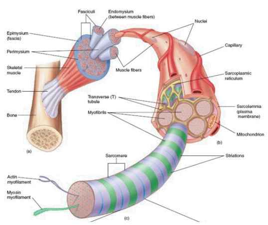
POLITECNICO
MILANO 1863

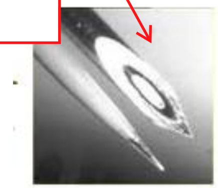
Myoelectric signal

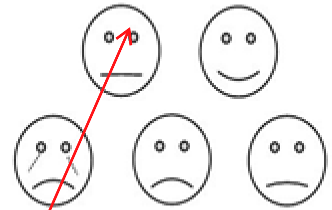
Lecture 2

EMG signal detection and processing chain

interface: how we can detect the signal. will be surface or inside







Signal generation

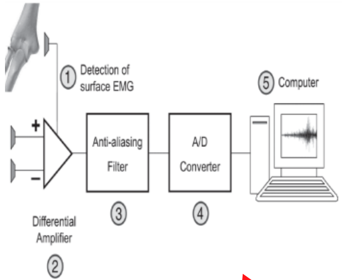
Electrodes chemistry

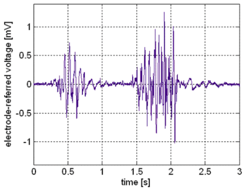
Electrodes types

Requirements

Performances

optimize some performances: some are deminished by the " situation": for example the interface of the electrodes creates a layer that """filters""" the signal. We should consider factor like these





Electromiograph

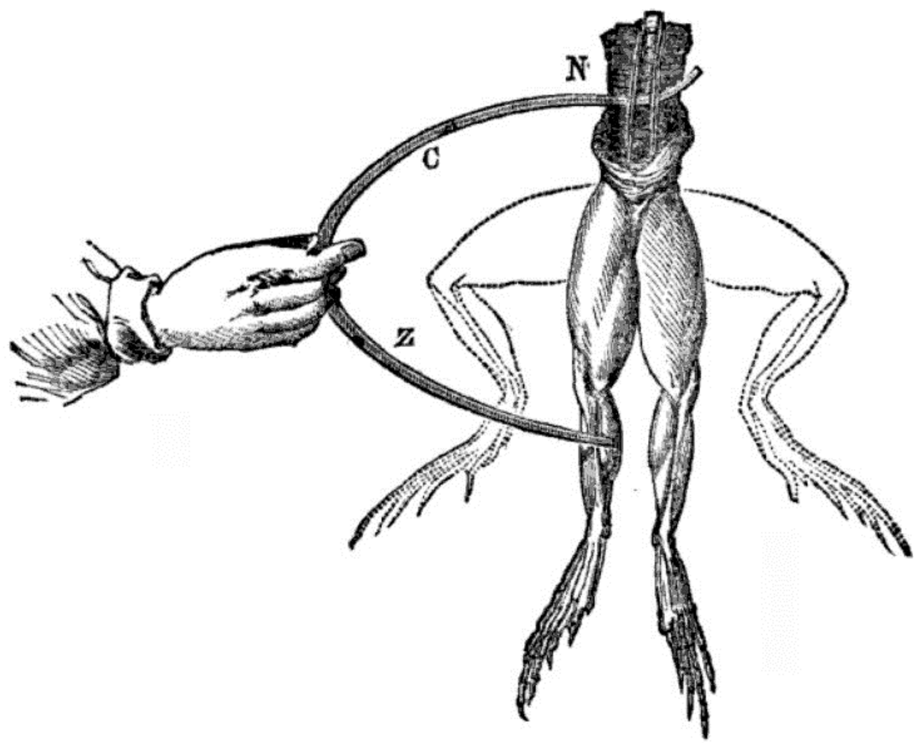
Device needed to amplify the signal. Then we can do pre-processing.

Pre - processing

Electricity of muscles
(electricity from ἤλεκτρον = amber – fossile resin)

Galvani (1791) is the first investigator to appreciate the relationship between electricity and animation. This finding provided the basis for the new understanding that the impetus behind muscle movement was electrical energy carried by a liquid (ions), and not air or fluid as in earlier balloonist theories.

Galvani coined the term *animal electricity* to describe the force that activated the muscles of his specimens.



Alternative theory: Balloonist theory

The Greek physician Galen believed that muscles contracted due to a fluid flowing into them, and for 1500 years afterward, it was believed that nerves were hollow and carried fluid. René Descartes, proposed that "animal spirits" flowed into muscle and were responsible for their contraction. In the model, which Descartes used to explain reflexes, the spirits would flow from the ventricles of the brain, through the nerves, to the muscles.

McKibbean pneumatic muscles work similarly.

artificial muscles used in robotics in order to produce a mechanical work. If it flows from right to left there's an extension.

Electricity - Electromyography (EMG)

Actually two! Actually our is kinesiological EMG, and we'll call that EMG. The neurological emg is the study of the response of the muscle to an artificial stimulation directly on the fiber. Can be studied on a macrolevel, or few fibers. We are looking in static condition to the direct response! It's a setup we are constructing artificially to understand the response. Kinesiological is at MACRO level, we want to study at a macrolevel in "natural" condition, without stimulating.

"… is the study of muscle function through the inquiry of the electrical signal the muscle emanate" (i.e. myo-electric signals)

Study of the muscles' signal

(Basmajian JV, De Luca C, Muscles alive, 1985)

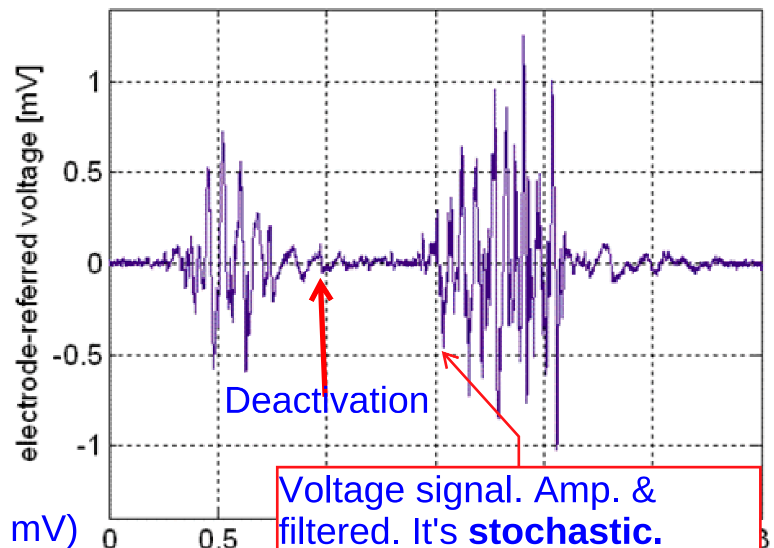
Neurological EMG – static conditions

(micro level few fibers)

Kinesiological EMG **our**

(macro level, many fibres)

Stochastic nature



Deactivation

Voltage signal. Amp. & filtered. It's **stochastic.** When it's similar to 0 the muscle is relaxed, when the noise is increased is associated to contraction.

stage 1) amplification (indeed the amplitude in mV)
stage 2) filtering (indeed the baseline is 0)

Use of EMG as analytical methodology

Application of the signal. Ofc in these cases we are not using ONLY the emg! it's coupled with other things. For example in sport we are using motion sensors

Medical research

- Functional neurology
- Gait and posture analysis
- Low back pain

understanding in healthy subject how the muscles work. I use the EMG to do this.

