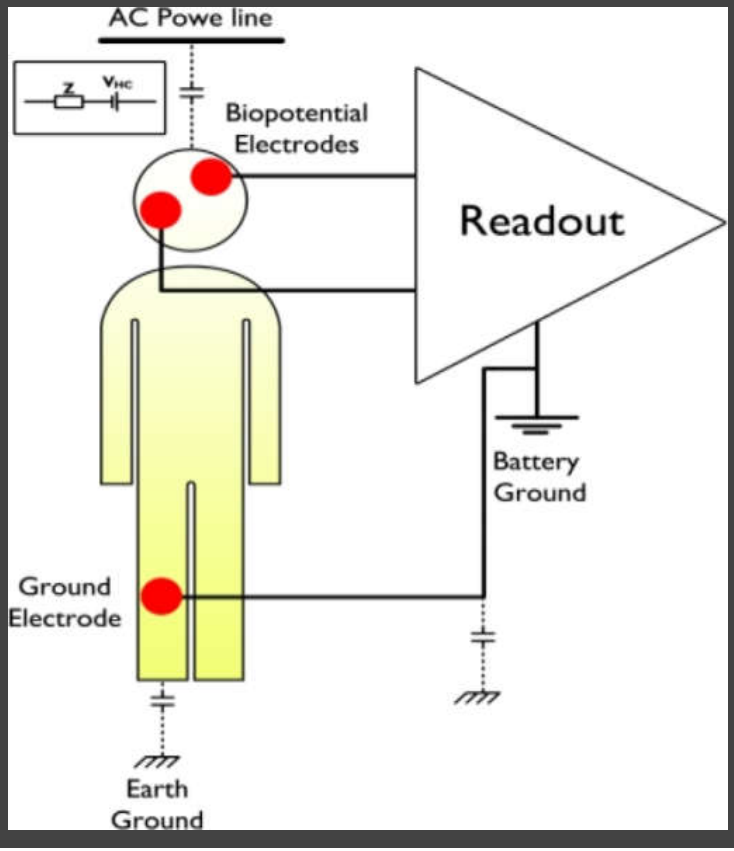
ECG – electrocardiogram

EMG – electromyogram

Other cells

EOG – electrooculorgam

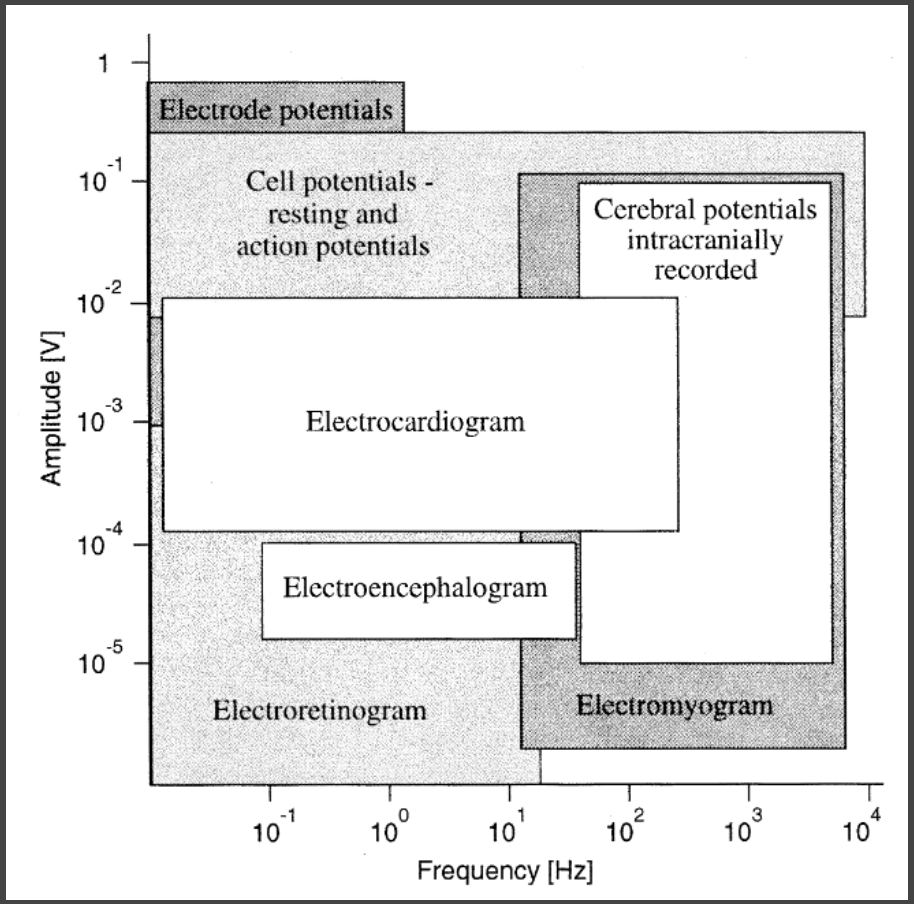
GSR – galvanic skin response



ECG generation

Bioelectric signals

Amplitude and spectral ranges of bioelectric signals



Magnetic biosignals

Weak magnetic fields are generated by different organs and cells.

Neural cells

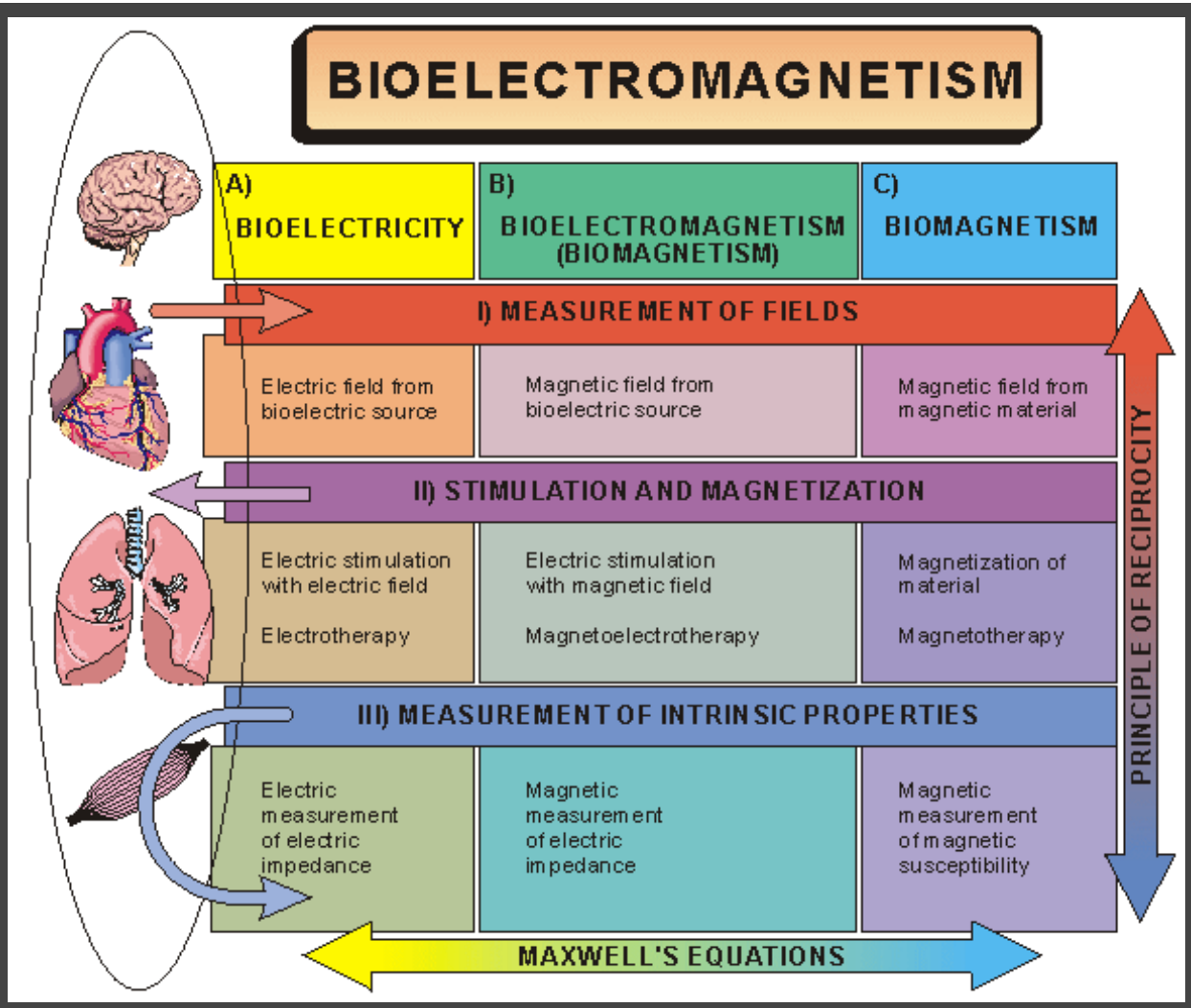
MNG – magnetoneurogram

MEG – magnetoencephalogram

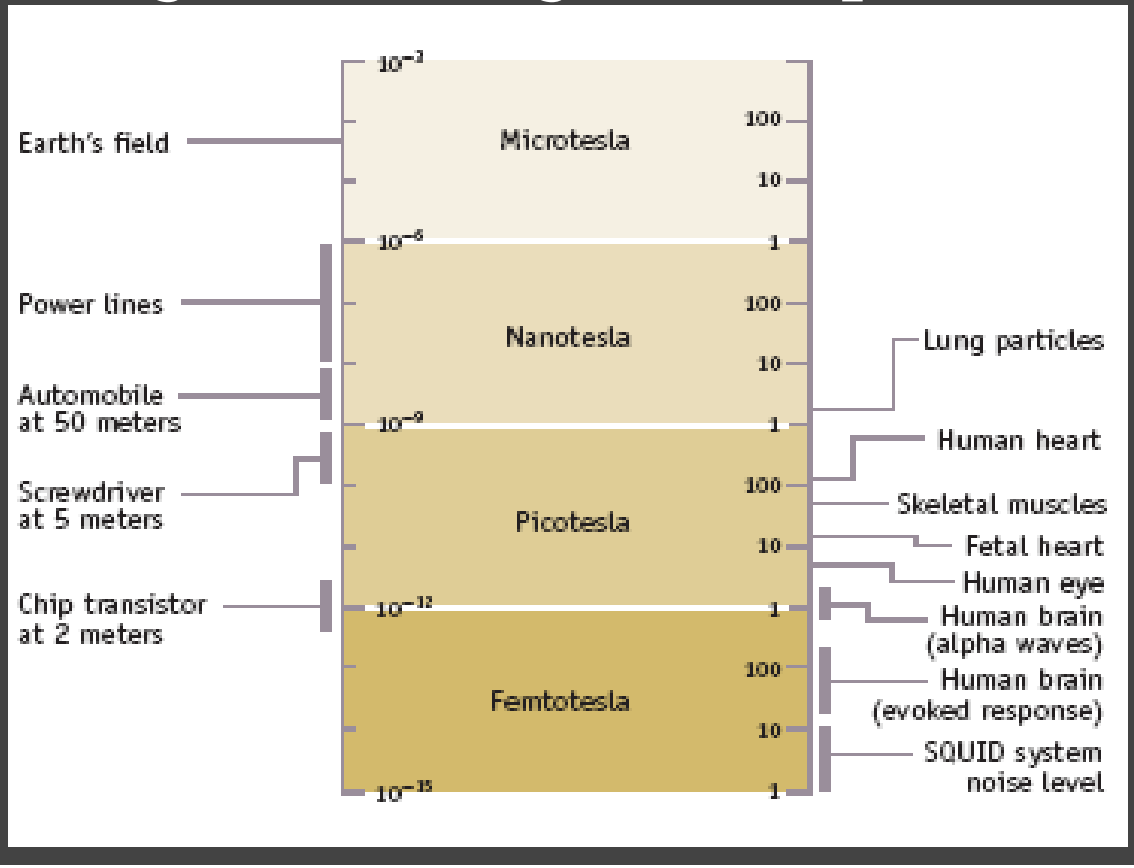
Muscle cells

MCG – magnetocardiogram

MMG – magnetomyogram


BIOELECTROMAGNETISM
A)
BIOELECTRICITY
B)
BIOELECTROMAGNETISM
(BIOMAGNETISM)
C)
BIOMAGNETISM
I) MEASUREMENT OF FIELDS
Electric field from bioelectric source
Magnetic field from bioelectric source
Magnetic field from magnetic material
II) STIMULATION AND MAGNETIZATION
Electric stimulation with electric field
Electrotherapy
Electric stimulation with magnetic field
Magnetoelectrotherapy
Magnetization of material
Magnetotherapy
III) MEASUREMENT OF INTRINSIC PROPERTIES
Electric measurement of electric impedance
Magnetic measurement of electric impedance
Magnetic measurement of magnetic susceptibility
PRINCIPLE OF RECIPROCITY
MAXWELL'S EQUATIONS

Magnetic signal strength comparison



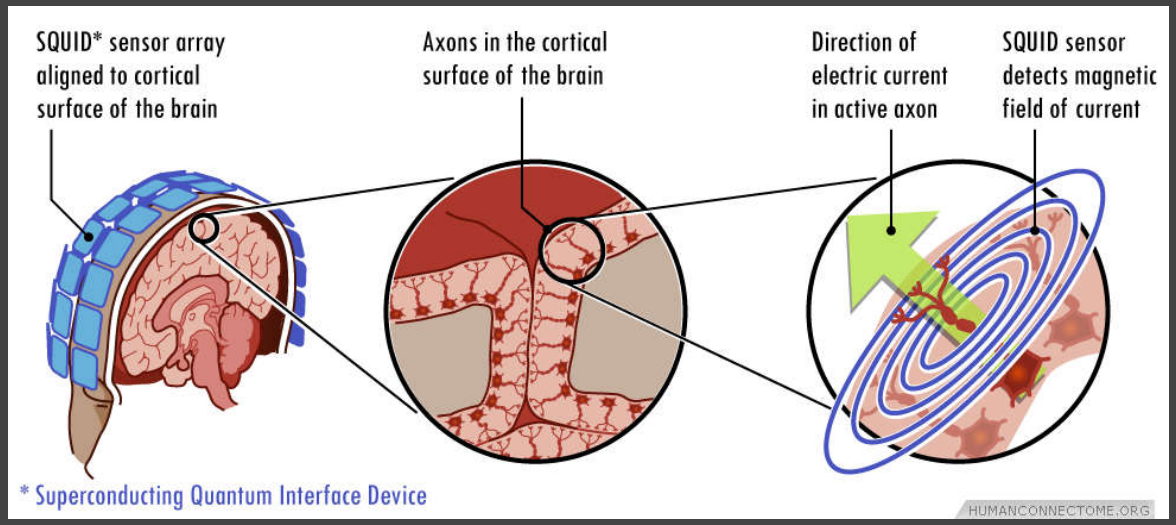
Magnetoencephalography (MEG)

MEG is based on measuring the magnetic field outside the head using an array of very sensitive magnetic field detectors (magnetometers).

