Acquisition and Analysis of Biosignals DTEK0042

Origins, Significance and Acquisition of Biosignals: Nervous and Muscular Systems

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Introduction

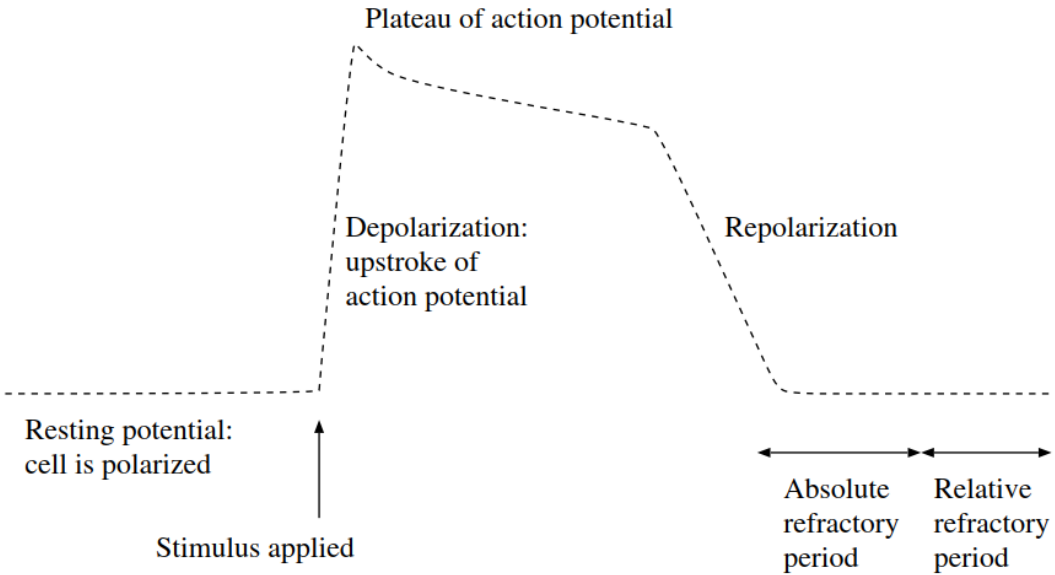
In the previous session, we learned:

- ❑ Basics of biosignals
- ❑ Their role in health applications

In this session, we will learn:

- ❑ The origin of electric biosignals
- ❑ Different biosignals, collected to monitor the muscular and nervous systems
- ❑ Speech signal

Action potential

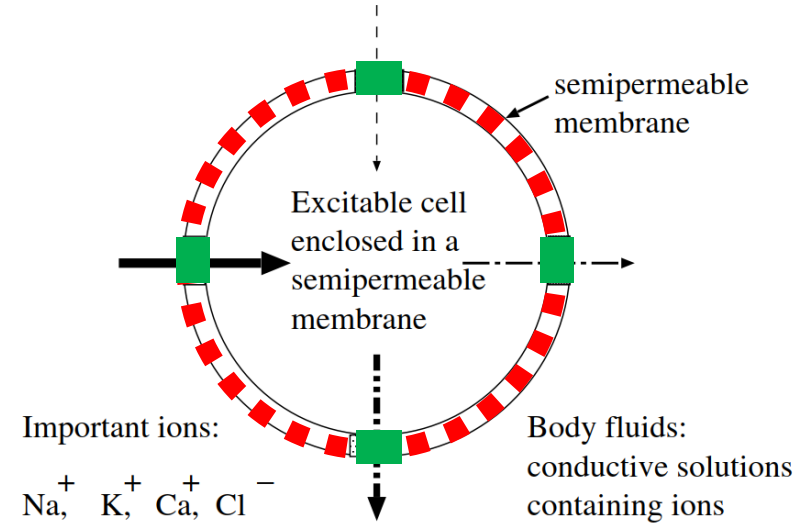


Basic component of bioelectrical signals

- The source of different bioelectrical signals is the action potential
  - ECG, EEG, EMG, …
- Action potential is:
  - the changes in the **potential** of a **cell.**
  - the **electrical signal** created in **excitable cells** along with
    1. the mechanical contraction of a single muscle cell when stimulated by an electrical current
    2. signals and messages transmitted in the nervous system.
  - caused by the flow of sodium (Na^+), potassium (K^+), chloride (Cl^-), and other ions across the cell membrane.
- Recording an action potential requires the isolation of a single cell to stimulate the cell and record the response.

Semipermeable membrane of an excitable cell

- **Semipermeable membrane** allows selected substances to pass through and others kept out
  - There are **channels** on the membrane than ions (i.e., substances) pass through.
  - E.g., K^+ channels and Na^+ channels.



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Resting state of a myocyte cell

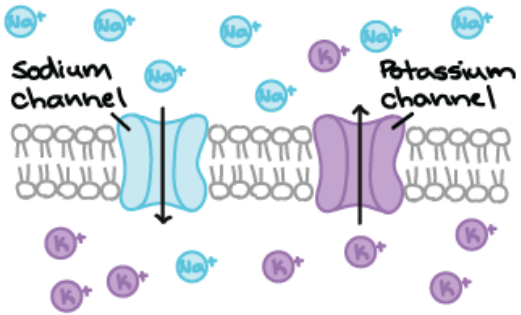
In **resting state**, the membrane allows the entry of K^+ and Cl^-, but blocks Na^+

- ❑ permeability of K^+ is 50-100 times more than Na^+.

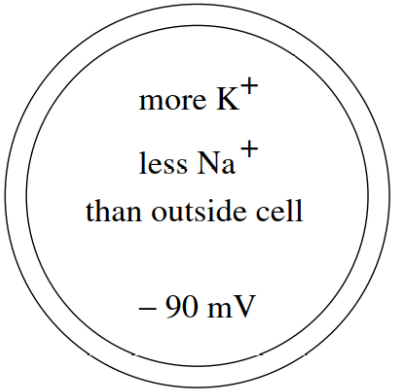
A state of equilibrium is established:

- ❑ In the cell, Na^+ are far less than K^+.
- ❑ Inside is more **negative** than outside.
- ❑ Most cells maintain a resting potential of -60mV to -100mV

A cell in the resting state is called **polarized**.



https://www.khanacademy.org/science/biology/human-biology/neuron-nervous-system/a/the-membrane-potential



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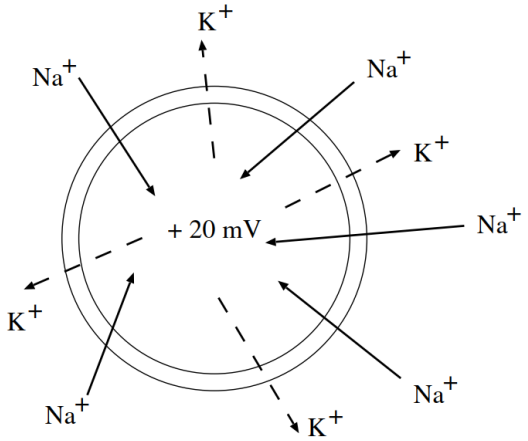
Depolarization

The cell is excited by ionic currents or an external stimulus which upsets the equilibrium:

1. Changes in the membrane's characteristics
2. Allows Na^+ to enter the cell
3. At a threshold, Na^+ channels open, allowing Avalanche effect: Na^+ rush into the cell
4. K^+ try to leave the cell, but cannot move as fast as Na^+.

Inside is more **positive** than outside.

An excited cell is called **depolarized**.



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Repolarization

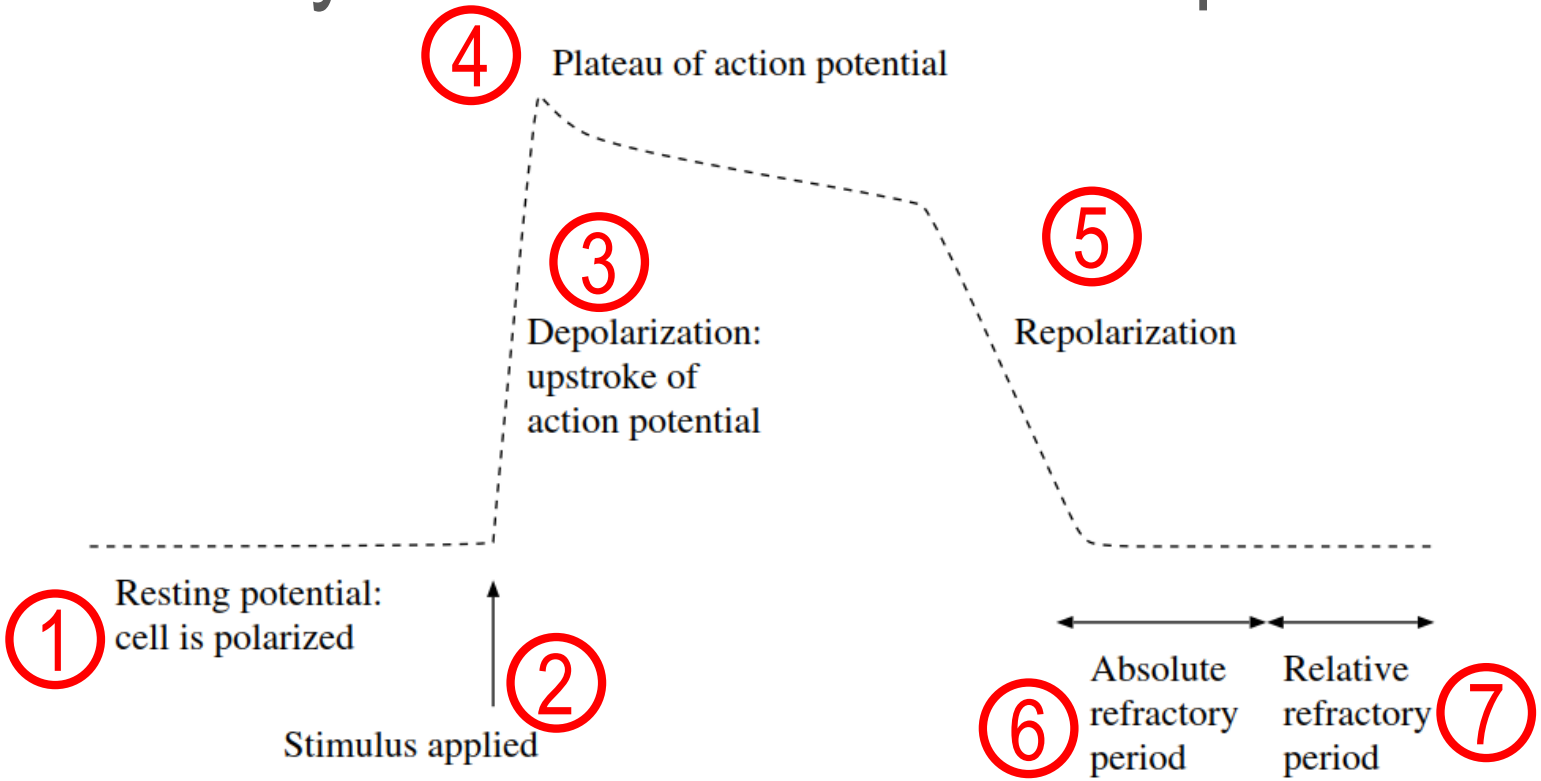
After a certain period, the cell becomes polarized again and returns to the resting state:

- Principal ions involved in repolarization are K^+.
- Predominant membrane permeability for K^+ (net efflux of K^+)
- The inside becomes more negative
- The cell becomes **polarized** again

Refractory periods

- After the repolarization, there are two periods:
  1. **Absolute refractory period**: cell cannot respond to any new stimulus (no action potential)
  2. **Relative refractory period**: another action potential may be triggered by a much stronger stimulus than in the normal situation

In summary: Phases of an action potential



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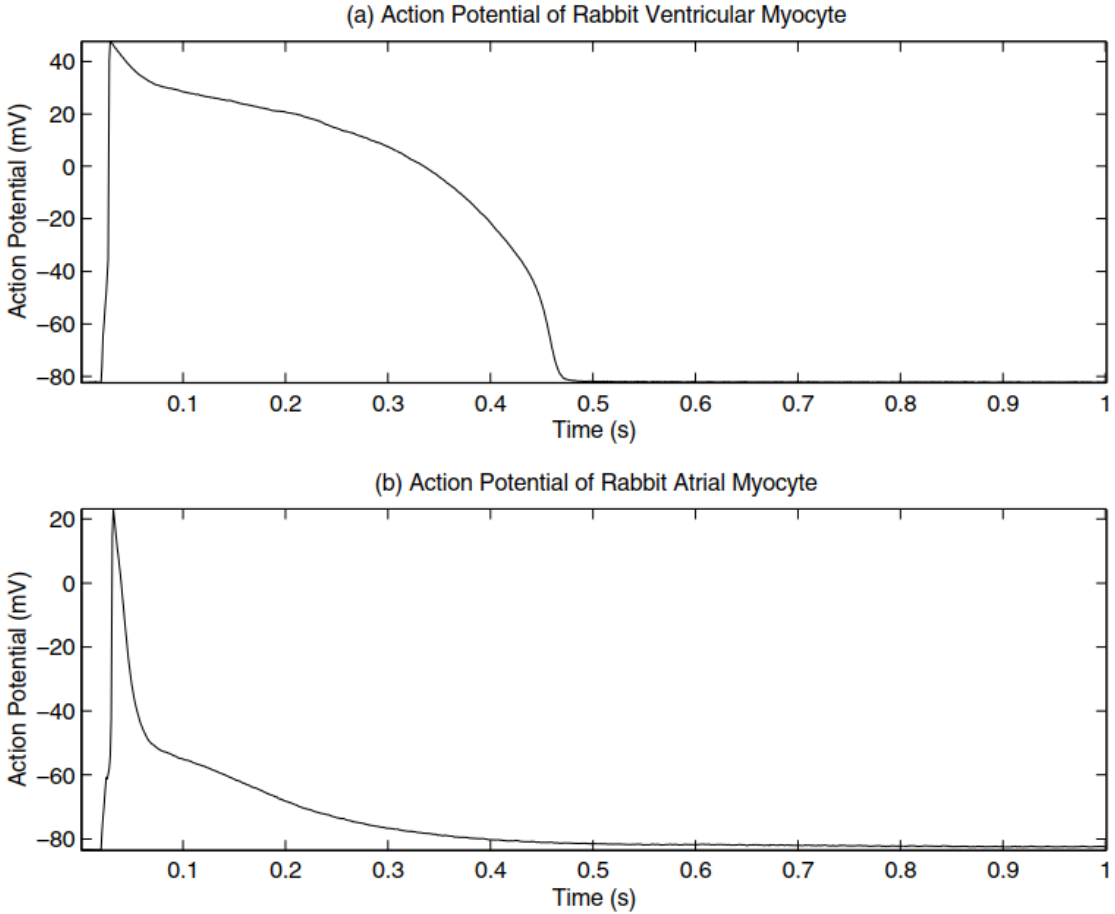
Example

- Action potentials of rabbit ventricular and atrial myocytes (heart tissues)
- Stimulus was a square pulse of current:
  - Duration: 3 ms
  - Amplitude: 1 nA



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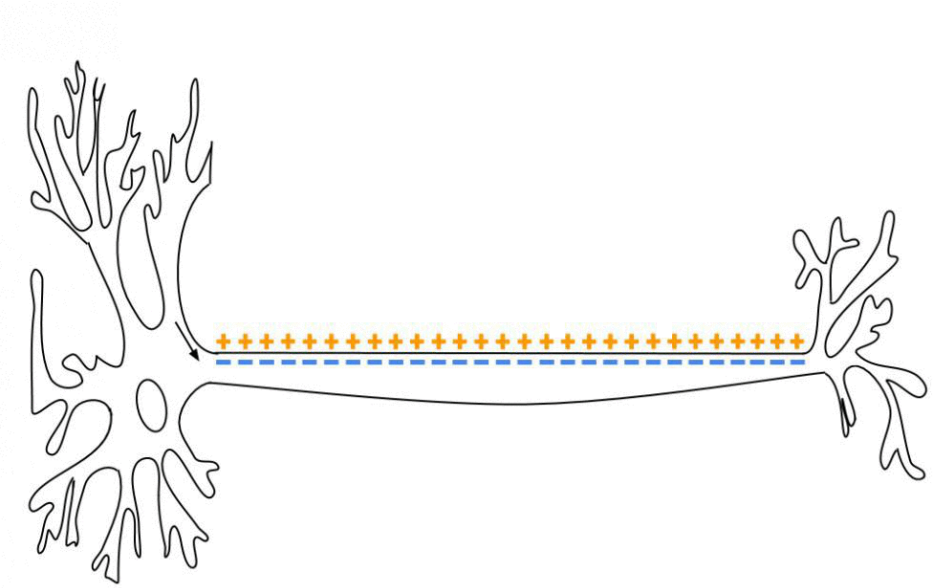
Action potentials in body cells (1)

- Nerve and muscle cells repolarize rapidly:
  - Duration of an action potential = 1 – 5 ms
- Heart muscle cells repolarize slowly:
  - Duration of an action potential = 150 – 300 ms
- The action potential is always the same for a given cell regardless of the **method** of excitation or the **intensity**.
  - **all-or-none** or **all-or-nothing** phenomenon

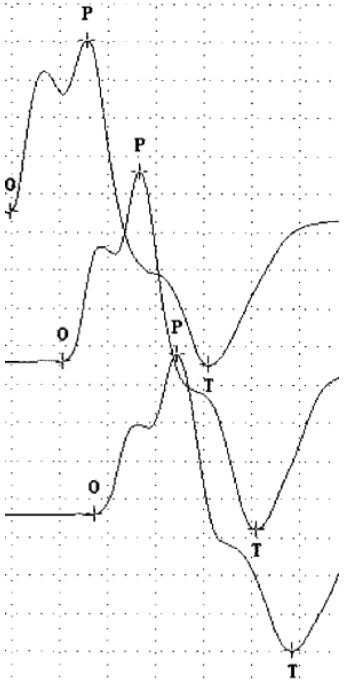
Action potentials in body cells (2)

- In a muscle or nerve fiber, when a (sufficient) stimulus is applied:
  1. The action potential is occurred
  2. Current flows from a depolarized region through the intracellular fluid to adjacent inactive regions
  3. Depolarize the adjacent inactive regions
- So, the action potential propagates along the whole length of a fiber without decrease in amplitude



https://en.wikipedia.org/wiki/File:Action_Potential.gif

Electroneurogram (ENG)



Electroneurogram (ENG)

- The ENG is an electrical signal observed to measure the velocity of propagation (or conduction) of an action potential over the length of a nerve.
  1. Stimulating a motor nerve and
  2. measuring the related activity at two points at known distances along its course
- ENG may be recorded using concentric needle electrodes (Ag-AgCl) at the surface of the body
- Typical conduction velocity:
  - Nerve fiber: 45 − 70 m/s
  - Heart muscle: 0.2 − 0.4 m/s
- Neural diseases may cause a decrease in conduction velocity.