Functional neurology: I associate the EMG to the neural signals.

Rehabilitation

- Post surgery/accident
- Neurological rehabilitation
- Physical therapy
- Active training therapy

Use of EMG to understand what changes when a surgery is done. Ex: anti spasticity.

Also to evaluate rehabilitation, watching the EMG before and after. Maybe with gait analysis.

Ergonomics

- Analysis of requirements
- Risk prevention
- Ergonomic design

Sport science

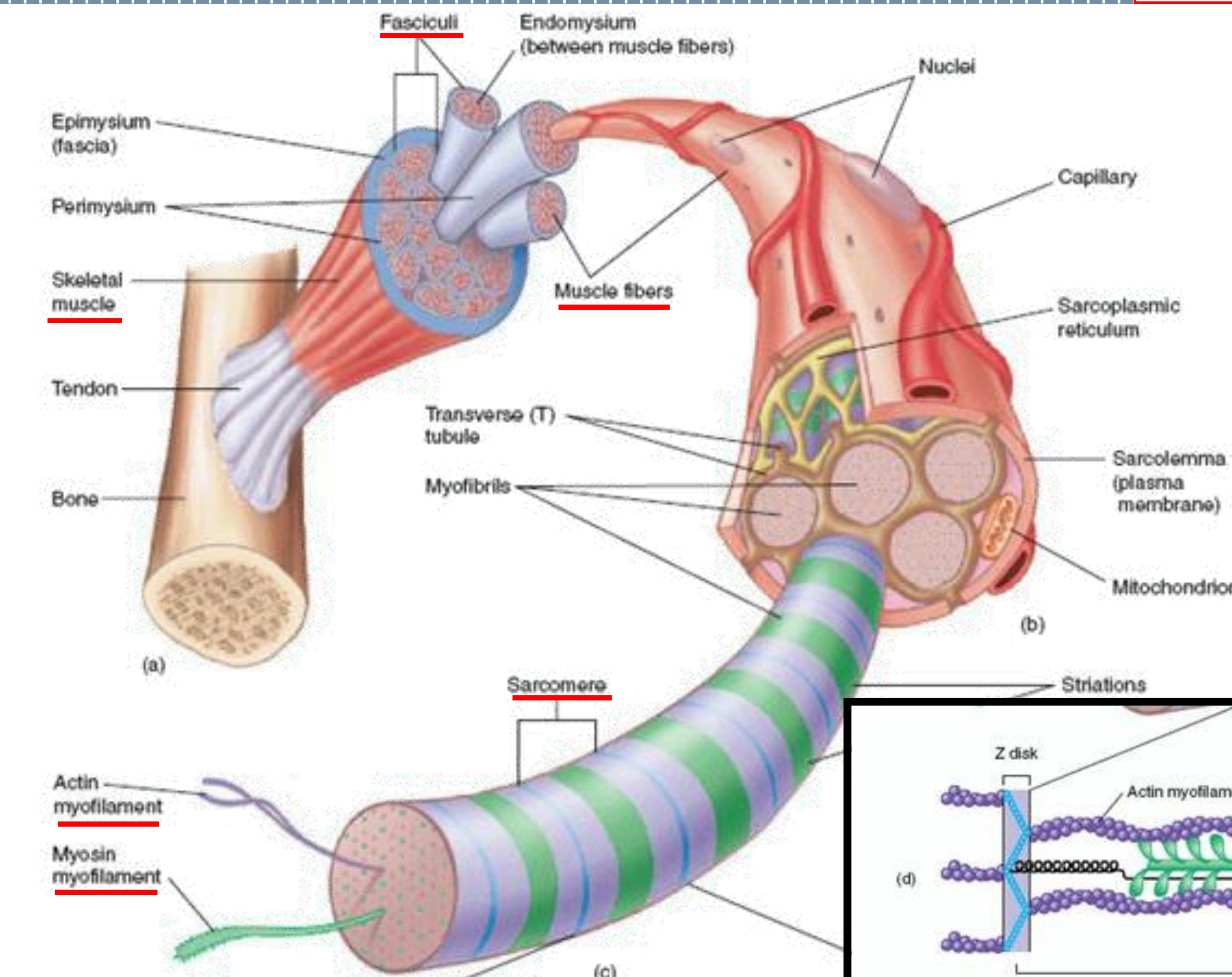
- Biomechanics
- Movement analysis
- Athletes strength training
- Sports rehabilitation

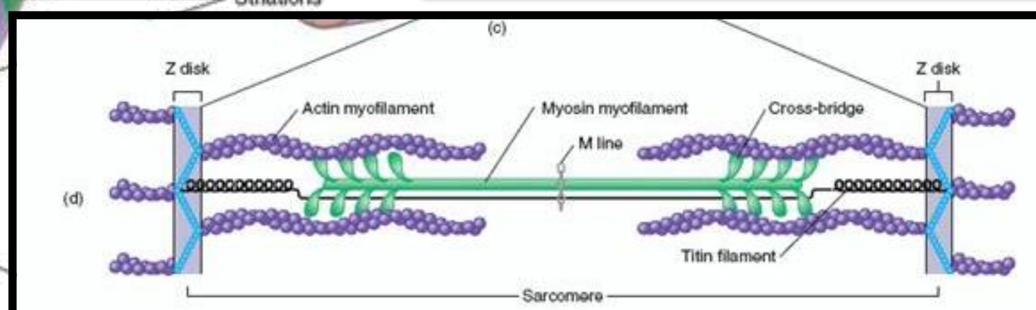
Ergonomics: EMG is used to see if we are minimazing the unwanted contraction. We can design seats in order to avoid this.

Muscular structure

every motorneuron innervate different branches. Each branches goes to one fiber.

