Development of Complex Curricula for Molecular Bionics and Infobionics Programs within a consortial* framework**

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**Molekuláris bionika és Infobionika Szakok tananyagának komplex fejlesztése konzorciumi keretben

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Neuromorph Movement Control

Neuromorf mozgás szabályozás

Application of electrical stimulation in medical rehabilitation

(Az elektromos stimuláció alkalmazása az orvosi rehabilitációban)

József LACZKÓ PhD; Róbert TIBOLD

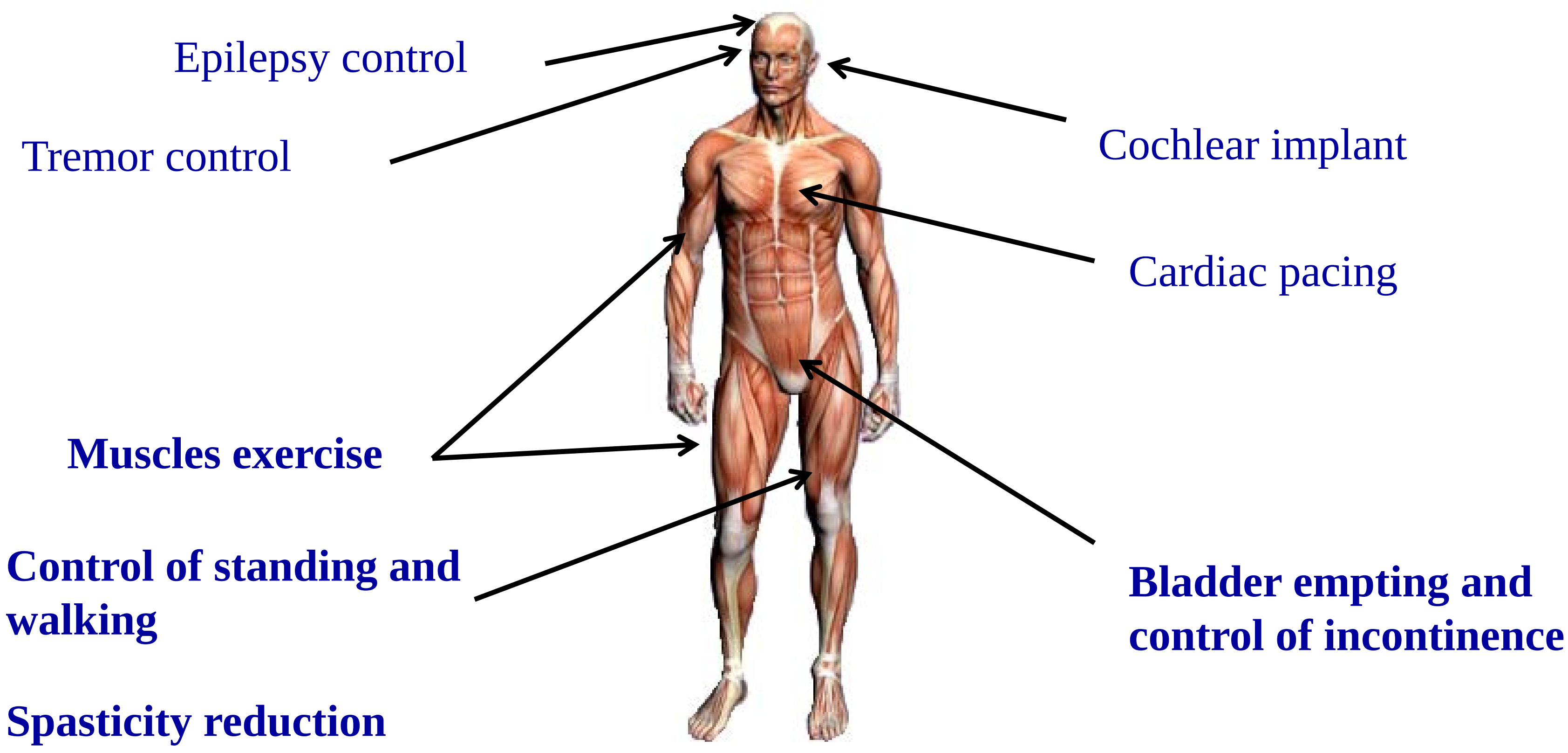
Main points of the lecture

- **Electrical stimulation in general**
- **Equipments and methods applied in ES**
  - **Current**
  - **Electrodes**
  - **Modes**
  - **Waveforms**
- **Electrical Muscle Stimulation (EMS) in general**
- **Functional Electrical Stimulation in general**
- **Case study: FES-Cycling**

Electrical stimulation in general applications

- **Electrical stimulation(ES):** is one of the most effective modalities used in physical therapy.
- **The purpose of electrical stimulators**: the stimulation of tissue for therapeutic purposes.
- Tissues to be stimulated: a muscle to relax or contract, a nerve to produce action potentials or a bone to enhance growth.
- **Different types of ES:**
  - Neuromuscular stimulation (NMS).
  - Electrical muscle stimulation (EMS).
  - Functional electrical stimulation (FES).
  - Transcutaneous electrical nerve stimulation (TENS).

Electrical stimulation in general applications



Equipments and methods applied in ES (Generators)

- **Low-voltage current generators:**
  less than 100 volts applied, under 1Hz.

