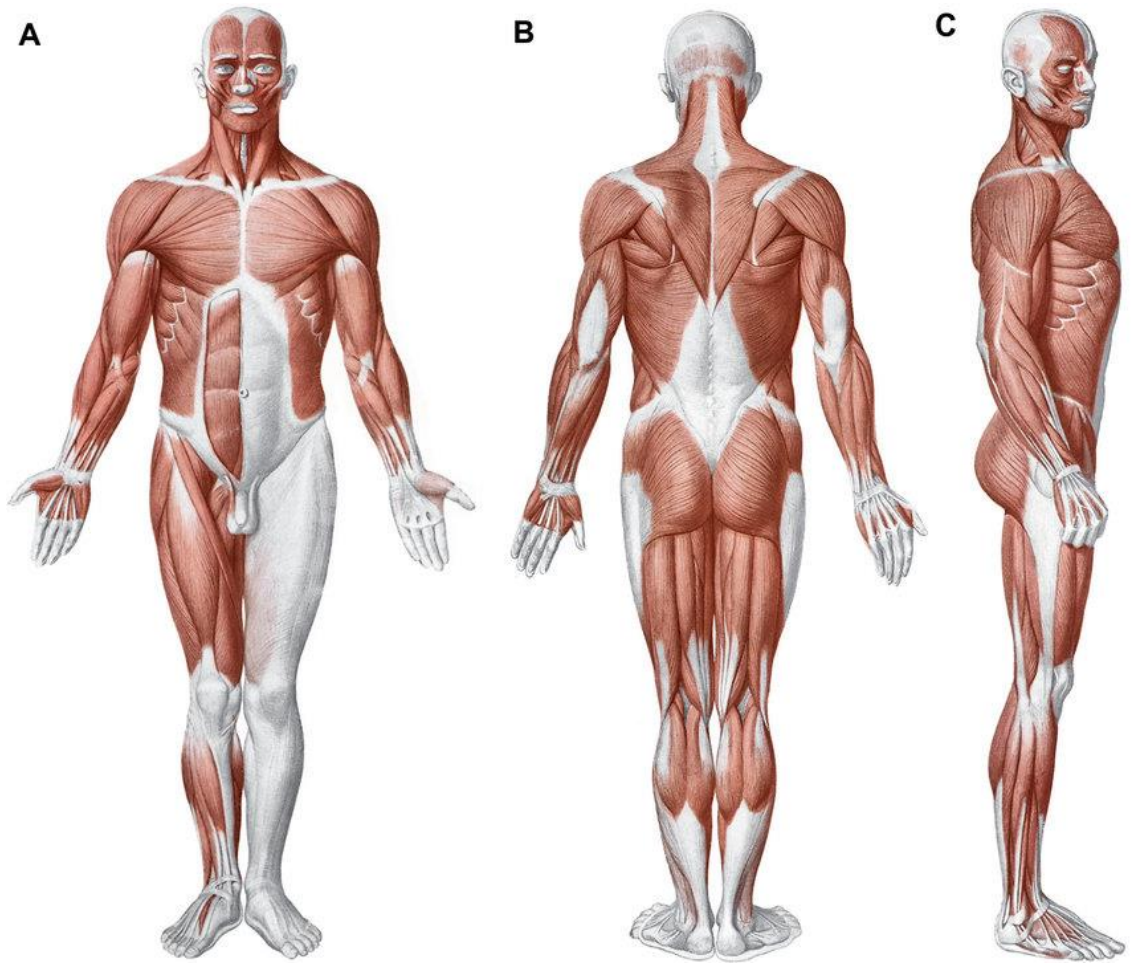
Signals of muscles and peripheral nerves

Michal Novotny

Muscles

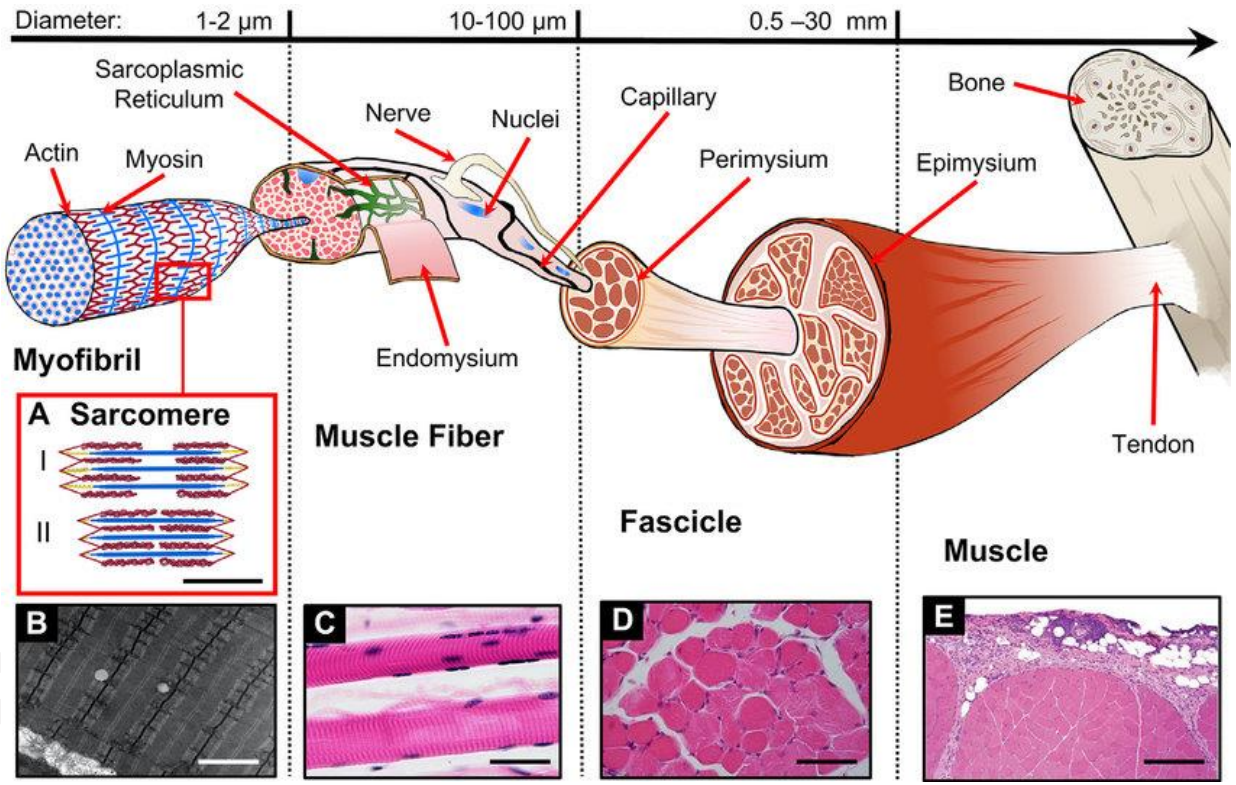
- Smooth muscles
  - Slow automatic movements of organs (oesophagus, stomach, bowels)
- Striated muscles
  - Cardiac muscles – automatic movements of heart
  - Skeletal muscles – voluntary movements



https://www.researchgate.net/publication/266253578_Clinical_and_symptomatological_reflections_The_fascial_system/figures?lo=1

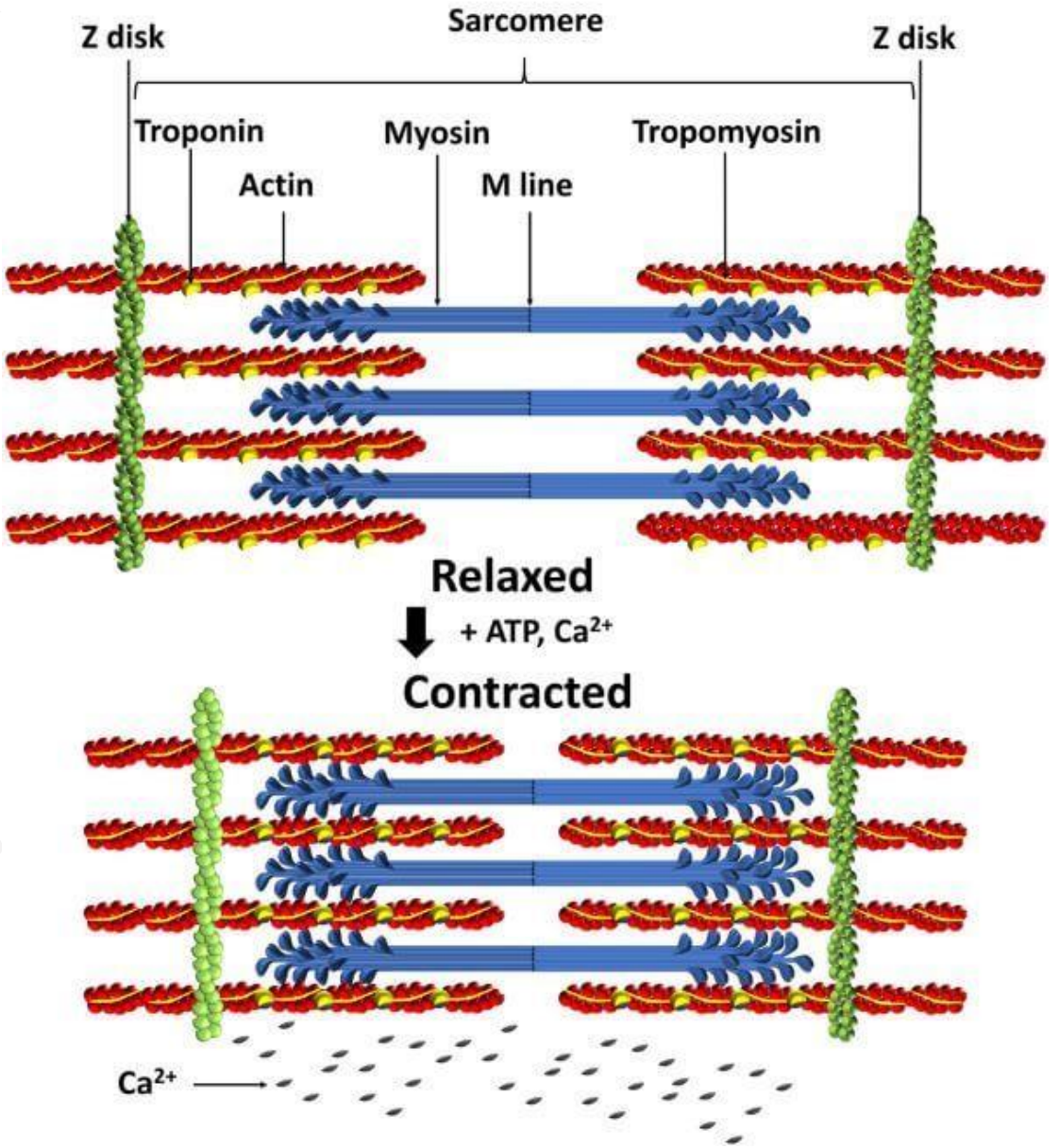
Hierarchical structures for muscles

- Muscle can only contract
- Contraction is caused by emision of acetylcholine to the membrane of muscle fiber -> action potential leads to opening of Ca+ canals and leakage of Ca+ ions to sarkoplasma



https://www.researchgate.net/publication/343590590_Hierarchical_fibrous_structures_for_muscle-inspired_soft-actuators_A_review/figures?lo=1

Sarcomere

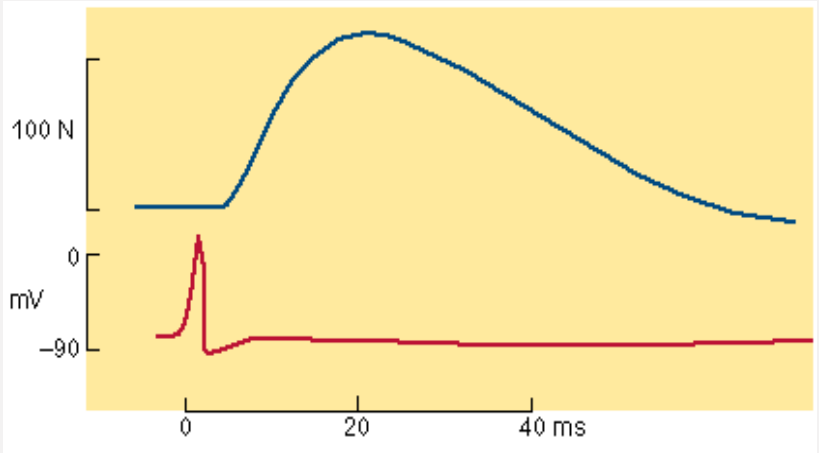


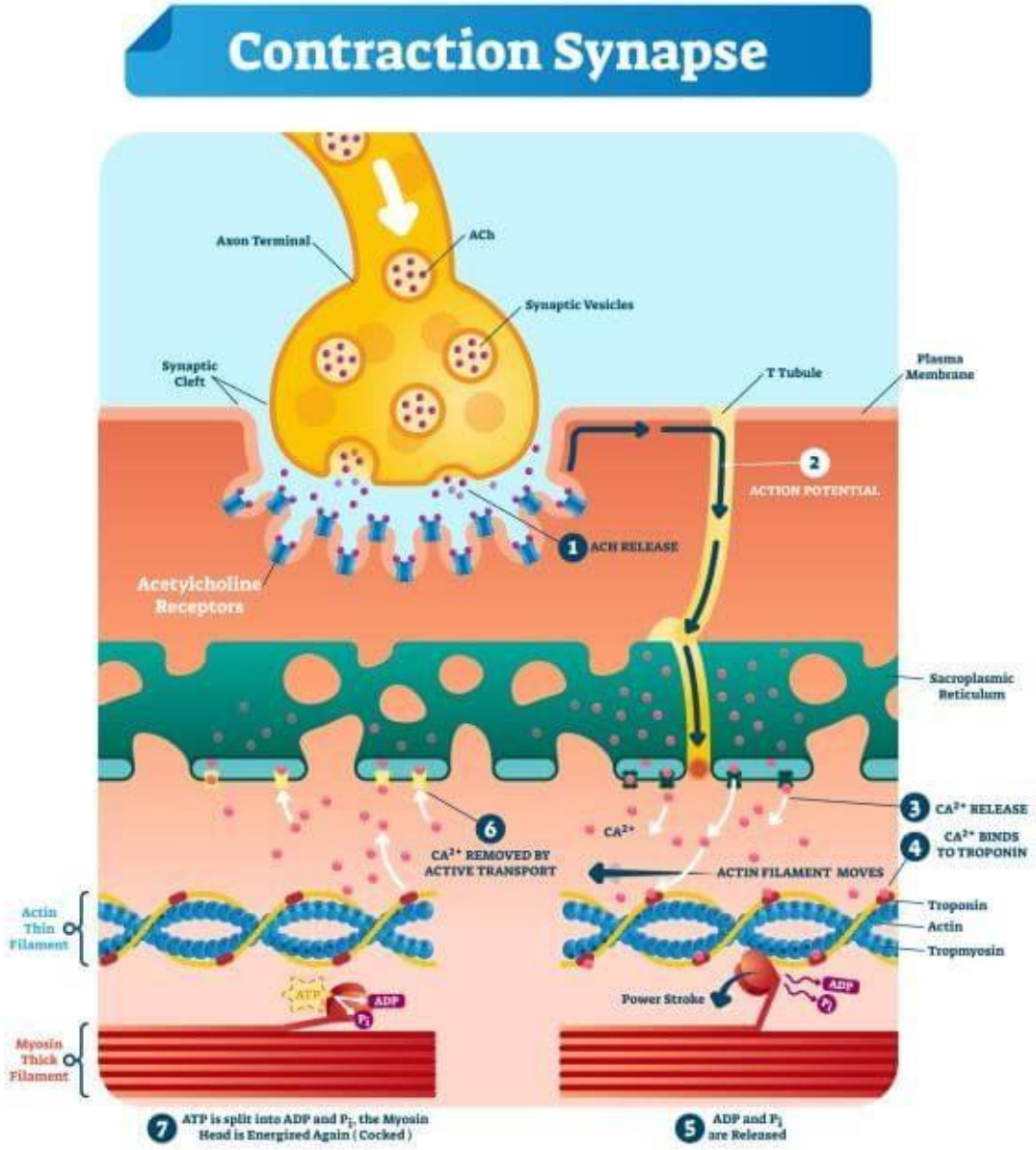
https://biologydictionary.net/actin-and-myosin/

Contraction

- ATP arival sauses bending and and the myosin head pulls actine and myosine fibers towards each other