Example

The ulnar nerve near the wrist

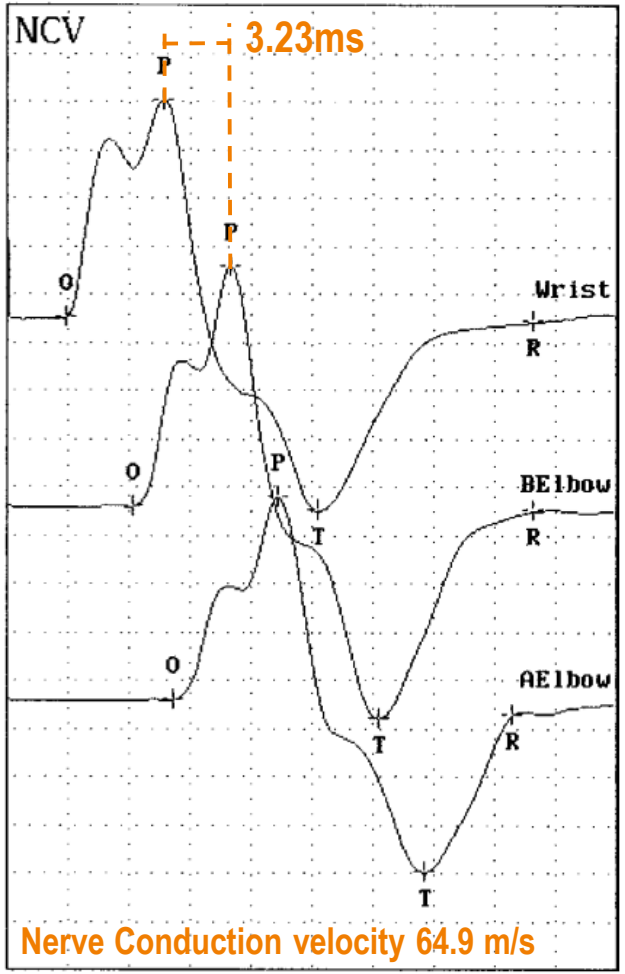
Stimulus was a pulse:

- Duration: 100 − 300 μs
- Amplitude: 100 V

ENG amplitude is 10 μV

The output is:

- Collected via surface electrodes
- Amplified with:
  - Gain: 2, 000
  - Bandwidth:10 − 10000 Hz



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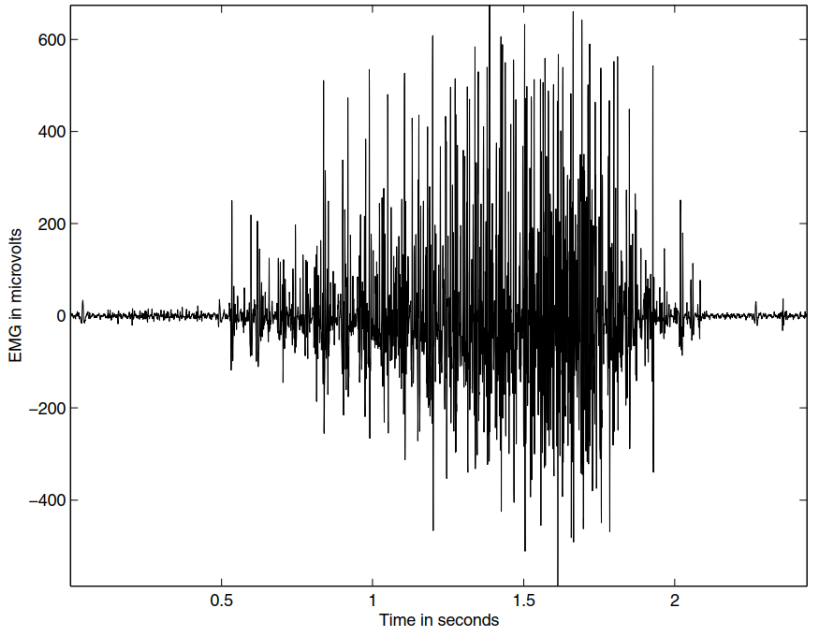
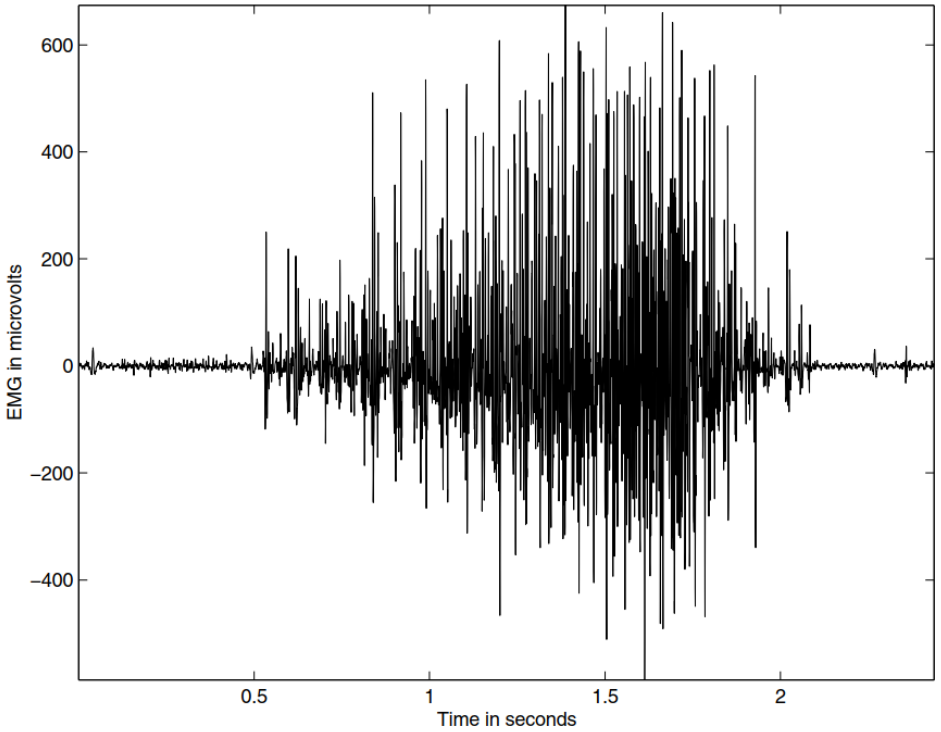
Electromyogram (EMG)



Electromyogram (EMG)

- EMG is an electrical signal generated by neuromuscular activity
- EMG signal indicates the level of activity of a muscle

EMG recorded from the crural diaphragm muscle of a dog



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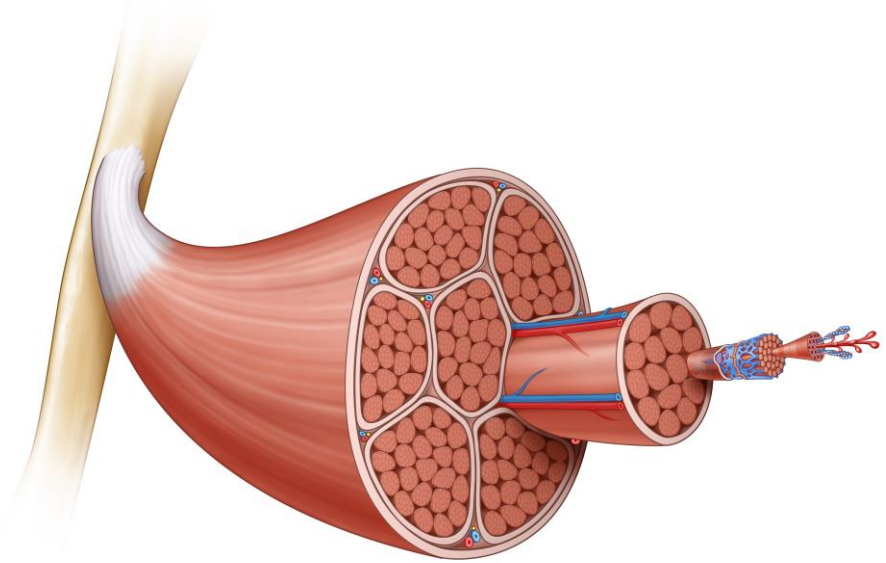
Skeletal muscle

- Skeletal muscle fibers are twitch fibers:
  - Produce a mechanical twitch response for a stimulus
- Skeletal muscles made up of collections of **motor unit**