- **High-voltage direct current generators:** extremely short-duration pulse to increase penetration, in the range of 300 to 500 volts.

- **Interferential current generators** between the range: 4000 Hz - 4100 Hz, with a net frequency in the interference zone of 80 to 100 Hz. (low-voltage power)

- **TENS units: (used for nerve stimulation) frequencies in the range of 1 Hz to 120 Hz, pulse width from 50 ms to 300 ms with a medium range amplitude of 10 mA to 50 mA.**

- **Medium-frequency generators:** specific frequencies (2400 Hz to 2500 Hz)

- **Programmed units:** utilized for home use (common used in FES)
  - pre programmed stimulation strategies
  - allowes different parameter selection

Equipments and methods applied in ES (Current)

Direct (galvanic) current: a constant electron flow from the negative to the positive electrode with constant polarity

Types:

Continuous: used only for iontophoresis (a technique using small electric charge to deliver a medicine or chemicals through the skin).

Equipments and methods applied in ES (Current)

Pulsed: for stimulation of neuromuscular components with reaction of degeneration (RD), as the ability to respond to alternating current has been lost.

Because its adverse effects on muscle fibers it is not used

Surged: Because of its slow wave rise leading to tissue accommodation (minimal or zero contraction) it is not used

Alternating current: the movement of electric charge periodically reverses direction(from positive to negative and vica-versa).

Equipments and methods applied in ES (Current)

When the alternating phases are smooth and equal in energy: sine waves.

Generally applied: in neuromuscular components with no reaction of degeneration (RD).

Interferential current: a combination of 2 high-frequency waveforms (4000 and 4100 Hz) in crossed pattern. The net frequency, resulting from cancellation / reinforcement near or at the crossing point, equals to 100 Hz. (Does not produce visible contractions, unless applied in high amplitudes.)

Equipments and methods applied in ES (Current)

- **High voltage-pulsed galvanic current(HVPC):** an effective ES should produce muscle force through muscular contraction with low pain.
- **Therefore:** the characteristics for an electric pulse should be capable of minimizing pain by altering its waveform, duration, frequency and intensity.
- HVPC with short duration and deep penetration is effective in ES to produce muscle force
- **Parameters:** 150-500V with short duration (100ms); with a high peak (nearly 2A) and with low average current (less than 150 mA).
- **Waveform:** twin-peaked pulse (40-80 ms spacing between pulses).

Equipments and methods applied in ES (Electrodes)

Electrode types:

- Commercial pads and rubber-backed electrodes
- Moistened paper towels, with aluminum foil plates
- Sponge types, with inserted electrodes and rubber carriers.
- Carbonized, rubber electrodes with transmission gel.

Electrode dimensions: Sizes are application dependent (determined by the treatment technique and the current configuration)

- *Equal sizes*: equal distribution of current.
- *Differential sizes*: current shaping.
- *Special instruments*: internal purposes.

Equipments and methods applied in ES
(Modes applied in all current types)

Each of the previously mentioned forms of current: could be applied in the following modes

- **Continuous:** If its frequency exceeds 50 Hz, it is then becoming tetanizing, being used for relaxation of muscle spasm.

- **Surged:** The maximum current intensity can be reached in microseconds or milliseconds. Slow surges (5 to 10 per minute) can stimulate slow fibers.

- **Pulsed mode:** The alternating current when interrupted reaches peak intensity immediately.

- **Result:**
  - fast response in the muscle, being suitable for stimulation of fast fibers.
  - Interruption at higher rates exceeding 50 Hz causes a tetanic type of contraction.

Equipments and methods applied in ES (waveforms)

- **Sine wave:** equal energy levels under positive and negative phases.
- **Rectangular (square) wave:** describes usually the direct current with a rapid instantaneous rise, prolonged duration and a sharp fall.
- **Spike wave:** the rise rate is rapid but not instantaneous. Falling back rapidly to zero immediately after reaching the maximum.

- *Combined waves:* A combination form of both rectangular and spike waves.
- *Twin-spiked forms:* More penetration is available because of the extremely short-pulse width (microseconds), as in high-voltage galvanic stimulation.

Electrical muscle stimulation (EMS)

- **Electrical muscle stimulation** (EMS): or **neuromuscular electrical stimulation** (NMES) is a muscle contraction effected by electric impulses.
- These impulses are generated by sign generator and transmitted through electrodes.

Electrical muscle stimulation (EMS)

- **Electrodes are commonly placed:** on the skin just above the muscle to be stimulated. The impulses generate action potential (AP) coming from the central nervous system (CNS) causing the muscles to contract.
- The electrodes are generally pads located on the skin.

- **EMS has 2 commonly used forms:**
  1. **electrotherapy (e.g.: used in rehabilitation of paraplegics, tetraplegics, hemiplegics, paralysis)**
  2. muscle training

Electrical muscle stimulation (EMS) – Action Potential

Action potential: is a short-lasting event in which the electrical membrane potential rapidly rises and suddenly falls. It is an all or none neural command issued by a neuron or muscle fiber.