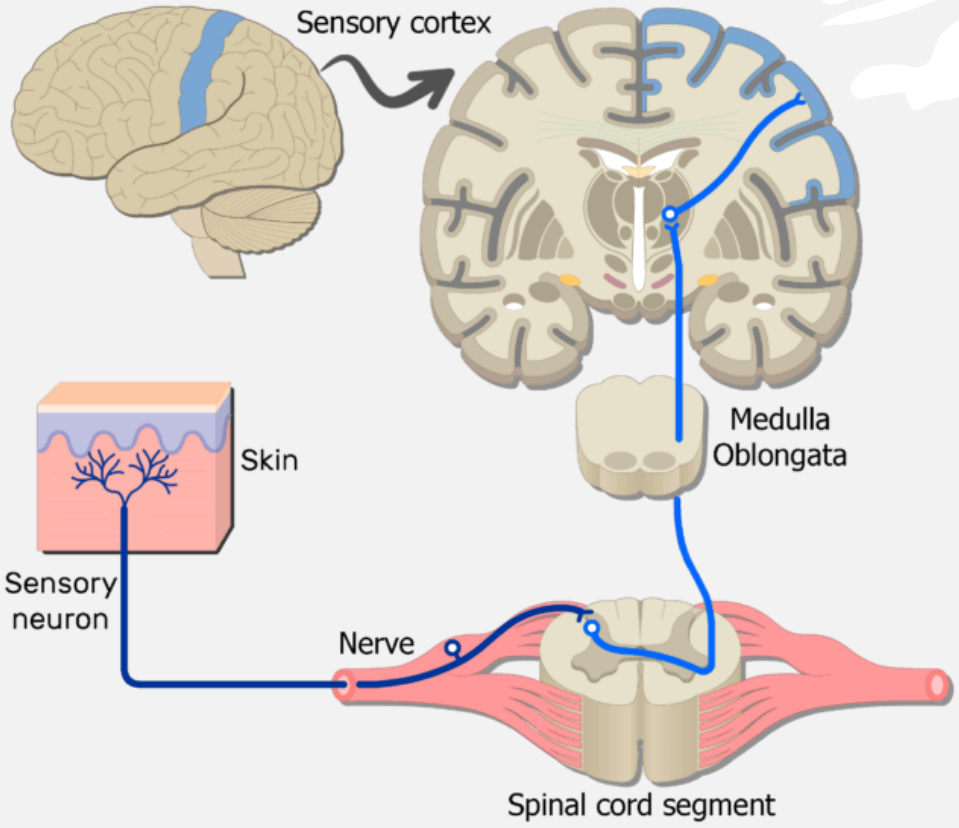
Event order during muscle contraction

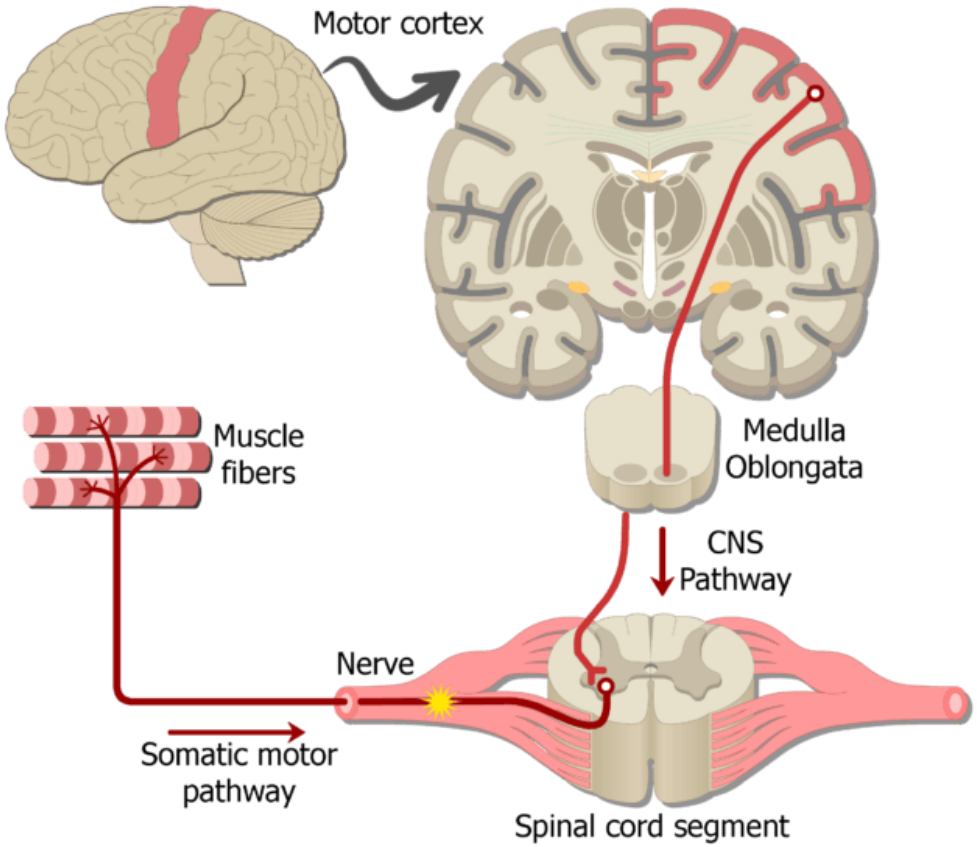




https://biologydictionary.net/actin-and-myosin/

Muscle control

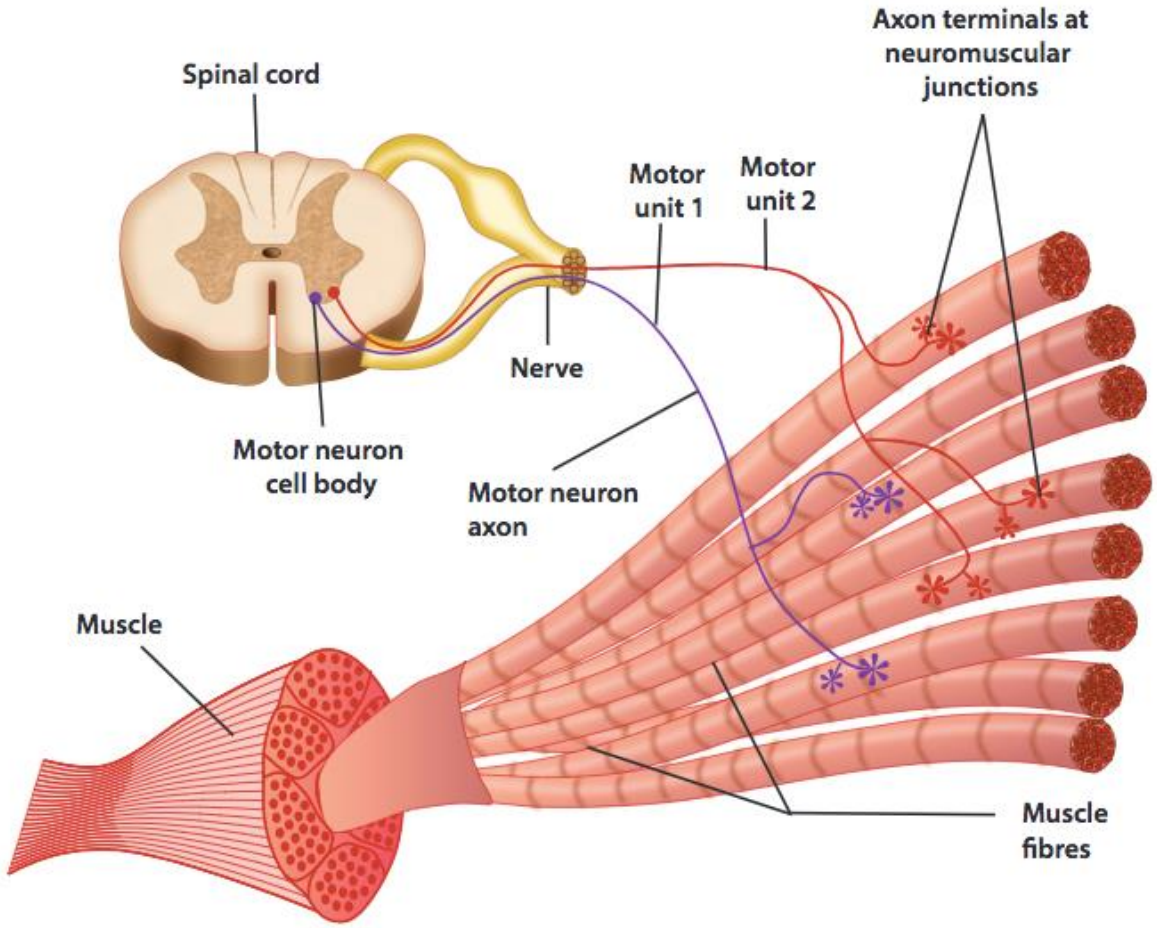




https://www.getbodysmart.com/organization/somatic-nervous-pathway

Motor unit

- Motor unit = spinal motoneuron + axon + all innervated muscle fibers
- The most basic voluntarily activated muscle unit
- Excitation vs. inhibition

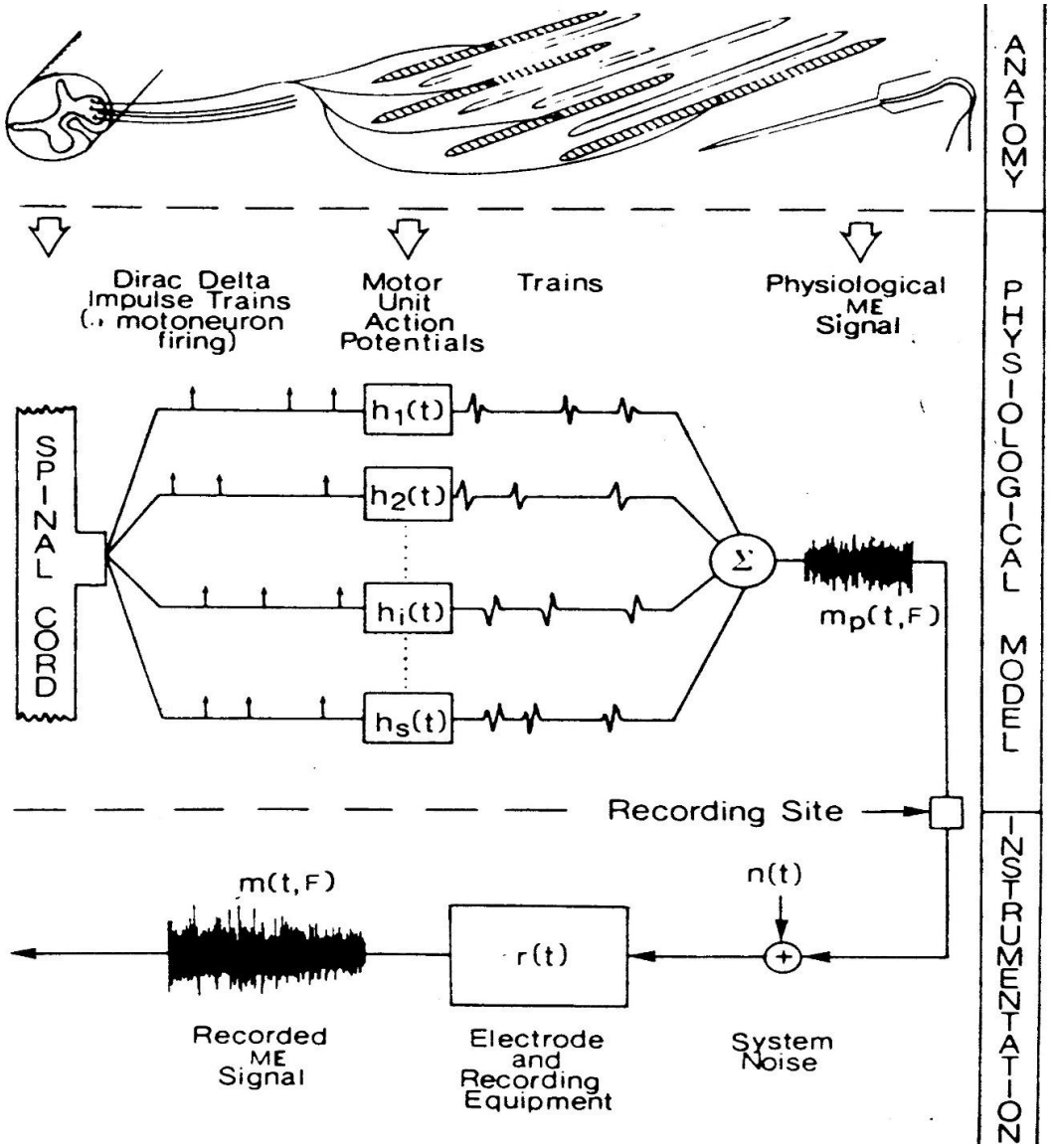


Axon of motor neurons extend from the spinal cord to the muscle. There each axon divides into a number of axon terminals that form neromuscular junctions with muscle fibers scattered throughout the muscle.

https://github.com/iandanforth/pymuscle

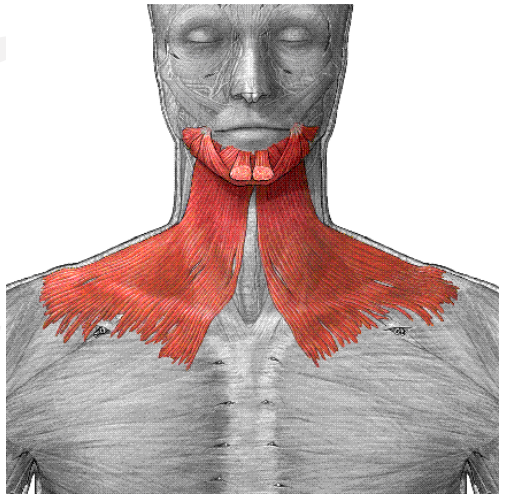
Motor unit EMG generation

- Anatomy:
  - Motor units – ventral spinal horn, moto-neuron, axon, muscle fibers
- Physiological model:
  - Summation of impulses ariving from spinal cord activates motor units generatin action potentials
  - Very low voltage (100µV) but synchronuous in many fibers
- Instrumentation:

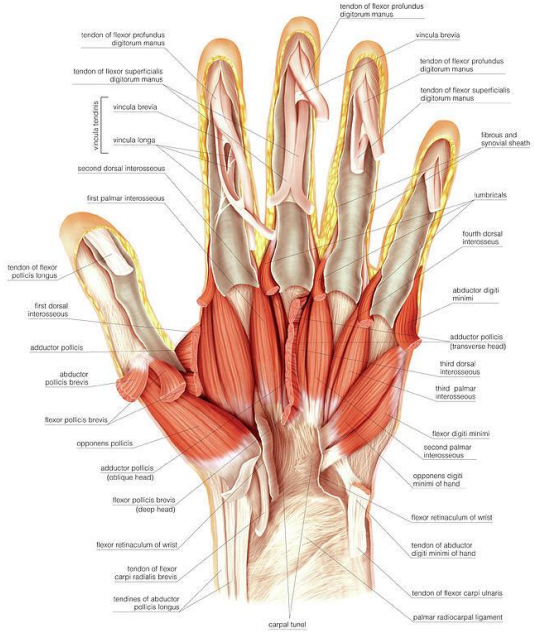


Motor unit size

Muscle	# neuronal fibers	# muscle fibers	# motor units	# muscle fibers in motor unit
Platysma	1826	27100	1096	~25
Pointing finger muscles	199	40500	119	~340
Lower limbs muscles	965	1120000	579	~1934



Platysma
https://eluc.kr-olomoucky.cz/verejne/lekce/188

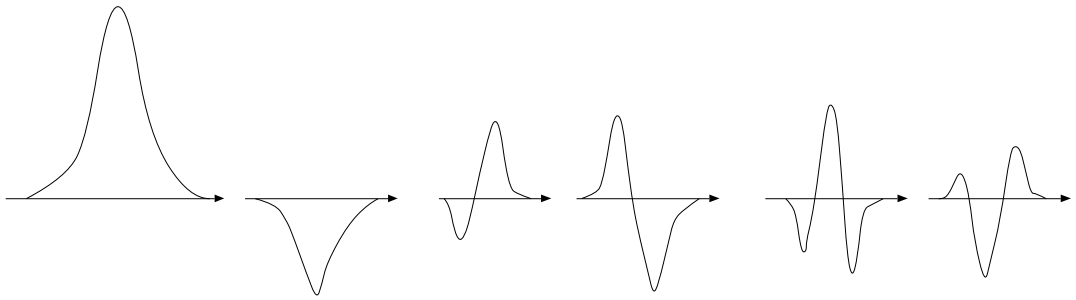


Hand muscles
https://fineartamerica.com/featured/9-muscles-of-the-hand-asklepios-medical-atlas.html

Lower limb muscles
https://anatomyzone.com/lower-limb/

Wave types and action potentials

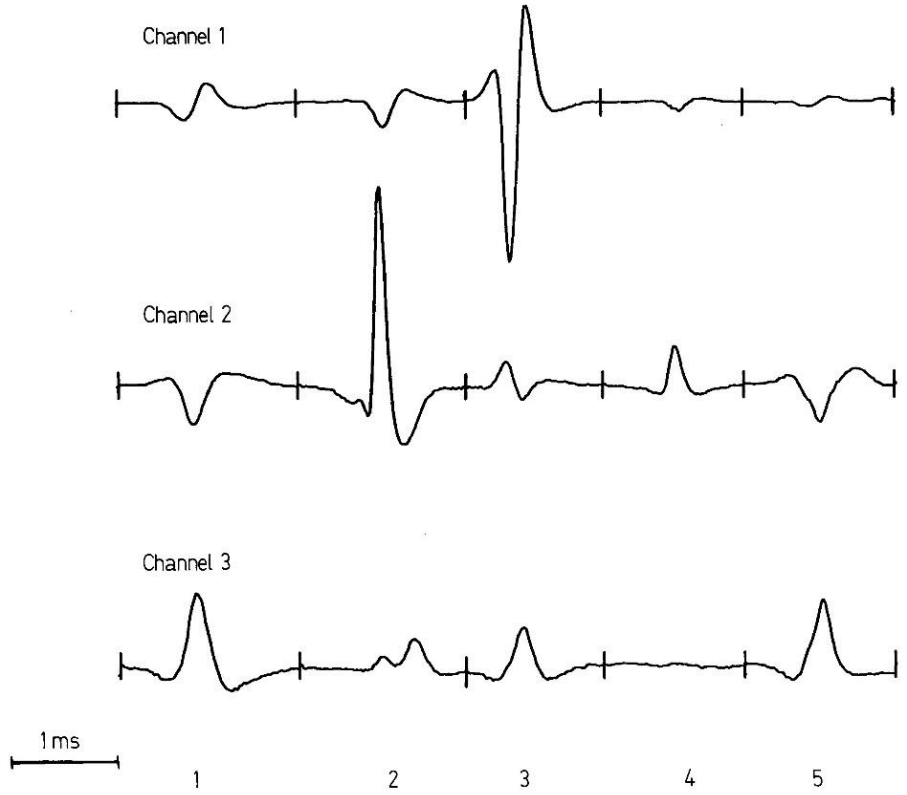
- Needle electrodes
- Usually bi or triphasic
- 3-15 ms in length, 100 - 300µV and 6 – 30 Hz
- Shape is given by used electrode



Monophasic waves

Biphasic waves

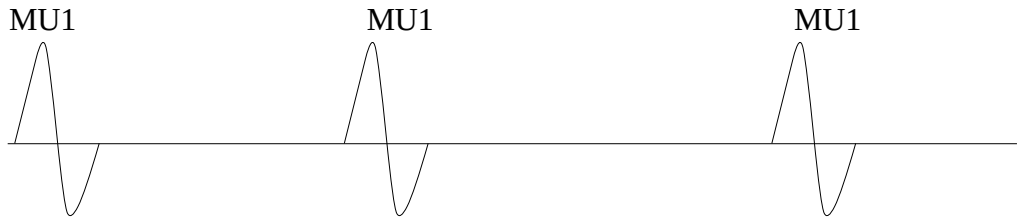
Triphasic waves



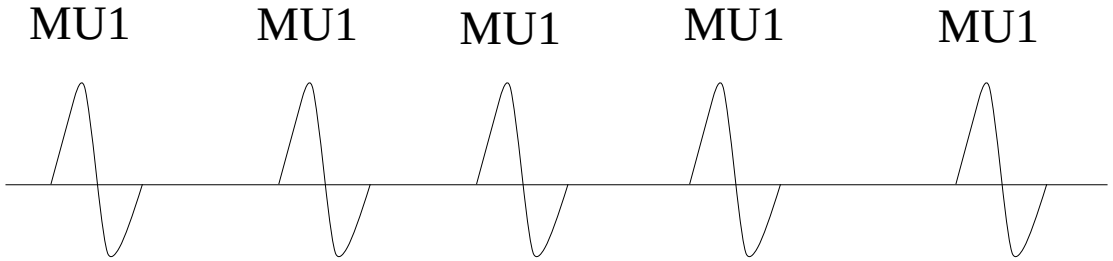
Motor units activation

- Spatial activation
- Temporal activation
- Quantitative characteristics due to the signal complexity