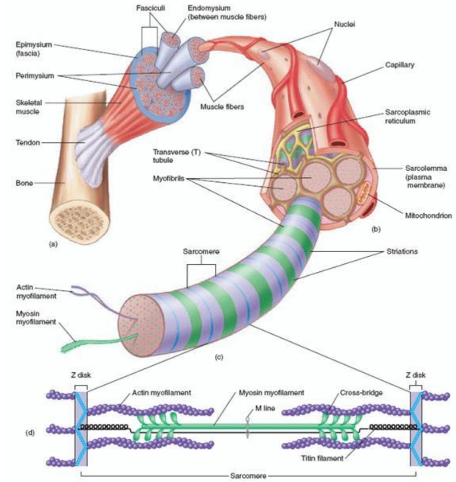
Motor neuron action potential (AP) causes Ach release, which originates a muscular cell depolarization and AP. AP releases Ca^{++}, which makes the sarcomere contracting . Energy for the process is provided by ATP-ADP transformation, restored by mitochondria.
Aerobic and anaerobic function

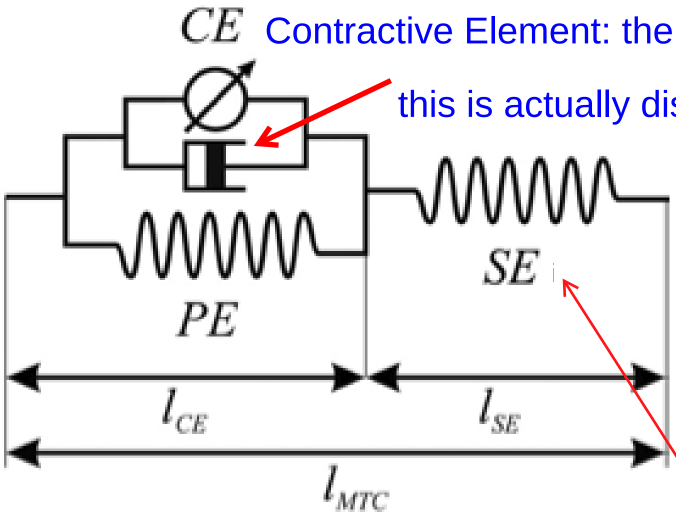




Muscular structure: Hill model

The three-element Hill muscle model is a representation of the muscle mechanical response. The model is constituted by a contractile element (CE - Fibres), two non-linear spring elements, one in series (SE - Tendon) and another in parallel (PE – Collagen tissue), and a non-linear distributed viscous damper (FD).





Contractive Element: the fiber

this is actually distributed

actually a NL spring

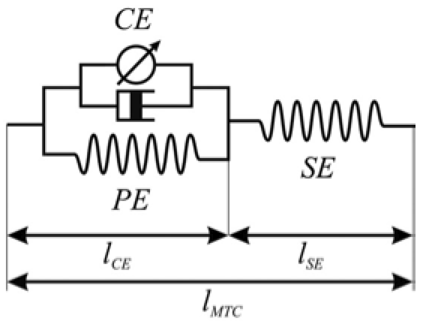
$$F_{SE} = (k_{SE}(L_{SE0} - L_{SE}))^2$$

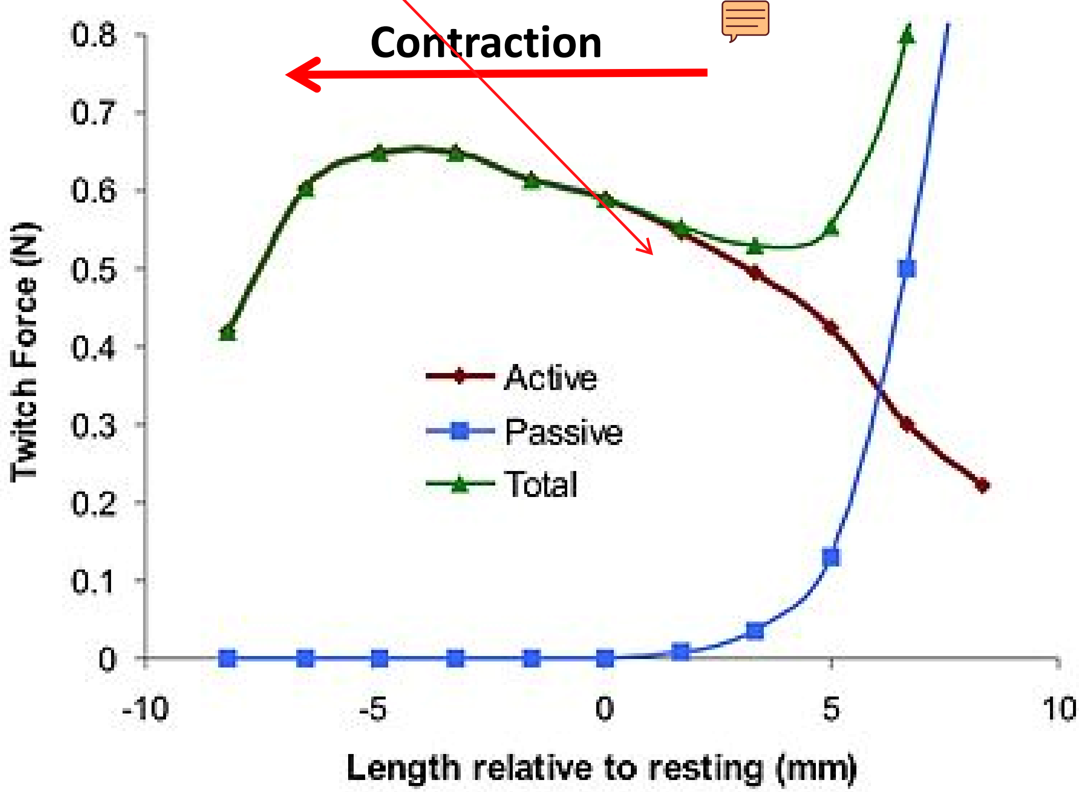
$$F_D = k\left(\dot{L}_D\right)^a$$

Viscous damping (distributed in the 3 elements, reported as in parallel to CE)

Using the **hill model** we endup with this graph. The lenght is relative, so 0 is the relaxed. The passive forces are produced by the damping and passive structures: not volontarly activated. The active it's the opposite. Indeed the passive is not present when the muscle is short. If we contract while the muscle is elongated we have the sum of the two. This is useful to understand:
1) isomectric (with L=0)
2) concentric (L<0)
3) eccentric (L>0) which could damage the muscle

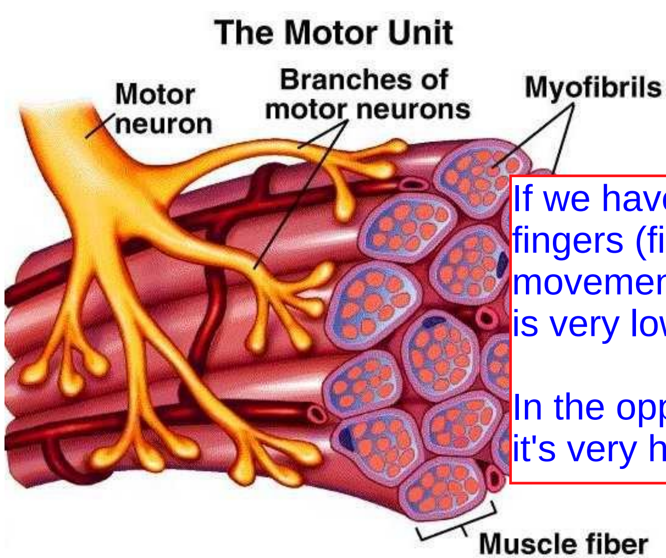
Muscle force versus length of CE and PE (non linear behaviour)