APs are generated: by voltage-gated ion channels in a cell's membrane. Ion channels:

1. are shut when the membrane potential is near the resting potential of the cell,
2. start to open if the membrane potential gains a given threshold. (inward flow of Na^+)

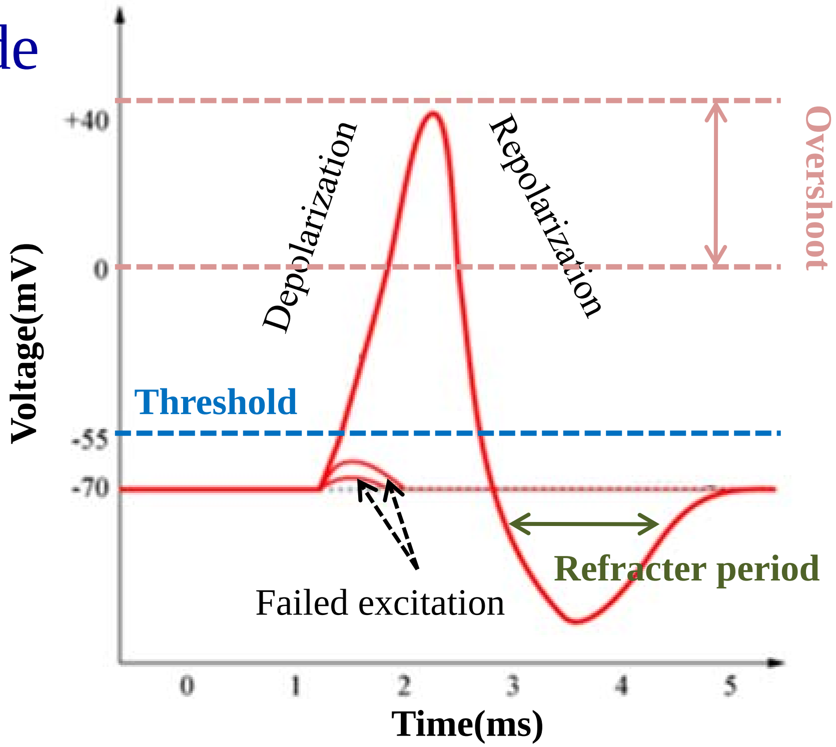
Electrical muscle stimulation (EMS) – Action Potential

3. the electrochemical gradient changes producing continous rise in the membrane potential. (proceeds explosively until all ion channels are open)
4. The rapid increase of Na^{+} concentrate reverses the polarity of the membrane (ion channels rapidly inactivate). Na^{+} are actively transported out the plasma membrane.
5. K^{+} channels are activated: resulting outward current of K^{+}. (the electrochemical gradient returns to the resting state).
6. After an AP, there is a transient negative shift, called the afterhyperpolaryzation

Electrical muscle stimulation (EMS) – Action Potential (Some important features)

- Propagates without loss of amplitude
- No summation of AP’s
- Absolute and relative refracter period
  -AP cannot be evoked

- AP’s can be evoked on the axon or axon hillock (potential driven ion channels are located here)



Electrical muscle stimulation (EMS) – Notes on techniques applied

- **Frequency :**
  - acute conditions: high frequency of 80-120 Hz, when pain still presents. (The resulting normal tetanizing rate elicits smooth contraction, affecting relaxation of muscle spasm.)
  - chronic conditions: low frequency of 1-20 Hz as lower frequencies simulate endorphin production
- **Pulse width:** It ranges from 50 - 500 ms. A medium width of 150 msec is most preferable, with suitable adjustment in either direction when needed.

Electrical muscle stimulation (EMS) – Notes on techniques applied

Amplitude (intensity): During ES, the visible contraction is the recommended clinical guide.

- **Modulation:** is often used with long-term applications of transcutaneous electrical nerve stimulation for pain control.

