EMG

The study of muscle function through the investigation of the electrical signal the muscles produce

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Program

A. Theory (today)

1. Background
   - Electricity
   - EMG-applications
   - Signal origin
2. Data acquisition
   - Equipment
   - Preparing a subject
   - Checking the signal
3. Signal processing
   - Rectification
   - Filters
   - EMG-parameters

B. Practice

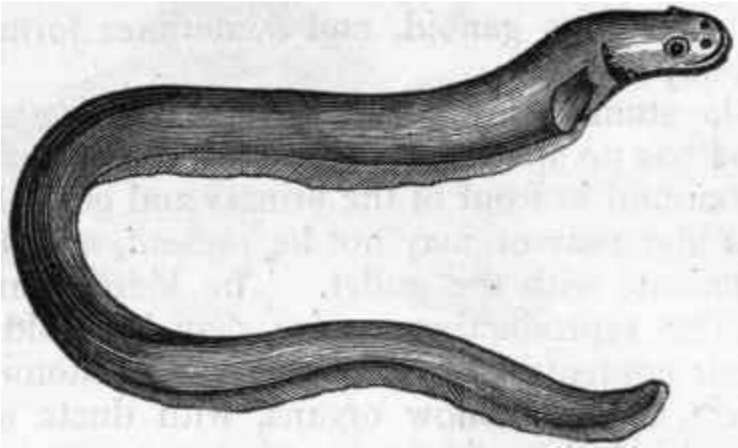
1. Preparing a subject (Practicum 1)
   - Locating the correct spot
   - Placing the electrodes – checking signal
   - Nov 30, 10.30 (group A); 13.30 (group B)
2. An experiment (Practicum 2)
   - Ballistic arm movements
   - Recording triphasic EMG
   - Dec 2 (group A); Dec 7 (group B)
3. Signal processing (Data analysis)
   - Rectification
   - Amplitude measures & Timing
   - Jan 13 (group A and B)

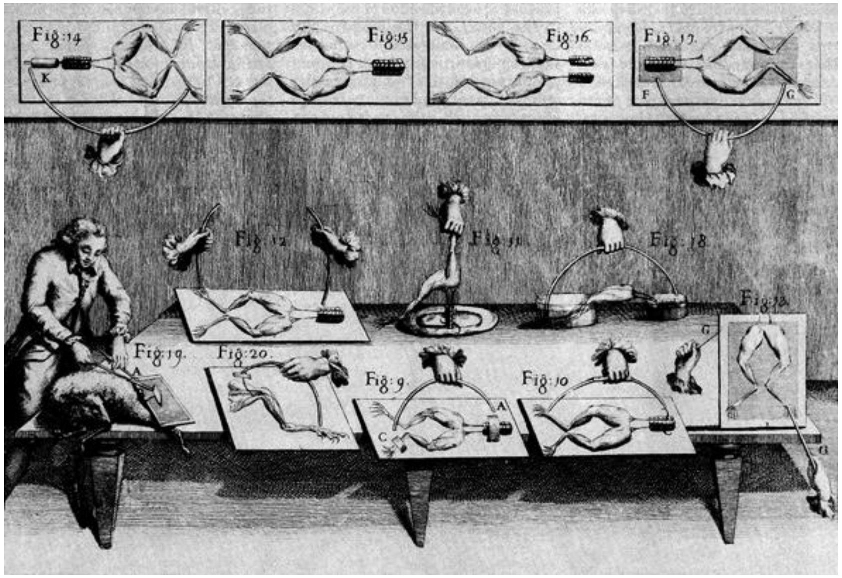
Resources:

- Konrad (2005). The ABC of EMG
- DeLuca (2008). A practicum on the use of surface EMG signals in movement sciences
- DeLuca (1997). The use of surface electromyography in biomechanics. *J Applied Biomechanics, 13, 135-163*
- European SENIAM project: *http://www.seniam.org*

In the beginning: Electric eels & frogs

Francesco Redi (1626 – 1698)

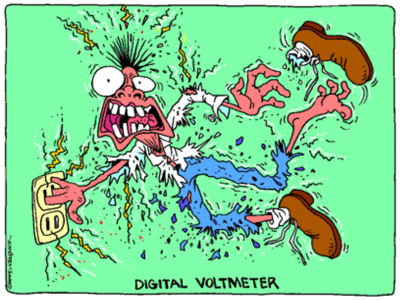


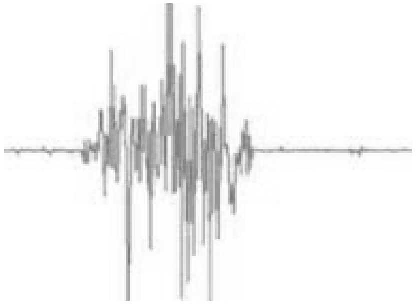


Luigi Galvani (1737 - 1798)