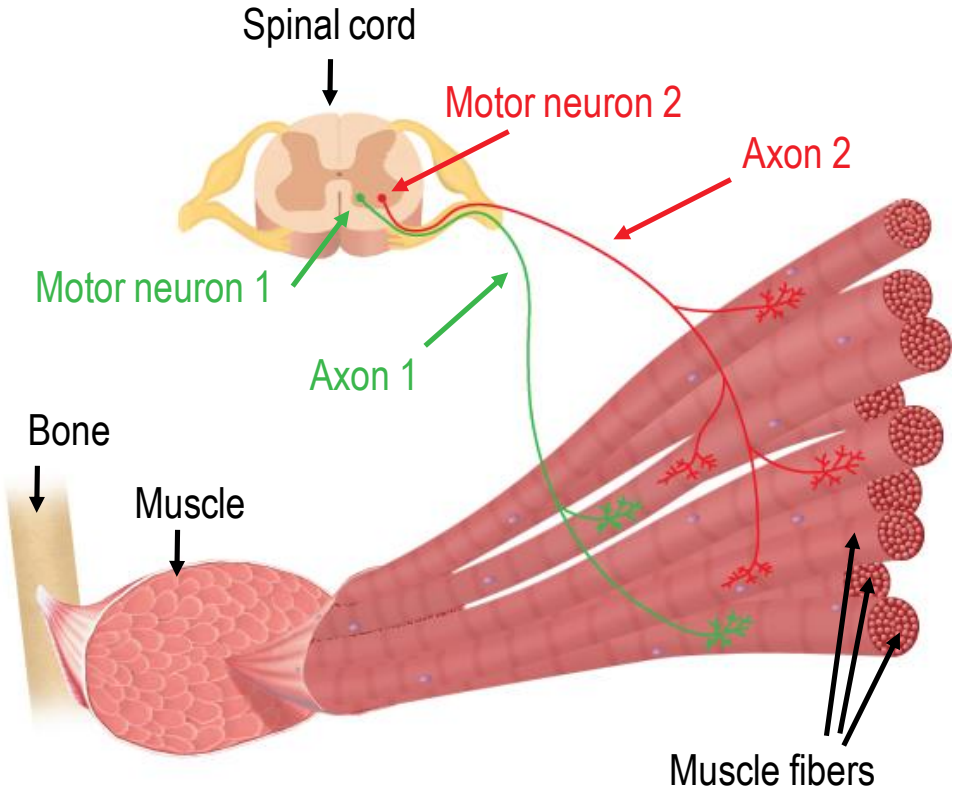


http://www.imagineeringart.com/item/skeletal-muscle-tour/

Motor units (MU)

- Motor units (MU): smallest muscle unit that can be activated by volitional effort.
- MU includes:
  - Motor neuron
  - Axon
  - Muscle fibers
- Component fibers of an MU extend lengthwise in loose bundles along the muscle.

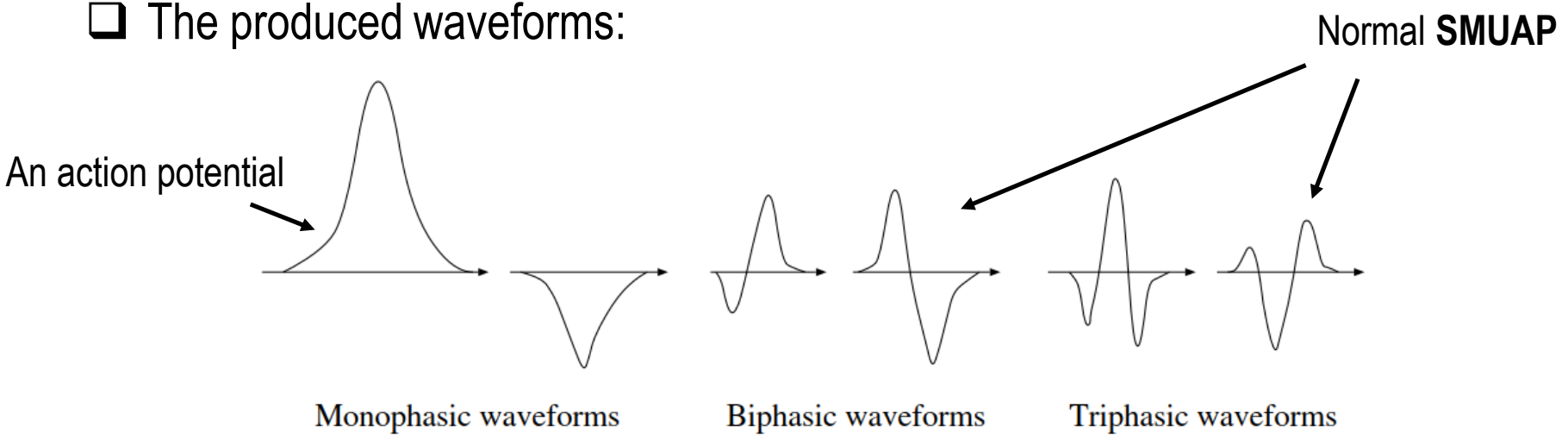
Two motor units: Motor unit 1 and Motor unit 2



https://content.byui.edu/file/a236934c-3c60-4fe9-90aa-d343b3e3a640/1/module7/readings/muscle_twitches.html

Single-motor-unit action potential

- Each motor unit contracts and causes an electrical signal that is the summation of the action potentials of all its cells.
  - Known as **single-motor-unit action potential (SMUAP)**
- The produced waveforms:



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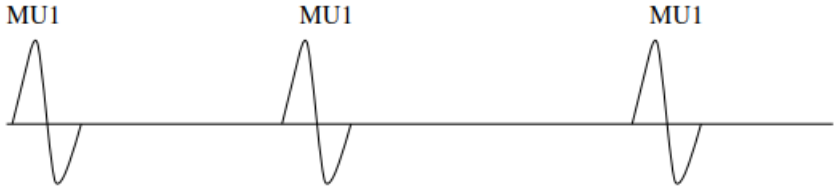
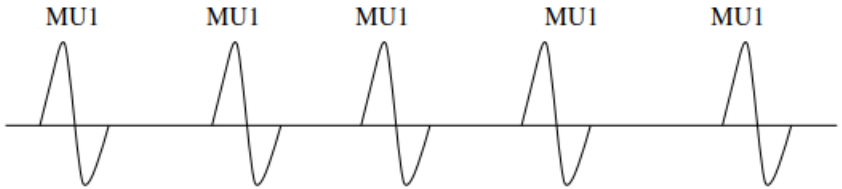
Gradation of muscular contraction

- Muscular contraction levels are controlled in two ways:
  1. Temporal recruitment
  2. Spatial recruitment

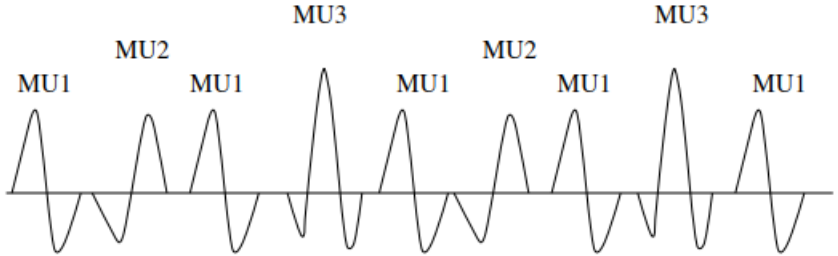
Only motor unit MU1 is firing



Higher level of effort => rate of MU1 is increased (Temporal recruitment)



Even higher level of effort => activated MU1 + MU2 and MU3 (Spatial recruitment)



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SMUAP collection and shape

- **SMUAP** is collected using needle electrodes.
- Normal **SMUAP:**

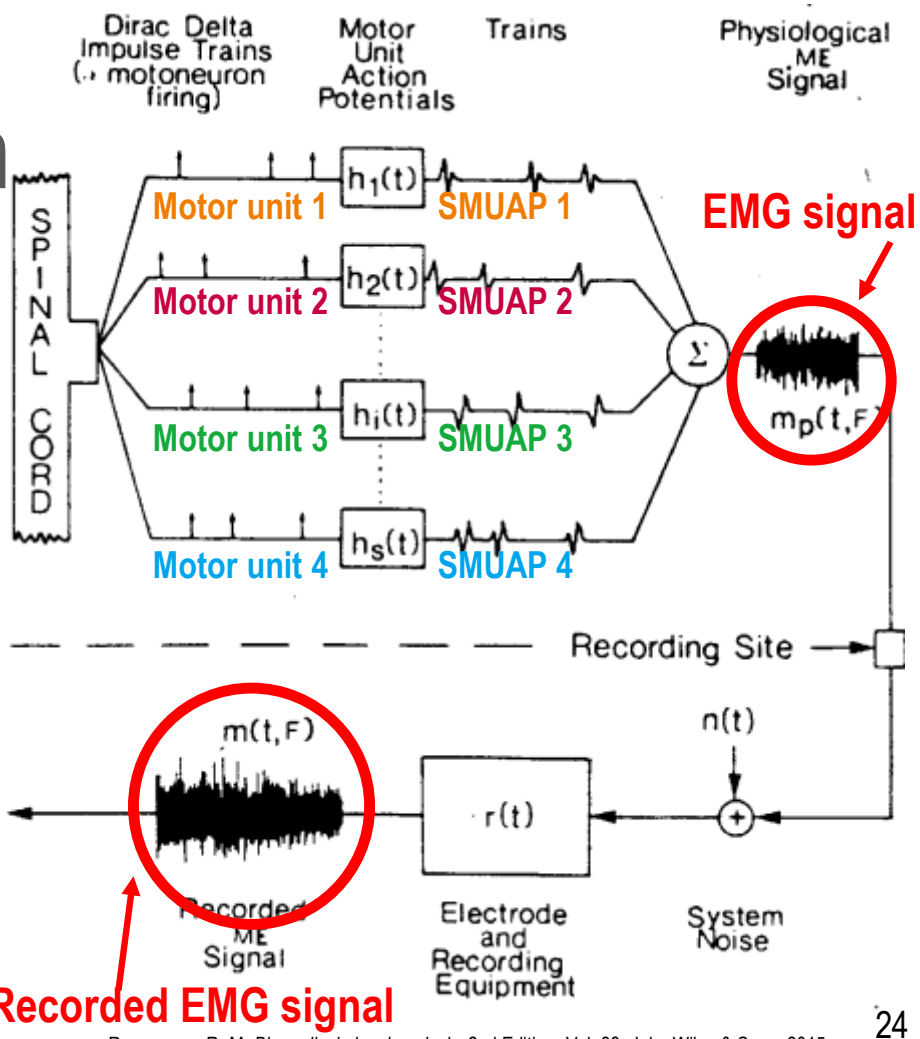
  Duration: 3 − 15 ms

  Amplitude: 100 − 300 μV

  Frequency: 6 − 30/s
- Shape of a **SMUAP** depends on the type of the electrode and its position
- The shape is affected by diseases.
  - Slow conduction
  - Amplitude larger than normal
  - Asynchrony in activation

EMG signal acquisition

- Muscles for gross movement have 100s of fibers per MU
- Muscles for precise movement have fewer fibers per MU
- The EMG is the sum of SMUAPs.
- The shape of EMG signal is affected by diseases.



