# Applied Case Studies in Machine Learning and Deep Learning in Key Areas II

Francesca Faraci , BSP Group Leader
Course Coordinator

# Contacts


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# Who am I ?

*Laurea* in Physics, **Genova** 2002

PhD in Electronics (GA Algorithms) **University of York,** UK 2006

PostDocs: **Universidade de Coimbra** (PT) 2005

**IT'IS Foundation**, Zürich 2005

**DBSSE BEL ETH Zürich** / Basel 2006-2008

**Since 2009 in SUPSI** as Lecturer and Researcher, leading several research projects in the field of Biomedical Signal Processing, Application of AI in Healthcare

LinkedIn

Google Scholar

ORCID iD

https://orcid.org/0000-0002-8720-1256

# Content of the Course

- Introduction to Biosignals
- Biosignals Pre-processing
- ECG feature based analysis
- EEG feature based analysis
- EEG deep learning based analysis
- Clinical data challenges
- Final Project

# Competences you will acquire

- Execute Basic Signal Processing on BioMedical Signals
- Extract Features from BioMedical Signals
- Work with ML and DL models
- Understand the challenges of working with Clinical Data

# The Team

- 5 PhD Students, 2 Post-Docs, 2 Assistants (ex DSAI Bachelor)
- Our Focus : Brain, Heart and Body

# Evaluation

- Minimum 2 Minitest (30%)
- Final Project in Group (last two weeks, supervised)
- Exam: Presentation of the Final Project (70%) (unsupervised :-) )

# Let’s start !

# Today's agenda

- Biomedical Signals Categories
- Action Potential
- Electroneurogram
- Electro-oculogram
- Electroencephalogram (EEG)
- Electrocardiogram (ECG)
- Electromyogram
- HRV via PPG

# Classification of Biomedical Signal

**Nature**:

- Electric (potential or current) / Magnetic / Chemical
- Mechanical / Acoustic / Optical / Thermal
- Biochemical (hormones, neurotransmitters, glucose level, blood oxygen level ... )

**System of Origin:**

- Nervous / Cardiovascular / Auditory/ Vision / Respiratory / Musculoskeletal / Gastrointestinal...

# Biomedical Signal and Math

**Deterministic signals** are signals which can be determined and described exactly using mathematics or graphics. Periodic signals belong to this group and are expressed by s(t)= s(t+nT) n is integer and T is period. Blood pressure could be characterized as a complex periodic signal.

**Stochastic signals** can be expressed only in terms of probabilities. Stationary stochastic processes will not change in time. The expectations of such a process is time independent. Most of them are non stationary. Consequently, statistical properties and probabilities must be used to describe stochastic signals.

**In practice, biological signals often have both deterministic and stochastic components.**

Non-stationary process is a signal whose statistical properties vary with time.

! It may be difficult to process a non-stationary process.

# Key Differences

| | Deterministic Biomedical Signals | Stochastic Biomedical Signals |
|---|---|---|
| **Predictability** | Follows a fixed, predictable pattern | Contains randomness and variability |
| **Mathematical Model** | Can be modeled by exact equations | Best analyzed using statistical properties |
| **Examples** | ECG of a healthy person, controlled breathing signals | EEG, HRV, blood pressure fluctuations |
| **Analysis Methods** | Time-domain, frequency-domain analysis | Probability, machine learning, statistical methods |

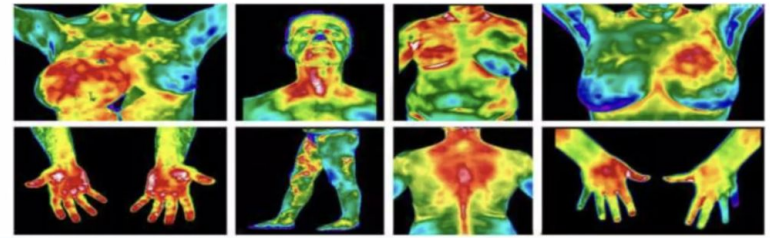
# Biomedical Signals

**Electrical** : EEG, ECG, EMG, EOG

**Mechanical** : Blood Pressure, Motion (Accelerometer/Video), Lung Volume and Capacity (Spirometry) , Heart Sound (Phocardiogram), Blood Volume Changes (PPG)

**Chemical** : Sp02 (Capillary Oxigen Saturation)

**Thermal** : Heat Patterns, Blood Flow



# Action Potential

An action potential occurs when the membrane potential of a specific cell location rapidly rises and falls. This depolarization then causes adjacent locations to similarly depolarize. Excitable cells include **neurons**, **muscle** cells, **pancreas beta** cells.

Neuronal action potentials are short (1–2 ms) for fast signaling.

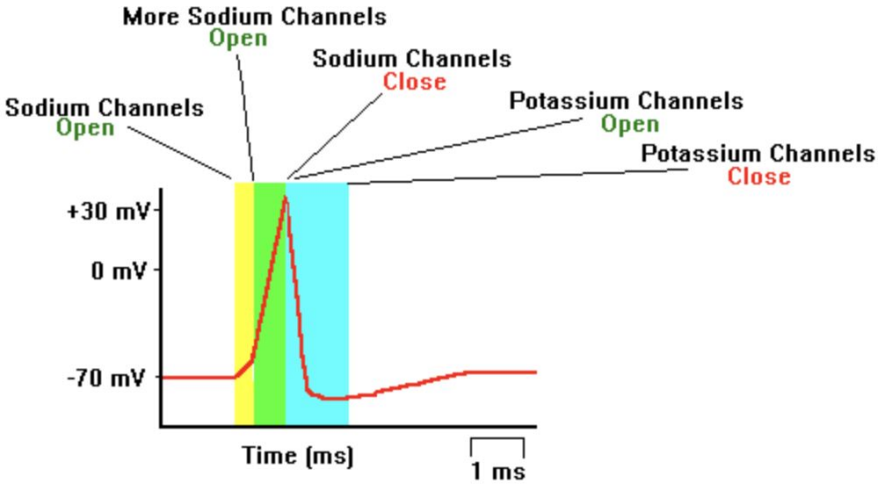
Skeletal muscle action potentials are slightly longer (2–5 ms).

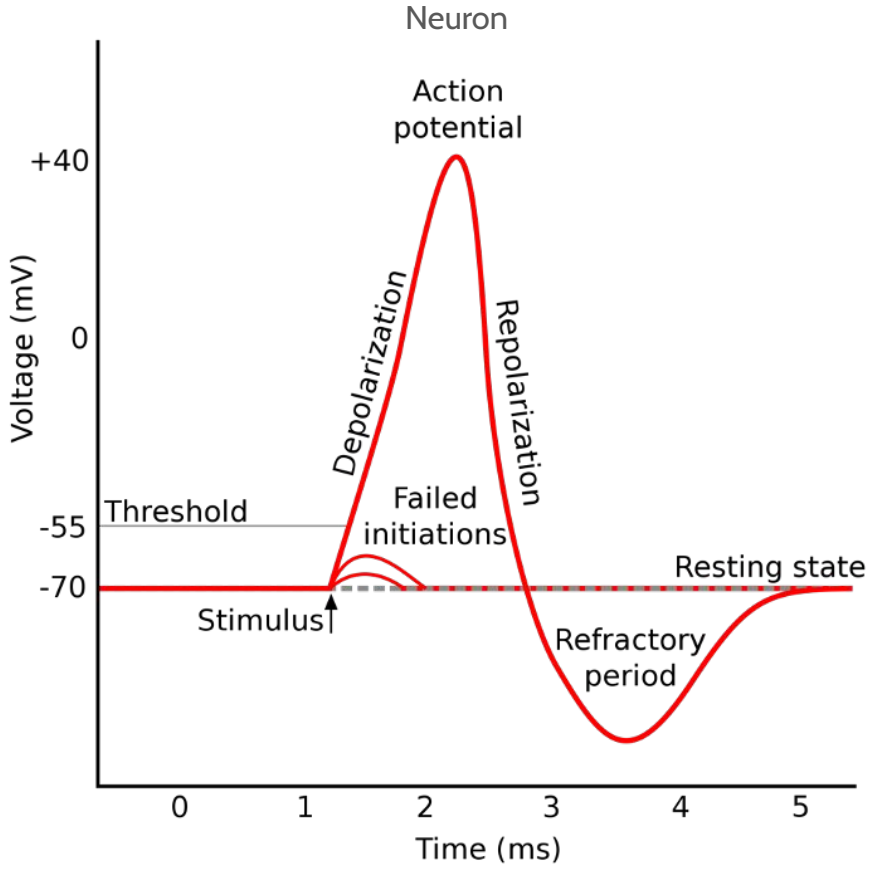
Cardiac muscle action potentials are significantly longer (200–400 ms) to allow proper heart function.