Electricity – Electric potential

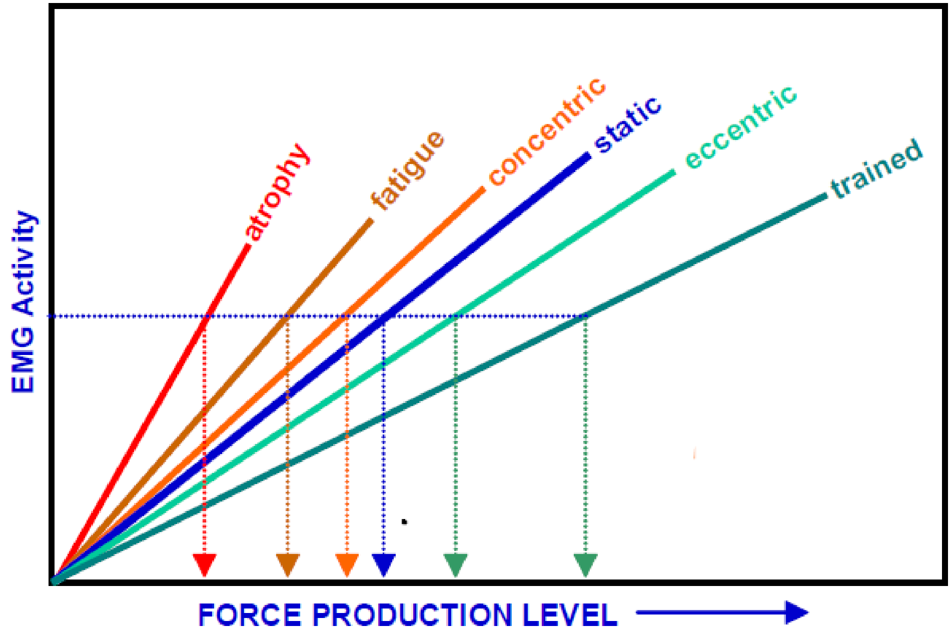
- EMG: the electric potential difference between 2 electrodes
  - Electric potential in *Voltage* (1 V = 10^{-3} mV = 10^{-6} µV)
  - *Grounding*: earth potential = 0 V
- Order of magnitude
  - Lightning: > 10^{7} V
  - Household electricity: 220 – 240 V
  - AAA battery: 1.5 V
  - Resting potential of a cell membrane: - 0.080 V = - 80 mV
  - Raw EMG: ± 0.005 V = ± 5 mV



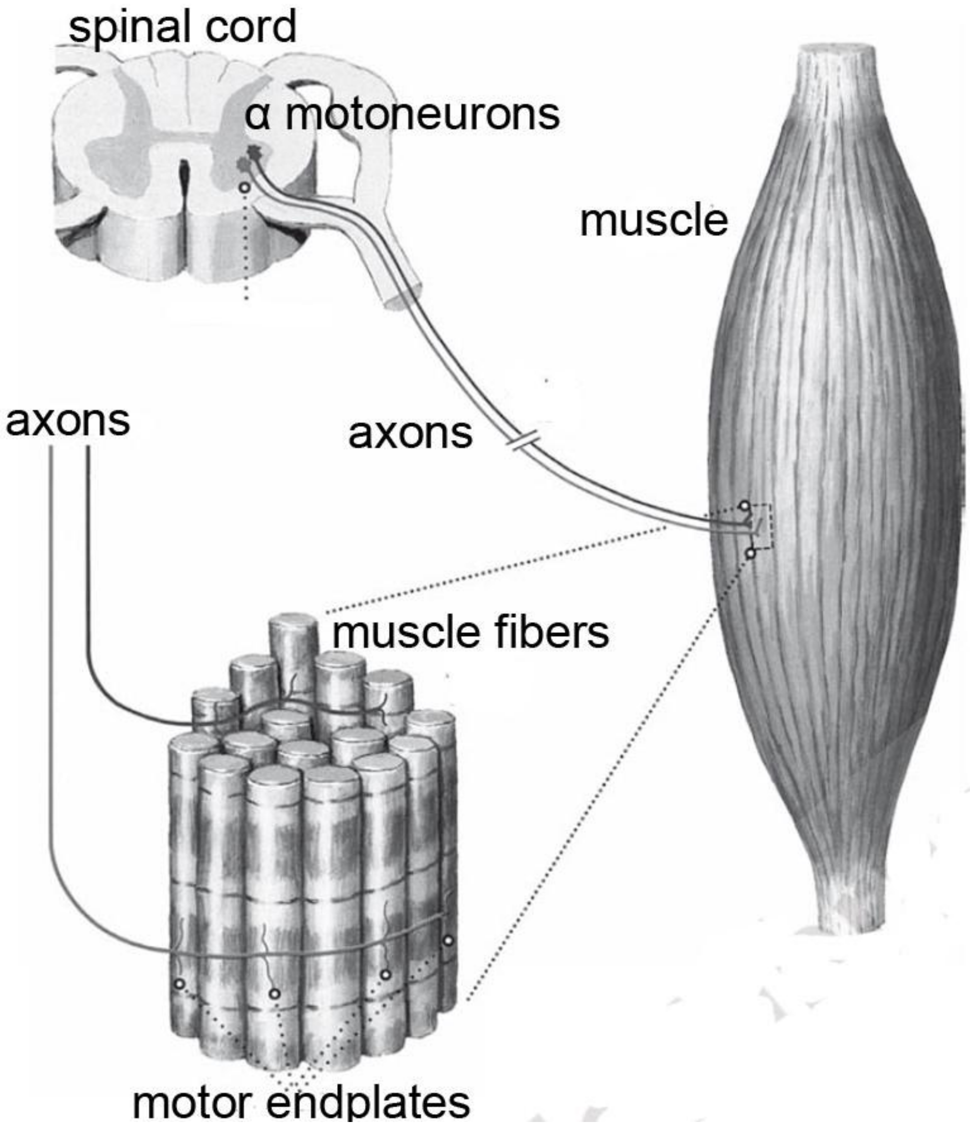


Applications

- Sport / Training / Rehabilitation
  - Force (isometric contraction)
  - Muscle fatigue
  - Activation patterns
  - Co-activation / synergies
  - Biofeedback
- Scientific research
  - TMS
  - Facial EMG
  - Motor control (gait, posture, etc.)
  - …