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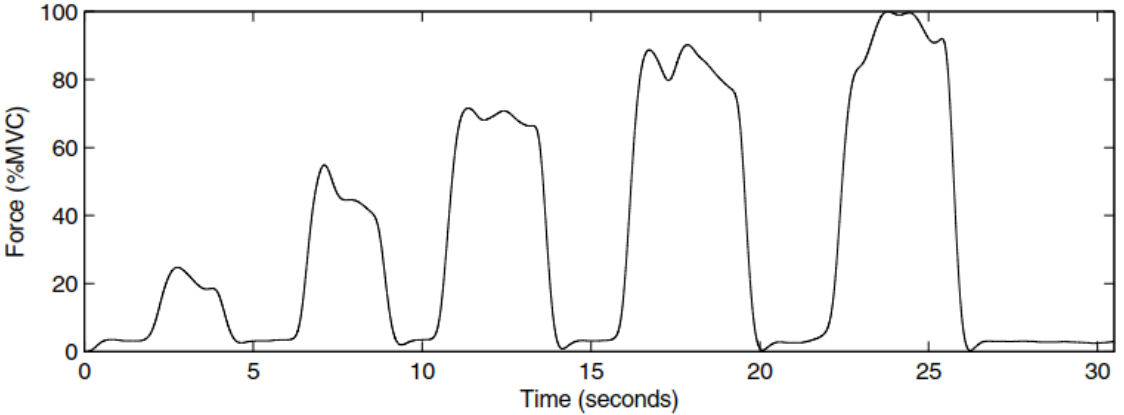
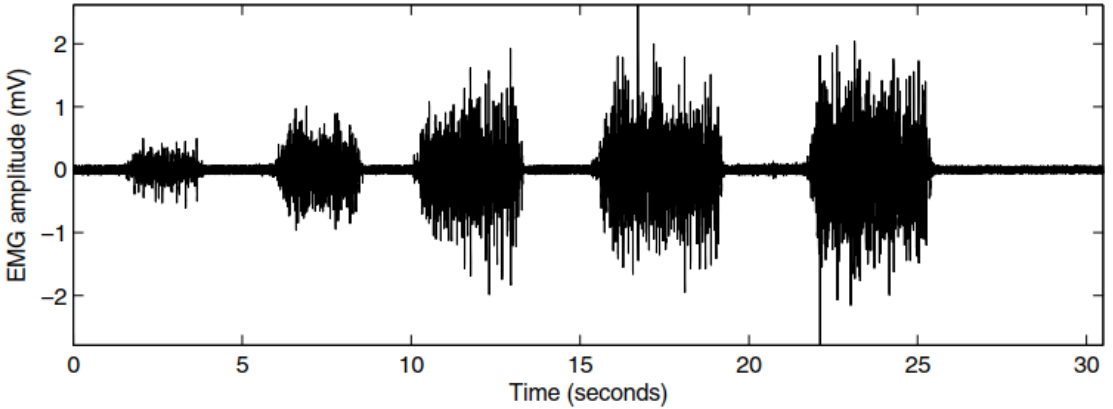
Example

- Surface electrodes placed on the forearm of a subject
- Contractions using a gripping device equipped with a force transducer
- The EMG and force signals:
  - Sampling rate: 2kHz
  - Bandpass filter: 10 − 1KHz





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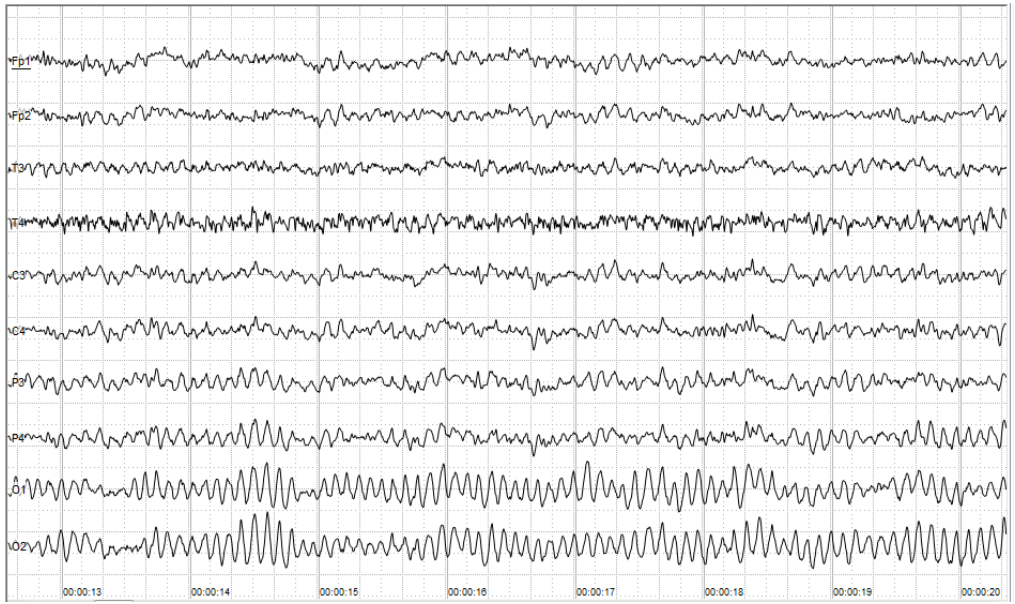
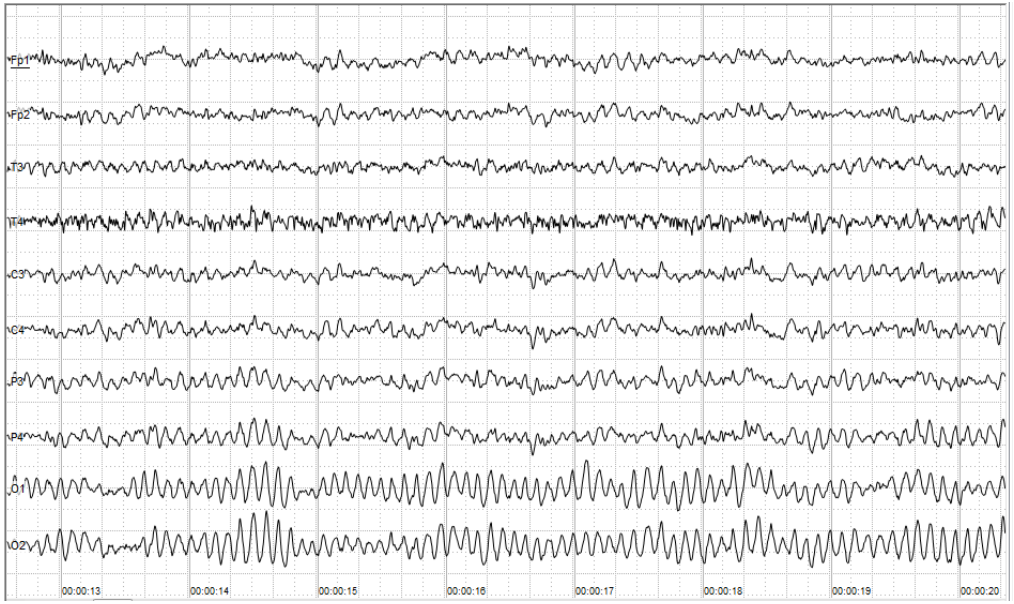
Electroencephalogram (EEG)



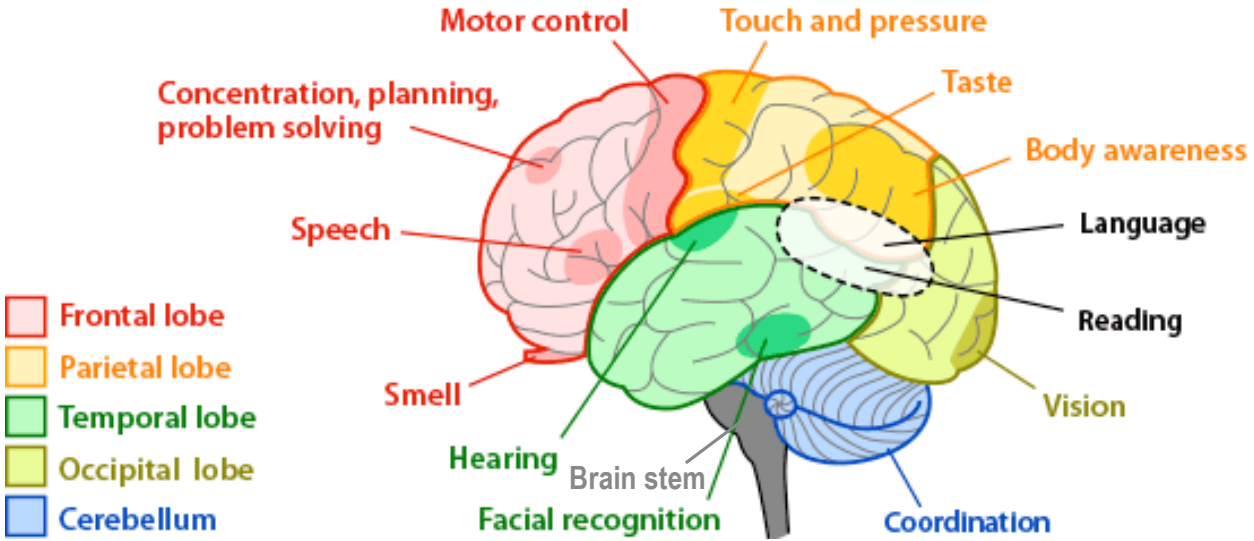
Electroencephalogram (EEG)