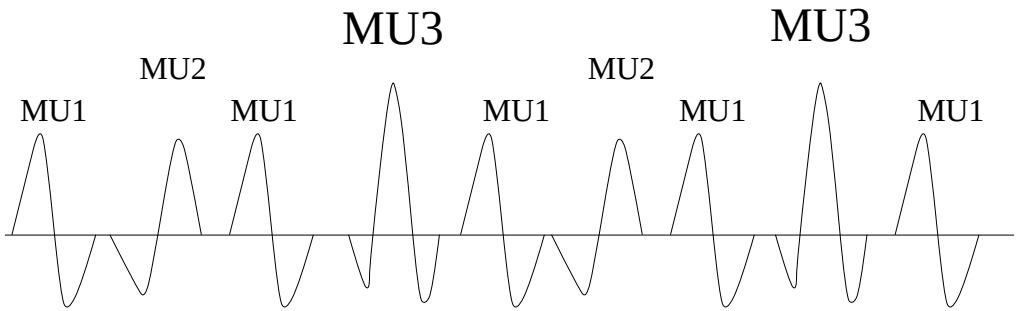
Easy work



Medium work

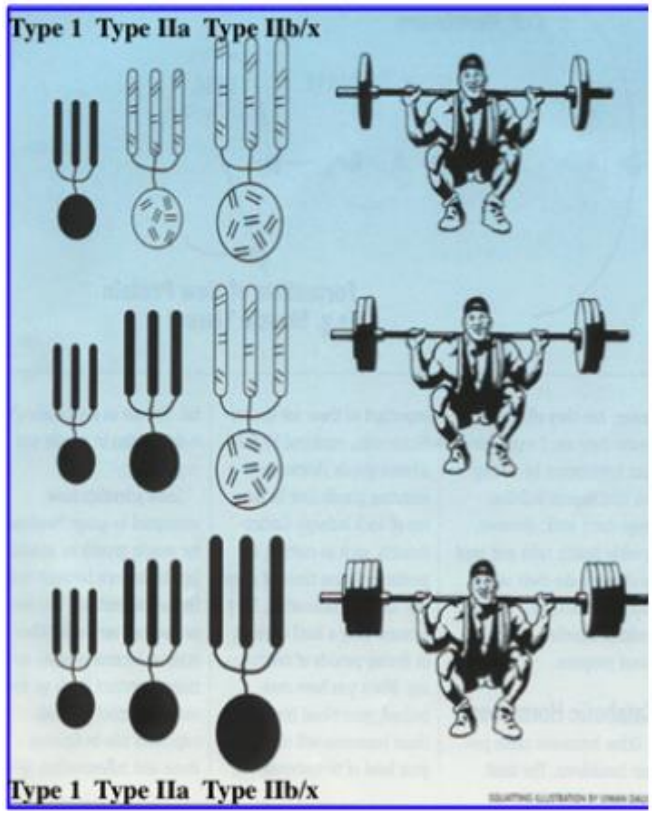


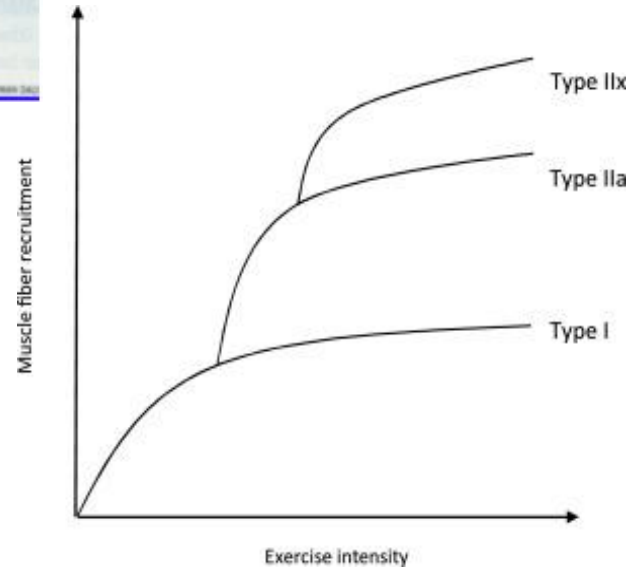
Hard work



Motor units activation

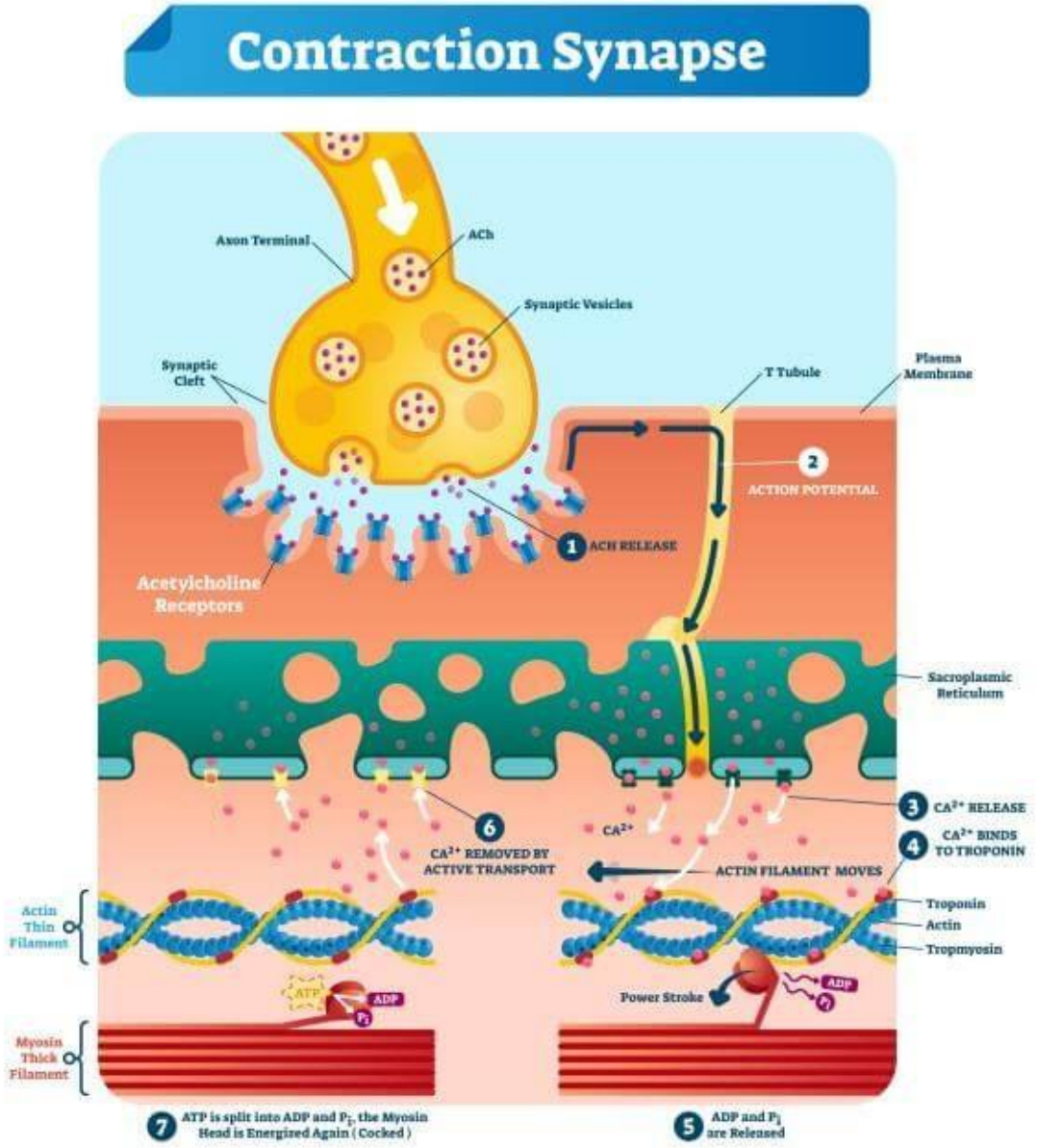
- Hanemann's rule – motor units are activated sequentially
- Muscle force is dependent on number of activated motor units
- Muscle fibers
  - Type I (slow 110ms, 50%, endurance, activated first)
  - Type II (fast 50ms, force)
    - Type IIa 25%
    - Type IIx 25% (strongest, activated last)



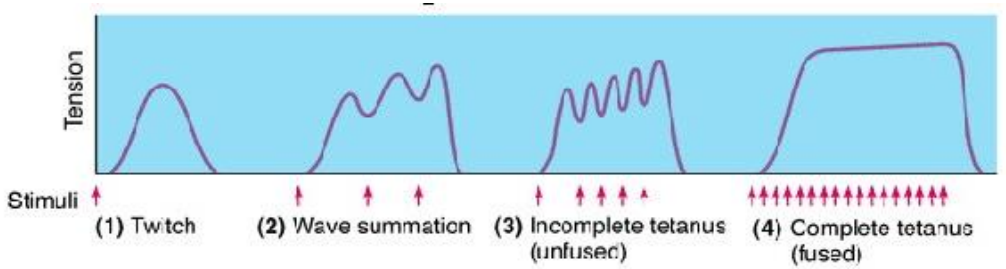


Muscle stimulation

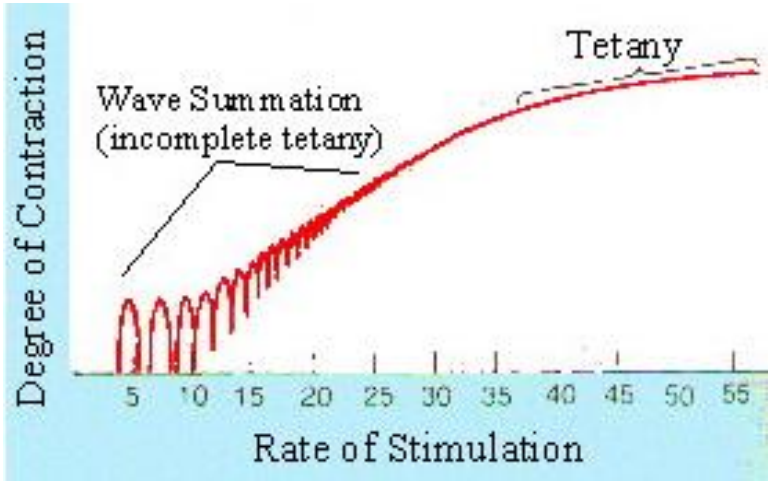
- Indirect
  - Local potential at neuromuscular junction
- Direct
  - Electric signal causes artificial depolarization

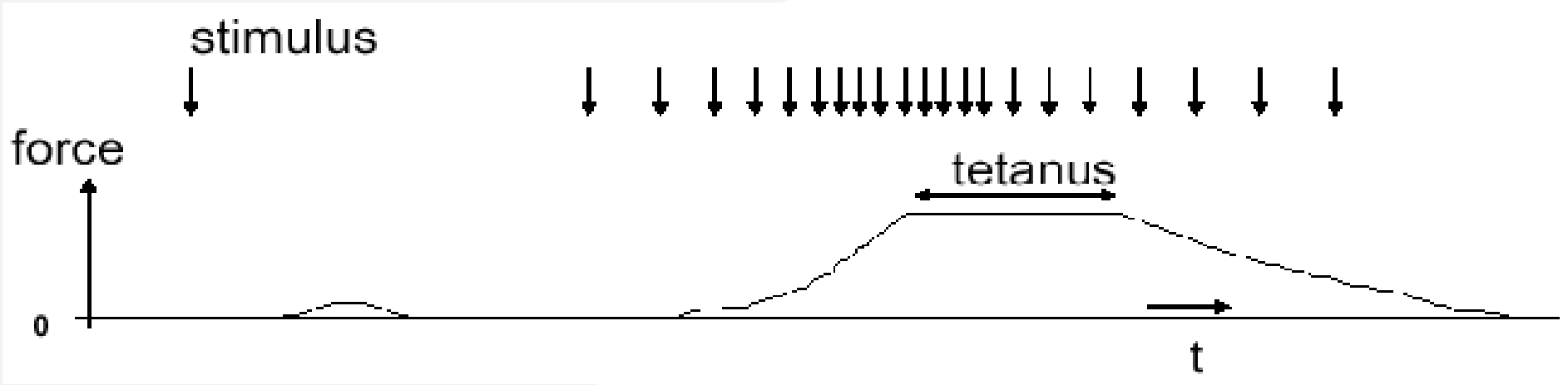


EMG and contraction power

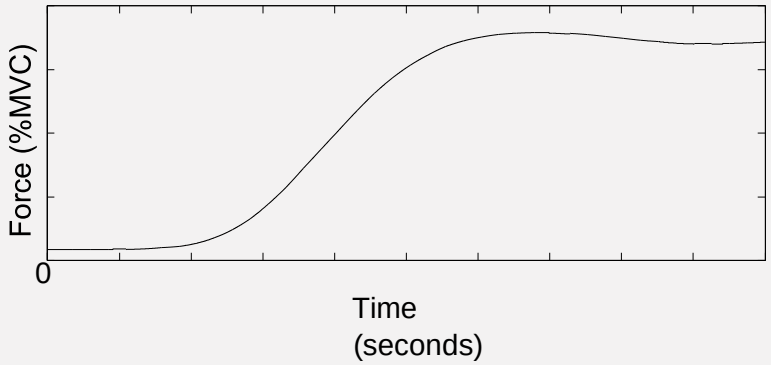


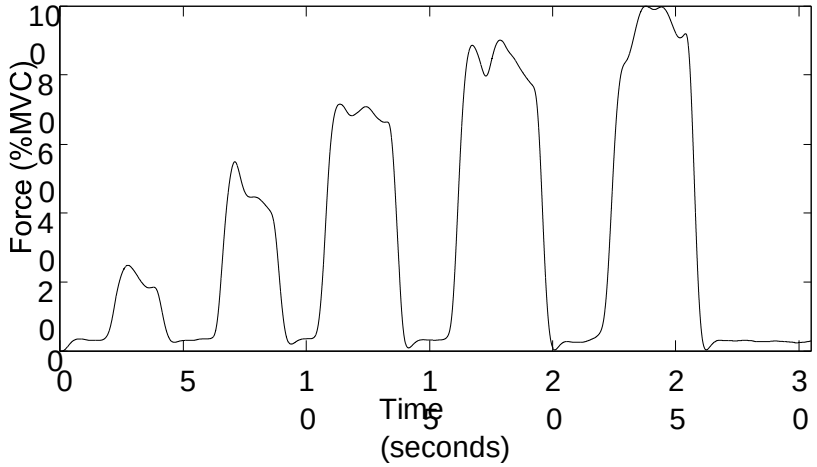
- Muscle force is given by motor unit recruitment and frequency of incoming impulses
- Frequency modulation
- Similar force can be produced by recruitment of smaller MU stimulated by higherrequency or larger MU with lower frequency

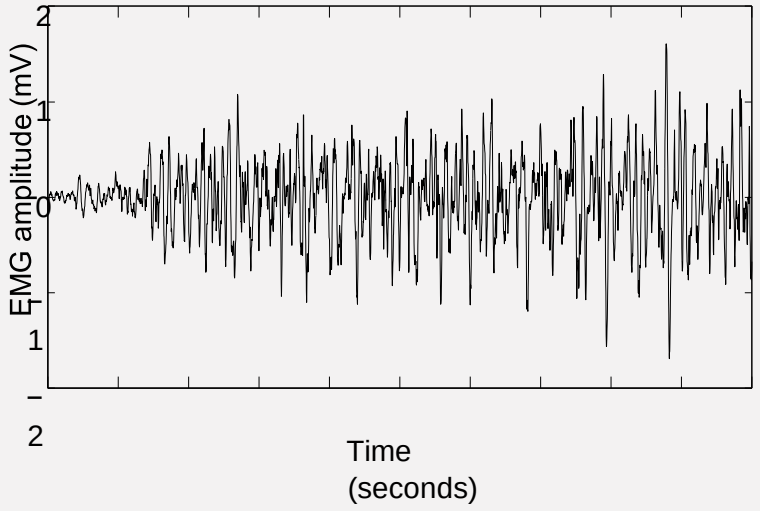


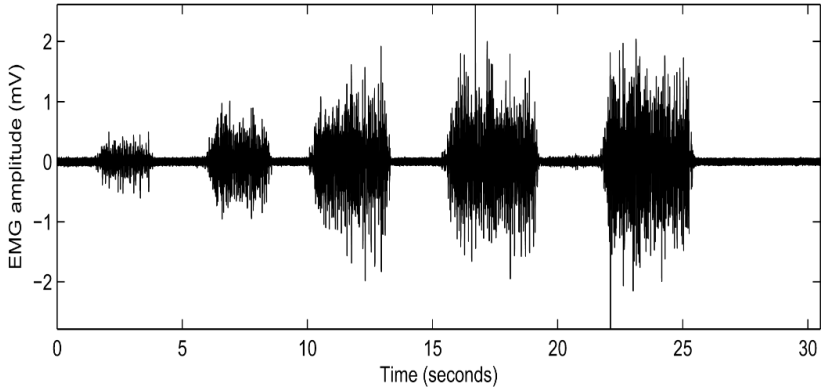


EMG and contraction power





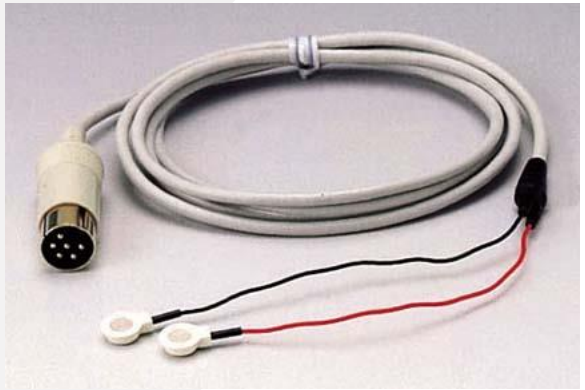




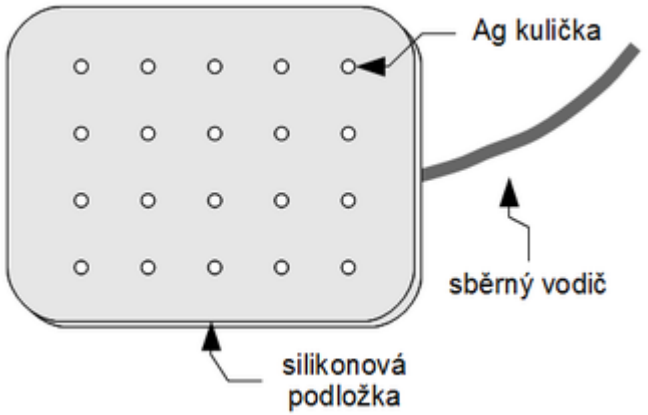
EMG recording

- Surface electrodes
  - Less invasive
  - Easy application
  - 20-500Hz
  - Generalized signal

Bagnolli - surface



Nihon-Kohden
Surface, Disc

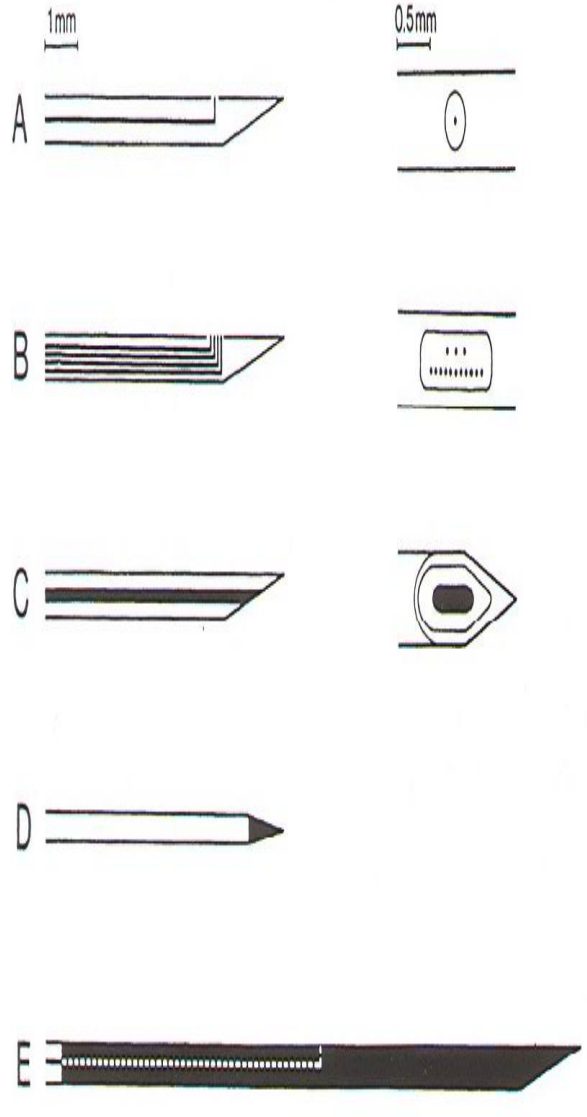


EMG recording

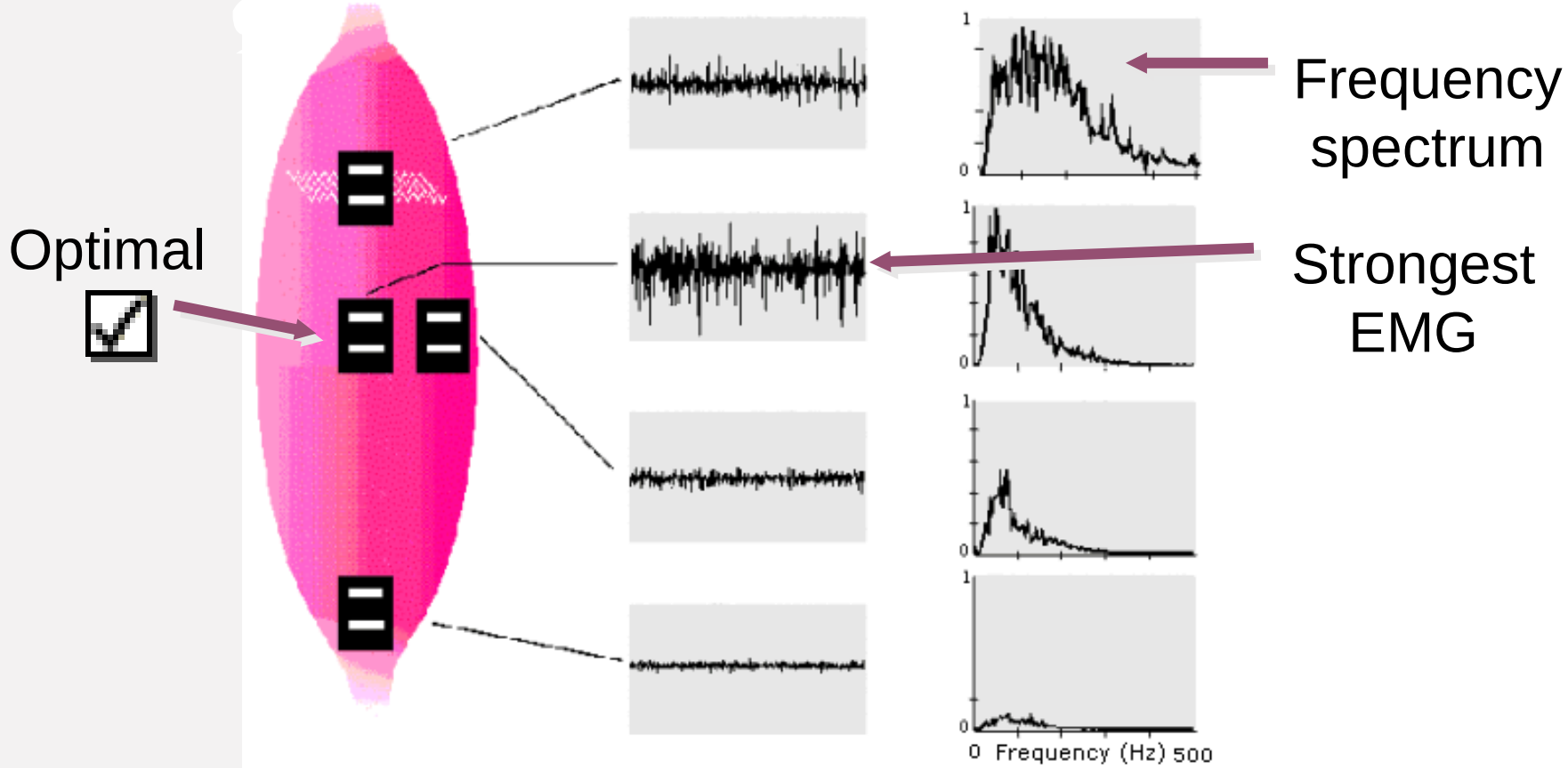
- Needle electrodes
  - Invasive
  - Up to 5000 Hz
  - Localized
  - Expensive and complicated application