# Action Potential Video

https://www.youtube.com/watch?v=W2hHt_PXe5o

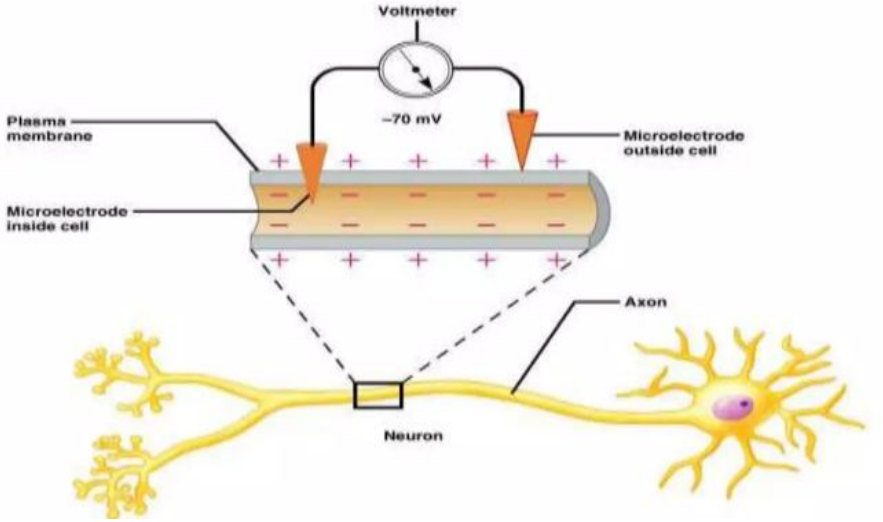
# Action Potential



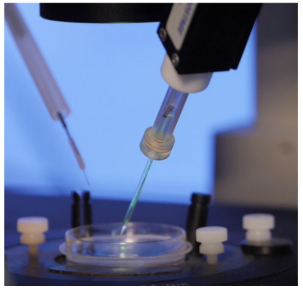



# How to measure it ?

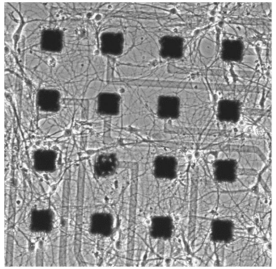
# Direct Measurements




*In vitro* Patch clamp



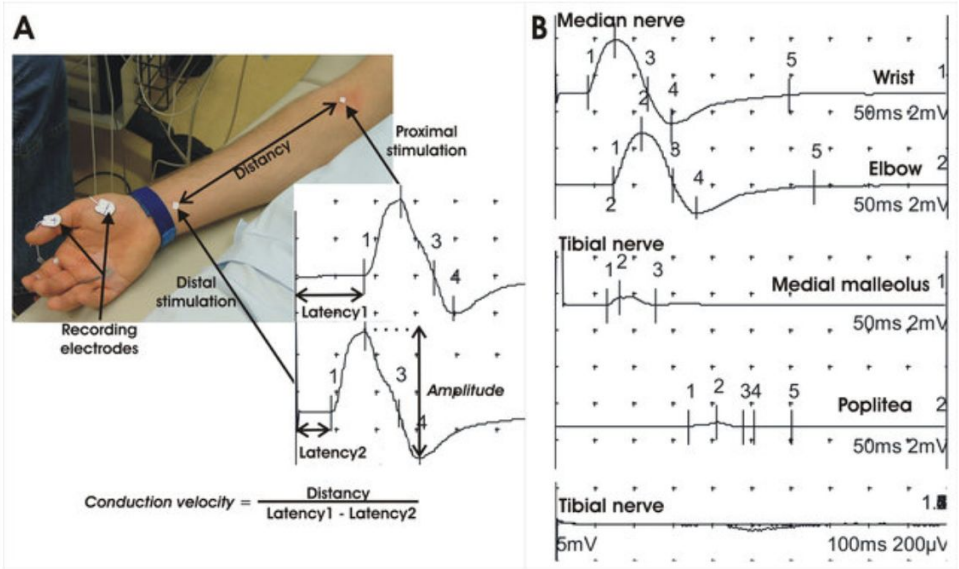
Multielectrode array



https://www.mxwbio.com/resources/mea/
https://ephys.institutducerveau-icm.org/services/

# Electroneurography ENG

Source:https://www.researchgate.net/publication/274198330_Neurological_Sequelae_of_Sepsis_II_Neuromuscular_Weakness/figures?lo=1




The velocity of action potential conduction in nerve fibers varies depending on factors such as fiber diameter, myelination, and temperature. It typically ranges from 0.5 m/s to 120 m/s. Neural diseases may cause a decrease in conduction velocity.

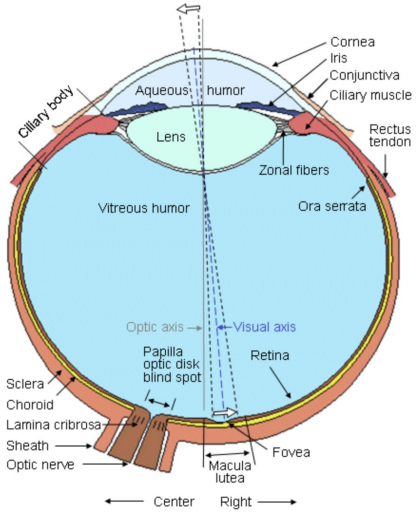
## Figure

Caption

Fig. (1). Electroneurography. A) Principle: The nerve is electrically stimulated and a compound motor action potential (CMAP) is recorded from the muscle. Nerve conduction velocity can be calculated from the latencies and the distance between two stimulation sites, its reduction point to demyelinisation. Amplitudes of CMAPs can be measured and its reduction point to axonal loss. B) Typical findings of CIP are amplitude reductions of CMAPs or missing CMAPs as sign of axonal neuropathy.

# Electric Signals Originating in the Eye

In the eye there is a steady electric potential field. It can be described as a fixed dipole with positive pole at the cornea and negative pole at the retina. The magnitude of this corneoretinal potential is in the range 0.4-1.0 mV.



# How to measure it ?

# Electro-oculogram

This potential difference and the rotation of the eye are the basis for a signal measured at a pair of periorbital surface electrodes.

The signal is known  as the electro-oculogram, (EOG). It is useful in the study of eye movement.

A concentration of negatively charged nerves is in the retina on the back of the eye.

As the eye rotates, the field vector rotates correspondingly.

**Left gaze** -> negative-trending change in the recorded potential difference

**Right gaze** -> positive - trending change in the recorded potential difference

The EOG is used to assess the function of the pigment epithelium.