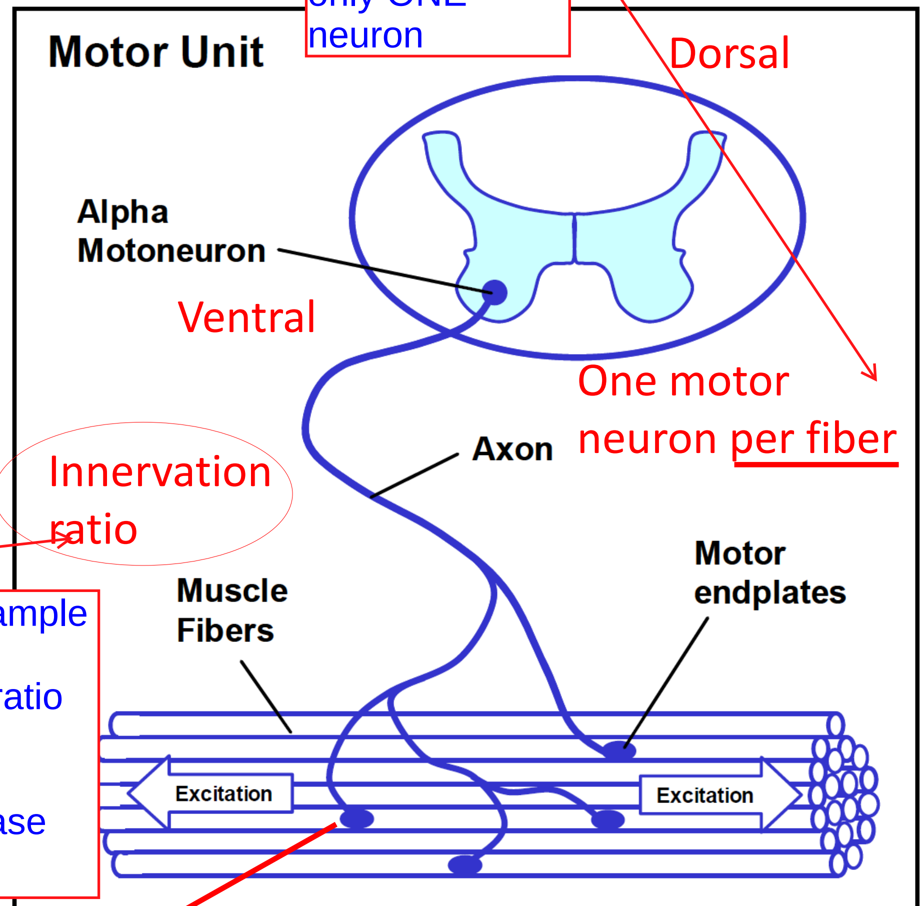




The motor unit (MU)

MU Is "… the **soma** and **dendrites of a motor neuron**, the **multiple branches of its axon**, and the **muscle fibers** that it innervates"





each fiber is innervated by only ONE neuron

Dorsal

Ventral

One motor neuron per fiber

Innervation ratio

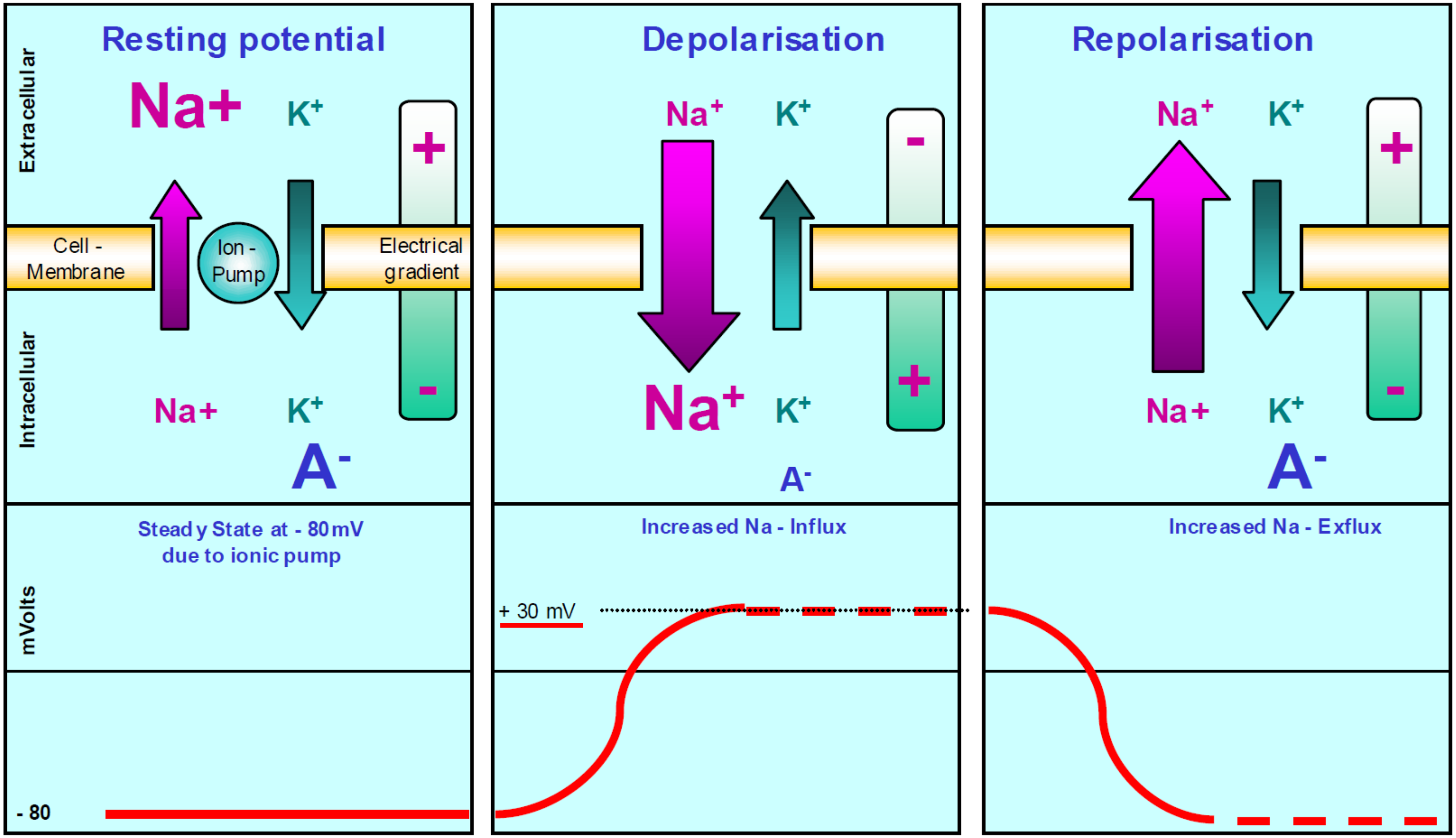
If we have for example fingers (fine movements) the ratio is very low.