At the basic level…

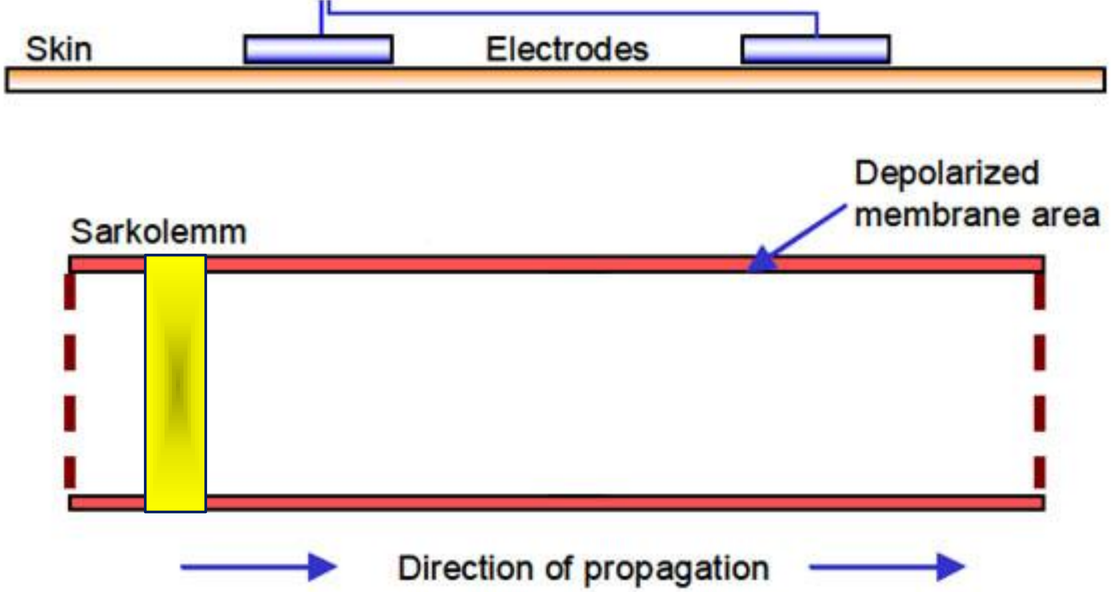


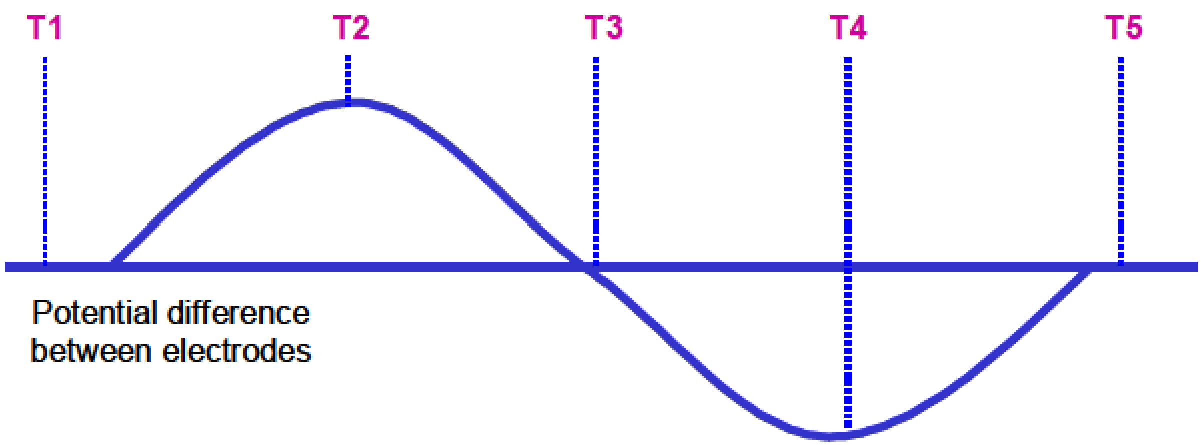
1. Action potential travels along motoneuron axon
2. Triggers release of ACh at neuromuscular junction > Endplate potential
3. **Depolarization of muscle membrane > action potential travels along the muscle fiber**
4. Triggers release of Ca^{2+}
5. Cross-bridge interactions
6. Muscle fiber contraction

Action potential: MFAPs & MUAPs

- Resting membrane potential: -80 mV
  - Voltage gradient across the muscle fiber membrane
  - Negative intracellular potential compared to the external surface
- Muscle fiber action potential (MFAP): -80 mV → + 30 mV
  - Depolarization of muscle fiber
  - Conduction velocity along muscle fiber: 2-6 m/s
- A motor unit consists of an α motoneuron and all the fibers it innervates
  - Cat gastrocnemius: 300 MU/muscle, 1000 fibers/MU > 300000 fibers (Henneman)
- Individual MFAPs sum up to a MUAP: Motor Unit Action Potential