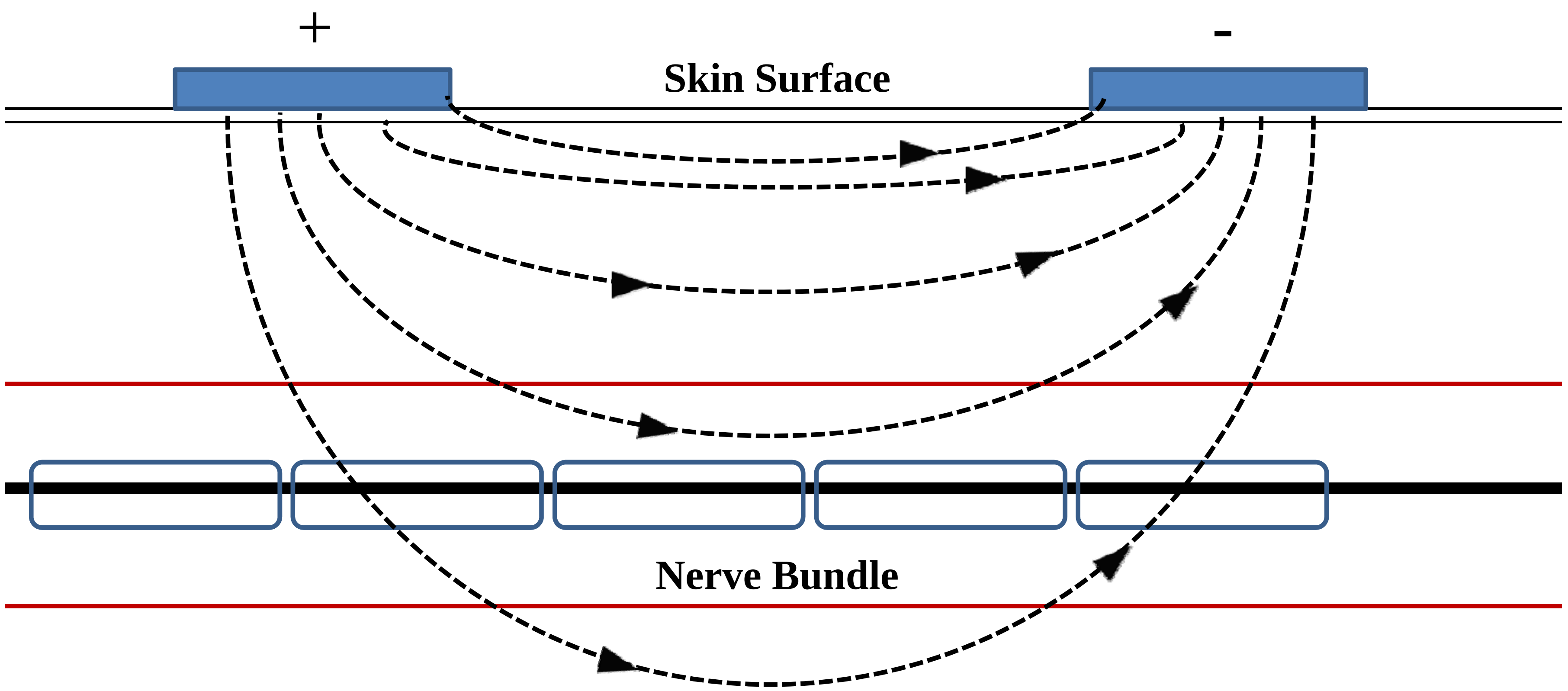
The main goal: is to reduce the body adaptation of passing current.

The optimal protocol of EMS and the appropriate parameters differ among muscles.

Functional Electrical Stimulation (FES) – Applications across the world

- Applications for both upper(U)-lower(L) limb
- Parastep (Sigmedics Inc.) [L]
  - Step assistant
- Odstock foot drop stimulator [L]
- Freehand (FES grasping system) [U]
- The Belgrade Grasping System [U]
- FES Hand Grasp (FEScenter) [U]
- **FES cycling (PPCU-FIT - Budapest; LMU-Munich) [L]**
  - **Paraplegic and tetraplegic patiets during cycling movements**
- Bladder Management

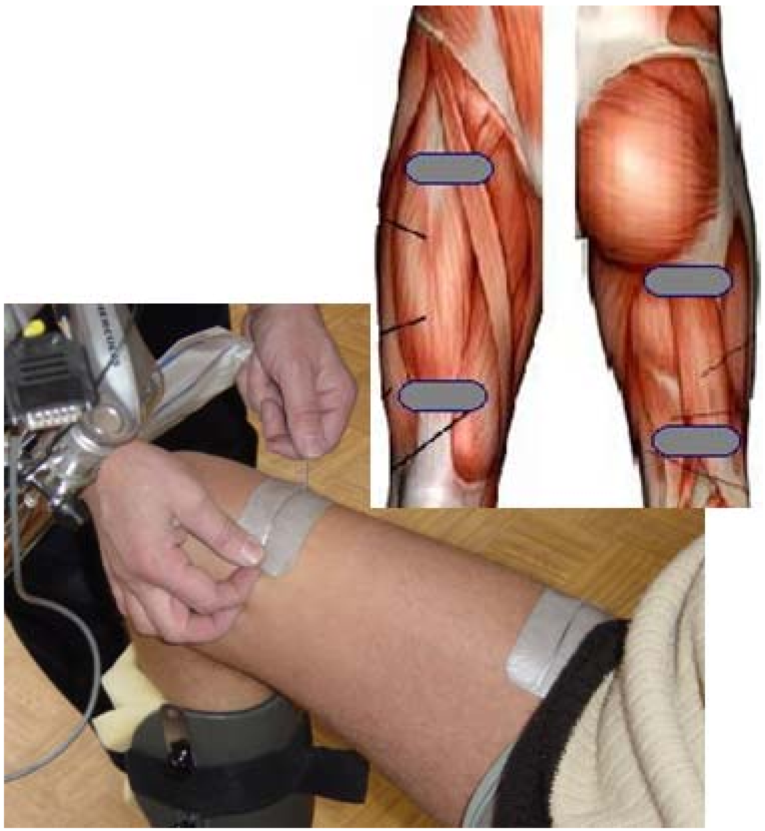
Representation of current density in surface nerve stimulation