Nihon-Kohden concentric

Nihon-Kohden needle



Surface electrode placement

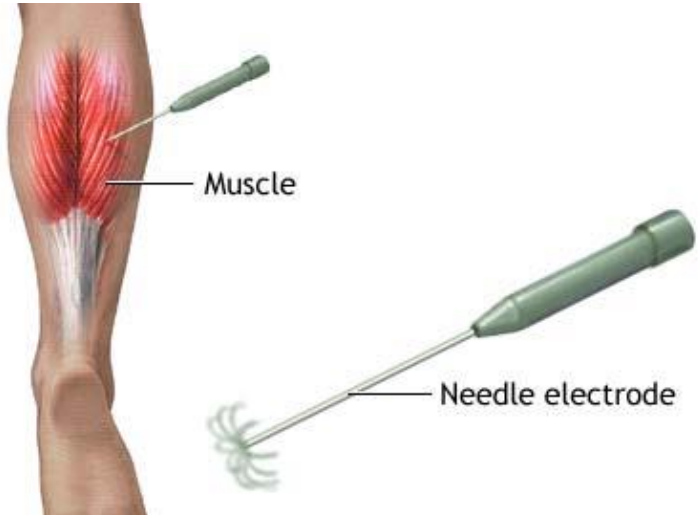


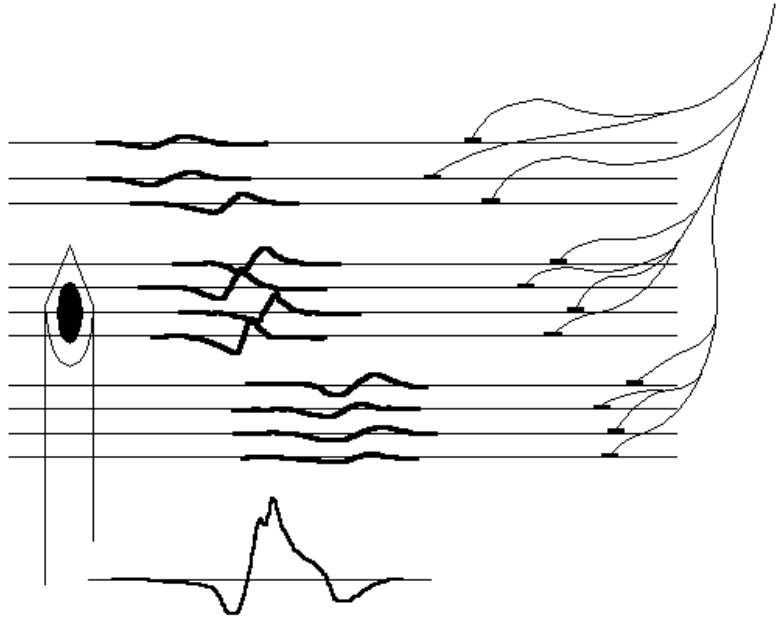
Electromyography

- Applications
  - Diagnostic
    - Needle EMG
    - Conduction study
  - Kinesiology
    - Fatigue analysis
  - Prosthetics
  - Others

Native EMG

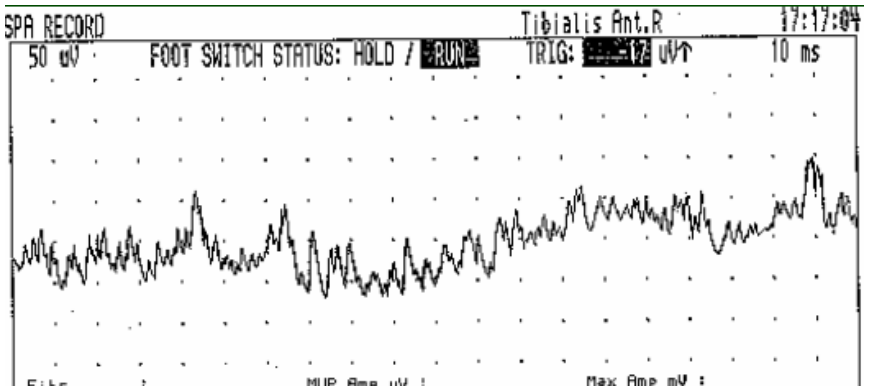
- Acquisition during muscle relaxation
- Needle
- Comarison of features of motor units (duration, amplitude number)



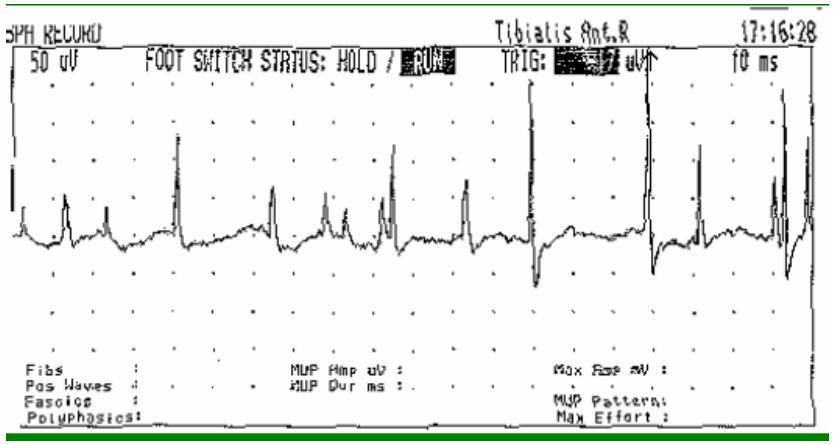


Physiological EMG activity

- No activity during relaxation
- Insertion aktivity
  - Caused by the mechanical stimulation by needle insertion
- Neuromuscular junction aktivity
  - Neuromuscular noise
  - Neuromuscular peaks



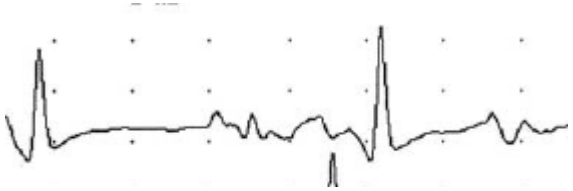
Neuromuscular noise

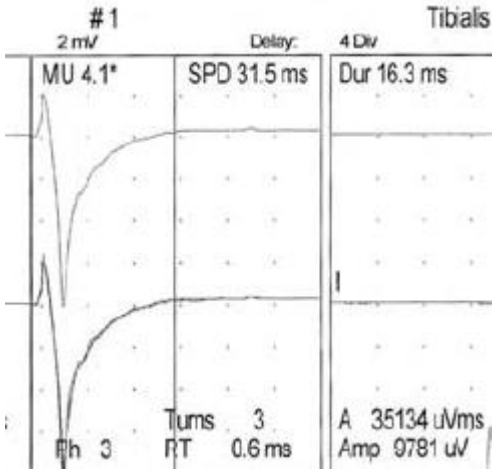


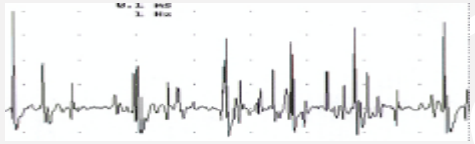
Neuromuscular peaks

Physiological EMG activity

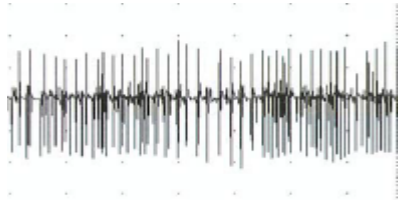
- Voluntary aktivity
  - MU recruitment
  - Interferention
  - Willis analysis





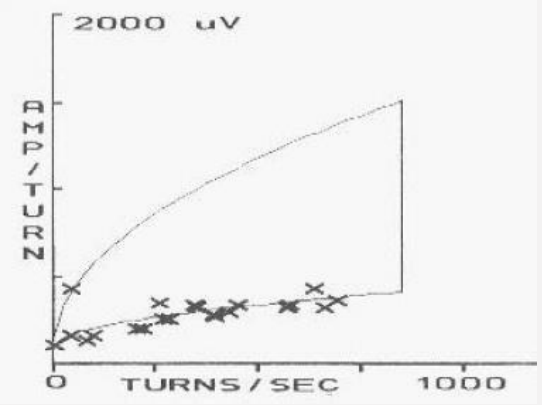


Minimal contraction



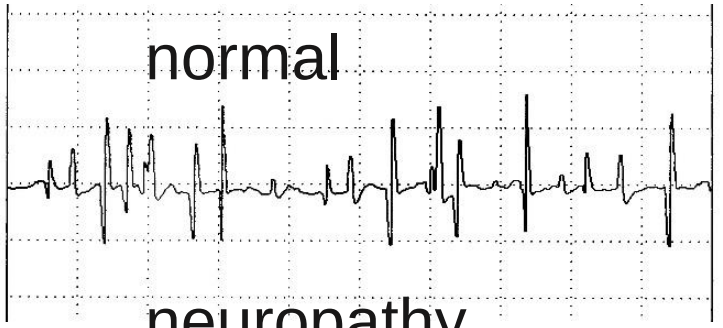
Medium contraction 30%-40%

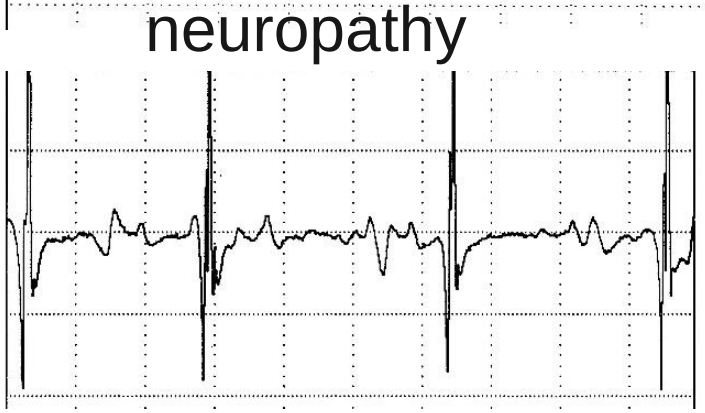
Maximal contraction

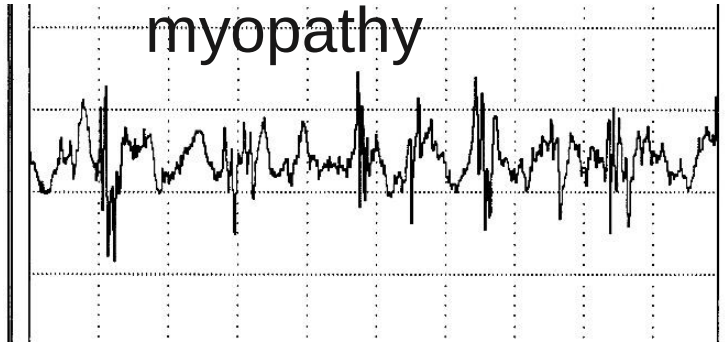


Pathological EMG activity

- Neuropathy
  - Slow lead, not synchronized activation causing polyphasic action potential with greater amplitude
  - Similar Mus shows relatively high frequency of firing in low, median and high effort levels
- Myopathy
  - Loss of muslce fibers,
  - Muscula dystrophy leading to dispersed action potentials with low amplitude
  - During low effort level more Mus is involved

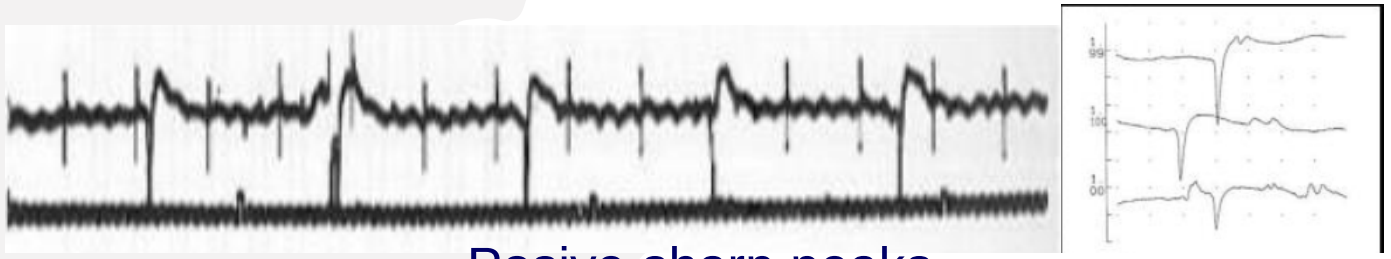




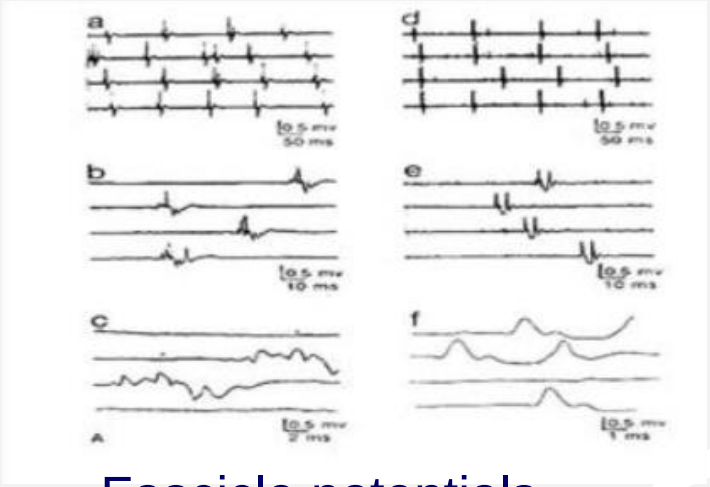


Abnormal EMG activity

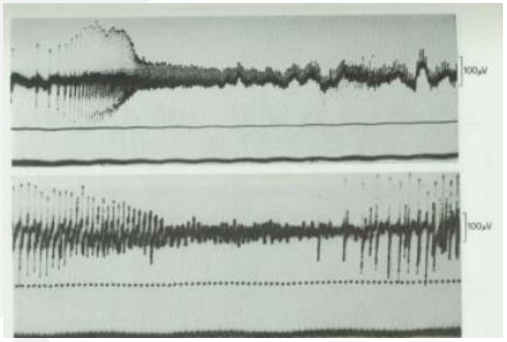
Denerved muscle fibrilation



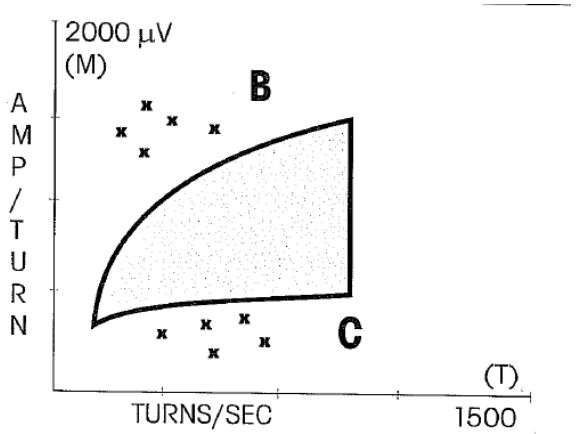
Posive sharp peaks



Fascicle potentials



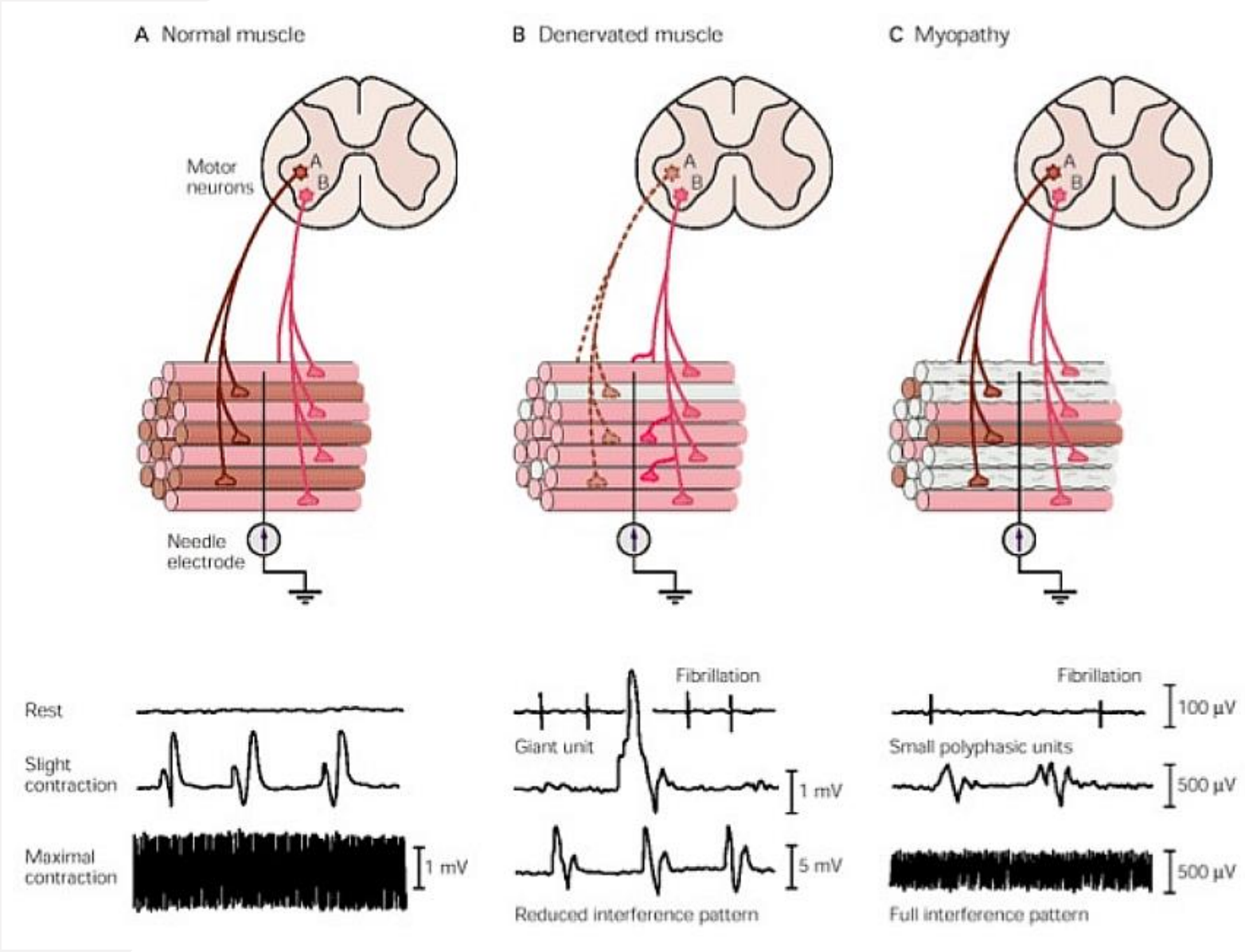
Myotonic impulses



Needle EMG Audiomyogram

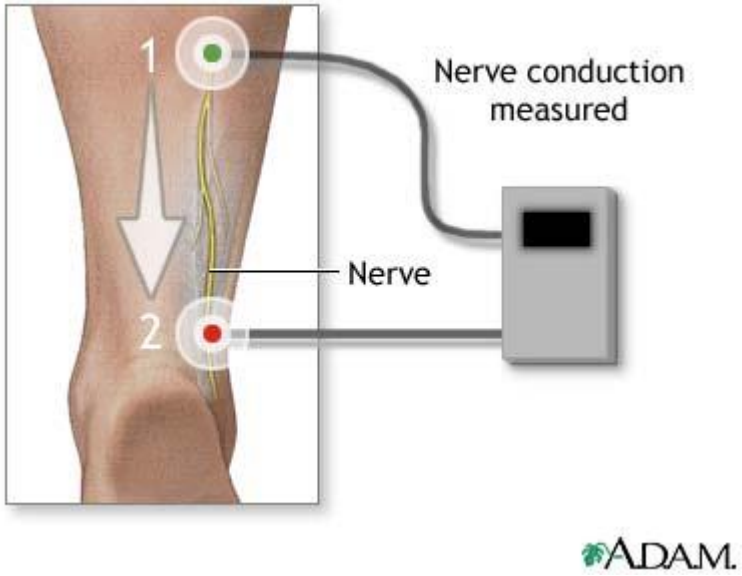
Potential	Source	Sound character	Frequency	Regularity
Junction noise	MEPP	Shell	20-40Hz	Irregular
Junction potential	Terminal axon branching	Crackling	5-50Hz	Irregular
Fibrilation	Denerved muscle fiber	Rain/ ticking	0.5-10Hz	Regular
Positve sharp peak	Denerved muscle fiber	Rain/ticking	0.5-10Hz	Regular
Myotonic firing	Transversal tubulae	Motorbike start	20-150Hz	In/decreasing
Fasciculation	Motoneuron or axon	Popcorn	0.1-10Hz	Irregular
Complex repetitive firing	Denerved fibers	Engine	5-100Hz	Regular
Myokymia	Motoneron or axon	Steps	5-60Hz	Groups
Neuromyothonia	Motoneuron or axon	Release	150-250Hz	Decreasing