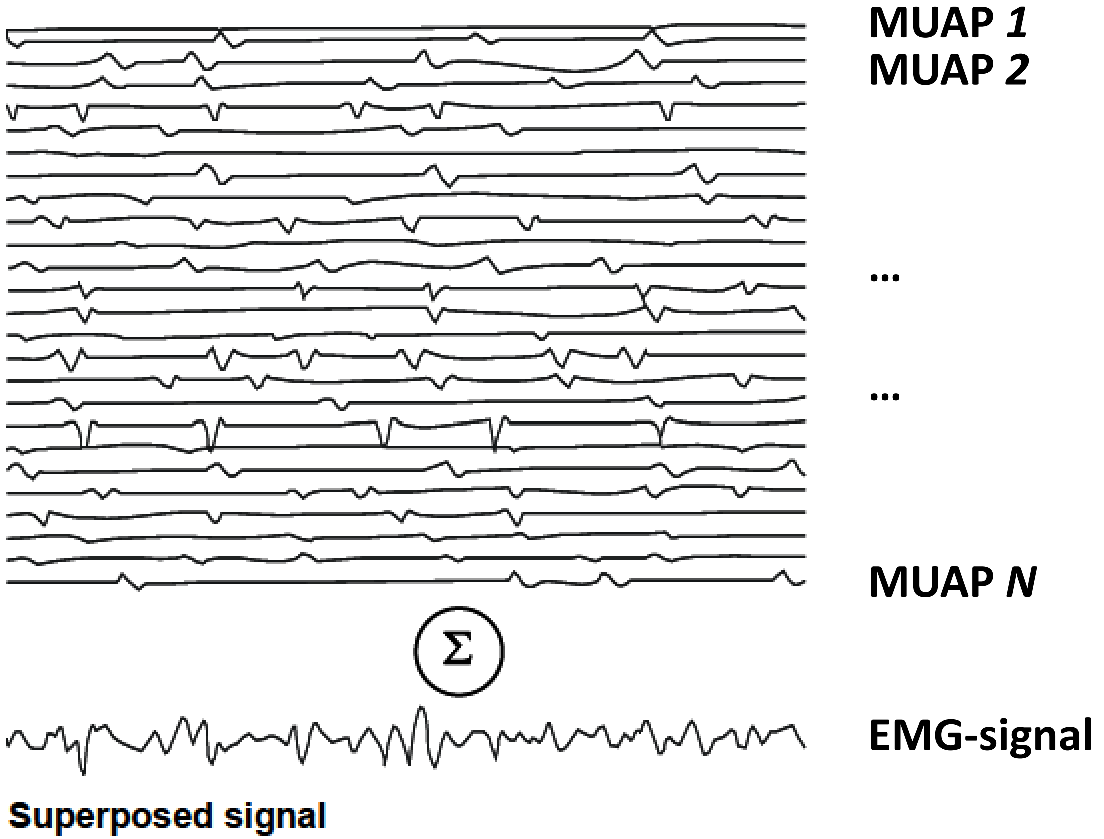
MFAP


Skin
Electrodes
Depolarized
membrane area
Sarkolemm
Direction of propagation


T1
T2
T3
T4
T5
Potential difference
between electrodes

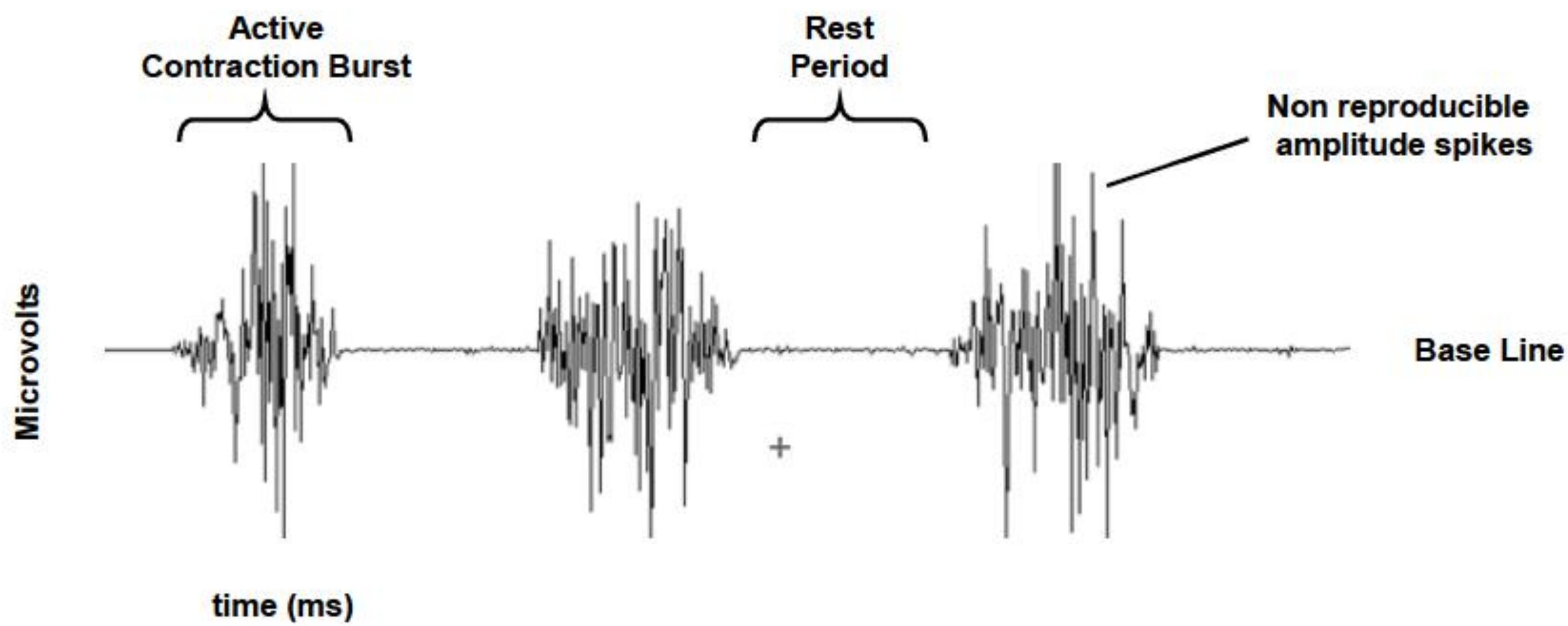
EMG: Σ MUAP

- MUAP = Σ MFAP
- EMG = Σ MUAP



Raw EMG-signal

- Unprocessed signal reflecting superposed MUAPS
- Baseline noise
- Stochastic to a large extent