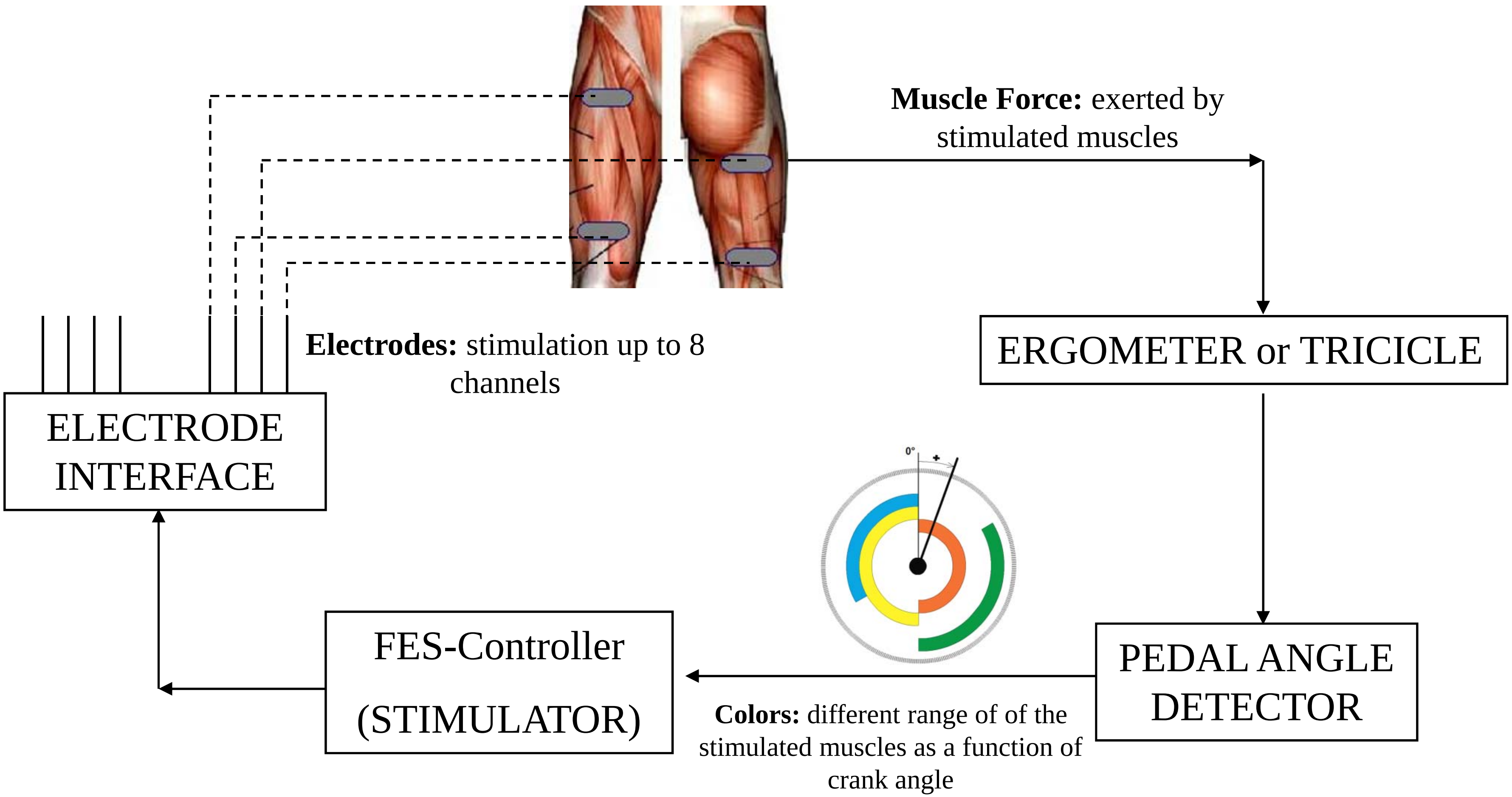
A case study applying FES – Cycling (The rehabilitation process)

1. Subjects are submitted to medical examination
2. If they meet the requirements
   - Spastic muscles
3. They participate in the study
   - FES-cycling

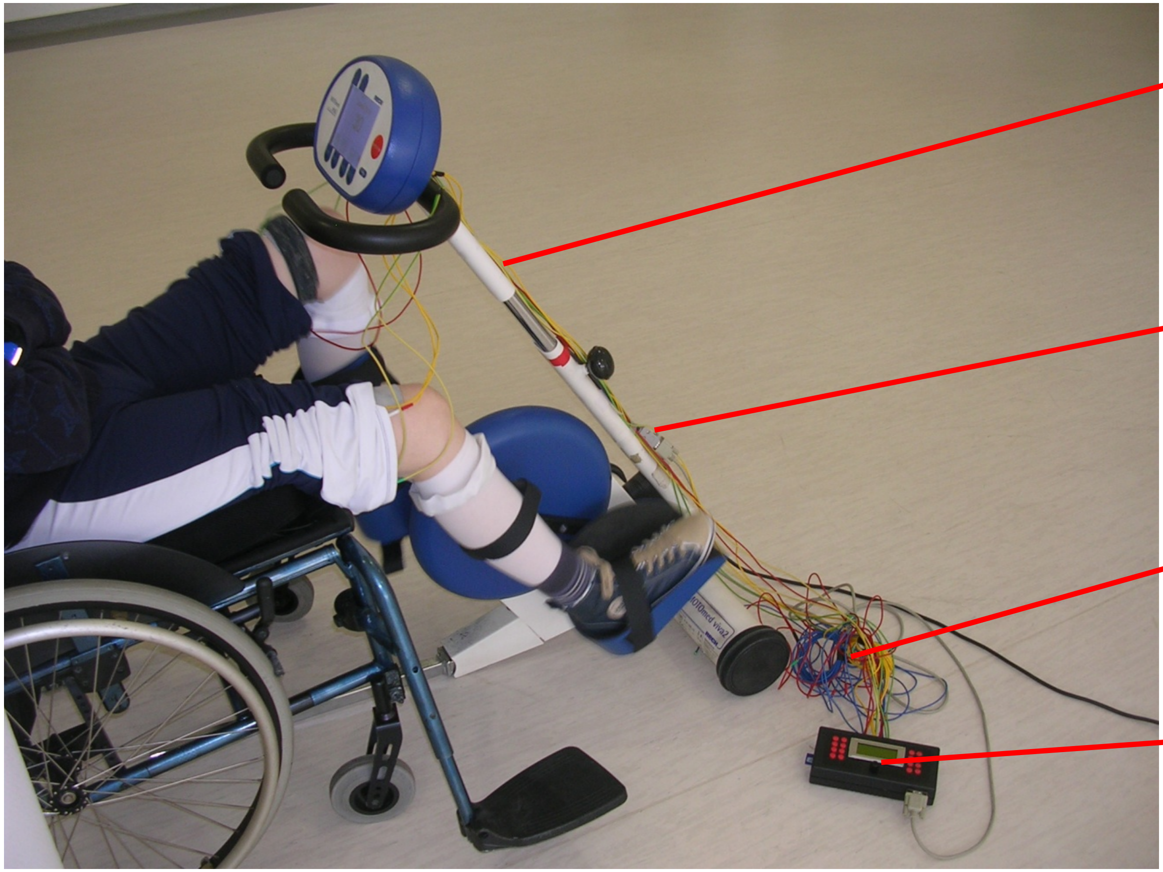
A case study applying FES – Cycling – Placement of the bipolar electrodes and measurement setup (MotionStim)