# Electro-oculogram

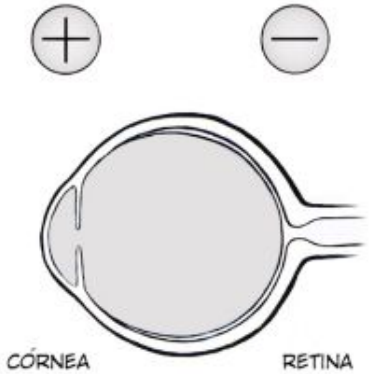
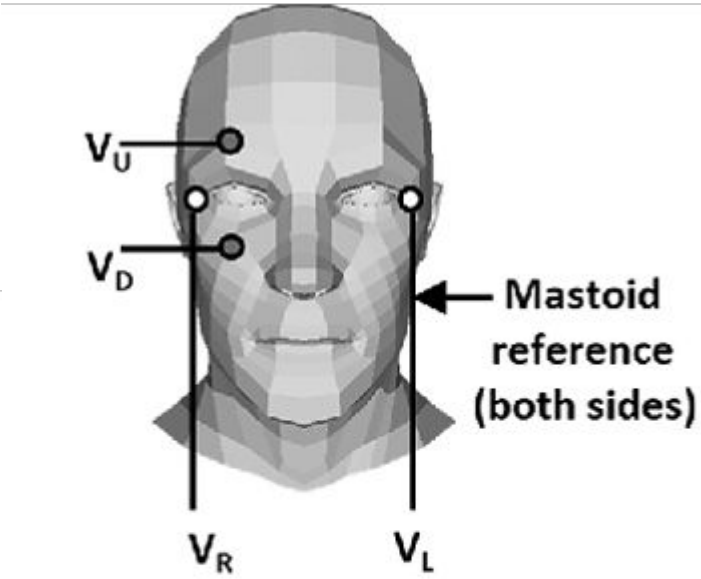
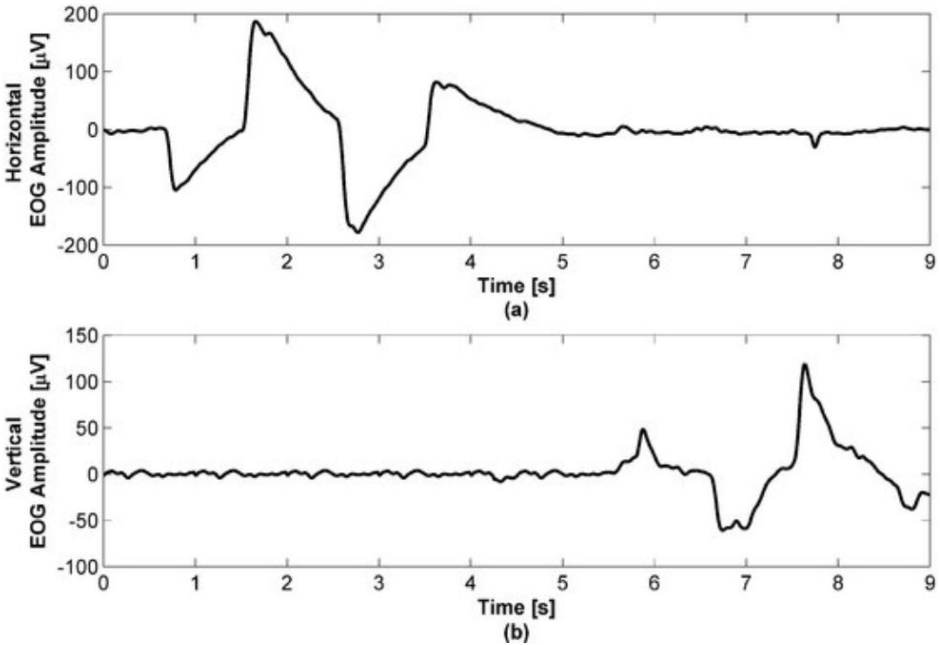



**Figure 1.** EOGs record eye movements due to the potential difference between the cornea and the retina.




Source: Wikipedia




## Figure

Caption

Fig. 3. Typical EOG signals for eye movements (a) Horizontal EOG: look left, right then left again (b) Vertical EOG: look up, down and then up again



Source https://www.researchgate.net/publication/267923672_A_Three_Sensor_Eye_Tracking_System_based_on_Electrooculography/figures?lo=1

# AI for Healthcare and EOG ?

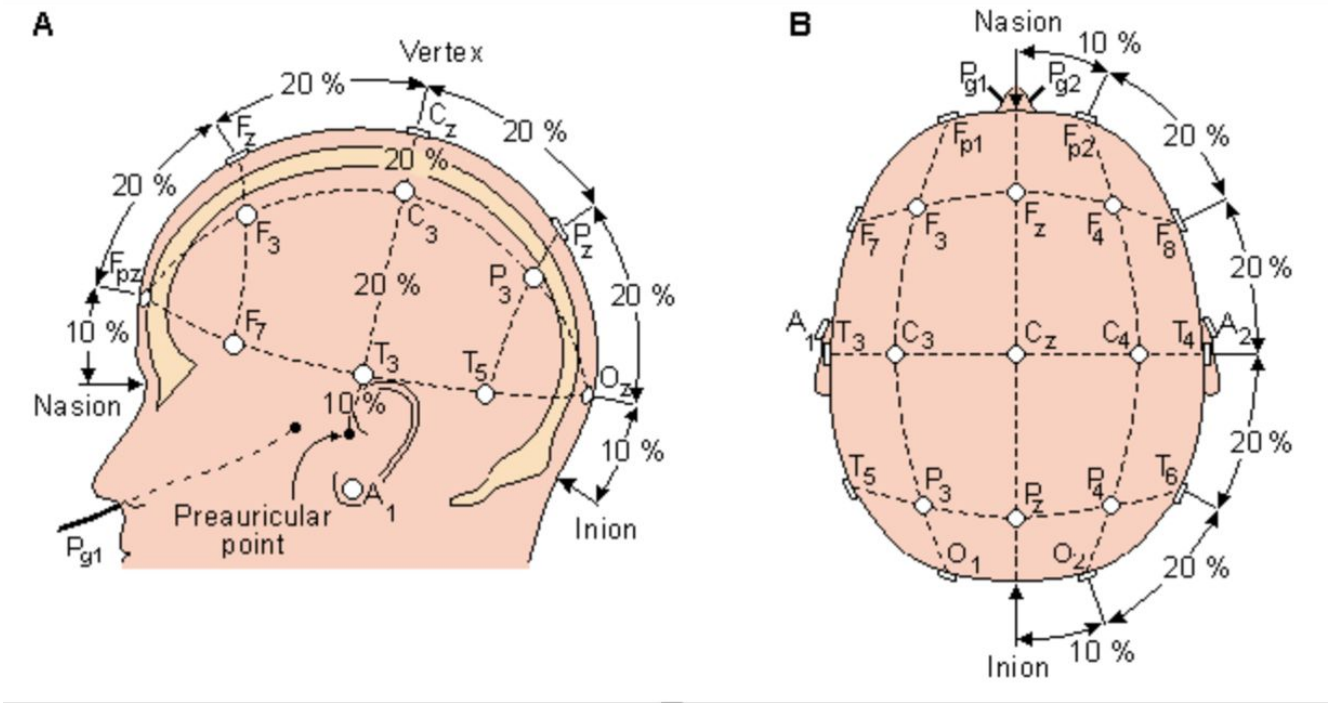
# Electric Signals Originating in Brain the EEG

It is a particular type of electroneurogram. It is an electrical recording of the activity of the brain taken from the scalp. An EEG can be used to diagnose seizures, sleep disorders, for monitoring of level of anesthesia during surgery etc.

German physiologist and psychiatrist Hans Berger (1873–1941) recorded the first human EEG in 1924.