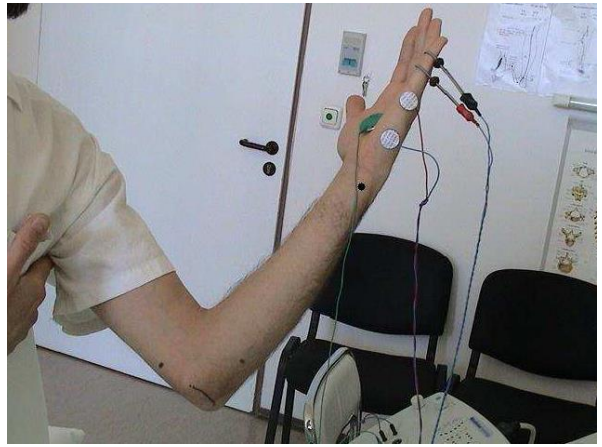
Needle EMG


A Normal muscle
B Denervated muscle
C Myopathy
Motor neurons
A
B
Needle electrode
Rest
Slight contraction
Maximal contraction
1 mV
Fibrillation
Giant unit
1 mV
5 mV
Reduced interference pattern
Fibrillation
100 µV
Small polyphasic units
500 µV
500 µV
Full interference pattern

Stimulation EMG (Conduction study)

- Stimulation and acquisiton
- Electric stimulation resulting in muscle twitch
- uncomfortable
- Examination aims:
  - Comarison of propagation speed
  - Comparison of the potential size
    - Abnormal values:
      - Nerv damage by injury, chronical pressure, infalmation, metabolic disorder aot intoxication
      - Detection of leision
        - Demyelinization
        - Axonal

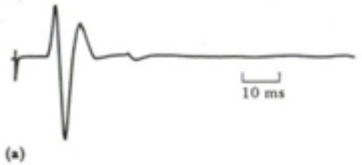




Conduction study

Muscle response on stimulus

Normal

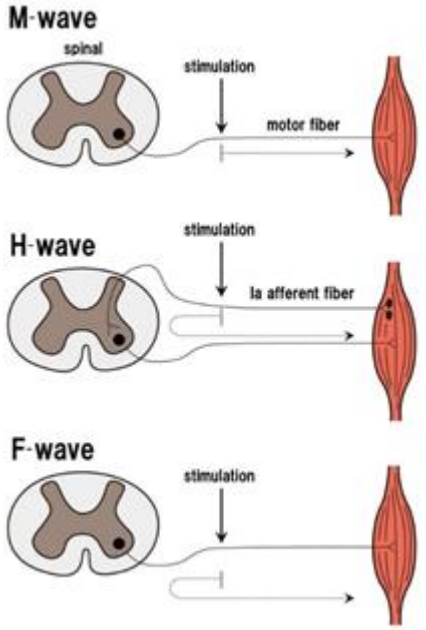


Pathological

Direct response: M-wave

Pozdní odpovědi: F-wave

H-reflex



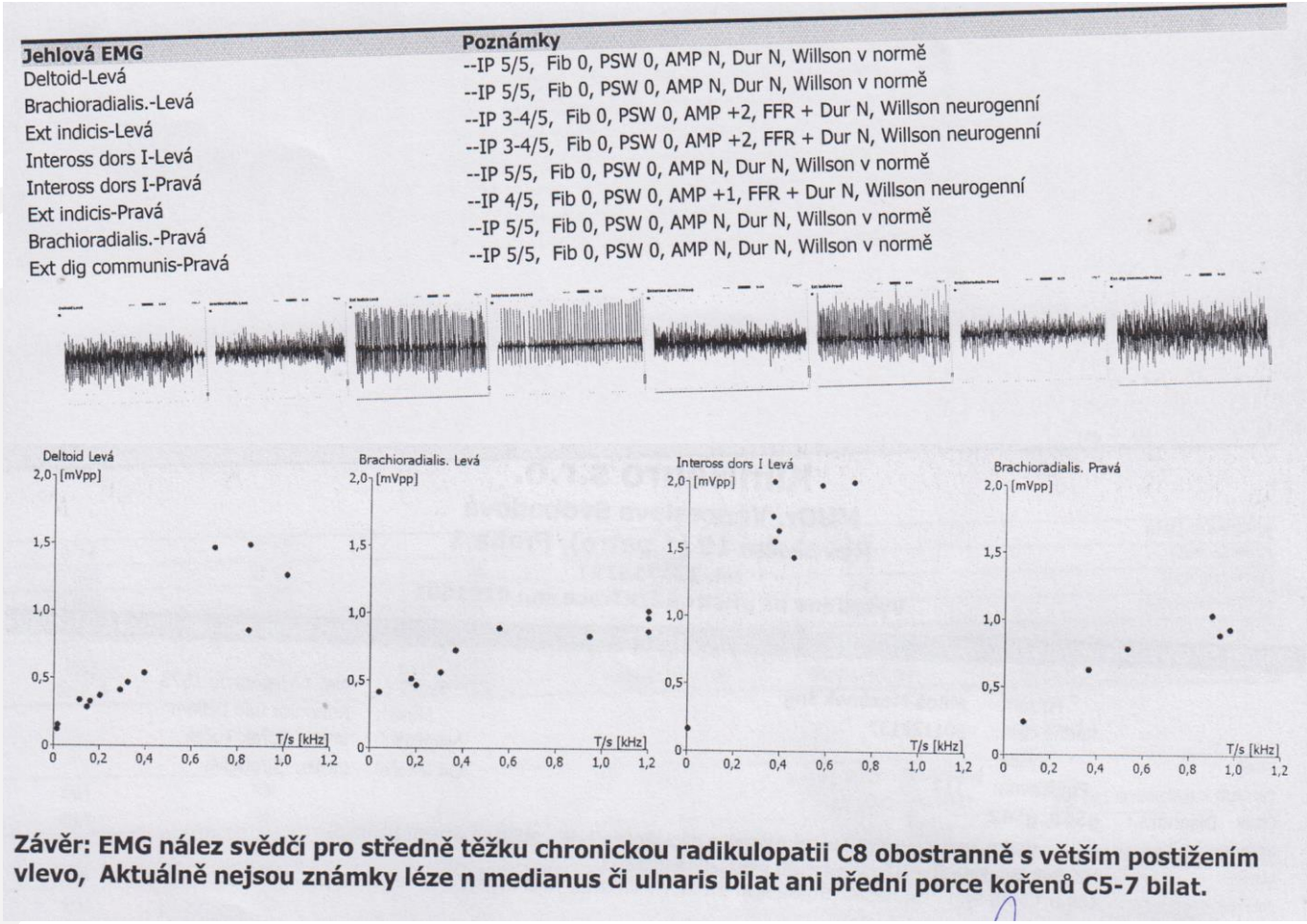
EMG examination

MNC	Pozice	Latence [ms]	Amplituda [mV]	CV [m/s]	Amp % [%]	Vzdálenost [mm]
Medianus-Pravá	Wrist - APB	3,9	12,0	--	--	--
Ulnaris-Pravá	Wrist - ADQ	2,5	8,0	--	--	--
Ulnaris-Levá	Wrist - ADQ	3,4	4,5	--	--	--
Medianus-Levá	Wrist - APB	4,5	6,4	--	--	--

SNC	Pozice	Latence peak [ms]	Amplituda [mV]	CV [m/s]	Vzdálenost [mm]
Median-Palm-II, Wrist-Pravá	Palm - Digit II	1,6	29,4	67	75
	Wrist - Palm	3,8	18,6	53	100
Ulnaris x Medianus Dig IV-Pravá	Ulnaris - Digit IV	3,7	9,0	67	160
	Medianus - Digit IV	3,8	10,5	52	150
Median-Palm-II, Wrist-Levá	Palm - Digit II	1,9	24,9	60	80
	Wrist - Palm	3,9	19,1	39	80
Ulnaris x Medianus Dig IV-Levá	Ulnaris - Digit IV	3,4	17,9	56	140
	Medianus - Digit IV	4,0	7,9	43	140

F-Vlna	M-Latence [ms]	M-Amplituda [mV]	Fmin [ms]	F-M [ms]	F / M [%]
Medianus-Pravá	4,0	12,0	29,0	25,1	80,0
Ulnaris-Pravá	2,4	7,8	28,4	25,9	100,0
Ulnaris-Levá	3,4	4,7	29,1	25,8	100,0
Medianus-Levá	4,5	8,2	29,4	24,9	71,0

EMG examination



Jehlová EMG	Poznámky
Deltoid-Levá	--IP 5/5, Fib 0, PSW 0, AMP N, Dur N, Willson v normě
Brachioradialis.-Levá	--IP 5/5, Fib 0, PSW 0, AMP N, Dur N, Willson v normě
Ext indicis-Levá	--IP 3-4/5, Fib 0, PSW 0, AMP +2, FFR + Dur N, Willson neurogenní
Inteross dors I-Levá	--IP 3-4/5, Fib 0, PSW 0, AMP +2, FFR + Dur N, Willson neurogenní
Inteross dors I-Pravá	--IP 5/5, Fib 0, PSW 0, AMP N, Dur N, Willson v normě
Ext indicis-Pravá	--IP 4/5, Fib 0, PSW 0, AMP +1, FFR + Dur N, Willson neurogenní
Brachioradialis.-Pravá	--IP 5/5, Fib 0, PSW 0, AMP N, Dur N, Willson v normě
Ext dig communis-Pravá	--IP 5/5, Fib 0, PSW 0, AMP N, Dur N, Willson v normě

Závěr: EMG nález svědčí pro středně těžku chronickou radikulopatii C8 obostranně s větším postižením vlevo, Aktuálně nejsou známky léze n medianus či ulnaris bilat ani přední porce kořenů C5-7 bilat.

EMG examination

KT Motor

Nerve / Sites	Lat ms	Amp mV	Dist cm
R MEDIANUS - APB KT			
1. Zápěstí	8,80	0,4	8
L MEDIANUS - APB KT			
1. Zápěstí	4,75	3,5	8

F Wave

Nerve	Mean FLat ms	Min F Lat ms	Max F Lat ms	% F %	Mean FAmp mV
L TIBIAL (KNEE) - AH	52,09	51,50	52,40	100	0,2
L COMM PERONEAL - EDB	50,48	49,55	51,35	75	0,2

Tabulka EMG										
	Spontaneous					MUAP			Recruitment	Reduction
	IA	Fib	PSW	Fasc	H.F.	Amp	Dur.	PPP	Pattern	Klasifikace
L. TIB ANTERIOR	N	None	None	None		N	N	N	N	5

Závěr:
EMG vyšetření neprokázalo polyneuropatii HK či DK, ani významnější radikulopatii L5, svědčí pro středně těžkou kompresivní lézi n. medianus v oblasti zápěstí vlevo, vpravo je téměř úplná axonopatie tohoto nervu (dle anamnézy již 15 let).

MUDr. [redacted]

Pacient: [redacted]
r.č.: [redacted]
Adresa: [redacted]
Výška: 1,6 m

Age: 75 Years 9 Months
z.p.: 111
Dg.: G 61.9

Sensory NCS

Nerve / Sites	Rec. Site	Latency ms	Peak Ampl µV	Distance cm	Velocity m/s
L SURAL - Lat Malleolus					
1. Lýtko	Zevní kotník	2,00	13,5	10	50,0
R SURAL - Lat Malleolus					
1. Lýtko	Zevní kotník	2,05	23,3	10	48,8
L SUP PERONEAL - Foot					
1. Nad kotníkem	Nárt	3,10	1,5	12	38,7

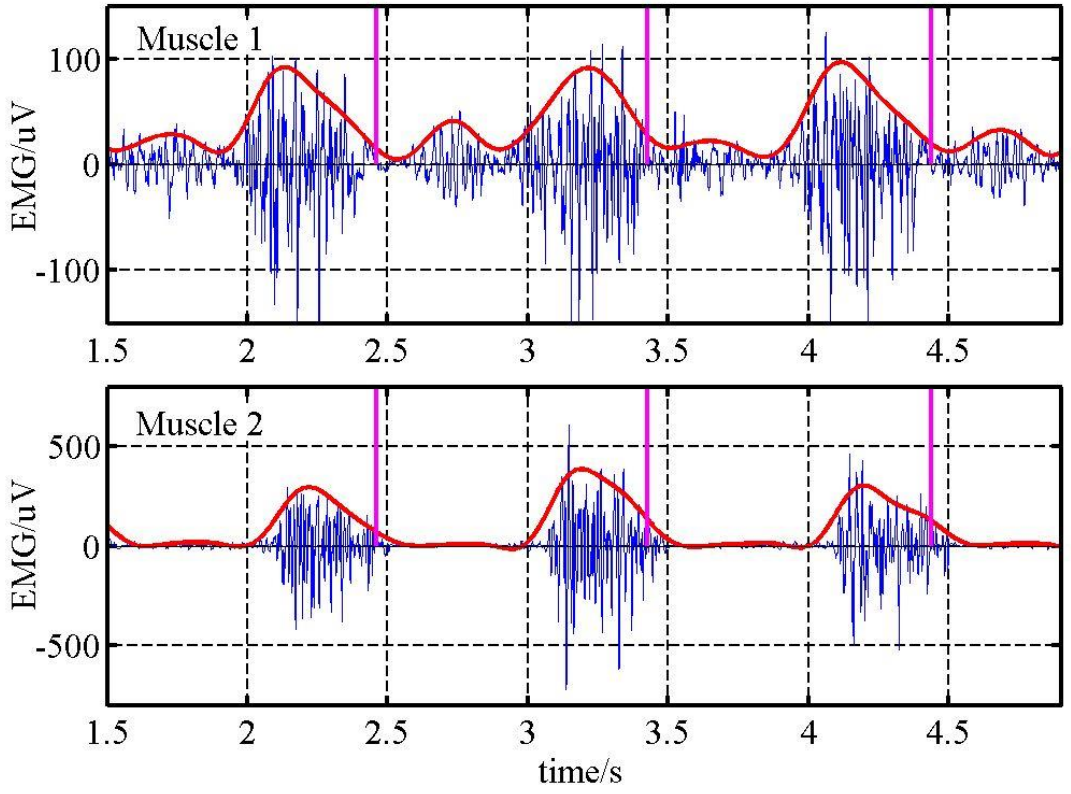
KT Sens

Nerve / Sites	Rec. Site	Latency ms	Peak Ampl µV	Distance cm	Velocity m/s
L MEDIANUS - 2 prst					
1. Dlaň	II	1,85	9,8	7,3	39,5
2. Zápěstí	II	3,60	19,0	7,5	42,9
R MEDIANUS - 2 prst					
1. Dlaň	II	0,00			
2. Zápěstí	II	4,20	6,6	14,7	35,0
L MEDIANUS - x ULNAR 4, prst					
1. zápěstí - ulnar	IV	2,85	7,9	14,2	49,8
2. zápěstí - median	IV	3,50	6,0	14,2	40,6
R MEDIANUS - x ULNAR 4, prst					
1. zápěstí - ulnar	IV	2,90	9,3	14,2	49,0
2. zápěstí - median	IV	3,80	6,0	14	36,8

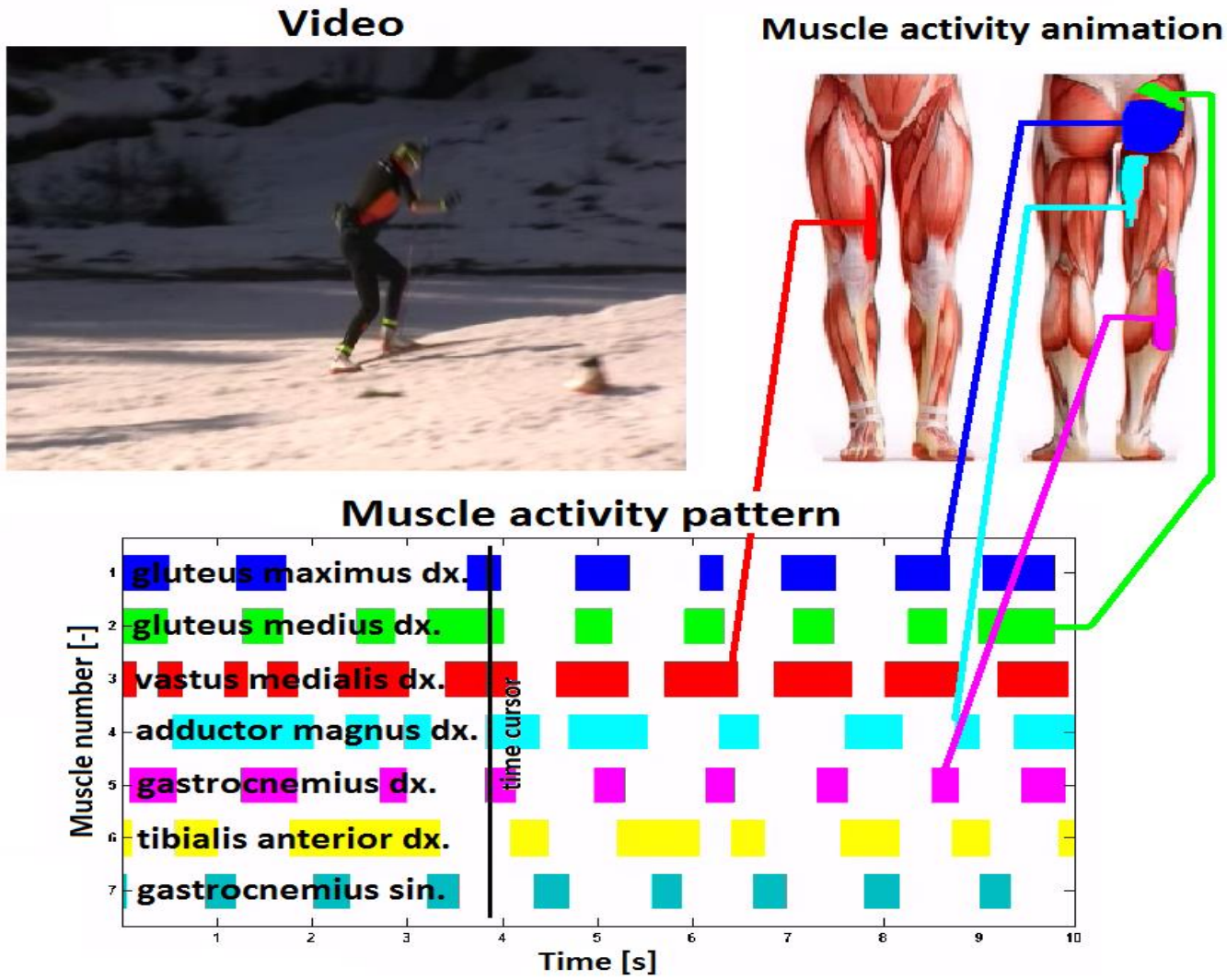
Motor NCS

Nerve / Sites	Lat. ms	Amp. mV	Dist. cm	RV m/s
L TIBIAL (KNEE) - AH				
1. Ankle	4,80	6,9		
2. Knee	13,30	4,5	38,2	44,9
L COMM PERONEAL - EDB				
1. Ankle	5,50	5,1		
2. Fib Head	11,90	5,0	29	45,3
3. Knee	13,55	5,1	8,5	51,5