A case study applying FES – Cycling(Self developed stimulator)



A case study applying FES – Cycling(Self developed stimulator)



ERGOMETER or TRICICLE

PEDAL ANGLE DETECTOR

ELECTRODE INTERFACE

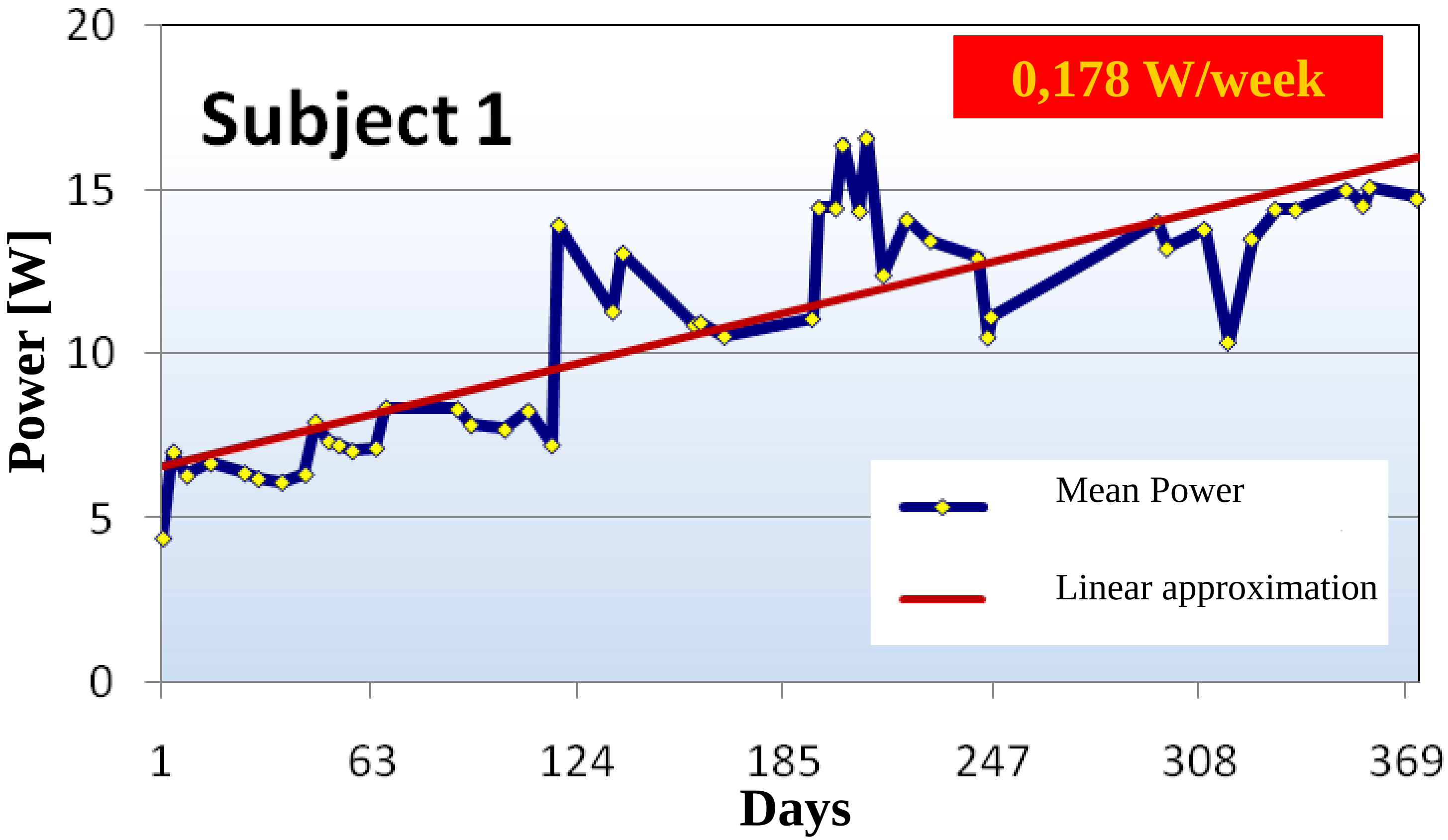
FES-Controller

(STIMULATOR)