# How to measure it ?

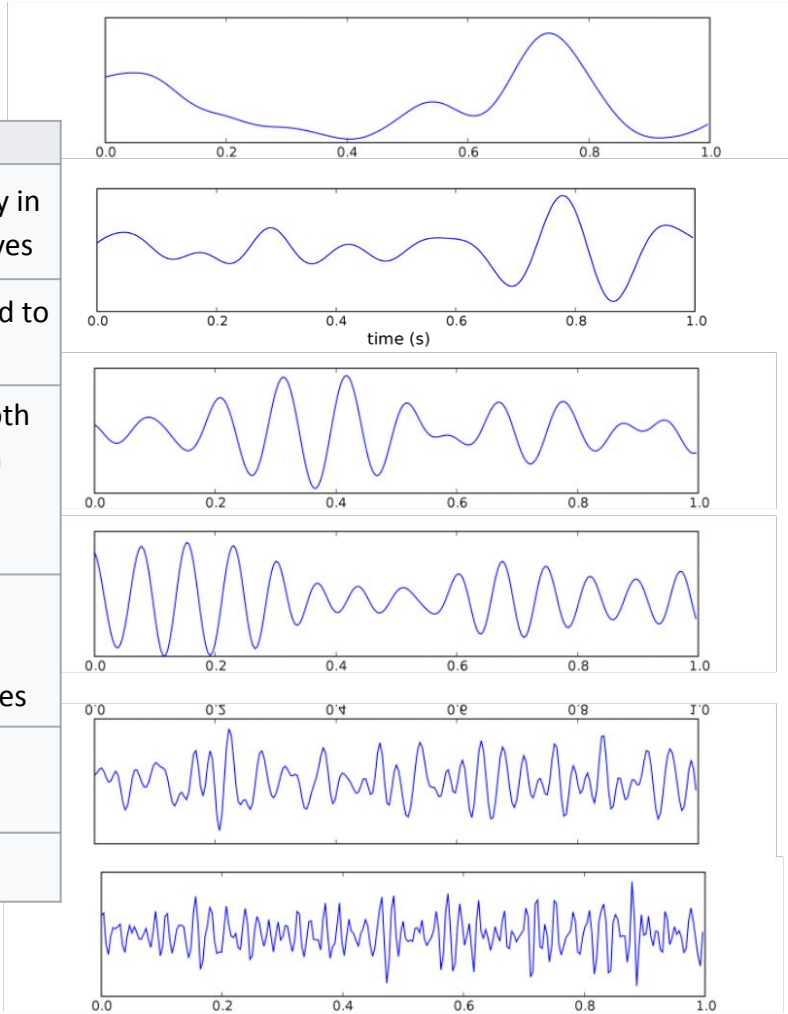
# 10-20 system - EEG electrodes placement



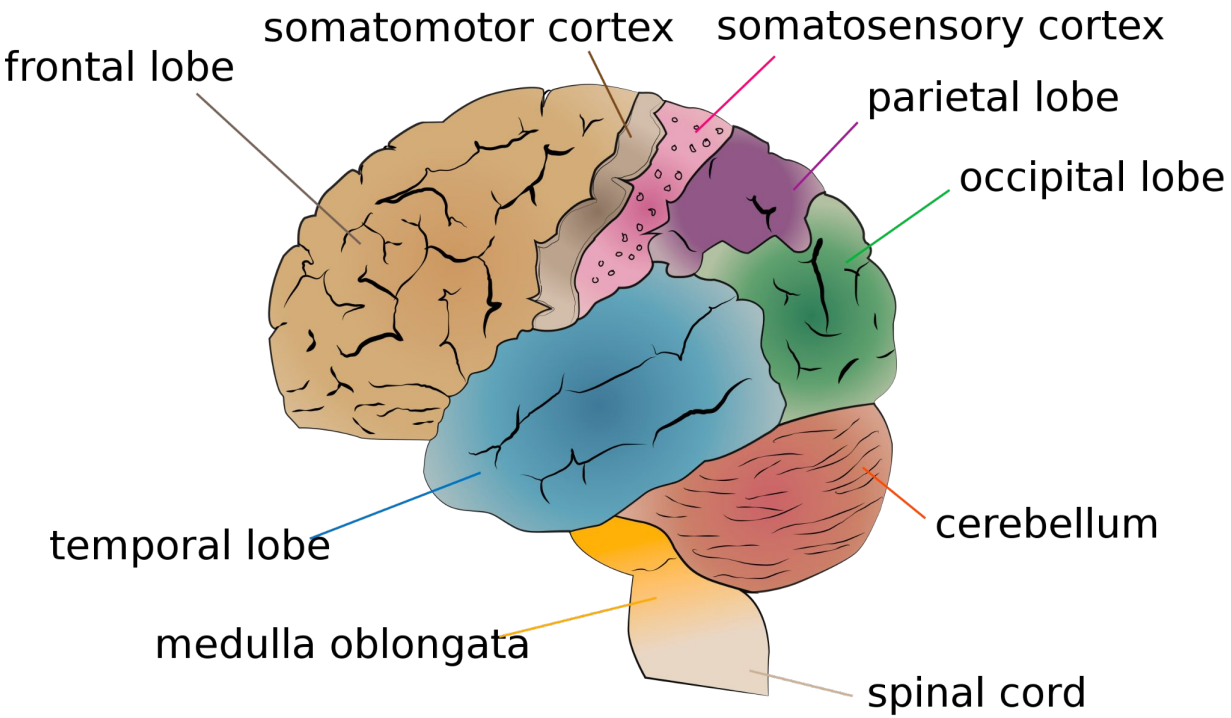

pre-frontal(Fp), frontal (F), temporal (T), parietal (P), occipital (O), and central (C).
A "Z" (zero) refers to an electrode placed on the midline sagittal plane of the skull, (FpZ, Fz, Cz, Oz) and is present mostly for reference/measurement points

# EEG Frequency Bands

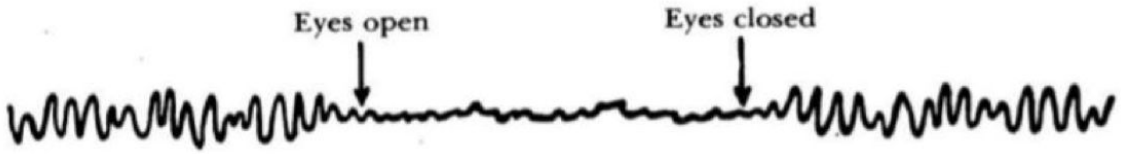
| Band | Frequency (Hz) | Location |
|---|---|---|
| Delta | < 4 | frontally in adults, posteriorly in children; high-amplitude waves |
| Theta | 4–7 | Found in locations not related to task at hand |
| Alpha | 8–12 | posterior regions of head, both sides, higher in amplitude on dominant side. Central sites (c3-c4) at rest |
| Beta | 13–30 | both sides, symmetrical distribution, most evident frontally; low-amplitude waves |
| Gamma | > 32 | Somatosensory cortex |
| Mu | 8–12 | Sensorimotor cortex |



# The Brain


somatomotor cortex
somatosensory cortex
frontal lobe
parietal lobe
occipital lobe
cerebellum
temporal lobe
medulla oblongata
spinal cord

# The Alpha Block




- When the awake subject's attention is directed to some specific type of mental activity, the alpha waves are replaced by asynchronous waves of higher frequency but lower amplitudes.
- Above figure demonstrates the effect on the alpha waves of simple opening the eyes in bright light and then closing them again.
- The visual sensation causes immediate cessation of the alpha waves; these are replaced by low-voltage, asynchronous waves.

# AI for Healthcare and EEG ?

# Electric Signals Originating in Heart the ECG

Willem Einthoven was a Dutch medical doctor and physiologist. He invented the first practical electrocardiograph (ECG or EKG) in 1895 and received the Nobel Prize in Physiology or Medicine in 1924 for it ("for the discovery of the mechanism of the electrocardiogram").