Equipment

- Electrodes
  - Types
    - Surface: Ag/AgCl pre-gelled electrodes
    - Indwelling: needle or fine-wire
  - Configurations
    - Monopolar
    - Bipolar
- Amplifier
- Computer interface
  - AD-converter
- Computer

- Alcohol
- Razors (for shaving)
- Some soft tissues
- Tape-measure (ruler)
- Tape to attach to skin/cables
- Pen

Equipment: electrode configurations

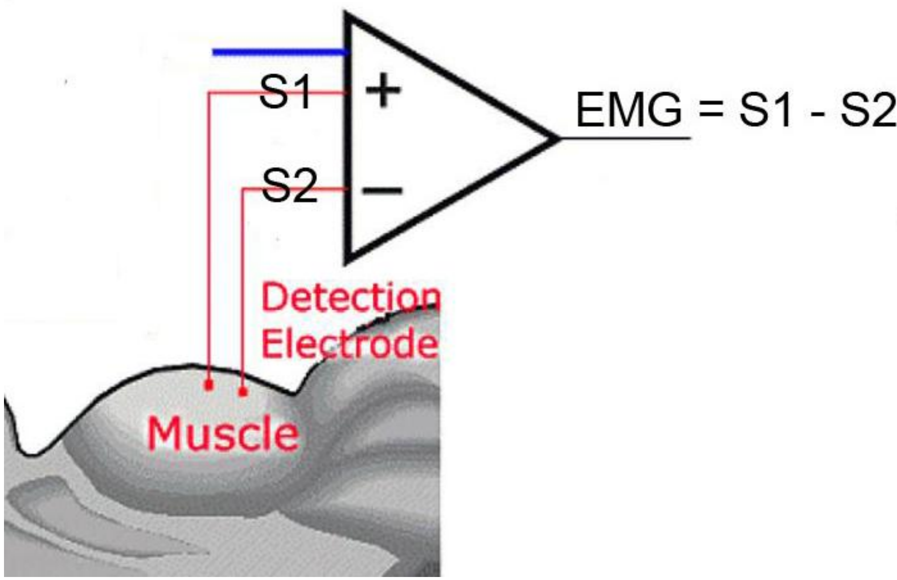
- Monopolar recordings
  - Per muscle
    - 1 electrode on the muscle
    - 1 electrode on a bony area
  - 1 grounding electrode (on bony surface)
- Bipolar recordings
  - Per muscle
    - 2 electrodes on the muscle
  - 1 reference and/or grounding electrode (depends on manufacturer/equipment)

Equipment: wireless electrodes

- In the biomechanics lab:
  - Wireless electrodes (Aurion – Zerowire): WiFi transmission
  - Bipolar recording: 2 electrodes on the muscle
  - No need for subject grounding or reference electrodes
    - Subject is not attached to electrical devices
    - There are no cables that can cause electrical or magnetic fields
  - Attention: batteries (recharge after use)

Equipment: amplification

- Differential amplification and the Common Mode Rejection Ratio (CMRR)
  - Differential amplification: EMG signal = constant × (S1 – S2)
  - CMRR: a signal (e.g., noise N) that is common to both electrodes will be removed
    - S1 consists of 'actual signal' M1 + 'common signal' N; S2 idem (M2 + N)
    - S1 = M1 + N
    - S2 = M2 + N
    - EMG signal = S1 – S2
      = (M1+N) – (M2+N)
      = M1 – M2



Equipment: amplification

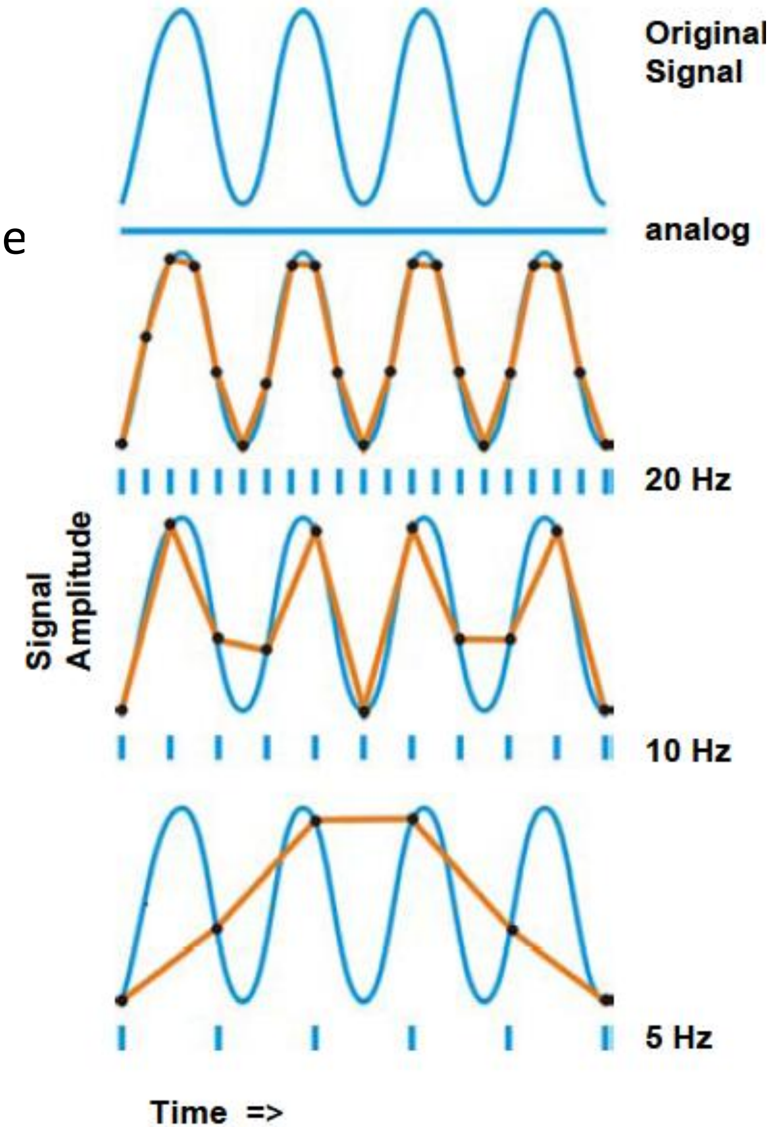
- Differential amplification and the Common Mode Rejection Ratio (CMRR)
- Gain
  - Increase signal-to-noise ratio: amplification
  - The EMG signal is generally amplified by a factor of 500 or 1000 (gain)
  - EMG signal = gain × (S1 – S2)
- Hardware filter
  - Band-pass of 10 Hz to 500 Hz, meaning:
    - Reduce effect of noise < 10 Hz (e.g., movement artifacts)
    - Reduce effect of noise > 500 Hz (e.g., contains no information)
  - Sometimes a specific notch-filter; not recommended