In the opposite case it's very high

Note the direction of AP

we are detecting signals generated here

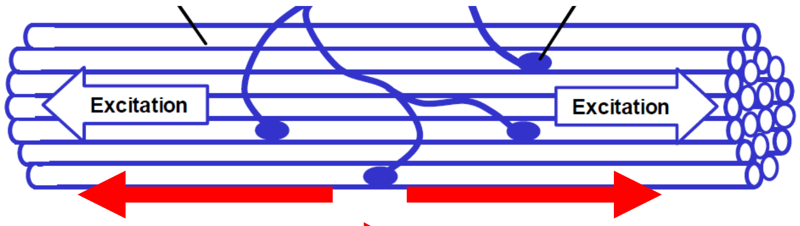
Excitability of muscle membranes



Excitability of muscle membranes: some peculiarities

In neurons the potential rises from the cell body (Axon hillock) and proceed in only one direction due to refractory period.

Muscular fibres are innervated in the middle, so different directions are possible.



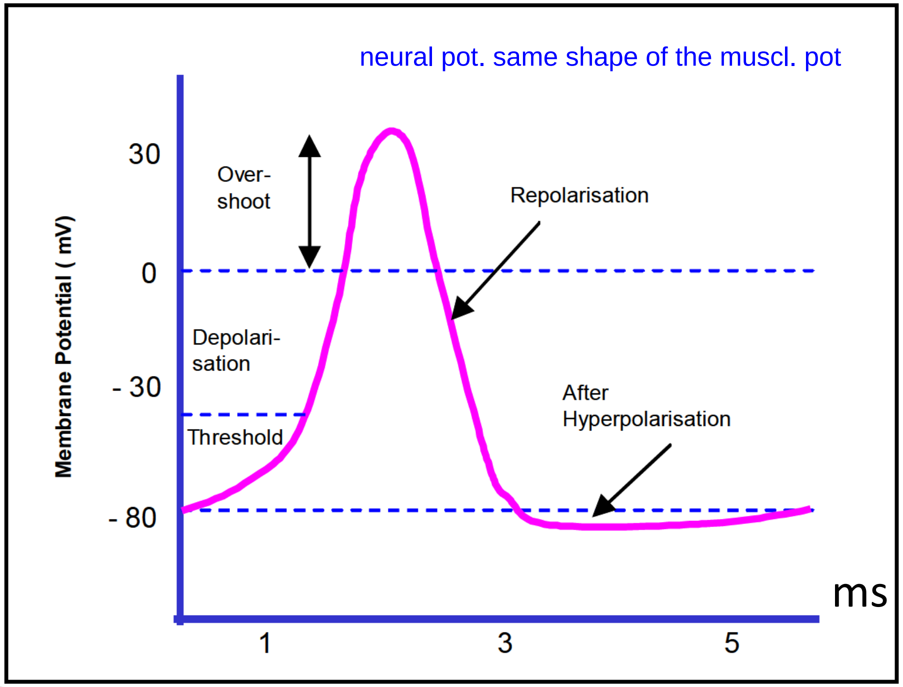
aha! in the muscle it's flowing in both direction

Generation of the EMG signal – Action potential (AP)

If the influx of Na+ overcomes a pre-defined **threshold**, the membrane potential changes from -80mV to +30mV.

Starting from the motor end plates, the action potential spreads along the muscle fiber in both directions.

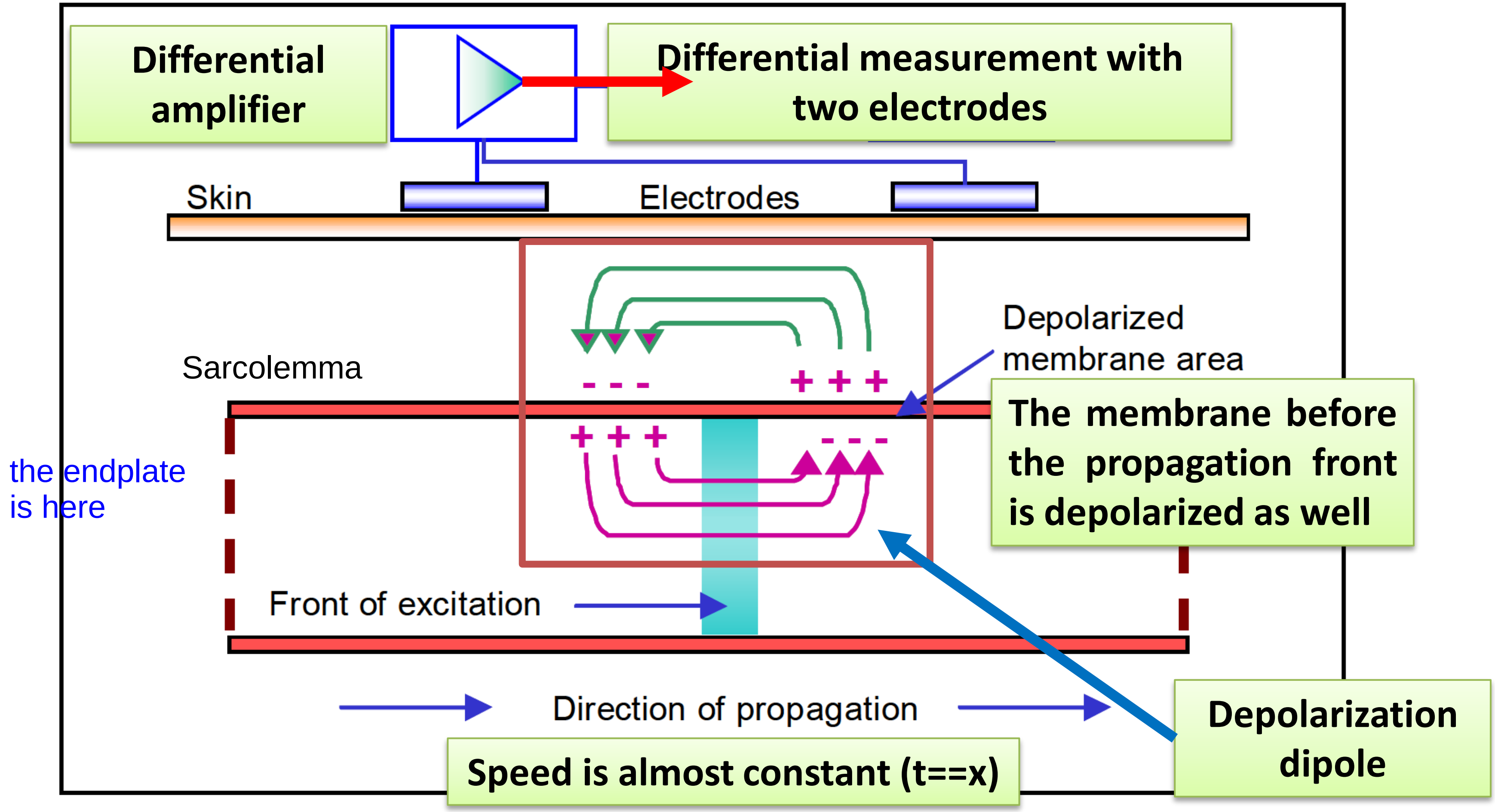
Calcium ions are released in the intra-cellular space. Contractile elements of the muscle cell shortens (**electro-mechanical coupling**).