A case study applying FES – Cycling

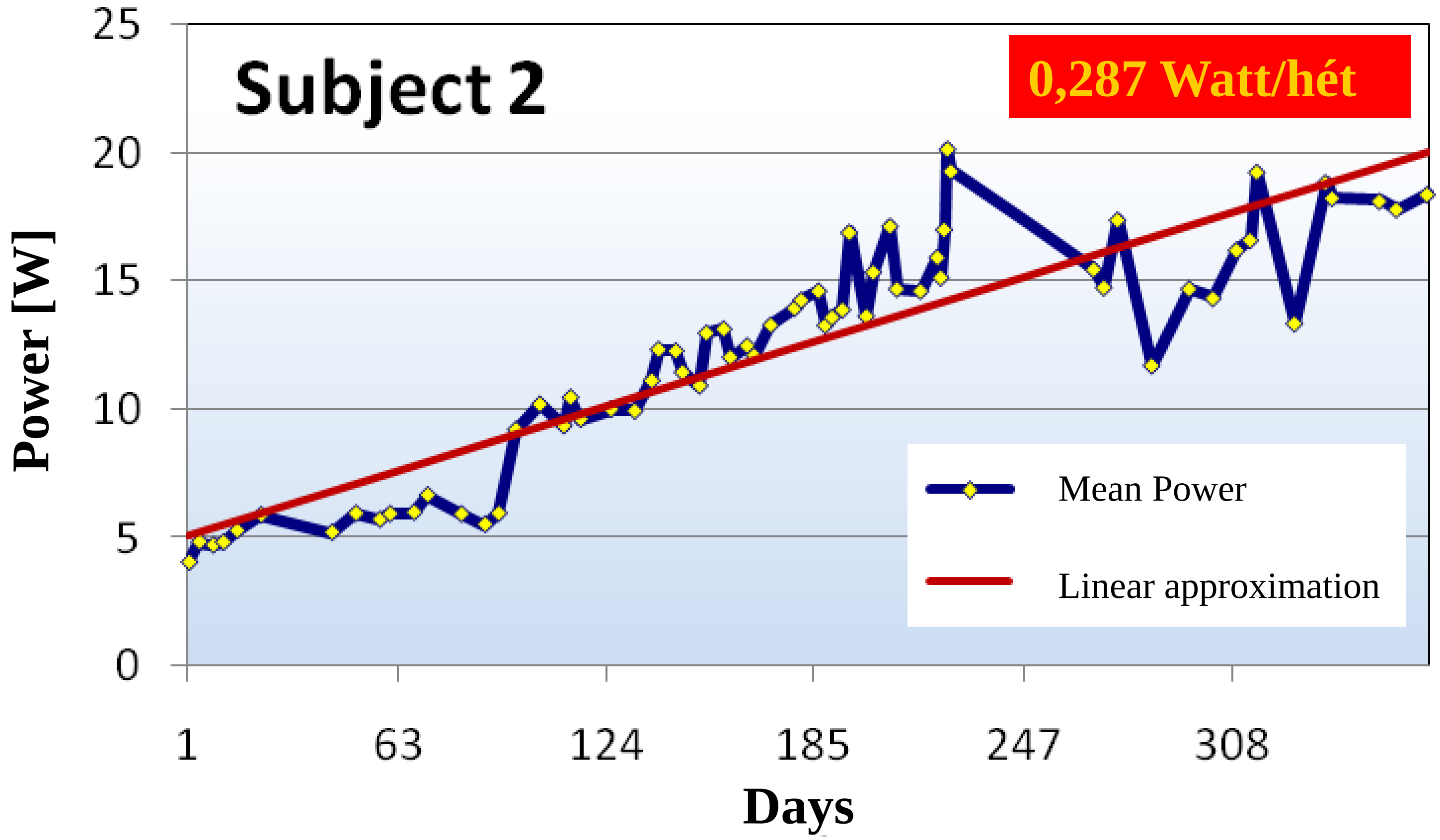
1. **Subject is sitting in his/her wheelchair in front of an ergometer**
2. **2 muscle groups on each leg are to be stimulated**
   - **Right: hamstrings, quadriceps**
   - **Left: hamstrings, quadriceps**
3. **Application of pedal angle detector:**
   - **It detects pedal angular changes and transmits to the FES controller**
4. **The FES controller generates stimulation patterns**
   - **As a function of crank angle**
5. **Electrode interface attached to proper muscles**
   - **Stimulates the muscles by transmitting electrical signals**

A case study applying FES – Cycling(Self developed stimulator) Mean Gain of Power in subject 1