- EEG is an electrical signal generated by the activity of the brain (brain waves).
- EEG represents the electrical activity of the brain
- EEG may be used:
  - To study the nervous system
  - To monitor sleep stages
  - To detect epilepsy (seizure)



https://en.wikipedia.org/wiki/File:Human_EEG_with_prominent_alpha-rhythm.png

The brain

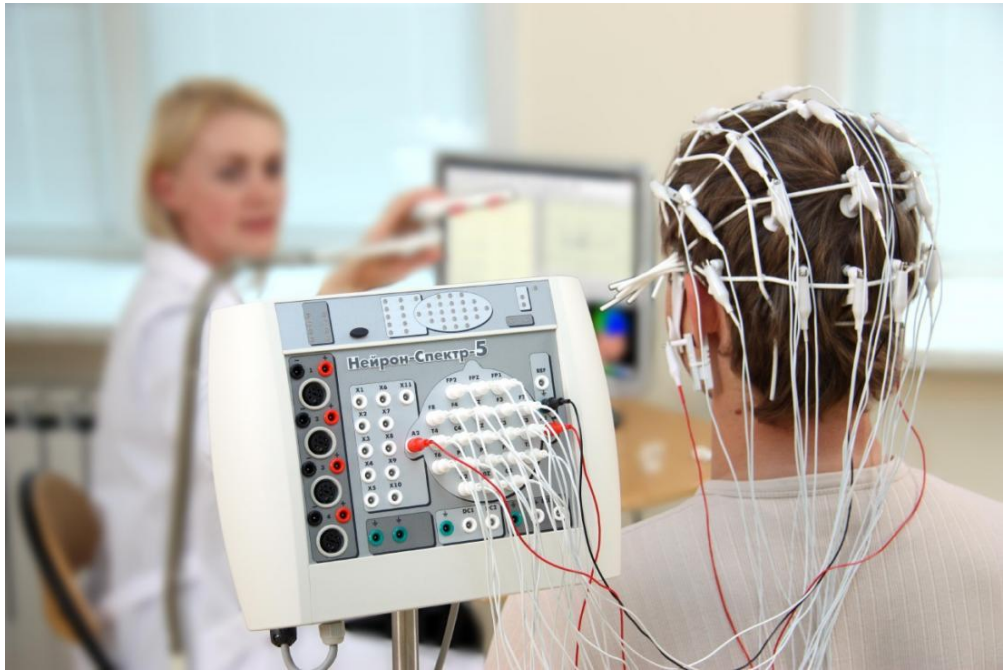


https://askabiologist.asu.edu/brain-regions

- Main parts of the brain:
  1. Cerebrum includes two hemispheres; each hemisphere is divided into four lobes: Frontal lobe, Parietal lobe, Temporal lobe, and Occipital lobe
     - Outer surface of the cerebral hemispheres (cerebral cortex) composed of neurons (grey matter) in convoluted patterns. Beneath the cortex lie nerve fibers that lead to other parts of the brain and the body (white matter)
  2. Cerebellum
  3. Brain stem includes midbrain, pons, and medulla

EEG signal acquisition (1)

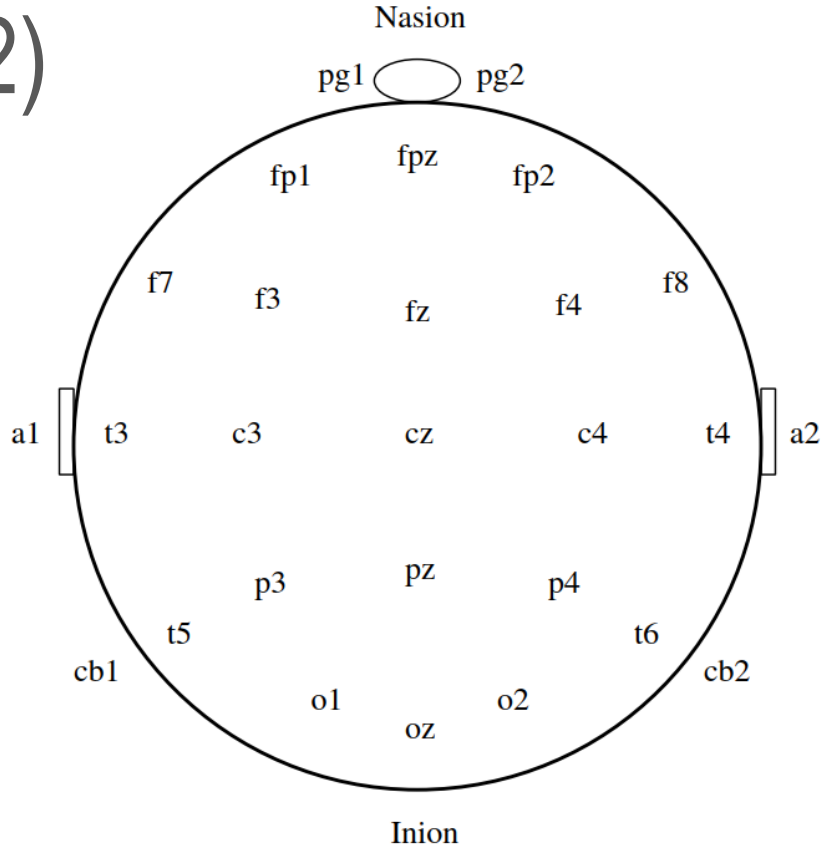
- In clinical practice, several channels of the EEG are recorded simultaneously from various locations on the scalp
  - For analysis of activities in different regions of the brain.



https://www.medicalnewstoday.com/articles/325191.php#uses

EEG signal acquisition (2)

- 10 − 20 system of electrode placement for EEG recording
  - The interelectrode distances are equal along any anteroposterior or transverse line
- The instrumentation settings:
  - Lowpass filtering at 75 Hz
  - Paper recording at 100 μV/cm, 30 mm/s
  - For 10 − 20 minutes in typical settings
  - But several hours for sleep quality assessment



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EEG signal acquisition (3)

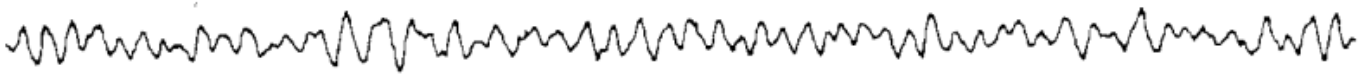
- Evocative techniques for recording the EEG:
  - Initial recording at rest (eyes open, eyes closed)
  - Hyperventilation (after breathing at 20 respirations per minute for 2 – 4 minutes)
  - Photic stimulation (with 1 – 50 flashes of light per second)
  - Auditory stimulation with loud clicks,
  - Sleep (different stages),
  - Pharmaceuticals or drugs

EEG rhythms (1)

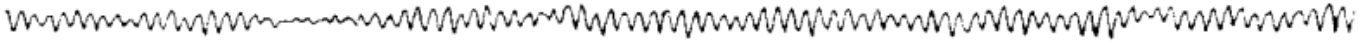
- EEG signals exhibit several patterns of rhythmic or periodic activity, which are associated with various physiological and mental processes.

Delta (δ): $0.5 \leq f < 4$ Hz

Theta (θ): $4 \leq f < 8$ Hz



Alpha (α): $8 \leq f \leq 13$ Hz



Beta (β): $f > 13$ Hz.

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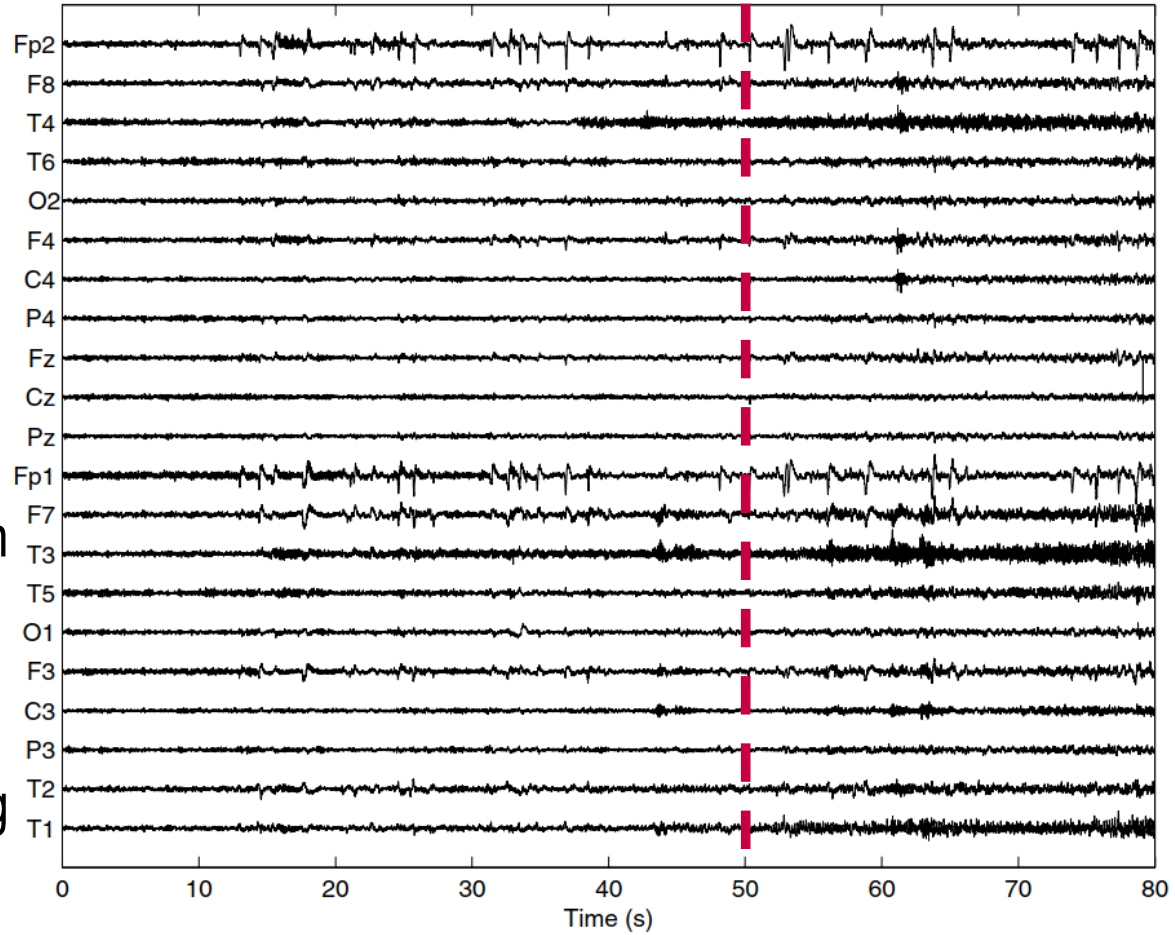
EEG rhythms (2)