# Electro-cardiogram (ECG)

## Pulmonary and Systemic Circulation

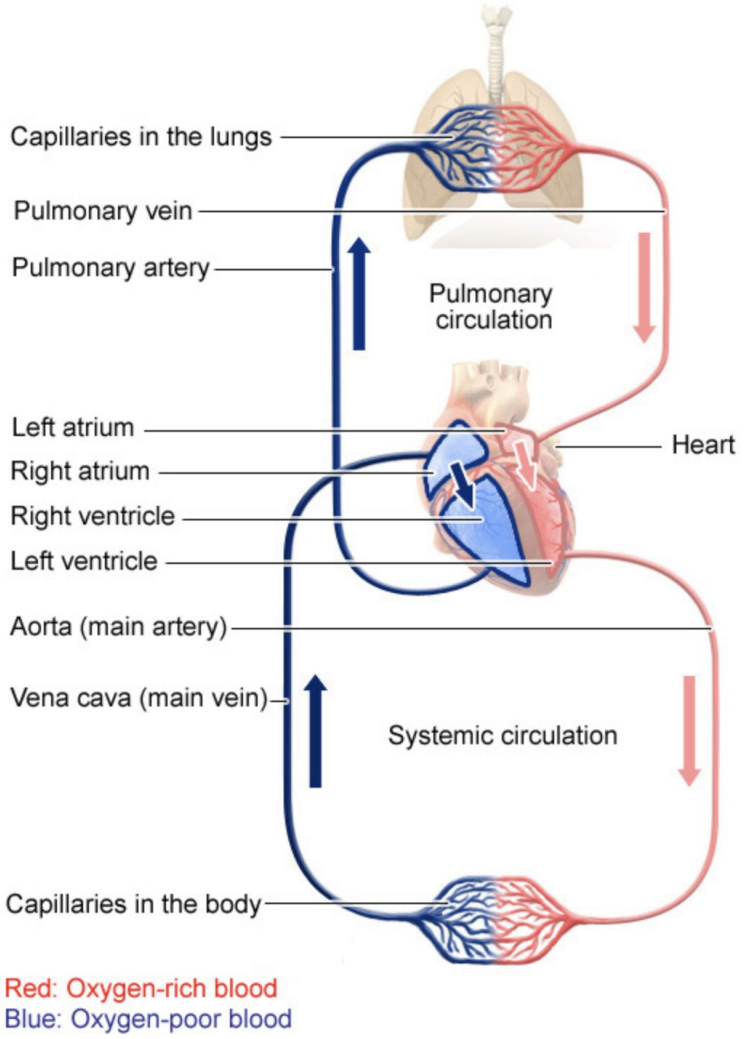
Blood is gathered from all parts of the body into the **right atrium**, from whence it is then transferred to the **right ventricle**. The right ventricle contracts to force blood out to the **lungs** where carbon dioxide is removed from it and fresh oxygen is absorbed. From the lungs the reoxygenated blood travels back to the heart and into the **left atrium**. This loop is called the pulmonary circulation. Blood is then transferred to the **left ventricle**, which contracts with strength to force the blood out under pressure to all limbs and organs in the body. Once oxygen and nutrients have been distributed via the blood to nourish all of the cells around the body and waste products have been collected and delivered for excretion, the blood returns to the right atrium again.

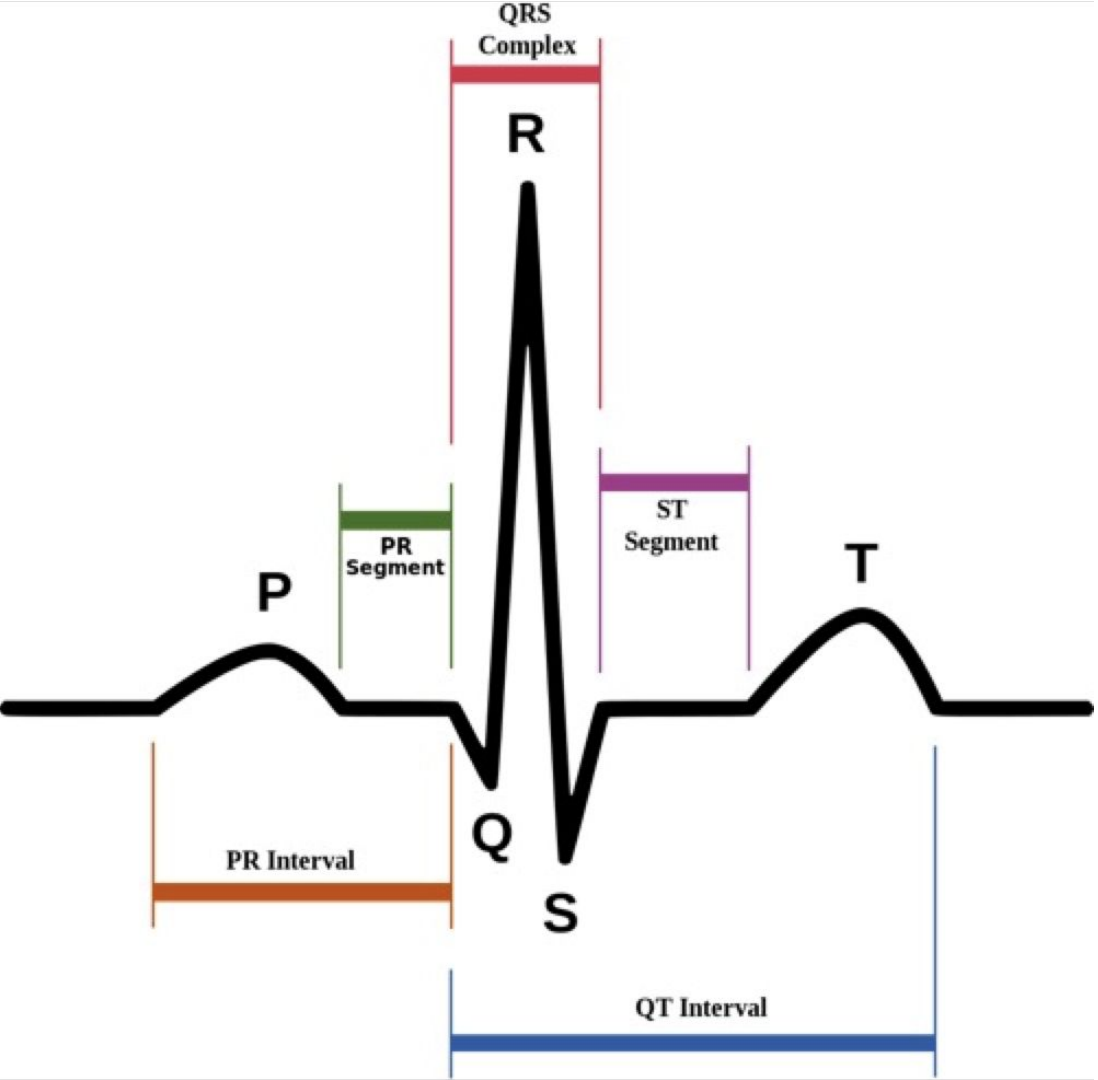
# Videos

Pulmonary and Systemic Circulation

https://www.youtube.com/watch?v=NDk8fmIl9V8&t=5s (2min)

https://www.youtube.com/watch?v=jBt5jZSWhMI&t=3s (2min)