Shape detected with a monopolar electrode wrt a goriund electrode placed far away on the body

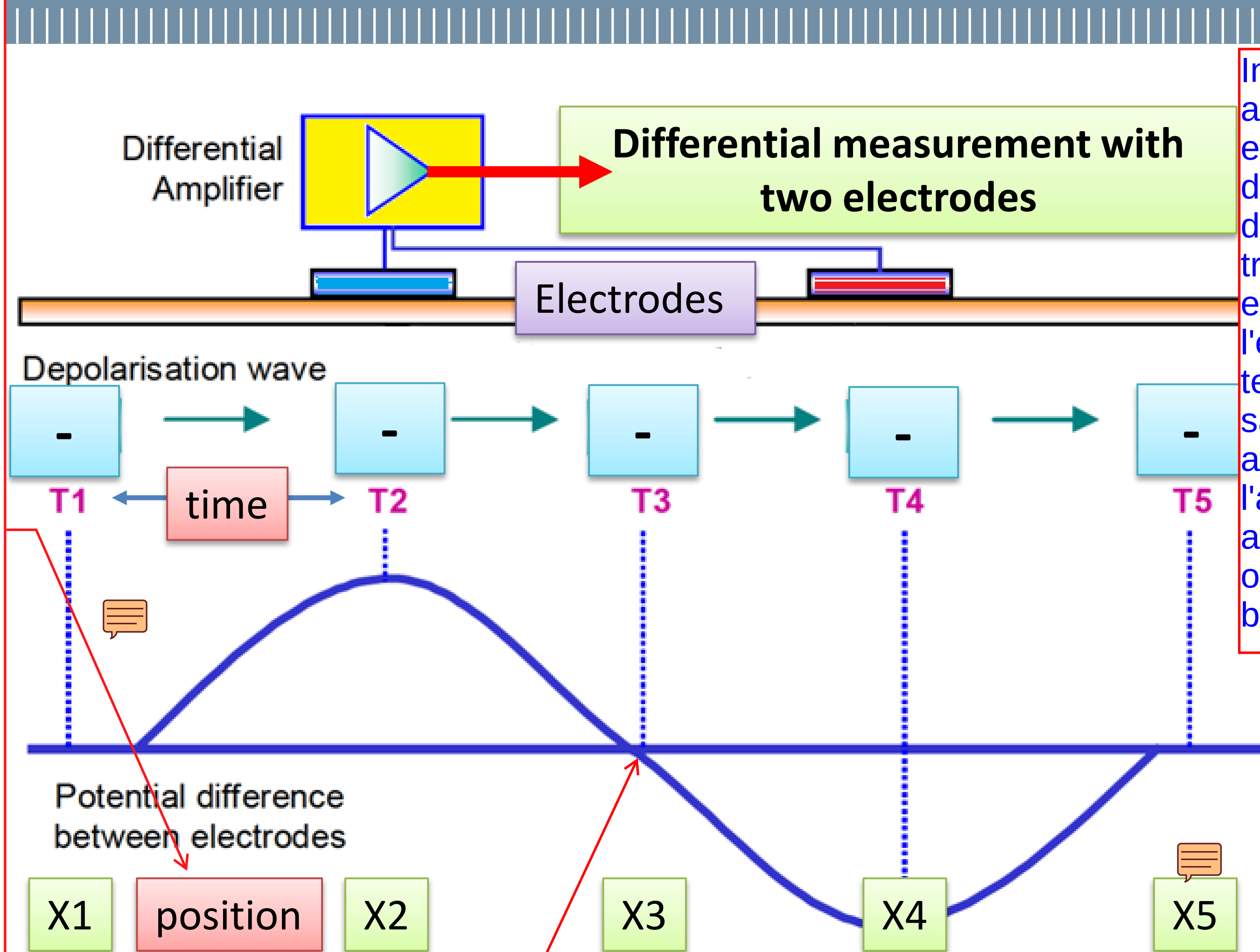
Generation of the EMG signal – Propagation of Action potential EMG measurement

We are at the muscle fiber, we want to dectect these AP propagating.



Signal propagation and Differential detection: the monopolar action potential creates a bipolar signal by differential amplification process

we have a depolarization wave that is flowing. What do we see with electrodes? We usually use differential, so we amplify the difference of two. So the output is depeding on the difference between the two. Let's say that the wave is a potential difference read by the el. Why this shape? at first nothing can be read by the el. At the first maxium one is max and the other is at his minimum



Intereptazione:
al tempo t2 ad esempio il picco dell'onda depolarizzante si trova in X2, ergo esattamente sotto l'elettrodo, ergo la tensione di uscita sarà massima, anche perché l'altro elettrodo avrà ancora ""0"" o comunque la base di partenza.

here they are the same

Motor Unit Action Potential (MUAP)

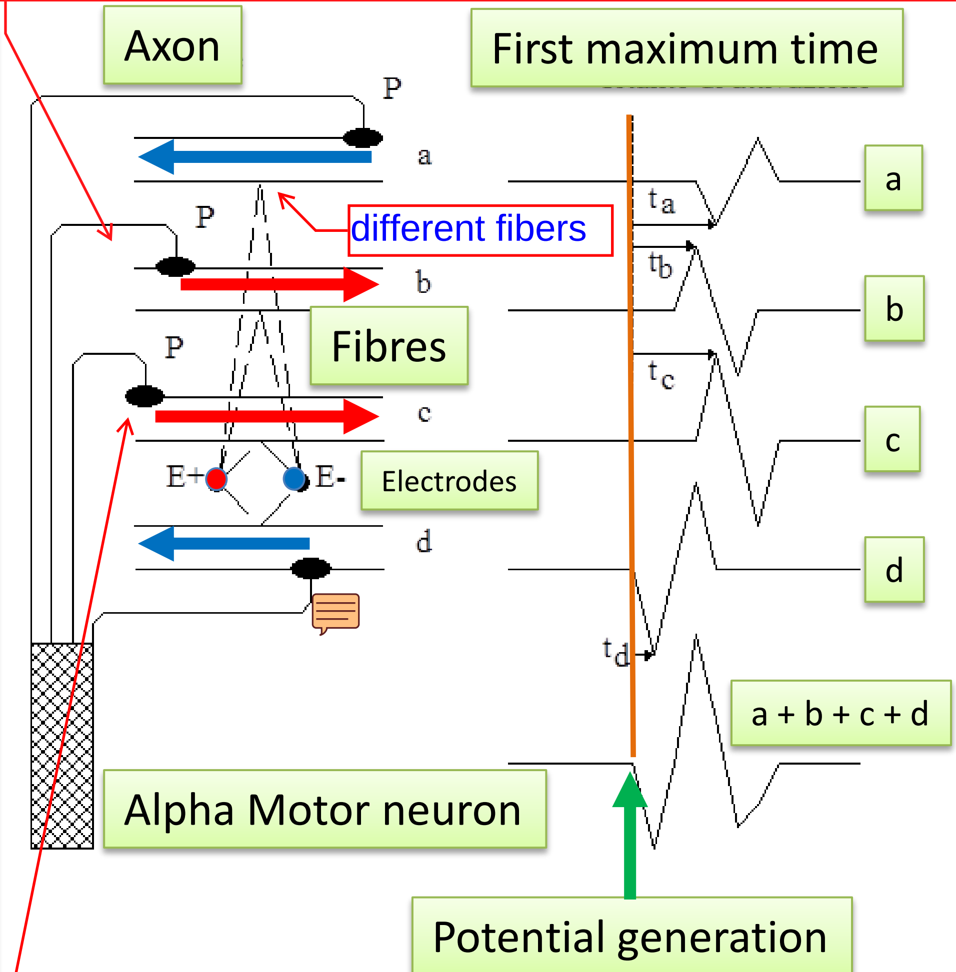
At the beginning I'm sensing a negative pot. Ofc we use straight lines but these would be smoother. Then we have the change of polarity. BUT, c and d are at more or less the same distance to E+ and E-, so the amplitude is more or less the same (it depends inversily on the distance). So the amplitude is about the same. There's also a DELAY that depends on the distance! (delay of the electrode time to read the signal). The speed of propagation is considered constant.