Equipment: A/D-conversion

- From an analogue signal (Voltage) to a digital signal (zeros and ones)
  - Analogue = Continuous
  - Digital = Discrete
- Sampling frequency (Fs)
  - Signal power between 10 and 500 Hz
  - For EMG Fs >= 1000 Hz
  - Why? To prevent aliasing

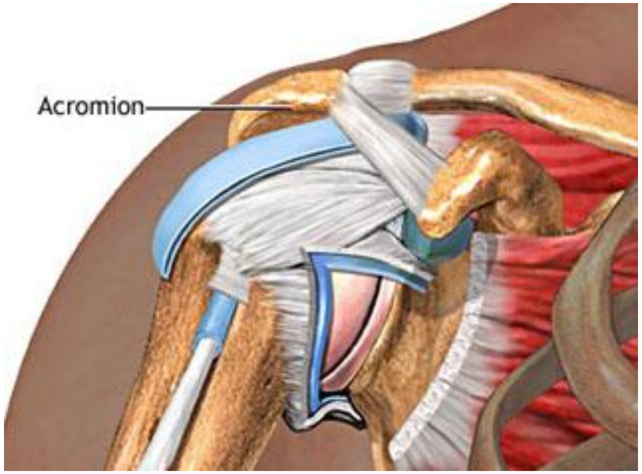
Equipment: A/D-conversion

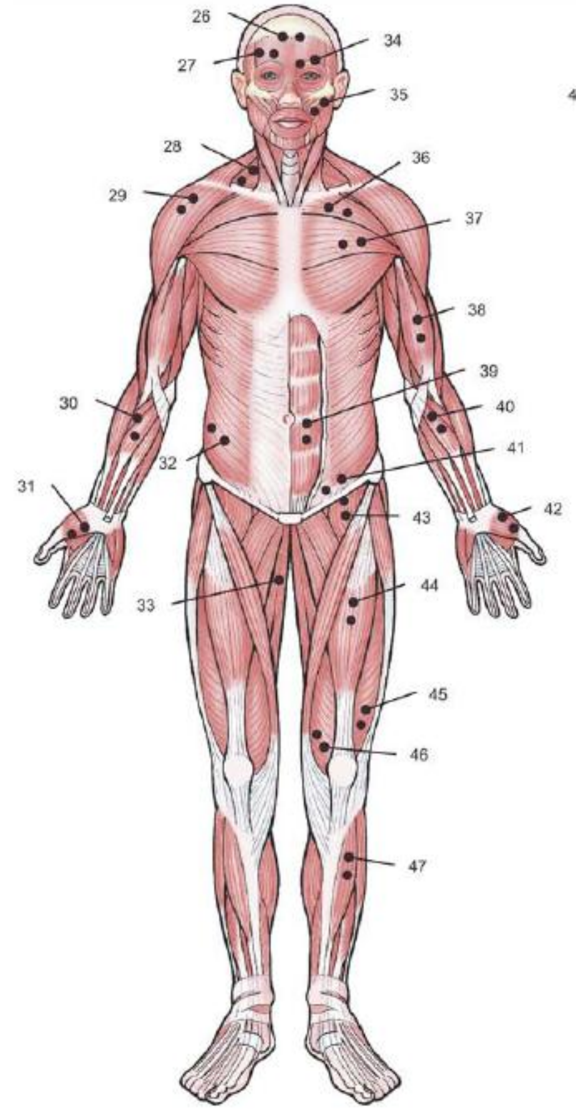
- Aliasing effect
  - Nyquist frequency: the frequency that is twice the highest frequency in the signal
  - Fs should be >= Nyquist frequency
  - EMG signal power between 10 and 500 Hz
  - For EMG Fs >= 1000 Hz