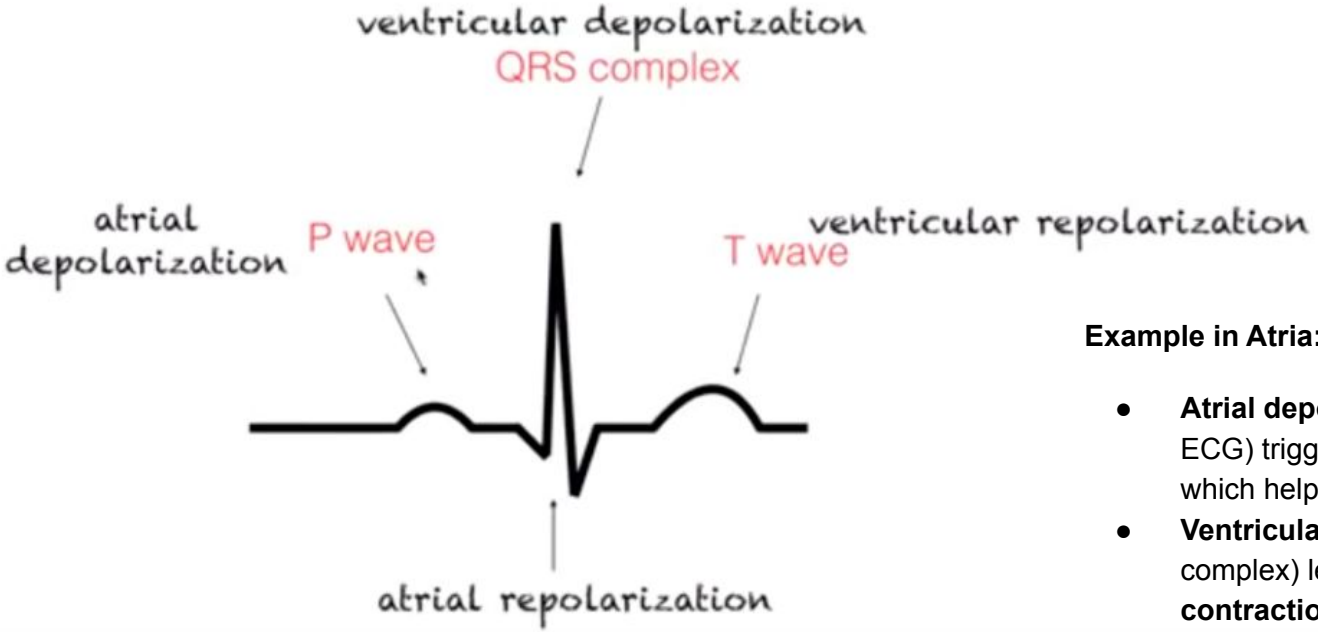



# P QRS T

**P waves** represent **atrial depolarisation**.

The **PR interval represents** the **time taken** for electrical activity to move **between the atria and the ventricles**.
The **QRS complex** represents **depolarisation of the ventricles**.
The **ST segment starts** at the **end** of the **S wave** and **ends** at the **beginning** of the **T wave**. It is the time **between depolarisation** and **repolarisation** of the **ventricles** (i.e. ventricular contraction).
The **T wave** represents **ventricular repolarisation**.
It appears as a small wave **after** the **QRS complex**.
The **RR interval begins** at the **peak of one R wave** and ends at the **peak of the next R wave**.
It **represents** the **time between two QRS complexes**.
The **QT interval** begins at the start of the **QRS complex** and finishes at the end of the **T wave**. It **represents** the time taken for the **ventricles** to **depolarise** and then **repolarise**.

Amplitude 1-5 mV



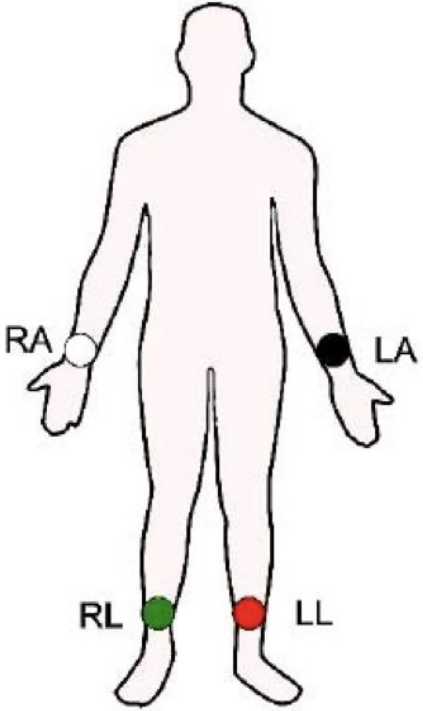

**Example in Atria:**

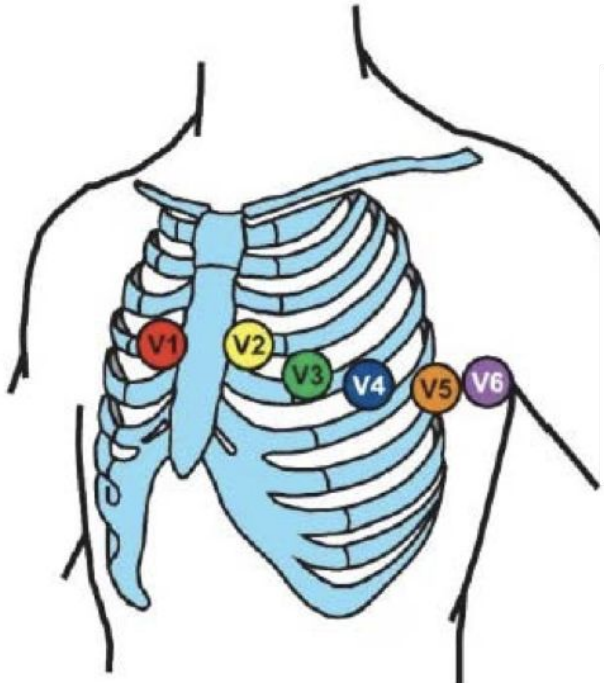
- **Atrial depolarization** (P wave on ECG) triggers **atrial contraction**, which helps fill the ventricles.
- **Ventricular depolarization** (QRS complex) leads to **ventricular contraction**, pumping blood to the lungs and body.

So, **depolarization = electrical trigger, contraction = mechanical response**.

# How to measure it ?

# ECG Electrodes Positioning




**RA** – right forearm or wrist
**LA** – left forearm or wrist
**LL** – left lower leg, proximal to ankle
**RL** – right lower leg, proximal to ankle
**V1** – 4-th intercostal space, right sternal edge
**V2** – 4-th intercostal space, left sternal edge
**V3** – midway between V2 and V4
**V4** – 5-th intercostal space, mid-clavicular line
**V5** – anterior axillary line in straight line with V4
**V6** – mid-axillary line in straight line with V4 and V5

# 12 ECG Leads

An **ECG lead** is a **graphical representation** of the **heart's electrical activity** which is calculated by analysing data from **several ECG electrodes**.

## Chest leads

**V1**: septal view of the heart
**V2**: septal view of the heart
**V3**: anterior view of the heart
**V4**: anterior view of the heart
**V5**: lateral view of the heart
**V6**: lateral view of the heart

## Other leads

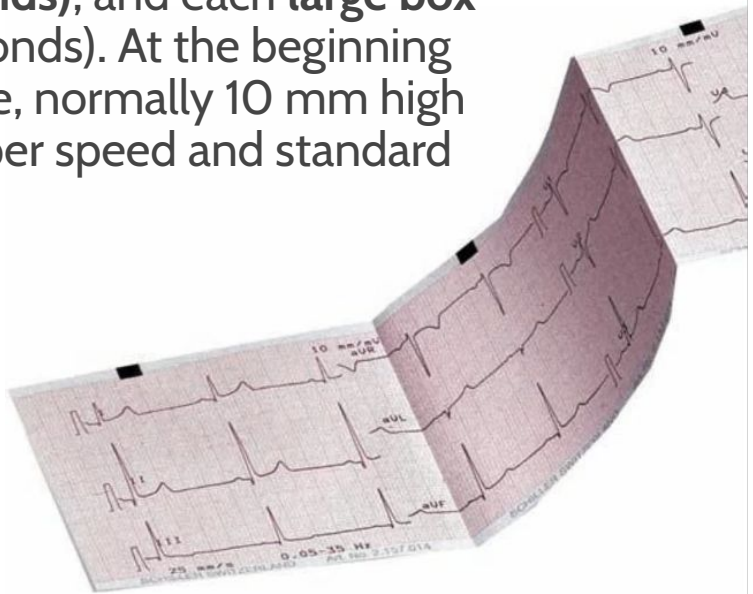
**Lead I**: lateral view (calculated by analysing activity between the RA and LA electrodes)
**Lead II**: inferior view (calculated by analysing activity between the RA and LL electrodes)
**Lead III**: inferior view (calculated by analysing activity between the LA and LL electrodes)
**aVR**: lateral view (calculated by analysing activity between LA+LL -> RA)
**aVL**: lateral view (calculated by analysing activity between RA+LL -> LA)
**aVF**: inferior view (calculated by analysing activity between RA+LA -> LL)

# Question ?

**Why are there 12 leads but only 10 electrodes?**

# ECG Paper

ECG paper commonly moves at **25 mm/second**; thus, **each small box (1 mm) is equivalent to 0.04 seconds (40 milliseconds)**, and each **large box** (5 mm) is equivalent to **0.2 seconds** (200 milliseconds). At the beginning of an ECG, make note of the standardization square, normally 10 mm high by 5 mm wide. This will alert you to the correct paper speed and standard amplification of P, QRS, and T-wave complexes.