MUAP is the sum of the AP of a single motor unit (i.e. a motor unit is made by fibers innervated by a single alpha motor neuron).

AP generation happens in the motor endplate and its propagation happens in the fibre direction

I'll use just a couple of electrodes

Left: Electrodes E+ and E- are positioned among the muscle fibres. They detect the potential difference (**Right**) resulting from AP propagation. The potential difference amplitude is proportional to the distance between AP generation and AP detection sites.



Clearly this means that tc will be >> td.

Motor Unit Action Potential (MUAP): time vs. space

$$t_D = D/v_c$$

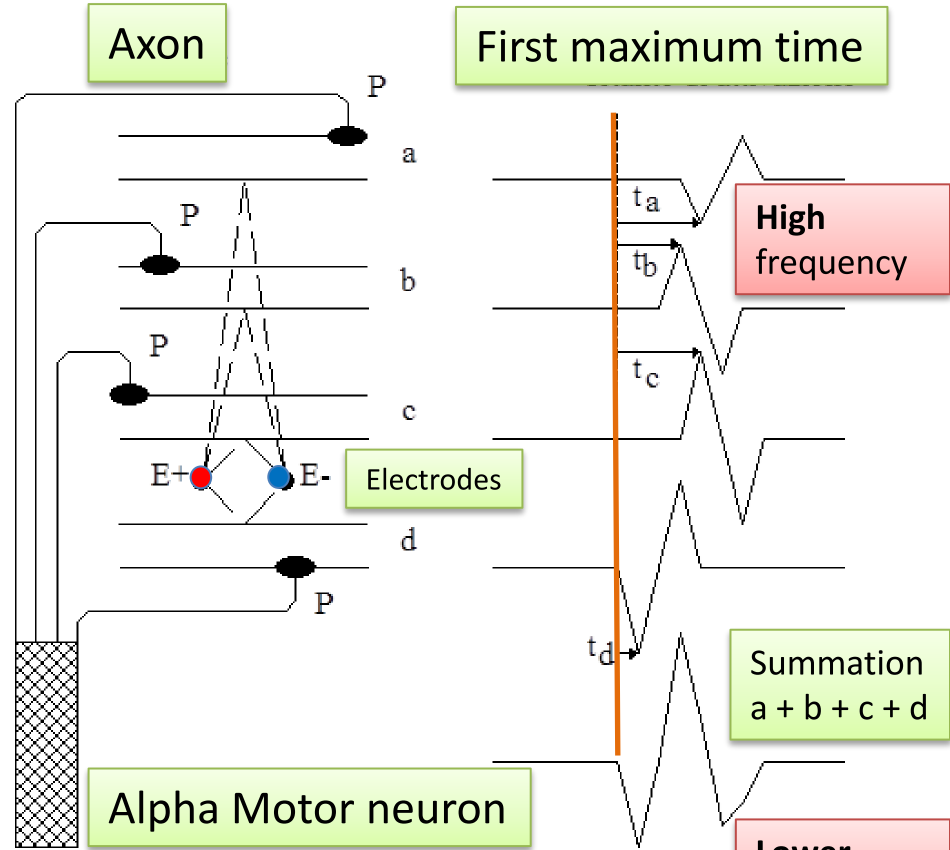
t_D is the delay between the AP generation and AP detection

v_c is the fiber conduction velocity

D is the distance between the motor endplate and the detection location

In cases *a)* and *d)*, positive AP reaches E- before E+

High frequencies are attenuated in the summation due to the transfer function of tissues between AP generation and detection.



We are sensing the sum of the many contributions. In this case 4. The summation is the so called **MOTOR UNIT ACTION POTENTIAL**

we get a "lower freq" signal.This is because summing up is basically doing a MA., a LP filtering. So high freq. is lost when I'm detecting the sum.

Motor Unit Action Potential Train (MUAPT) ($u_i(t)$)

*in una MU (i-esima) le fibre sono tutte in sync e si ripetono temporizzate sempre uguali, quindi abbiamo che il MUAP si ripete sempre uguale ad h.i. Immagino che il tempo di delay tra due possa cambiare, come si evince dall'andamento nel tempo in basso a dx. Reality: they are spiking in time. "Temporal summation". Each fiber is spiking with a certain frequency. We get the M.U.A.P. Train

Muscle force is regulated by:

- Number (and kind) of fibers recruited
- Frequency of fibers recruitment

The repeated recruitment of a single motor unit gives rise to a MUAP train (MUAPT), which is a temporal summation, such as:

$$u_i(t) = \sum_k h_i\left(t - \tau_{k,i}\right)$$

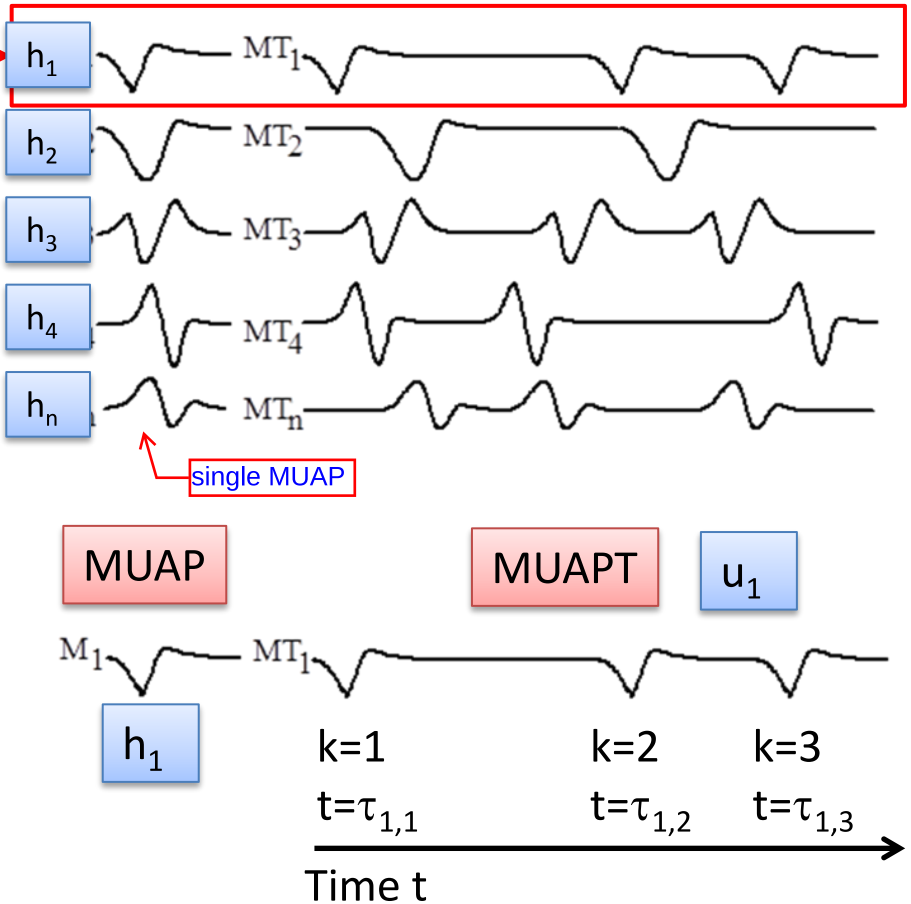
Where:

h_i is the MUAP i at time instant k

u_i is the resulting MUAPT

k is the replica index

i is the index of the MU



Motor Unit Action Potential Train (MUAPT): alternative formulation

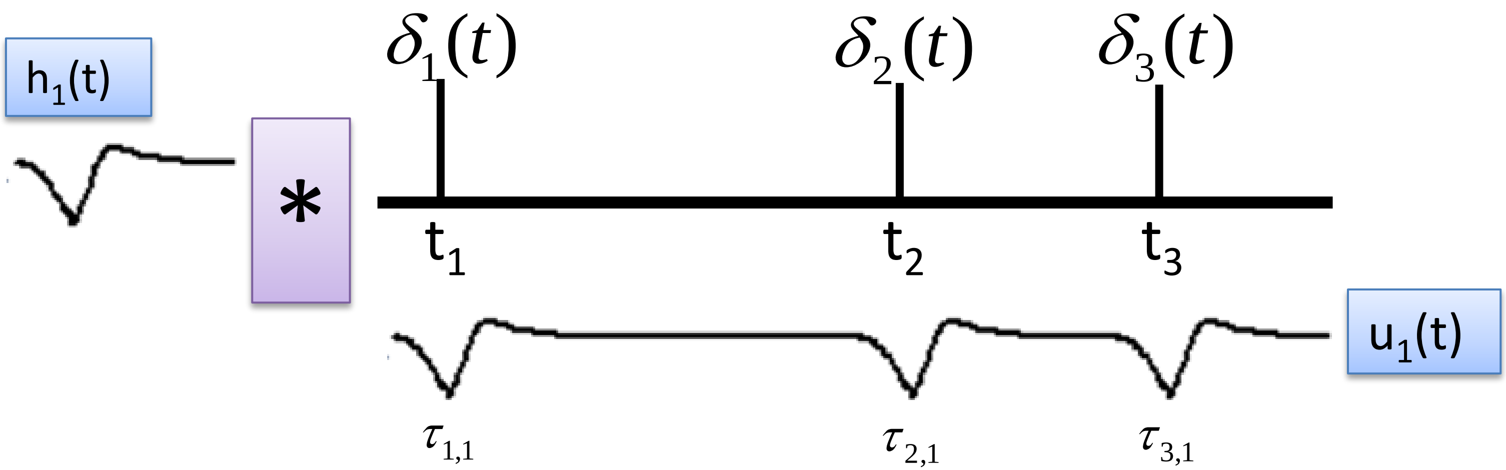
MUAP

$$u_i(t) = \sum_k h_i(t) * \delta\left(t - \tau_{k,i}\right)$$

semplicemente si ripete sui delta il pattern

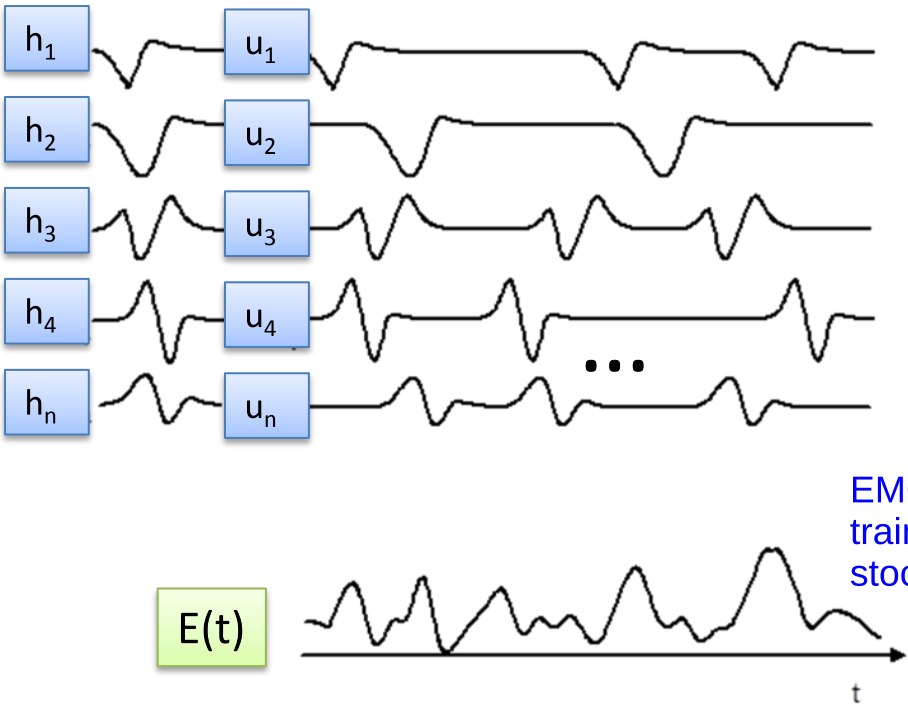
convolution with the dirac delta.

where * is the convolution with Dirac delta function $\lim_{\varepsilon \to 0} \int_{-\varepsilon}^{+\varepsilon} \delta(t)dt = 1$



Interferential electromyographic signal E(t)

$$E(t) = \sum_i u_i(t) = \sum_i \sum_k h_i(t - \tau_{k,i})$$



EMG: Sommation of all the trains! It's a noise! It's very stochastic!