Preparation: the correct muscle

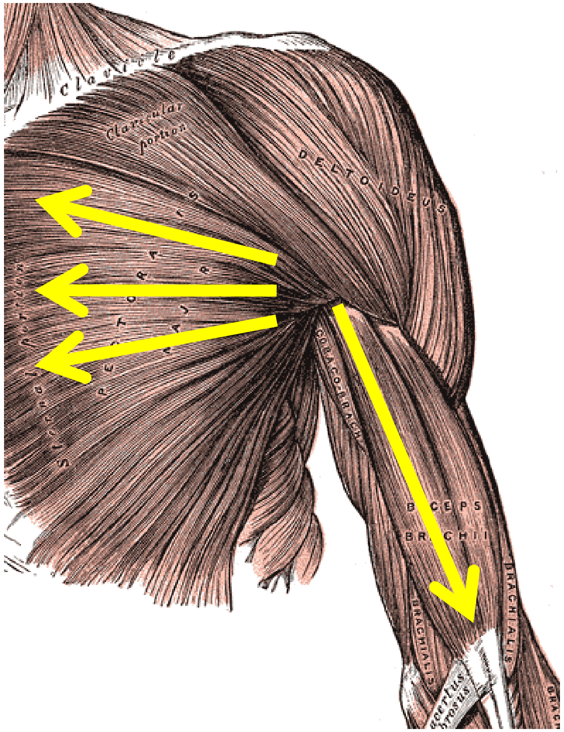
- Use muscle maps / atlas of anatomy
- Find anatomical landmarks
- Activate/deactivate muscle – palpation
  - Find out the best way to activate particular muscles
- European recommendations: www.seniam.org





Preparation: the correct location

- In general: middle of the muscle belly, see also *www.seniam.org*
- Two electrodes must be placed in line with the direction of the muscle fibers
- Mark the spot with a pen



Preparation: the skin

- Different techniques in the literature
- *Deluca et al. (1997)* and *Seniam* advice:
  - Shave the skin to remove excessive hair
  - Clean the skin with alcohol
  - Allow alcohol to vaporize so that skin is dry before electrode placement
- So: don't use scrub paste or sandpaper

- Why skin preparation? > In order to get a good electrode-skin contact
  - Better EMG-recordings (in terms of amplitude characteristics)
  - Fewer and smaller artefacts (electrical interference)
  - Less noise (better Signal-to-Noise ratio)

Preparation: electrode placement

- Around marked spot
- Inter-electrode placement: ca. 10-20 mm
- In parallel with direction of muscle fiber
- Fixate electrodes/cables with elastic band or tape such that:
  - Electrodes are properly fixed to the skin and stay in a fixed position
  - Required movements of subjects are not hindered
  - Cables are not pulling the electrodes
  - Cables do not make strange angles/hooks

Why all this boring stuff?

- To obtain a signal that:
- *Is an undistorted representation of ΣMUAP*
- *Is free of noise (as much as possible) and artifacts*
- *Is stable and reliable*
- *Has a minimum of cross talk from other muscles*
- *Has a high signal-to-noise ratio*

Checking the signal

- Do I measure the right muscle with the right electrodes?
- Activate each muscle to check if the signal reflects this activity
- Check skin impedance: < 10 kOhm
  - Resistance between electrode pairs
- Inspect EMG-baseline quality (around 10 – 20 µV)

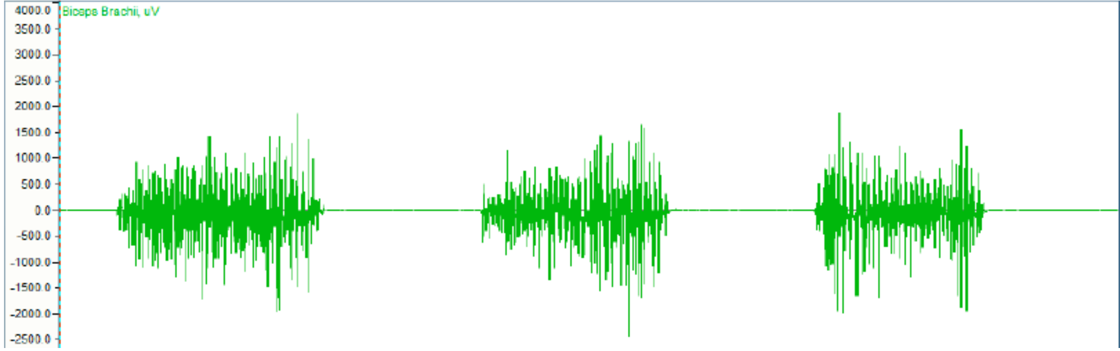
What can affect signal quality?

- Tissue characteristics (e.g., thickness, temperature)
- Cross talk from other muscles
- Movement artifacts (relative movement of electrodes)
- External noise (e.g., power hum)
- ECG artifacts (when measuring muscles close to the heart)
- Bad skin preparation and/or electrode placement
- Just a bad subject or an unlucky day

Action list

1. Prepare your lab before subject arrives
2. Ask subject to wear appropriate clothes
3. Explain procedure to subject
4. Find and mark electrode locations
5. Clean the skin (shaving & alcohol)
6. Attach electrodes
7. Fixate electrodes/cables in proper way
8. Wait some minutes before checking the signal
9. Check the signal
10. Tutto bene? VAI!