Normal ECG values for waves and intervals are as follows:

RR interval: 0.6-1.2 seconds

P wave: 80 milliseconds

PR interval: 120-200 milliseconds

PR segment: 50-120 milliseconds

QRS complex: 80-100 milliseconds

ST segment: 80-120 milliseconds

T wave: 160 milliseconds

QT interval: 420 milliseconds or less if heart rate is 60 beats per minute (bpm

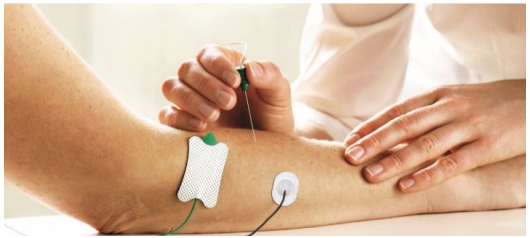
# AI for Healthcare and ECG ?

# Electric Signals in the Muscles

The muscles response to the electrical signal of the brain

# How to measure it ?

# EMG Measurements



https://biologydictionary.net/motor-neuron/

https://www.healthline.com/health/electromyography#results

Electromyography (EMG) & Nerve conduction studies (NCS) Mayfield
https://www.youtube.com/watch?v=4kkIvP1jNLA&t=455s

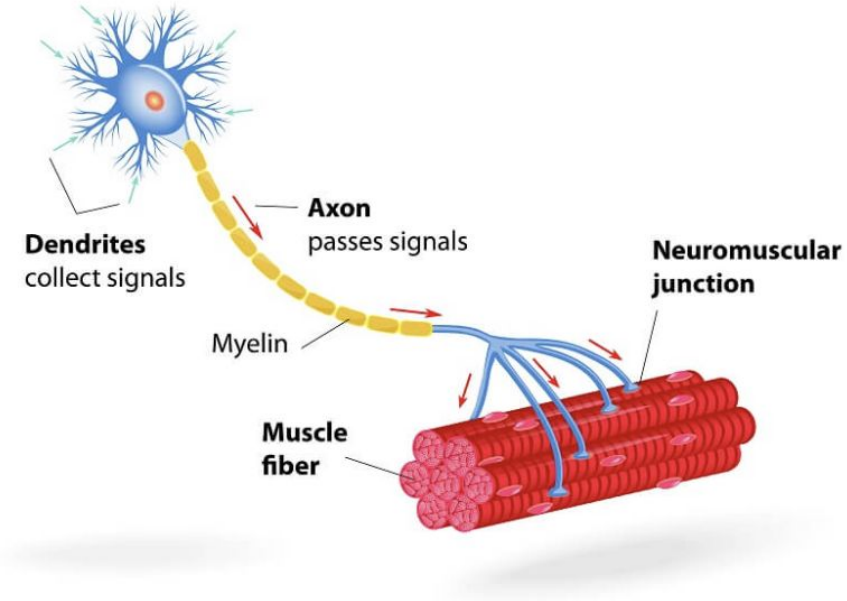
# EMG - Electromyography

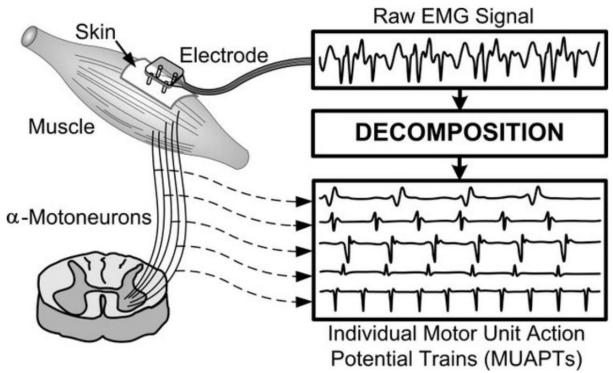
It measures muscle response or electrical activity in response to a nerve's stimulation of the muscle. It is a diagnostic procedure to assess the health of muscles and the nerve cells that control them (motor neurons).

In Computer Science, EMG is also used as middleware in gesture recognition towards allowing the input of physical action to a computer as a form of human-computer interaction.

Typical MUAP duration is between 5 and 15 ms. Amplitude Microvolts.  It depends primarily on the number of muscle fibers within the motor unit and the dispersion of their depolarizations over time.

# Motor Neuron



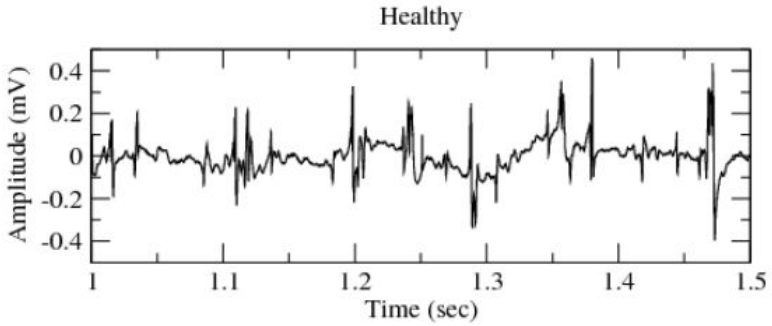



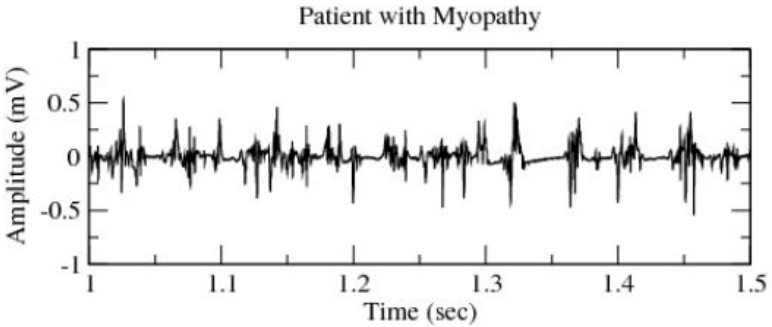

**Figure**

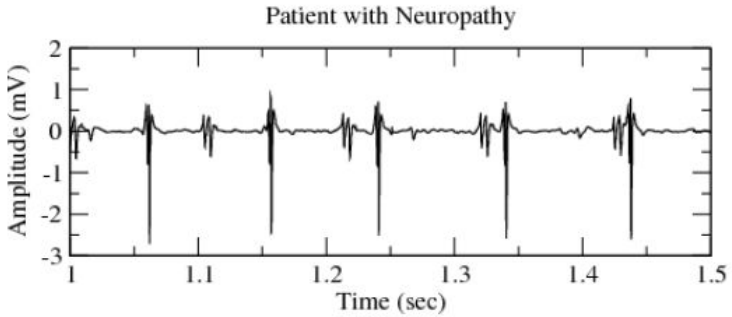
Caption

FIG. 1. Pictorial outline of the decomposition of the surface EMG signal into its constituent motor unit action potentials. (Adapted from De Luca et al. 1982a.)

# EMG Signals




Swaroop, R., et al. "Classification of myopathy and neuropathy EMG signals using neural network." *2017 International Conference on Circuit, Power and Computing Technologies (ICCPCT)*. IEEE, 2017.