- **Delta (δ):** Deep-sleep stages
- **Theta (θ):** Beginning stages of sleep
- **Alpha (α):** Principal resting rhythm of the brain
  - Common in wakeful, resting adults
  - Auditory and mental arithmetic tasks with the eyes closed lead to strong alpha waves
  - Suppressed when the eyes are opened
  - Replaced by slower rhythms at various stages of sleep.
- **Beta (β):** Tense and anxious subjects

Example

- A 21-channel record of a patient with a seizure
- The seizure starts at **50-s**
- The signal is characterized by a recruiting theta rhythm in the channels T2, F8, T4, and T6.
- Artifacts are evident due to muscle activity and blinking of the eye.



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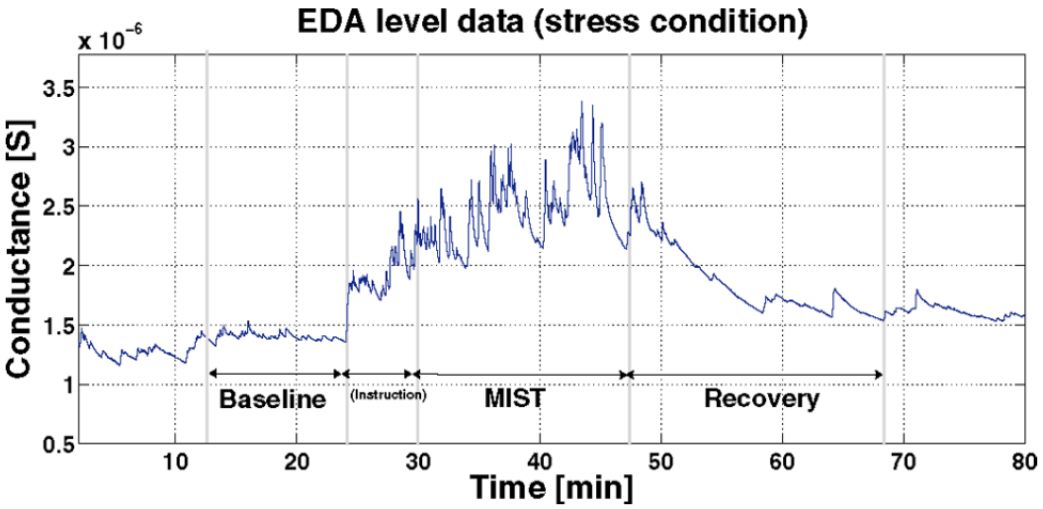
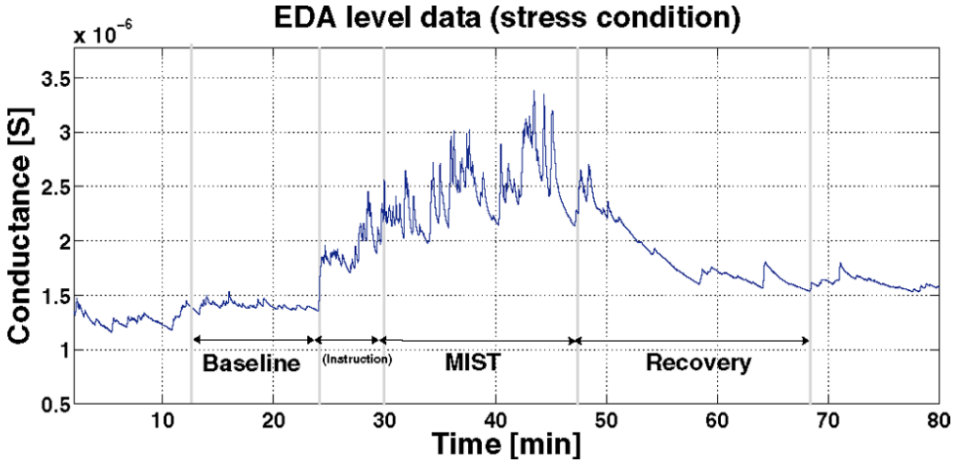
Electrodermal activity (EDA)



Electrodermal activity (EDA)

- Electrodermal activity (EDA) is an electrical signal indicates changes in the electrical properties of the skin (e.g., conductance or resistance)
- EDA is used to detect changes in the level of sweating caused by emotional activation, increased cognitive workload or physical efforts.
- EDA may be used for long-term recording:
  - sleep quality assessment and operations

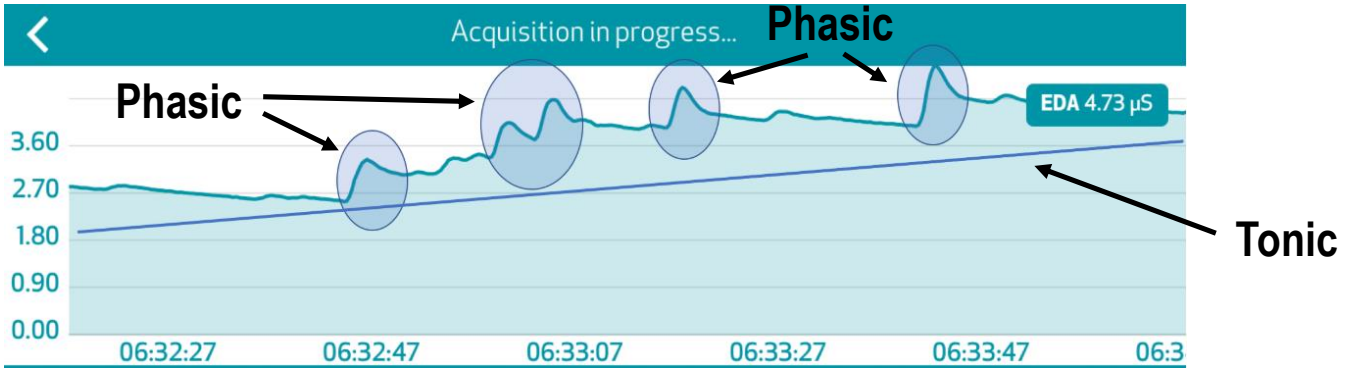


MIST is a standardized computer-based task consisting of a stress and a control condition

Setz, C., et al. "Discriminating stress from cognitive load using a wearable EDA device." IEEE Transactions on information technology in biomedicine 14.2 (2009): 410-417.

EDA features

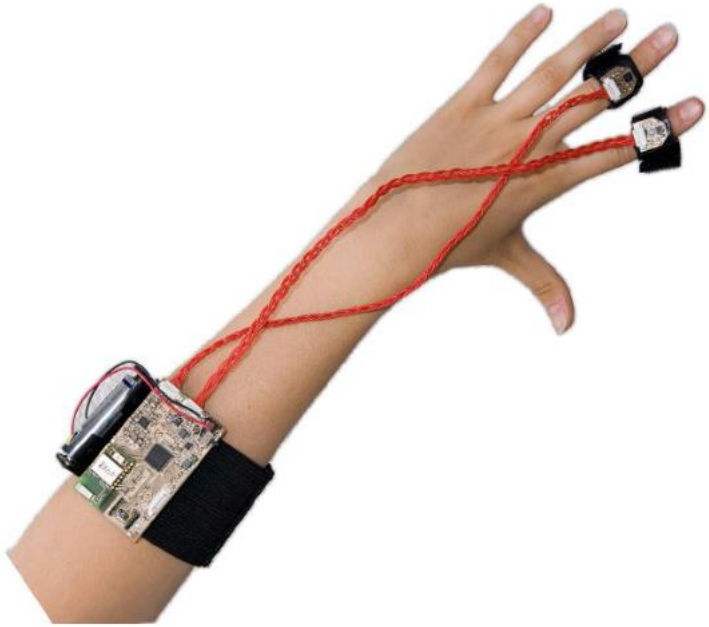
- Different parameters can be extracted from the signal.
  - **Phasic**: short-term events and occur in the presence of discrete environmental stimuli - sight, sound, smell, cognitive processes, etc.
  - **Tonic**: level of skin conductance in the absence of any particular discrete environmental event or external stimuli.