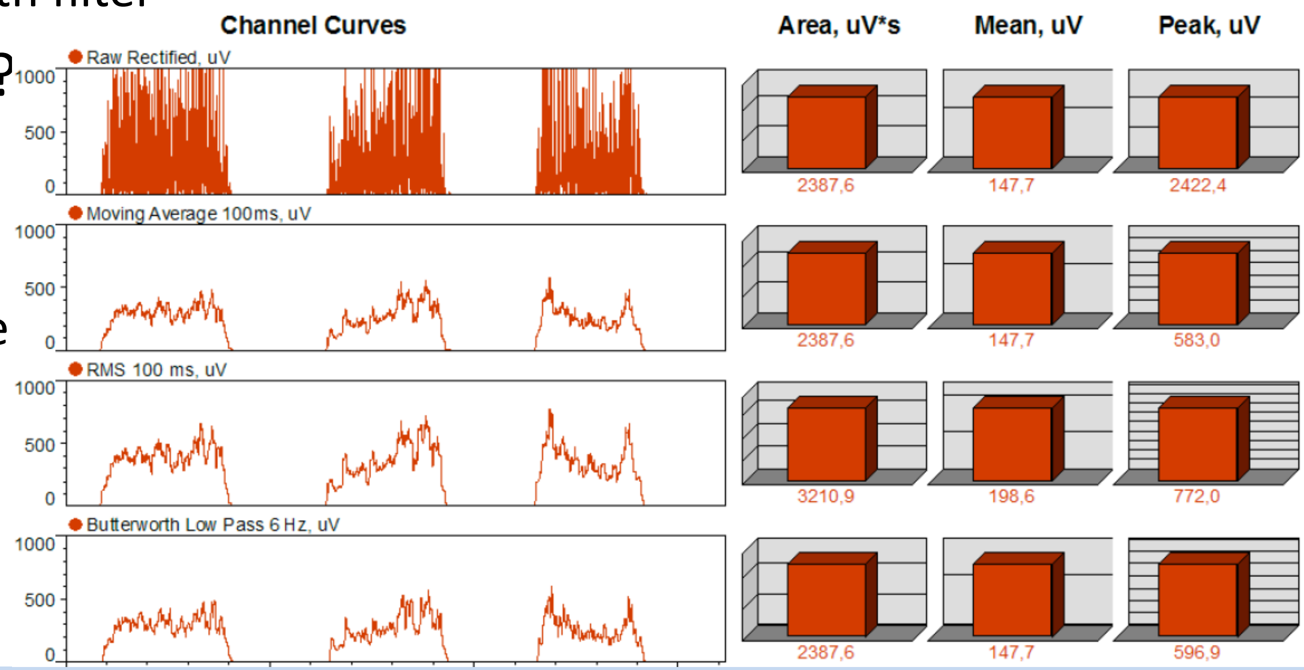
Signal processing



- Detrending
- Full-wave rectification (turn negative values into positive ones)
  - Taking the |absolute| of the signal
  - Amplitude parameters like mean, max. value and area can be applied to the signal (raw EMG has a mean value of zero)
- Depending on purpose:
  - Filter or smooth the signal
  - Amplitude normalization to MVC
- Calculate parameters
- Advice: learn how to use Matlab

Filters and smoothing

- Smoothing the signal / creating a linear envelope / outlining trend / contour following
  - Moving average (or Average Rectified Value, AVR)
  - Root Mean Square (RMS)
  - Low-pass Butterworth filter
- Movement artifacts?
  - High-pass filter
- Choice of filter
  - Depends on purpose
  - Loss of information



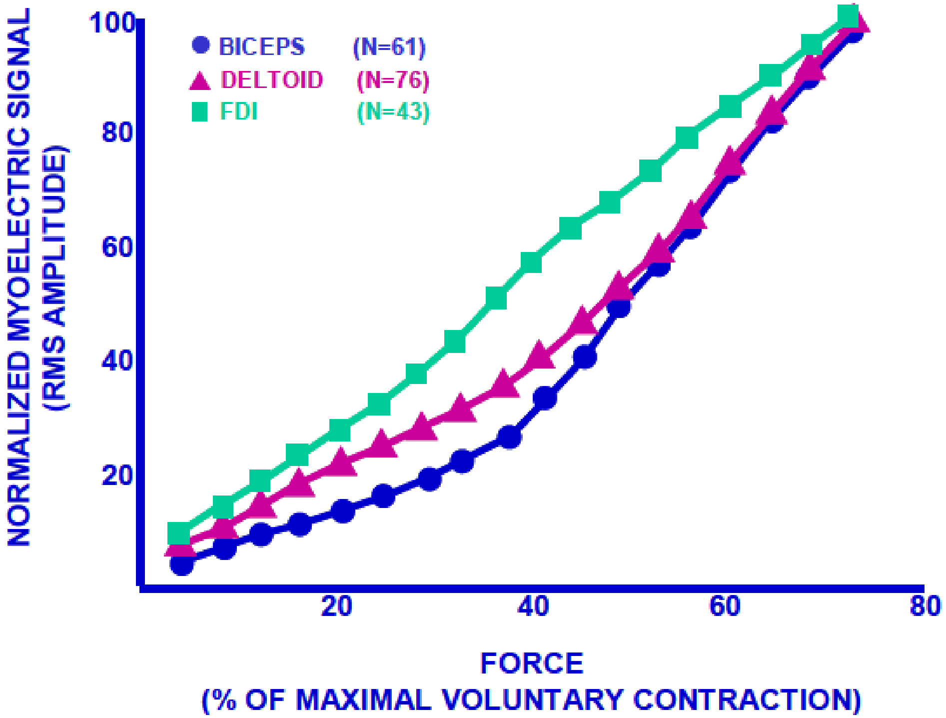
EMG-parameters

- EMG-amplitude parameters
  - Maximum (average peak calculation)
  - Mean (or median)
  - Area (related to time interval)
- EMG-frequency parameters: Can tell you something about conduction velocity of Aps (firing patterns)
  - Fast Fourier Transformation (FFT)
  - Mean or median frequency
  - Total power
- EMG-timing parameters
  - Time to Peak
  - On/Off-characteristics

EMG-parameters

- Questions:
  - Active during certain task?
  - More or less active in comparison with…?
  - When active (timing)?
  - How much (in relation to MVC)?
  - What kind of coordination?

EMG-parameters



- EMG-Force relationship
  - Isometric contractions
  - Most studies show linear relations
  - Also nonlinear relations
  - In general, positive correlation
- EMG-Fatigue relationship