# AI for Healthcare  & EMG

# Body Composition Impedance/Resistance

Our body response to the flow of an electrical current

# How to measure it ?

# Bioimpedance

Bioelectrical impedance analysis (BIA) is a method for estimating body composition, in particular body fat and muscle mass, where a weak electric current flows through the body and the voltage is measured in order to calculate impedance (resistance and reactance) of the body. **Most body water is stored in muscle, more muscle leads to lower impedance.** Since the advent of the first commercially available devices in the mid-1980s the method has become popular owing to its ease of use and portability of the equipment. It is familiar in the consumer market as a simple instrument for estimating body fat and total body water (TBW),

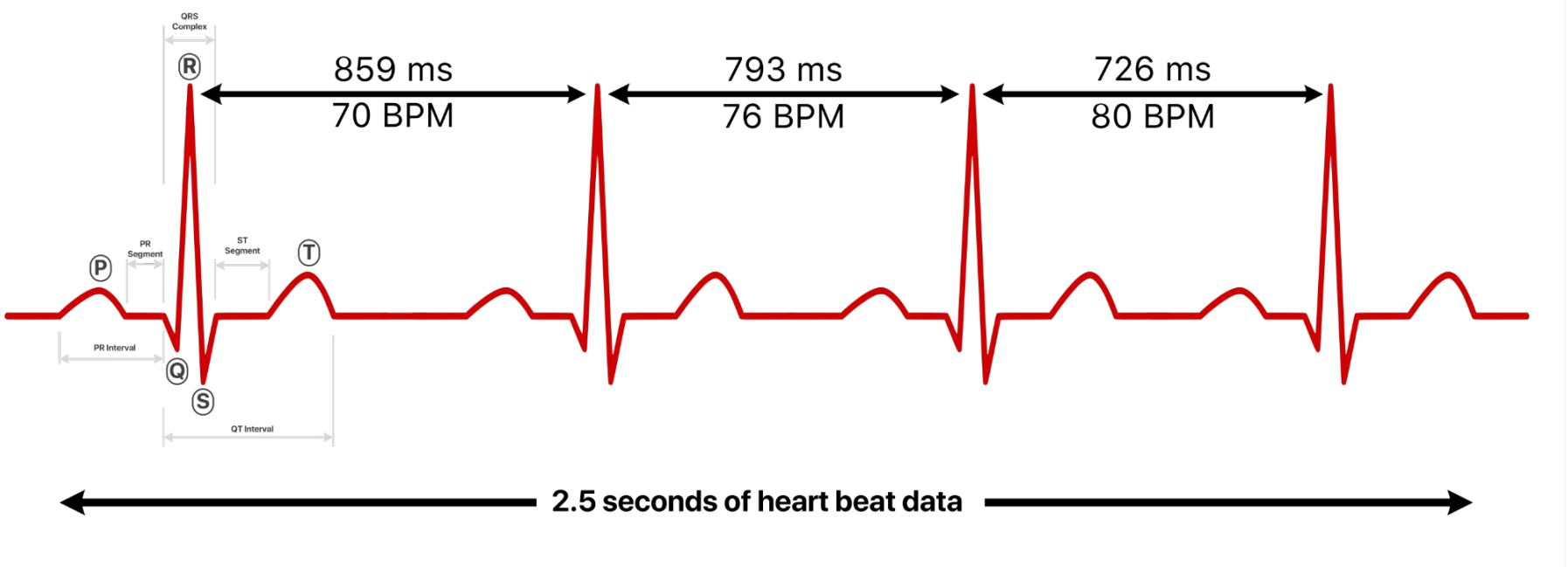
# AI for Healthcare & Bioimpedance

https://www.youtube.com/watch?v=jMVq0lk-IQQ

# Heart Rate Variability

Is the physiological phenomenon of variation in the time interval between heartbeats. It is measured by the variation in the beat-to-beat interval.

# Heart Rate Variability

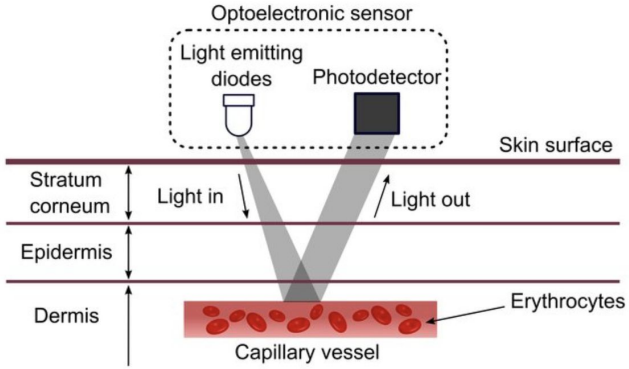


HRV can be a measure of our autonomic nervous system and the balance between our parasympathetic and sympathetic branches. The **parasympathetic branch** is our “Rest & Digest” and correlates with a **high HRV.** The **sympathetic branch** is our “Fight or Flight” and correlates with a **low HRV.**

**Heart Rate Variability is an indicator of the state of our health & fitness, recovery, and readiness.** This makes it a valuable tool to monitor when exercising. A high HRV indicates a day to attempt that PR. A low HRV should lead to an active recovery day. Research correlates HRV to disease risk and progression.

# How to measure it ?

# Photoplethysmography (PPG)




**Figure**

Caption

Figure 6. Working principle of PPG sensors [19].



The photoplethysmographic wave describes changes in the attenuation of light energy in its pathway when transmitted or reflected in tissues and bloodstream

**TABLE 52.1** Biomedical Signals

| Classification | Acquisition | Frequency Range | Dynamic Range | Comments |
|---|---|---|---|---|
| **Bioelectric** | | | | |
| Action potential | Microelectrodes | 100 Hz–2 kHz | 10 μV–100 mV | Invasive measurement of cell membrane potential |
| Electroneurogram (ENG) | Needle electrode | 100 Hz–1 kHz | 5 μV–10 mV | Potential of a nerve bundle |
| Electroretinogram (ERG) | Microelectrode | 0.2–200 Hz | 0.5 μV–1 mV | Evoked flash potential |
| Electro-oculogram (EOG) | Surface electrodes | dc–100 Hz | 10 μV–5 mV | Steady-corneal-retinal potential |
| Electroencephalogram (EEG) | | | | |
| Surface | Surface electrodes | 0.5–100 Hz | 2–100 μV | Multichannel (6–32) scalp potential |
| Delta range | | 0.5–4 Hz | | Young children, deep sleep and pathologies |
| Theta range | | 4–8 Hz | | Temporal and central areas during alert states |
| Alpha range | | 8–13 Hz | | Awake, relaxed, closed eyes |
| Beta range | | 13–22 Hz | | |
| Sleep spindles | | 6–15 Hz | 50–100 μV | Bursts of about 0.2 to 0.6 s |
| K-complexes | | 12–14 Hz | 100–200 μV | Bursts during moderate and deep sleep |
| Evoked potentials (EP) | Surface electrodes | | 0.1–20 μV | Response of brain potential to stimulus |
| Visual (VEP) | | 1–300 Hz | 1–20 μV | Occipital lobe recordings, 200-ms duration |
| Somatosensory (SEP) | | 2 Hz–3 kHz | | Sensory cortex |
| Auditory (AEP) | | 100 Hz–3 kHz | 0.5–10 μV | Vertex recordings |
| Electrocorticogram | Needle electrodes | 100 Hz–5 kHz | | Recordings from exposed surface of brain |
| Electromyography (EMG) | | | | |
| Single-fiber (SFEMG) | Needle electrode | 500 Hz–10 kHz | 1–10 μV | Action potentials from single muscle fiber |
| Motor unit action potential (MUAP) | Needle electrode | 5 Hz–10 kHz | 100 μV–2 mV | |
| Surface EMG (SEMG) | Surface electrodes | | | |
| Skeletal muscle | | 2–500 Hz | 50 μV–5 mV | |
| Smooth muscle | | 0.01–1 Hz | | |
| Electrocardiogram (ECG) | Surface electrodes | 0.05–100 Hz | 1–10 mV | |
| High-Frequency ECG | Surface electrodes | 100 Hz–1 kHz | 100 μV–2 mV | Notchs and slus waveforms superimposed on the ECG. |

# Summary

Rangayyan, Rangaraj M. *Biomedical signal analysis*. John Wiley & Sons, 2015.

# Questions to me ?

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