Kineziological surface EMG

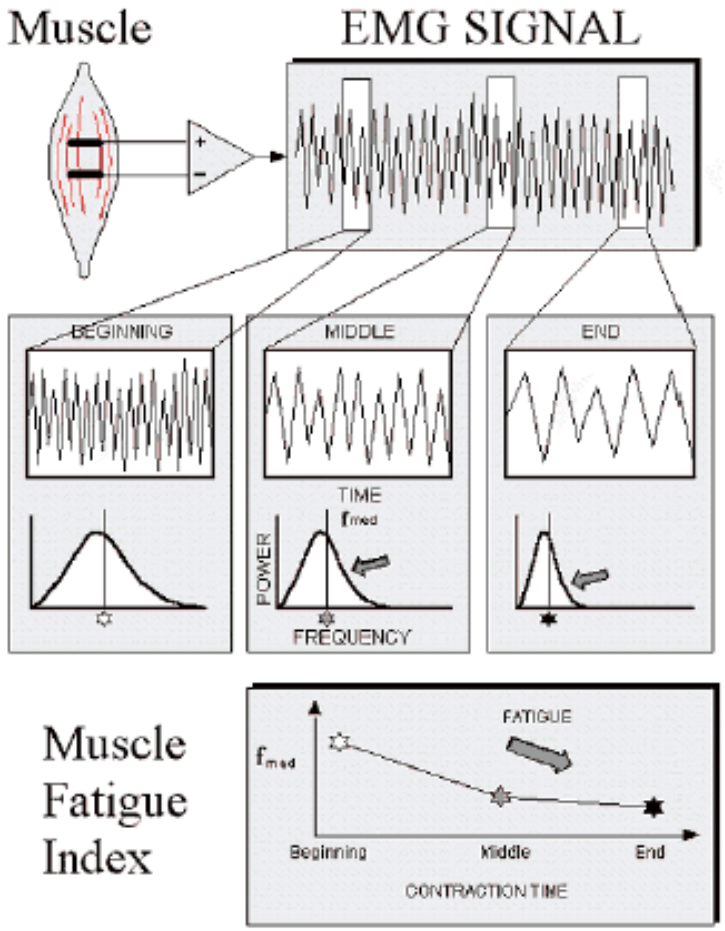


Kineziological surface EMG

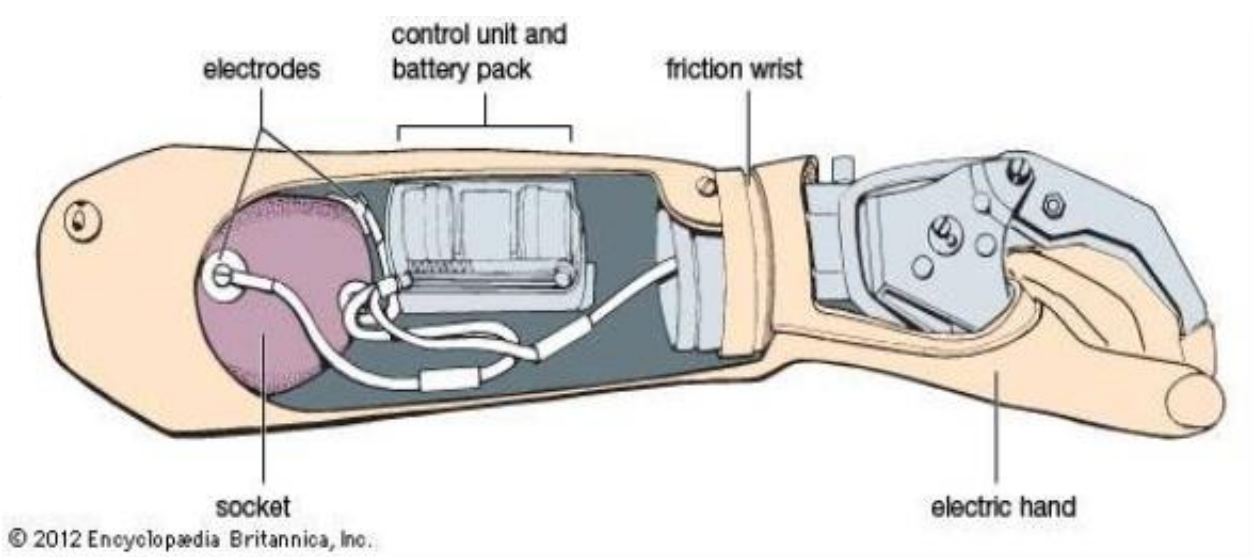


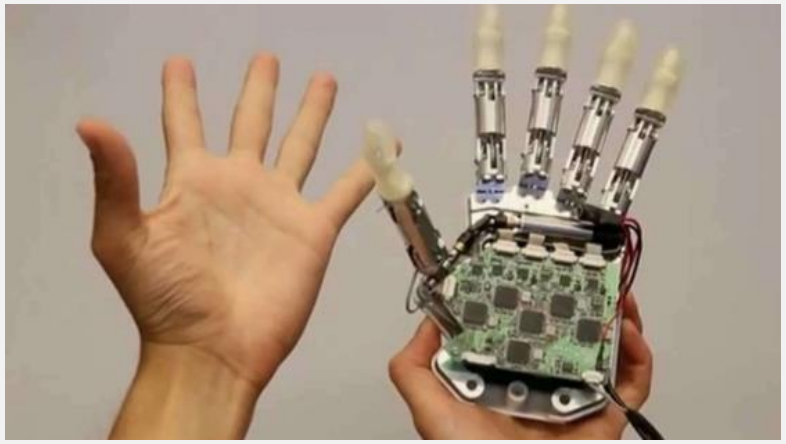
Kineziological surface EMG

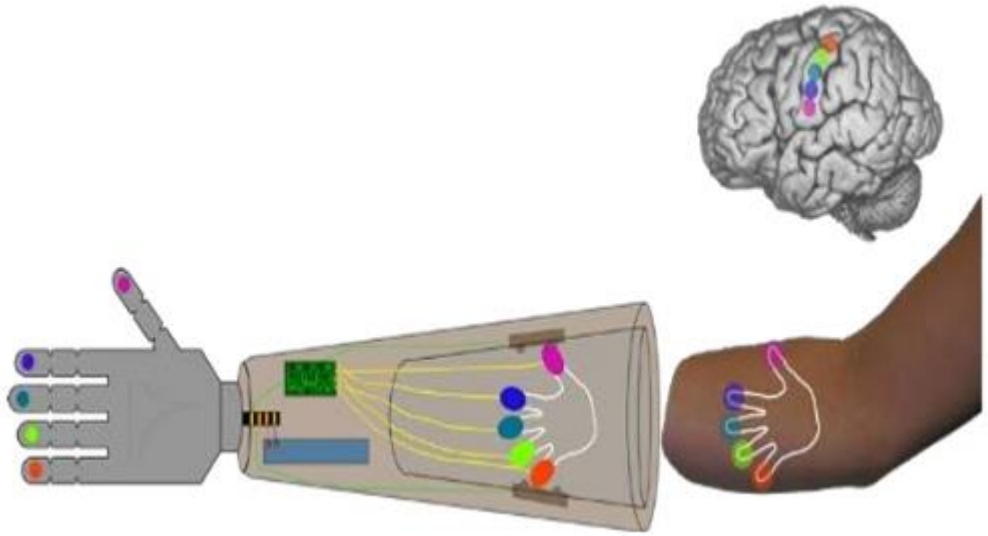
- Sequential Fourier analysis
- Window length (1 to 5 s)
- Segment overlap increases resolution
- Decision threshold for the fatigue level



Prosthetics

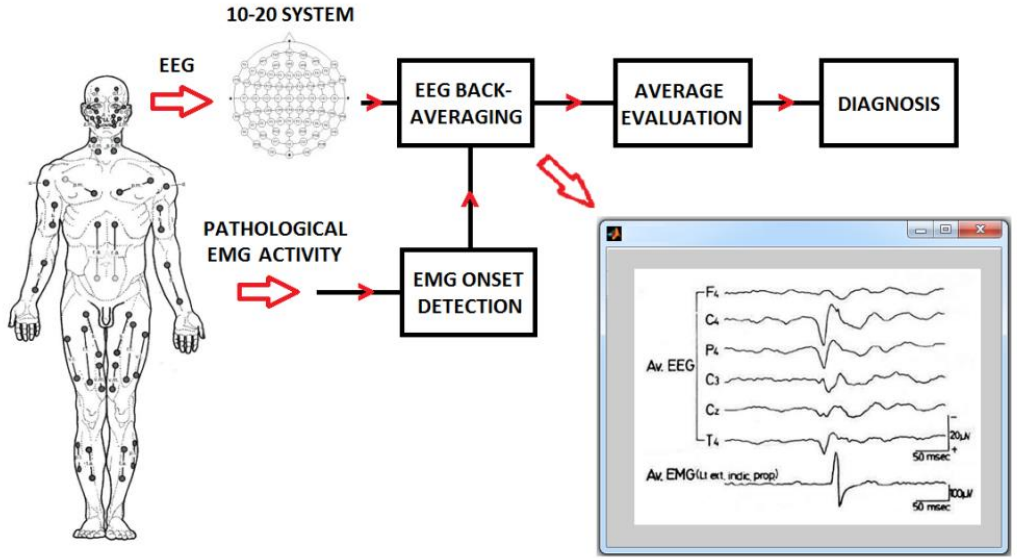






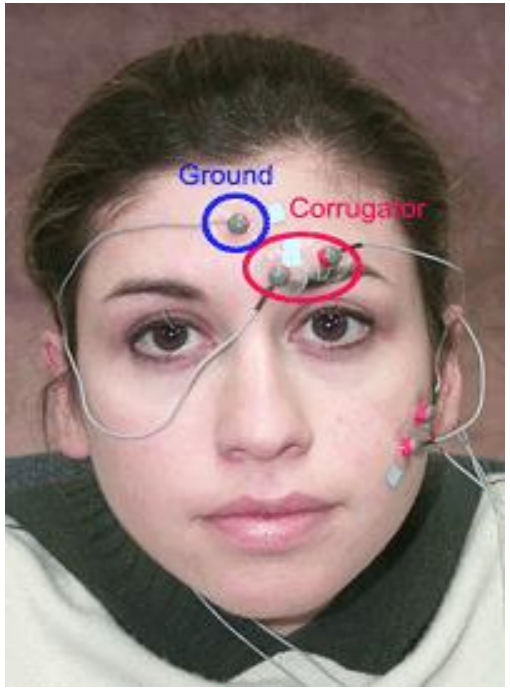
Other EMG applications

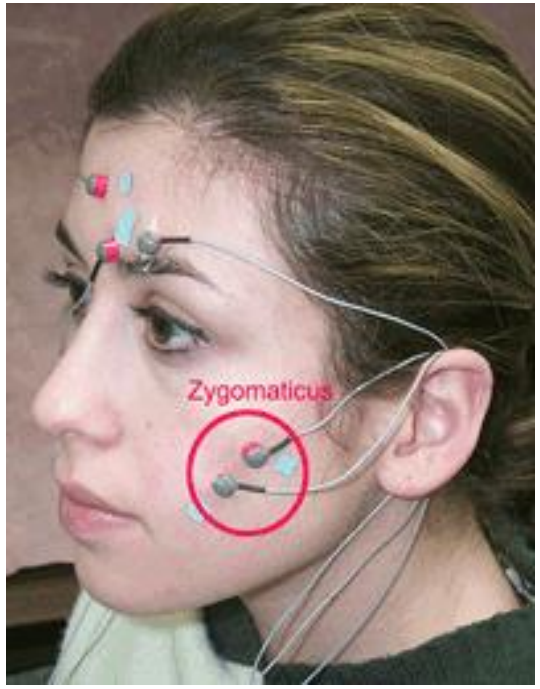
- Detection of myoclonic twitches
- Localisation CNS source



Other EMG applications

- Emotion detection





EMG analysis

- Artefcts
- EMG envelopes
- Feature extraction
  - Temporal
  - Frequency
- Advanced methods

EMG history

1791 - Luigi Galvani (Italy)

Relationship between elektricity and muscle contractions

- **19. century**

  Muscle contractions by electro stimulation
- **1907 - Louis Lapicque (France)**

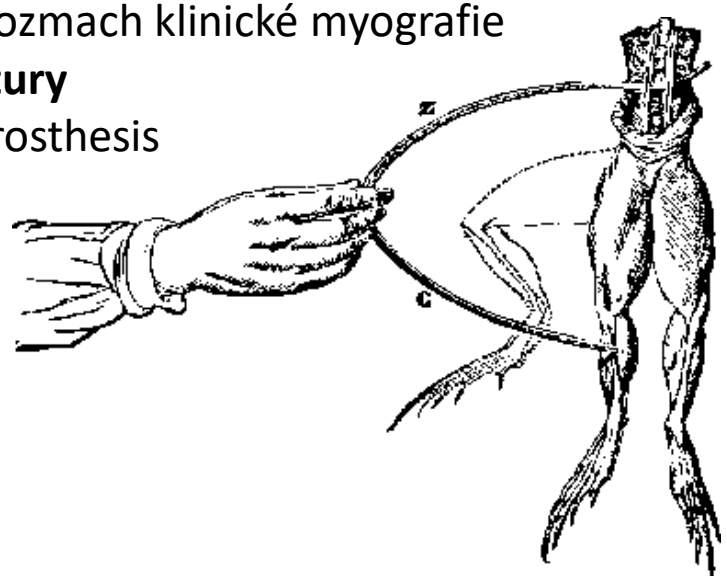
  Cell membrane model
- **1918 - Arthur E. Baines (england)**

  First cable model of stimulus propagation
- **1928 - R. Proebster (Germany)**

  First pathological signaů
- **1929 – needle electrode**

  následuje rychlý rozmach klinické myografie
- **2nd half of 20th century**

  Electronichand prosthesis

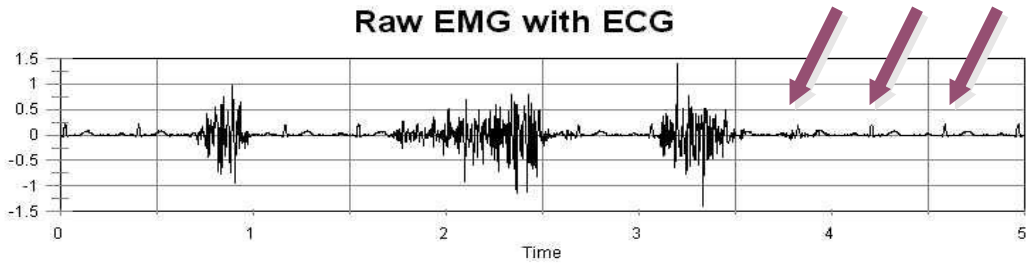


EMG signal

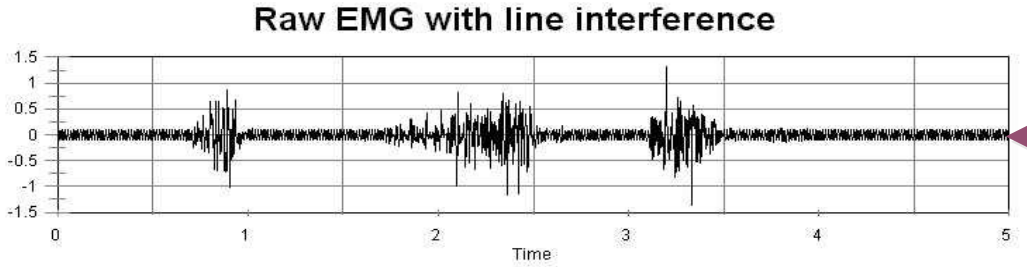
- 20-500Hz
- Minimal Fs = 1000Hz
- Median frequencies around 70 to 80Hz
- Do not use narow band stopbands to suppres 50Hz brum
- It is complicated to estimate contraction level