MEG *directly* reflect current flows generated by neurons within the brain.

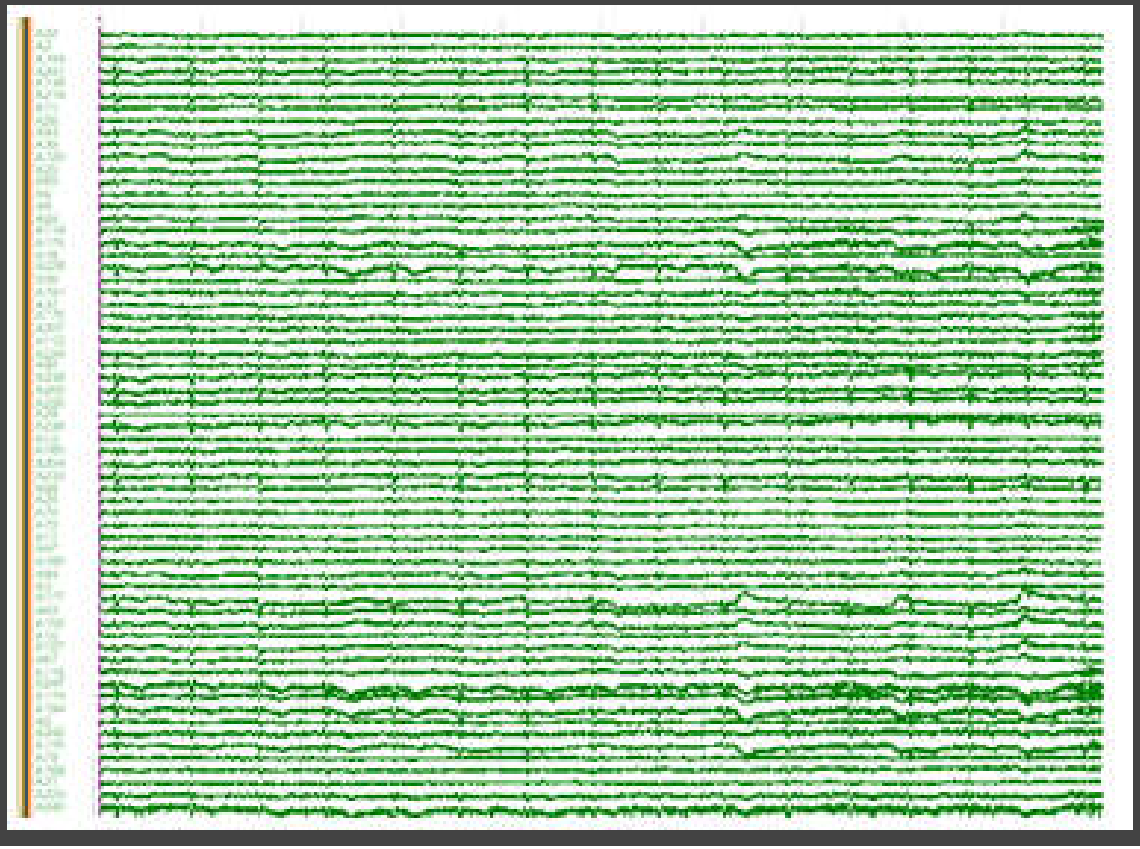
The temporal frequency content of these signals ranges from less than 1 Hz (one cycle per second) to over 100 Hz (100 cycles per second).

MEG measurement

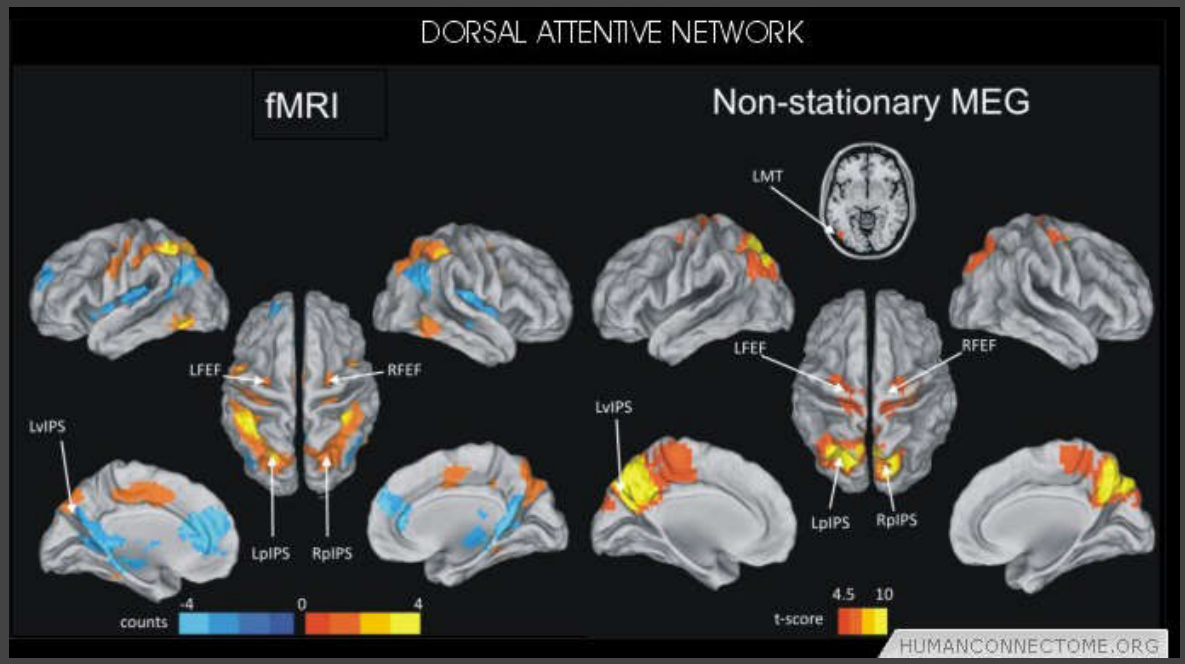


Magnes 3600 with 248 magnetometers within a shielded room with 64 EEG Voltage Channels and 23 MEG reference channels (5 gradiometer, and 18 magnetometer).

MEG signal



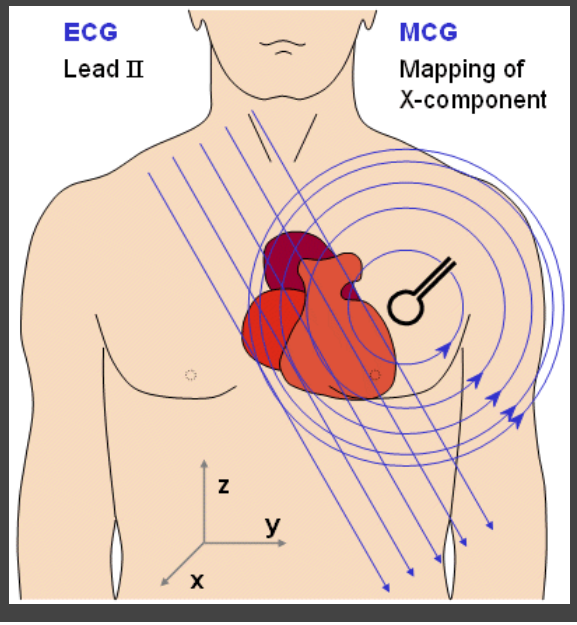
fMRI+MEG during rest



Source-space band-limited power (BLP) correlation maps obtained for the Dorsal Attentive Network. Left: fMRI seed based conjunction maps. Right: MEG t-statistic images across subjects computed using epochs of maximum correlation. The topography of the non-stationary MEG Resting State Network (RSN) is similar to the RSN obtained by fMRI.

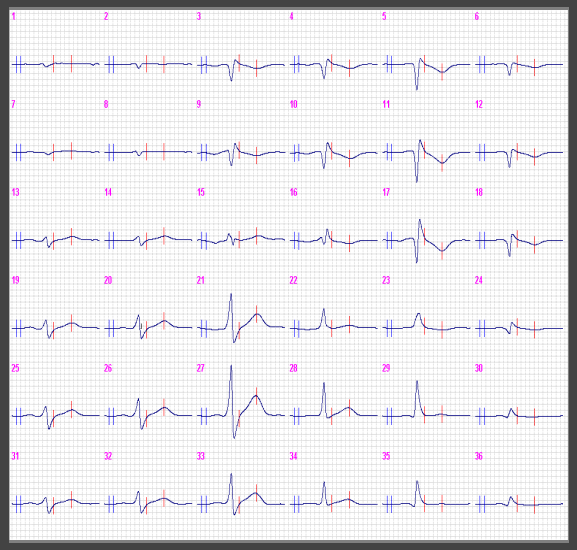
Magnetocardiography (MCG)

MCG is the measurement of magnetic fields emitted by the human heart from small currents by electrically active cells of the heart muscle.