https://support.empatica.com/hc/en-us/articles/203621955-What-should-I-know-to-use-EDA-data-in-my-experiment-

EDA Electrodes

- Two electrodes are attached to the subject's skin and connected in series with a system reference resistor
- The fluctuations in the electrodermal system can be read through the variations of the partial voltages
- External and internal influences on recordings
  - E.g., climate conditions, ambient temperature, physiological influences, age, and gender



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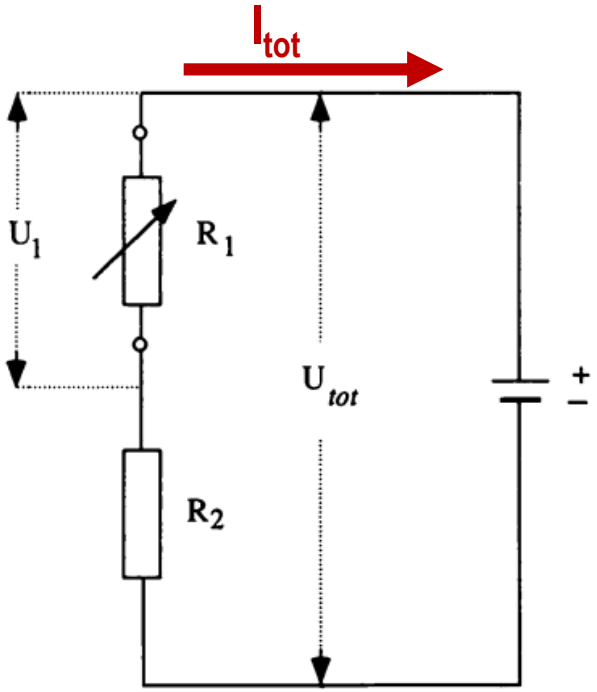
A simple resistive model

- For most applications of EDA recording, a simple resistive model is sufficient to explain the phenomena observed.
- R_1 is the skin resistance
- $I_{tot} = \frac{U_{tot}}{R_1 + R_2}$
- If $R_2 >> R_1$, U_1 is almost proportional to variations of the skin resistance R_1



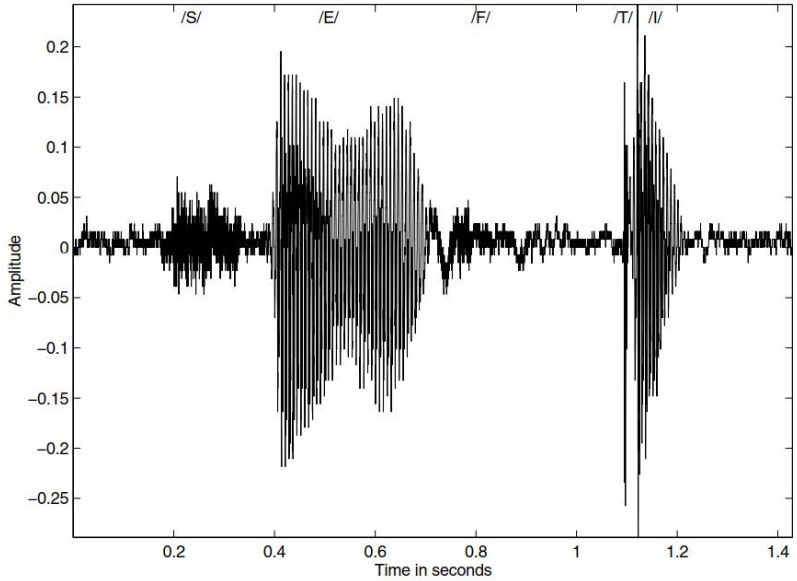
Boucsein, W. (2012). Electrodermal activity. Springer Science & Business Media.

EDA signal acquisition

- Mainly there are three methods:
  1. Without externally applied voltage (Endosomatic)
  2. Applied DC voltage (Exosomatic DC)
     - The majority of EDA studies
     - The data is easier to analysis
     - Less noise and artifacts
  3. Applied AC voltage (Exosomatic AC)
     - It is rare
- A recording technique proposed by Boucsein[1]:
  - DC recording with constant voltage of 0.5 V or constant current not exceeding 10 mA/cm2
  - Using Ag/AgCl chamber electrodes with 0.5–1 cm2 area

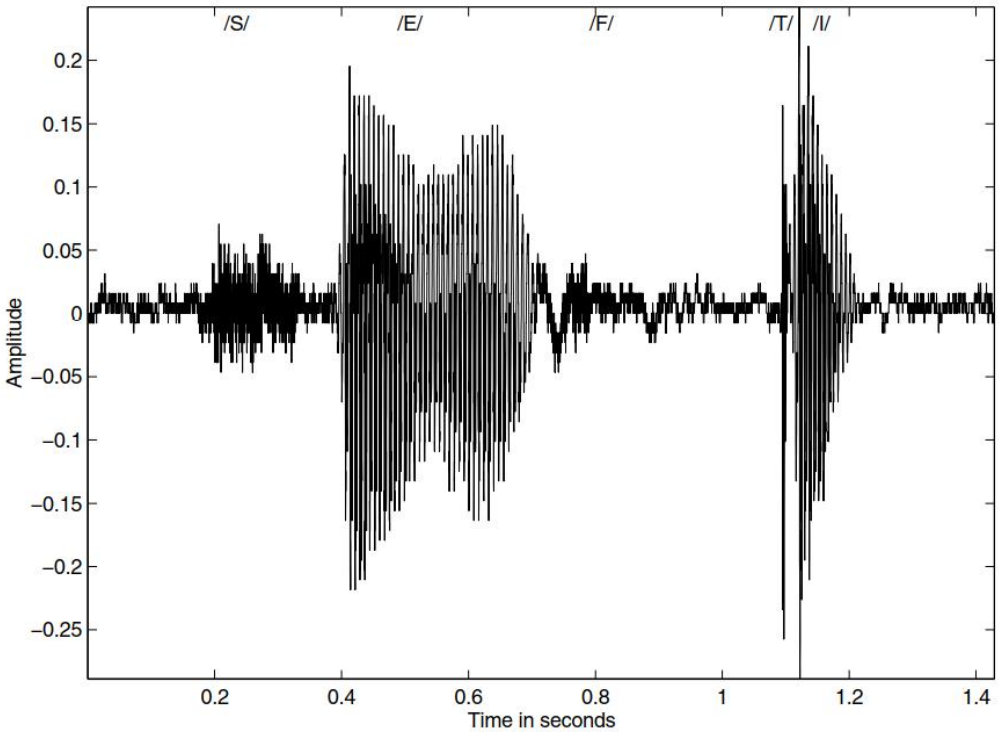
[1]Boucsein, W. (2012). Electrodermal activity. Springer Science & Business Media.

The speech signal



The speech signal

- Speech produced by transmitting puffs of air from the lungs through the vocal tract as well as the nasal tract.

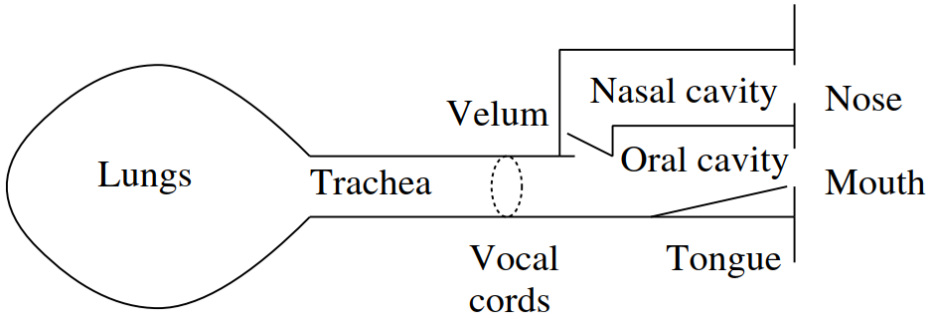


Speech signal of the word “safety”

Rangayyan, R. M. *Biomedical signal analysis*. 2nd Edition, Vol. 33. John Wiley & Sons, 2015.

Speech production system

- Vocal tract:
  - Starts at the vocal cords in the throat and ends at the lips and the nostrils.
  - the shape is varied to produce different types of sound units.



Rangayyan, R. M. *Biomedical signal analysis*. 2nd Edition, Vol. 33. John Wiley & Sons, 2015.

- Speech sounds may be classified as:
  1. **Voiced**: air is forced through the vocal cords held at a certain tension (e.g., vowels). Pitch and the resonance are important features.
  2. **Unvoiced**: The vocal cords do not vibrate for such sounds (e.g., : /S/, /Z/, and /F/ (Fricatives))
  3. **Plosive (stops)**: complete closure of the vocal tract, followed by an abrupt release of built-up pressure (e.g., /P/, /T/ and /K/)

Diagnosis using the speech signal

- The speech signal can serve as a diagnostic signal when speech and vocal-tract disorders need to be investigated.
- Parkinson's disease, which causes tremor, rigidity, and loss of muscle control, is also known to affect speech.
- The changes in speech caused by the disease include reduced loudness, increased vocal tremor, and breath-related noise.

Conclusion

In this session, we learned:

- ❑ We learned about the action potential, i.e., the origin of electric signal
- ❑ We learned different biosignals, collected to monitor the muscular and nervous systems

In the next session, we will learn:

- ❑ We will learn about biosignals, collected to monitor the cardiovascular system

Thank You

Questions?

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