Artefacts

ECG artefacts

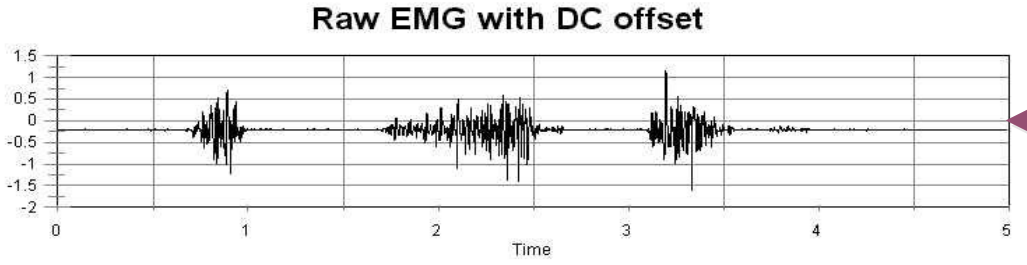


Powergrid brum



50 Hz

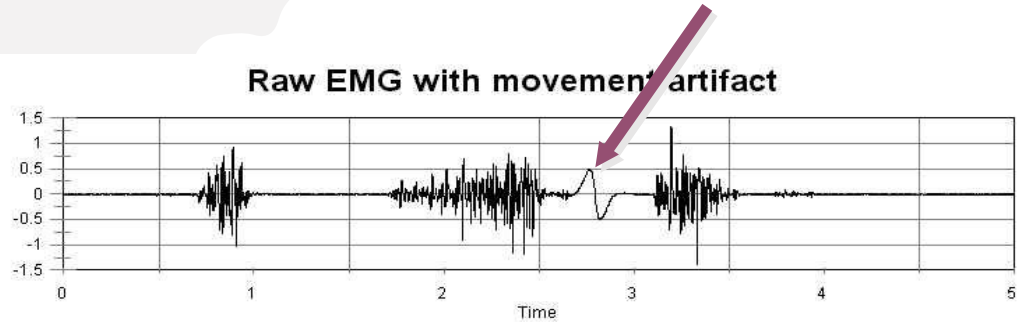
DC offset



Nonzero DC component

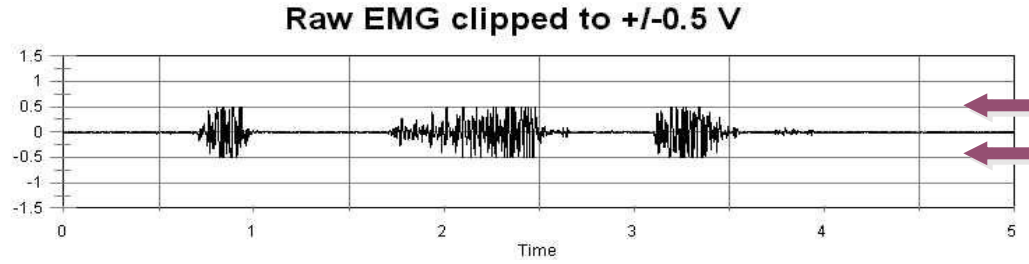
Artefacts

- Movement artefact



Electrode movement

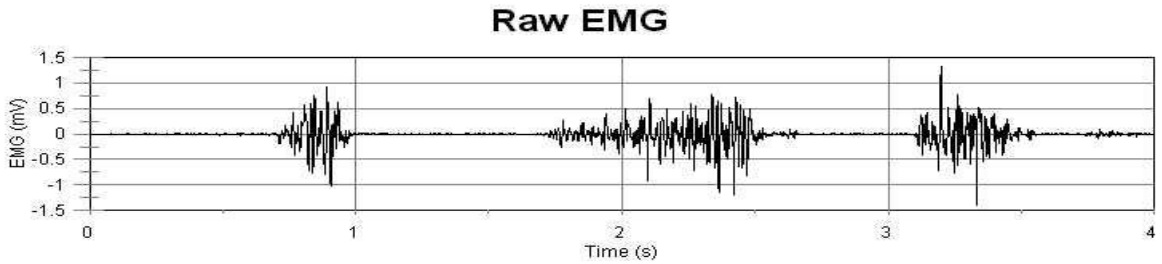
- Amplifier saturation



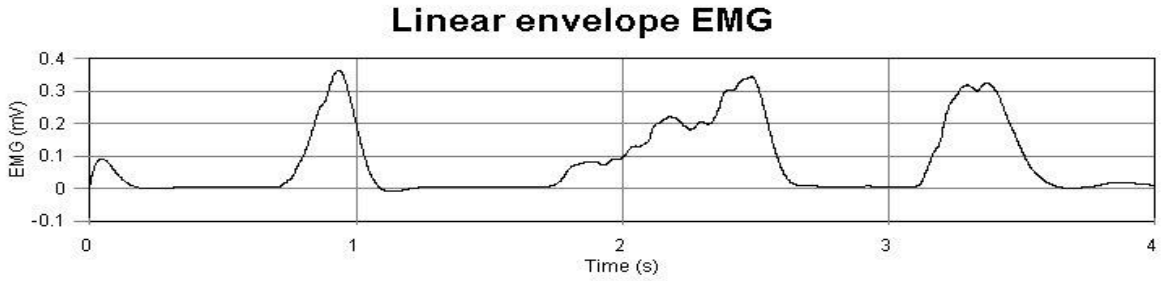
clipping +/–0.5 V

Envelope EMG

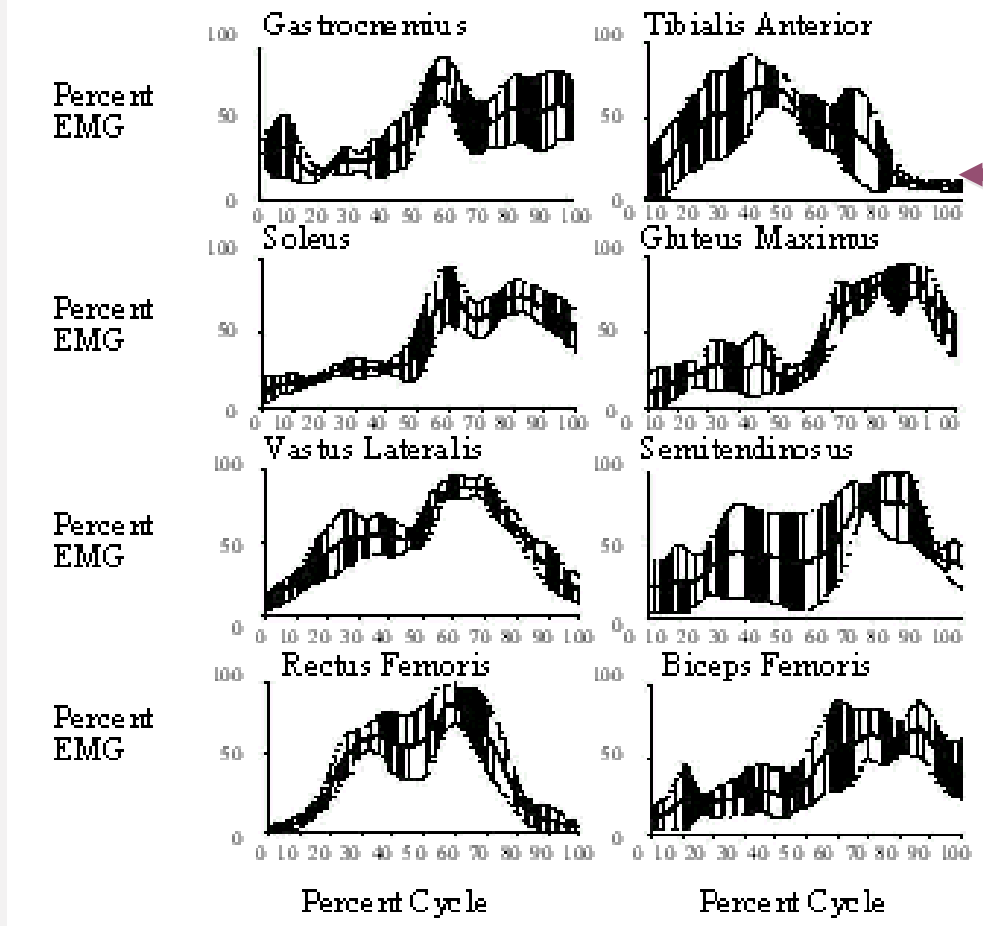
- (band pass) EMG



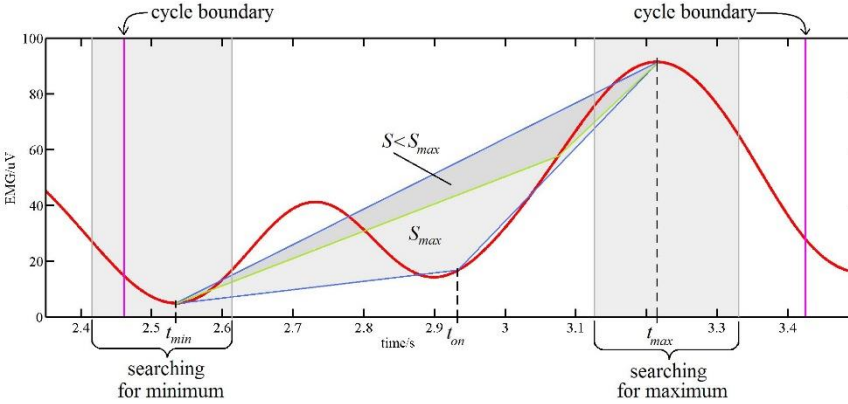
- envelope EMG (threshold frequency 4 Hz)



Synchronous averaging

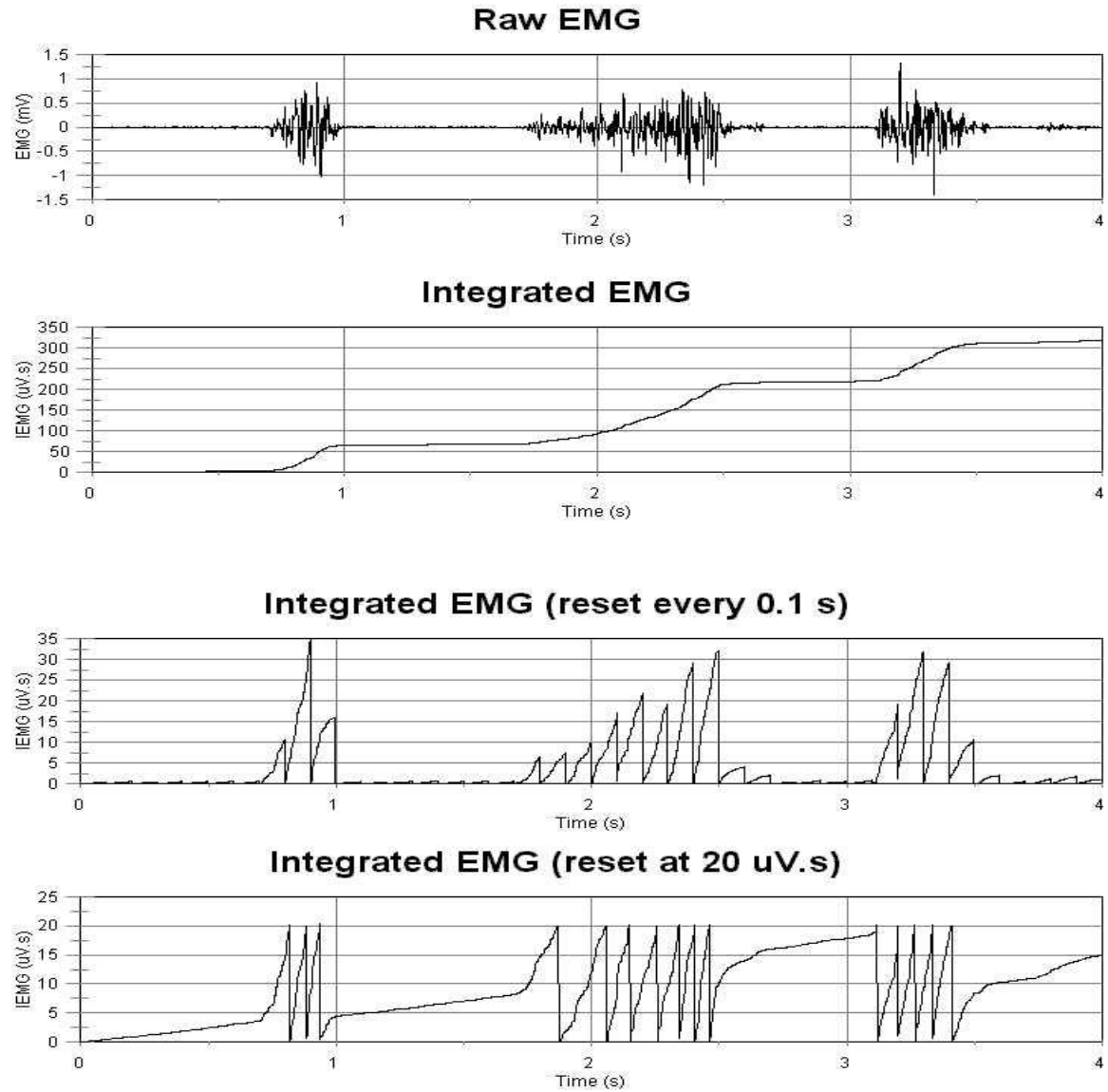


Mean value+/–std



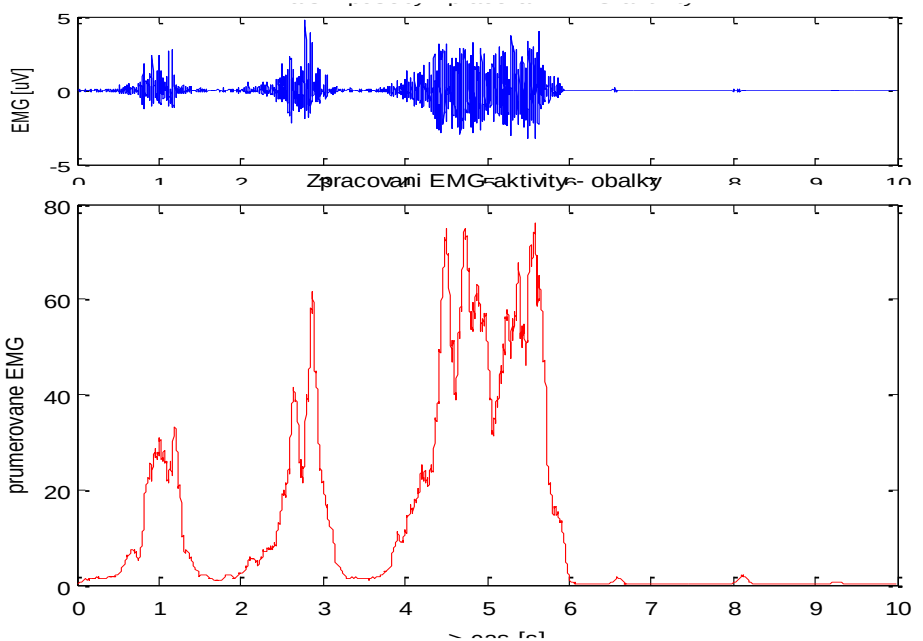
Triangular detection method

Integrated EMG

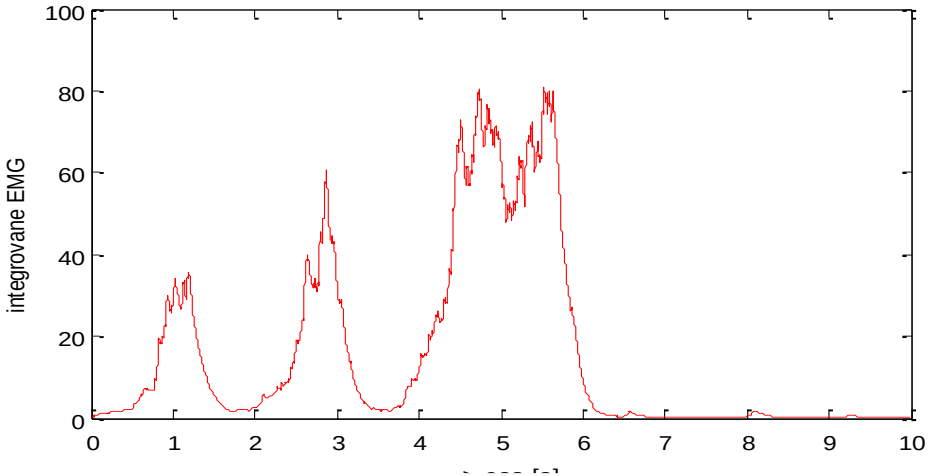


Envelope EMG examples

Moving Average

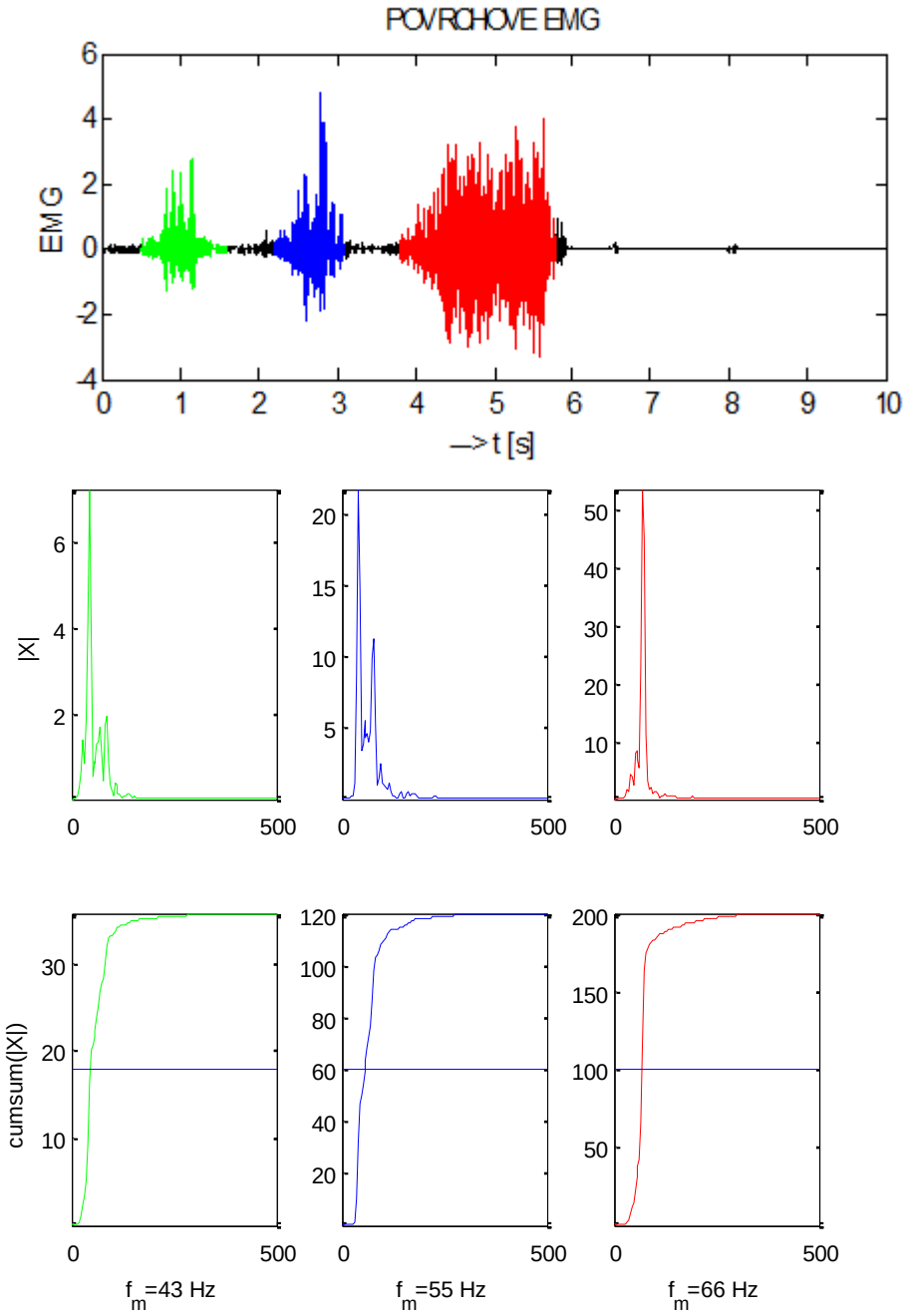


Numerical integration



Quantitive characteristics in Frequency domain

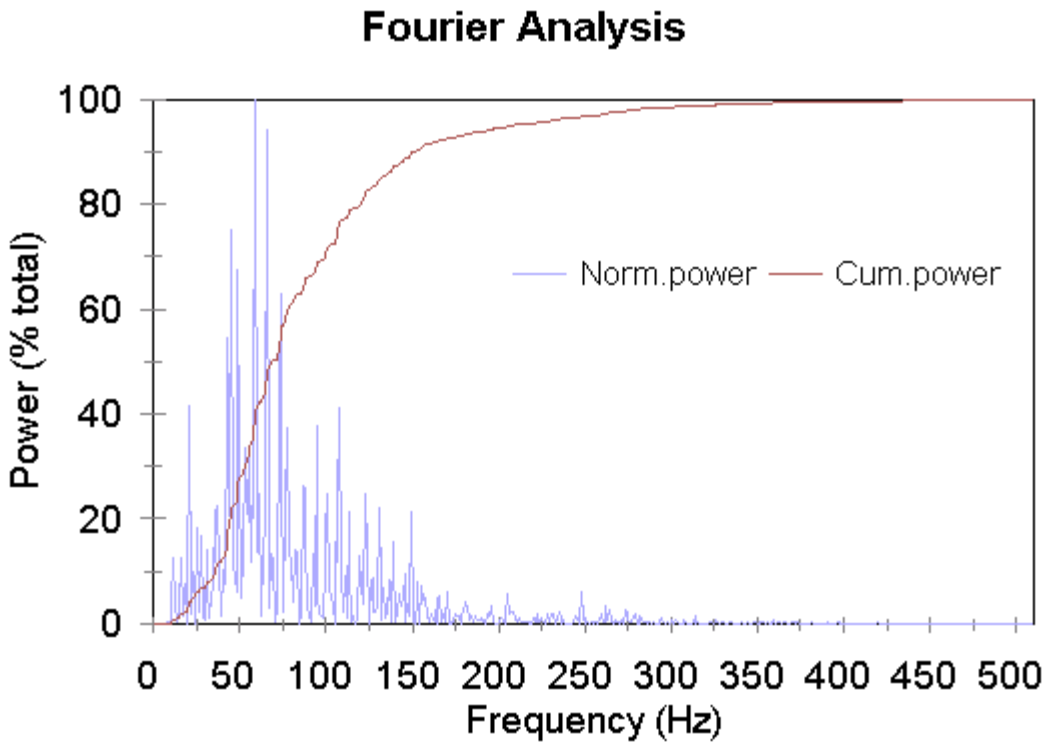
- Median frequency
- First spectral moment
- Second spectral moment