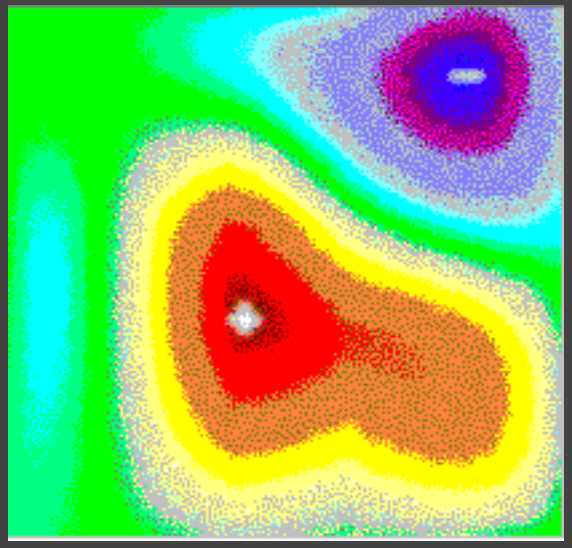


Data derived from MCG

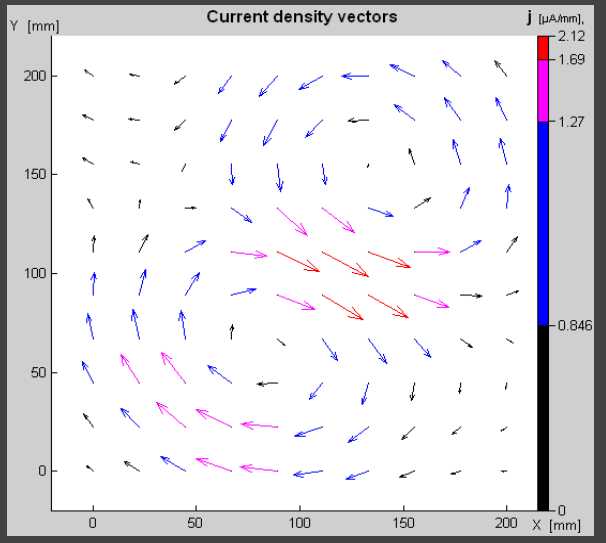
Averaged MCG 36-channels



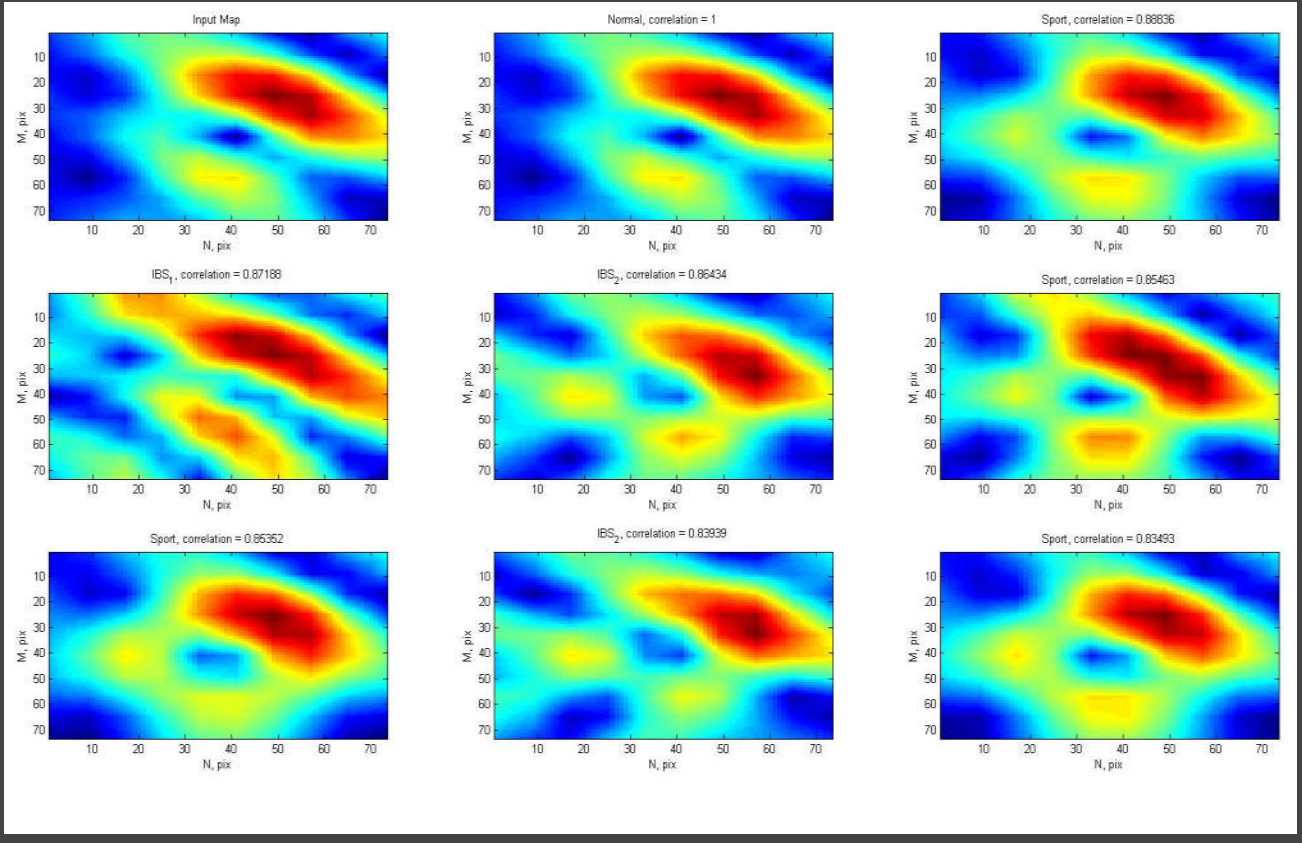
Map of magnetic field distribution



Map of current density distribution



Myocardium current density maps



Chemical biosignals

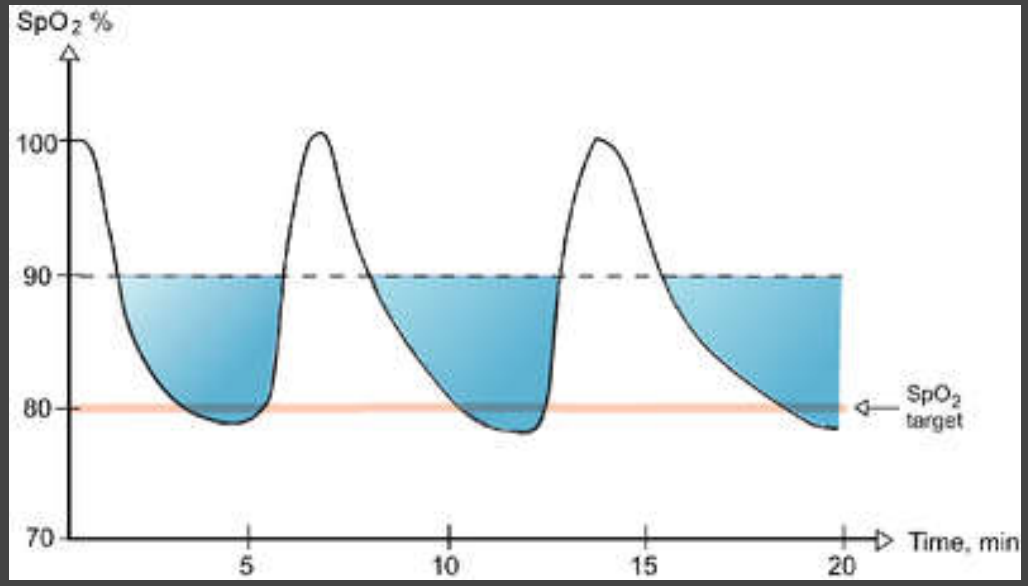
Signals providing information about **concentration** of various chemical agents in the body

- Level of glucose (diabetes)
- Blood oxygen level (asthma, obstructive pulmonary disease, heart and kidney failure)
- Gases in blood and breathing airflow (anesthetic gases, carbon dioxide etc.)
- pH

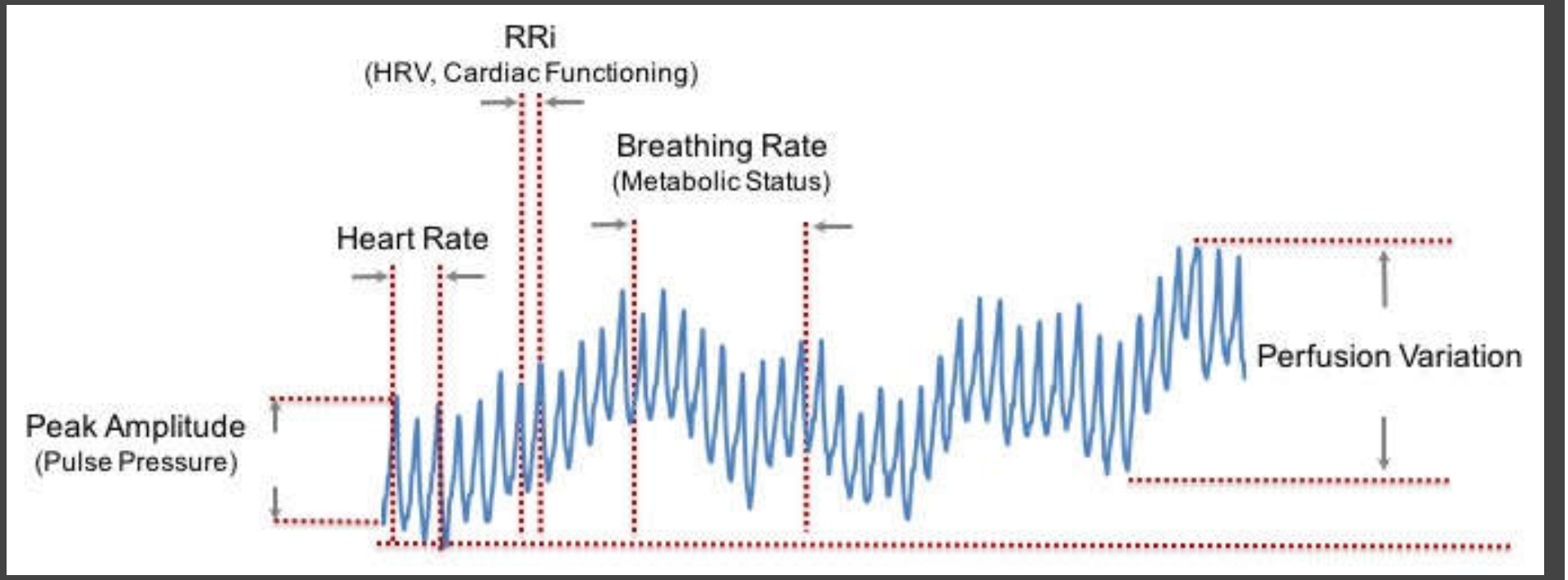
Blood saturation of gases

SaO_2 – arterial blood oxygen saturation, describes the percentage of hemoglobin molecules carrying oxygen.
SvO_2 – venous oxygen saturation, describes how much oxygen the body consumes
SpO_2 – peripheral capillary oxygen saturation – the same as SaO_2 but in the capillary system
$SpCO_2$ – concentration of carboxyhemoglobin in blood

Photoplethysmography



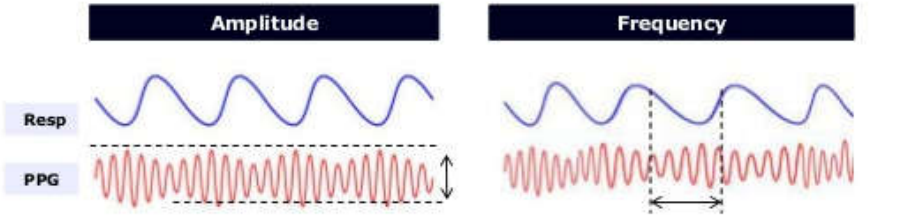
Influences on the pulse wave



Respiration from pulse wave

Breathing rate from PPG waveform

Respiration modulates the PPG waveform amplitude and frequency (heart rate variability)



Respiratory-induced intensity variation (RIIV) is the amplitude modulation of the pulsatile PPG waveform by respiration. **During inspiration, there is a reduction in tissue blood volume.**

Respiratory sinus arrhythmia (RSA) is the cyclic variation of heart rate associated with respiration (heart rate variability). **The vagus nerve is stimulated during expiration, which slows down the heart rate.**

Mechanical biosignals

Biomechanical signals reflect mechanical functions of body parts

Examples:

- Blood Pressure
- Accelerometer signals describing human movements, gait, balance and pose (Parkinson disease, mobile applications, fitness)
- Chest movements during respiration
- Air flow characteristics during MLV

3D tracking using accelerometer

Acoustic biosignals

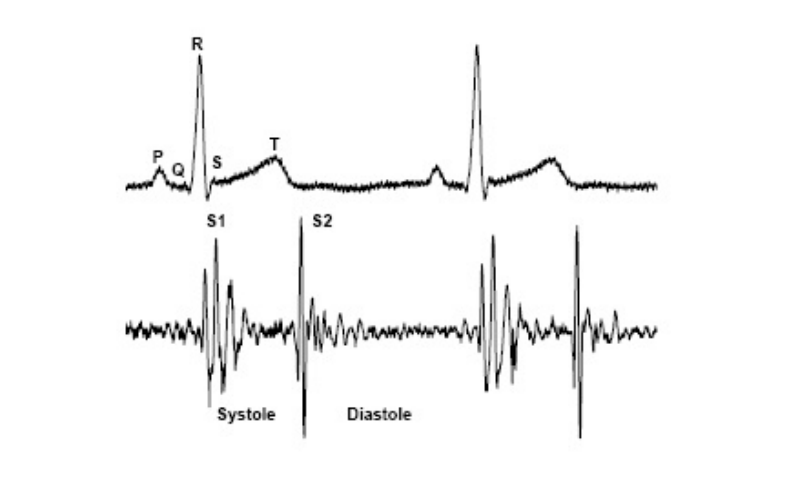
Subset of mechanical signals that describe the acoustic sound produced by the body (vibrations and motions). Bioacoustic signals give access to diverse body sounds:

- Cardiac sounds (phonocardiography)
- Snoring (Obstructive Sleep Apnea detction)
- Swallowing
- Respiratory sounds
- Crackles of joints and muscles

Often measured at the skin using acoustic transducers such as microphones and accelerometers.

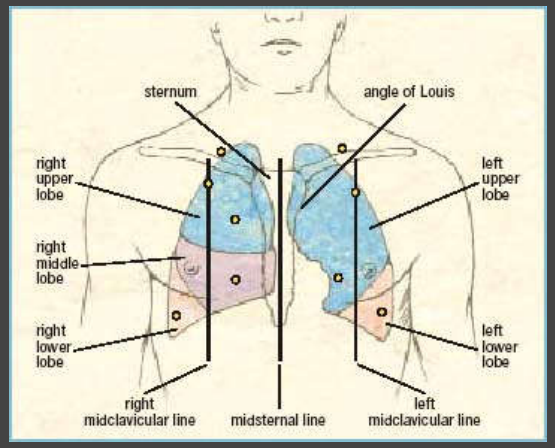
Phonocardiogram (PCG)

PCG reflects sounds of heartbeats, produced by heart sounds corresponding to two consecutive heart valve closures. Indicates closure strength and the valve's stiffness.