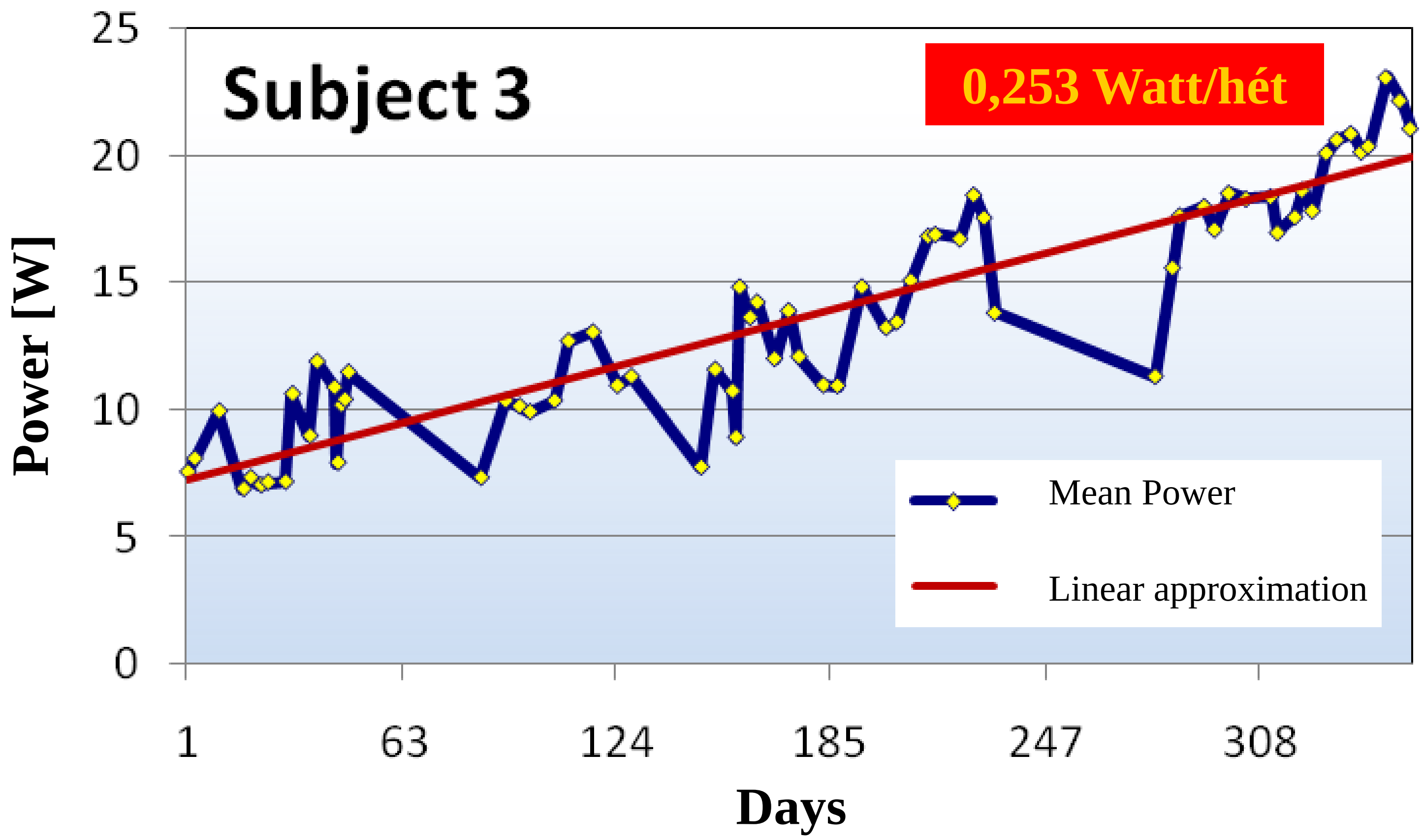


A case study applying FES – Cycling(Self developed stimulator)

Mean Gain of Power in subject 2



A case study applying FES – Cycling(Self developed stimulator) Mean Gain of Power in subject 3



Sample application to enhance artificial movement patterns:

According to inverse kinematics it is not obvious that all of the three joint's angular velocities must be increased by the same rate in order to reach higher pedaling speed.

However, it was found experimentally that healthy subjects use this strategy. This finding has a useful application:

Controlling FES driven cycling lower limb movements of SCI patients, if one wish to increase pedaling speed, than all joint's angular velocity should be increased by the same rate.

Thus the activity of the flexor and extensor muscles of all of the 3 joints (hip, knee, and ankle) must be increased to have natural cycling pattern.

Summary

- **Electrical stimulation turned out to be one of the most effective methods used in physical therapy and rehabilitation.**

- **Different techniques were presented** that may be applied during electrical stimulation of the human body
  - **Different parameters** are applied depending on the main area of the rehabilitation
  - **Such parameters are: electrode parameters**(size,material); applied **signal parameters**(voltage,current,frequency); **shape of the signal**(pulse width)

Summary

- The lecture was focused on the EMS(electrical muscle stimulation). EMS is applied as a training and a therapeutic and a medical rehabilitation tool.

  As the part of EMS **FES(functional electrical stimulation) during cycling** was presented

  - As a part of a case study performed by the cooperation of SCI(spinal coord injured) patients an **increment in power production** was presented in 3 different subjects caused by FES

Suggested literature

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