Quantitive characteristics in Frequency domain

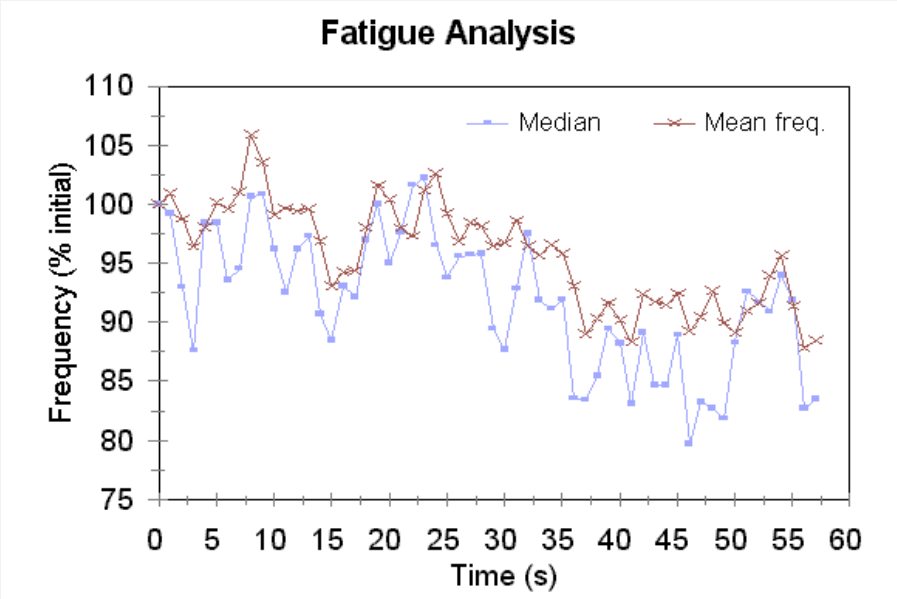
- Power spectral density

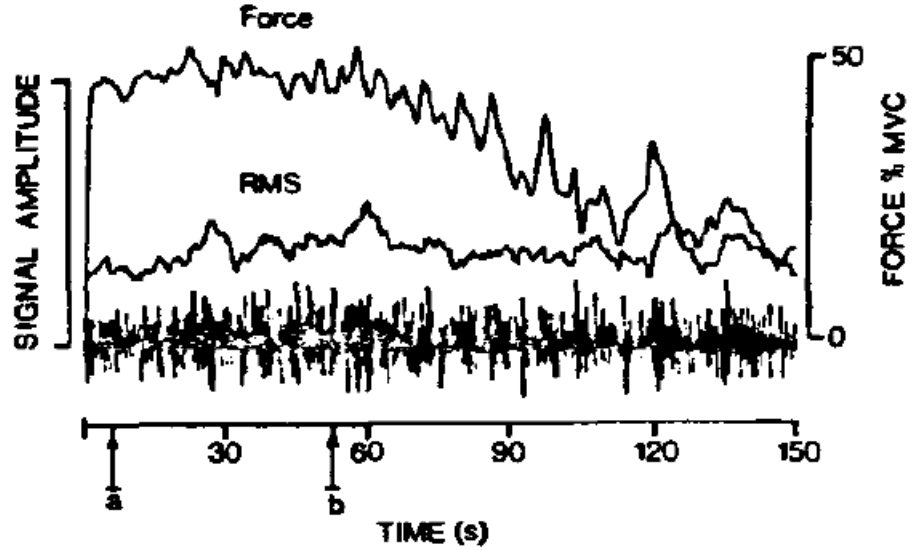
flexor digitorum longus (MVC)

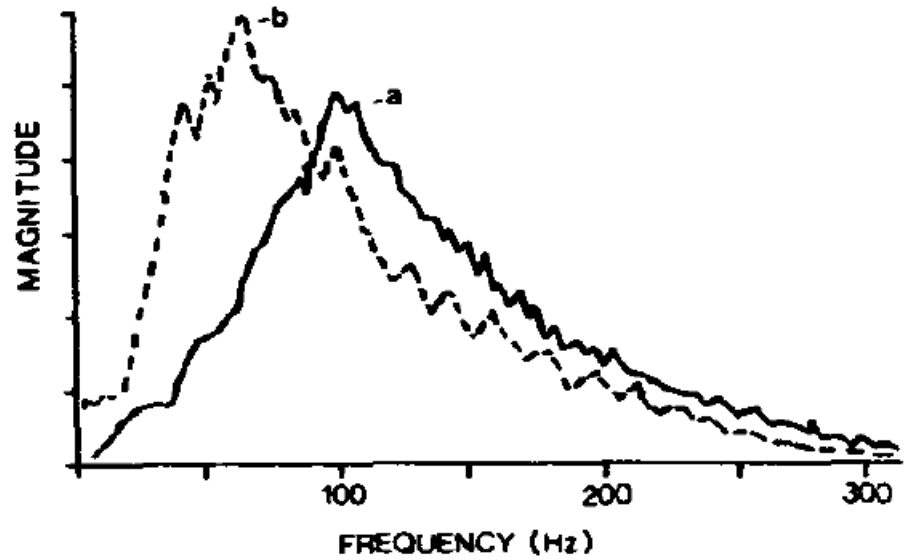


Fatigue analysis

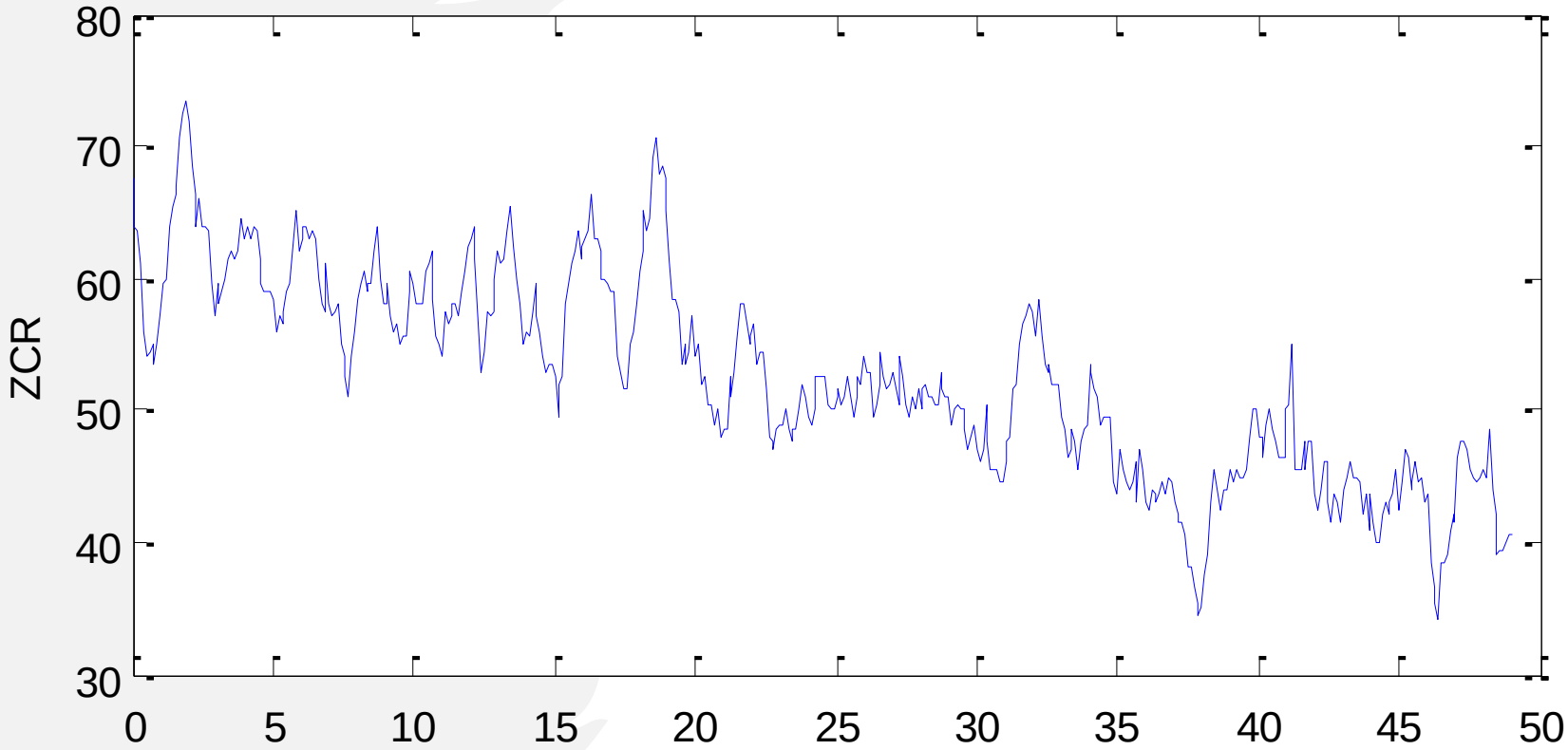
- erector spinae 60 seconds (50% overlap)



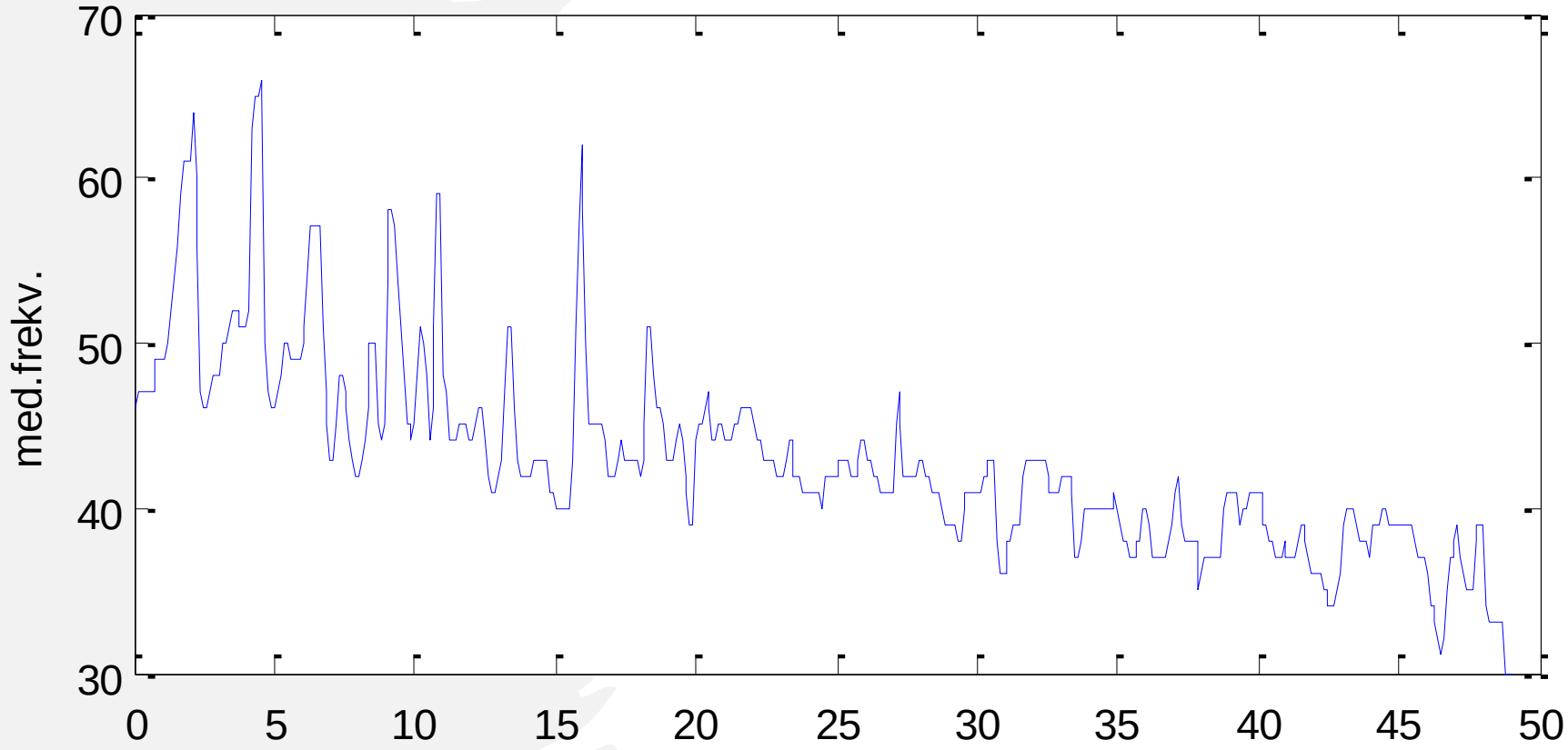




Zerocrossing



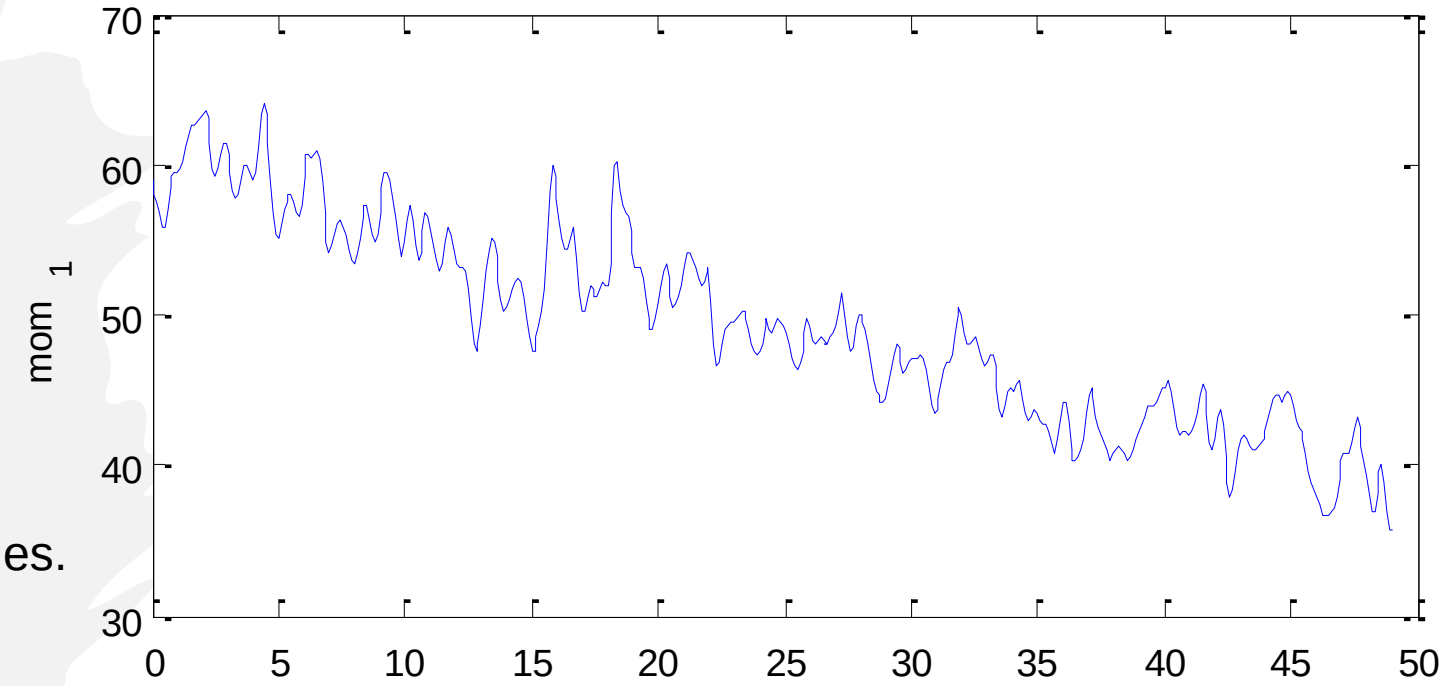
Frequency median



First spectral moment

$$mom_1 = \frac{\sum \mathbf{f} \cdot \mathbf{I}}{\sum \mathbf{I}}$$

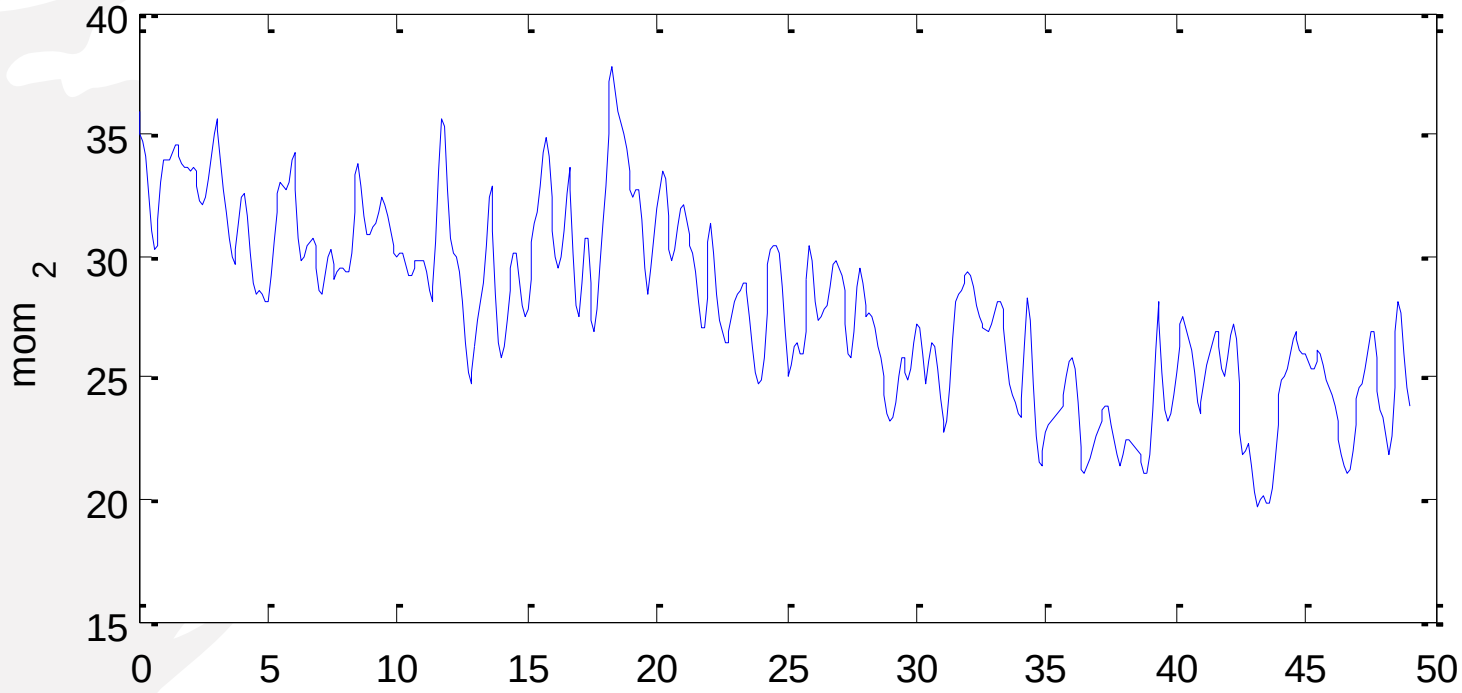
where **f** is vector of corresponding frequencies.
Defines spectrum center of gravity



Second spectral moment

$$mom_2 = \sqrt{\frac{\sum \mathbf{f}^2 \cdot \mathbf{I}}{\sum \mathbf{I}} - \left(\frac{\sum \mathbf{f} \cdot \mathbf{I}}{\sum \mathbf{I}}\right)^2}$$

Is analogous to static dispersion and represent spectrum dispersion



Advanced DSP methods

Decomposition of intramuscular and surface EMG