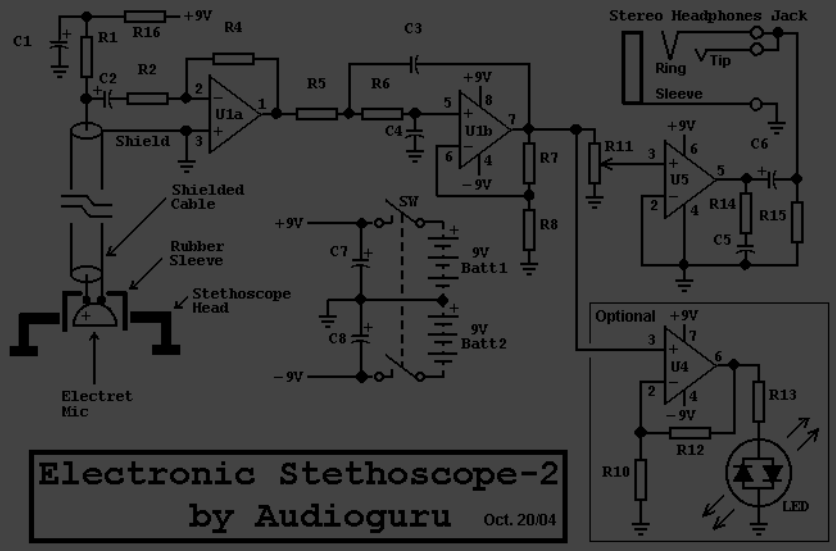


Respiratory sounds

Reflect normal breathing sounds superimposed with crackles, cough sounds, rhonchus, snoring, squawk, stridor and wheeze sounds, which are associated with pulmonary disorders.

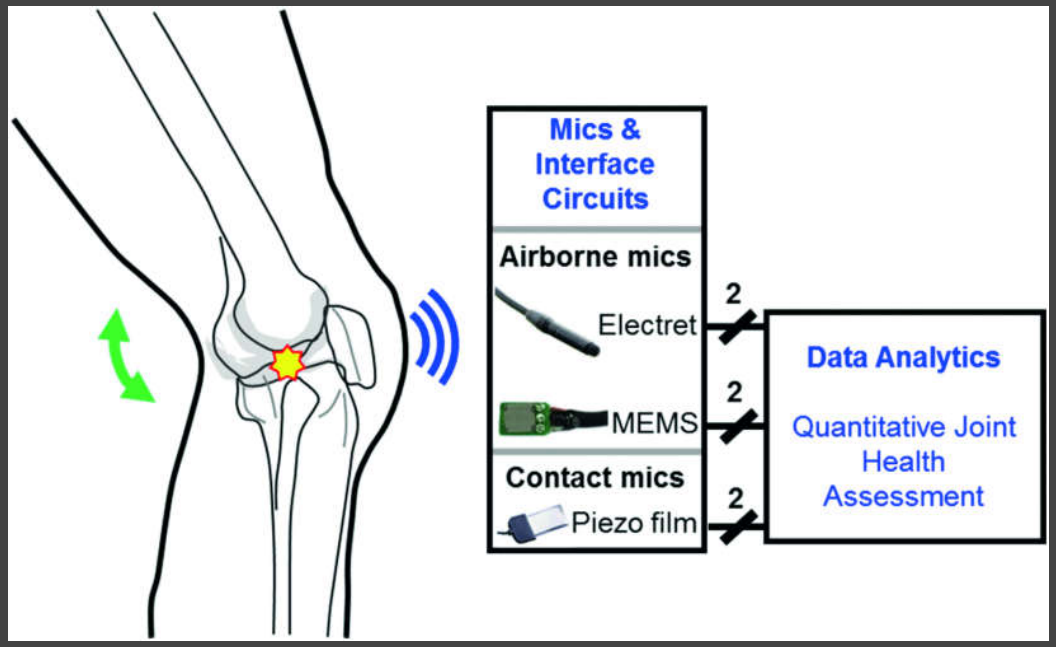


Electronic stethoscope



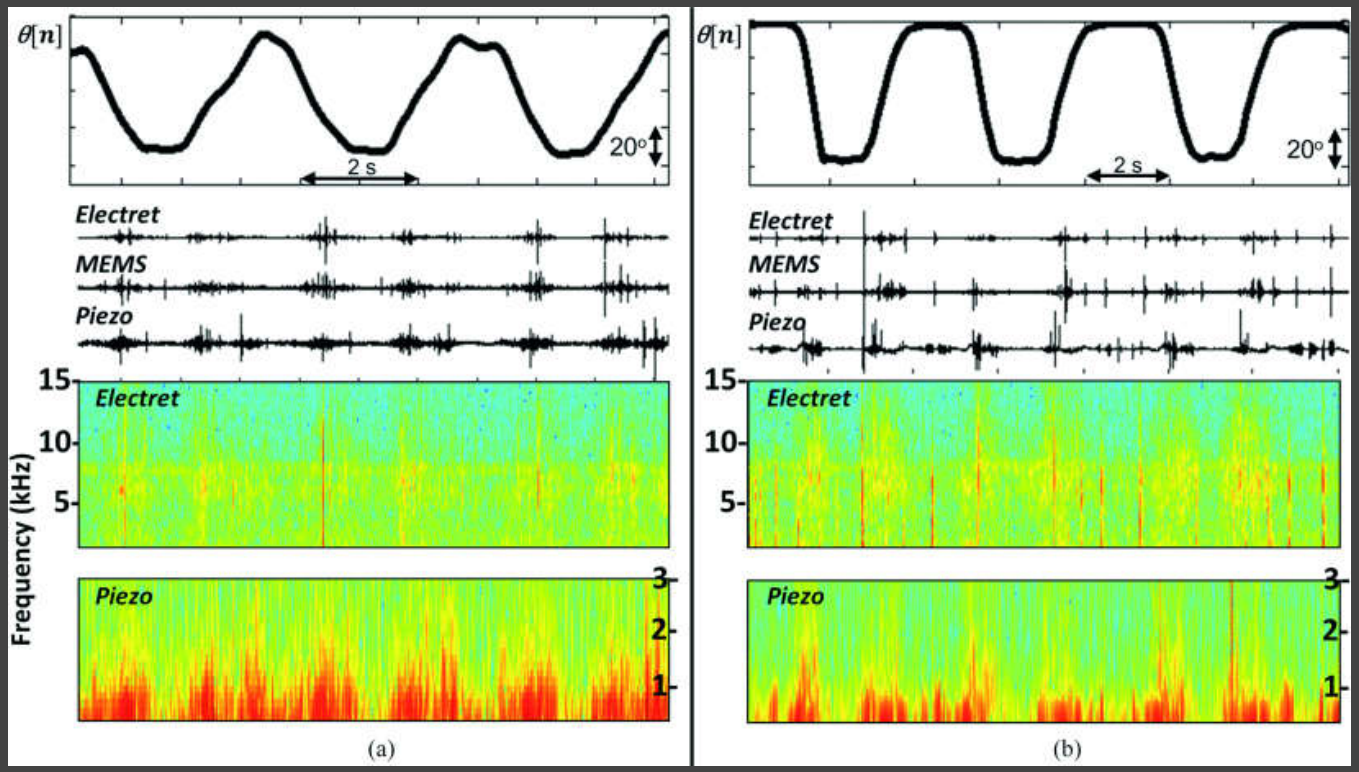
Knee joints sounds

Wearable joint rehabilitation assessment following acute knee injury based on the measurement of acoustical emissions from the knee with miniature microphones.

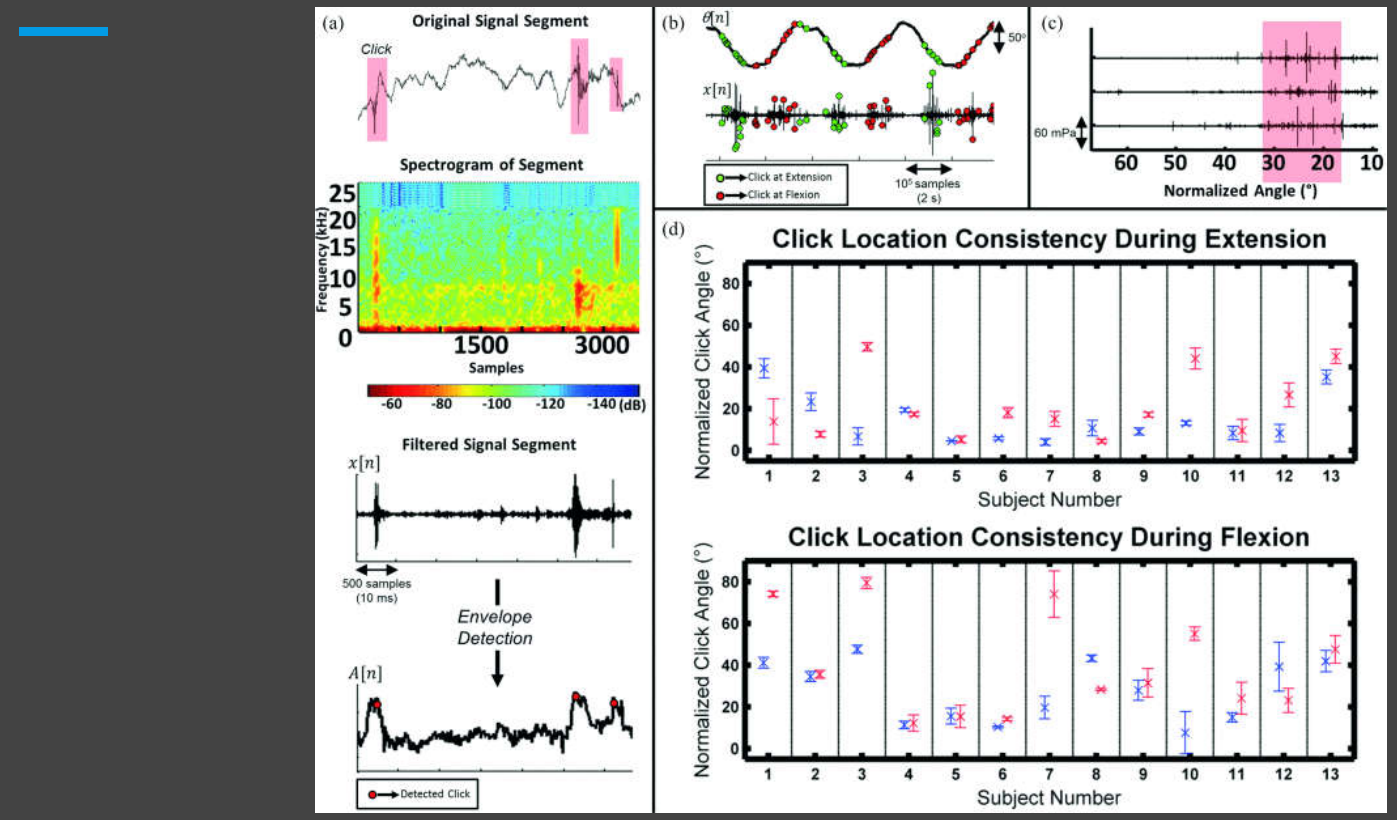


C. N. Teague *et al.*, "Novel Methods for Sensing Acoustical Emissions From the Knee for Wearable Joint Health Assessment," in *IEEE Transactions on Biomedical Engineering*, vol. 63, no. 8, pp. 1581-1590, Aug. 2016. doi: 10.1109/TBME.2016.2543226

Frequency characteristics of different microphones

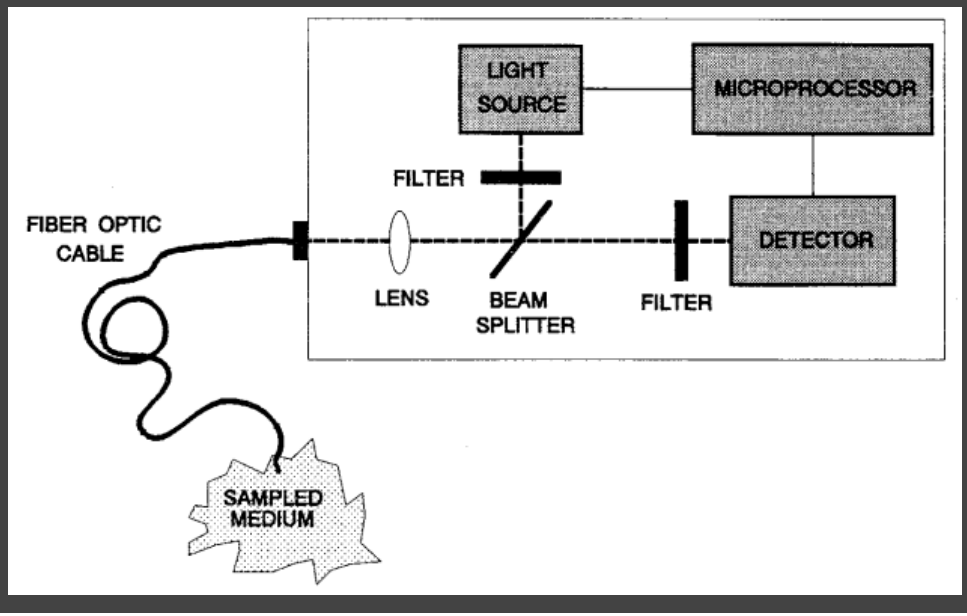


Summary of results

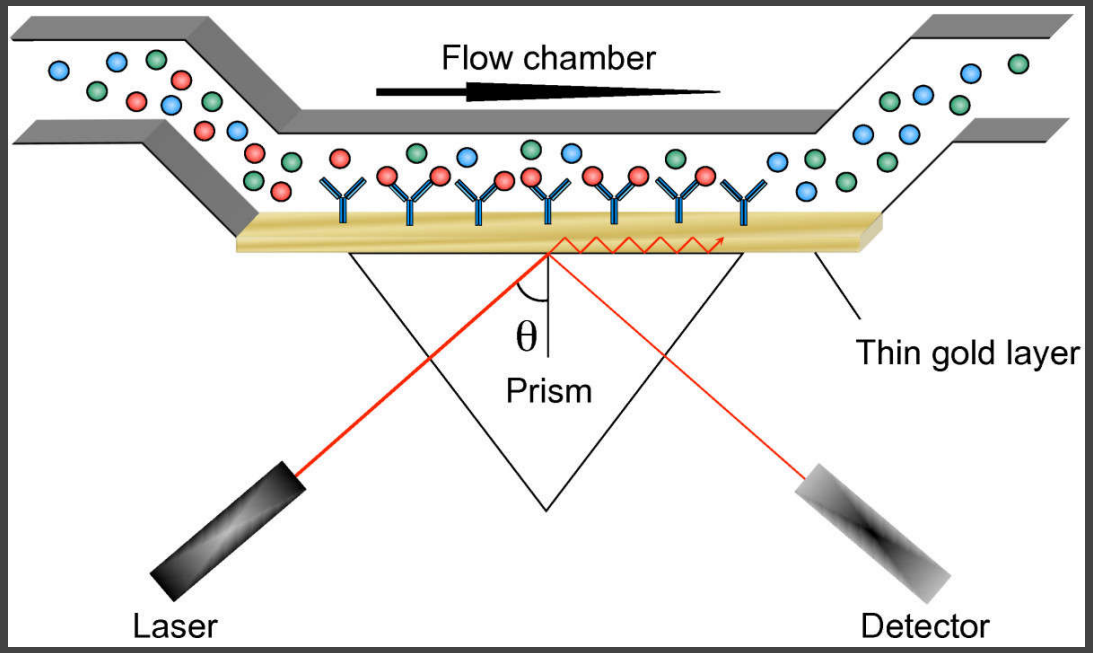


Optical biosignals

Optical methods are among the oldest and best-established techniques for sensing biochemical analytes.



Immunology (antibody-antigen interaction)



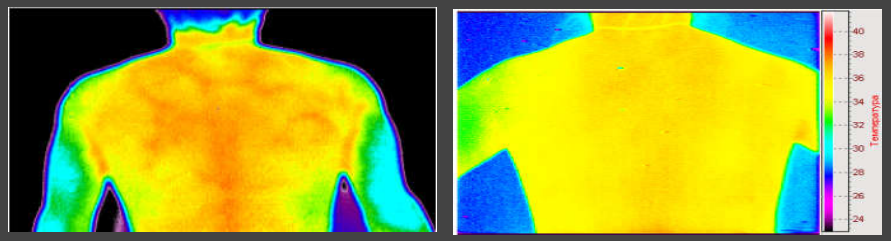
Surface plasmon resonance is the collective oscillation of electrons stimulated by incident light.

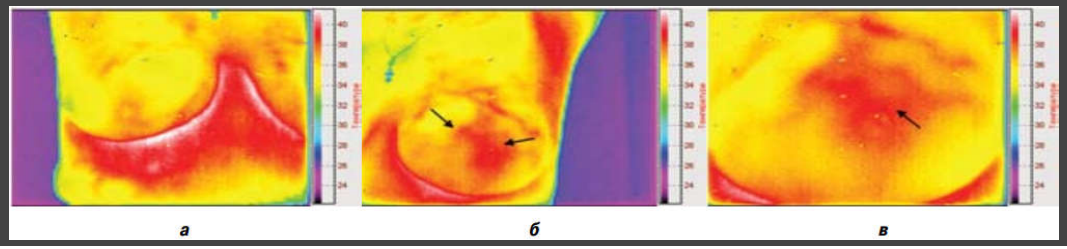
Thermal biosignals

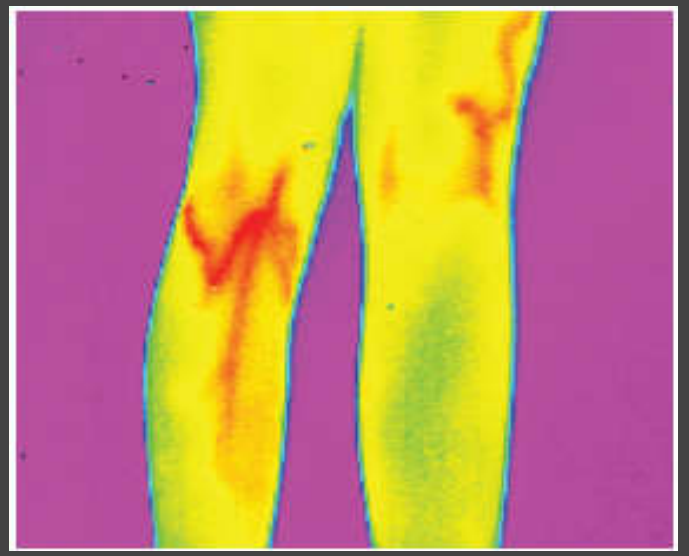
Body temperature in the point and temperature maps, may describe heat loss and heat absorption in the body, or temperature distribution over the body surface.

Thermography (temperature maps)

- Cancer
- Varicose veins
- Osteochondrosis, osteoporosis







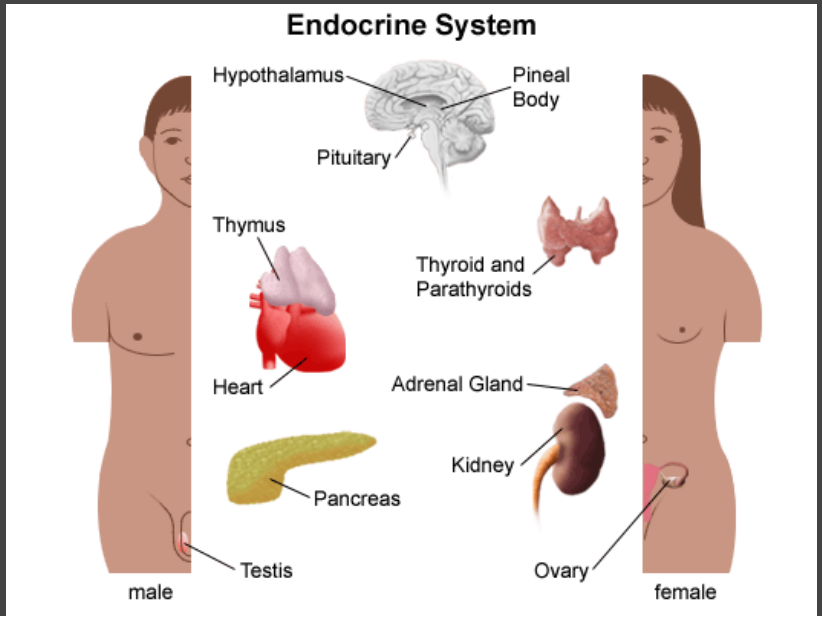
Classification according to the system of origin of signal

Endocrine System

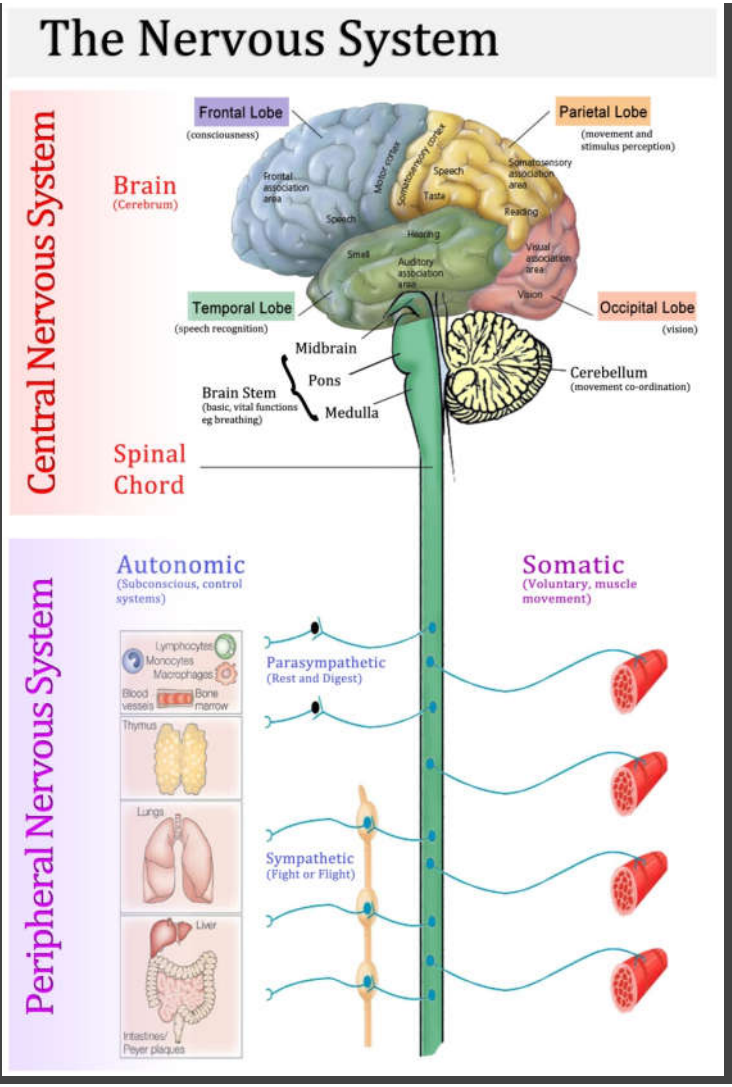
Is the collection of glands of an organism that secrete hormones directly into the circulatory system to be carried toward a distant target organ.

Signals:

- Chemical
- Optical



The Nervous System



Signals from Nervous System

Neurons and spinal cord

- Electroneurogram (Spike trains)
- Magnetoneurogram

Brain

- EEG, MEG
- Event-Related Potentials (acoustic, visual)
- Neurovisualization (MRI/fMRI, CT, PET, SPECT)

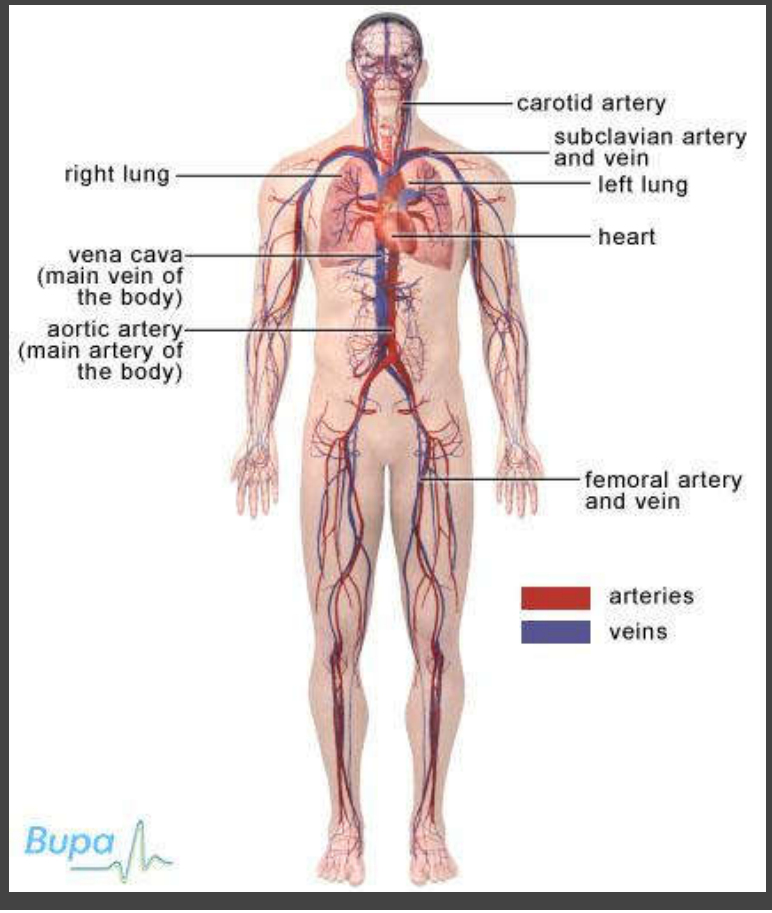
Cardiovascular System

Heart & blood vessels

- ECG
- MCG (Current Density Maps)
- Blood pressure
- Heart Rate Variability

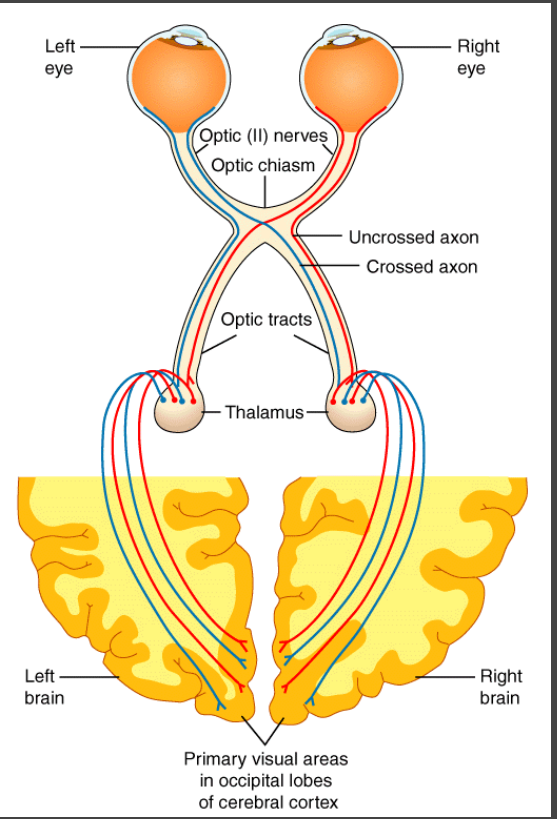
Visualization

- Ultrasonic Imaging
- MRI, Ultrasonic, X-ray



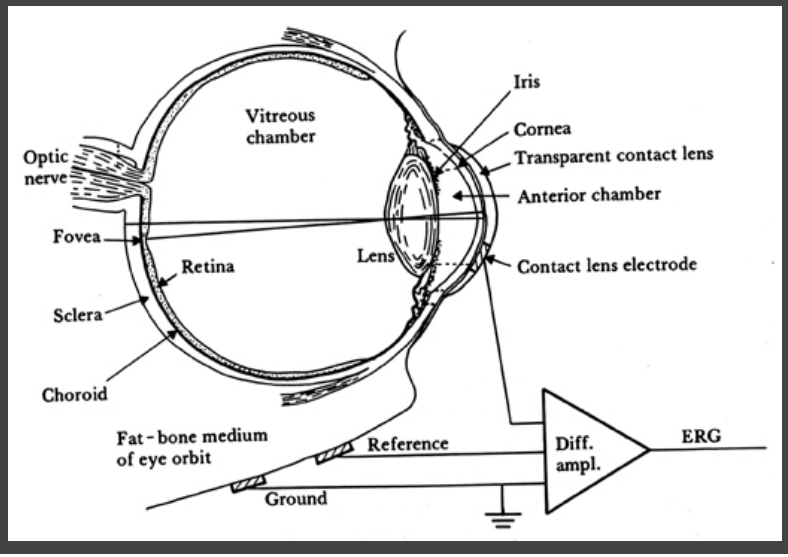
Vision system

- EEG (visual cortex)
- VEP (Visual Evoked Potentials)
- EOG (Electrooculogram)
- ERG (Electroretinogram)



Electroretinography

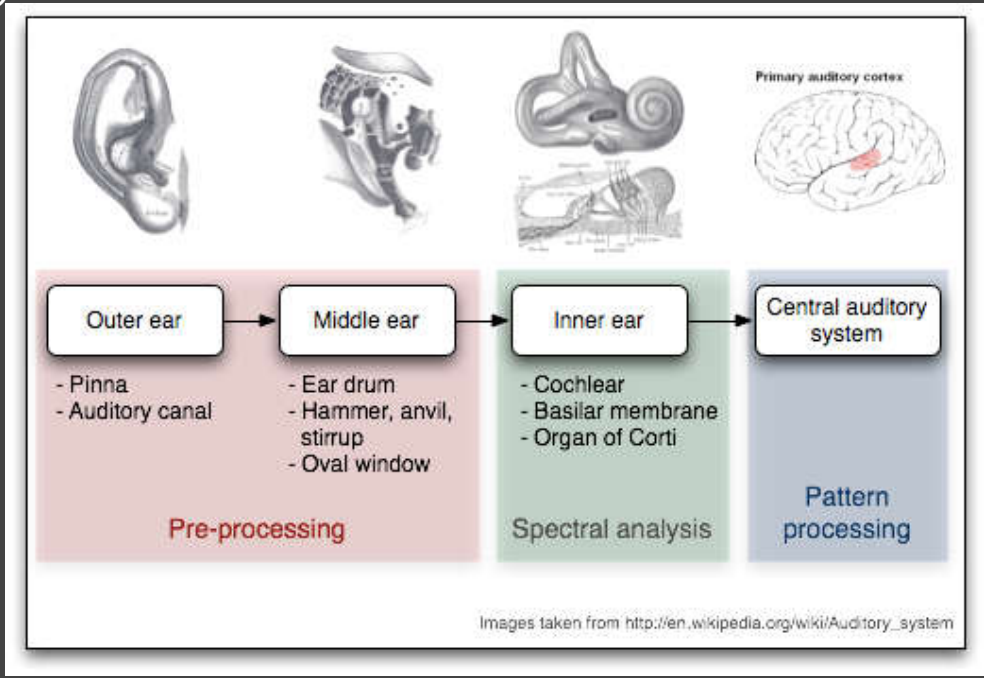
Electroretinography measures the electrical responses of various cell types in the retina, including the photoreceptors (rods and cones), inner retinal cells (bipolar and amacrine cells), and the ganglion cells.



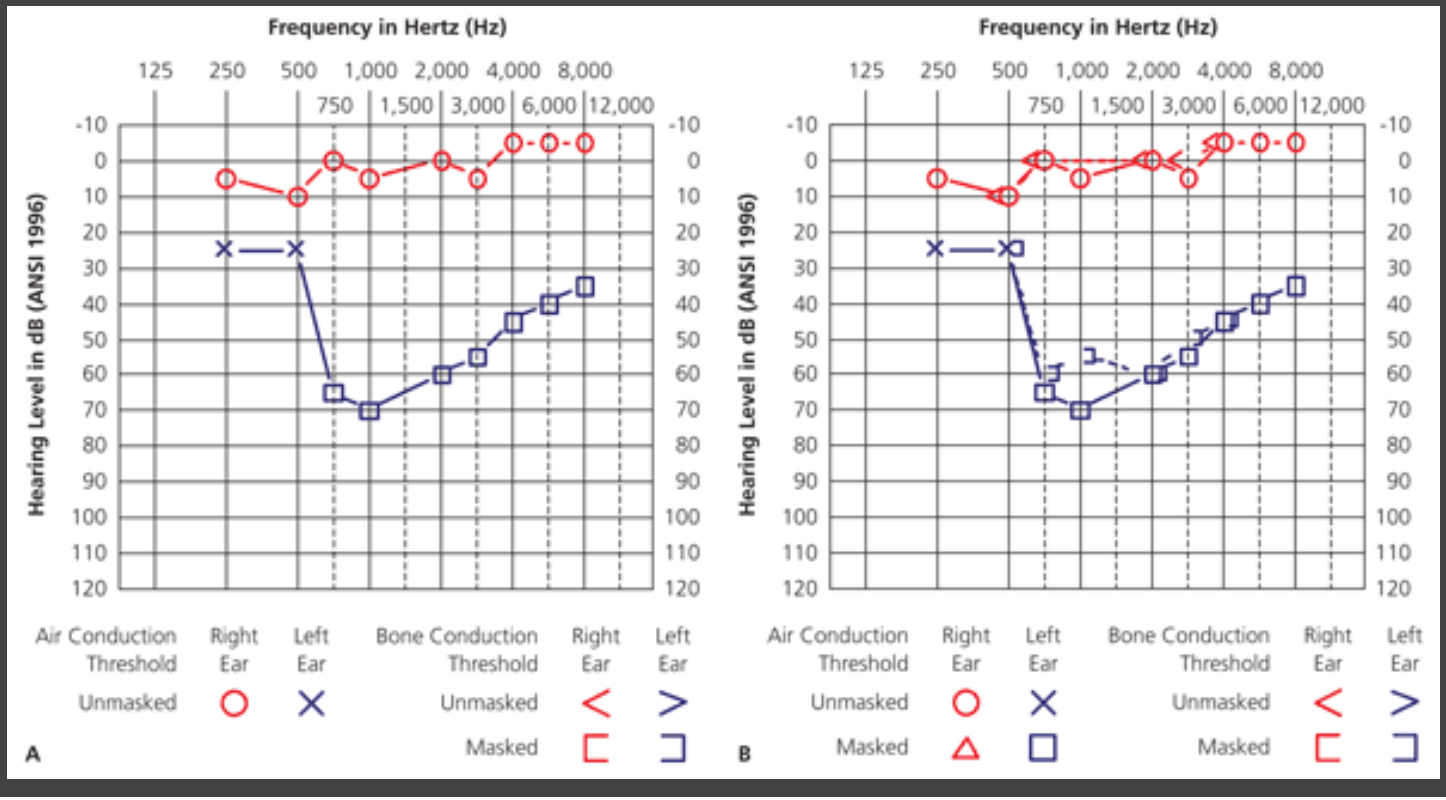
some corneal ERG electrodes

Auditory system

- EEG (Auditory Evoked Potentials)
- Audiometry

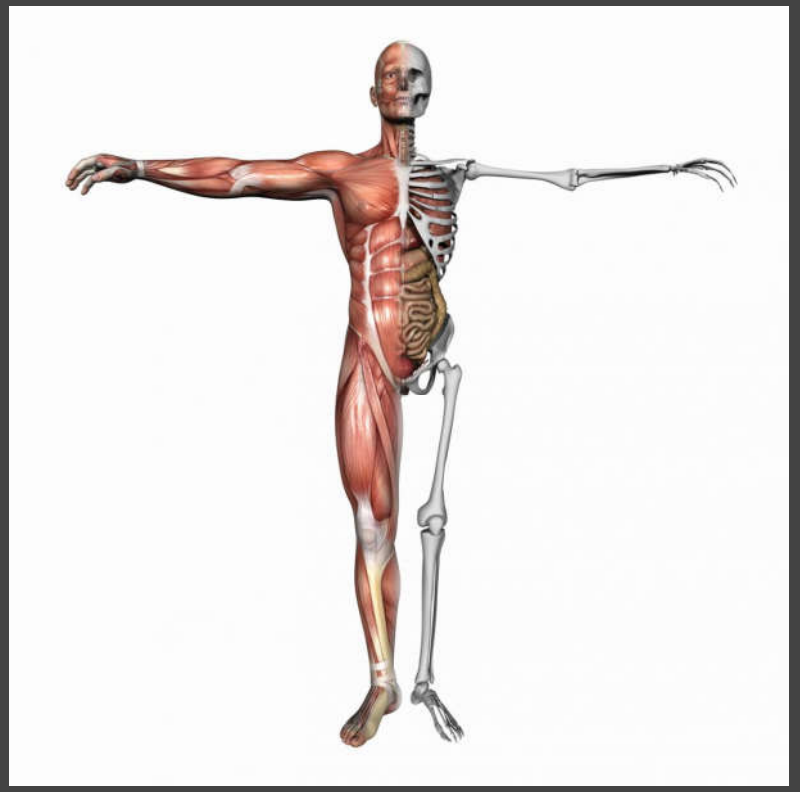


Example of audiogram



Musculoskeletal system

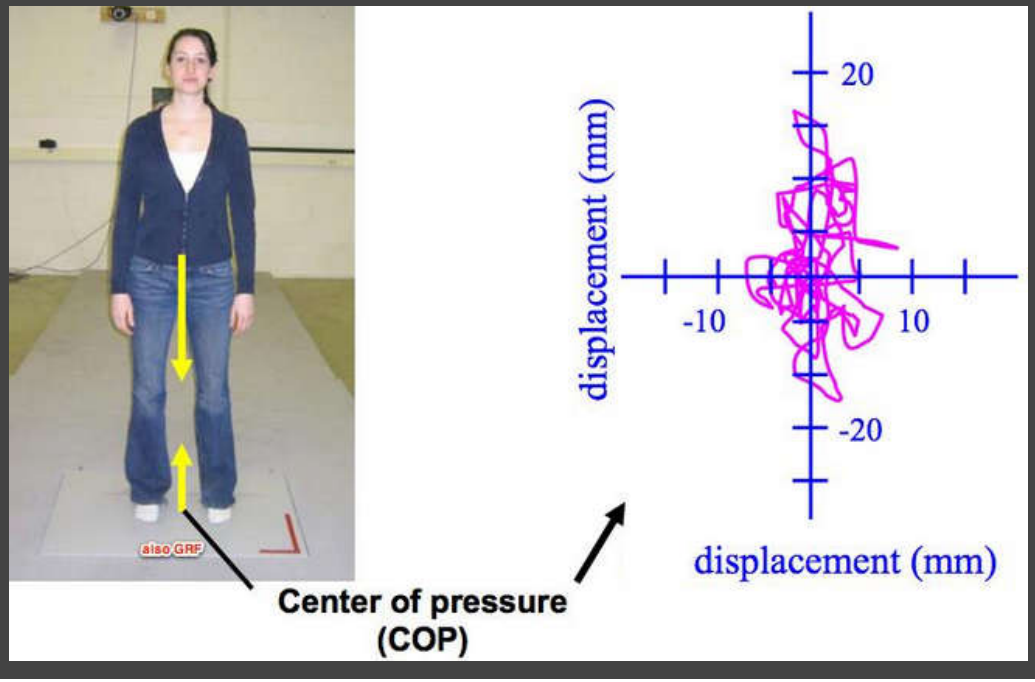
- EMG (Electromyogram)
- Visualization (MRI, X-Ray)
- Reography (myorelaxation)
- Accelerometry (gait)
- Stabilorgaphy (Parkinson’s)



form, support, stability, and movement

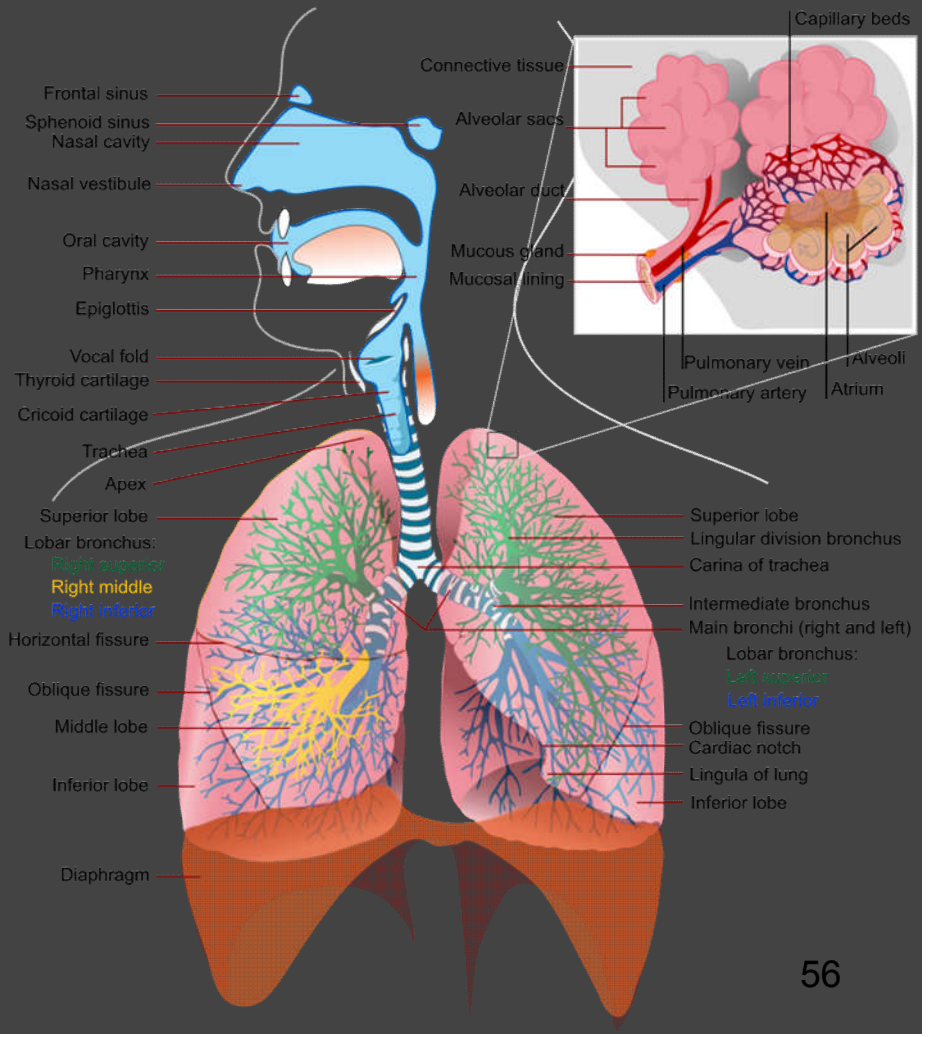
Stabilography

Analysis of balancing act and postural control

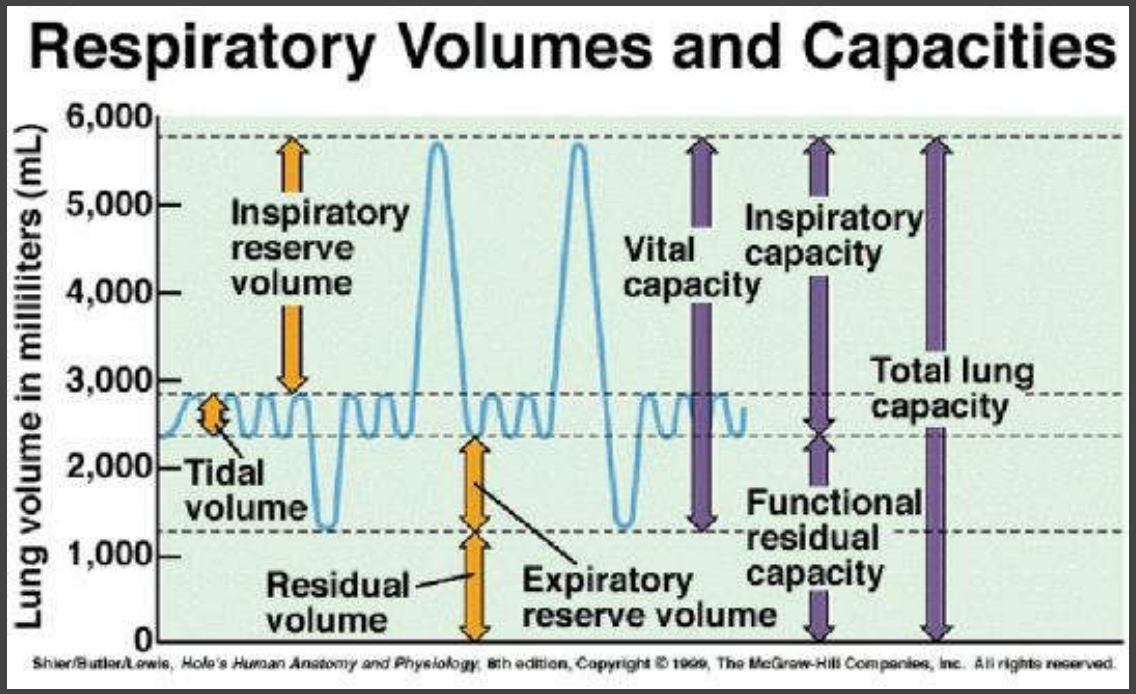


Respiratory system

- Chemical signals (gas concentration)
- Mechanical (airflow, pressure, volume)
- Spirometry (flow-volume)
- Plethysmography (volume)

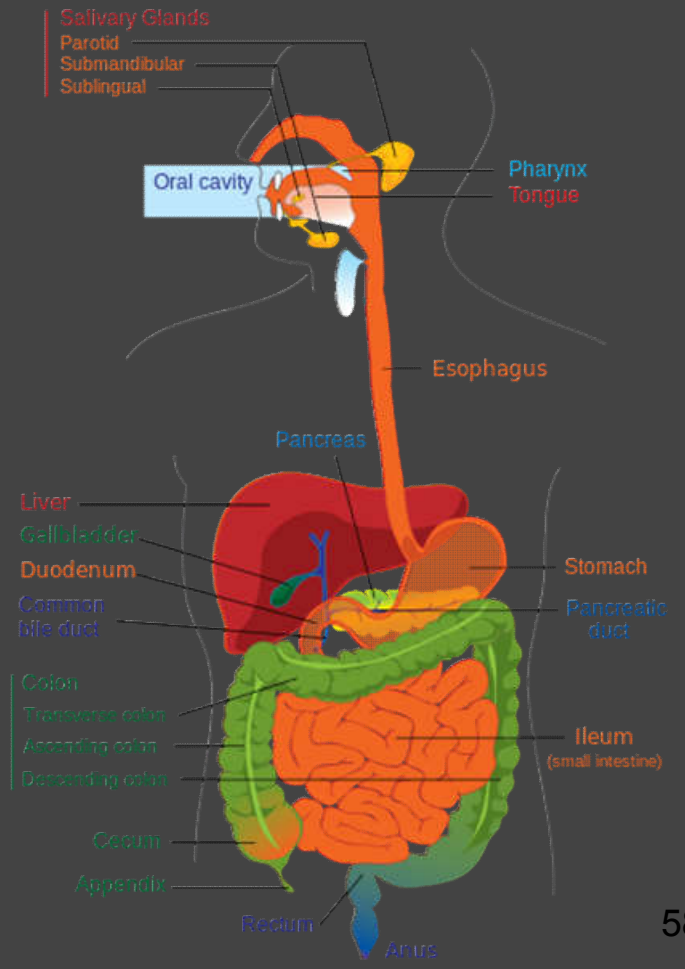


Spyrography



Gastrointestinal System

- MRI
- X-ray
- Ultrasound Imaging
- Chemical signals
- Electrogastrogram



Elecrtogastrogram

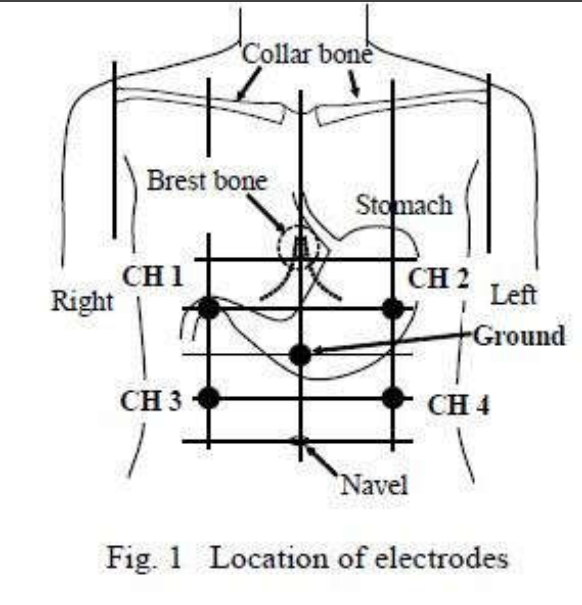
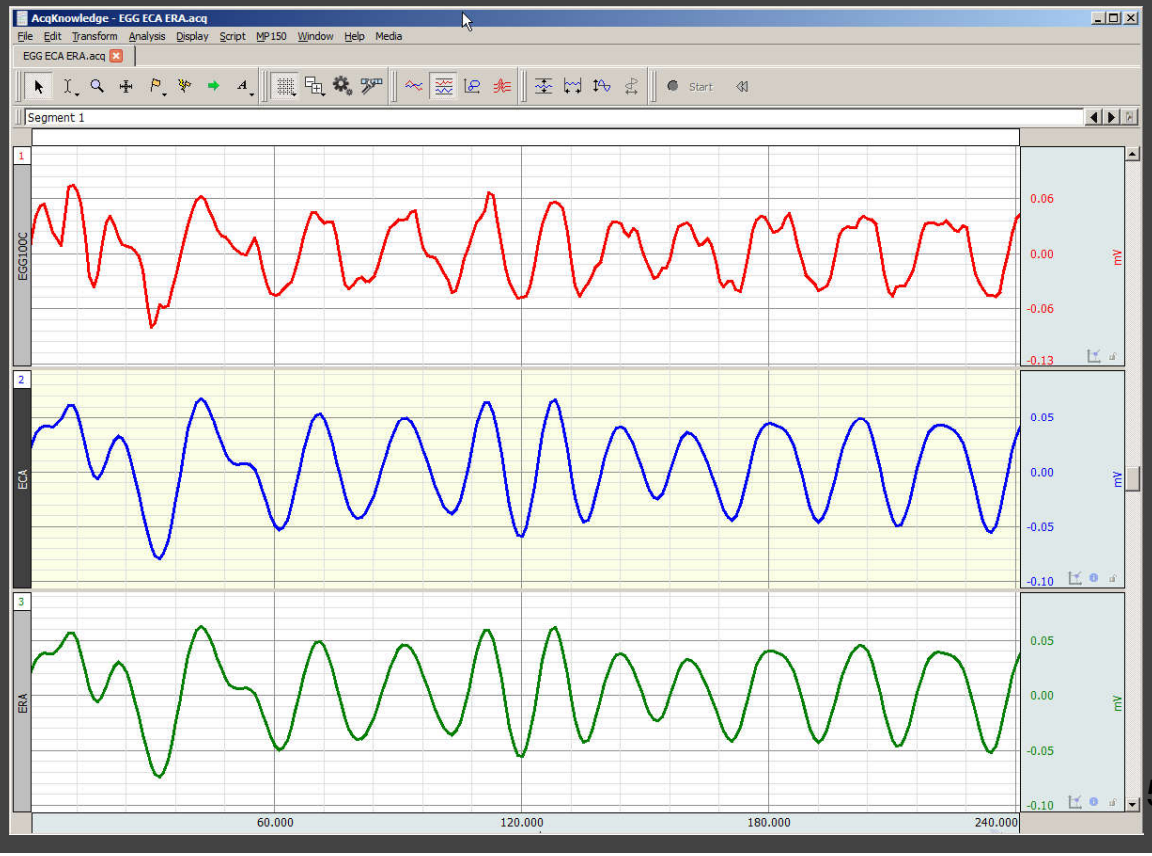
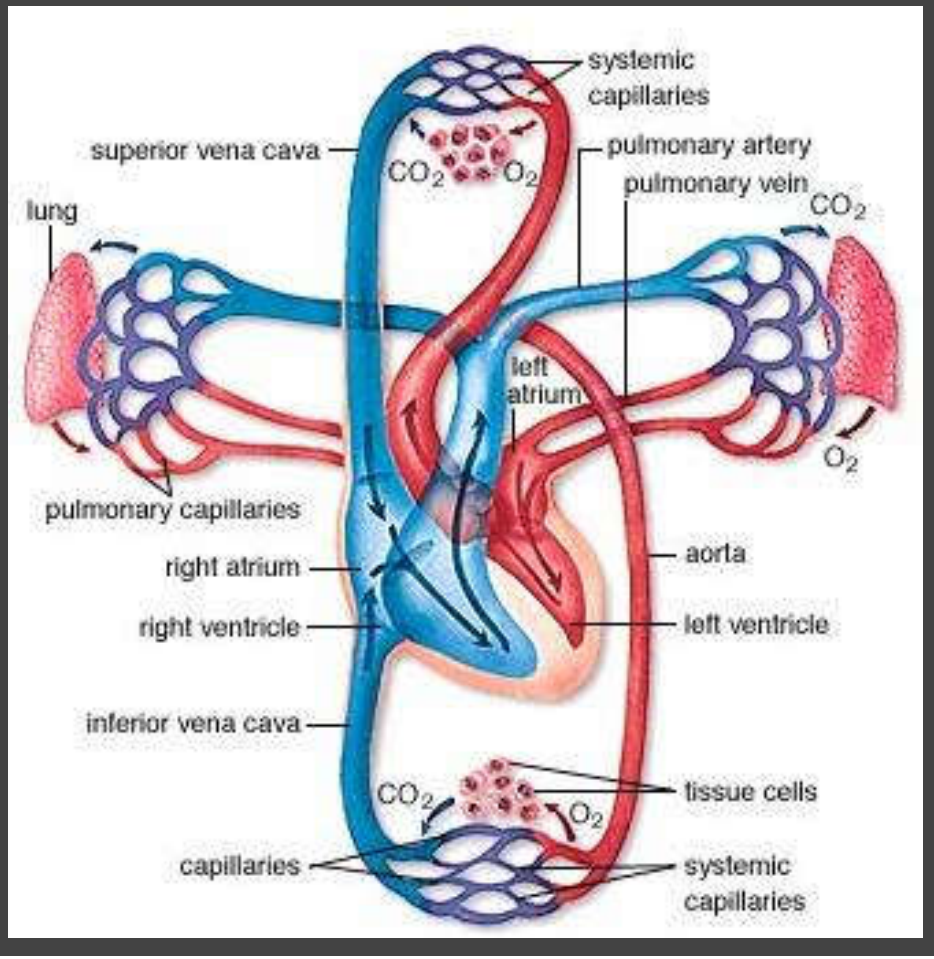


Fig. 1 Location of electrodes



Blood System

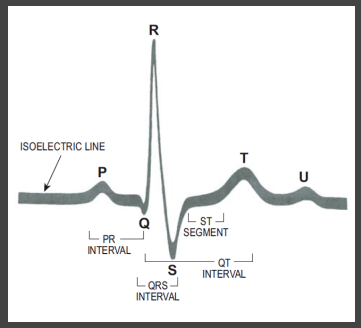
- Chemical signals (concentrations)

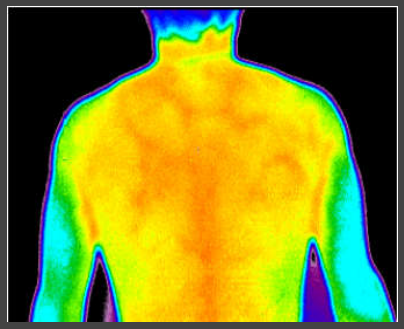


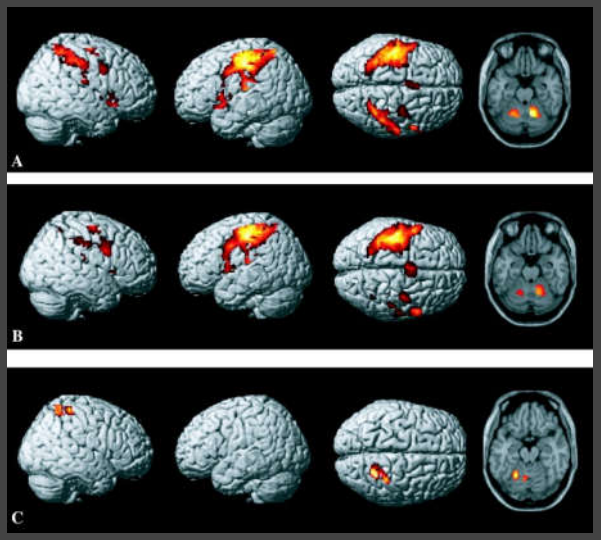
Other Classification of biosignals

Dimesionality

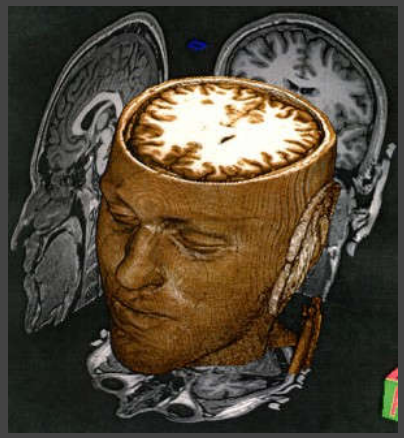
- 1D (ECG)
- 2D (temperature map)
- 3D (MRI image)
- 4D (fMRI image)





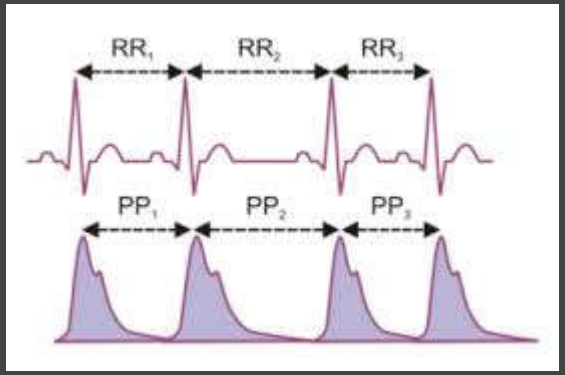


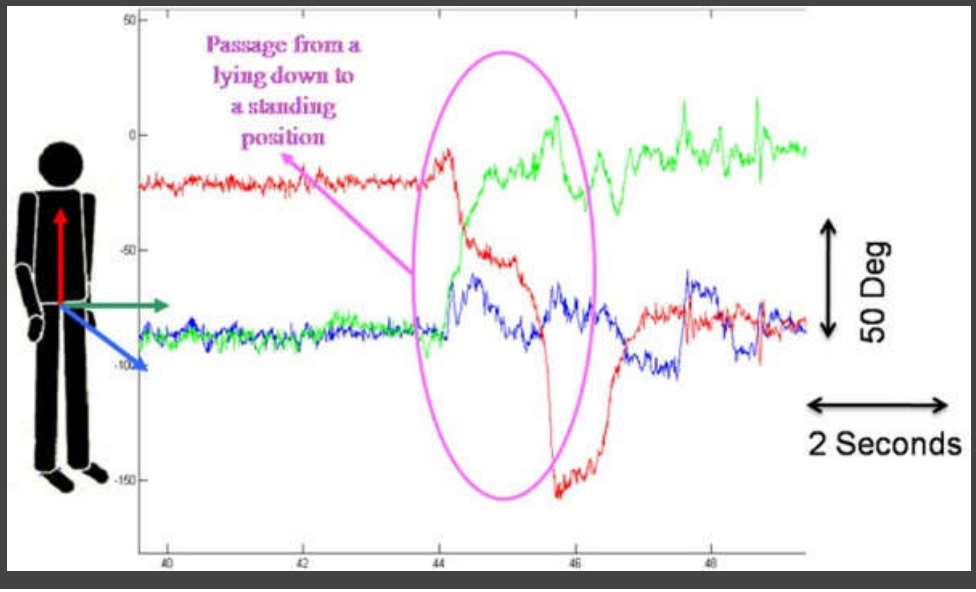
Task-related activation



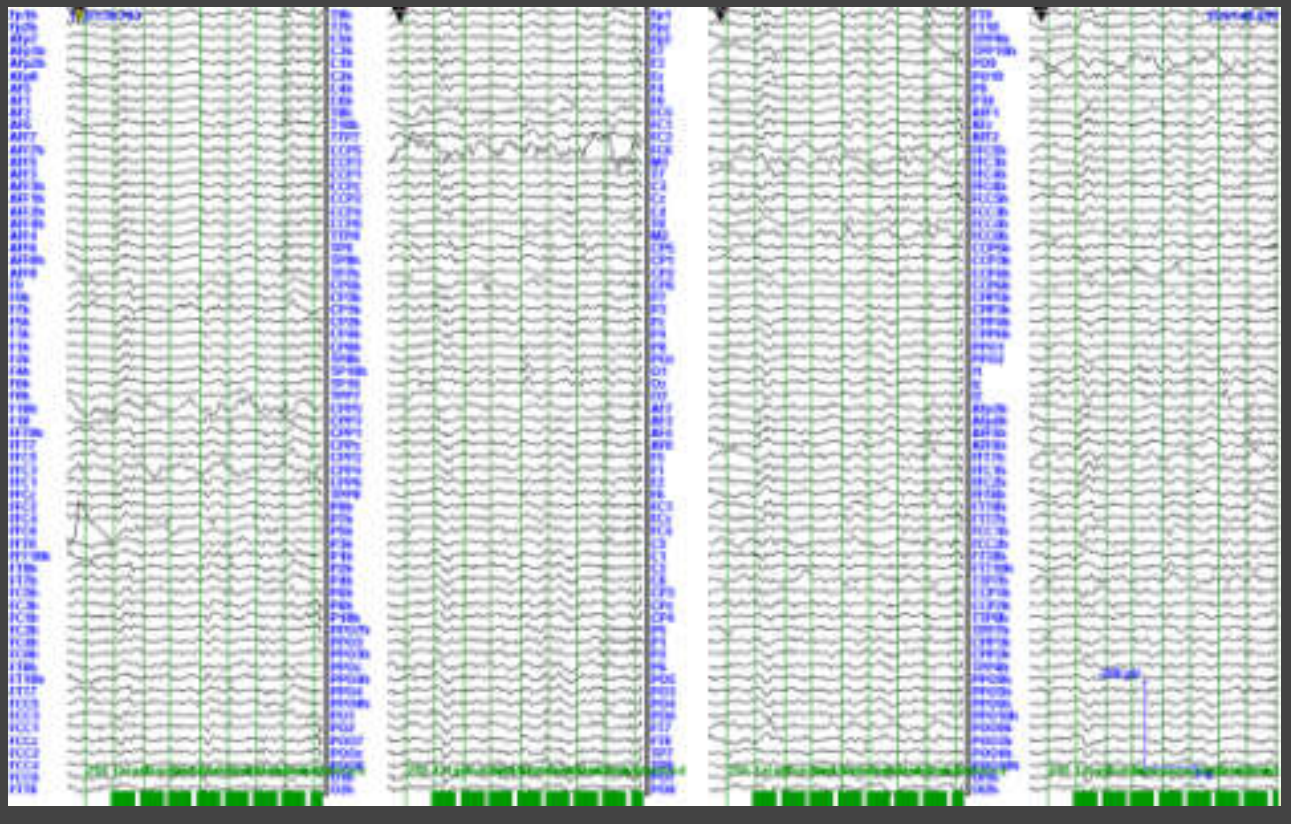
Number of channels

- One channel (pulse wave)
- Three channels (accelerometer data)
- Multichannel (EEG)

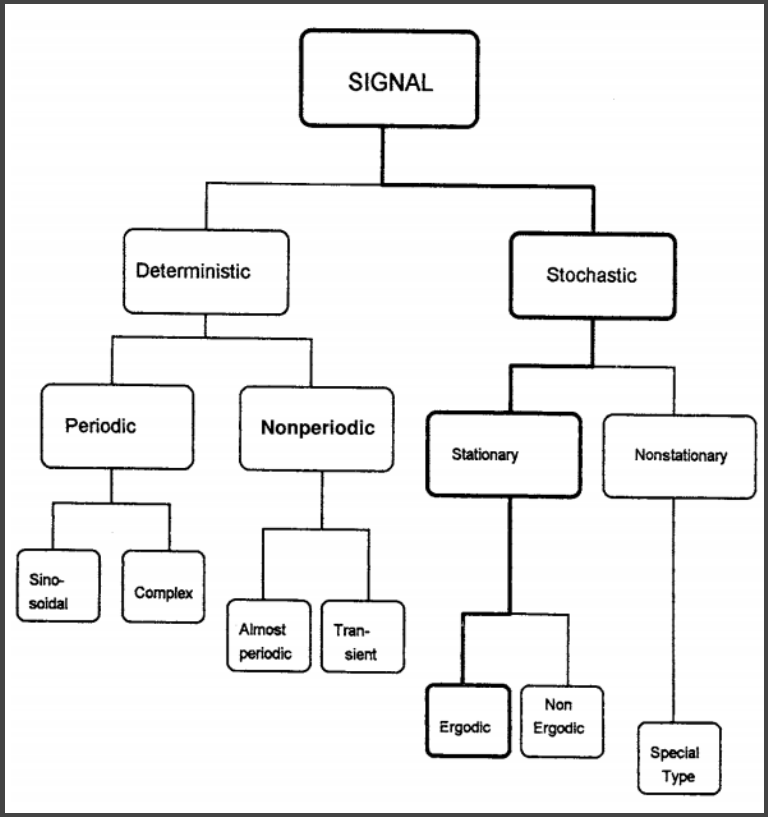




256 channels of EEG



Analysis approach (signal models)



Summary

Biosignals are the only source of information describing the functioning of the human body in healthy and disease conditions.
Biosignals are of various nature and origin.
Many biosignals can contain information about same organ or system.
Researchers and practitioners should do

measurement,
processing,
analysis,
interpretation